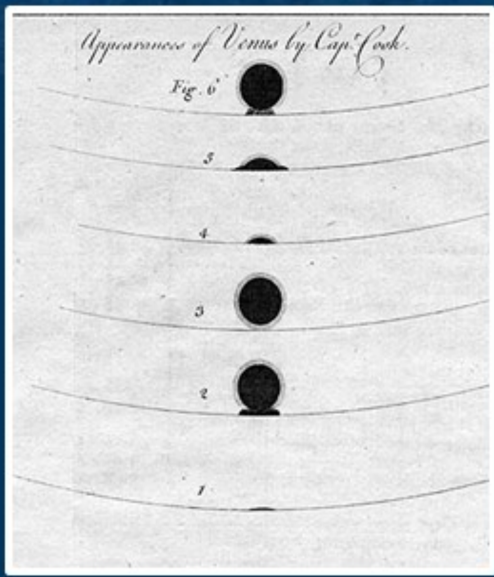
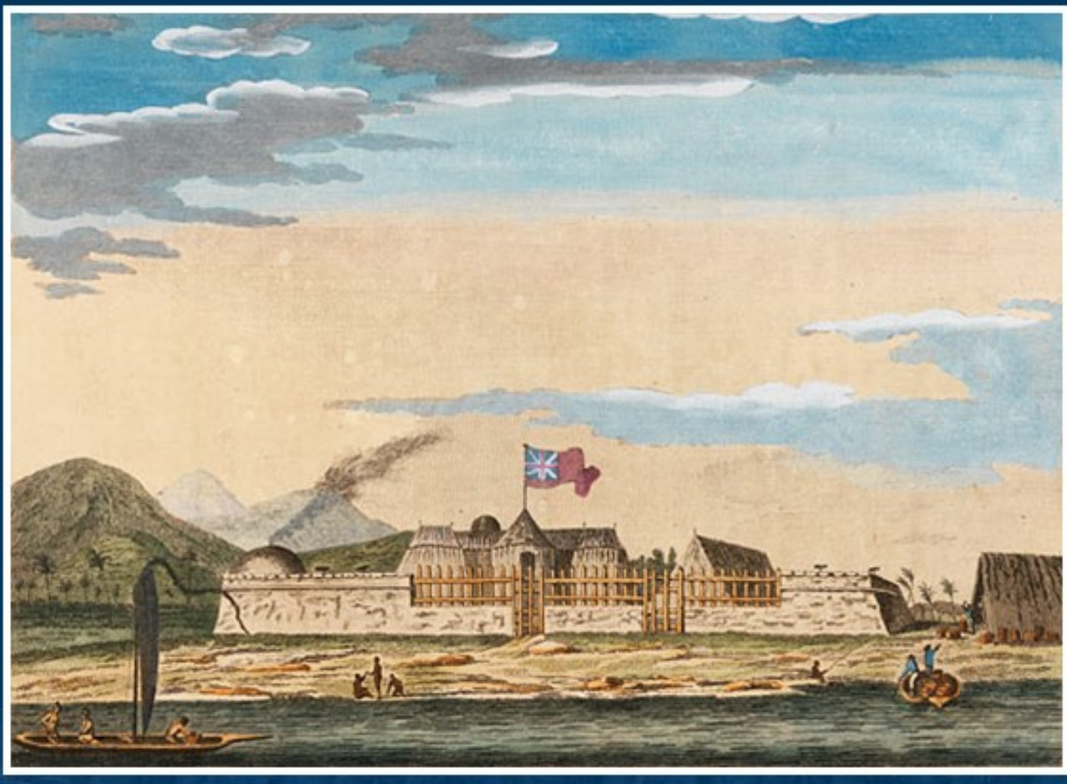
JOURNAL OF ASTRONOMICAL HISTORY AND HERITAGE





Vol. 20 No. 1 March/April 2017

JOURNAL OF ASTRONOMICAL HISTORY AND HERITAGE

ISSN 1440-2807

The *Journal of Astronomical History and Heritage* (*JAHH*) was founded in 1998, and since 2007 has been produced three times yearly, now in March/April, July/August and November/December. It features review papers, research papers, short communications, correspondence, IAU reports and book reviews.

Papers on all aspects of astronomical history are considered, including studies that place the evolution of astronomy in political, economic and cultural contexts. Papers on astronomical heritage may deal with historic telescopes and observatories, conservation projects (including the conversion of historic observatories into museums of astronomy), and historical or industrial archaeological investigations of astronomical sites and buildings. All papers are refereed prior to publication. There are no page charges, and *in lieu* of reprints authors are sent a pdf or Word camera-ready version of their paper so that they can generate their own reprints on demand.

Prospective contributors may download the 'Guide for Authors' directly from the internet by accessing http://www.narit.or.th/en/files/GuideforAuthors.pdf or request it from Professor Wayne Orchiston (wayne.orchiston@narit.or.th). Intending contributors should carefully follow these guidelines when preparing manuscripts. Papers and book reviews should be e-mailed to Professor Orchiston, or posted to him at:

National Astronomical Research Institute of Thailand
191 Huay Kaew Road
Suthep District
Muang
Chiang Mai 50200
Thailand

Book reviews should be sent to Dr Clifford Cunningham (asteroid4276@comcast.net)

The *JAHH* is now an electronic journal. All content back to Vol. 1 (1998) may be downloaded free of charge from either the Journal's web site at http://www.narit.or.th/en/index.php/jahh or the SAO/NASA Astrophysics Data System site (http://bit.ly/1bMwxBr) and its 11 mirror sites around the world. The electronic version of the journal will continue to be produced three times a year (nominally in April, August and December) and posted on both sites. Those who want a hard copy may print it out or have it done by their local printers. For this reason a single pdf of each entire issue(including the cover) is available on the NARIT site.

COVER IMAGES

These images relate to observations of the 3 June 1769 transit of Venus from Tahiti, the result of a British expedition arranged by the Royal Society. As discussed in the paper starting on page 35 in this issue, three different observing sites were established in Tahiti and nearby Moorea, and eleven different observers successfully recorded the transit. Yet most of their observations were ignored when the official account was written up, and all of the associated records have disappeared. Shown here are: a telescope by Short, similar to the two taken on the voyage; Cook's drawings of the transit, and a view of Fort Venus, Tahiti, where Cook, Green and Solander were based.

JOURNAL OF ASTRONOMICAL HISTORY AND HERITAGE

ISSN 1440-2807

VOLUME 20 NUMBER 1 **MARCH/APRIL 2017**

CONTENTS

Published by the National Astronomical Research Institute of Thailand, 191 Huay Kaew Road, Suthep DistrIct, Muang, Chiang Mai 50200, Thailand.

IS THE UNIVERSE EXPANDING? FRITZ ZWICKY AND EARLY TIRED-LIGHT HYPOTHESES

Helge Kragh
Niels Bohr Institute, Blegdamsvej 17, 2100 Copenhagen, Denmark.
Email: helge.kragh@nbi.ku.dk

Abstract: The recognition that the Universe is in a state of expansion is a milestone in modern astronomy and cosmology. The discovery dates from the early 1930s but was not unanimously accepted by either astronomers or physicists. The relativistic theory of the expanding Universe rested empirically on the redshift–distance law established by Edwin Hubble in 1929. However, although the theory offered a natural explanation of the observed galactic redshifts, these could be explained also on the assumption of a Static Universe. This was what Fritz Zwicky did when he introduced the idea of "tired light" in the fall of 1929. Hypotheses of a similar kind were proposed by several other scientists but their impact on mainstream astronomy and cosmology was limited. The paper offers a survey of tired-light hypotheses in the 1930s and briefly alludes to the later development.

Keywords: Expanding Universe, tired light, redshifts, Fritz Zwicky, cosmology

1 HUBBLE'S UNIVERSE

Edwin Hubble (1889–1953; Figure 1; Christianson, 1995) is often, if mistakenly, considered the discoverer of the Expanding Universe (Kragh and Smith, 2003; Nussbaumer and Bieri, 2009). The claim rests on Hubble's seminal paper published in March 1929 and in which he established the fundamental velocity–distance law named after him. The law can be stated as

$$v = c\frac{\Delta\lambda}{\lambda} = Hr \qquad (1)$$

Here $\Delta\lambda/\lambda$ denotes the redshift of a receding galaxy and r its distance; v is the radial velocity on the assumption that the observed redshifts are Doppler shifts, and H is the Hubble constant

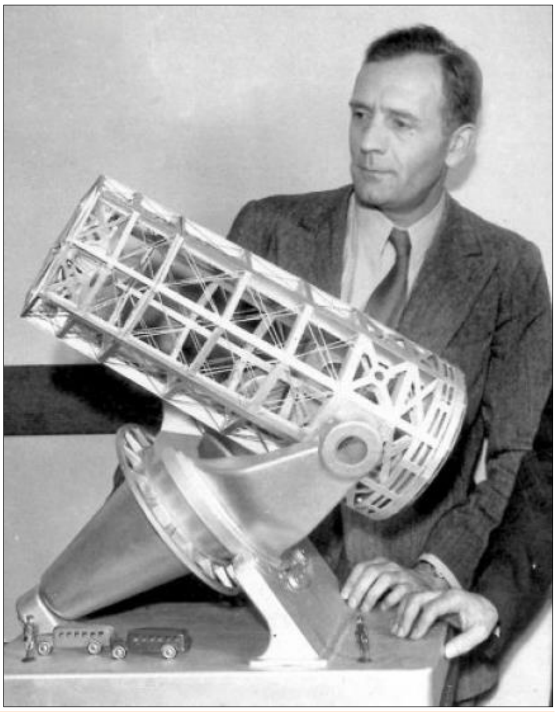


Figure 1: Edwin Hubble with a model of the proposed 200-in telescope, this is a cropped version of a photograph that appeared in the *New York Sun* on 18 June 1931 (adapted from citizensvoice.com/news/silvered-stargazer-1.1869195).

or parameter (Figure 2). It may come as a surprise that the same year, Hubble (1929: 96) left no doubt that he preferred a non-recession explanation of the galactic redshifts. In a popular account of his discovery, he wrote:

> It is difficult to believe that the velocities are real; that all matter is actually scattering away from our region of space. It is easier to suppose that the light-waves are lengthened and the lines of the spectra are shifted to the red, as though the objects were receding, by some property of space or by forces acting on the light during its long journey to the Earth.

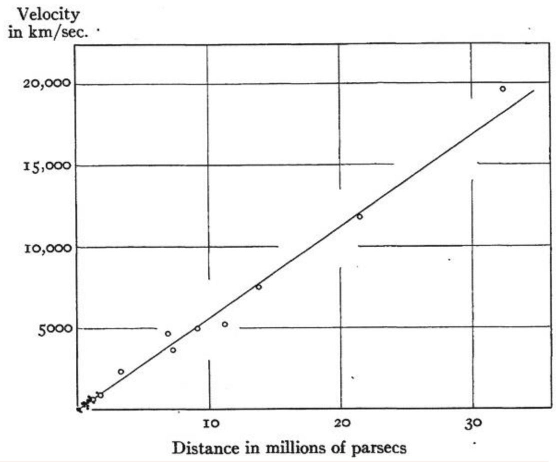


Figure 2: The Hubble law (after Hubble & Humason, 1931: 74).

In his later writings Hubble was more ambiguous and he never clearly endorsed alternatives to the recession theory. One of the first scientists to comment on Hubble's discovery was the Bulgarian-born Swiss-American astronomer Fritz Zwicky (1898–1974; Figure 3; Knill, 2014), who from 1925 had worked at the California Institute of Technology (Caltech). Zwicky knew Hubble personally and was part of the discussion club consisting of astronomers and physicists that regularly met at Hubble's home (Christianson, 1995: 197) and which also included Richard Tolman (1881–1948), Milton Humason (1891–1972) and Walter Baade (1893–1960). There is little doubt that Hubble, when referring to the possibility of "… forces acting on the light …", had in mind Zwicky's still unpublished explanation of the redshifts in terms of aging light. Zwicky submitted his paper on the subject in late August 1929 and it appeared in the October issue of the same journal as Hubble's paper, the *Proceedings of the National Academy of Sciences*.

Zwicky was the founder of 'tired light' mechanisms, a term that in general refers to the idea that photons slowly lose energy on their journey through space and therefore (since $E = hv = hc/\lambda$) arrive at the observer with an increased wavelength. According to this view, the galactic redshifts are not cosmological in nature and not peculiar to the galaxies; the light from all celestial objects will be redshifted proportionally to their distances from the Earth. The name 'tired light' is sometimes ascribed to Tolman, but always without a proper reference. It may have been coined by Howard Percy Robertson (1903–1961; Figure 4; Bogdan, 2014b) who, in a semi-popular address on the Expanding Universe, referred to the hypothesis that "… the observed red shift would be due to the properties of 'tired' light rather than the nebulae themselves." (Robertson, 1932: 226). Robertson found explanations of this kind to be unsatisfactory and *ad hoc*. The name may have been used informally at earlier occasions, for the Princeton astrophysicist John Quincy Stewart (1894–1972; Mumford, 2014) referred to "… what has been called the 'fatigue' of light quanta." (Stewart, 1931). Note that Zwicky did not use the term in any of his publications between 1929 and 1940.

In a little-known paper published shortly after Zwicky's, the Russian astronomer Aristarkh Belopolsky (1854–1934; Figure 5; Bogdan, 2014a) independently suggested that the Hubble redshifts might not be due to nebular recession (Belopolsky, 1929). A pioneer in the use of spectroscopy for the study of stellar motion, Belopolsky was a respected and internationally-oriented astronomer (Struve, 1935). In a brief note dated September 1929, 75-year-old Belopolsky questioned whether the redshifts were really to be understood as Doppler shifts of receding nebulae:

> If we only look at the spectral shifts we have to relate the phenomenon – the generally positive shifts – to light itself and the dilatation of waves or a diminution of its frequency. It follows that the celestial objects closer to us exhibit a smaller diminution of the vibrations of the ether particles than distant objects and that the diminution is proportional to the distance. To phrase it differently, if the light quantum at the source is hv, an observer at distance r from the source will receive it as hv/r. (Belopolsky, 1929).

The following year Belopolsky (1930) published a paper in a Russian astronomical year-

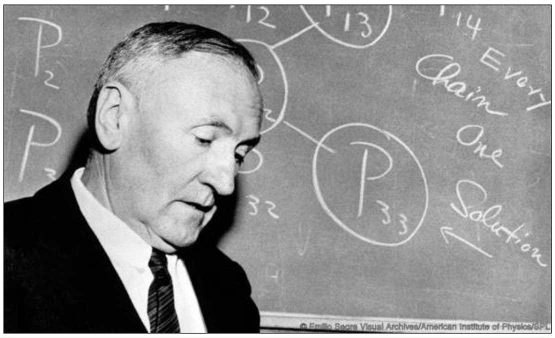


Figure 3: Fritz Zwicky (courtesy: Emilio Segrè Visual Archives/American Institute of Physics).

book in which he summarized Hubble's 1929 paper and again called attention to the interpretation of the redshifts (Tropp et al., 1993: 221). Although he admitted that the redshifts could be explained in terms of recession, he was more inclined to the hypothesis that they were due to some unknown quantum factor causing the wavelength to increase with the distance traversed by the light.


Figure 4: Howard Percy Robertson (courtesy: Emilio Segrè Visual Archives/American Institute of Physics).

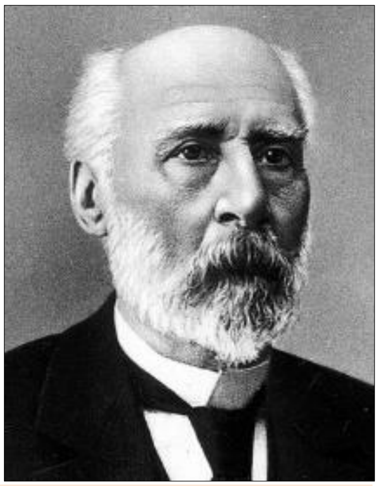


Figure 5: Aristarkh Apolionovich Belopolsky (WikiVisual).

2 ZWICKY'S GRAVITATIONAL DRAG HYPOTHESIS

Until 1929 Zwicky had mostly worked in areas of physical chemistry, such as the quantum theory of crystals and electrolytes, and he had only recently become interested in astrophysics. Realizing that Hubble's discovery was greatly important for "… the future development of our cosmological views …", Zwicky (1929a: 773) discussed a number of possible explanations of the spectral shifts. The 'curious phenomenon' might conceivably be due to an ordinary gravitational shift of spectral lines or Compton scattering of photons on free electrons, but these explanations he dismissed as inadequate. As a better alternative Zwicky focused on what he called "… a gravitational analogue of the Compton effect." (Zwicky, 1929a: 776). According to the theory of relativity a photon of frequency ν has a gravitational mass $h\nu/c^2$ and therefore should be able to transfer momentum and energy to an atom. As a result of the recoil the photon's frequency would be diminished. Zwicky calculated that according to this mechanism a photon travelling a distance r would be redshifted by the amount

Figure 6: Paul Willem ten Bruggencate (http://dutchgenie.net/bruggencate/brugg-e-o/ p4381.htm).

$$\frac{\Delta\nu}{\nu} = \frac{1.4G\rho D}{c^2} r \qquad (2)$$

The quantity $D >> r$ is a measure of the distance over which the gravitational 'drag' operates, and ρ is the average density of matter in the Universe, which Zwicky took to lie in the interval $10^{-25} > \rho > 10^{-31}$ g/cm^3. Estimating D to be of the order 10^3 R, where R ~ 1 Mpc is the mutual distance of the galactic systems, he got $D \sim 3 \times 10^{27}$ cm. Zwicky thus arrived at a frequency shift of

$$3 \times 10^{-2} > \frac{\Delta\nu}{\nu} > 3 \times 10^{-7} \qquad (3)$$

Comparing this estimate with Hubble's value of approximately 1.7×10^{-3} for R ~ 1 Mpc, Zwicky suggested (1929a: 779) that his explanation was in "… qualitative accordance with all of the observational facts known so far." As a possible test he remarked that an absorption line shifted due to gravitational drag would be asymmetrically broadened toward the red. His theory was admittedly just a 'rough idea' which in its further development needed to be based on the General Theory of Relativity and possibly include the effects of "… absorption of gravitational waves." (Zwicky, 1929a: 778).

It should be noted that at the time Zwicky did not present his theory as an alternative to the relativistic view of the Expanding Universe. This view was still in the future, if not for long. Moreover, Zwicky solely proposed a rival interpretation of the redshifts and not, either in 1929 or in his later papers, a new cosmological model. Although the literature on cosmology contains references to 'Zwicky's model', there never was such a model (Hetherington, 1982).

In a follow-up paper later in the year Zwicky (1929b: 1623) admitted that he had made a mathematical error, which "Professor Eddington kindly informs me in a letter." As a result of Eddington's criticism, he stressed that his derivation of the gravitational drag of light needed to be "… derived or disproved by the general theory of relativity." (Zwicky, 1929b: 1624). Zwicky again referred to gravitational waves propagating with the speed of light. Moreover, he discussed observations which might possibly confirm his theory and distinguish it from the Doppler theory of receding galaxies. It followed from Zwicky's hypothesis that the redshift should depend on the distribution of matter in space and one would therefore expect that "… an appreciable effect should also be observed in our galaxy." (Zwicky 1929a: 774). Moreover, the redshifts from within the Milky Way should depend on the direction. According to the cosmological view, there should be no such direction effect, indeed no distance-related redshifts within the Milky Way at all.

For observational support of his theory Zwicky referred to discussions with the young Dutch-German astronomer Paul ten Bruggencate Figure 6; Broughton, 2014), who at the time was working at Mount Wilson Observatory and was acquainted with the results obtained by Hubble and Humason. Inspired by Zwicky, ten Bruggencate (1930) studied the radial velocities of globular clusters on the assumption of the gravitational drag hypothesis. From his study he concluded that the number of stars required to bring the observed redshifts into agreement with the hypothesis was justified. It was "… of the right general order of magnitude to reconcile the observed red-shift with Zwicky's prediction." (ten

Bruggencate, 1930: 117). Several years later, after taking up the position as chief observer at the Potsdam Solar Observatory, better known as the Einstein Tower, ten Bruggencate (1937) returned to the question of the origin of the redshifts. However, his study of the luminosity–redshift relation for galaxies failed to discriminate clearly between the Expanding Universe and a static one with redshifts caused by a tired-light mechanism.

During the 1930s Zwicky published two more papers on his theory characterized by a redshift that depended not only on the distance but also on the amount and distribution of cosmic matter. Zwicky (1933), published in German in a Swiss physics journal, has today the status of a scientific classic because of its bold prediction of dark matter (English translation in Zwicky, 2009). But Zwicky (1933: 121) also reviewed the galactic redshift problem, now distinguishing between two alternatives, one of which was cosmic expansion and the other "… an interaction of light and the matter in the universe." Zwicky did not conclude that his own tired-light explanation was superior but only that it was no less unsatisfactory than the relativistic theory of the Universe. Both theories, he wrote,

> … have been developed on a most hypothetical basis, and none of them has succeeded to uncover any new physical relationships. (Zwicky, 1933: 124).

This was also Zwicky's message in 1935 when he listed a number of methodological and other objections to the relativistic theory of galactic redshifts. It is, he said,

> … scientifically more economical *not* to link the redshift from nebulae with any *purely hypothetical* curvature and expansion of space. (Zwicky, 1935: 803).

Zwicky did not claim that his own theory was better but rather recommended cautiousness, not unlike what Hubble did. Astronomers should not "… interpret too dogmatically the observed redshifts as caused by an actual expansion …" but wait for more experimental facts which "… is badly needed before we can hope to arrive at a satisfactory theory." (ibid.). In Zwicky's mind the gravitational-drag hypothesis had one advantage over the expansion hypothesis, namely that it was empirically testable:

> An initially parallel beam of light, on this theory, will gradually open itself because of small angle scattering. Observational tests on this point will be important. (Zwicky, 1935: 806).

Although Zwicky did not stress the connection between his tired-light hypothesis and the Static Universe, there is no doubt that he preferred the latter model over the Expanding Universe model. In a paper of 1939 he challenged the Expanding Universe on one of its weak points, namely that it led to an age of the Universe smaller than the age of stars and galaxies. According to Zwicky's analysis, the time of formation for a large cluster out of a random distribution of nebulae was more than 10^{18} years, immensely longer than allowed by most models of the Expanding Universe. This and other observations, he wrote, "… rule out any possibility of interpretation of the nebular red-shift on the basis of an expanding universe." (Zwicky, 1939: 607). Vera Reade (1905–1986; Kinder, 2009), a British amateur astronomer, reported on Zwicky's arguments in the *Journal of the British Astronomical Association*. She wrote:

> It may seem bold to challenge the expansion universe theory, but some observational facts pointed out by Dr. F. Zwicky seem to warrant this. (Reade, 1940: 162).

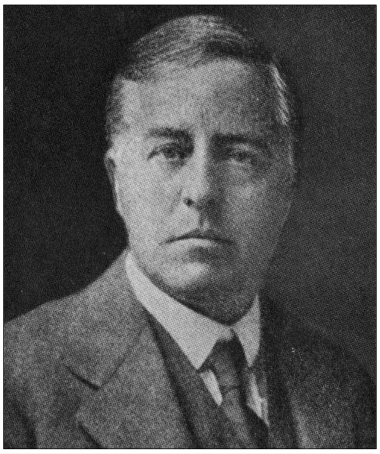


Figure 7: Sir James Hopwood Jeans (en.wikipedia.org).

Three years later Zwicky listed a number of observations which, to his mind, favoured the Static Universe over the hypothesis of the Expanding Universe. Zwicky (1942) argued that models of the Expanding Universe contradicted observed features of the large-scale distribution of matter.

3 TESTING TIRED LIGHT

Zwicky was a recognized scientist and his theory of redshifts attracted considerable interest among his peers. Although frequently rejected as inadequate, speculative or *ad hoc*, it was well known and taken seriously enough that proponents of the relativistic Expanding Universe often commented on it. As mentioned, Eddington did it informally, in a private letter. Sir James Jeans (1877–1946; Figure 7; Milne, 1952) dealt in some detail with Zwicky's theory in his popular book *The Mysterious Universe*. He obviously found the theory to be attractive and thought that it received support from ten Bruggencate's study of globular clusters. According to Jeans (1930:

87), most of the reddening of the spectral lines "... may be attributed to the effects suggested by Zwicky, or to some similar cause."

As Zwicky had argued for his theory in methodological terms, so Robertson (1932: 226) criticized it from a methodological point of view by invoking Occam's principle of simplicity and economy. Referring to "... a group which would attribute the observed red shift … to a property of light which has traveled the tremendous internebular distances ...", he singled out Zwicky's hypothesis. But, he concluded,

> ... in the lack of further facts I should prefer to wield Occam's razor on all ad hoc explanations of the red shift and accept that one which follows so naturally from our present views of the nature of the physical world.

Richard Tolman (Figure 8; Kirkwood et al., 1952), another mainstream cosmologist and advocate of the Expanding Universe, argued theoretically that the frequency of light could not be appreciably affected by passing the gravitational fields of particles on its way from source to observer. He consequently concluded that Zwicky's gravitational-drag hypothesis was "... improbable." (Tolman, 1934: 288).

This seems also to have been the view of Albert Einstein (1879–1955; Figure 8), who spent the first two months of 1931 in Pasadena. He met with Zwicky and most likely discussed cosmological issues with him. Einstein at the time was aware of the Expanding Universe, but he still hesitated in converting to the new theory. He believed that the nature of the galactic redshifts was "... a mystery ...", according to a *New York Times* report on a meeting that took place at Mount Wilson Laboratory on 11 February 1931. On the other hand, Einstein did not accept Zwicky's tired-light explanation of redshifts. According to the report,

> He [Einstein] said the red shift might be interpreted as the light quanta getting redder by losing energy as they went long distances. 'But no man can get a picture of how this happens', he said. (Nussbaumer, 2014: 50).

The reference obviously was to Zwicky's hypothesis.

Not only did ten Bruggencate's luminosity–redshift test fail to distinguish observationally between an Expanding and a Static Universe, but the same was the case with an extensive investigation undertaken by Hubble and Tolman (1935; see also Peebles, 1971). For the variation of a galaxy's surface brightness S with redshift $z = \Delta\lambda/\lambda$ they found different relations for simple expanding models (E) and tired-light models (TL), namely

$$S_{\mathrm{E}} \propto (1+z)^{-4} \quad \text{and} \quad S_{\mathrm{TL}} \propto (1+z)^{-1} \qquad (4)$$

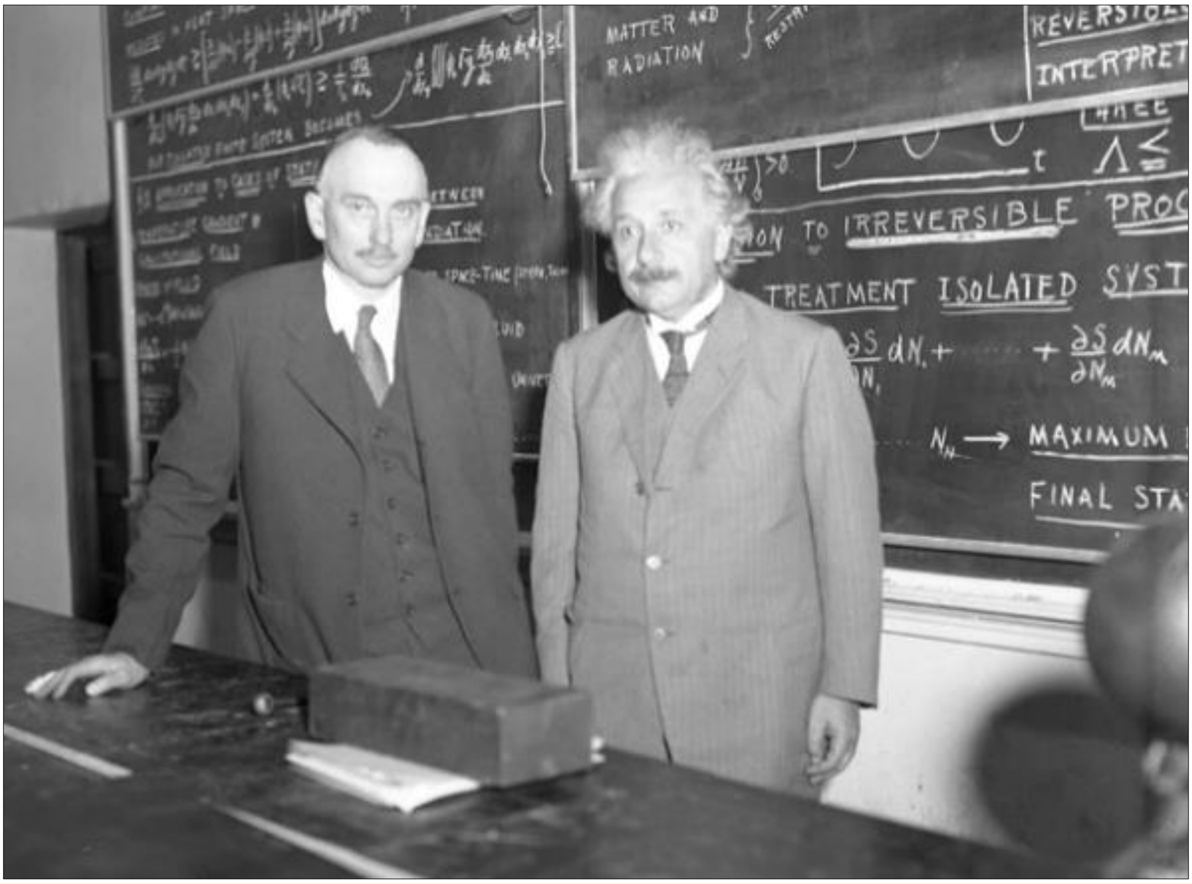


Figure 8: Richard Chase Tolman and Albert Einstein at Caltech in 1932 (en.wikipedia.org).

However, due to lack of reliable data neither this test nor other tests proposed by Hubble and Tolman provided a clear answer. As Hubble and Tolman (1935: 303) noted,

> The possibility that the redshift may be due to some other cause [decrease of the energy of galactic photons] ... should not be neglected; and several investigators have indeed suggested such other causes, although without as yet giving an entirely satisfactory detailed account of their mechanism.

Hubble and Tolman did not refer to the names of the investigators, but presumably they thought of Zwicky in particular.

If observations were of little use, perhaps tired-light hypotheses could be subjected to experimental testing. According to Roy Kennedy and Walter Barkas (1912–1969) at the University of Washington, experiments proved that Zwicky's hypothesis was wrong. The aim of Kennedy and Barkas (1936) was to test whether or not the 'Hubble–Humason law' could be reproduced on the basis of a tired-light hypothesis assuming that a photon loses energy to free electrons in proportion to its frequency. Let the photon's initial frequency be ν_0 and the density of the medium of free electrons through which it passes be ρ. From the Beer–Lambert law

$$\mathrm{d}\nu = -k\rho\nu\mathrm{d}x \tag{5}$$

where k is an unknown constant, it follows that

$$\nu = \nu_0 \exp(-k\rho x) \tag{6}$$

or approximately

$$\frac{\Delta\nu}{\nu} = \frac{\nu_0 - \nu}{\nu_0} = k\rho x \tag{7}$$

This is an expression similar in form to Hubble's relation. To test the expression experimentally Kennedy and Barkas needed a very high value of ρ to compensate for the small value of x = 40 cm in the experiment. This they obtained by using an ionized helium gas of $\rho = 5 \times 10^{12}$ electrons per cc, whereas they estimated the electron density in the intergalactic medium to be $\rho \geq 5 \times 10^{-4}$ per cc. Their interferometer showed a null result from which they concluded that "... the nebular redshift is not to be attributed to interstellar electrons in a static universe." (Kennedy and Barkas, 1936: 451). To make a Static Einstein Universe comply with their data it had to be unrealistically small, of a radius less than 10^8 light-years. Moreover, Kennedy and Barkas failed to detect the asymmetric broadening toward the red in absorption lines that Zwicky's theory required. Because it was published in *Physical Review* the Kennedy–Barkas experiment was well known, but neither Zwicky nor other proponents of tired-light hypotheses responded to it.

4 OTHER PHOTON-DECAY HYPOTHESES

Although Zwicky's gravitational drag hypothesis was the best known and most elaborated alternative to the relativistic interpretation of the galactic redshifts, it was far from the only one. During the 1930s more than twenty scientists or amateur scientists suggested alternatives to the Expanding Universe, many of them belonging to the tired-light category (see Table 1). I shall mention just a few of the ideas.

Table 1: Alternatives to the Expanding Universe, 1929–1939

Name	Year	Nationality	Profession	Comment
Zwicky, F.	1929	Swiss-American	astronomer	see text
Belopolsky, A.	1929	Russian	astronomer	see text
Stewart, J.	1931	American	astrophysicist	see text
MacMillan, W.	1932	American	astronomer	see text
Buc, H.	1932	American	engineer	tired light
Arx, W.	1932	American	amateur astronomer	tired light
Mason, W.	1932	American	author	classical gas theory
Eigenson, M.	1932	Russian	astronomer	galactic mass decrease
Schier, H.	1932	Austrian	amateur astronomer	decreasing speed of light
Kaiser, F.	1934	German	amateur astronomer	gravitational redshift
Gramatzki, H.	1934	German	amateur astronomer	varying speed of light
Northtrop, F.	1934	American	philosopher	Whitehead's gravitation theory
Wold, P.	1935	American	physicist	varying speed of light
Underwood, R.	1935	American	amateur astronomer	tired light
Chalmers, J. and Chalmers, B.	1935	British	physicists	variation of Planck's constant
Gunn, R.	1935	American	physicist	classical radiation forces
Halm, J.	1935	German-British	astronomer	modification of optical theory
Nernst, W.	1935	German	chemist	see text
Haas, A.	1936	Austrian-American	physicist	photon decay
Sambursky, S.	1937	American	physicist	see text
Lorenz, H.	1937	German	amateur astronomer	classical gas theory
Freeman, I.	1938	American	physicist	varying gravity
Arnot, F.	1938	British	physicist	inspired by Milne's cosmology
Kalmar, L.	1938	Hungarian	amateur astronomer	modification of classical mechanics
Gheury de Bray, M.	1939	British	amateur physicist	varying speed of light

Figure 9: John Henry Reynolds (en.wikipedia.org).

The first to propose a tired-light hypothesis after Zwicky and Belopolsky was Princeton's John Quincy Stewart, who was known as the co-author, together with R.S. Dugan and H.N. Russell, of the widely-used textbook *Astronomy*. From manipulations with the fundamental constants of nature, among which he counted Hubble's constant, Stewart (1931) suggested that photons lost their energy $E = h\nu$ in proportion to the distance r from the source. Confusingly, instead of using the standard definition of Hubble's constant H he took it to be the corresponding length given by c/H. Re-written in the conventional form, Stewart (1931) proposed that

$$\nu(r) = \nu_0 \exp\left(-\frac{H}{c} r\right) \qquad (8)$$

This simplest possible form of the tired-light hypothesis was to reappear several times over the next decade. While Zwicky's tired-light hypothesis assumed nebular photons to interact with intergalactic matter, according to Stewart's proposal photons just lost energy without any external agency.

Figure 10: Walther Nernst (en.wikipedia.org).

Inspired by quantum mechanics, other hypotheses in the period supposed that a photon of energy $h\nu$ might spontaneously split into two or more photons of lesser energy and frequency (Halpern, 1933). The reduction in energy would on the average be proportional to the distance travelled by the photon through empty space.

> Is the Doppler effect the only possible interpretation? If the slowing down of light over vast distances is a possibility, shifts toward the red should be expected.

This is how the British astronomer John Reynolds (1874–1949; Figure 9; Johnson, 1950), a specialist in galactic astronomy, ended a survey paper on the evidence for the Expanding Universe (Reynolds, 1932: 462). He referred to a recent proposal by his colleague in Chicago, Astronomy Professor William Duncan MacMillan (1871–1948), who had long advocated an eternal, stationary and self-perpetuating Classical Universe (Kragh, 1995). MacMillan (1932) supposed that if

> ... there is a leakage of energy from the photon in its long journey over millions of years, due perhaps to an inherent instability in the photon, or, possibly, to collisions with other photons.

From this he derived the same frequency–distance relation as Stewart, commenting that

> ... the assumed tendency of the energy of the photon to evaporate in its long journey through space leads to a law of frequency which is indistinguishable from the law of Doppler effect as given by Hubble and Humason.

MacMillan's conception of the Universe was to a large extent shared by the German physical chemist and Nobel Prize Laureate Walther Nernst (1864–1941; Figure 10; Bartel and Huebener, 2007), who during the 1930s turned from chemistry to astrophysics and cosmology. Nernst's tired-light explanation of the redshifts, essentially the same as the one of Stewart and MacMillan, led to a redshift–distance formula of the form

$$c\frac{\Delta\nu}{\nu} = Hr \qquad (9)$$

According to Nernst (1935), the constant H was not really a constant of the Universe but a 'quantum constant' giving the decay rate of photons.

Other tired-light proposals in the period were based on the assumption that one or more of the constants of nature varied slowly in cosmic time. For example, Samuel Sambursky (1900–1990; Figure 11) at the Hebrew University in Jerusalem suggested that

> ... a static universe with a quantum of action decreasing with time is equivalent to an expanding universe with a constant quantum of action. (Sambursky, 1937: 336).

Sambursky assumed that Hubble's constant H and the variation of Planck's constant h were related, since

$$H = -\frac{1}{h}\frac{\mathrm{d}h}{\mathrm{d}t} \quad (10)$$

From this it followed that

$$\mathrm{d}h/\mathrm{d}t \cong 10^{-50}\ \mathrm{J} \quad (11)$$

Although there was not the slightest empirical evidence that the constants of nature varied in time, Zwicky welcomed the hypothesis. He believed that it might contribute to "... a deeper understanding of the redshift of light from distant nebulae and other astronomical phenomena." (Zwicky, 1938). On the other hand, he denied that the speed of light depended on the age of the Universe, a hypothesis which at the time was suggested by several writers (Table 1). According to some versions of the hypothesis, as proposed by Gheury de Bray in England, Hugh Gramatzki in Germany, and Peter Wold in the United States, a decreasing speed of light might explain the redshifts on the basis of a Static Universe (North, 1990: 231).

5 THE STATUS OF NON-EXPANDING HYPOTHESES

Astronomers in the 1930s realized that observational evidence for the Expanding Universe was limited to the galactic redshifts and the Hubble law. They were aware of the alternative, a Static Universe supplied with a redshift mechanism, and consequently some astronomers adopted an agnostic attitude. Hubble was among them, and he was followed by his colleague at Mount Wilson Observatory, the stellar spectroscopist Olin Wilson (1909–1994; Apt, 2002), who wrote:

> At the present time it is not possible to decide observationally whether the red shift is a true Doppler effect, representing relative motion, or whether it is a hitherto unrecognized phenomenon of a different kind, such as, for example, the gradual dissipation of photonic energy. (Wilson, 1939: 634–635).

However, most mainstream physicists and astronomers accepted that the galactic redshifts were due to recession, if not necessarily to the relativistic expansion of space. When they referred to the static alternative it was not because they found it attractive but because it offered a solution to the serious time-scale problem of the Expanding Universe. The British astronomer Harrold Knox-Shaw (1885–1970; Wilds, 2014), President of the Royal Astronomical Society during 1931–1932, probably spoke for the majority of astronomers when he said:

> Some doubt has been expressed as to whether the red-shifts in their [the nebulae's] spectra should be interpreted as a Doppler effect, but in the absence of any satisfactory alternative explanation I consider that we are justified in expressing them in terms of velocity. (Knox-Shaw, 1933: 308).

Astronomers had for decades been used to stellar Doppler shifts and could therefore regard the galactic redshifts as just an extension of previous practice. This is what Richard Richardson at Mount Wilson Observatory suggested in a comment on what he called "... the greatest puzzle facing astronomers today." According to Richardson (1940: 332),

> Astronomers hesitate to believe that displacements of spectral lines toward the violet or red on which they have relied so long do not indicate real velocities of approach or recession.

The core group of relativist cosmologists conceived the alternatives to be speculative and based on arbitrary assumptions with no support in known physics. According to them, the redshifts followed naturally from relativistic cosmology whereas tired-light theories were contrived, *ad hoc* and unnecessary. This judgment was later expressed in much stronger language by the French astronomer Paul Couderc (1899–1981; Marché, 2014) from Paris Observatory. Describing those who denied the expansion of the Universe as 'conservative spirits', Couderc (1952: 97) wrote:

Figure 11: Samuel Sambursky (en.wikipedia.org).

> The vanity and sterility of twenty years' opposition to recession is characteristic of a poor intellectual discipline. To hunt for an *ad hoc* interpretation, to search for a means of sidestepping a phenomenon which is strongly indicated by observation simply because it leads to "excessive" conclusions is surely contrary to scientific method worthy of the name. As long as there is no precise, concrete phenomenon capable of casting doubts on the reality of the recession and of explaining the shifts differently, I maintain that it is *a priori* unreasonable to reject recession.

By and large, and despite the reservations expressed by Hubble and a few others, by 1940 the Static Universe was no longer part of mainstream astronomy. On the other hand, it had not yet been replaced by the Expanding Universe in the sense of relativistic cosmology.

6 A GLANCE INTO LATER DEVELOPMENTS

Although redshift alternatives to the Expanding Universe were not held in high regard after WWII, a large number of tired-light hypotheses continued to be proposed. In 1954 the German-born British astronomer Erwin Finlay-Freundlich (1885–1964; Figure 12) revived interest in the tradition initiated by Zwicky. Finlay-Freundlich, whose name was originally Freundlich, was a former collaborator of Einstein and by 1954 he served as Professor of Astronomy at St. Andrews University in Scotland (Batten, 2014). For stellar redshifts he suggested a linear redshift–distance law which he believed was valid also for

Figure 12: A painting of Erwin Finlay-Freundlich by Ernest Mandler (courtesy: Art UK).

the galactic redshifts and whose physical mechanism might be a kind of photon–photon interaction (Finlay-Freundlich, 1954; Born, 1954). With r denoting the distance light passes through a radiation field of temperature T, he stated the formula as

$$\frac{\Delta\lambda}{\lambda} \propto T^4 r \qquad (12)$$

Finlay-Freundlich's proposal attracted considerable interest and during the following three decades a large number of tired-light hypotheses were published by physicists, astronomers and amateur scientists.

However, according to nearly all mainstream astrophysicists and cosmologists they are untenable. Not only are they in conflict with observations, but they also rested on unverifiable assumptions of an *ad hoc* nature. Consequently, tired-light alternatives to the Expanding Universe are no longer found in reputable journals devoted to research in astronomy and cosmology but are largely relegated to journals and internet sites of a more speculative nature. Still, in 1986 the prestigious *Astrophysical Journal* included a paper arguing a tired-light alternative to the Expanding Universe. The author, a recent Ph.D. graduate from Portland State University writing from a private home address, concluded in favour of

> ... a cosmology in which the universe is conceived of as being stationary, Euclidean, and slowly evolving, and in which photons lose a small fraction of their total energy for every distance increment they cover on their journey through space. (LaViolette, 1986: 552).

Zwicky's spirit was still alive!

7 CONCLUSION

Tired-light hypotheses for the origin of the galactic redshifts are still considered as possible alternatives to the Expanding Universe, but they are no longer taken seriously in mainstream cosmology. The situation in the 1930s was different, with Hubble and a few other astronomers expressing interest in the hypotheses. The first and most influential proposal of a tired-light mechanism, Zwicky's gravitational drag hypothesis of 1929, was followed by a dozen similar but less detailed proposals. In most cases the *raison d'être* was to retain a Static Universe and avoid the conclusion that galaxies were receding at very high velocities. The cool response from astronomers was in part based on methodological arguments and in part on comparison with observations. It is worth noting that many astronomers at the time subscribed to a Doppler interpretation of the redshifts without accepting the expansion of the Universe associated with the new theory of relativistic cosmology.

8 REFERENCES

Apt, H., 2002. Olin Craddock Wilson. *Biographical Memoirs, National Academy of Sciences*, 82, 353–371.

Arnot, F.L., 1938. Cosmological theory. *Nature*, 141, 1142–1143.

Arx, W., 1932. Light and the universe. *Popular Astronomy*, 40, 438–439.

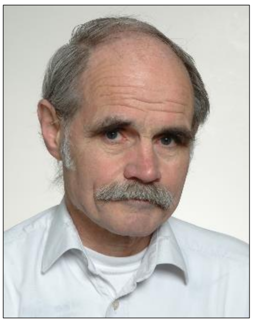
Bartel, H., and Heubener, R., 2007. *Walther Nemst: Pioneer of Physics and Chemistry*. Singapore, World Scientific.

Batten, A.H., 2014. The beginnings of modern astronomy at the University of St. Andrews. *Journal of Astronomical History and Heritage*, 17, 3–44.

Belopolsky, A., 1929. Die Fixsterne und extra-galak-

tischen Nebel. *Astronomische Nachrichten*, 236, 357.
Belopolsky, A., 1930. http://luchemet.narod.ru/hubble.html (accessed January 2017).
Bogdan, T.J., 2014a. Belopolsky, Aristarkh Apollonovich. In T. Hockey et al., 193–194.
Bogdan, T.J., 2014b. Robertson, Howard Percy. In T. Hockey et al., 1848–1850.
Born, M., 1954. On the interpretation of Freundlich's red-shift formula. *Proceedings of the Physical Society A*, 67, 193–194.
Broughton, P., 2014. ten Bruggencate, Paul. In T. Hockey et al., 2135–2137.
Buc, H.E., 1932. The red shift. *Journal of the Franklin Institute*, 214, 197–198.
Chalmers, J.A., and Chalmers, B., 1935. The expanding universe – an alternative view. *Philosophical Magazine*, 19, 436–446.
Christianson, G.E., 1995. *Edwin Hubble: Mariner of the Nebulae*. New York, Farrar, Strauss and Giroux.
Couderc, P., 1952. *The Expansion of the Universe*. London, Faber and Faber.
Eigenson, M.S., 1932. Über die Ursache der positiven Radialgeschwindigkeiten der extragalaktischen Nebel und ihrer Korrelation mit den Entfernungen derselben. *Zeitschrift für Astrophysik*, 4, 224–230.
Finlay-Freundlich, E., 1954. Red shifts in the spectra of celestial bodies. *Philosophical Magazine*, 45, 303–319.
Freeman, I.M., 1938. The red shift of the nebular spectrum lines. *Physical Review*, 53, 207.
Gheury de Bray, M.E., 1939. Interpretation of the red-shifts of the light from extra-galactic nebulae. *Nature*, 144, 285.
Gramatzki, H.J., 1934. Zur Elektrodynamik des interstellaren Raumes. *Zeitschrift für Astrophysik*, 8, 87–95.
Gunn, R., 1935. Radiation reaction forces and the expanding universe. *Journal of the Franklin Institute*, 220, 167–186.
Haas, A.E., 1936. The size of the universe and the fundamental constants of physics. *Science* 84, 578–579.
Halm, J., 1935. On the theory of an "expanding universe." *Journal of the Astronomical Society of South Africa*, 4, 29–31.
Halpern, O., 1933. Scattering processes produced by electrons in negative energy states. *Physical Review*, 44, 855–856.
Hetherington, N., 1982. Philosophical values and observations in Edwin Hubble's choice of a model of the universe. *Historical Studies in the Physical Sciences*, 13, 41–67.
Hockey, T. et al. (eds.), 2014. *Biographical Encyclopedia of Astronomers. Second Edition*. New York, Springer.
Hubble, E.P., 1929. A clue to the structure of the universe. *Astronomical Society of the Pacific Leaflets,* 1, 93–96.
Hubble, E.P, and Humason, M., 1931. The velocity-distance relation among extra-galactic nebulae. *Astrophysical Journal*, 74, 43–80.
Hubble, E.P., and Tolman, R.C., 1935. Two methods of investigating the nature of the nebular red-shift. *Astrophysical Journal*, 82, 302–337.
Jeans, J., 1930. *The Mysterious Universe*. Cambridge, Cambridge University Press.
Johnson, M., 1950. John Henry Reynolds, obituary. *Monthly Notices of the Royal Astronomical Society*, 110,131–133.
Kaiser, F., 1934. Zur Deutung der Spektrallinien-Rotverschiebung in den Spiralnebeln und Nebelhaufen. *Astronomische Nachrichtung*, 252, 11–12.
Kalmar, L., 1938. Die klassische Deutung der Hubble-Erscheinung. *Astronomische Nachrichtung*, 266, 147–148.
Kennedy, R.J., and Barkas, W., 1936. The nebular redshift. *Physical Review*, 49, 449–452.
Kinder, A.J., 2009. Mrs Vera Reade, FRAS (1905–1986). *Journal of the British Astronomical Association*, 119, 13–16.
Kirkwood, J.G., Wulf, O.R., and Epstein, P.S., 1952. Richard Chase Tolman. *Biographical Memoirs, National Academy of Sciences*, 27, 139–153.
Knill, O., 2014. Zwicky, Fritz. In T. Hockey et al., 2432–2434.
Knox-Shaw, H., 1933. Distances and motions of the extra-galactic nebulae. *Monthly Notices of the Royal Astronomical Society*, 93, 304–310.
Kragh, H., 1995. Cosmology between the wars: The Nernst-MacMillan alternative. *Journal for the History of Astronomy*, 26, 94–115.
Kragh, H., and Smith, R., 2003. Who discovered the expanding universe? *History of Science*, 41, 141–162.
LaViolette, P.A., 1986. Is the universe really expanding? *Astrophysical Journal*, 301, 544–553.
Lorenz, H. 1937. Radialschwingungen in Gaskugeln und Spiralnebelflucht. *Astronomische Nachrichten*, 263, 141–148.
MacMillan, W.D., 1932. Velocities of the spiral nebulae. *Nature*, 129, 93.
Marché, J.D., 2014. Couderc, Paul. In T. Hockey et al., 471–472.
Mason, W.R., 1932. A Newtonian gravitational system and the expanding universe. *Philosophical Magazine*, 92, 386–400.
Milne, A.E., 1952. *Sir James Jeans. A Biography*. Cambridge, Cambridge University Press.
Mumford, G.S., 2014. Stewart, John Quincy. In T. Hockey et al., 2059–2060.
Nernst, W., 1935. Einige weitere Anwendungen der Physik auf die Sternentwicklung. *Sitzungsberichte der Preussische Akademie der Wissenschaften*, 28, 473–479.
North, J., 1990. *The Measure of the Universe: A History of Modern Cosmology*. New York, Dover Publications.
Northrop, F.S.C., 1934. A material universe which is static and compatible with the observed red-shift. *Physical Review*, 45, 737.
Nussbaumer, H., 2014. Einstein's conversion from his static to an expanding universe. *European Physical Journal H*, 39, 37–62.
Nussbaumer, H., and Bieri, L., 2009. *Discovering the Expanding Universe.* Cambridge, Cambridge University Press.
Peebles, P.J E., 1971. Two old cosmological tests. *Comments on Astrophysics and Space Physics*, 3, 173–177.
Reade, V., 1940. A possible disproof of the expanding universe theory. *Journal of the British Astronomical Association*, 50, 161–162.
Reynolds, J.H., 1932. Physical and observational evidence for the expanding universe. *Nature*, 130, 458–462.
Richardson, R.S., 1940. Illusion or reality in the uni-

verse. *Astronomical Society of the Pacific Leaflets*, 3, 325–332.
Robertson, H.P., 1932. The expansion of the universe. *Science*, 76, 221–226.
Sambursky, S., 1937. Static universe and nebular red shift. *Physical Review*, 52, 335–338.
Schier, H., 1932. Dynamische Ursachen von Spektrallinienverschiebungen? *Astronomische Nachrichtungen*, 246, 269–286.
Stewart, J.Q., 1931. Nebular red shift and universal constants. *Physical Review*, 38, 2071.
Struve, O., 1935. A. A. Belopolsky. *Popular Astronomy*, 43, 16–17.
ten Bruggencate, P., 1930. The radial velocities of globular clusters. *Proceedings of the National Academy of Sciences*, 16, 111–118.
ten Bruggencate, P., 1937. Dehnt sich das Weltall aus? *Naturwissenschaften*, 25, 561–566.
Tolman, R.C., 1934. *Relativity, Thermodynamics, and Cosmology*. Oxford, Oxford University Press.
Tropp, E., Frenkel, V., and Chernin, A., 1993. *Alexander A. Friedmann: The Man Who Made the Universe Expand*. Cambridge, Cambridge University Press.
Underwood, R.S., 1935. A suggested test of the "expanding universe" and alternative theories. *Popular Astronomy*, 43, 194–195.
Wilds, R.P., 2014. Knox-Shaw, Harold. In T. Hockey et al., 1230–1231.
Wilson, O.C., 1939. Possible applications of supernovae to the study of the nebular red shifts. *Astrophysical Journal*, 90, 634–636.
Wold, P.I., 1935. On the redward shift of spectral lines of nebulae. *Physical Review*, 47, 217–219.
Zwicky, F., 1929a. On the red shift of spectral lines through interstellar space. *Proceedings of the National Academy of Sciences*, 15, 773–779.
Zwicky, F., 1929b. On the possibilities of a gravitational drag of light. *Physical Review*, 34, 1623–1624.
Zwicky, F., 1933. Die Rotverschiebung von extragalaktischen Nebeln. *Helvetica Physica Acta*, 6, 110–127.
Zwicky, F., 1935. Remarks on the redshift from nebulae. *Physical Review*, 48, 802–806.
Zwicky, F., 1938. Intrinsic variability of the so-called fundamental physical constants. *Physical Review*, 53, 315.
Zwicky, F., 1939. On the formation of clusters of nebulae and the cosmological time scale. *Proceedings of the National Academy of Sciences*, 25, 604–609.
Zwicky, F., 1942. On the large scale distribution of matter in the universe. *Physical Review*, 61, 489–504.
Zwicky, F., 2009. The redshift of extragalactic nebulae. *General Relativity and Gravitation*, 41, 207–224.



Helge Kragh is Emeritus Professor at the University of Copenhagen, Denmark. His main work is on the history of post-1850 physical sciences, including topics such as quantum theory, astrophysics, cosmology and physical chemistry. Among his recent books are *Masters of the Universe* (2015) and *Vary-ing Gravity* (2016). He and Malcolm Longair currently are co-editing *The Oxford Handbook of the History of Modern Cosmology*, which is expected to be published in 2018.

Journal of Astronomical History and Heritage, 20(1), 13–20 (2017).

APIANUS' LATITUDE VOLVELLES – HOW WERE THEY MADE?

Lars Gislén
Lund University, Dala 7163, 24297 Hörby, Sweden.
Email: LarsG@vasterstad.se

Abstract: This paper studies the working and construction of the volvelles in Petrus Apianus' *Astronomicum Caesareum* that describe the latitudes of the planets. It is found that they can be constructed using a graphical method.

Keywords: volvelle, planetary latitudes, Petrus Apianus.

1 INTRODUCTION

Petrus Apianus' *Astronomicum Caesareum* contains a large set of complicated and ingenious volvelles that can be used to compute the longitudes of the planets, the Sun and the Moon, as well as the latitudes of the planets and the Moon. Besides there are volvelles for finding different astrological quantities and for determining the date of religious seasons like the Easter and Passover. In an earlier paper (Gislén, 2016) I studied the working and construction one of Apianus' lunar eclipse volvelles and also provided some biographical data on him.

In this paper I will study the volvelles used for computing the planetary latitudes in *Astronomicum Caesareum*. I will study one superior planet, Mars, and the two inferior planets, Venus and Mercury. Apianus used the theory of planetary latitudes as implemented in the *Almagest* (Toomer, 1984). The Ptolemaic theory of the planetary latitudes is very complicated, and below I give a much condensed description of it; further details can be found in Neugebauer (1975), Pedersen (1974: 355), and Swerdlow (2005).

2 DESCRIPTION OF THE VOLVELLES

In order to use the latitude volvelles you need two input parameters: the longitude λ of the epicycle centre, counted from the top of the deferent (see below), and the anomaly angle γ. The Mars volvelle (Figure 1) has a rim with two sets of graduations, the inner rim being graduated counter-clockwise 0˚ to 180˚ from the top left to the top right, then going back clockwise from 180˚ to the left top 360˚. This is the entry of the longitude of the centre. Radially you set the anomaly angle starting at the periphery of the central disk at 0˚ and reaching the rim at 180˚, then returning back to the central disk at 360˚. This scale is displayed in the wedge-formed area at the top of the volvelle. There is a thread going from the centre of the volvelle with a small bead that can slide along the thread.

The working is as follows. First you use the anomaly scale to set the position of the bead on the thread. Then the tread with the bead is set against the longitude of the centre on the rim and then the latitude is read off from the line found below the bead, if necessary interpolating between two adjacent lines. The red area of the volvelle signifies northern, positive (*septentrionalis*) latitudes while the green area signifies southern, negative (*meridionalis*) latitudes. For the Venus and Jupiter volvelles the colours are reversed.

The Saturn and Jupiter volvelles are very similar but the rim graduation is displaced taking into account that the ascending node of Saturn is assumed to have an ecliptic longitude of 50˚ and that of Jupiter of –20˚. These values are the same as those used in the *Almagest* and the Toledan Tables.

The Venus volvelle (Figure 2) has an outer longitude rim graduated counter-clockwise from 0˚ to 360˚ and is to be used for anomalies from 0˚to 180˚. The inner rim is graduated clockwise from 0˚ to 360˚ from the bottom of the volvelle and is to be used for anomalies from 180˚ to 360˚.

The Mercury volvelle (Figure 3) is divided into two sections, a left part and a right part. The left rim is graduated counter-clockwise from 0˚ to 360˚ with the zodiacal signs written with Latin numbers and is to be used for anomalies from 0˚to 180˚. The right rim is graduated clockwise from 0˚ to 360˚ with Arabic numbers and is to be used for anomalies from 180˚to 360˚.

3 THEORY

The planetary latitude in the Ptolemaic scheme used by Apianus is calculated using two input variables, the longitude of centre counted from the top of the deferent circle and the anomaly. Ptolemy then uses these variables as entries in a set of tables with two columns for each planet (Toomer, 1984: 632). Identical tables can be found for instance in Al-Battani (Nallino, 1903(II): 140) and several versions of the Alfonsine Tables. The Handy Tables (Halma, 1822–1825), the Toledan Tables (Pedersen, 2002:1309) and Al-Khwarizmi (Suter, 1914:139) use a different scheme.

3.1 Superior Planets

The superior planets have a deferent circle that is inclined by a fixed angle relative to the ecliptic plane (see Figure 4). The nodes are located at the crossings between the deferent circle plane and the ecliptic plane. The epicycle in turn is deviated from the deferent plane by an angle relative to a line in the deferent plane from the deferent centre to the epicycle centre. This deviation is maximum when the epicycle centre is at the top/bottom of the inclined deferent and zero at the nodes. The Ptolemaic procedure to compute the latitude for a superior planet is to use Table 1 with the anomaly, γ, as an argument. For Mars, the first column, C_1, is used for longitude of centre arguments less than 90˚ and larger than 270˚, the second one C_2, for longitude of centre arguments between 90˚ and 270˚.

The longitude of centre argument, λ, is as stated above, the longitude of the epicycle centre, measured from the top of the deferent circle. Mathematically the latitude is then computed from

$$\beta = C_{1,2}(\gamma) \sin(\lambda + 90^\circ) \quad (1)$$

In the *Almagest* the last sine function is represented by a separate column.

The original unit of the tables is degrees: minutes, and I have converted this to decimal units in an extra third column for each planet in Table 1.

3.2 Inferior Planets

The inferior planets have a more complicated mechanism to account for the latitude. As for the superior planets the deferent circle is inclin-

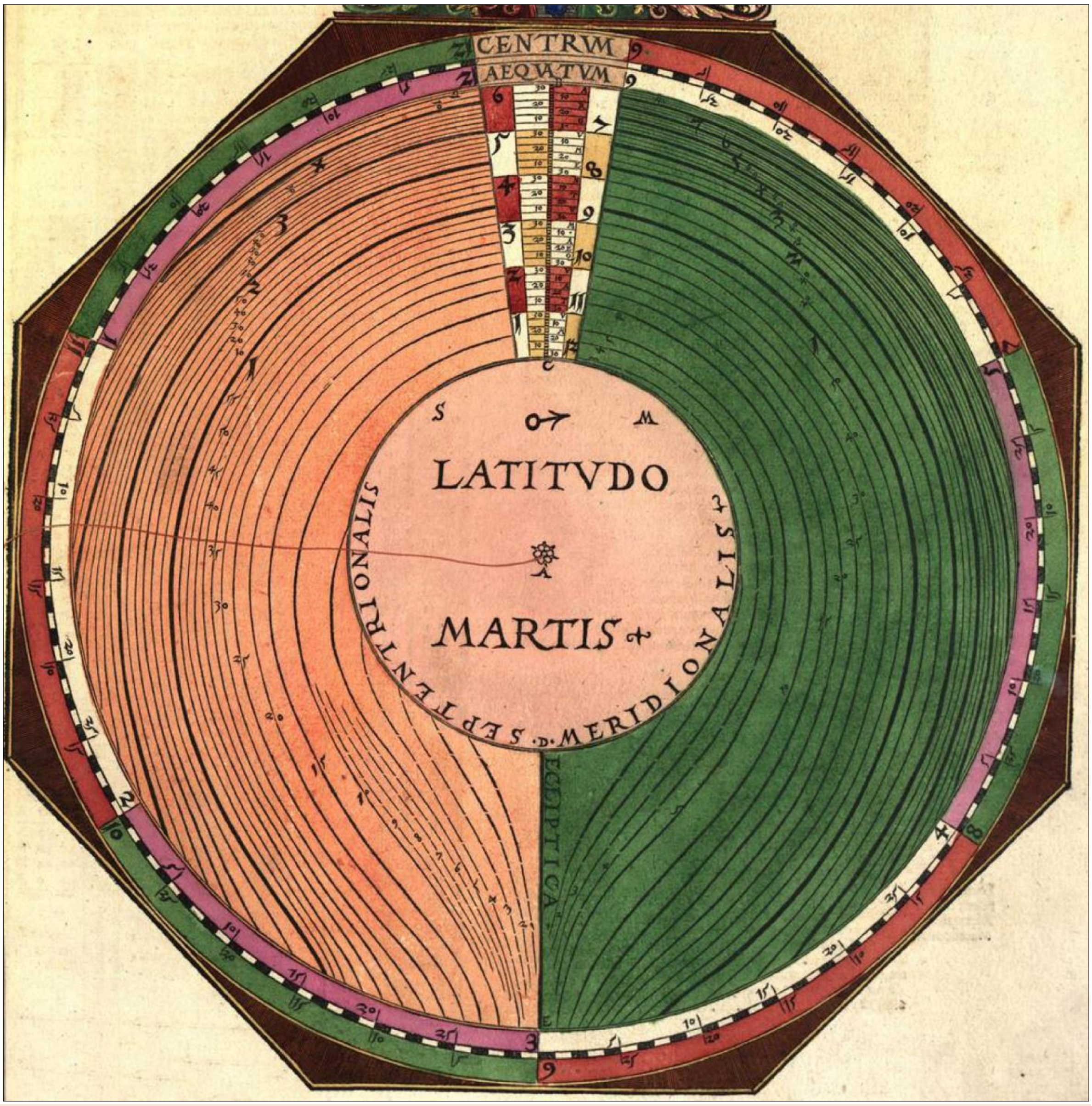


Figure 1: The Mars volvelle.

ed by an angle relative to the ecliptic plane, but this inclination is variable, being zero when the planet is at the nodes and maximum/minimum at right angles to the nodes. Secondly, the epicycle is, as for the superior planets, deviated relative to the deferent plane, but the deviation is zero at the top/bottom of the deferent and maximum/minimum at the nodes. Thirdly, the epicycle has a rocking motion perpendicular to the epicycle deviation. The rocking angle (slant, obliquity) is zero at the nodes and maximum/minimum at the top/bottom of the deferent. This complicated motion is then approximated by Ptolemy as a sum of three separate latitudes:

$$\beta = C_0 \sin^2(\lambda + 90^\circ) + C_1(\gamma)\sin(\lambda) + C_2(\gamma)\, f \sin(\lambda + 90^\circ) \qquad (2)$$

The first term describes the inclination of the deferent plane, the second term the deviation of the epicycle, and the third term the rocking motion. C_0 is a fixed angle being $0^\circ 10' \approx 0.167^\circ$ for Venus and $-0^\circ 45' = -0.75^\circ$ for Mercury. $C_1(\gamma)$ and $C_2(\gamma)$ are to be taken from Table 1 with the anomaly as an argument. For Mercury the second and third terms in (2) are taken with the opposite sign.

The factor f is 1 for Venus but for Mercury it is 0.9 if $\lambda < 180^\circ$ and 1.1 if $\lambda > 180^\circ$.

The combined effect of the three terms in (2) is "... to give the epicycle a heaving, pitching, and rolling motion like that of a ship in a heavy sea." (Pedersen, 1974: 370).

In the C_1 table I have changed the sign of the values of γ for values larger than 90° and less than 270° in the decimal column. This makes

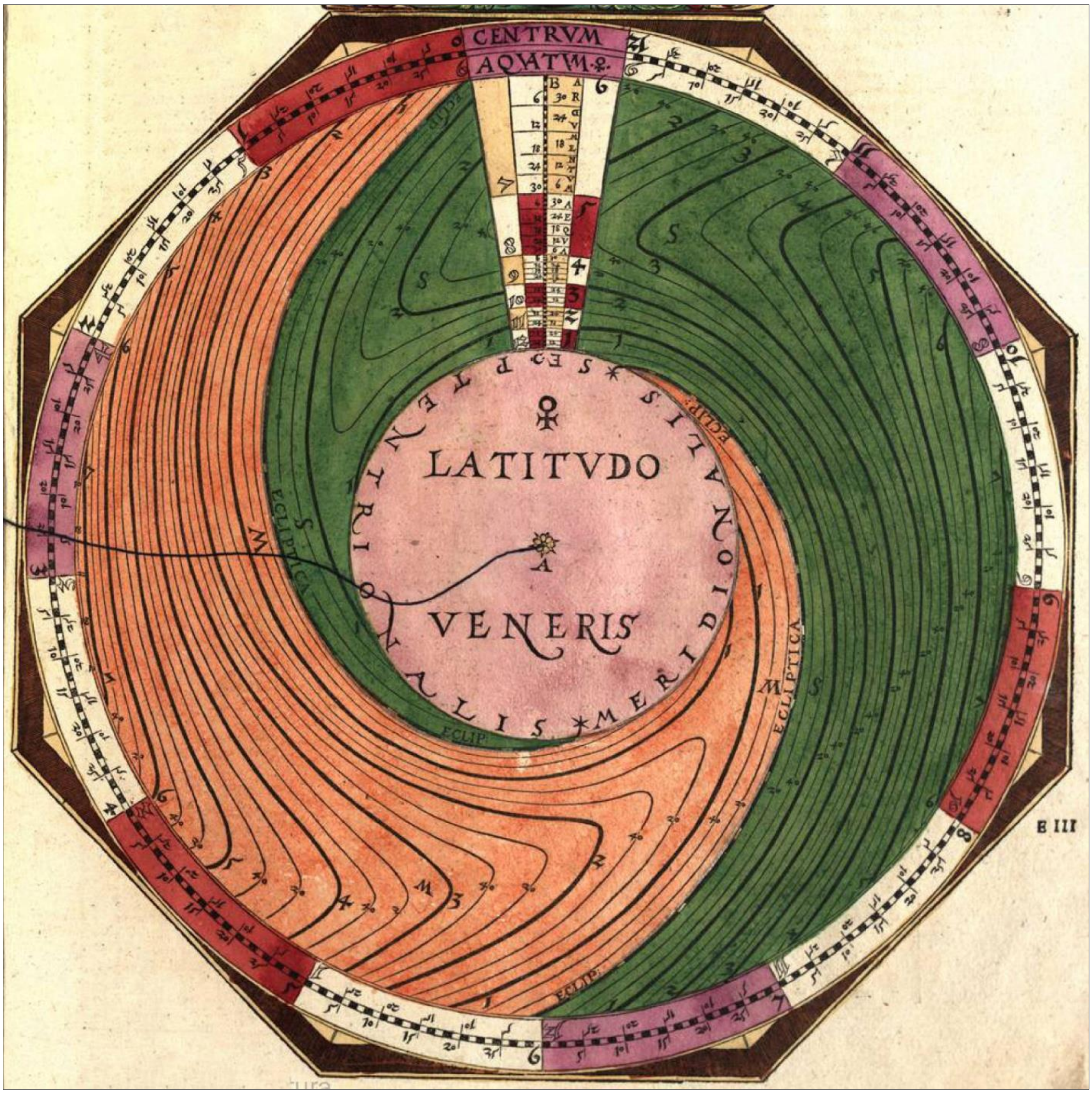


Figure 2: The Venus volvelle.

some of the subsequent calculations easier. In the *Almagest* this is taken care of by a special rule.

On my website http://home.thep.lu.se/~larsg/Site/Welcome.html there is a Java application (LatitudeViewer1.jar) that can be freely downloaded. It illustrates in a qualitative way the complicated motion of the deferent and epicycle for the superior and inferior planets in the Ptolemaic model. You will need to have the Java Runtime Environment (JRE) installed on the computer in order to run the file. The JRE can be freely downloaded from https://www.java.com/en/download. On a Macintosh you may need to change your security settings in System Preferences/Security & Privacy/Open Anyway button to be allowed to run the program.

4 DISCUSSION AND CONCLUDING REMARKS

It is interesting to speculate how Apianus constructed the quite intricate set of lines showing the latitudes. One way would be to invert the mathematical relations above, something that is analytically impossible, but could be done numerically. Another and more likely way for Apianus would be to try to graph the relations and then use the graphs to extract the necessary data. I used Microsoft Excel to make tables for the three planets Mars, Venus, and Mercury for a selected set of values of γ and λ and then graphed these tables. Figures 5, 6, and 7 show the results.

For Mars and Venus, you use the anomaly $\gamma' = 360 - \gamma$ if $\gamma > 180^\circ$.

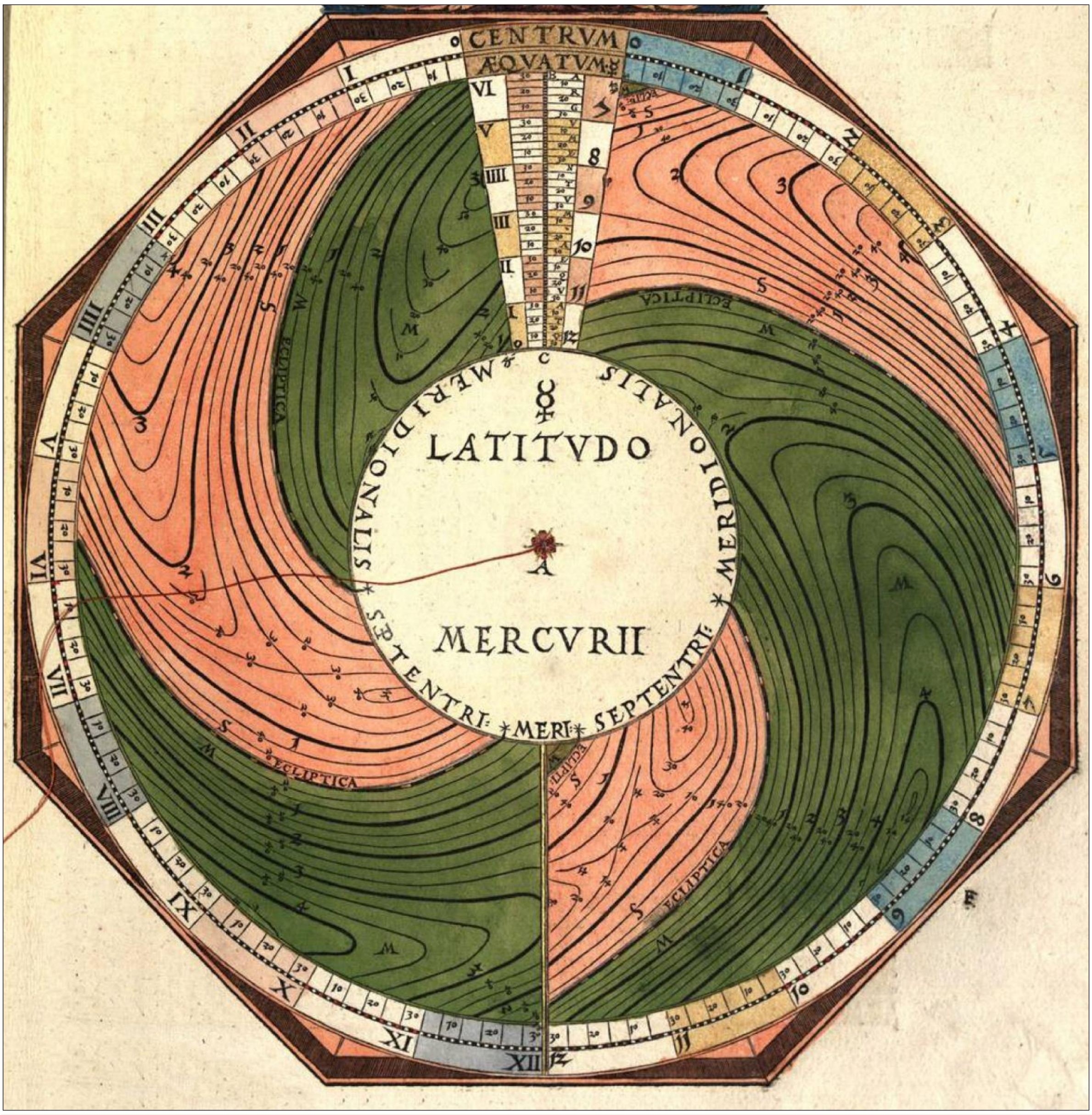


Figure 3: The Mercury volvelle.

It is quite tedious to do the computations leading to these graphs but mathematically it is rather simple and could be done by even an inexperienced person given a set of simple instructions. In order to construct his volvelles with some accuracy, Apianus would certainly have to draw the graphs in a larger scale than can be represented in this paper. But I have found it quite possible to use the graphs to find specific points (λ, γ) in the volvelle plane and then to connect the points by lines and reproduce

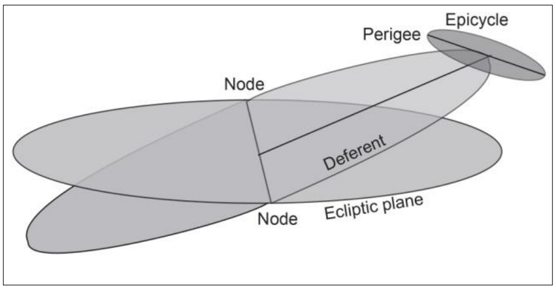


Figure 4: Deferent inclination and epicycle deviation.

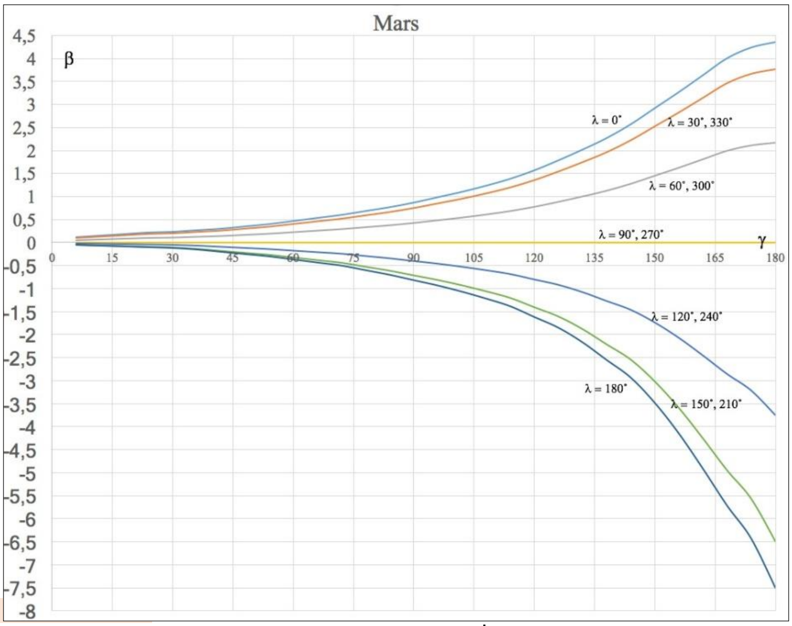


Figure 5: (γ, λ) graph for Mars.

Table 1: Fundamental tables

Anomaly		Mars						Venus						Mercury					
□		C1			C2			C1			C2			C1			C2		
0	360	0	5	0.08	0	2	0.03	1	3	1.05	0	0	0	1	46	1.77	0	0	0.00
6	354	0	7	0.12	0	3	0.05	1	2	1.03	0	8	0.13	1	45	1.75	0	11	0.18
12	348	0	9	0.15	0	4	0.07	1	1	1.02	0	16	0.27	1	44	1.73	0	22	0.37
18	342	0	11	0.18	0	5	0.08	1	0	1.00	0	24	0.40	1	43	1.72	0	33	0.55
24	336	0	13	0.22	0	6	0.10	0	59	0.98	0	33	0.55	1	40	1.67	0	44	0.73
30	330	0	14	0.23	0	7	0.12	0	57	0.95	0	41	0.68	1	36	1.60	0	55	0.92
36	324	0	16	0.27	0	9	0.15	0	55	0.92	0	49	0.82	1	30	1.50	1	6	1.10
42	318	0	18	0.30	0	12	0.20	0	51	0.85	0	57	0.95	1	24	1.40	1	17	1.28
48	312	0	21	0.35	0	15	0.25	0	46	0.77	1	5	1.08	1	16	1.27	1	27	1.45
54	306	0	24	0.40	0	18	0.30	0	41	0.68	1	13	1.22	1	8	1.13	1	35	1.58
60	300	0	28	0.47	0	22	0.37	0	36	0.60	1	20	1.33	0	59	0.98	1	44	1.73
66	294	0	32	0.53	0	26	0.43	0	29	0.48	1	28	1.47	0	49	0.82	1	51	1.85
72	288	0	36	0.60	0	30	0.50	0	23	0.38	1	35	1.58	0	38	0.63	2	0	2.00
78	282	0	41	0.68	0	36	0.60	0	16	0.27	1	43	1.72	0	26	0.43	2	7	2.12
84	276	0	46	0.77	0	42	0.70	0	8	0.13	1	50	1.83	0	16	0.27	2	14	2.23
90	270	0	52	0.87	0	49	0.82	0	0	0.00	1	57	1.95	0	0	0.00	2	20	2.33
96	264	0	59	0.98	0	56	0.93	0	10	-0.17	2	3	2.05	0	15	-0.25	2	27	2.45
102	258	1	6	1.10	1	4	1.07	0	20	-0.33	2	9	2.15	0	31	-0.52	2	28	2.47
108	252	1	14	1.23	1	13	1.22	0	32	-0.53	2	15	2.25	0	48	-0.80	2	29	2.48
114	246	1	23	1.38	1	23	1.38	0	45	-0.75	2	20	2.33	1	6	-1.10	2	30	2.50
120	240	1	34	1.57	1	37	1.62	0	59	-0.98	2	25	2.42	1	25	-1.42	2	29	2.48
126	234	1	47	1.78	1	51	1.85	1	13	-1.22	2	28	2.47	1	45	-1.75	2	26	2.43
132	228	2	1	2.02	2	10	2.17	1	38	-1.63	2	30	2.50	2	6	-2.10	2	20	2.33
138	222	2	16	2.27	2	33	2.55	1	57	-1.95	2	30	2.50	2	26	-2.43	2	11	2.18
144	216	2	34	2.57	2	56	2.93	2	23	-2.38	2	28	2.47	2	47	-2.78	2	0	2.00
150	210	2	55	2.92	3	29	3.48	3	13	-3.22	2	22	2.37	3	7	-3.12	1	45	1.75
156	204	3	16	3.27	4	9	4.15	3	43	-3.72	2	12	2.20	3	26	-3.43	1	29	1.48
162	198	3	38	3.63	4	55	4.92	4	26	-4.43	1	55	1.92	3	42	-3.70	1	10	1.17
168	192	4	0	4.00	5	43	5.72	5	24	-5.40	1	27	1.45	3	54	-3.90	0	48	0.80
174	186	4	14	4.23	6	26	6.43	6	24	-6.40	0	48	0.80	4	2	-4.03	0	28	0.47
180	180	4	21	4.35	7	30	7.50	7	12	-7.20	0	0	0.00	4	5	-4.08	0	0	0.00

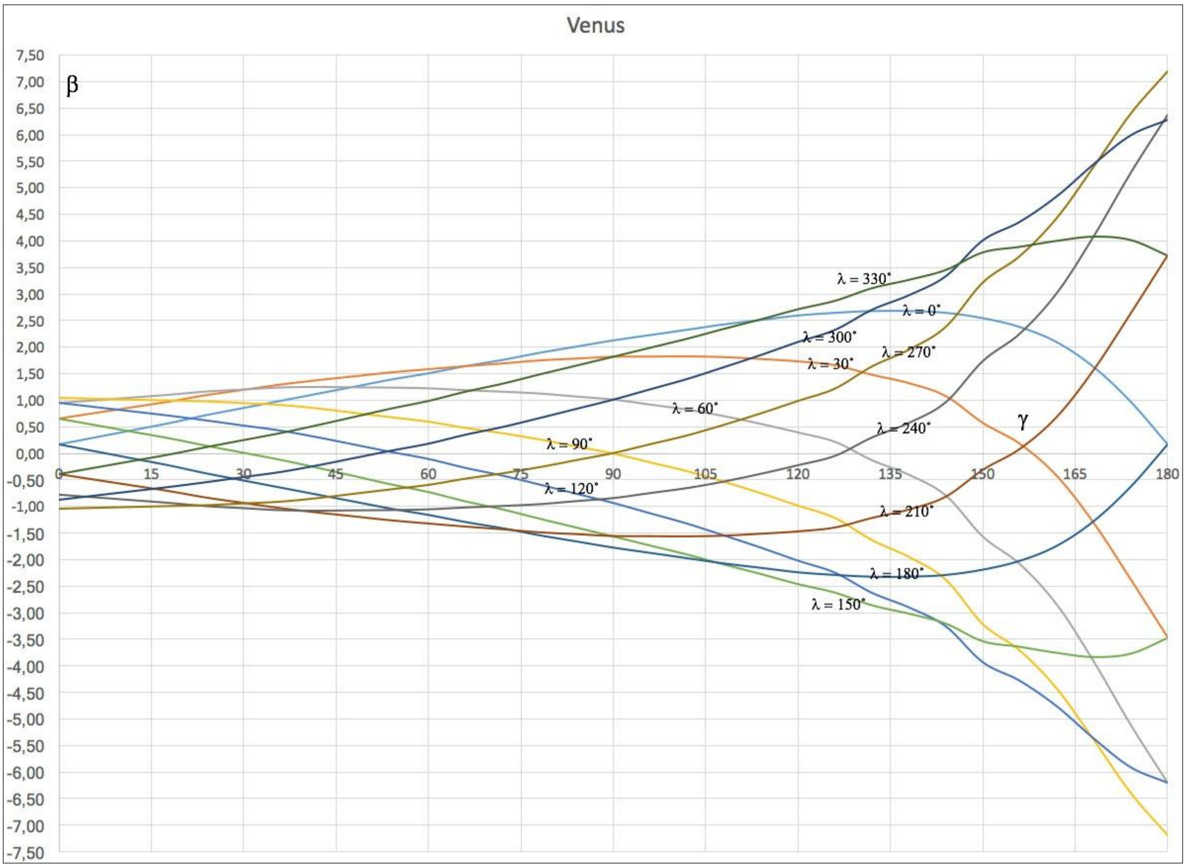


Figure 6: (γ, λ) graph for Venus.

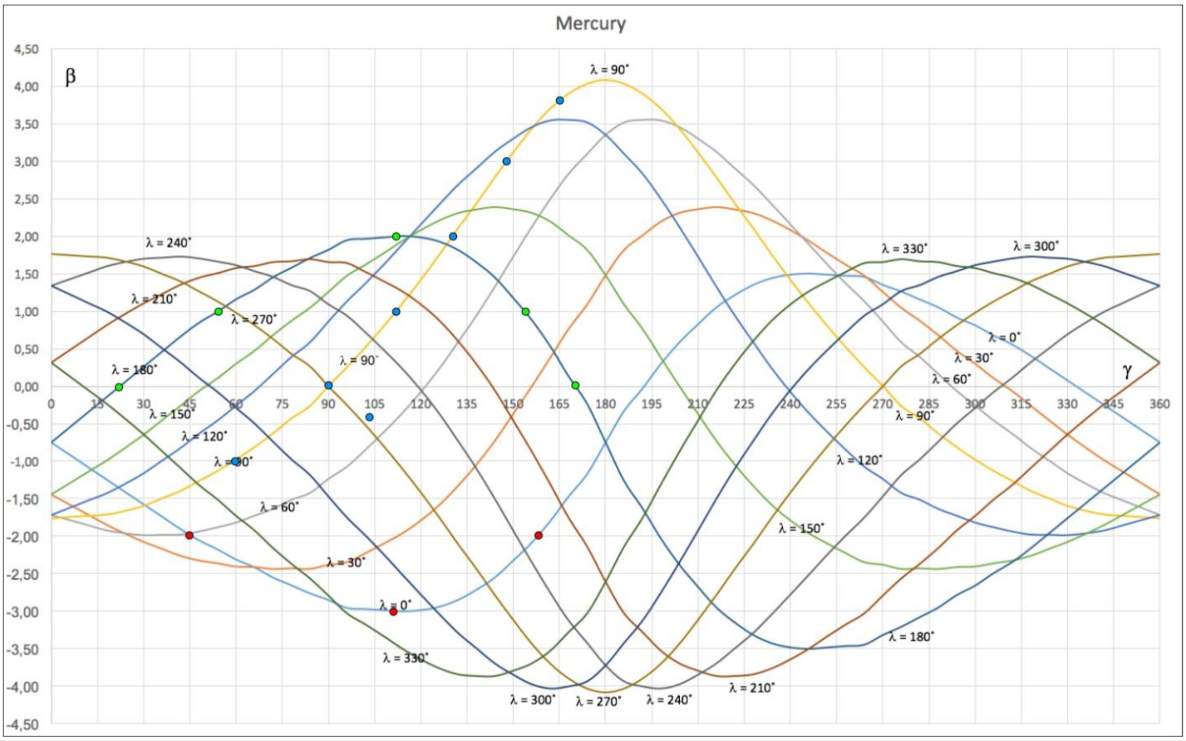


Figure 7: (γ, λ) graph for Mercury.

Apianus' results quite well. It is even possible to interpolate between the curves and in that way find points for intermediate values of γ and λ. As an illustration of how the construction may have been done, we can use the Mercury graph, Mercury being the most complicated case.

Following the light blue curve ($\lambda = 0^\circ$) in Figure 7, it crosses $\beta = -2^\circ$ for $\gamma = 45^\circ$ (1 sign 15˚). This point is marked by a red dot in Figure 8 and in the graph. The curve then just touches $\beta = -3^\circ$ for $\gamma = 110^\circ$, then crosses $\beta = -2^\circ$ again for $\gamma = 158^\circ$.

The yellow curve ($\lambda = 90^\circ$) crosses $\beta = -1^\circ$ for $\gamma = 60^\circ$, passes $\beta = 0^\circ$ for $\gamma = 90^\circ$, then $\beta = 1^\circ$ for $\gamma = 90^\circ$, $\beta = 2^\circ$ for $\gamma = 130^\circ$, $\beta = 3^\circ$ for $\gamma = 147^\circ$, and finally $\beta = 4^\circ$ for $\gamma = 172^\circ$. These points are marked in blue.

The dark blue curve ($\lambda = 180^\circ$) crosses $\beta = 0^\circ$ for $\gamma = 22^\circ$, then $\beta = 1^\circ$ for $\gamma = 55^\circ$, almost touches $\beta = 2^\circ$ for $\gamma = 115^\circ$, again crosses $\beta = 1^\circ$ for $\gamma = 153^\circ$ and $\beta = 0^\circ$ for $\gamma = 170^\circ$. These points are marked in green.

Given some patience it is no doubt possible to use this procedure to construct the latitude curves of the volvelles. If one does a detailed check it is found that Apianus has some errors in his latitude curves in the volvelles of the inferior planets where the latitude curves change direction, like for Mercury around $\lambda = 60^\circ$, $\gamma = 15^\circ$. But this is an exception; in general the points generated agree very well with the volvelles. The craftsmanship and elegance of these volvelles once again confirms the impression that Petrus Apianus had one of the most interesting and creative minds of the Middle Ages.

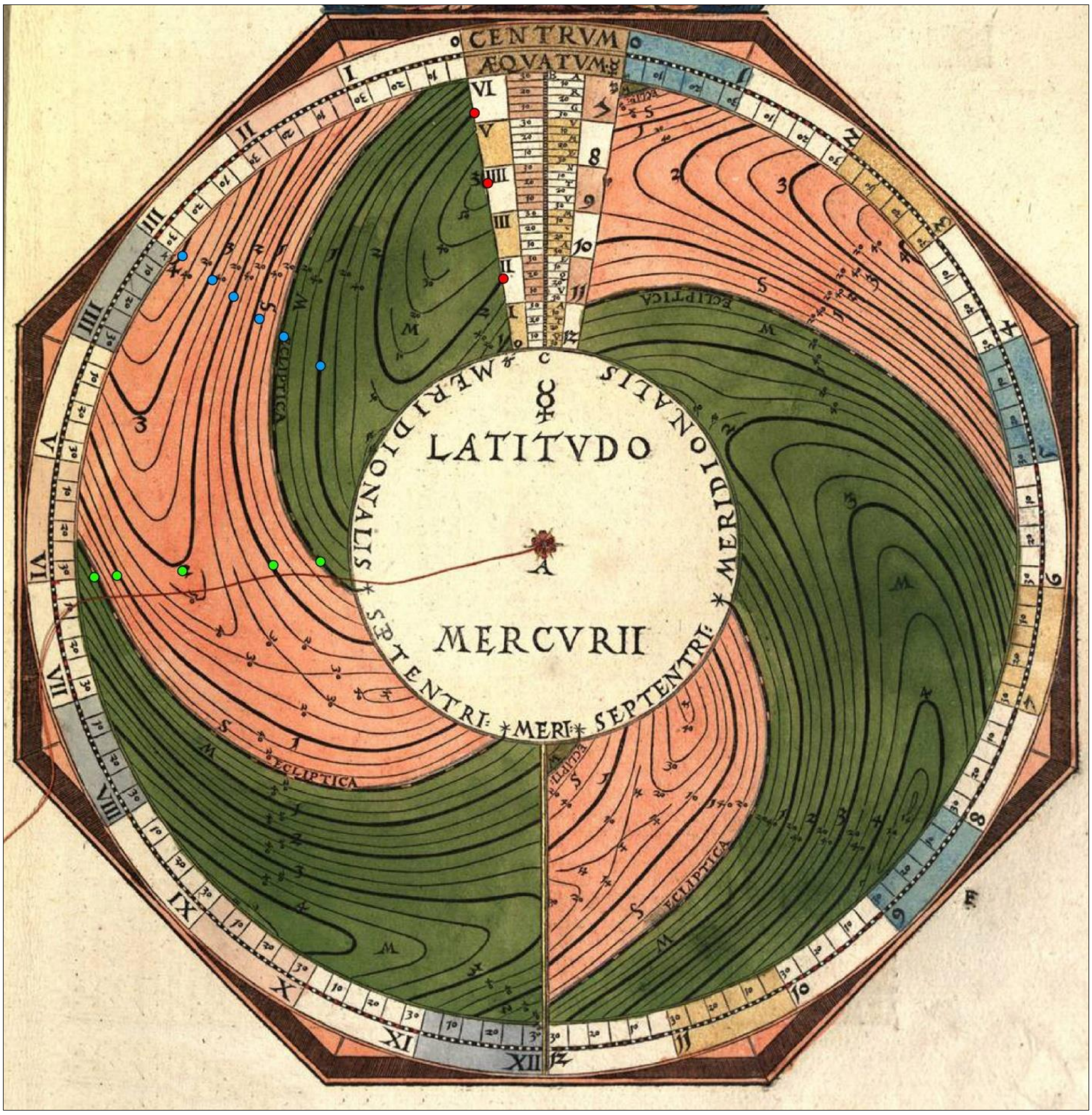


Figure 8: Mercury verification.

5 REFERENCES

Alfonsine Tables, 1492. *Tabula Astronomice Alfonsi Regis*. Venedig, Johann Hamann. https://books.google.se/books?id=4ppKAAAAcAAJ&redir_esc=y

Apianus, P., 1540. *Astronomicum Caesareum*. Ingolstadt, Arnt von Aych. http://bvpb.mcu.es/es/catalogo_imagenes/grupo.cmd?posicion=1&path=11002499&forma=&presentacion=pagina

Gislén, L., 2016. A lunar eclipse volvelle in Petrus Apianus' *Astronomicum Caesareum*. *Journal of Astronomical History and Heritage*, 19, 247–254.

Halma, N., 1822–1825. *Tables Manuelles des Mouvements des Astres*. Paris, Librairie A. Blanchard.

Nallino, C.A., 1903. *Al-Battani sive Albatenii, Opus Astronomicum*. Hirschberg, Georg Olms Verlag.

Neugebauer, O., 1975. *A History of Ancient Mathematical Astronomy*. New York, Springer-Verlag.

Pedersen, O., 1974. *A Survey of the Almagest*. Odense, Odense University Press.

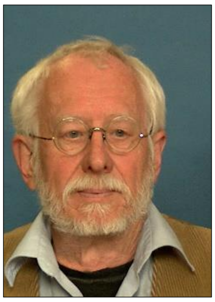
Pedersen, F.R., 2002. *The Toledan Tables*. Det Kongelige Danske Videnskabernes Selskab, Historisk-filosofiske Skrifter 24:4.

Suter, H., 1914. *Die Astronomischen Tafeln des Muhammed ibn Musa Al-Khwarizmi*. Det Kongelige Danske Videnskabernes Selskab Skrifter 7. Række, Historisk og Filosofisk Afdelning. III.1.

Swerdlow, N.L., 2005. Ptolemy's theories of the latitude of the planets in the *Almagest*, handy tables, and planetary hypotheses. *Archimedes*, 5, 41–71.

Toomer, G.J., 1984. *Ptolemy's Almagest*. *Translated and Annotated*. London, Duckworth.

Dr Lars Gislén is a former lector in the Department of Theoretical Physics at the University of Lund, Sweden, and retired in 2003. In 1970 and 1971 he studied



for a Ph.D. in the Faculté des Sciences, at Orsay, France. He has been doing research in elementary particle physics, complex system with applications of physics in biology and with atmospheric optics. During the last fifteen years he has developed several computer programs and Excel sheets implementing calendars and medieval astronomical models from Europe, India and South-East Asia (see http://home.thep.lu.se/~larsg/).

Journal of Astronomical History and Heritage, 20(1), 21–34 (2017).

SCIENTISTS OF THE *GWANSANG-GAM*. 1: OBSERVERS OF COMET 1P/HALLEY IN 1759

Nha Il-Seong
Korea Meteorologist Association and Yonsei University Observatory,
15, Yeonhui-ro 11a-gil, Seodaemun-gu, Seoul 03701 Republic of Korea.
E-mail: slisnha@chol.com

Oh Wan-Tak, **Oh Yong-Hae**
Korea Meteorologist Association, *39, Daebangdong 1-gil, Dongjak-gu*
06955 Seoul, Republic of Korea.
E-mails: owt365@hanmail.net; ooh1365@naver.com

and

Nha Sarah
Korea Meteorologist Association and The Nha Il-Seong Museum of Astronomy,
1074, Chunghyo-ro, Deogyul-ri, Gamcheon-myeon, Yecheon-gun,
Gyeongsangbuk-do 36811, Republic of Korea.
E-mail: christin@chol.com

Abstract: A project on researching the scientists of the Joseon Dynasty (Korea) has been carried out by the authors in the last decade by focusing mainly on the officials of the *Gwansang-gam*, the Bureau of Astronomy and Meteorology. This paper presents research that relies on the 1759 *Seongbyeon Deungrok* (*Compilation of Daily Observational Records of Celestial Events*) of the *Gwansang-gam*, and reviews the records of observations and observers of Comet IP/Halley during its 1759 apparition. This record includes a series of archival sketches of the comet.

In order to describe this work, the *Seongbyeon Deungrok* is first introduced, and then the observations of Comet 1P/Halley in the 1759 *Deungrok* are presented. The observers on duty each night during this series of observations from 1 to 14 April 1759 are also introduced, and there is a brief biographical investigation of five hereditary astronomers who made important contributions at the *Gwansang-gam* during the mid-eighteenth century, both as observers and calendrical researchers.

Keywords: *Gwansang-gam***,** 1759 *Seongbyeon Deungrok***,** Comet 1P/Halley, An Gook-bin, Song Whan-gyu, Bak Jae-so, Kim Tae-seo, Kim Je-gong

1 INTRODUCTION

The *Gwansang-gam* 觀象監 is the name of the Bureau of Astronomy and Meteorology in the Joseon Dynasty (1392–1910), and its organization was succeeded from its predecessor, the *Seowoon-gwan* 書雲觀 in the previous Koryo Dynasty 高麗 (918–1392) in Korea. All of the original observations made by the observers at the *Gwansang-gam* were reported in the *Seongbyeon Chookhoo Danja* 星變測候單子 (*Danja* for short), which were compiled afterwards in a separate book, the *Seongbyeon Deungrok* 星變謄錄 (*Deungrok* for short) by the Bureau. Most of these observations were transcribed without any changes into the *Seungjeong-won Ilgi* 承政院日記 (the *Daily Journals*) by scholar-officials in the Office of the Royal Secretary at that time, and later into the *Wangjo Sillok* 王朝實錄 (the *Veritable Records of the Joseon Dynasty*), in a much-reduced form where the names of the observers were omitted.

The *Seongbyeon Chookhoo Danja* (*Danja*) is the name of the observer's report of celestial and terrestrial phenomena that was made by each observer on duty at the Observatory during the Joseon Dynasty. *Danja*s, signed jointly by the participating observers, had to be submitted to the court after dawn each day. The recording format of a *Danja* for the observation of a comet was set by the *Gwansang-gam*, and had to include the following information:

> ① Date and time, ② location of the comet among the stars, ③ reference star of the *xiu* 宿距星, which is equivalent to the Right Ascension and the polar distance (Declination), ④ color, ⑤ length of the tail, ⑥ brightness, and ⑦ a sketch if possible. (Seong, 1818).

The paper size of a *Danja* is approximately 28 × 40 cm. *Danja*s for each comet were made until the comet was no longer visible to the naked eye. Therefore, the number of *Danja*s for each comet differed, depending on how long they remained visible. *Danja*s were disposable and not meant to last, but some of them survived in a transcribed form in the *Deungroks*.

In fact, with the passage of time, it was difficult to preserve the large amount of paper (*Danja*s) that accumulated. Therefore, the *Gwansang-gam* had skilled calligraphers made a series of copies, and these were bound in a separate volume called a *Deungrok* for each object or event. Therefore, *Deungrok* is a generic name for a compilation of *Danja*s*,* but often they were referred to by three different names: *Seong-*

byeon Deungrok 星變謄錄, *Cheongbyeon Deung-rok* 天變謄錄 and *Gaekseong Deungrok* 客星謄錄. Their literal meanings are respectively: the Register of Stellar Changes, the Register of Heavenly Changes and the Register of Guest Stars, but none of these matched perfectly the actual events recorded except for the *Seongbyeon*.

In 1917 the Korean-based Japanese meteorologist Wada Yuji (1859–1918; Nha and Nha 2017) discovered the existences of eight *Deungrok*s in an old *Gwansang-gam* warehouse, and he published a paper in Japanese that included a photograph of a sketch of the Great Comet of 1664 (Wada, 1917). Nearly two decades later, four more photographs of sketches of this comet appeared in a paper written in English by the American astronomer W.C. Rufus (1936). These are the eight *Deungrok*s discovered by Wada:

The 1661 *Seongbyeon Deungrok*
The 1664 *Cheonbyeon (天變) Deungrok*
The 1668 *Seongbyeon Deungrok*
The 1695 *(?) Deungrok*
The 1702 *(?) Deungrok*
The 1723 *Seongbyeon (星變) Deungrok*
The 1759 *Seongbyeon (星變) Deungrok*
The 1760 *Gaekseong (客星) Deungrok*

But, unfortunately, their locations were kept hidden for a long time, and it seems that until the early 1970s no-one was interested in this sort of material. About that time a few researchers realized that the *Deungrok*s had all disappeared. Accordingly, a search was initiated, and fortunately the last three *Deungroks* listed above (and see Figure 1) were purchased by Yonsei University Library in Seoul in 1978 from an undisclosed vendor. Subsequently, these three *Deungroks* were designated a Seoul City Treasure, which was a cause for great celebration. General information about these three volumes and their contents is given by Nha (1982).

In the caption of Figure 1, "… the twenty-fourth year of the Qianlong reign" is the 35th year of the Joseon King Yeongjo's reign. During the Joseon Dynasty, the Chinese Emperor's reign title was used until 1894. There are a number of publications available for the cross-checking of days and years for the three countries, China, Korea and Japan. We can refer to a table by Kang (1997) for the first half of the fifteenth cen-

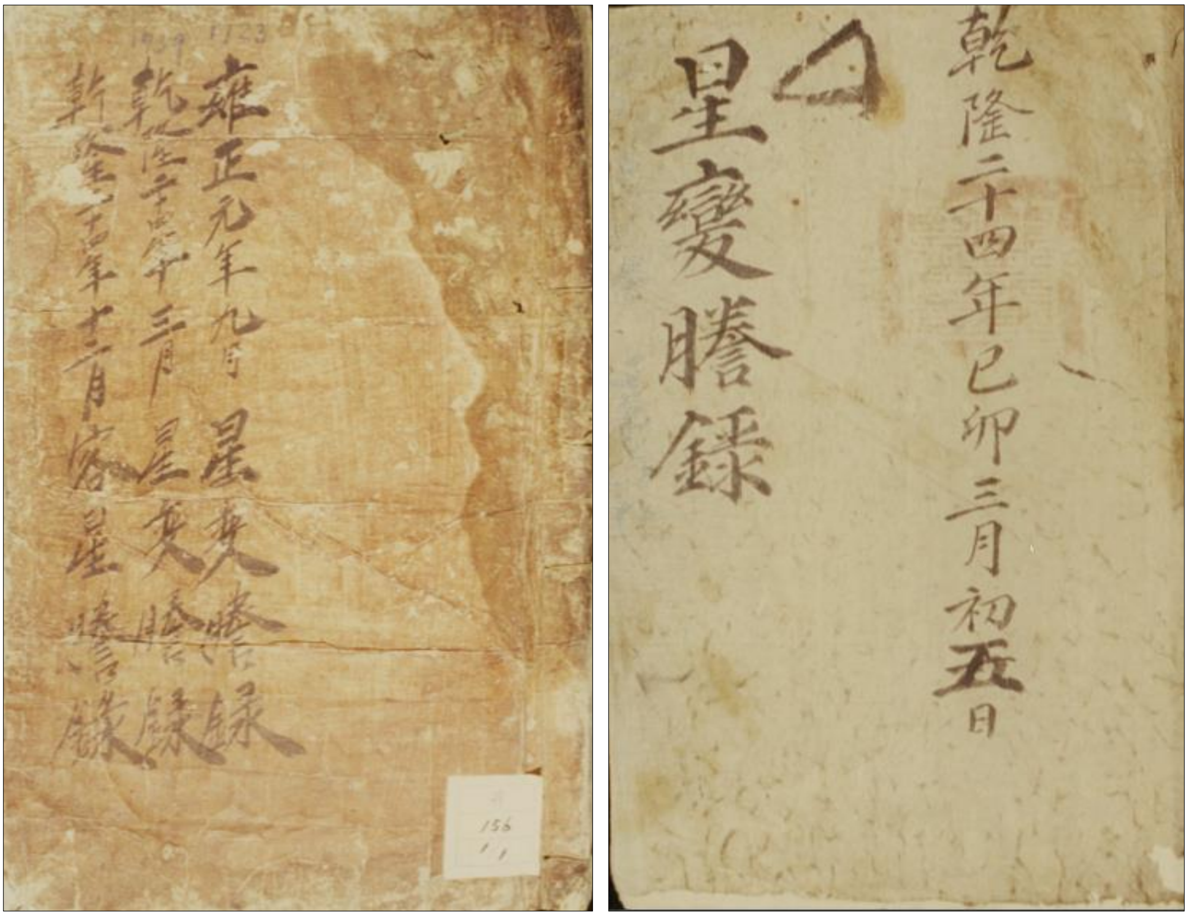


Figure 1. The image on the left shows the front cover of the 1723 and 1759 *Seongbyeon Deungrok*s and the 1760 *Gaekseong Deungrok*, all of which are bound together. The image on the right is the front cover of the 1759 *Seongbyeon Deungrok*, which has the date on the right-hand side: "The fifth day of the third month of the twenty-fourth year of the Qianlong reign (1759), jimao (己卯 [16])".

tury. Meanwhile, the number [16] after *jimao* in the caption indicates the number of the sixty-year cycle *ganzhi* 干支 counted from the first *ganzhi jiazi*甲子[1] to the sixtieth *guihai*癸亥[60]. This number will be listed whenever *ganzhi* appears in this manuscript.

The marvel is that nearly two decades later photocopies of the first three *Deungrok*s, of 1661, 1664 and 1668, were delivered to one of us (NI-S) by the late Professor Hasegawa Ichiro in Japan. However, these were not originals and accordingly the quality was inferior. Therefore, they were reprinted by the Korea Academy of Meteorology and Climate in 2014, as shown in Figure 2 (Hong, 2012). Unfortunately, the locations of the originals, and the two remaining *Deungrok*s (1695 and 1702), are still unknown.

In the case of *Danja*s and *Deungrok*s that contain records of Comet 1P/Halley, these documents include the names of observers, which is a unique feature of Korean manuscripts unless they belong to private individuals. Each *Danja* has a description and sketch of the comet if the night was clear, and the names of the observers, with their official titles at the Bureau, are always recorded. For these reasons, the 1759 *Deungrok* became an important source of data for those astronomers researching observations made of Comet 1P/ Halley during its 1759 apparition. Some observers were unable to make any observations because of bad weather during their assigned shifts, but we included them in our research because we are very interested in the names of scientists who were active during the Joseon Dynasty.

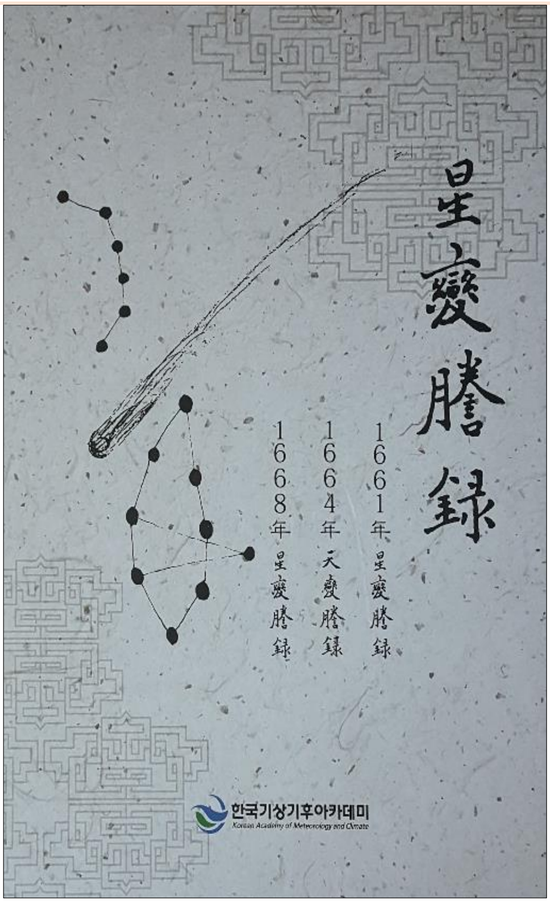


Figure 2: The cover of the box that was made for the copies of the 1661, 1664 and 1668 *Seongbyeon Deungrok*s. These *Deungrok*s were restored by conservation staff at the Korea Academy of Meteorology and Climate on the basis of photocopies provided by Nha Il-Seong (2012).

2 RECORDS OF COMET 1P/HALLEY DURING THE 1759 APPARITION

The 1759 Korean records of Comet 1P/Halley have already been mentioned by Nha and Lee (2004), but that paper merely contained a brief introduction to the archival records of the comet observations and there was no mention of the associated observers. In this paper, on the other hand, we plan to focus on two topics. Firstly, we will review the records and sketches of the comet as recorded in the 1759 *Deungrok*, and secondly we will scrutinize the observers who made the observations. All observations were carried out with the naked-eye from *Gwangwha-bang Cheomseong-dae* 廣化坊瞻星臺 (Figure 3), one of three small observatories that were located in the north-eastern part of old Seoul.

Figure 3: The current appearance of *Gwangwha-bang Cheomseong-dae* (photograph: Nha Il-Seong).

The *1759 Deungrok* has 29 *Danja*s altogether for the period 1–29 April (inclusive), and observations of Comet 1P/Halley were recorded on ten nights: 1, 2, 4, 6, 7, 9, 10, 11, 12 and 13 April. Eight of these *Danja*s have sketches of the comet and background stars. Although no

Figure 4: The *Danja* of Comet 1P/Halley on 1 April 1759. The comet is barely visible in the lower part of the drawing as a star with a short tail.

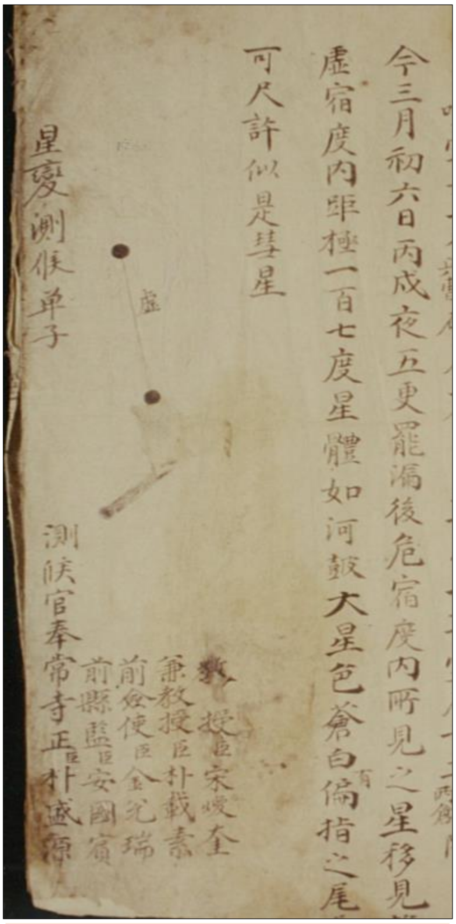


Figure 5: The *Danja* of Comet 1P/Halley on 2 April 1759. The comet had moved westward, and its tail was clear and longer.

observations were made on the remaining nineteen nights, because of cloudy or rain, or because the comet was too faint to be seen with the naked-eye, five observers were required to remain at the observatory throughout the night on these nights. Although they could not carry out comet observations on these nineteen nights, it is worth mentioning that their time was not wasted because other natural phenomena—such as clouds, rain, thunderstorms etc.—also were important objects or events that had to be observed and recorded for the Bureau of Astronomy and Meteorology. Therefore, the observer's name and official title in each *Danja* is, needless to say, extremely important for our research project on the scientists of the Joseon Dynasty. For this reason, we have listed all of the observers in Appendix 1.

Now we will present ten *Danja*s and Figures 4–13, where observations of the comet are recorded in detail. They are followed by the last *Danja* (Figure 14), which marked the end of the Korean observations of this famous comet.

2.1 1 April 1759

On the 5th day of the 3rd month [i.e. 1 April 1759], at night after the fifth gyeong [3–5h] *paru,*[1] a star was seen in the Wei lunar lodge [危宿 α Aqr and θ, ε Peg]. It has a trace of a tail. [See Figure 4.]

2.2 2 April 1759

On the 6th day [丙戌 *bingxu* [23]] of the 3rd month [2 April 1759], at night after the fifth gyeong [3–5h] *paru,* a star was seen in the Wei lunar lodge [危宿 α Aqr and θ, ε Peg]. This star moved into the Xu lunar lodge [虛宿 β Aqr and α Equ]. Its polar distance is 107 *do*[2] and it is as large [bright] as Altair [α Aql, m_v = 0.8]. The color is whitish [蒼白] and its tail 1 *cheok*[3] long, and thus this is certainly a comet. Observers: Song Whan-gyu, Bak Jae-so, An Gook-bin, Kim Tae-seo, Bak Seong-won. [See Figure 5.]

2.3 4 April 1759

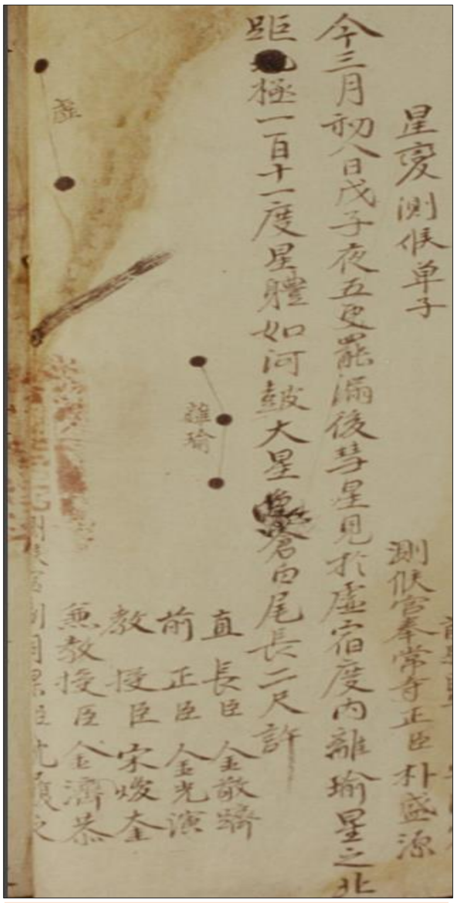
On the 8th day [戊子 wuzi [25]] of the 3rd month [4 April 1759], at night after the fifth gyeong [3–5h] *paru,* the comet was seen in the Xu lunar lodge [虛宿, β Aqr and α Equ] and to the north of the constellation of Liyu [離瑜, α, γ, ε Mic]. Its polar distance is 111 *do* and it is as large [bright] as Altair [α Aql, m_v = 0.8]. The color is whitish and its tail 2 *cheok*s long. [See Figure 6.]

2.4 6 April 1759

On the 10th day [庚寅 gengyin [27]] of the 3rd month [6 April 1759] at night after the fifth gyeong [3–5h] *paru,* the comet has moved and is now in the Xu lunar lodge [虛宿, β Aqr and α Equ] and north of the constellation of Liyu [離瑜, α, γ, ε Mic]. Its polar distance is 115 *do*. The brightness, color and length of the tail are the same as the previous sight. [See Figure 7.]

2.5 7 April 1759

On the 11th day [辛卯 xinmao [28]] of the 3rd month [7 April 1759], at night after the fifth gyeong [3–5h] *paru,* the comet was seen in the Xu lunar lodge [虛宿, β Aqr and α Equ] and above the constellation of Liyu [離瑜, α, γ, ε Mic]. Its polar distance is 116 *do*. The brightness and color are the same as the previous sighting, but the length of the tail is 1.5 *cheok*s long. [See Figure 8.]



星變測候單子
今三月初八日戊子夜五更罷漏後彗星見於虛宿度內離瑜星之北
距極一百十一度星體如河鼓大星蒼白尾長二尺許

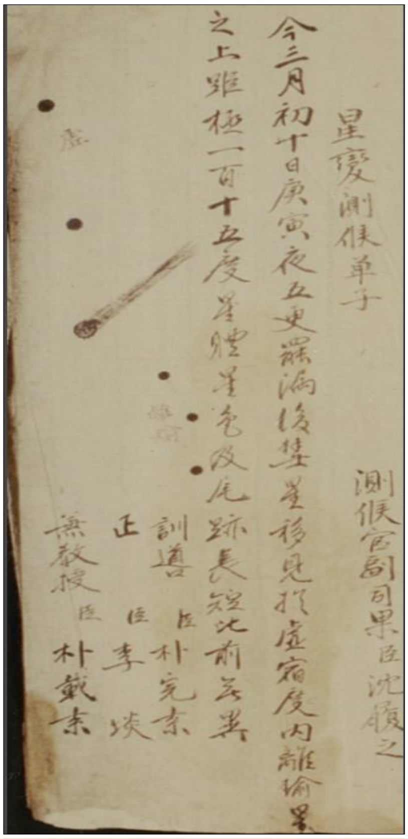
Figure 6: The *Danja* of Comet 1P/Halley on 4 April 1759.

2.6 9 April 1759

On the 13th day [癸巳 guise [30]] of the 3rd month [9 April 1759], at night after the fifth gyeong [3–5h] *paru,* the comet was seen in the Xu lunar lodge [虛宿, β Aqr and α Equ] and above the constellation of Liyu [離瑜, α, γ, ε Mic]. Its polar distance is 117 *do*. The brightness and color are slightly fainter than on the previous sighting, and the length of the tail is about 1 *cheok*s long. [See Figure 9.]

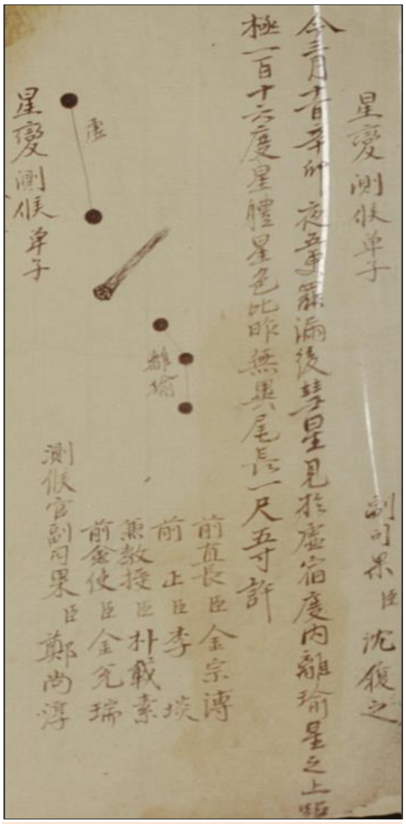
2.7 10 April 1759]

On the 14th day [甲午 jiawu [31]] of the 3rd month [10 April 1759], at night after the fifth gyeong [3–5h] *paru,* the comet was seen in the Xu lunar lodge [虛宿, β Aqr and α Equ) and



星變測候單子
今三月初十日庚寅夜五更罷漏後彗星移見於虛宿度內離瑜星
之上距極一百十五度星體星色及尾跡長短比前差異

Figure 7: The *Danja* of Comet 1P/Halley on 6 April 1759. For some unknown reason there were only three observers on this night.



星變測候單子
今三月十一日辛卯夜五更罷漏後彗星見於虛宿度內離瑜星之上距
極一百十六度星體星色比昨無異尾長一尺五寸許

Figure 8: The *Danja* of Comet 1P/Halley on 7 April 1759.

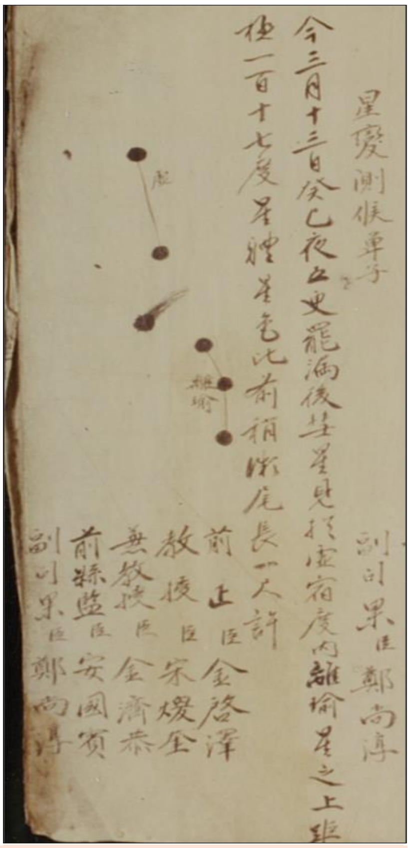


Figure 9: The *Danja* of Comet 1P/Halley on 9 April 1759.

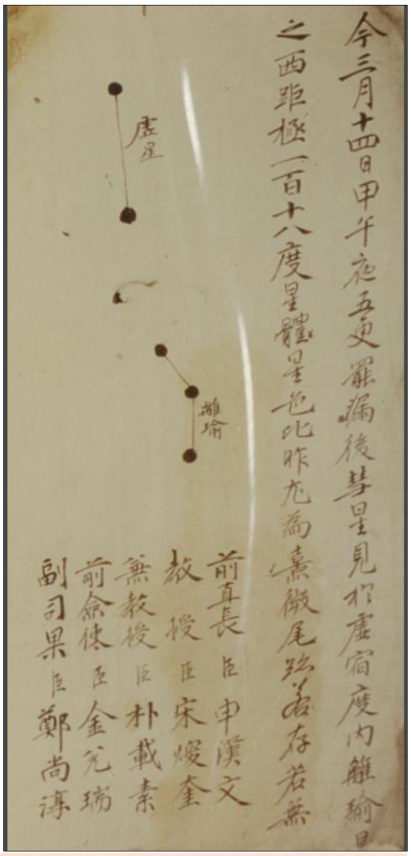


Figure 10: The *Danja* of Comet 1P/Halley on 10 April 1759.

to the west of the constellation of Liyu [離瑜, α, γ, ε Mic]. Its polar distance is 118 *do*. The brightness and color are slightly fainter than on the previous sighting, but the trace of the tail is difficult to judge. [See Figure 10.]

2.8 11 April 1759

On the 15th day [乙未 yiwei [32]] of the 3rd month [11 April 1759], at night after the fifth gyeong [3–5h] *paru,* the comet was seen in the Xu lunar lodge [虛宿, β Aqr and α Equ] and to the west of the constellation of Liyu [離瑜, α, γ, ε Mic]. Its polar distance is 119 *do*. The brightness, color and the trace of the tail are fainter than on the previous sight. [See Figure 11.]

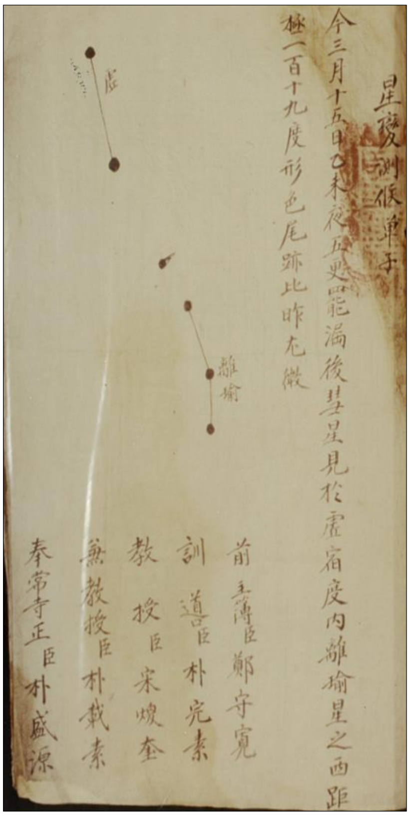


Figure 11: The *Danja* of Comet 1P/Halley on 11 April 1759.

2.9 12 April 1759

On the 16th day [丙申 bingshen [33]] of the 3rd month [12 April 1759], at night after the fifth gyeong [3–5h] *paru,* the comet had moved into the Nu lunar lodge [女宿, ε, μ Aqr]. Its polar distance is 121 *do*. The brightness and color are no different to the previous sighting. [See Figure 12.]

2.10 13 April 1759

On the 17th day [丁酉 dingyou [34]] of the 3rd month [13 April 1759], at night after the fifth gyeong [3–5h] *paru,* the comet was seen in the Xu lunar lodge [女宿, ε, μ Aqr]. Its polar distance is 121 *do* and a half. The brightness and color are fainter than on the previous sighting. [See Figure 13.]

2.11 25 April 1759

On the 29th day [己酉 jiyou [46]] of the 3rd month [25 April 1759], after the fifth gyeong [3–5h] *paru,* moonlight was no longer a problem and many stars are visible in the sky, but the comet's whereabouts could not be confirmed. There is now no doubt that it is too faint to observe.
Observers: Song Whan-gyu, Kim Je-gong, An Gook-bin, Kim Tae-seo, Jeong Sang-soon. [See Figure 14.]

2.12 A Review of the Korean Observations

As Figure 4 shows, the first reported Korean sighting of this comet was made by the three observers on duty at the Royal Observatory in the

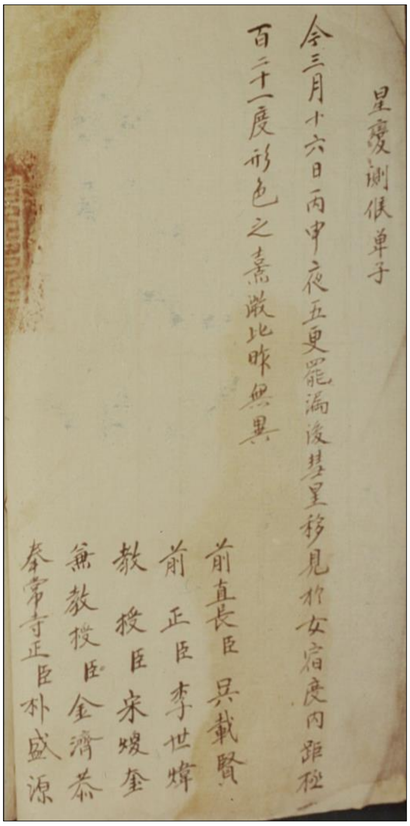

星變測候單子
今三月十六日丙申夜五更罷漏後彗星移見於女宿度內距極
百二十一度形色之熹微比昨無異
前直長臣吳載賢
前正臣李世烽
教授臣宋煥奎
兼教授臣金濟恭
奉常寺正臣朴盛源

Figure 12: The *Danja* of Comet 1P/Halley on 12 April 1759. No sketch of the comet is included on this or the following days.

35th year (1759) of the reign of King Yeongjo (r. 1725–1776), the 21st King of Joseon Dynasty.

These observations were made in Korea without the knowledge that Edmond Halley (1656–1742) had suggested that the object now known by his name was a periodic comet and "Hence I do venture to foretell, That it will return again in the Year 1758." (Halley, 1705: 22). At the Cabinet meeting early next morning in the presence of King Yeongjo this comet came high on the agenda to arrange further observations. His Majesty accepted the recommendation put forward by Seo Myeong-eun (1716–1787) and other

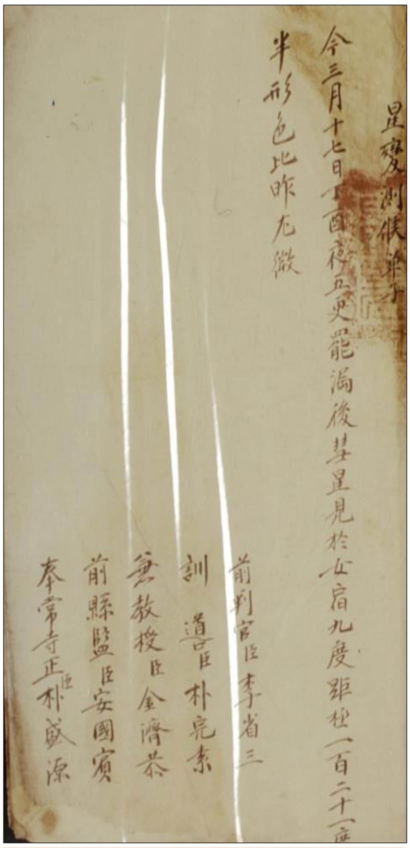

星變測候單子
今三月十七日丁酉夜五更罷漏後彗星見於女宿九度距極一百二十一度
半形色比昨尤微
前判官臣李省三
訓導臣朴亮素
兼教授臣金濟恭
前縣監臣安國賓
奉常寺正臣朴盛源

Figure 13: The *Danja* of Comet 1P/Halley on 13 April 1759.

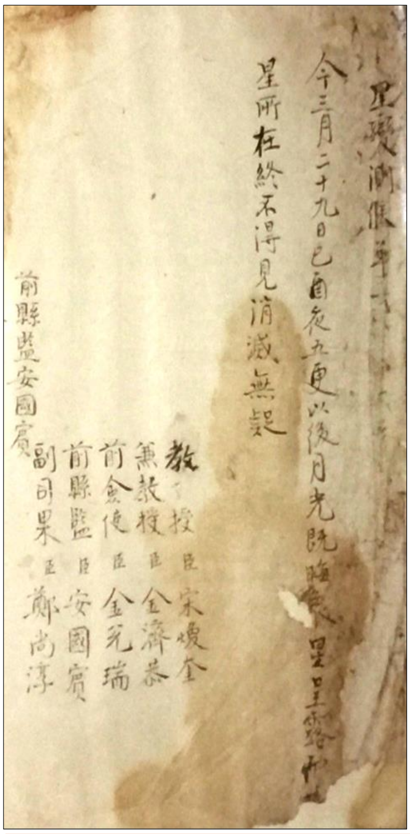

星變測候單子
今三月二十九日己酉夜五更以後月光既晦彗星所在終不得見消滅無疑
教授臣宋煥奎
兼教授臣金濟恭
前僉使臣金元瑞
前縣監臣安國賓
副司果臣鄭尚淳
前縣監安國賓

Figure 14: The last *Danja* for Comet 1P/Halley, on 25 April 1759.

cabinet members that the staff of the Observatory should be reinforced by the appointment of more observers, including Bak Seong-won (1711–1779), Jeong Sang-soon (1723–1786) and Sim I-ji (1720–1780).[4]

It is very interesting that the five new observers appointed only one day after the first observations of the comet were by then all well-known veteran astronomers (see Figure 4, Table 1 and Appendix 1). Actually, two of them, An Gook-bin and Kim Tae-seo, had already retired and probably were resting and enjoying life in Seoul. Therefore, the appointment of this urgent 'task force' of five observers indicates how important King Yeongjo and his high-ranking officials felt it was to clarify the nature of this rare celestial visitor.

From that date, observations were continued for the next 25 nights, regardless of whether the skies were clear or cloudy. Although the observers rostered on each night at the Observatory (Appendix 1) worked on rotation so that there would be non-stop observation of the sky in every direction, on the final night a further group of five very experienced observers was present to confirm that the comet was no longer visible (Figure 14). The three observers (Song Whan-gyu, An Gook-bin and Kn Tae-seo) who had reported the discovery of the comet on 2 April were there again on this final night, 25 April, to confirm its disappearance.

Korean observers involved in the 1759 Comet 1P/Halley apparition are listed alphabetically in Table 1, and the red stars (✱) indicate the dates when they made observations. However, 31 individuals who were present on 24 April and 35 astronomers present on 25 April are not included in this table because they were not on duty on these nights. Instead, they are listed in Appendix 1.

Table 1: The thirty-five observers who were on duty at *Gwangwha-bang Cheomseong-dae* and made observations of Comet 1P/Halley in 1759.

Name	Days of April, 1760																									Total
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
An Gook-bin		✱	✱		✱			✱	✱				✱			✱	✱		✱			✱	✱	✱	✱	13
An Sa-haeng	✱																	✱								2
Bak Jae-so		✱	✱			✱	✱			✱	✱				✱	✱	✱				✱	✱	✱			12
Bak Seong-won		✱	✱								✱	✱	✱	✱	✱		✱	✱								9
Bak Wan-so					✱	✱					✱		✱													4
Choe Taek-wha																							✱			1
Gang Hui-eon																					✱					1
Jeon Jong-ui																✱										1
Jeong Sang-soon							✱	✱	✱	✱													✱	✱	✱	7
Jeong Soo-gwan											✱															1
Jeong Soo-wan																	✱									1
Kim Ge-taek								✱	✱																	2
Kim Gwang-yeon				✱	✱																	✱		✱		4
Kim Gyeong-je				✱																						1
Kim Je-gong				✱	✱			✱	✱			✱	✱	✱				✱	✱	✱				✱	✱	12
Kim Jong-bu	✱						✱	✱																		3
Kim Jong-yoon																			✱	✱						2
Kim Tae-seo		✱	✱			✱	✱			✱				✱	✱	✱	✱			✱			✱	✱	✱	13
Oh Jae-hyeon												✱														1
Sim Yi-ji				✱	✱	✱													✱	✱	✱					6
Sin Han-moon										✱																1
Song Whan-gyu		✱	✱	✱					✱	✱	✱	✱						✱		✱	✱				✱	11
Yang Do-min																						✱				1
Yang Do-sang																			✱							1
Yi Dam						✱	✱																			2
Yi Dong-seong														✱												1

Yi Gyeong-bin	✸																									1
Yi Gyeong-jik														✸												1
Yi Gyeong-sim															✸											1
Yi In-dae															✸											1
Yi Jeong-boong																					✸					1
Yi Jeong-han																		✸								1
Yi Se-wui												✸														1
Yi Seong-gyu																						✸				1
Yi Seong-sam													✸													1

3 FIVE DISTINGUISHED SCIENTISTS

We wish to introduce five observers in order of their birth who were intensively dedicated to the observation of Comet 1P/Halley in 1759. Each of them participated on more than ten nights during the 25 nights that observations were attempted of the comet. They were promoted, becoming higher-level staff members of the Bureau of Astronomy and Meteorology, and they also left their names as calculators of the Shixian-li calendars. However, the main archival records contain almost no mention of these individuals, and thus their lives and careers are poorly known. Yet it is certain that other members of their families also proudly served the Dynasty for generations as astronomers at the Bureau.

3.1 An Gook-bin and His Grandson

An Gook-bin 安國賓 was born in 1699. In the 40th year of King Sookjong's reign (i.e. in 1714) Gook-bin passed the State Examination for Astronomy and Meteorology in first place, even though he was only 16 years of age (Lee and Choi, 2002; Whang and Lee, 1991a; 1991b). He became *Gwansang-gam Jeong* 正 in 1721, which is the highest position at the Bureau of Astronomy and Meteorology that middle-class citizens could achieve. Gook-bin went to Beijing in China at least four times (in 1741, 1743, 1745 and 1756), and developed a good working relationship with the Jesuit astronomer Ignatius Kögler, from whom he learnt new methods of calendrical calculation (Sillok, 1744). In 1743, when he was 43, Gook-bin and five collaborators made an eight-fold screen star map, now referred to as the Screen Star Map-2. Currently, this is well preserved in the Beobjoo Temple, and it has been identified as Treasure No. 848 by the Korean Ministry of Culture. Gook-bin also joined with Yi Se-yeon and Kim Tae-seo (b. 1714) to edit the book *Noojoo Tongui*, on meridian stars.

Gook-bin had four grandsons, and the name of one of them, An Sa-haeng 安思行 (b. 1738), is listed immediately below Gook-bin in Table 1. An Sa-haeng passed the State Examination for Astronomy and Meteorology in 1756, and four years later joined his grandfather in observing Comet 1P/Halley. Sa-haeng was extensively involved in calendar-making at the Bureau of Astronomy and Meteorology (i.e. the Shixian-li in 1765, 1767, 1772, 1774, 1775, 1777, 1784, 1787, 1789, 1793, 1795 and 1797).

Gook-Bin's family is well known as one of outstanding hereditary astronomical families in Korea. Gook-Bin observed Comet 1P/Halley on 13 nights in 1760.

3.2 Song Whan-gyu

Song Whan-gyu 宋煥奎 was born in 1709, and passed the State Examination for Astronomy and Meteorology in first place when he was only 17 years of age (Lee and Choi, 2002; Whang and Lee, 1991c; 1991d). This was in 1725, the first year of King Yeongjo's reign. Song Whan-gyu then joined the Bureau of Astronomy and Meteorology, and devoted his whole life to calendar-making, retiring at age 81. By this time he had published many annual calendars (i.e. the Shixian-li in 1732, 1746, 1767, 1772, 1773, 1775, 1779, 1782, 1787, 1788 and 1789). He observed Comet 1P/Halley on 11 nights.

Song Whan-gyu's father, Hyeong-geol 宋亨傑, also was an astronomer at the Bureau, and he participated in calendar-making and observing.

Whan-gyu's son-in-law, Kim Jong-bu 金宗溥 (b. 1732), also was an astronomer, who passed the State Examination for Astronomy and Meteorology in 1763 (Lee and Choi, 2002). The Kim family also seems to have been a well-established astronomical family.

Jong-bu's father, Kim Won-heung 金遠興 (b. 1709, also was a successful candidate at the State Examination for Astronomy and Meteorology, in 1735 (Lee and Choi, 2002). This Kim went to Qing, China, in 1754 and studied calendar-making (Ilgi, 1754). Thus far, five calendars have been found where his name is listed as one of the contributors (i.e. the Shixian-li in 1746, 1752, 1754, 1765 and 1773).

3.3 Bak Jae-so

Bak Jae-so 朴載素 was born in 1713, and in the fourteenth year of King Yeongjo's reign (1738) he passed the State Examination for Astronomy and Meteorology (Lee and Choi, 2002; Whang and Lee, 1991e; 1991f). He was then 26 years of age. Jae-so's major contribution was in calendar-making (the Naeyong Samseo in 1752; and the Shixiao-li in 1754, 1765 and 1773). He observed Comet 1P/Halley on 12 nights. Bak Jae-so was raised as a member of an astronomical family, in which his father, step-father, one brother and two sons were all hereditary astronomers.

3.4 Kim Tae-seo

Kim Tae-seo 金兌瑞 (b. 1714) is younger than An Gook-bin by 15 years, but they collaborated with each other for a long time. Tae-seo passed the State Examination for Astronomy and Meteorology in the eleventh year of King Yeong-jo's reign (i.e. 1735) at his age 22 (Lee and Choi, 2002; Whang and Lee, 1991g; 1991h), the year in which his second son, Kim Je-gong was born (see Section 3.5 below). Kim Tae-seo visited Beijing (China) often with An Gook-bin and brought back home a large telescope and a set of the *Xinfa Lixiang Kaocheng Houbian* (Moonheon Bigo, 1906; Sillok, 1745). He observed Comet 1P/Halley on 13 nights. He also engaged in calendar-making at the Bureau of Astonomy and Meteorology (e.g. the Shixian-li in 1744 and 1746).

Apart from his son Kim Je-gong, Kim Tae-seo had another son, Kim Je-yang, and a grandson, Kim Seong-won, who were astronomers.

3.5 Kim Je-gong

Kim Je-gong 金濟恭 was born in 1735, and passed the State Examination for Astronomy and Meteorology in the 24th year of King Yeongjo's reign (i.e. 1753), at the age of 19 (Lee and Choi, 2002; Whang and Lee, 1991i, 1991j). He observed Comet 1P/Halley on different 12 nights, four of them jointly with his father Kim Tae-seo, but his other contributions to Korean astronomy and meteorology are unknown at present and will be the subject of future research.

4 CONCLUDING REMARKS

One of the primary aims of this paper, as stated in Section 2, was to learn about the Korean astronomers from the Bureau of Astronomy and Meteorology who observed Comet 1P/Halley during its 1759 apparition. By using the *1759 Seongbyeon Deungrok*, the names of 35 astronomers were collected, some of whom were already known from previous studies. Nonetheless, it was a triumph to uncover so many new astronomers' names through the study of just this one *Seongbyeon Deungrok*.

Although the birth years of most of these observers are known, it is pity that we know the years in which very few of them died. Fortunately, the years in which they were born, along with their home town and father's name, were recorded on the application form when they applied for the National Examination for Astronomy and Meteorology, but there are no official documents that record their deaths. None of the scientists under discussion is listed in directories such as the *Joseon Myeongsin-rok* 朝鮮名臣錄 (Yi, 1925), and only two names are mentioned briefly in the latest directory, the *Hankuk Jeongsin Moonwha Dae-baek'gua Sajeon* (Daebaek'gua, 1991). Since it is not an easy task to determine the dates when and the places where most of these astronomers died, this will be left for a future project.

In spite of this setback, we have discovered some very interesting and unusual families, as a by-product in our study. For instance, we found several cases of two generations of the same family working together during the observation of Comet 1P/Halley. As listed in Table 1, An Gook-bin and his grandson An Sa-haeng were on duty for 13 and 2 nights, respectively. Kim Tae-seo and his son Kim Je-gong also were on duty for 13 and 12 nights, respectively, and worked together on 4 of these nights. A third example involves Song Whan-Gyu and his son-in-law Kim Jong-bu. The former was on duty for 11 nights, and the latter for 3 nights, but they never observed together. The case of Song Whan-gyu and his ties to the Kim family—another Korean dynasty of hereditary astronomers—is worthy of further study.

The second objective of this paper was to document the observations made by the astronomers from the Bureau of Astronomy and Meteorology during the apparition in 1759 of what is now known as Comet 1P/Halley. This comet was visible as a naked-eye object for 10 nights between 1 and 13 April, and fortunately clouds only prevented observation on three of these nights (3, 5 and 8 April). This means that at that time the Korean astronomers enjoyed nearly 77% clear nights, which is far better than the present-day statistic of ~45% clear nights recorded in Seoul during the first half of April in 1995 and 1996 (Nha Observatory Log book 1995–1997).

The 1759 apparition of Comet 1P/Halley is discussed in detail by Kronk (1999) in his masterful *Cometography,* and he summarizes all known naked-eye and telescopic observations by different observers in various locations, but the Korean observational records were not available to him when he researched his book. Accordingly, the Korean observations provide some useful new data, and they also offer confirmation of some of the details recorded in his book.

According to Kronk, the French astronomer Charles Messier (1730–1817) detected the comet on 1 April using a Newtonian reflector of

4.5-foot focal length. He reported that the nucleus ex-ceeded in appearance stars of the 1st magnitude and was whitish, while there was a tail over 25° in length. Messier's observations agree rather well with the Korean *Danja* of 2 April except for the length of the tail. Although the length of the tail is not recorded in every *Danja*, the series of sketches in the *Danja*s show that the tail reach-ed its greatest length between 2 and 6 April. By then the comet was positioned in the sky between the first star in the Xu lunar mansion 虛一 (β Aquarii) and the third star in the con-stellation of Liyu 離瑜三 (δ Microscopium), with the polar distance changing from 107° to 115°.

The comet then faded rapidly, showing no significant change in right ascension while it continued to move towards the south. The *Dan-ja*s of 14 April and thereafter describe how the skies were then cloudy or moonlight interfered with the observations, and from that date until 25 April the comet was not seen again.

5 NOTES

1. *Paru* is a signal that was beaten 33 times on iron drum in Seoul after the curfew was lifted at 5h in the morning.
2. A *do* is 360°/365 = 0.986°.
3. A *cheok* (尺) is a unit of length and also an angle. 1 *cheok* = 10 *chon* (寸), 1 *chon* ≒ 1°.
4. Normally the sky was watched at any time day or night by a group of three astronomers from the *Gwansang-gam*. There were three 8-hr shifts every 24 hours, so a different astronomer was rostered on duty for each shift. However, the number of astronomers mers assigned to each 24-hr observing period was automatically increased from three to five as soon as a strange object was observ-ed and reported next morning at the Court. This is why there were three astronomers on the final observing shift on 1 April, and they were increased to five for the next 24-hr per-iod. The cabinet searched for astronomers who were experienced in cometary observa-tions, because the *Danja* of 1 April stated that the newcomer "… has a trace of a tail."

6 ACKNOWLEDGEMENTS

The authors wish to thank the anonymous ref-erees for their critical comments and helpful suggestions which greatly improved our original version of the manuscript. We also thank Mrs Kim Myungju of Yonsei University Library for her assistance in searching genealogies and other archival documents.

This work was funded by the Korea Meteor-ological Administration Research and Develop-ment Program under Grant See-At KMIPA2015-5106.

7 REFERENCES

Daebaek'gua, 1991. *Hankuk Jeongsin Moonwha Daebaek'gua Sajeon.*

Halley, E., 1705. *A Synopsis of the Astronomy of Comets*. London, John Senex.

Hong, Y., 2012. Preface. *Seongbyon Deungrok*. Seoul, Korea Academy of Meteorology and Climate. Pp. III, VII.

Ilgi, 1754, *Seungjeong-won Ilgi*, National Institute of Korean History, 61, 627.

Kang, Y-W., 1997. Cross index of dates used in Chinese, Korean and Japanese calendars for the period, 1401–1450. In Nha, I.-S., and Stephenson. F.R. (eds.). *Oriental Astronomy from Guo Shoujing to King Sejong* [The Proceedings of ICOA-1]. Seoul, Yonsei University Press. Pp. 349–350, and 383–401.

Kronk, G.W., 1999. *Cometography. A Catalogue of Comets. Volume 1: Ancient – 1799*. Cambridge, Cambridge University Press.

Lee, S.-M., and Choi, J.-O., 2002. *Japgua Bangmok (雜科榜目) CD-ROM.*

Moonheon Bigo, 1906. *Jeungbo Moonheon Bigo*, 1, 74.

Naeyong Samseo, 1752.

Nha, I.-S., 1982. Seongbyeon Deungroks reserved in the Yonsei University Library. *The Dong Bang Hak Chi (The Journal of Korean Studies, Institute of Kor-ean Studies, Yonsei University)*, 143, 207–247 (in Korean).

Nha, I.-S., 2012. Annotation. *Seongbyon Deungrok*. Seoul, Korea Academy of Meteorology and Climate. Pp. III, VII.

Nha, I.-S. and Lee, J.-B., 2004. The long-term pro-ject on astronomical archives in Korean history. In Chen, K-Y., Orchiston, W., Soonthornthum, B. and Strom, R. (eds.), 2006. *The Fifth Internation-al Conference on Oriental Astronomy (ICOA-5)*. Chiang Mai, Chiang Mai University, Pp. 103–108.

Nha, I.-S., Nha, S.L., and Orchiston, W., 2017. The development of astronomy in Korea and the emerg-ence of astrophysics in South Korea. In Nakamura, T., and Orchiston, W. (eds.). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nha Observatory Log book 1995–1997. Nha I-S. Collection.

Rufus, W.C., 1936. Astronomy in Korea. *The Trans-actions of the Korea Branch of the Royal Asiatic Society*, 26, 1–53.

Seong Ju-deok, 1818. *Seowun'gwan-ji.*

Shixian-li, 1732 calendar.

Shixian-li, 1744 calendar.

Shixian-li, 1746 calendar.

Shixian-li, 1752 calendar.

Shixian-li, 1754 calendar.

Shixian-li, 1765 calendar.

Shixian-li, 1767 calendar.

Shixian-li, 1772 calendar.

Shixian-li, 1773 calendar.

Shixian-li, 1774 calendar.

Shixian-li, 1775 calendar.

Shixian-li, 1777 calendar.

Shixian-li, 1779 calendar,

Shixian-li, 1782 calendar.

Shixian-li, 1784 calendar.

Shixian-li, 1787 calendar.

Shixian-li, 1788 calendar.

Shixian-li, 1789 calendar.
Shixian-li, 1793 calendar.
Shixian-li, 1795 calendar.
Shixian-li, 1797 calendar.
Sillok, 1744. *Yeongjo Sillok*, 59:29b. 15th day (壬辰) of the 5th month of the 20th year of Yeongjo reign.
Sillok, 1745. *Yeongjo Sillok*, 62:4b. 13th day (癸未) of the 7th month of the 21st year of Yeongjo reign.
Wada, Y., 1917. Seongbyeon Chookhoo Danja. In *Josen Kodai Kansoku Kiroku Josha Hokoku*. Kansokusho, Josen Sotokufu. Pp. 173–176.
Whang, W.-G., and Lee, J.-Y., 1991a. Samryeokcheong Seonsaeng-an. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 878.
Whang, W.-G., and Lee, J.-Y., 1991b. Un'gua Bamgmok. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 813.
Whang, W.-G., and Lee, J.-Y., 1991c. Samryeokcheong Seonsaeng-an. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 876.
Whang, W.-G., and Lee, J.-Y., 1991d. Un'gua Bamgmok. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 810.
Whang, W.-G., and Lee, J.-Y., 1991e. Samryeokcheong Seonsaeng-an. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 874.
Whang, W.-G., and Lee, J.-Y., 1991f. Un'gua Bamgmok. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 807.
Whang, W.-G., and Lee, J.-Y., 1991g. Samryeokcheong Seonsaeng-an. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 875.
Whang, W.-G., and Lee, J.-Y., 1991h. Un'gua Bamgmok. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 808.
Whang, W.-G., and Lee, J.-Y., 1991i. Samryeokcheong Seonsaeng-an. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 872.
Whang, W.-G., and Lee, J.-Y., 1991j. Un'gua Bamgmok. In *Roster of Calendar-makers in the Late-Joseon Dynasty and Index*. Seoul, Han'gook Moonwha-sa. P. 803.
Yi, J.-H., 1925. *Joseon Myeongsin-rok.*

Appendix 1: Names of observers on duty each night for Comet 1P/Halley. The symbol ○ in the third column indicates that the characters are indecipherable.

Days of the 3rd month of the 35th year of King Yeongjo	Days of April, 1759	Observers
5th	1	An Sa-haeng 安思行, Kim Jong-boo 金宗溥, Yi Gyeong-bin 李景彬
6th	2	Song Whan-gyu 宋煥奎, Bak Jae-so 朴載素, Kim Tae-seo 金兌瑞, An Gook-bin 安國賓, Bak Seong-won 朴盛源
7th	3	Song Whan-gyu 宋煥奎, Bak Jae-so 朴載素, Kim Tae-seo 金兌瑞, An Gook-bin 安國賓, Ak Seong-won 朴盛源
8th	4	Kim Gyeong-je 金敬躋, Kim Gwang-yeon 金光演, Song Whan-gyu 宋煥奎, Kim Je-gong 金濟恭, Sim Yi-ji 沈履之
9th	5	Kim Gwang-yeon 金光演, Bak Wan-so 朴完素, Kim Je-gong 金濟恭, An Gook-bin 安國賓, Sim Yi-ji 沈履之
10th	6	Bak Wan-so 朴完素, Yi Dam 李淡, Bak Jae-so 朴載素, Kim Tae-seo 金兌瑞, Sim Yi-ji 沈履之
11th	7	Kim Jong-boo 金宗溥, Yi Dam 李淡, Bak Jae-so 朴載素, Kim Tae-seo 金兌瑞, Jeong Sang-soon 鄭尚淳
12th	8	Kim Jong-boo 金宗溥, Kim Ge-taek 金啓澤, Kim Je-gong 金濟恭, An Gook-bin 安國賓, Jeong Sang-soon 鄭尚淳
13th	9	Kim Ge-taek 金啓澤, Song Whan-gyu 宋煥奎, Kim Je-gong 金濟恭, An Gook-bin 安國賓, Jeong Sang-soon 鄭尚淳
14th	10	Sin Han-moon 申漢文, Song Whan-gyu 宋煥奎, Bak Jae-so 朴載素, Kim Tae-seo 金兌瑞, Jeong Sang-soon 鄭尚淳
15th	11	Jeong Soo-gwan 鄭守寬, Bak Wan-so 朴完素, Song Whan-gyu 宋煥奎, Bak Jae-so 朴載素, Bak Seong-won 朴盛源
16th	12	Oh Jae-hyeon 吳載賢, Yi Se-wui 李世煒, Song Whan-gyu 宋煥奎, Kim Je-gong 金濟恭, Bak Seong-won 朴盛源
17th	13	Yi Seong-sam 李省三, Bak Wan-so 朴完素, Kim Je-gong 金濟恭, An Gook-bin 安國賓, Bak Seong-won 朴盛源

18th	14	Yi Dong-seong 李東成, Yi Gyeong-jik 李擎稷, Kim Je-gong 金濟恭, Kim Tae-seo 金兌瑞, Bak Seong-won 朴盛源
19th	15	Yi In-dae 李仁大, Yi Gyeong-sim 李景深, Bak Jae-so 朴載素, Kim Tae-seo 金兌瑞, Bak Seong-won 朴盛源
20th	16	Jeon Jong-ui 全宗毅, Bak Jae-so 朴載素, Kim Tae-seo 金兌瑞, An Gook-bin 安國賓
21st	17	Jeong Soo-wan 鄭守完, Bak Jae-so 朴載素, Kim Tae-seo 金兌瑞, An Gook-bin 安國賓, Bak Seong-won 朴盛源
22nd	18	An Sa-haeng 安思行, Yi Jeong-han 李挻漢, Song Whan-gyu 宋煥奎, Kim Je-gong 金濟恭, Bak Seong-won 朴盛源
23rd	19	Kim Jong-yoon 金宗潤, Yang Do-sang 梁道常, Kim Je-gong 金濟恭, An Gook-bin 安國賓, Sim Yi-ji 沈履之)
24th	20	Kim Jong-yoon 金宗潤, Song Whan-gyu 宋煥奎, Kim Je-gong 金濟恭, Kim Tae-seo 金兌瑞, Sim Yi-ji 沈履之
25th	21	Gang Hui-eon 姜凞彦, Yi Jeong-boong 李廷鵬, Song Whan-gyu 宋煥奎, Bak Jae-so 朴載素, Sim Yi-ji 沈履之
26th	22	Kim Gwang-yeon 金光演, Yang Do-min 梁道敏, Bak Jae-so 朴載素, An Gook-bin 安國賓, Yi Seong-gyu 李聖圭
27th	23	Choe Daek-wha 崔宅華, Bak Jae-so 朴載素, Kim Tae-seo 金兌瑞, An Gook-bin 安國賓, Jeong Sang-soon 鄭尚淳
28th	24	Kim Gwang-yeon 金光演, Kim Je-gong 金濟恭, Kim Tae-seo 金兌瑞, An Gook-bin 安國賓, Jeong Sang-soon 鄭尚淳
	same day	Yi Ung-seo 李應瑞, Yi Cheon-pil 李天弼, Jo Sa-yang 趙思良, Yi Gyeong-jik 李擎稷, Song Whan-gyu 宋煥奎, Yi Se-wui 李世煒, Yi Jin-tae 李震泰, Bak Jae-so 朴載素, Jeon Deok-yoon 田德潤, Yi Je-○ 李齊○, Yi Dam 李淡, Yang Do-min 梁道敏, Bak Choon-wook 朴春煜, Bak Wan-so 朴完素, Yi Jeong-boong 李廷鵬, Yi Jeong-han 李挻漢, Song Seo-gyu 宋瑞奎, Yi Jeong-seo 李挻瑞, Yi Dong-○ 李東○, Yang Do-min 梁道敏 (appeared twice), Choe Daek-wha 崔宅華, Kim Jong-yoon 金宗潤, Yi Dong-seong 李東成, An Sa-haeng 安思行, Yi Gyeong-sim 李景深, Gang Hui-eon 姜凞彦, Yi Seong-sam 李省三, Yi In-dae 李仁大, Jeong Soo-gwan 鄭守寬, Kim Jong-yeon 金宗連, Yi Dong-Jeub 李東楫
29th	25	Song Whan-gyu 宋煥奎, Kim Je-gong 金濟恭, Kim Tae-Seo 金兌瑞, An Gook-Bin 安國賓, Jeong Sang-soon 鄭尚淳
	same day	Yi Ung-seo 李應瑞, Yi Dong-yang 李東樑, Jo Sa-yang 趙思良, Yi Gyeong-jik 李擎稷, Song Whan-gyu 宋煥奎, Yi Se-wui 李世煒, Yi Jin-tae 李震泰, Bak Sang-in 朴尚寅, Bak Jae-so 朴載素, Jeon Deok-yoon 田德潤, Yang Do-min 梁道敏, Yi ○-○ 李○○, Bak Choon-○ 朴春○, Yi Jeong-han 李挻漢, Song Seo-gyu 宋瑞奎, Kim Gwang-yeon 金光演, Bak Jong-so 朴綜素, Yi Jeong-seo 李정瑞, Yi Dong-joo 李東柱, Kim Je-gong 金濟恭, Yang Do-sang 梁道常, Choe Taek-wha 崔宅華, Kim Heong-taek 金興澤, Kim Jong-yoon 金宗潤, ○ ○-il ○ ○一, ○ ○-○ ○○○, ○ ○-sim ○○深, Gang Hui-eon 姜凞彦, Yi Seong-sam 李省三, Yi In-cheon 李仁天, Jeong Soo-gwan 鄭守寬, Yi Haeng-○ 李行○, Yi Dong-Jeub 李東楫, Kim Ge-jin 金啓晋, Yi Eui-chang 李宜昌

Nha Il-Seong is a Professor Emeritus at Yonsei University in Seoul, Korea. His main research interests are the photometric study of close binary stars, comets and meteors. He also has an interest the history of astronomy in the Far Eastern region. He has published numerous papers and books on modern astronomy and on the history of astronomy, including *Oriental Astronomy from Guo Shoujing to King Sejong* (edited by Nha and Stephenson, 1997), *History of Astronomy in Korea* (2000; in Korean), *The Story of Lunar and Solar Eclipses* (co-authored by Lee, 2002, in Korean), *Astronomical Instruments and Archives from the Asia-Pacific Region* (edited by Orchiston, Stephenson, Débarbat and Nha, 2004), *Acceptance of Western Science in Korea* (2004, in Korean), *Murals of Four Holy Animals* (co-authored by S.L. Nha, 2008, in Korean, Japanese and English), and *History of Cosmology in Korea* (2016, in Korean). Il-Seong is a former President of IAU Commission 41 (History of Astronomy); a former Chairman of the IAU Working Group on Historical Instruments; and is the founder of the ICOA series of Asian history of astronomy conferences. In 1999 the IAU named minor planet 8895Nha in his honour. At present, he is working on the restoration of historical star maps from three countries: China, Korea and Japan.

Oh Wan-Tak is a President of the Korea Meteorologist Association in Seoul, Korea. His major interest is the prediction of climate in and around the Korean

Peninsula. He has worked as a Director of the Climate Science Bureau of the Korea Meteorological Administration in Seoul, and successively as the President of Regional Offices of Meteorology in Busan, Gwangju and Daejeon.

Oh Yong-Hae is a Research Associate of the Korea Meteorologist Association in Seoul, Korea. His major interest is the observation and analysis of meteorological data. He also has an interest in the history of meteorology and in old records of meteorological phenomena in Korean history.

Nha Sarah is a Research Associate of the Korea Meteorologist Association in Seoul, Korea, and is the Deputy Director of The Nha Il-Seong Museum of Astronomy. Her major fields of interest are the photometric study of eclipsing binary stars and the history of astronomy in the Far Eastern region. She has published many research papers and one book, and now she is deeply engaged in restoring old historical star maps together with her father, Il-Seong.

Journal of Astronomical History and Heritage, 20(1), 35–68 (2017).

COOK, GREEN, MASKELYNE AND THE 1769 TRANSIT OF VENUS: THE LEGACY OF THE TAHITIAN OBSERVATIONS

Wayne Orchiston
National Astronomical Research Institute of Thailand, 191 Huay Kaew Road, Suthep District, Muang, Chiang Mai 50200, Thailand.
Email: wayne.orchiston@narit.or.th

Abstract: The 1769 transit of Venus was seen by astronomers as an important opportunity to pin down a figure for the solar parallax (*P*), and thus establish the Astronomical Unit and the size of the Solar System. Britain therefore mounted a number of expeditions, the most important of which was led by Lieutenant James Cook in the *Endeavour*, with Tahiti as the intended observing location.

In this paper we trace the planning that preceded this expedition; provide biographical accounts of the *Endeavour's* two astronomers and others who also carried out astronomical observations; describe the astronomical instruments taken on the voyage; document the various transit observations; and track the post-transit path of the *Endeavour* as it returned to England. We then discuss the values of *P* that derived from this expedition and others, and end the paper by examining a number of research issues relating to the astronomical aspects of Cook's voyage that have yet to be resolved.

Keywords: 1769 transit of Venus, Tahiti, James Cook, Charles Green, solar parallax, Thomas Hornsby, Simon Newcomb, astronomical records, scientific instruments, Daniel Solander

1 INTRODUCTION

Transits of Venus are rare astronomical events, and it was the Scottish mathematician and astronomer James Gregory (1638–1675) who first suggested that they could be used to determine the Astronomical Unit (i.e. the distance from the Earth to the Sun). The celebrated English astronomer Edmund Halley (1656–1742) and the French astronomer Joseph-Nicolas Delisle (1688–1768) elaborated on this idea, and so it was that the pair of eighteenth century transits (in 1761 and 1769) came to assume immense importance for the international astronomical fraternity.

The critical measurements were the precise times of the second ingress and first egress contacts during the transit (i.e. 2 and 3 in Figure 1), and from these one eventually could calculate a figure for the solar parallax, *P* (defined as "Half of the angular equatorial diameter of the Earth, as seen from the Sun").

The 1761 transit of Venus (Woolf, 1959) produced a plethora of figures for the solar parallax, but the range in values from 8.28″ to 10.6″ was unacceptable, and so the focus shifted to the 1769 transit (Betts, 1993; Moore, 1977). In this paper we build on Orchiston (2005) and examine the British 1769 transit program, especially that associated with James Cook and Tahiti.

2 PLANNING THE BRITISH EXPEDITIONS

Britain and Prussia were at war with Austria, France, Russia, Saxony and Sweden when the 1761 transit occurred, but by 1769 the Seven Years' War was becoming a distant memory for some. Thus, what better way could Britain demonstrate her scientific supremacy than through astronomy, and particularly the up-coming transit of Venus? Thomas Hornsby (1733–1810), the highly respected Savilian Professor of Astronomy at Oxford University (Wallis, 2008), more or less suggested this when he wrote:

> It behoves us therefore to profit as much as possible by the favourable situation of Venus in 1769, when we may be assured the several Powers of Europe will again contend which of them shall be most instrumental in contributing to the solution of this grand problem. (Hornsby, 1765: 343).

Clearly, British pride was at stake.

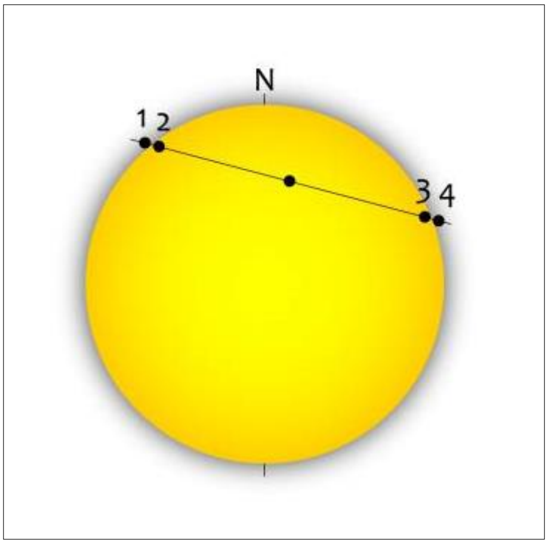


Figure 1: A drawing of a transit of Venus, showing the two ingress contacts (1 and 2) and two egress contacts (3 and 4). Critical for calculation of the solar parallax, *P,* and hence the Astronomical Unit, were contacts 2 and 3 (http://blogs.esa.int/venustransit/2012/24/transit-terminology/).

The Royal Society responded by forming a Transit of Venus Committee in 1767, two years before the grand event, and its members included Nevil Maskelyne (1732–1811; the Astronomer Royal), and three of London's leading astronomers, Dr John Bevis (1693–1771), and the Scots James Ferguson (1710–1776) and James Short (1710–1768). They began by reviewing the very useful 19-page paper, "On the transit of Venus in 1769", that Hornsby (1765) had published in the *Philosophical Transactions of the Royal Society*, where he identified three ideal overseas observing sites: North Cape in Norway, Hudson Bay in Canada and a suitable spot in the Pacific Ocean. The trouble was that no known land existed at this Pacific location at the time Hornsby wrote his paper, but fortune favoured the British because in May 1768—just over a year before the all-important transit—HMS *Dolphin* arrived back in port after a lengthy voyage of exploration in the Pacific (see Robertson, 1948), and its commander, Samuel Wallis, reported his discovery on 17 June 1767 of 'King George III Island' (now called Tahiti) at precisely the desired Pacific location! He also reported that the climate was pleasant, Port Royal (now Matavai Bay) offered an excellent harbour, and the local Tahitian people (eventually) were friendly and co-operative. The Transit of Venus Committee then adopted all three observing sites (see Beaglehole, 1963(I): 20–21), and so the Tahitian expedition was born (Herdendorf, 1986). However, Tahiti (Figure 2) was seen as host to the principal station, for two important reasons: the beginning *and* end of the transit could be observed there, and the duration of the transit would be significantly shorter than at the North Cape or Hudson Bay (Hornsby, 1765).

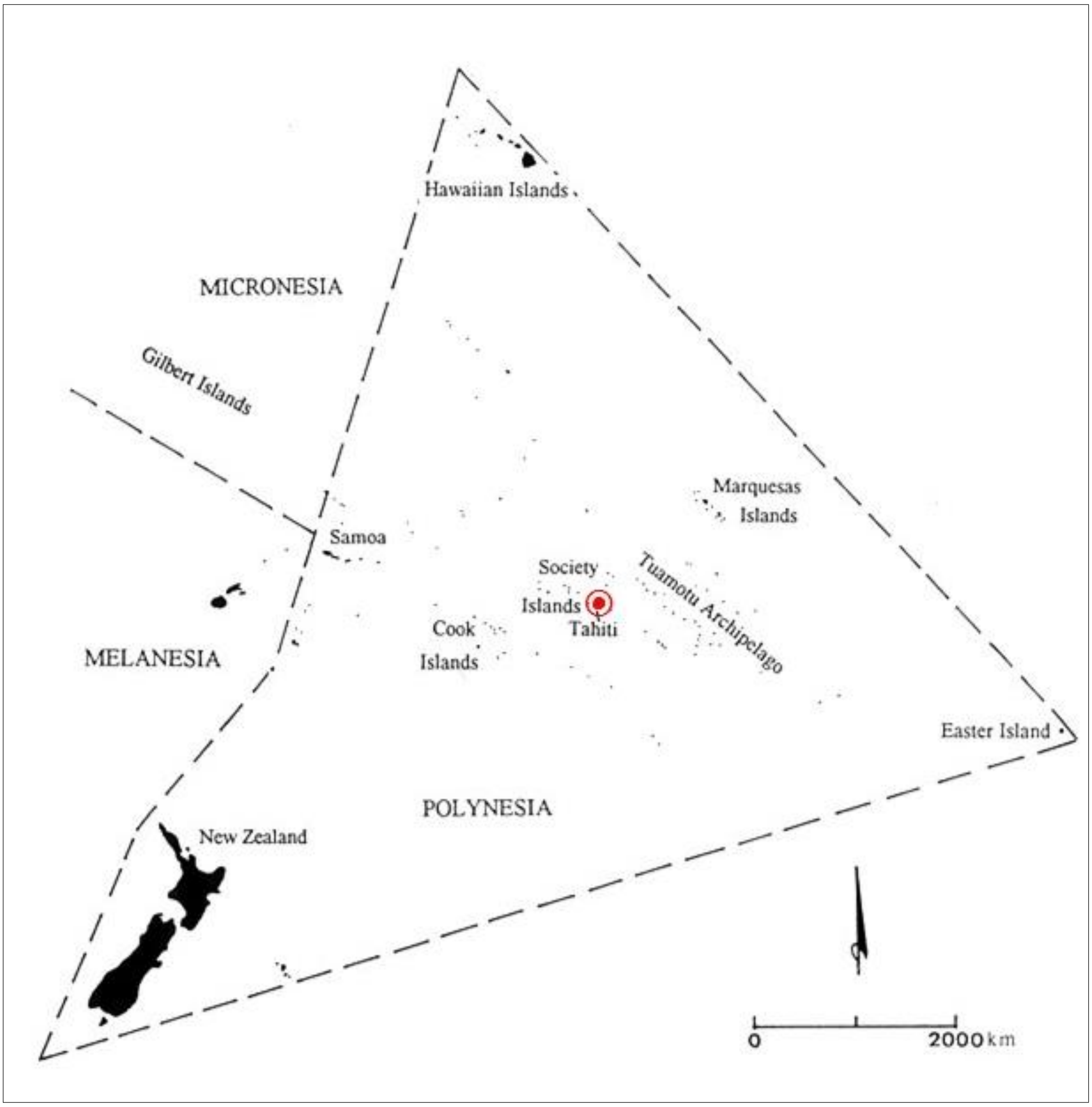


Figure 2: Map showing the location of Tahiti, the largest island in the Society Islands, very close to the centre of the 'Polynesian Triangle', which is bordered by the Hawaiian Islands, Easter Island and New Zealand (Map: Wayne Orchiston).

3 THE TAHITIAN EXPEDITION

3.1 The Vessel

The Transit of Venus Committee petitioned King George III to provide funding for the South Seas transit of Venus expedition (Banks, n.d.: 512–513), and he was happy to oblige. The Seven Years' War may be over, but what better way of demonstrating continued British supremacy than to excel in scientific endeavours. Elsewhere (Orchiston, 2005: 52) I have used the term "… fighting the peace ..." to characterise this philosophy. In hindsight, it is not surprising that King George III supported the transit of Venus proposal, as he was

> ... the first British monarch to have studied science as part of his formal education. He was known 'for his love of the sciences' and had been taught physics and chemistry as a boy, holding a particular interest in *scientific instruments*, *astronomy*, the quest for longitude, botany and *the work of the Royal Society*. (Wulf, 2012: 101; my italics).

The Admiralty then spent £2,307.5s.6d purchasing a suitable vessel, the 370-ton *Earl of Pembroke* (Deptford Yard Officers, 1768a), and a further £2,293.17s.7d modifying it for the voyage (Deptford Yard Officers 1768b). This ex-Whitby collier was renamed *Endeavour* (Figure 3), and was a type of vessel very familiar to Cook from his pre-naval days. However, even after refitting, space was at a premium, and it was to prove cramped quarters for close on 100 men, comprising officers, marines and able-bodied seamen from the Royal Navy, and non-naval personnel referred to collectively as 'supernumeraries'. Most of the supernumeraries were members of Joseph Banks' team of scientists, artists and servants, but there were two notable exceptions: Charles Green, who was one of the two official astronomers on the *Endeavour*, and his servant, John Reynolds.

3.2 The Astronomers

The Royal Society appointed two astronomers to accompany the *Endeavour* on its voyage of scientific investigation to the South Seas. As we have just noted, Charles Green was one of these, but surprisingly, the other was James Cook.

3.2.1 James Cook

Lieutenant James Cook (Figure 4) would serve the dual roles of astronomer, *and* commander of the *Endeavour* and of the expedition. Badger (1970: 30) claims that we are fully justified in classing Cook as a 'scientist' (*cum* 'astronomer'), in that he was "… a scrupulously careful observer … [and] His attitude to measurement

Figure 3: Close-up photograph of the HMS Bark *Endeavour* full-scale replica (en.wikimedia.org).

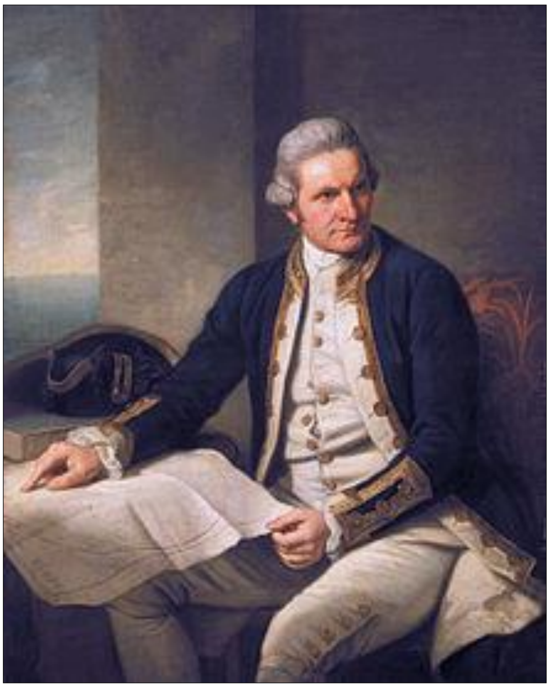


Figure 4: Oil painting of Captain James Cook by Nathaniel Dance-Holland, ca. 1775, and now in the National Maritime Museum, Greenwich (en.wikipedia.org).

and inquiry would do credit to any conventionally-trained scientist."

James Cook was born on 27 October 1728 in Marton-on-Cleveland in Yorkshire (for English and Scottish localities see Figure 5) to a Scottish labourer father and an English mother (Beaglehole, 1974), but soon after the family moved to a farm at Great Ayton. This is where young James grew up and was educated (see Beaglehole, 1968: cvi). Apparently, to his fellow school-pupils he had

> ….such an obstinate and sturdy way of his own, as made him sometimes appear in an unpleasant light; notwithstanding which, *there was a something* in his manners and deportment, which attracted the reverence and respect of his companions. (Beaglehole, 1974: 5; his italics).

After completing his schooling Cook worked briefly for a grocer and draper in the nearby small fishing port of Staithes, before choosing his future career by going to sea. From July 1746 he served a 3-year apprenticeship with the respected Whitby-based ship-owner, John Walker, and it was during this period of transferring coal between North Sea ports along the east coast of England that he received sound training in mathematics and navigation (Beaglehole, 1968: cvi).

In 1746, when he was just 24 years of age, Cook was promoted from ordinary seaman to Mate, and in 1755 Walker offered him the command of his own ship. However, Cook saw war approaching and felt he would have a better future in the Navy so he turned down this generous offer. At the time this must have been a brave move when compared to the merchant service, for Royal Navy

> … physical conditions were worse; its pay was worse; its food was worse, its discipline was harsh, its record of sickness was appalling. To the chance of being drowned could be added the chance of being flogged, hanged or even shot, though it was true that deaths in battle were infinitely fewer than deaths from disease. The enemy might kill in tens, scurvy and typhus killed in tens of hundreds. (Beaglehole, 1974: 15).

Despite this depressing description, Cook joined the Navy as an able seaman, or A.B. as it was known. He joined at the bottom of a hierarchy that extended from able seamen, to petty and warrant officers, and culminated in the commissioned officers. Initially Cook was assigned to the *Eagle* under Captain (later Sir) Hugh Palliser (1723–1796), and must have impressed for within a month he was promoted to Master's Mate, and after two years had progressed to Boatswain and then Mate (Beaglehole, 1968: cvii).

On 27 October 1757—his 29th birthday—Cook joined the *Pembroke* with a rank equivalent to Navigating-Lieutenant. This was during the height of the Seven Years' War (or the 'French and Indian War', as it was referred to at the time in North America) when Britain was

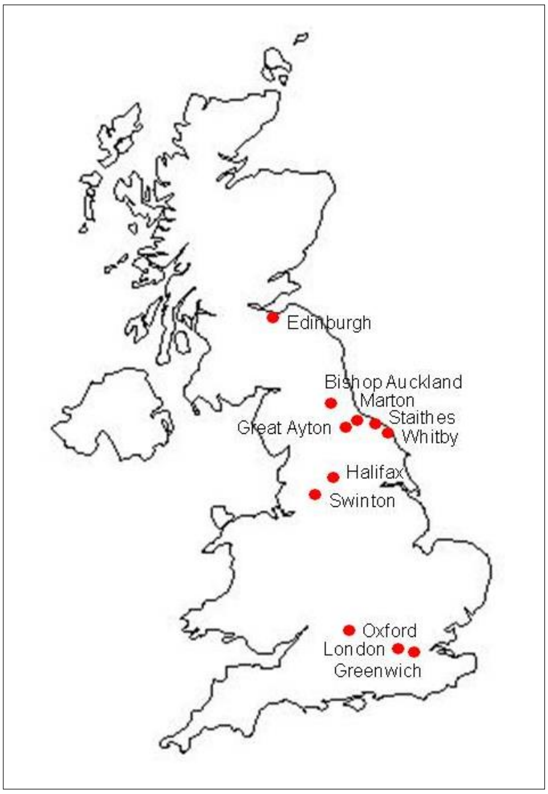


Figure 5: English and Scottish localities mentioned in this paper are shown in red (after Orchiston, 2016: 116).

mounting a concerted campaign to consolidate its own hold on the North American continent and capture French territory in what is now Canada and the USA. The British had the most formidable navy in the world, and it was to play a crucial role in these campaigns (e.g. see Anderson, 2000; Fowler, 2005). Therefore, Cook's timing in joining the Royal Navy was perfect, and it was during the siege of the French fortress of Louisbourg that he gained invaluable hydrographic surveying and cartographic experience charting the St Lawrence River (see Ritchie, 1978; Skelton, 1954), which hosted the major population centres of Quebec and Montreal. Louisbourg was strategically located on Cape Breton Island near the mouth of the river.

Cook then transferred to the *Northumberland* as a Master, and

> … began to emerge from that valuable body of persons, the masters of His Majesty's ships, as an unusually valuable person; and that the senior officers with whom he has come in contact are aware of the fact. In the context of naval journals, under their standard headings, he can virtually be classed, along with court martials and Public Demonstrations of Joy, as a Remarkable Occurrence. (Beaglehole, 1974: 55).

After conducting further cartographic work on the St Lawrence River Cook returned to England, and on 21 December 1762 he married 20-yr old Elizabeth Batts (1742–1835) at St. Margaret's Church in Barking, Essex. He was 14 years her senior.

In April 1763, following the end of the Seven Years' War, Cook sailed for North America again, to chart the coasts of Nova Scotia and Newfoundland. Then, through the influence of his old commander Hugh Palliser, he was offered his own command in 1764, the 60-ton naval schooner *Grenville* (Beaglehole, 1974). By this time Palliser was Governor and Commander in Chief of Newfoundland, and he had not forgotten the enthusiastic young man who began life on the *Eagle* as a common sailor, quickly moved through the petty officer ranks, and showed much promise as a marine navigator, surveyor and cartographer. Patronage was an important factor in British military life at this time, and Cook had a powerful supporter.

For the next three years, Cook and his crew continued the North American survey (see Figure 6), but with winter interludes in London,

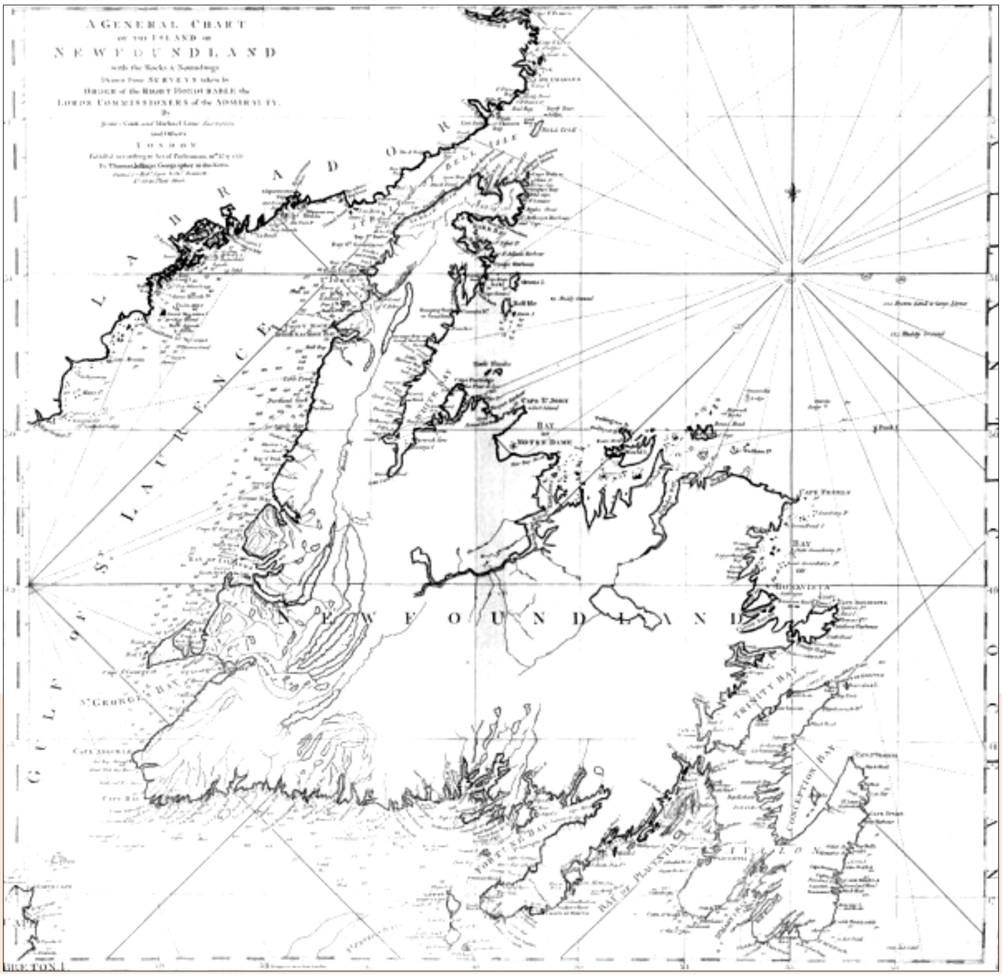
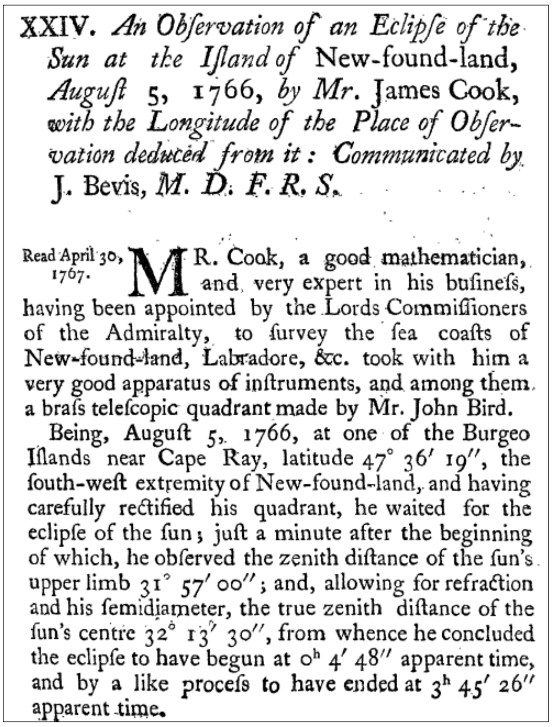


Figure 6: Cook's chart, published in 1775, was the first detailed map of the coast of Newfoundland, and reflected his skills in both hydrographic surveying and cartography (after Prowse, 1896).


XXIV. *An Obſervation of an Eclipſe of the Sun at the Iſland of* New-found-land, *Auguſt* 5, 1766, *by Mr.* James Cook, *with the Longitude of the Place of Obſervation deduced from it: Communicated by* J. Bevis, *M. D. F. R. S.*

Read April 30, 1767.

MR. Cook, a good mathematician, and very expert in his buſineſs, having been appointed by the Lords Commiſſioners of the Admiralty, to ſurvey the ſea coaſts of New-found-land, Labradore, &c. took with him a very good apparatus of inſtruments, and among them a braſs teleſcopic quadrant made by Mr. John Bird.

Being, Auguſt 5, 1766, at one of the Burgeo Iſlands near Cape Ray, latitude 47° 36′ 19″, the ſouth-weſt extremity of New-found-land, and having carefully rectified his quadrant, he waited for the eclipſe of the ſun; juſt a minute after the beginning of which, he obſerved the zenith diſtance of the ſun's upper limb 31° 57′ 00″; and, allowing for refraction and his ſemidiameter, the true zenith diſtance of the ſun's centre 32° 13′ 30″, from whence he concluded the eclipſe to have begun at 0h 4′ 48″ apparent time, and by a like proceſs to have ended at 3h 45′ 26″ apparent time.

Figure 7: The first page of Cook's short paper in the *Philosophical Transactions of the Royal Society* reporting his observation of the 5 August 1766 partial solar eclipse.

and it was during this period that Cook continued his self-education by carefully reading Charles Leadbetter's books, *A Compleat System of Astronomy* and *The Young Mathematician's Companion of 1739* (see Villiers, 1971). He also engaged in his first serious non-nautical astronomy project by observing a partial eclipse of the Sun from Newfoundland on 5 August 1766, and publishing a short account in the *Philosophical Transaction of the Royal Society* (Cook, 1767; see Figure 7). This was his first astronomical publication in this prestigious scientific journal, but it would not be his last.


Figure 8: Hugh Palliser, 1723–1796 (art-books.com).

Through these exploits, by the end of 1767 the 'power-brokers' in the Admiralty and the Royal Society were well aware of Cook's talents and capabilities, and although he was only a lowly Master and there were others of superior rank in the Royal Navy (Beaglehole, 1974), and astronomers with more experience, he was the obvious choice as the *Endeavour's* commander *and* one of its astronomers. We can presume that Palliser (Figure 8), shortly to become Comptroller of the Navy Board, would have played a role in reaching this decision (Beaglehole, 1968: cviii).

This may have been an easy decision for the Admiralty and the Royal Society, but when Cook received a letter dated 25 May 1768 (Admiralty, 1768) informing him that he had been promoted to First Lieutenant and offered the dual posts on the *Endeavour* he was fully aware of the onerous workload that captaincy of the vessel commanded, so he only agreed also to serve as an astronomer on condition that the Royal Society paid him a salary supplement of 100 guineas (see Beaglehole, 1968: cv; cxxvi; Banks, n.d.: 513–514).

That he subsequently was offered two further voyages to the South Seas only serves to demonstrate that Cook admirably carried out the role of captain of the *Endeavour* (and later the *Resolution*), while the following pages will show that he also served the Royal Society effectively and efficiently as an astronomer. Cook also combined the duties of commander and astronomer on his third voyage to the South Seas (see Orchiston, 1998a; 1998b), but both distinguished careers were prematurely terminated on 14 February 1779 when he was suddenly slain while the *Resolution* and *Discovery* were visiting Hawaii. He was just 50 years of age, and elsewhere I have written: "Thus ended the life of a colossus of British discovery, exploration, hydrographic surveying and nautical astronomy." (Orchiston, 1998b: 19). Meanwhile, Lloyd (1968: 230) epitomizes Cook as surely the "… classic example of how a man could rise [in rank] if he had exceptional talent, opportunity and patronage."

3.2.2 Charles Green

The second astronomer on the *Endeavour*, Charles Green, was a Yorkshireman like Cook, but was born in Swinton in 1735 (making him seven years Cook's junior). Green's father was a prosperous farmer (Howse, 1993). It seems that Green's education fell to his older brother, the Reverend John Green, who was the master of a school known as 'the Academy', which was in Denmark Street in London (Wales, 2008). Charles so excelled in mathematics that he was appointed an assistant teacher at the school. While at the school he taught himself astronomy, so successfully as it turned out that towards the end of 1760 he joined the staff of the Royal Observatory at Greenwich as assistant to James Bradley (1693–1762), the Astronomer Royal (Kippis, 1788). For many, the idea of working at a professional observatory may have seemed exciting, but for an 'assistant' at the Royal Observatory nothing could be further from the truth:

> Nothing can exceed the tediousness and ennui of the life the assistant leads in this place, excluded from all society, except, perhaps, that of a poor mouse which may occasionally sally forth from a hole in the wall, to seek after crumbs of bread dropt by his lonely companion at his last meal ... Here forlorn, he spends days, weeks, and months, in the same long wearisome computations, without a friend to shorten the tedious hours, or a soul with whom he can converse. (cited in Morris, 1980).

Bradley planned to observe the 1761 transit from the Royal Observatory but became ill and could not do so. Instead it was his close friend, the Reverend Nathaniel Bliss (1700–1764, Savilian Professor of Geometry at Oxford), who observed it, with assistance from Green (see Bliss, 1762).

When Bradley died in 1762 Bliss became Astronomer Royal, and Green remained at the Observatory. In 1763 he and the Reverend Dr Nevil Maskelyne (Figure 9) sailed to Barbados in the Caribbean aboard the *Princess Louisa*, by order of the Board of Longitude, so that they could determine the longitude of the capital, Georgetown. They would do this by observing Jovian satellite phenomena and by using Maskelyne's system of lunar distances, and then comparing both results with the longitude offered by Harrison's H4 marine chronometer (see Higgitt, 2010). John Harrison (1693–1776) was keen to claim the Board of Longitude's £20,000 'longitude prize' (see Betts, 2006; Sobel, 1995), but Maskelyne—with an obvious conflict of interest (see Kippis, 1788)—was equally determined the prize should be awarded for his system of 'lunars' that also could be used to determine longitude on land or while at sea (Howse, 1989). Green was not involved in this 'competition', and Harrison's chronometer did not go on the *Endeavour's* voyage to the South Seas.

Although Maskelyne apparently wrote a very good report on Green (Paulding, 2000), during the Barbados expedition Maskelyne and Green did not see eye-to-eye on all matters because when Bliss died suddenly in 1764 and Maskelyne became the new Astronomer Royal, after a brief interval he and Green argued and Green promptly resigned (Kippis, 1788). But, as Higgitt (2010) perceptively points out,

> ... because Bradley and Bliss … were both quite unwell while Green was there, he was effectively in charge of the Observatory himself for some of the time. So he was a sort of Astronomer Royal stand-in for some of the period ... and he [also] tided over the period between Bliss's death and the arrival of Maskelyne as Astronomer Royal.

After investigating London's water supply, in 1768 Green joined the Royal Navy and served as a Purser on HMS *Aurora* (Kippis, 1788). A Purser was a warrant officer whose primary responsibility was meant to be the ship's accounts and supplies, but in reality astronomers were sometimes listed as Pursers (Beaglehole, 1968:

Figure 9: The Reverend Nevil Maskelyne, 1732–1811 (en.wikipedia.org).

119), and they assisted in navigation, where astronomical knowledge was at a premium. So if Green could not work as an official astronomer he did the next best thing.

However, his return to the ranks of 'astronomer' was not long in coming, for later that same year (1768) the Royal Society appointed him as one of the two astronomers on the *Endeavour*. Despite their prior differences, Maskelyne was one of his supporters (Kippis, 1788). Green, who was married (Wales, 2008), agreed to a salary of 200 guineas, plus 100 guineas per year if the voyage extended beyond two years (Beaglehole, 1974: 131). Subsequently, on 30 July 1769 Cook was sent the following order by the Admiralty:

> You are hereby requir'd and directed to receive the said Mr Charles Green with his Servant

> [John Reynolds] Instruments and Baggage, on board the said Bark, and proceed in her according to the following Instructions ... (cited in Morris, 1981).

Following the transit, Green was one of many who were destined to die before the *Endeavour* arrived safely back in England. After safely circumnavigating New Zealand, Green fell ill with scurvy during the exploration and mapping of the east coast of Australia. Cook then headed for Batavia (present-day Jakarta) in the Dutch East Indies (Indonesia) as the *Endeavour* needed further repairs if it was to successfully sail to England. However, Batavia would turn out to be a hell-hole for the *Endeavour* and its crew, for looks can be deceiving. At the time Batavia was:

> … a rather picturesque city showing evidence in its architecture of the Dutch colonists. However, it was built on swampy ground. The climate was most unappealing – high temperatures and high humidity proved debilitating. There were frequent thunderstorms. Additionally, in 1699 Batavia had suffered a severe earthquake. The rivers about it were choked with mud and flooded the surrounding country. Batavia became notorious for being unhealthy and was in danger of being abandoned. In the 22 years from 1730 to 1752, 1,100,000 deaths are said to have been recorded. *Endeavour* had been a healthy ship but at Batavia the ship's company were exposed to dysentery, malaria and a variety of other tropical diseases. Green's servant, Reynolds, died of dysentery here on 18 December 1770 ... (Morris, 1981).

At the time, Batavia had a thriving astronomical society with an observatory, and Pastor Johan Maurits Mohr (1716–1775) also had an impressive private observatory atop his mansion on the outskirts of the city (Figure 10). People with an interest in astronomy were delighted by the *Endeavour*'s visit (ibid.), and since Mohr had observed the 1761 *and* 1769 transits (see van Gent, 2005; Zuidervaart and van Gent, 2004), it is a safe assumption that he met with Green (and maybe also Cook). Subsequently, the *London Evening Post* printed a letter from 'a gentleman' on board the *Endeavour* which described how

> ... great respect was paid here to Mr. Green by the principal people of Batavia, but no particular notice was taken of the rest of us by the Dutch. (cited in Morris, 1981).

Yet all was not well for Green, as towards the end of his stay in Batavia he also contracted dysentery, and his condition continued to deteriorate. Nearly two weeks after the *Endeavour* left Batavia he was gravely ill and on 29 January 1771 Cook recorded in his journal:

> In the night Died M^{r} Charls Green who was sent out by the Royal Society to Observe the Transit of Venus; he had long been in a bad state of hilth, which he took no care to repair but on the contrary lived in such a manner as greatly promoted the disorders he had had long upon him, this brought on the Flux which put a period to his life. (Beaglehole, 1968: 448).

Figure 10: A view of Paster Mohr's mansion and observatory (after van Gent, 2005: 69).

He was buried at sea, in the middle of the Indian Ocean. Between them, scurvy and dysentery almost decimated the *Endeavour* at this time: Green was but one of twenty-three different crew members (about a quarter of the entire complement) who died within the space of six short weeks (see Watt, 1979). Given this mortality rate, elsewhere I have suggested that "... fatalists could be excused for thinking that the Tahitian transit carried a curse of Tutankhamen-like proportions!" (Orchiston, 2005: 58).

Subsequently, the *General Evening Post* newspaper in London published a rather graphic account of Green's demise:

> Mr. Greene, the astronomer, who went out with Mr. Bankes, died soon after the ship left Batavia. He had been ill some time, and was directed by the surgeon to keep himself warm, but in a fit of phrensy he got up in the night and put his legs out of the portholes, which was the occasion of his death. (Cited in Morris, 1981).

The *General Evening Post* also stated that

> All his papers relative to the transit of Venus, of which he had made the most accurate observation, were happily completed and preserved. (ibid.).

As we shall see, shortly, this was a gross over-exaggeration.

Nonetheless, Green had proved himself a competent astronomer, and faithfully trained the officers and some of the seamen in the specifics of nautical astronomy, including the calculation of Maskelyne's 'lunars' (Beaglehole, 1968: 599). Among his effects was a log-journal (Green, 1768–1770) which Beaglehole (1968: ccxlii) thought somewhat pedestrian in nature, but it did show that Green was "… a highly conscientious as well as sprightly person." and thought himself a wit. Given the events that precipitated his death, we might judge that he was half right! Meanwhile, Green's brother-in-law, William Wales (who was destined to go on Cook's Second Voyage as an Astronomer), said that Green "... was a most excellent observer ... and tolerably well versed in most branches of mathematics." (cited in Morris, 1981).

Notwithstanding extensive searches, no drawings or paintings of Charles Green are known to exist (ibid.).

3.2.3 The '*De Facto* Assistant Astronomers'

As we have noted, above, Cook and Green were the official astronomers assigned by the Royal Society to the *Endeavour*, but

> … a coterie of officers, seamen, and even supernumeraries were involved in astronomical observations during the voyage, effectively serving as *de facto* assistant astronomers. These included Clerke, Harvey, Hicks, Hood, Molyneux, both Monkhouses, Pickersgill, Saunders, Smith, Solander and Spöring. Some of these acquired their observational skills from Green during the voyage, and even those with prior training honed their expertise between England and Tahiti – in anticipation of the Transit. (Orchiston, 2004a: 32).

Brief biographies of those who were involved in observing the transit of Venus will be presented later, in Section 3.6.

3.3 The Astronomical Instruments

If successful observations of the 1769 transit of Venus were to be made, then appropriate scientific instruments were essential (Howse, 1979; Howse and Hutchinson, 1969a). Accordingly, with Maskelyne's assistance, the Royal Society assigned the *Endeavour*

> … 2 Reflecting telescopes of two feet focus, with a Dolland's micrometer to one of them and moveable wires for the other … 2 Wooden Stands for the telescopes with polar axes suited to the Equator … an astronomical quadrant of one foot radius, made by Mr. Bird … An Astronomical Clock [by Shelton] and Alar[e]m Clock … [and] a Journeyman Clock bespoke of Mr Shelton ... 1 Stand for Bird's quadrant. (Beaglehole, 1968: cxliii).

Apart from the all-important transit of Venus, these instruments also would serve for other astronomical observations required throughout the voyage, mainly for the determination of latitude and longitude, both of which were vital for navigation and in charting the coasts of newly-discovered islands and other land masses.

Latitude was best obtained from altitude observations of the Sun as it crossed the meridian, using either a sextant (if at sea) or the quadrant (if ashore). Longitude was a more difficult proposition as it relied on accurate time-keeping. One commonly-used technique when ashore was to use the telescopes to observe specific astronomical events (e.g. occultations of stars by the Moon, Jovian satellite phenomena, solar or lunar eclipses, transits of Mercury) and compare the local occurrence times (provided by the clocks) with those listed for Greenwich in the *Nautical Almanac*. Alternatively, one could employ Nevil Maskelyne's 'lunars' method', and use a sextant to measure the angular separation of selected stars from the limb of the Moon. The longitude could then be determined by reading off the listed values in the *Nautical Almanac*. This type of astronomy, widely used on voyages of exploration during the eighteenth century, was known as 'nautical astronomy' or 'maritime astronomy', and it played a vital role, linked as it was with navigation. It has been suggested, somewhat melodramatically, that "Astronomy and navigation were mutually inseparable ..." on Cook's three voyages to the South Seas, and "… without

Figure 11: A painting of James Short (courtesy: Museum of the History of Science, Oxford University).

the astronomers these voyages could have ended in tragedy." (Orchiston, 1998b: 9).

3.3.1 The Telescopes

The two telescopes supplied by the Royal Society were made by the noted Scottish telescope-maker and astronomer, James Short (Green and Cook, 1771: 398), "… a full-faced, well-built man of medium height." (Bryden, 1968: 6). Short (1710–1768; Figure 11) had an M.A. degree and had qualified as a Church of Scotland minister, but had a passion for scientific instrument-making, and also observational astronomy (cf. Turner, 1969). Initially he began commercial operations in Edinburgh, but in 1738 moved his business to London, the acknowledged centre of the British scientific instrument-making industry (Clifton, 1996; King, 1979). Short has been described as "A most celebrated personality he accrued a fortune by supplying excellent instruments (about 1360) to amateurs and professionals." (Andrews, 1996: 99). The two Short telescopes consigned to the *Endeavour* were Gregorian reflectors, with perforated speculum metal primary mirrors 4 inches in diameter, and speculum metal ellipsoidal secondary mirrors (see Figure 12). Short received the contract to make all of the astronomical telescopes for the British 1769 transit of Venus expeditions, which must have pleased him given that he had personally carried out successful observations of the 1761 transit (see Short, 1764).

Figure 12: A Gregorian telescope by James Short, very similar if not identical to the ones that accompanied Cook and Green to Tahiti. At the bottom right is an object-glass micrometer that was used for measuring the angular separation of Venus from the limb of the Sun in the course of the transit (courtesy: The Royal Society, London).

The object glass micrometer supplied with one of the Short telescopes was made by John Dollond (Figure 13), and is described by him in a paper that was published in the *Philosophical Transactions of the Royal Society* (Dollond, 1754). This ingenious device was invented by Dollond in 1753, and allowed astronomers to measure the angular separation of two nearby celestial objects or two parts of the same object (see Dollond, 1753). This would surely prove useful during the transit.

In addition to the two Short telescopes, two other telescopes went to the South Seas on the *Endeavour*. One was Cook's own telescope, which he had used while surveying the North American coast, and which he describes as follows:

> The Navy Board have been pleas'd to supply His Majestys Bark the Endeavour under my command with the Reflector Telescope that was on board the Grenville Schooner for makeing Astronomical Observations at Newfoundland … (cited in Beaglehole, 1968: 621).

Cook (1768) then had a micrometer made for it, "… which will be of great service in the observation of the Transit Vinus …" Documentation provided during Cook's later Second and Third Voyages to the Pacific reveals that this Gregorian reflector was made by Watkins, had a focal length of 18 inches and was owned personally by Cook (Beaglehole, 1969: 532; Beaglehole, 1967, I: 243; Green and Cook, 1771: 416). In telescope-making circles, the Watkins name was not as well known as Short, but the *Directory of British Scientific Instrument Makers 1550–1851* (Clifton, 1995) lists an eighteenth-century London instrument-maker named Francis Watkins, who began his optical apprenticeship in 1737 and practised as a scientific instrument-maker from 1747. He made a variety of instruments, and apparently had close links with the renowned London telescope-maker John Dollond. Andrews (1997:157) gives Watkins' birth and death dates as ca. 1732–1782. Figure 14 shows a Watkins telescope of the same vintage, that we can presume is similar in appearance to the one owned by Cook.

In addition, Dr Daniel Solander, one of Banks' party, had a telescope that he used to successfully observe the transit, and Green and Cook (1771: 411–412) mention that it was a 3-ft long reflecting telescope and magnified more than their two Short reflectors, but nowhere do they, or Solander, describe this instrument or even mention the name of its manufacturer.

A Gregorian telescope 3-ft in length is considerably longer than the other telescopes of this type that accompanied the various British transit of Venus expeditions in 1769, so any telescope of this length with reputed Cook First Voyage associations in a museum collection warrants close scrutiny. Such a telescope exists in the scientific collections of The Museum of New Zealand Te Papa Tongarewa in Wellington (Accession Number NS000010), which has a convoluted history with supposed links to either Sir Joseph Banks or Charles Burney, both of whom were closely associated with Cook and his voyages to the South Seas. In a paper published in the *Journal of the Antique Telescope Society* in 1999 (where the telescope features on the front cover), I examine the documentation accompanying this telescope, particularly its supposed Cook voyage provenance, and conclude

> The only possible Cook-voyage association that we have been able to identify for this instrument is that it was the Gregorian reflector used by Dr Daniel Solander in 1769 to observe the transit of Venus. However, the evidence for this is slim and largely circumstantial, and the fact that Solander was part of Banks' retinue should not be seen as persuasive.
>
> Scientific instruments, memorabilia and indigenous artifacts of eighteenth century vintage and reputedly associated with Cook's voyages were eagerly sought after during the nineteenth and twentieth centuries and attracted high sale prices. As a result, many objects with bogus 'Cook' histories made their way into private collections and the world's museums … and it is possible that the Wellington telescope is yet another example of this trade. (Orchiston, 1999: 8).

Upon subsequently re-examining all of the available documentation I decided that perhaps I was overly cautious in my 1999 paper, so at the International Astronomical Union's 2004 transit of Venus conference in Preston, England, I announced that "... the telescope used by Solander at Fort Venus is probably the Heath and Wing reflector now housed in The Museum of New Zealand Te Papa Tongarewa, in Wellington ..." (Orchiston, 2005: 62).

Figure 13: An oil painting of John Dollond by Benjamin Wilson now in the Royal Museums, Greenwich (en.wikipedia.org).

In fact this idea was first promoted by Edward Rock Garnsey (1864–1935), the New South Wales Agent-General in London, who had an intimate knowledge

> ... of art, literature, history, and science [which] led to his being chosen from time to time to decide the authenticity or the value of documents, manuscripts, paintings, or relics alleged to have some connection with the early history of Australia. (Garnsey ..., 1935).

Acting on behalf of the Australian Government, in 1930 Garnsey carefully examined the telescope and associated documentation and concluded

Figure 14: A brass Gregorian telescope made by Francis Watkins in about 1765 and similar to the one that Cook took to Tahiti for the transit of Venus (adapted from www.arsmachina.com/t-watkins5038.htm).

> … that he had no doubt in his own mind that it was the identical Instrument used by Dr. Solander of the British Museum on the memorable voyage with Cook & Banks & others undertaken in 1769 to observe the transit of Venus at Tahiti. (Ellis, 1932).

So what does this telescope look like? Figure 15 shows its present appearance, and in a letter written in 1918, the owner of the telescope at that time included the following 'bullet point' summary of its features:

> Gregorian Reflector
> Mounted as an altimuth [*sic*.], with horizontal circle and vertical circle attached to the body of the Telescope, both circles graduated and having verniers attached.

Figure 15: The Gregorian telescope in the Museum of New Zealand Te Papa Tongarewa in Wellington that has tentatively been identified as the one Solander used to observe the transit at Fort Venus (courtesy: Museum of New Zealand Te Papa Tongarewa, NS000010/1).

> Aperture 5" diameter.
> Made by Heath & Wing, London. No date. Two eyepieces, high and low, each having its own small concave lens.
> Diameter 1½".
> Length of low eye piece 5¾".
> Length of high eye piece 4¼".
> Both fitted with sun glasses.
> Length of Telescope 2ft. 10½ins.
> Height of vertical column 1ft.
> The instrument can be clamped so that by holding each screw with either hand the star, etc. can be kept in the field of vision.
> Unclamped the instrument is free to move in any direction.
> There is also a finder which is a refractor with cross wires in the eye piece.
> Diameter of object glass 1". (Relton, 1918)

The tube of the telescope and fittings were made of brass, and the telescope came with an oak travelling case into which it fitted (Ellis, 1932).

Apart from its excessive length, in overall appearance this telescope bears a striking resemblance to the Gregorian reflectors manufactured by Short that were supplied to Cook and Green. Furthermore, it may be more than a coincidence that Solander's telescope was almost identical in length to the Heath and Wing Gregorian reflector in the museum in Wellington.

What do we know of the firm 'Heath & Wing London', whose name is engraved on the telescope, near the eyepiece assembly? Thomas Heath was one of London's most prominent scientific instrument-makers during the first half of the eighteenth century, before going into partnership with Tycho Wing, who was some years his junior (and with a name like that surely could be excused for making astronomical telescopes). The firm of Heath and Wing ran successfully from 1751 to 1773 as makers of mathematical, philosophical and optical instruments. So this time-frame sits comfortably with an acquisition date some during the late 1760s, prior to Cook's First Voyage. Apart from astronomical telescopes, Heath and Wing also made barometers, protractors, sextants, sundials, theodolites and thermometers. Thomas Heath died in 1773 and Tycho Wing retired in that same year and died just three years later (B. Ariail, pers. comm., 1999; Clifton, 1995).

3.3.2 The Quadrant

As we have seen, one 12-inch quadrant made by John Bird (see Figure 16) was taken on the *Endeavour*, and this was used ashore to make positional observations of the Sun, Moon and selected stars, which after an intricate series of calculations produced values of longitude, while meridian observations of the Sun provided the latitude. Chapman (1983) has demonstrated that quadrants underwent a rapid evolution during the late eighteenth century.

John Bird (1709–1776; Figure 17) was an accomplished British scientific instrument-maker (Hellman, 1932), and was famous for his astronomical quadrants (Bird, 1768). Chapman (1995: 75) described these as

> ... mechanical, not optical, instruments, and aimed to eliminate every possible source of tension or imbalance in the fabric, for which they employed the simplest optical system.

Bird began his adult life as a weaver, but in 1740 moved to London and joined the well-known instrument-maker, Jonathan Sisson, where he gained his training (see Gould, 1976). He then decided to open his own business, and this soon became the centre of the astronomical instrument-trade, "... especially after Bradley [the

Astronomer Royal], with £1000 available for new instruments, gave Bird his first large order." (King, 1979: 115). Apart from quadrants, Bird also made a few reflecting telescopes, as well as thermometers, barometers and drawing instruments (King, 1979: 117). Astronomy was his hobby, and he used one of his own Gregorian telescopes to observe the 1761 transit of Venus and an annular solar eclipse in 1765 (Andrews, 1992: 122). Beaglehole (1968: 87) notes that Bird "... displayed a talent for delicate and precise work which brought him European fame."

On Cook's First Voyage, when in use the quadrant normally was housed in a tent observatory, which protected it from the elements:

> [Near the main tent] ... stood the observatory, in which were set up the journeyman clock and astronomical quadrant: this last, made by Mr. Bird, of one foot radius, stood upon the head of a large cask fixed firm in the ground, and well filled with wet heavy sand. (Green and Cook, 1771: 398).

In May 1769 the quadrant was 'borrowed' by some of the local Tahitians and damaged. Although Spöring did his best to repair it (Beaglehole, 1968: 527–529), after this event there was always some doubt about its reliability.

3.3.3 The Astronomical Clocks

Time-keeping was critical on Cook's First Voyage, not only in recording the all-important contacts during the transit of Venus, but throughout the voyage, for accurate time gave the astronomers access to longitude. There were three different types of clocks on the *Endeavour*: an astronomical clock, a journeyman clock and an alarum clock.

The astronomical clock was the largest, most expensive and most accurate of the three (providing time to the nearest second), and was only used when a shore-based tent could be set up. The usual procedure was to install the clock inside a tent that afforded protection from the elements and uninvited human interference, as the following Tahitian account dating to April 1769 indicates:

> The astronomical clock, made by Shelton and furnished with a gridiron pendulum, was set up in the middle of one end of a large tent, in a frame of wood made for the purpose at Greenwich, fixed firm and as low in the ground as the door of the clock-case would admit, and to prevent its being disturbed by any accident, another framing of wood was made round this, at the distance of one foot from it. (Green and Cook, 1771: 397).

The Royal Society had already purchased astronomical clocks by John Shelton (costing 30 guineas each) for the 1761 transit of Venus, and these were available for the 1769 event. One

Figure 16: A 12-inch quadrant made by John Bird, which may have been on one of the British 1769 transit of Venus expeditions, but not necessarily the one to Tahiti (courtesy: The Royal Society, London).

Shelton clock was taken on the *Endeavour*, and Figure 18 shows this, while Figure 19 reveals the instructions that Shelton supplied for setting up the clock.

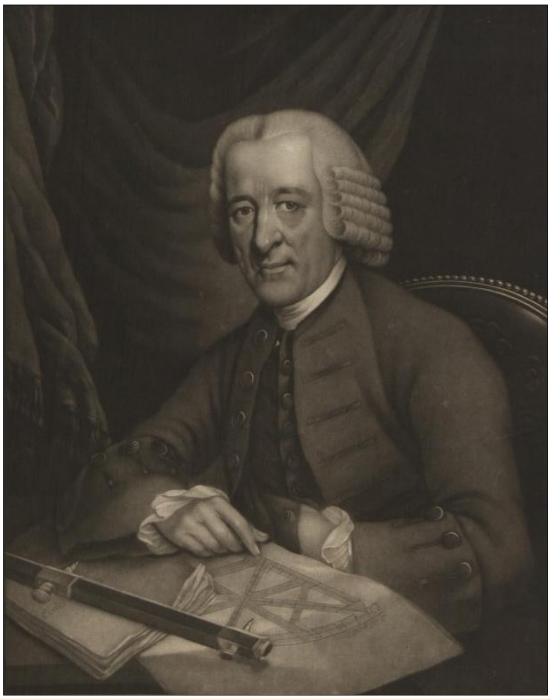


Figure 17: A mezzotint of John Bird of London, by Valentine Green after Lewis, Published by Valentine Green, London, 1776. Inv 14176 (https://blogs.mhs.ox.ac.uk/insidemhs/making-prints-public-john-bird-connecting-collections/).

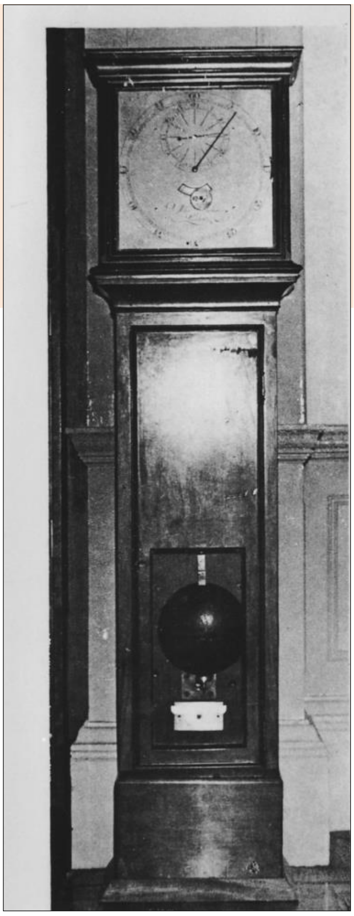
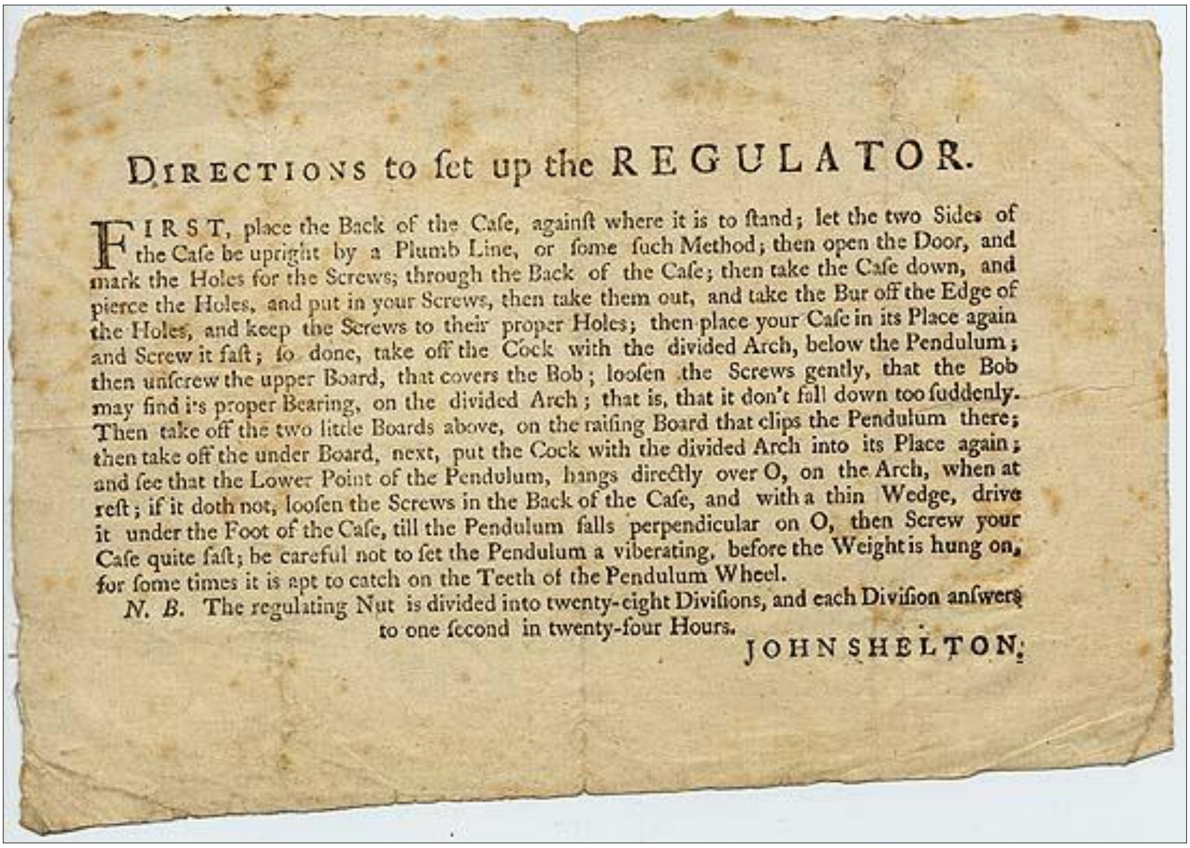


Figure 18: This Shelton astronomical clock has been identified by Howse and Hutchison (1969b) as the one that accompanied the *Endeavour* to Tahiti (courtesy: the late Derek Howse).

In *The Clocks and Watches of Captain James Cook 1769-1969* Howse and Hutchinson (1969b: 289–291) supply the following description of a typical Shelton astronomical clock, based on one now in St John's College, Cambridge, which was manufactured for one of the 1761 British transit of Venus expeditions (and therefore would have been very similar to the clock that accompanied Cook and Green to Tahiti):

> *The basic movement* consists of a pair of shaped brass plates ... The average dimensions in the series are approximately 10.25 × 6.25 in. The six pillars are riveted to the back plate; the front plate is fastened by latches.
>
> *The train* has five wheels and is constructed for a month's duration. Where feasible, the pivots bear on end-plates which minimise friction and preserve the oil. One large end-plate covers all pivot holes on the back plate ...
>
> *The escapement* is dead-beat, and has a 30 tooth brass wheel with relieved teeth; the anchor is steel and has a long shank and curved arms which terminate in the pallets. The collets for the escape wheel and anchor are characteristically long ...
>
> *Bolt-and-shutter maintaining power* is fitted, with an additional device to prevent the clock stopping while the mechanism is being engaged. Although the movement is weight driven, stopwork (acting on a principle similar to that used in fuzee clocks) is fitted to prevent



DIRECTIONS to ſet up the REGULATOR.

FIRST, place the Back of the Caſe, againſt where it is to ſtand; let the two Sides of the Caſe be upright by a Plumb Line, or ſome ſuch Method; then open the Door, and mark the Holes for the Screws; through the Back of the Caſe; then take the Caſe down, and pierce the Holes, and put in your Screws, then take them out, and take the Bur off the Edge of the Holes, and keep the Screws to their proper Holes; then place your Caſe in its Place again and Screw it faſt; ſo done, take off the Cock with the divided Arch, below the Pendulum; then unſcrew the upper Board, that covers the Bob; looſen the Screws gently, that the Bob may find it's proper Bearing, on the divided Arch; that is, that it don't fall down too ſuddenly. Then take off the two little Boards above, on the raiſing Board that clips the Pendulum there; then take off the under Board, next, put the Cock with the divided Arch into its Place again; and ſee that the Lower Point of the Pendulum, hangs directly over O, on the Arch, when at reſt; if it doth not, looſen the Screws in the Back of the Caſe, and with a thin Wedge, drive it under the Foot of the Caſe, till the Pendulum falls perpendicular on O, then Screw your Caſe quite faſt; be careful not to ſet the Pendulum a viberating, before the Weight is hung on, for ſome times it is apt to catch on the Teeth of the Pendulum Wheel.

N. B. The regulating Nut is divided into twenty-eight Diviſions, and each Diviſion anſwers to one ſecond in twenty-four Hours.

JOHN SHELTON.

Figure 19: Shelton's instructions for successfully setting up his transit of Venus astronomical clocks (after Johnston, 2005).

> overwinding.
>
> *The motion work* is conventional; the hour-wheel pipe carries a friction-mounted hour circle instead of an hour hand. The cannon pinion and minute wheel are only partially crossed out, and thus counterpoise the minute hand. The minute wheel and pinion are pivoted on a cock screwed to the front plate, and the arbor is extended to pivot on the back plate.
>
> *The dial* is a square plate of brass – engraved, waxed, and silvered ... The dial is mounted on four pillars and can be removed by the screws ... The pillars are turned with wide feet, and are located with steady pins and screwed to brass plates which in turn are fastened to the front plate ...
>
> *The pendulum* is of gridiron construction and is suspended from the back cock by a steel strip. The crutch is steel and has a brass pin which engages in a slot in the central rod ...
>
> *Shelton's punch-mark* on the Cambridge movement is on the front plate ...
>
> *The movement* is rigidly mounted, and is secured to the seat-board with four brass hold-fasts and screws. Two more holdfasts are screwed to the back plate, and line up with brackets screwed to the back-board.

The constant motion of the ship made it impossible for the astronomers to use the Shelton astronomical clock (also termed a 'regulator') on board the *Endeavour*, while it was at sea. The clock could only be used ashore, and even then after being properly set up.

The second type of clock assigned to the *Endeavour* was a journeyman (or assistant) clock. This was a smaller, less accurate clock that was generally used on shore in a tent or observatory, alongside an astronomical quadrant. Maskelyne (1764: 373) provides an excellent description of one of these clocks:

> ... I fixed up a little clock there, which may be called a journeyman, or secondary clock, having a pendulum swinging seconds, which after being well adjusted would keep time very regularly for several hours. It had only a minute and second hands, and struck every minute exactly as the second hand came to sixty, which was very convenient for the counting of seconds ...

The Royal Society ordered a new journeyman clock from Shelton, costing £5, and this was taken on the *Endeavour*.

An alarum clock appears to have been a small, portable clock that was used when astronomical observations were made. It cost only a small fraction of the price of an astronomical clock, and seemed prone to damage and breakdown. As Howse (1969a) notes, since none of these clocks survived from any of Cook's voyages and written descriptions of them have not been found, we know very little about them. The Royal Society also ordered a new alarum clock for the *Endeavour*, and this probably also was made by Shelton.

The final time piece taken on the *Endeavour* was a watch made by George Graham. This was owned by Nevil Maskelyne, who loaned it the Royal Society (Howse, 1969a; 1969b).

As we have noted, all of the clocks were manufactured by John Shelton (1712–1777), who at the time was one of Britain's foremost makers of astronomical time-pieces. At the age of seven he began an apprenticeship with the London clock-maker Henry Stanbury, and in 1720 he became a member of the Clockmakers' Company. By the middle of the eighteenth century Shelton was the main person used by the noted London instrument-maker George Graham to fabricate astronomical clocks, yet despite his obvious technical acumen and orders for transit of Venus clocks in 1761 *and* 1769 Shelton did not have a good business sense and soon after was in financial straits (Bonhams ..., 2006; Clifton, 1995).

3.4 The Voyage (1768–1771)

The Seven Years' War ended with the signing of the Treaty of Paris on 10 February 1763 between Great Britain and France, and involved a complex series of land exchanges, mainly in North America, the Caribbean and India (see Baugh, 2011; Marston, 2001). No longer would international scientific expeditions run the threat of military intervention—as sometimes occurred during the 1761 transit of Venus—and with the world now at peace, British (and also French) astronomers attracted by the 1769 transit were free to proceed unimpeded to far-flung observing destinations. This must have been a great relief to Cook, given the long and hazardous journey he was facing to the far side of the globe.

Thus on 26 August 1768 Cook sailed from Plymouth on

> … one of the most expensive and ambitious expeditions ever undertaken by Mother England … To all intents and purposes this was a scientific voyage: at issue was the most pressing problem in world astronomy, and at stake was British pride and prestige. (Orchiston, 2005: 54).

After sailing across the Atlantic Ocean and rounding Cape Horn, the *Endeavour* penetrated the Pacific, and on 13 April 1769 anchored in Matavai Bay on the northern coast of Tahiti (see Figure 20). This left Cook, Green and others who would observe the transit more than seven weeks to prepare for the grand event on 3 June.

Only after the transit would Cook open the sealed orders provided by the Royal Society, and discovered his charter for the remainder of the voyage, which would take the *Endeavour* in search of Terra Australis Incognita, the large southern continent that was assumed to exist in the Pacific and counter-balance the presumed over-accumulation of land masses in the Northern Hemisphere. So the voyage of scientific exploration would become one of geographical exploration, and lead to the re-discovery and circumnavigation of New Zealand and the exploration and charting of the east coast of Australia. After carefully threading its way through the seemingly endless islands, reefs and shoals of the Great Barrier Reef and sailing through Torres Strait, the *Endeavour* would head for England via Batavia (present-day Jakarta, in Indonesia), Cape Town and Ascension Island, eventually reaching Plymouth on 13 July 1771.

3.5 The Tahitian Observing Sites

Let us now return to Tahiti and the transit. Soon after the *Endeavour* arrived in Matavai Bay Cook and Green decided that nearby Point Venus was an ideal site for the observatory: it was easy to reach from the ship, and lay on a narrow strip of land that could be fortified (which would ensure there were no interruptions during the transit, when precise observations and measurements called for total concentration). Figures 21 and 22 show details of the Fort.

Fort Venus was established, with an assortment of tents for men and instruments:

> The astronomical clock ... was set up in the middle of one end of a large tent, [and] ... Without the end of the tent facing the clock, and 12 feet from it, stood the observatory, in

Figure 20: Part of the lithograph 'View of Matavai Bay in Otaheite from One Tree Hill', showing the *Endeavour* at anchor, and on shore to starboard (to its right) is Fort Venus (based on the original lithograph in Hawkesworth, 1774).

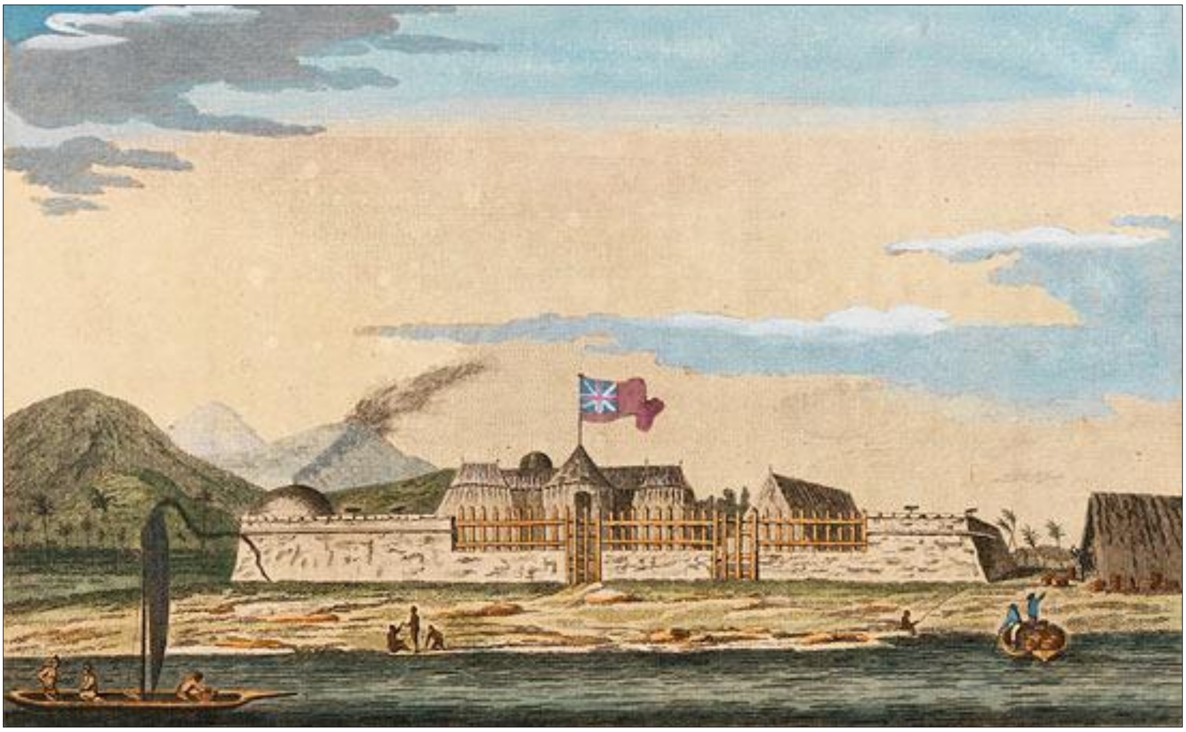


Figure 21: This undated tinted lithograph is based on an original untinted lithograph that was published by Parkinson (1784). Although it displays some artistic licence, it does show the *general* appearance of Fort Venus (Orchiston Collection).

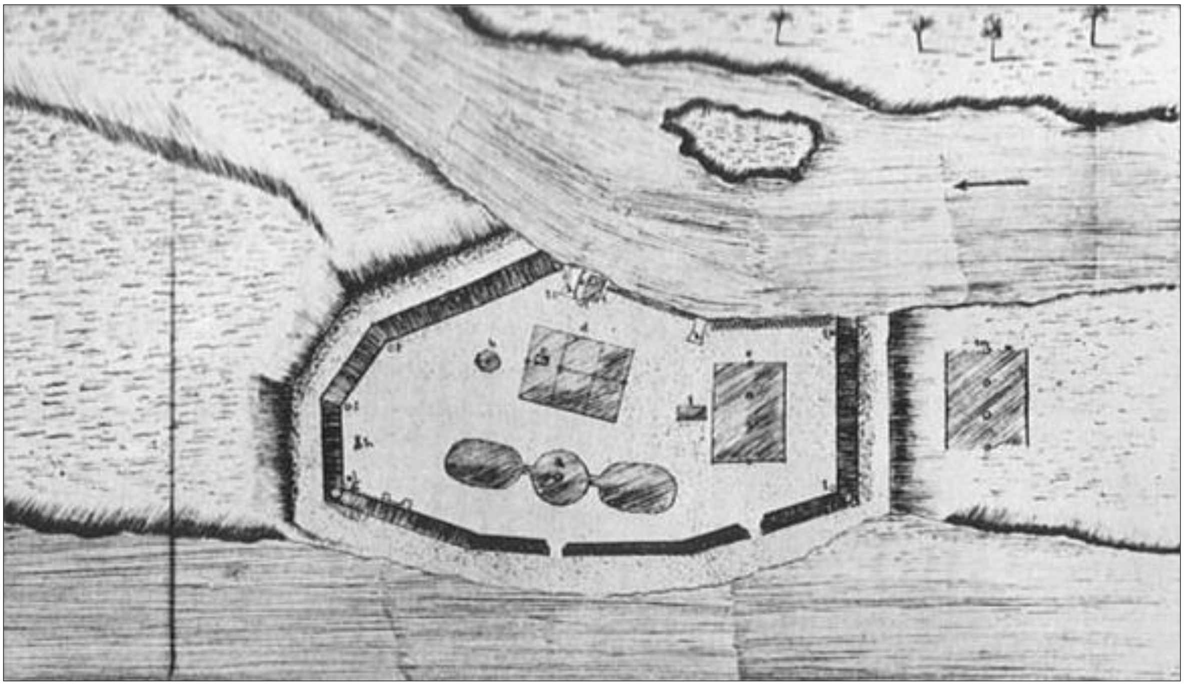


Figure 22: Plan view of Fort Venus, showing the palisade, three adjacent tents near the foreshore, two large rectangular tents, the centrally located one housing the astronomical clock, and to the left of this tent the small circular tent-observatory where the journeyman clock and the quadrant were located (adapted from Parkinson, 1784: Plate IV).

> which were set up the journeyman clock and astronomical quadrant … (Green and Cook, 1771: 397–398).

The 'observatory' mentioned above was an important innovation. It was a portable tent observatory, designed by Smeaton (who built the Eddystone Lighthouse), and constructed under the direction of Maskelyne and Cook (Beaglehole, 1968: cxliii).

Once Fort Venus was set up, establishing its latitude and longitude became one of Green's priorities. For latitude he used quadrant observations of meridian zenith distances of the Sun obtained between 6 May and 27 June and meridian zenith distances of fifteen bright stars observed between 21 June and 4 July. These produced a mean value of 17° 29′ 15″ S (Green and Cook, 1771: 405–406). For longitude, he measured 'lunars' with the quadrant or a sextant on sixteen evenings between 30 April and 30 June, deriving a figure of 149° 36′ 38″ W of Greenwich, which was similar to the value of 149° 32′ 30″ W, that Green and Cook obtained from observations of Jovian satellite eclipses made using the Short telescopes on seven nights between 4 June and 6 July (see Green and Cook, 1771: 407–409). In order to conduct these latter observations, the telescopes were mounted on top of empty casks that were sunk into the sand, and ballasted internally with more sand for stability (Green and Cook, 1771: 398). Figure 23 shows how these telescopes were used.

As the date of the transit neared, Cook notic-

Figure 23: A reconstruction at the Royal Observatory Greenwich of how the Short telescopes were used for astronomical observations on Cook's first voyage (courtesy: the late Derek Howse).

ed that the anchorage at Matavai Bay experienced as many cloudy days as clear ones (see Beaglehole, 1963 (I): 283), and so as a safeguard against inclement weather at Fort Venus on the critical day he decided to heed the sage advice proffered him before the voyage by the President of the Royal Society (see Douglas, n.d.: 516) and establish two temporary ancillary observing stations. One of these was on Irioa Island off the north-eastern tip of adjacent Moorea, and comprised no more than

> … a Coral rock about 150 yards from the shore … It was about 80 yards long and 60 broad and had in the middle of it a bed of white sand large enough for our tents …" (Beaglehole, 1963(I): 284n).

The other supplementary observing station was on Taaupiri Island, an islet off the shore of Tahiti to the east-southeast of Fort Venus (see Beaglehole, 1968: 97n). The locations of these three different 1769 Tahitian transit stations are shown in Figure 24. According to Cook (1770) there were enough instruments to equip the three observing stations, while on the voyage out to the Pacific Green offered instruction in nautical astronomy and transit of Venus observations (see Orchiston, 1998b), guaranteeing that there would be 'qualified' observers at each transit station.

3.6 The Observers and the Transit Observations

3.6.1 Fort Venus

The observing team at the principal transit station, Fort Venus, comprised James Cook, Charles Green, Daniel Solander and Robert Molyneux (Beaglehole, 1968: 559). We have already met Cook and Green in Section 3.2, so what do we know of Solander and Molyneux?

Dr Daniel Carl Solander (1733–1782; Figure 25) was a Swedish-born scientist who studied under the distinguished Professor of Botany, Linnaeus (Carl von Linné) at the University of Uppsala. Linneaus encouraged Solander to go to England to promote his system of botanical classification. Arriving in London in June 1760 he ultimately found employment at the newly established British Museum as Assistant Librarian and never returned to Sweden or completed his Uppsala Ph.D. although he was referred to as 'Dr Solander' (and indeed this title was formalised in 1771, after the *Endeavour* returned from the South Seas, when Solander was awarded an honorary doctorate by Oxford University). At the British Museum, Solander was able to catalogue the natural history collections using the Linnaean system (Gilbert, 1967), and in 1764 he was elected a Fellow of the Royal Society. With so much in common as natural history *oficionados*, it was inevitable that Daniel Solander would meet Joseph Banks (1743–1820) and the two became life-long friends. As "... the ablest botanist in England."

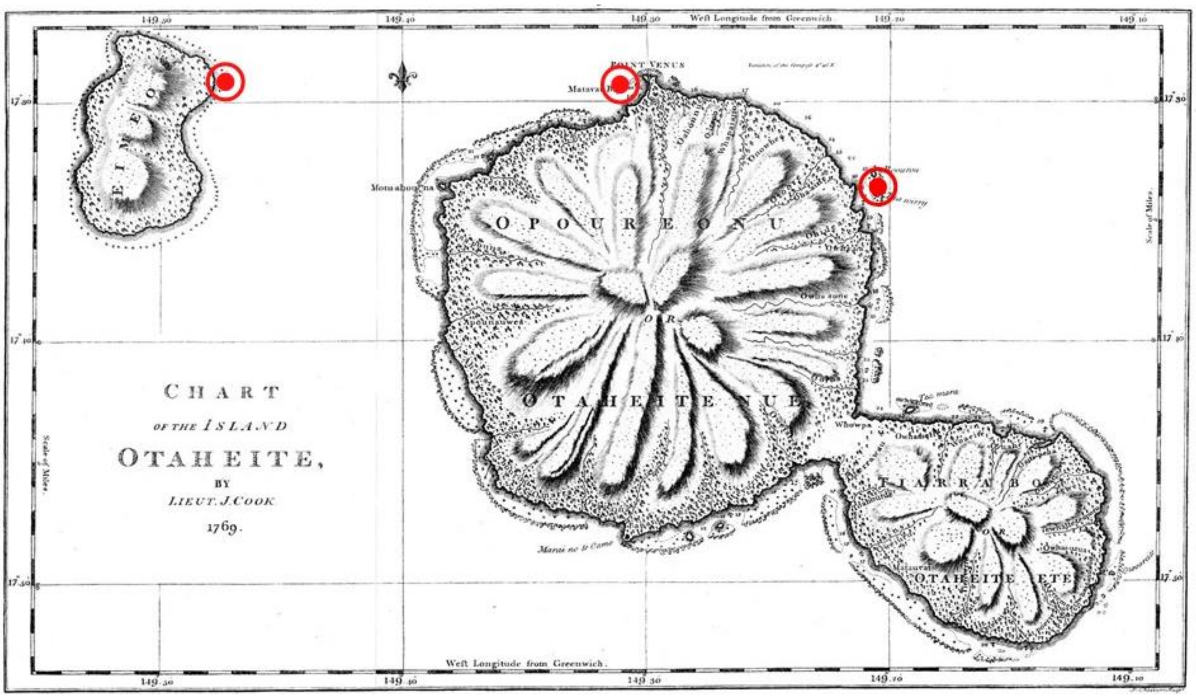


Figure 24: A modified version of Cook's original map of Tahiti, with the locations of the three different observing sites superimposed. From left to right they are Irioa Island, just off the north-eastern tip of Morea; Fort Venus at Matavai Bay, Tahiti; and Taaupiri Island, just off the coast of Tahiti (map modifications: Wayne Orchiston).

(Beaglehole, 1968: cxxxv), it was only natural that Banks would invite Solander to join his personal entourage of scientists and artists who would sail on the *Endeavour* to the Pacific (Duyker, 1998). Accompanying Solander was his assistant, Herman Spöring, who would prove to be a competent artist. When the *Endeavour* left England Solander was 35 years of age, and he was described as

> ... short and somewhat stout, with fair hair and complexion. He [was] ... a jovial sort of man, kind and obliging, with charm and humility ... By some writers he has been described as lazy, dissipated, indolent, dilatory and even in one case as being nothing more than a parasite. These accusations are most unjust ... (Marshall, 1977: 51).

In 1773, less than two years after the return of the *Endeavour*, Solander was appointed Keeper of the Natural History Department at the British Museum, and he also served as
' Curator-Librarian at Soho Square. He lived with Banks up until his death on 12 May 1782. Figure 21 shows a painting of Solander made after the return of the *Endeavour* to England.

Robert Molyneux was born in Hale, Lancashire, in 1746, and served as a Master's Mate on the *Dolphin* before joining the *Endeavour* with the rank of Master (Beaglehole, 1968: 593). He showed much aptitude in surveying and cartography, skills that were greatly appreciated by Cook (see Beaglehole, 1968: cxxxii). Molyneux was one of those who died when the *Endeavour* was returning to England, on 16 April 1771, as the vessel was leaving Cape Town (Beaglehole, 1968: 593), and although he reputedly had "... a good measure of intelligence ..." (Beaglehole, 1968: cxxxii) Cook's obituary of him paints a picture of a young man who "... had unfortunately given himself up to extravecancy and intemperance which brought on disorders that put a pirod to his life." (quoted in Beaglehole, 1968: cxxxii). Professor Arnold Wood (1926) is somewhat more forthright: Robert Molyneux, "The Master—a very important officer, who looked after matters of navigation—[was] ... an able fellow, who drank himself to death."

For their transit observations Green and Cook used the two Short telescopes supplied by the Royal Society; as we have noted already, Solander had access to his own telescope, while it appears that Cook loaned Molyneux his Watkins reflector. All four observers used the Shelton astronomical clock to record the times of the four contacts. As we have noted previously, critical from the viewpoint of calculating the solar parallax, *P*, were the second ingress contact and the first egress contact (numbered 2 and 3 respectively, in Figure 1).

Transit day, 3 June, was fine and sunny, although warmer than expected, and Cook reported on the observation of the transit in his journal:

> This day prov'd as favourable to our purpose as we could wish, not a Cloud was to be seen the whole day and the Air was perfectly clear, so that we had every advantage we could desire in Observing the whole of the passage of the Planet Venus over the Sun's disk ... (Beaglehole, 1968: 97–98).

The transit lasted about six hours, and Cook's account would suggest that all four observers succeeded in observing it and recording the times of the four contacts depicted in Figure 1. This was confirmed by Molyneux's comments, which are published by Beaglehole (1968: 560).

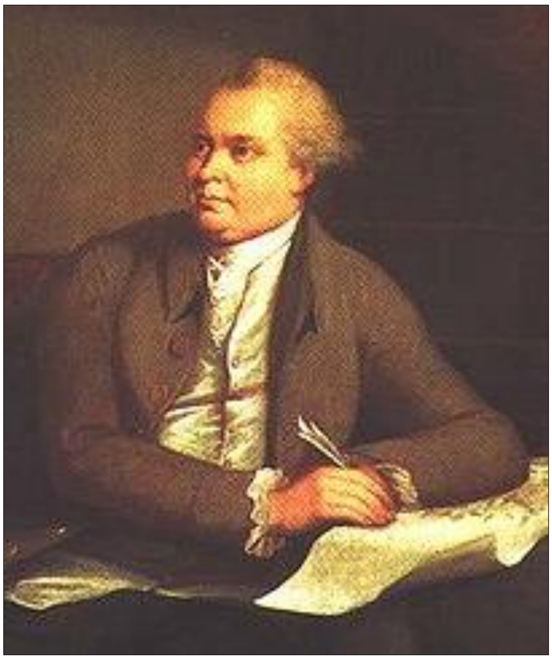


Figure 25: A post-First Voyage painting of Daniel Solander (en.wikipedia.org).

We also know that during the transit Green and Cook measured the diameter of Venus using the Short telescope with the Dollond object-glass micrometer, and obtained mean values of 54.97″ and 54.77″ respectively. Cook also measured the diameter with his Watkins telescope and a Dollond micrometer on three different occasions, and obtained mean values of 56.8″, 56.28″ and 56.02″ (Green and Cook, 1771: 412–418). Cook certainly was busy, for in addition he used his Short reflector and a Dollond micrometer to take a series of measurements of the separation between Venus' limb and the limb of the Sun, and to measure the diameter of the Sun (Green and Cook, 1771: 413–415).

3.6.2 Taaupiri Island

There were four members of the observing team located on Taaupiri Island, just off the east coast of Tahiti: Zachary Hicks, Charles Clerke, Richard Pickersgill and Patrick Saunders (Beaglehole, 1968: 559).

As a Second Lieutenant, Zachary Hicks was ranked number two on the *Endeavour*, after Cook. He was born in Stepney (London) in 1739 and first served in the Royal Navy as an able seaman and later a Master's Mate on the sloop *Launceston* in 1766–1767. In August 1767 he was transferred to the *Hornet* as an acting Lieutenant, and in March 1768 this rank was confirmed (Beaglehole, 1968: 591). As an officer, he was familiar with the rudiments of nautical astronomy and also was one of those trained in the niceties of transit observations on the voyage out to the Pacific. Beaglehole (1974: 138) on the one hand describes Hicks as "... experienced and mature, a good sailor and officer, a man with a good eye ... forethought and independent judgement." On the other hand, he somewhat less flatteringly says Hicks was "... an efficient, dependable, but quite unimaginative man ..." (Beaglehole, 1968: ccxxix). Fate would decree that the Tahitian transit would be his first and last major astronomical venture: he was ill in Batavia but recovered, only to die of tuberculosis on 26 May 1771 during the final leg of the voyage home (Beaglehole, 1968: 471).

Clerke was a Third Lieutenant and was ranked fourth on the *Endeavour*. Just four years Hicks' junior, he was born in Wethersfield (Essex) in 1743, and went to sea as a Captain's servant, but by the time he returned from Byron's voyage to the South Seas on the *Dolphin* in 1765 he was a Midshipman (Beaglehole, 1968: 593). Like Hicks, he was trained in nautical astronomy, and also tutored by Green on the voyage out to Tahiti. Clerke's astronomical talents were to prove most useful after Green died, as he was the one who assumed the role of the *Endeavour*'s second astronomer (Beaglehole, 1968: cclxiv). Great things were expected of Clerke, as reflected in the fact that he later was invited to join Cook's Second and Third Voyages to the Pacific, and on the latter Voyage commanded the *Discovery*, which was the consort to Cook's *Resolution*. Following Cook's death, he was in charge of the entire expedition until he died at sea on 22 August 1779 (Beaglehole, 1969: 878). Clerke was yet another example of a talented young naval officer who met an untimely death while in the service of King and country. Already terminally ill, five days before his death he wrote:

> ... my friends will have no reason to blush in owning themselves such, for I have most perfectly and justly done my duty to my country, so far as my abilities would enable me.

Apparently, according to his friends, his spirits were high and his talk was jolly right up to his demise (cited in Wood, 1926). Beaglehole (1974:139) has described Clerke as "... always cheerful, talkative, amusing, with some of the rollicking vices as well as the rollicking virtues; a generous spirit who made friends easily; tall, long-nosed, with an eye both roving and sparkling." He had "... enough mathematical ability to become a good navigator; with some interest in the scientific side of his profession ..." (Beaglehole, 1968: cxxxi).

Richard Pickersgill, was born at West Tanfield (Yorkshire) in 1749, and went to sea as a Captain's servant on the *Tartar* in 1766. Then he joined Wallis on his voyage to the South Seas in 1766–1767. Beginning as an able seaman, he had risen to Master's Mate by the end of the voyage. After joining the *Endeavour* he "... added to his reputation as a man of ability and a useful surveyor and maker of charts ..." and upon Molyneux's death in April 1771 was promoted to Master (Beaglehole, 1968: 592). Beaglehole (1968: ccxxxii), described him as "... a good observer, [who] ... drew numerous charts ... We see in him ability and amiability: unfortunately some instability as well." He also was

> ... able and amiable, a natural romantic, a little over-sensitive, a little given to the grandiose concept and the swelling word, yet a successful subordinate, he was to do good work for Cook. (Beaglehole, 1974: 139).

Pickersgill (1769–1770) kept a journal, and at the end of this is an interesting 2-page listing titled "A Table Shewing the Exact Lattd & Longitude of Capes Bays & head Lands seen in his Majestys Bark Endeavour & Settled by Astronimacal Observations." While he may have had obvious astronomical, cartographic and hydrographic surveying skills, spelling was not one of his fortés! Pickersgill also joined Cook on his Second Voyage to the Pacific (as a Third Lieutenant), and after that Voyage he took command of the *Lyon* but subsequently was court-martialled for 'drunkenness and other irregularities'. In July 1779 he was attempting to board a ship and slipped and fell into the Thames and drowned (Beaglehole, 1968: 592).

The fourth member of the Taaupiri Island observing team was the mysterious Patrick Saunders. We do not know where or when he was born (or, for that matter, when he died). He began the voyage as a Midshipman on the *Endeavour*, but following a series in indiscretions was demoted to ordinary seaman. His interest in the women of Tahiti led him to abandon ship there, and this also may have motivated him to desert ship in Batavia on the way home (Beaglehole, 1968: 594). It is not known what became of him after this.

While there is no description of the scientific equipment that was assigned to them, we can assume that because of the number of high-ranking officers involved Hicks' party was given the journeyman clock. Molyneux (1769) states that Green provided both ancillary transit parties "... with Telescopes & every thing necessary ... to observe the transit." Precisely how many telescopes were supplied is not stated, or whether these were Gregorian reflectors like Cook, Green, Solander and Molyneux had at Fort Venus, or the smaller telescopes that formed components of the astronomical quadrant and sextants. Since there is no First Voyage documentation to support the existence of more than four Gregorian reflectors on the *Endeavour*, my view is that the Taaupiri Island observers used sextants owned by the ship's officers and perhaps the quadrant to observe the transit. Although of modest aperture, all of the telescopes on these instruments had the requisite resolution to afford clear views of the transit. Long after the transit Cook (1771a: 694) stated that all four members of this transit party were observers.

There are no log or journal entries by the four observers describing their observations of the transit, but from Molyneux's comments (published in Beaglehole, 1968: 560) we do know that all four successfully observed the transit.

3.6.3 Irioa Island (Moorea)

The transit team that went to Irioa Island (Moorea) also contained four members: John Gore, Jonathan Monkhouse, William Monkhouse and Herman Spöring (Moylneux, 1769: 559). All played important roles on the *Endeavour.*

Gore was the leader of the party, and after Cook and Hicks as a Third Lieutenant ranked third amongst the naval officers and crew on the *Endeavour*. The only senior member of the expedition of trans-Atlantic extraction, Gore was born in the American colonies in about 1730. He went to sea in 1755, serving on the *Windsor*, *Bellona* and *Aeolus* in the Atlantic, the West Indies and the Mediterranean (Beaglehole, 1968: 595; 1974: 138). Then he visited the South Seas with both Byron and Wallis, each time as a Master's Mate, before joining Cook's expedition. He has been described as

> ... a particular type of sailor ... a man of commonsense and able practice – with the reputation in his maturity of being the best practical seaman in the navy ... he is ceaselessly active; he is the great sportsman of the expedition ... he is ready for any expedition into the country anywhere, of pleasure or of duty. (Beaglehole, 1968: cxxxi).

Gore excelled during the voyage to the point where Cook was happy to promote him to Second Lieutenant following Hicks' death in May 1771, and as well as being an excellent officer, Wood (1926) somewhat facetiously mentions that he also was ":.. a first-rate shot, [as] the first Englishman who ever shot a kangaroo." Like Clerke, Gore could look forward to a successful naval career, and like Clerke, he also joined Cook on the Third Voyage, serving as Cook's understudy or second in command on the *Resolution*. When Cook was murdered in Hawaii, Gore took command of the *Discovery* when Clerke transferred to the *Resolution* and assumed command of the entire expedition. Upon Clerke's demise Gore then took on this role and successfully brought the two vessels back to England. In commenting on Gore's scrappy, commonplace First Voyage journal, Beaglehole (1968: ccxxxi) perceptively remarks that "... no one would foresee in it a future commander of the Third Voyage." Obviously Gore's talents lay elsewhere than in record-keeping! After the Third Voyage he was promoted to Captain, and took the post at Greenwich Hospital vacated by Cook. He died in England in 1790 (Beaglehole, 1968: 595), one of the very few from Cook's First Voyage who lived to what, in those days, might be considered a 'ripe old age'.

The second member of the observing team was Jonathan Monkhouse, but little about his background has been documented, other than that he was the son of George Monkhouse of Penrith in Cumberland (Beaglehole, 1968: 634). He joined the *Endeavour* as a Midshipman, and was "Much trusted by Cook, and evidently the most responsible of the midshipmen." (Beaglehole, 1968: 594). He was an intelligent, hard working young man (Beaglehole, 1968: cxxxii), and was one of many on the *Endeavour* who died between Batavia and Cape Town—on 6 February 1771, to be precise (Beaglehole, 1968: 594)—on the way home to England after the transit.

The third member of the transit party was Jonathan's older brother, William Brougham Monkhouse, and we also have no knowledge of his date of birth. William Monkhouse served as the Surgeon on the *Endeavour*. Prior to this he had been the Surgeon on the *Niger* for some years (Beaglehole, 1974: 139). Although "... a man of some professional merit and a good observer." (Beaglehole, 1968: 594) he was also rather disorganised (Beaglehole, 1968: cxxxii). However, there is no trace of this latter trait in the surviving remnant of his journal kept on Cook's First Voyage. To the contrary, Beaglehole speaks glowingly of his literary skills:

> ... if the original journal was continuously as perceptive, fully detailed and well-written as this fragment it provided a description of eighteenth century New Zealand quite as good as Banks's, and perhaps better – which is praise of a very high order. It is composed with great vigour and lucidity, and the writer was obviously an extremely intelligent man. (Beaglehole, 1968: cccxxxi).

Intemperance eventually took its toll, and just like his brother, William Monkhouse died prematurely, but three months earlier, on 5 November 1770, while the *Endeavour* was anchored in Batavia. Notwithstanding his liking for 'the grog', Wood (1926) has described Monkhouse as "... a *most* excellent man; a splendid doctor, and a delightful companion if you get the chance of a walk ashore."

Rounding out the transit team was Swedish-born Herman Diedrich Spöring (Marshall, 1977) who was born in about 1733 at Åbo (now Turku, in Finland), where his father was Professor of Medicine at the local university. After also training in medicine, Spöring moved to Stockholm in 1753 where he practised surgery. In 1755 he settled in London, working at first as a watch-maker, and in February 1766 he was employed at the British Museum as Solander's assistant. When Solander joined Banks on Cook's First Voyage, Spöring went along too. In addition to his duties as an artist and draftsman, he also served as a 'Secretary and Recorder'. Spöring was "... a draughtsman of great ability, as some beautiful drawings show." (Beaglehole, 1968: cclxvii). He was one of those who perished in January 1771 (Beaglehole, 1968: 599) while the *Endeavour* was *en route* from Batavia to the Cape of Good Hope.

On the day of the transit Banks identified the two observers on Irioa Island as Jonathan Monkhouse and Gore (Beaglehole, 1963, 1: 284), while Cook says "... I sent Lieutenant Gore in the Long-boat to York Island [Moorea] with D^r^ Monkhouse and M^r^ Sporing to observe the transit of Venus, M^r^ Green having furnished them with Instruments for that purpose." (Beaglehole, 1968: 97). To confuse matters further, long after the transit Cook (1771a: 694) identified Spöring and Jonathan Monkhouse as the two observers. We should note that although Joseph Banks accompanied the Irioa Island party, he took no part in the transit observations (Beaglehole 1963(I): 284–285).

Nor do we know the number of telescopes involved, or their appearance. In his journal entry of 2 June, Banks describes how:

> Before night our observatory was in order, *telescopes all set up and tried* &c. And we went to rest anxious for the events of to-morrow. (Beaglehole, 1963(I): 284, my italics).

This indicates there were two or three different telescopes, and although the preparations mentioned by Banks suggest Gregorian reflectors, there is in fact no evidence to support this. Nor is there any information about the time-keeper used, which had to be the journeyman clock or the alarum clock. So the record of instrumentation supplied to the two ancillary transit stations remains confusing, to say the least.

All we know though, again on the basis of Molyneux's comments published in Beaglehole (1968: 560) and from letters penned by Cook (e.g. see Cook, 1770), is that all three teams successfully observed the transit.

3.7 Publication of the Transit Observations

Eventually a research paper co-authored by Charles Green (posthumously) and James Cook and titled "Observations made, by appointment of the Royal Society, at King George's Island in the South Seas" was published in 1771 in the *Philosophical Transactions of the Royal Society*. This 25-page paper provides details of the transit, including contact timings (see Table 1 and Figure 26) and contact drawings by Cook and Green (Figure 27); lists observations made for timekeeping purposes and in order to determine the latitude and longitude of Fort Venus; and includes some magnetic and tidal records. The transit itself occupies approximately half of the paper, but details only the observations made by Cook, Green and Solander (notwithstanding the aforementioned problems associated with Green's contact timings). Perhaps this is why, at the bottom of the very last page of the paper, Cook acknowledges Maskelyne's assistance in preparing the final manuscript. Surprisingly, none of the contact timings made at Irioa Island or Taaupiri Island is included, and indeed the sole mention of these two observing stations is almost an aside:

> Some of the other gentlemen, who were sent to observe at different places, saw at the ingress and egress the same phenomenon as we did; though much less distinct, which no doubt was owing to their telescopes being of less magnifying power ... (Green and Cook, 1771: 411).

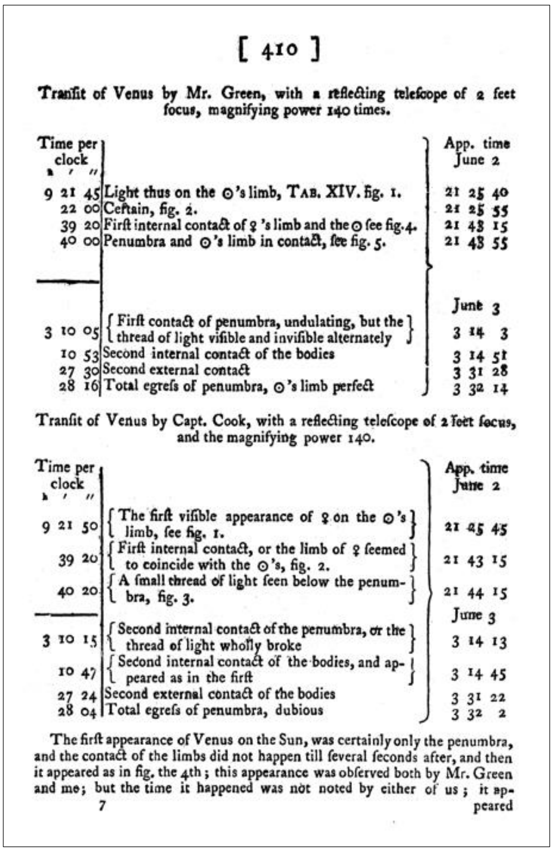
This appears to confirm the suggestion that the 'telescopes' that they used at the two ancillary observing stations were those associated with sextants and the quadrant rather than Gregorian reflectors.

For the purposes of calculating the solar parallax, *P*, the timings that were deemed critical were of the second ingress contact and the first egress contact (i.e. the second and third positions of Venus along each transect in Figure 1), and both Cook and Green had problems in accurately establishing these. Cook explains in his journal:

> ... we very distinctly saw an Atmosphere or dusky shade round the body of the Planet which very much disturbed the times of the Contacts particularly the two internal ones. Dr Solander observed as well as Mr Green and my self, and we dffer'd from one another in observeing the times of the Contacts much more than could be expected. Mr Green's Telescope and mine were of the same Magni-

Table 1: Contact timings listed in the Green and Cook paper.

Contact	Cook	Green	Solander
1	07h 21m 25s	07h 21m 20s	07h 21m 46s
2	07h 38m 55s	07h 38m 55s	07h 39m 08s
3	13h 09m 56s	13h 09m 46s	----
4	13h 27m 45s	13h 27m 57s	13h 27m 56s



[410]

Tranfit of Venus by Mr. Green, with a reflecting telefcope of 2 feet focus, magnifying power 140 times.

Time per clock h ′ ″		App. time June 2
9 21 45	Light thus on the ☉'s limb, Tab. XIV. fig. 1.	21 25 40
22 00	Certain, fig. 2.	21 25 55
39 20	Firft internal contact of ♀'s limb and the ☉ fee fig. 4.	21 43 15
40 00	Penumbra and ☉'s limb in contact, fee fig. 5.	21 43 55
		June 3
3 10 05	Firft contact of penumbra, undulating, but the thread of light vifible and invifible alternately	3 14 3
10 53	Second internal contact of the bodies	3 14 51
27 30	Second external contact	3 31 28
28 16	Total egrefs of penumbra, ☉'s limb perfect	3 32 14

Tranfit of Venus by Capt. Cook, with a reflecting telefcope of 2 feet focus, and the magnifying power 140.

Time per clock h ′ ″		App. time June 2
9 21 50	The firft vifible appearance of ♀ on the ☉'s limb, fee fig. 1.	21 25 45
39 20	Firft internal contact, or the limb of ♀ feemed to coincide with the ☉'s, fig. 2.	21 43 15
40 20	A fmall thread of light feen below the penumbra, fig. 3.	21 44 15
		June 3
3 10 15	Second internal contact of the penumbra, or the thread of light wholly broke	3 14 13
10 47	Second internal contact of the bodies, and appeared as in the firft	3 14 45
27 24	Second external contact of the bodies	3 31 22
28 04	Total egrefs of penumbra, dubious	3 32 2

The firft appearance of Venus on the Sun, was certainly only the penumbra, and the contact of the limbs did not happen till feveral feconds after, and then it appeared as in fig. the 4th; this appearance was obferved both by Mr. Green and me; but the time it happened was not noted by either of us; it ap-

7 peared

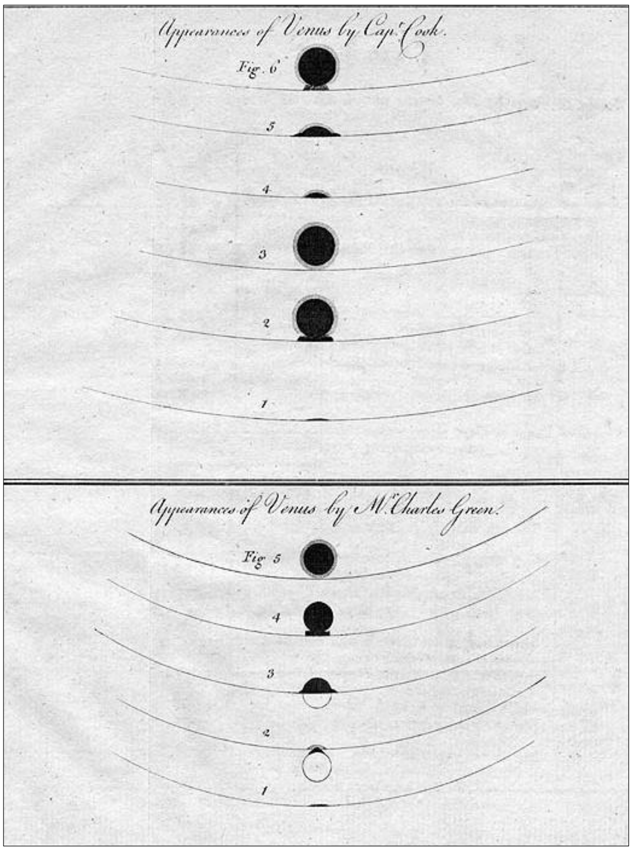


Figure 26 (left): The page in the *Philosophical Transactions of the Royal Society* paper listing the different contact times (after Green and Cook, 1771: 410).
Figure 27 (right): The page in the *Philosophical Transactions of the Royal Society* paper showing drawings of the different contacts made by Cook and Green (after Green and Cook, 1771: facing page 410).

fying power but that of the Dr was greater than ours. (Beaglehole, 1968: 97–98).

These disparate contact times are listed in Table 1. Cook and Green also allude to this problem in their 1771 paper:

> ... it appeared to be very difficult to judge precisely of the times that the internal contacts of the body of Venus happened, by reason of the darkness of the penumbra at the Sun's limb, it being there nearly, if not quite, as dark as the planet. At this time a faint light, much weaker than the rest of the penumbra, appeared to converge towards the point of contact, but did not quite reach it ... in like manner at the egress the thread of light was not broke off or diminished at once, but gradually, with the same uncertainty: the time noted was when the thread of light was wholly broke by the penumbra. (Green and Cook, 1771: 410–411).

Green noted the same thing, and his sketches of this contact, along with Cook's, are reproduced here in Figure 27. What was presumed to be the atmosphere of Venus is clearly represented in Green's sketch '5', and the internal contact is illustrated by '4'. What Cook and Green actually encountered was the notorious 'black drop effect' (see Pasachoff et al., 2005; Schaefer, 2001), which also was seen by some observers of the 1874 transit of Venus, and the dilemma then, as in 1769, was to decide precisely when Venus 'broke free' from the Sun's limb during ingress and make contact with it at egress.

When we examine Table 1 we see that the times that Cook, Green and Solander registered for the two critical internal contacts varied by as much as 13 seconds, and similar discrepancies also characterized the first and fourth contacts. With the various contact times listed in Table 1, Cook and Green were sometimes in accord and Solander's was the anomalous value, while at other times Green and Solander agreed and Cook's was the dissident reading. So there is no consistent pattern, and it is therefore impossible to derive correction factors for the different observers. However, we now know that discrepancies of this order are to be expected during a transit of Venus, with variations in contact timings of tens of seconds making little difference within the context of the total duration of the transit when values of *P* are calculated.

Nonetheless, it is fair to say that Cook was more than a little disappointed with the variations recorded in the contact timings (see Beaglehole, 1968: 98), and perhaps it was this that prompted the famous Cook biographer, Professor John Cawte Beaglehole (1963(I): 29), to erroneously claim that the Tahitian observations were a failure. Fortunately, nothing could be further from the truth, as we will see in Section 4 below.

4 HORNSBY'S ANALYSIS

In England it was left to Professor Thomas Hornsby to produce a value for the solar parallax, *P*, and in order to achieve this he combined the transit observations made by the British parties at Tahiti and Hudson Bay with those from three non-British stations: Chappe's French expedition to Baja California, Rumovsky's Russian site at Kola and Hell's Danish station at Vardö.

Reduction of the observations demanded consistent contact timings and an intimate knowledge of the latitude and longitude of each observing station, and then involved considerable computations (e.g. see Figure 28). It is interesting that Hornsby circumvented the problem we have encountered with the disparate Fort Venus contact timings by utilising Cook's figure for the ingress and a mean of Cook and Green's figures for the egress, and ignoring the values provided by Solander.

Hornsby published the outcome of his calculations in a short paper titled simply "The quantity of the Sun's parallax, as deduced from the observations of the transit of Venus, on June 3, 1769" which appeared in the same 1771 volume of the *Philosophical Transactions of the Royal Society* as the Green and Cook paper, but about 150 papers later (see Figure 29). Hornsby's result was a figure of 8.78″ (Hornsby, 1771), and to illustrate its reliability, we need only mention that when Howse and Murray (1997) reanalysed Hornsby's calculation using modern methods of reduction they arrived at a value of 8.74 ± 0.05″. Working from his figure of 8.78″, Hornsby (1771: 579) proceeded to calculate the Astronomical Unit:

> ... if the semidiameter of the Earth be supposed = 3985 English miles, the mean distance of the Earth from the Sun will be 93,726,900 English miles.

Hornsby (1771: 574) was very pleased with

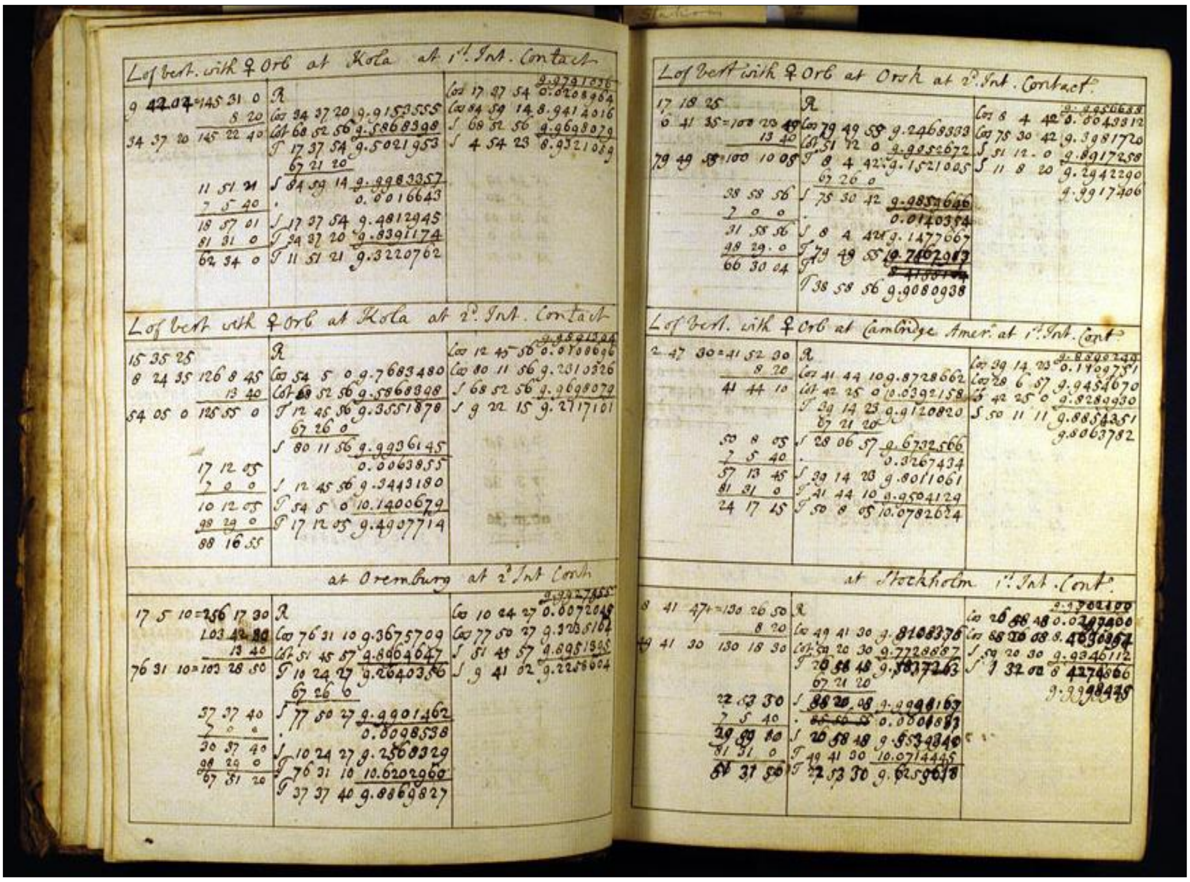


Figure 28: Examples of Hornsby's 1769 transit of Venus calculations, MHS Radcliffe MS 7 (after Johnston, 2005).

with his result, believing that

> ... from the observations made in distant parts by the astronomers of different nations, and especially from those made under the patronage and direction of this Society [the Royal Society, of London], the learned of the present time may congratulate themselves on obtaining as accurate a determination of the Sun's distance, as perhaps the nature of the subject will admit.

Meanwhile, Hornsby's French colleague, Professor Alexandre Guy Pingré (1711–1796; Figure 30) from the University of Rouen and a Corresponding Member of the Academie des Sciences, also conducted an analysis of French and some non-French observations of the transit (including the Tahitian results), coming up with P = 8.80″, a figure remarkably close to Hornsby's result.

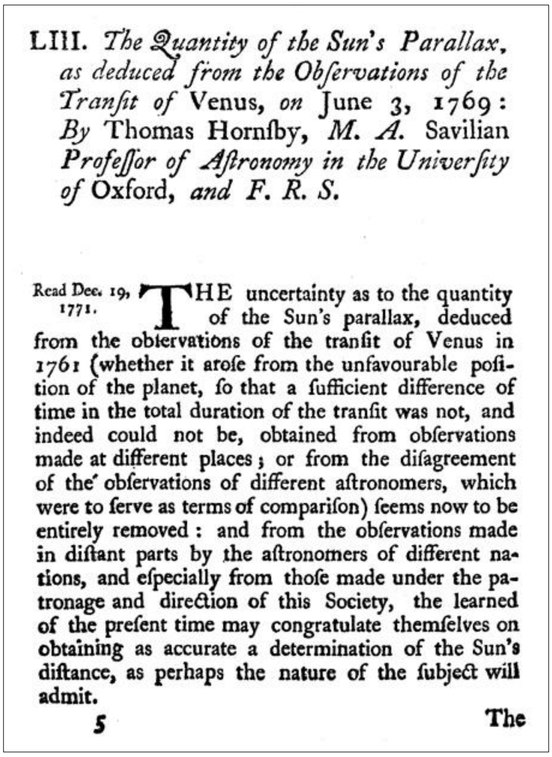
If these were the only values of P that were published following the transit there would have been no doubt that a mean value of 8.79″ was the best possible estimate for the solar parallax, meaning the a.u. was equal to 149,623,007 kilometres, but other astronomers dashed these hopes when they published their results. Admittedly, Hell's value of 8.70″ was not too far removed from the figures listed by Hornsby and Pingré, but Euler's value of 8. 63″, Lalande's of between 8.55″ and 8.63″, and especially Planmann's of 8.43″ (see Woolf, 1959: 190–191) plunged the overall interpretation into chaos. After all, the difference between 8.43″ and 8.80″ amounted to an uncertainty in the a.u. of about 6.5 million km! So the 1769 transit of Venus did not solve the puzzle of the distance from the Earth to the Sun, and astronomers were forced to wait for the 1874 and 1882 transits.

5 PROBLEM SOLVED: A FINAL FIGURE FOR THE ASTRONOMICAL UNIT

As we have seen, the 1769 transit produced values of P that ranged from 8.43″ to 8.80″. There were critics of the figures at the top end of this range that were published by Hornsby and Pingré, but as Waldersee (1969: 119) has commented, their concerns showed

> ... rather more evidence of professional and national rivalries than of serious mathematical disagreement ... [but] the mere fact that discordant notes had been sounded was sufficient to create the impression that the whole scheme had failed ...

Furthermore, Encke's subsequent re-analysis of the 1761 and 1769 transits merely added to the confusion when he published a figure of 8.57116″ in 1824, only to modify this slightly eleven years later (see Dick et al., 1998). This encouraged some astronomers to use other astronomical events, such as the oppositions of Mars during the 1850s and 1860s, in a bid to determine the



LIII. *The Quantity of the Sun's Parallax, as deduced from the Obſervations of the Tranſit of* Venus, *on* June 3, 1769: *By* Thomas Hornſby, *M. A.* Savilian *Profeſſor of Aſtronomy in the Univerſity of* Oxford, *and F. R. S.*

Read Dec. 19, 1771.

THE uncertainty as to the quantity of the Sun's parallax, deduced from the obſervations of the tranſit of Venus in 1761 (whether it aroſe from the unfavourable poſition of the planet, ſo that a ſufficient difference of time in the total duration of the tranſit was not, and indeed could not be, obtained from obſervations made at different places; or from the diſagreement of the obſervations of different aſtronomers, which were to ſerve as terms of compariſon) ſeems now to be entirely removed: and from the obſervations made in diſtant parts by the aſtronomers of different nations, and eſpecially from thoſe made under the patronage and direction of this Society, the learned of the preſent time may congratulate themſelves on obtaining as accurate a determination of the Sun's diſtance, as perhaps the nature of the ſubject will admit.

5 The

Figure 29: The title page of Hornsby's 1771 *Philosophical Transactions of the Royal Society* paper.

Astronomical Unit, but these also produced results that were as discordant as those derived from the eighteenth century transits of Venus. This, then, led to renewed interest in the 1874 and 1882 transits.

Fortuitously, both of the nineteenth century transits were visible—in full or in part—from Australia and New Zealand; as a result, transit parties from England, France, Germany and the

Figure 30: A bust of the distinguished French astronomer, Alexandre Guy Pingré (en.wikipedia.org).

USA flocked to the Antipodes, to join local professional and amateur astronomers (see Orchiston (2004b) for a useful overview).

As we have seen, the eighteenth century transits produced a wide range of values for *P*, the solar parallax, which can be divided into what I like to call the 'high values' (promoted by Hornsby and Pingré) and the 'low values' (published by Euler, Lalande and Planmann). What the 1874 and 1882 transits showed conclusively was that the true value lay among the 'high values'.

Later, the Canadian-American astronomer Simon Newcomb re-analysed all four eighteenth and nineteenth century transits, and in 1895 published a figure of 8.794″ ± 0.018″, which compares very favourably with the value of 8.794148″ ± 0.000007″ that was derived from radar observations and was ratified as the internationally-accepted value by the International Astronomical Union in 1976. This corresponds to a mean Earth-Sun distance of 149,597,870 km (see Van Helden, 1995: 168).

Note, incidentally, that Newcomb's 1895 value for *P* was almost identical to the figure published by Hornsby more than a century earlier, providing somewhat belated justification for the astronomical agenda of Cook's First Voyage.

6 PROBLEMS UNSOLVED: MYSTERIES SURROUNDING COOK'S 1769 TRANSIT EXPEDITION

During more than two decades I have been researching the historic transits of Venus, including their Cook-voyage associations, and I have encountered a number of aspects that warrant further discussion. These are discussed below.

6.1 Where Are All Those Records?

Once the transit was over, all of the observers from Fort Venus, Taaupiri Island and Irioa Island handed their records to Green for safe-keeping (Cook, 1771a: 692), and he then made copies of them and when the *Endeavour* reached Batavia he sent these to the Royal Society, enclosed in a packet that Cook sent to the Admiralty on a Dutch ship (Cook, 1771b: 694).

The *Endeavour* left Batavia on 26 December 1770 and it was only after Green died (about one month later) that Cook discovered the shocking state of the astronomical records:

> ... my first care was, to preserve, for the perusal of the Royal Society, all his papers that contained any Astronomical observations of what nature soever; many of which I had never seen before; and I found far from having been kept in that clear order their importance seemed to require ..." (ibid.; cf. Wales, 1788: i).

Unfortunately, Green had never briefed Cook on precisely which records he had sent to the Royal Society from Batavia, so Cook

> ... caused copies of all those that had any relation to the Transit of Venus, and for fear of any accident happening to us, I put them on board His Majesty's Ship Portland addressed to Mr Maskelyne ... (Cook, 1771b: 695).

This occurred on 10 May 1771, when the *Endeavour* and the *Portland* were anchored together at Ascension Island (Beaglehole, 1968: 469).

Cook (1771a: 693–694) reveals that his letter to Maskelyne contained the following enclosures:

> 1. Observations of equal altitudes of the sun for the time; and observed altitudes or Zenith distances of the sun and stars for the latitude.
> 2. Observations of Jupiters Satellites for the longitude; and of the times of the contacts of the limbs of the sun and Venus observed by M^r^ Green.
> 3. Lunar observations of the Moons distances from the sun and fixed stars for the longitude; and Capt^t^ Cook's observations of the times of the contacts of the limbs of the sun and Venus.
> 4. M^r^ Green's observations of the diameters of the Sun and Venus; nearest approach of their centers; difference of Declination, distances of their limbs in a direction parallel to the Equator; all observed with Dollond's Micrometer.
> 5. Observations of the transit of Venus made at York Island [= Moorea] by M^r^ Monkhouse and M^r^ Sporing; and Dr Solander's observations of the two external and first internal contacts of Venus at Georges Island.
> 6. Observations of the transit of Venus at Morton's Island [= Taaupiri Island] by Lieu^t^ Hicks, Clerk, Saunders, and Pickersgill.

Cook (1771a: 693) also explained to Maskelyne why these documents were sent to him rather than to the Royal Society:

> If I recollect right M^r^ Green has made some mistake in the observations he sent home, of the beginning and end of the Transit, as it was by him observed; at least I do not find the true times that he observed the different contacts faithfully entered in any of his books or papers; on the contrary I find them put down in two places, and different from each other, and neither the one nor the other are precisely the same as they were observed; the alterations that have been made will appear from the inclosed papers, and from them you will be able to judge how far it was reasonable to make such alterations, and this is the reason why I wish you to have the perusal of these papers before they are laid before the Royal Society ..."

Cook had yet another copy made "... of all or most of the observations relating to the Transit, that I know to be authentic, made by M^r^ Green, my self and others ..." (Cook, 1771b: 695), and on 11 July 1771, when the *Endeavour* reached England, he sent these plus all of Green's original papers to the Secretary of the Royal Society (ibid.).

The foregoing chronological narrative clearly reveals that at one time or another three copies of all of the Fort Venus, Irioa Island and Taaupiri Island transit observations were sent directly to the Royal Society or to Nevil Maskelyne, and that all of the original transit papers also were dispatched to the Royal Society once the *Endeavour* reached England. Yet despite searches in the Royal Society's archives and at other 'obvious' repositories such as the RGO Archives in Cambridge and the National Maritime Museum in Greenwich, none of these records seems to have survived. This is frustrating because it means that

> ... we cannot examine the original records to determine why Cook chose not to include contact times from the ancillary observing stations. Nor can we see what observations — if any — Molyneux contributed from Fort Venus, and how Green's various timings listed in the original records compare and contrast with those in the published paper. (Orchiston, 2005: 60).

Clearly, a further, more thorough, search for these all-important records is warranted.

6.2 Where Are the Instruments Now?

Like the records of the transit, most of the scientific instruments used during the Tahitian transit observations have disappeared, and the current whereabouts of very few of them is known with any degree of certainty.

Prior to his death, my friend and colleague the late Lieutenant-Commander Derek Howse (1919–1998), once Head of the Department of Navigation and Astronomy at the National Maritime Museum, Greenwich, was the undisputed authority on Cook voyage scientific instruments. He spent decades researching them, and in the process published a succession of papers and monographs, along with a handy biography of Astronomer Royal Nevil Maskelyne (Howse, 1989).

Although he had difficulty correlating extant telescopes, quadrants, sextants, clocks and chronometers in libraries, museums and private collections with specific Cook's voyage instruments, Howse (1979: 125) made a promising start by associating two Gregorian reflectors by Short lodged in the Science Museum, London, with the British 1769 transit of Venus expeditions. Although one of these has a Dollond micrometer, there is no proof that it was actually one of the two Short reflectors on the *Endeavour*. But if it was not, we are justified in assuming that it was remarkably similar—if not identical—in appearance. Therefore it is appropriate that we describe this telescope.

Gregorian reflector number 1900-136 (shown here in Figure 12) is on loan to the Science Museum from the Royal Society (which, as we have seen, supplied telescopes for the 1769 transit) and is inscribed with Short's serial number 44/1198 = 24. This code was deciphered by Baxandall during the 1920s, and the numerator refers to the serial number of the telescope of that aperture, the denominator gives the total number of telescopes made to that date, and the value after the equals sign indicates the focal length in inches (King, 1979: 87). This instrument therefore has a focal length of 24 inches (61 cm). Associated with this telescope is an object glass micrometer of the type described by Dollond in his 1754 paper.

Derek Howse (1979) also was able to attribute a second Short reflector in the Science Museum to the 1769 transit. This instrument (number 1939-389) was presented to the Museum by the Air Ministry, and the catalogue entry specifies that it was "Made by James Short c.1764". It is very similar in appearance and dimensions to the aforementioned Short telescope, and has a similar serial number (i.e. 42/1195 = 24). Stimson (1985) has established that originally the Royal Society and the Board of Longitude housed their scientific instruments in the same warehouse, where they were cared for by a single curator. As a result, the precise provenance of some of the instruments was lost. After the Board was abolished in 1828, what were thought to be its instruments were transferred to the Royal Navy, and during the 1840s the supposed Royal Society's instruments were relocated to the King's Observatory in Richmond Park. This Observatory subsequently was taken over by the British Association and then by the Air Ministry (for the Meteorological Office), which proceeded to transfer some instruments to the Science Museum (Howse, pers. comm., 1997). Given this historical chain of events, it is reasonable to associate this second Short reflector with the 1769 transit of Venus, but once again there is no proof that this was in fact one of the two instruments assigned to the *Endeavour*.

Unfortunately, the current whereabouts of Cook's own telescope—the 18-in Gregorian reflector made by Watkins—is unknown. After Cook died in Hawaii his property, including this telescope, was forwarded to Mrs Cook (Howse 1979). From all accounts, Elizabeth Cook (1742–1835; Figure 31)

> … was a hoarder, [and] the house in Clapham where she spent most of her widowhood, 'crowded and crammed in every room with relics, curiosities, drawings, maps, and collections'. Her will runs to more than ten pages of closely written script. It gives us an inkling of the many friends and relatives who were important in Elizabeth's life. As well as detaill-

> ing how her £60,000 should be distributed, the will also takes into account specific items—her husband's Copley Medal to the British Museum, the contents of the kitchen, washhouse and scullery to one of her servants, bedroom furniture to others. *Other items had already been distributed. Elizabeth lived long enough to see her husband pass into history, and knew the value of Cook memorabilia*. (Day, 2003, my italics; cf. Beaglehole, 1974: 690–695; Beddie, 1970).

Through into the late nineteenth century Cook memorabilia that can definitely be traced back to Mrs Cook and her sons and other Cook relatives would appear on the market, including the Mackrell Collection of 'ethnographic curiosities' that was acquired in 1887 by the New South

Figure 31: A portrait of Mrs Elizabeth Cook painted by William Henderson in 1830 (en.wikipedia.org).

Wales Government and ended up in the Australian Museum in Sydney (e.g. see Orchiston, 1972). I suspect that the Watkins reflector was one of the items donated by Mrs Cook, or her sons or other contemporary Cook relatives to a friend or relative, and it now lies forgotten in a private collection, waiting to be recognised!

As we have seen already, the only possible First Voyage telescope we have been able to track down is the 3-ft Gregorian reflector that probably was used by Solander at Fort Venus. This telescope, made by the London firm of Heath and Wing, now resides in The Museum of New Zealand Te Papa Tongarewa, in Wellington (see Orchiston 1999; 2005).

There is considerable confusion as to the current whereabouts of the Bird quadrant that journeyed to Tahiti on the *Endeavour*. Currently there are two virtually identical 12-inch Bird quadrants in the Science Museum, London (1900-138 and 1900-139), and both reputedly were associated with the British 1769 transit of Venus program. Both are owned by the Royal Society and were placed on long-term loan with the Museum in 1900. Documentation held by the Museum suggests that these two quadrants were made in about 1767, were used by Bailey at the North Cape and Dixon on the island of Hemmerfest, and are duplicates "... of the one provided by the Royal Society and used by Cook for observing the transit of Venus at Tahiti." Both of the telescopes have 1.9-cm objectives of 33-cm focal length, and the eyepiece end of the lower telescope is "… fitted with verniers, clamping screw and slow motion which traverses the limb which is divided into two scales one into 90° and the other 96°, according to Bird's method, each reading to 1' of arc ..." (Science Museum catalogue entry). Figure 16 shows one of these instruments.

In addition, there is a third Bird pillar quadrant in the Science Museum with a Cook-voyage attribution. This was donated to the Royal Astronomical Society in 1873 by a Dr W.T. Radford, and is listed in the catalogue of the Society's instrument collection as "Captain Cook's sextant [it is actually a quadrant], wooden frame; c. 1765; R [radius] = 18 in" (Howse, 1986: 224). No other information is available, and the Cook attribution is just that—an attribution only. This instrument was loaned to the Science Museum in 1908 (it now has a Museum number, 1908-159), and the display caption provides no further information, but it does place the date of manufacture at "... about 1772 ..." rather than 1765. It is important to stress that there are many items of reputed Cook voyage association with bogus or at best embellished histories (e.g. see Kaeppler, 1972), and until additional documentation of a more persuasive nature comes to light the imputed Cook origin of this quadrant must be treated as suspect.

Finally, as if to complicate matters further, Howse (1979) has reported the existence of another 30.5-cm Bird quadrant (catalogue number 1876-542), of unknown provenance, which is owned by the Science Museum but is on loan to the National Maritime Museum.

The saga of the Cook voyage time-keepers is only marginally better: to our knowledge, the First Voyage journeyman clock and the alarum clock have not survived (Howse and Hutchinson, 1969b), and a complicated history surrounds the five surviving Shelton astronomical clocks that reputedly were taken on Cook's three voyages to the Pacific:

> In the 1780s, the clocks became thoroughly mixed up, largely because the Board [of Longitude] and the [Royal] Society shared a warehouse and a storekeeper. It would not have been impossible at this time for the pendulums and even the movements of several clocks to have been cannibalised to produce one working clock. (Howse and Hutchinson, 1969b: 282).

Despite this, Howse and Hutchinson were able to tentatively identify the astronomical clocks now known as RS34 and RS35 with Cook's Second and Third Voyages, although they point out that it is not possible to exclude either the 'Royal Society Clock' or the 'Herstmonceux Clock' as possible contenders. However, the RS35 attribution seems sound, given the discovery of filled-in holes in the clock case which match those required for the attachment of the style of wooden tripod used on the Third Voyage (see Howse, 1969b). Indeed, in 1968 staff at the National Maritime Museum constructed and attached a replica of this tripod to RS35, and this is shown below in Figure 32.

Back in 1969 Howse and Hutchinson (1969b) had difficulty identifying the Shelton astronomical clock which went on the *Endeavour*, believing at the time that the 'KO Clock' at the Royal Observatory, Edinburgh (shown here in Figure 14) had the best claim. More recently, Howse and Murray (1997) confirmed this suspicion, stating that the Shelton regulator in question "... is almost certainly the one now preserved in the National Museum of Scotland in Edinburgh."

6.3 Daniel Solander's Astronomical Background and his Telescope

Daniel Solander is an astronomical enigma. He joined Banks' party and the *Endeavour* as a distinguished natural historian, not as an astronomer, yet he ended up at the principal transit station, armed with a substantially-larger Gregorian telescope than the two supplied by the Royal Society to the voyage's two official astronomers! And then, when the official account of the transit observations was published, he was the only person other than its authors, Cook and Green, to feature.

What little evidence there is (see Orchiston, 1999) suggests that Solander owned the Heath and Wing telescope himself—it was not owned by his friend and colleague Joseph Banks and simply loaned to him for the transit. Note that Banks is not known to have owned an astronomical telescope at this time, and that he did not wish to participate in the transit observations, even though he was present on Irioa Island at the time.

There is no evidence that Solander carried out any serious or systematic astronomical observations prior to Cook's First Voyage (Duyker, 1998), so it would appear that he purchased the Heath and Wing telescope specifically in order to observe the transit and that he was one of those tutored by Green on the trip out from England. Thus, by the time the *Endeavour* reached Tahiti he had acquired the requisite observing knowledge, skills and experience.

As we have seen, after the First Voyage Solander returned to his first passion, natural history, and there is no evidence to suggest that he continued to carry out astronomical observations. So it would appear that the 1769 transit of Venus was to be his first and last escapade in observational astronomy. Dedicated astronomers could only dream of observing a single astronomical event—albeit an important one like a transit of Venus—and then seeing their results included in a major paper that appeared in that most prestigious of scientific outlets, the *Philosophical Transactions of the Royal Society*!

Figure 32: Shelton astronomical clock RS35, showing the replica tripod support (courtesy: the late Derek Howse).

7 THE FIRST VOYAGE ASTRONOMICAL LEGACIES

One invaluable legacy of Cook's First Voyage is the official record of the astronomical observations that were made. Had circumstances been different, Green would have been responsible for preparing this, but his untimely death meant that its preparation devolved to William Wales (1734–1799), one of the two astronomers who accompanied Cook on his Second Voyage to the South Seas. Wales (Figure 33), who was

Figure 33: Pastel portrait of William Wales painted by J. Russell in 1894, now at Christ's Hospital, Horsham (photograph: Wayne Orchiston).

married to Charles Green's sister, was well qualified for this task as he was one of those who observed the 1769 transit of Venus from Hudson Bay. Beaglehole (1969: cxl) was impressed with Wales, in particular "... the breadth and play of his mind, his capacity for observation, his scientific exactitude, and his integrity as a man." After the *Resolution* returned to England in 1775, Wales and William Bayly (1737–1810), the other astronomer on the Second Voyage, worked together preparing the official astronomical account, and this was published two years later (Wales and Bayly, 1777). Only then could Wales devote himself to the task of preparing the First Voyage astronomical volume, but it was not until 1788 that *Astronomical Observations Made in the Voyages Which Were Undertaken By Order of His Present Majesty, for Making Discoveries in the Southern Hemisphere* ... rolled off the press. The full title goes on for several more lines and is truly astronomical in length! Part of the reason for the extraordinary delay in the publication of this volume was because Wales was obliged to also include the astronomical observations made during the earlier British Pacific voyages of Wallis and Byron. By the time Wales' weighty tome appeared, Bayly and James King (1750–1784) had already produced the Third Voyage official astronomical volume (Cooke, King and Bayly, 1782; note that this book includes a posthumous salute to Cook by including him among the authors, even if his name was spelt incorrectly)!

Another legacy of Cook's First Voyage is the monument at Point Venus (Figure 34) which now supposedly marks the site where the all-important 1769 transit observations took place.

Figure 34: The wrongly-positioned Point Venus monument in Tahiti (courtesy: the late Dr S. Murayama, Tokyo).

However, its position is wrong, and Beaglehole (1968: cxlii) laments the fact that it is some distance from the actual site of the fort, and on the wrong side of the river!

8 CONCLUDING REMARKS

The 3 June 1769 transit of Venus was the primary *raision d'etre* for Cook's First Voyage to the Pacific in the *Endeavour*, and despite his personal concern about the accuracy of the observations, the figure for the solar parallax, *P*, that Oxford University's Professor Thomas Hornsby derived from the Tahitian and other transit observations was remarkably similar to the currently accepted value. Yet despite this outcome, many unanswered questions remain relating to the fate of the various Tahitian records of the transit. Why were most of these not utilised in the official report on the transit published in the *Philosophical Transactions of the Royal Society*? What was Astronomer Royal Nevil Maskelyne's precise role in the preparation of this paper for publication? How were the discrepant contact values recorded by Green accommodated; and was Hornsby aware of this situation when he utilised the Tahitian transit observations in deriving his value for the solar parallax? These and other questions clearly warrant investigation, and currently are the focus of on-going research.

The success of this First Voyage led Cook to embark on to two further voyages to the Pacific, the first of these specifically to locate and chart the coast of the elusive 'Great Southern Continent' and the second to search for the postulated northwest passage between the Pacific and Atlantic Oceans. When the *Resolution* and *Discovery* reached England at the end of the latter voyage it brought ten years of Cook voyage astronomy to a successful close. Elsewhere I have summarised the substantial outcomes of these three voyages:

> Maritime astronomy had performed its task admirably: there were no shipwrecks, hundreds of islands had been placed on the world map, and thousands of miles of coastline had been charted. Three weighty astronomical tomes were published, and the future of the chronometer was assured. Matavai Bay cemented its place in Transit of Venus history, and Queen Charlotte Sound could boast the best-established latitude and longitude in the world after Greenwich. In the process, Cook, Bayly, Green, King and Wales all built on their already-respectable reputations, although two of these paid the ultimate price, losing their lives in the service of astronomy, King and country. For the British public, the terminal transit of a star like Cook was a particularly bitter pill to swallow. (Orchiston, 2004a: 35).

9 ACKNOWLEDGEMENTS

I am grateful to Drs Jonathan Betts and Gloria Clifton (formerly Royal Observatory, Greenwich), Dr Michael Fitzgerald, David Riley and Jennifer Twist (Museum of New Zealand Te Papa Tongarewa, Wellington), Dr Rebekah Higgitt (University of Kent, England), the late Commander Derek Howse (formerly National Maritime Museum, Greenwich), Dr Stephen Johnston (Museum of the History of Science, Oxford University), Katherine Marshall (the Royal Society, London), the late Sir Patrick Moore (Selsey, England) and the late Dr Sadao Murayama (formerly, Gotoh Planetarium and Astronomical Museum, Tokyo) for their assistance. I also wish to thank the Museum of History of Science, Oxford, Museum of New Zealand Te Papa Tongarewa and Royal Society for kindly supplying Figures 11, 12, 15 and 16. Finally, I am grateful to Dr Gloria Clifton, Professor Nick Lomb, Martin George (NARIT, Thailand) and Associate Professor Russell McGregor for reading and commenting on the MS.

10 REFERENCES

Admiralty, 1768. Letter to Lieut. James Cook, dated 25 May. Original in the Public Record Office, London (Adm 2/94). Abstract in Beaglehole, 1968, 609.

Anderson, F., 2000. *Crucible of War: The Seven Years' War and the Fate of Empire in British North America, 1754–1766*. London, Faber and Faber.

Andrews, A.D., 1992. Cyclopaedia of telescope makers. *Irish Astronomical Journal*, 20, 102–183.

Andrews, A.D., 1996. Cyclopaedia of telescope makers. Part 5 (Sae–Sim). *Irish Astronomical Journal*, 23, 57–117.

Andrews, A.D., 1997. Cyclopaedia of telescope makers. Part 7 (T–Z). *Irish Astronomical Journal*, 24, 125–192.

Badger, G.M., 1970. Cook the scientist. In Badger, G.M. (ed.). *Captain Cook. Navigator and Scientist*. Canberra, Australian National University Press. Pp. 30–49.

Banks, n.d. Transactions of the Royal Society relative to the sending out people to observe the transit of Venus in 1769. Original in the National Library of Australia, Canberra. Reprinted in Beaglehole, 1968, 511–514.

Baugh, D., 2011. *The Global Seven Years War, 1754–1763.* Upper Saddle River, Pearson Press.

Beaglehole, J.C. (ed.), 1963. *The Endeavour Journal of Joseph Banks*. Two Volumes. Sydney, Angus and Robertson.

Beaglehole, J.C. (ed.), 1967. *The Journals of Captain James Cook on His Voyages of Discovery. III. The Voyage of the* Resolution *and* Discovery *1778–1780*. Cambridge, Cambridge University Press.

Beaglehole, J.C. (ed.), 1968. *The Journals of Captain James Cook on His Voyages of Discovery. I. The Voyage of the* Endeavour *1768–1771*. Cambridge, Cambridge University Press.

Beaglehole, J.C. (ed.), 1969. *The Journals of Captain James Cook on His Voyages of Discovery. II. The Voyage of the* Resolution *and* Adventure *1772–1775*. Cambridge, Cambridge University Press.

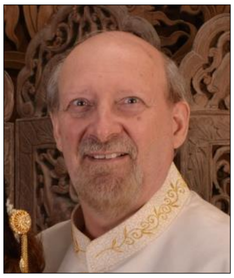
Beaglehole, J.C., 1974. *The Life of Captain James Cook*. London, Hakluyt Society.

Beddie, M.K. (ed.), 1970. *Bibliography of Captain James Cook R.N., F.R.S., Circumnavigator*. Sydney, Trustees of the Public Library of New South Wales.
Betts, J., 1993. The eighteenth century transits of Venus, the voyages of Captain James Cook and the early development of the marine chronometer. *Antiquarian Horology*, 21, 660–669.
Betts, J., 2006. *Time Restored: The Harrison Timekeepers and R.T. Gould, the Man who Knew (Almost) Everything*. Oxford, Oxford University Press.
Bird, J., 1768. *The Method of Constructing Mural Quadrants*. London, Richardson and Clark.
Bliss, N., 1761. Observations of the transit of Venus over the Sun, on the 6th of June 1761 … *Philosophical Transactions of the Royal Society*, 52, 173–177.
Bonhams Auction Catalogue, 2006. [Lot) 85 An important and very rare third quarter of the 18th century month going longcase [John Shelton] regulator now in a modern replica case (http://www.bonhams.com/auctions/14228/lot/85/).
Bryden, D.I., 1968. *James Short and His Telescopes*. Edinburgh, Royal Scottish Museum.
Chapman, A., 1983. The accuracy of angular measuring instruments used in astronomy between 1500 and 1850. *Journal for the History of Astronomy*, 14, 133–137.
Chapman, A., 1995. *Dividing the Circle. The Development of Critical Angular Measurement in Astronomy 1500–1850*. Chichester, John Wiley.
Clifton, G., 1995. *Directory of British Scientific Instrument Makers 1550–1851*. London, Zwemmer and the National Maritime Museum.
Cook, J. 1767. An observation of an eclipse of the Sun at the island of New-found-land, August 5, 1766. *Philosophical Transactions of the Royal Society*, 57, 215–216.
Cook, J. 1768. Letter to the Admiralty Secretary, dated 27 July. Original in the Public Record Office (Adm 1/1609). Reprinted in Beaglehole, 1968, 621.
Cook, J. 1770. Letter to the Admiralty Secretary, dated 23 October. Original in the Mitchell Library. Reprinted in Beaglehole, 1968, 499–501.
Cook, J. 1771a. Letter to Nevil Maskelyne, dated 9 May. In the Royal Society Council Minutes of 11 July 1771. Reprinted in Beaglehole, 1968, 692–694.
Cook, J. 1771b. Letter to the Secretary of the Royal Society, dated 11 July. In the Royal Society Council Minutes of 25 July 1771. Reprinted in Beaglehole, 1968, 694–695.
Cooke, J. [*sic*.], King, J., and Bayly, W., 1782. *The Original Astronomical Observations Made in the Course of a Voyage to the Northern Pacific Ocean, For the Discovery of a North East or North West Passage* ... London, Elmsly.
Day, M., 2003. *Mrs Cook: The Real and Imagined Life of the Captain's Wife*. Allen and Unwin.
Deptford Yard Officers 1768a. Letter to the Navy Board, dated 27 March. Original in the Public Record Office, London (Adm 106/3315). Abstract in Beaglehole, 1968, 606.
Deptford Yard Officers 1768b. Letter to the Navy Board, dated 7 October. Original in the Public Record Office, London (Adm 106/3315). Abstract in Beaglehole, 1968, 624.
Dick, S.J., Orchiston, W., and Love, T., 1998. Simon Newcomb, William Harkness and the nineteenth century American transit of Venus expeditions. *Journal for the History of Astronomy*, 29, 221–255.
Dollond, J., 1753. A description of a contrivance for measuring small angles. *Philosophical Transactions of the Royal Society*, 48, 178–181.
Dollond, J., 1754. An explanation of an instrument for measuring small angles … *Philosophical Transactions of the Royal Society*, 48, 551–564.
Douglas, J. n.d. Hints offered to the consideration of Captain Cooke, Mr Bankes, Doctor Solander, and the other Gentlemen who go upon the Expedition on Board *Endeavour*. Original in the National Library of Australia, Canberra. Reprinted in Beaglehole, 1968, 514–516.
Duyker, E., 1998. *Nature's Argonaut: Daniel Solander 1733–1782: Naturalist and Voyager with Cook and Banks*. Melbourne, Melbourne University Press.
Ellis, F., 1932. Letter to an unspecified Portsmouth antique dealer, dated 18 January. Original in the Archives of the Museum of New Zealand Te Papa Tongarewa (MU000002/067/0002; History: Cook's Relics deposited and presented; 1914-1975; paper).
Fowler, W.H.., 2005. *Empires at War: The Seven Years' War and the Struggle for North America*. Vancouver, Douglas & McIntyre.
Garnsey, Edward Rock (1864–1935). *Sydney Morning Herald*, 10 May 1935, page 17.
Gilbert, L.A., 1967. Solander, Daniel (1733–1782). In *Australian Dictionary of Biography*. *Volume Two*. Melbourne, Melbourne University Press.
Gould, J.A., 1976. John Bird: the astronomer's instrument maker (1709–1776). *Journal of the British Astronomical Association*, 86, 485–486.
Green, C., 1768–1770. Log-Journal. MS, PRO (Adm 51/4545/151).
Green, C., and Cook, J., 1771. Observations made, by appointment of the Royal Society, at King George's Island in the South Seas. *Philosophical Transactions of the Royal Society*, 61, 397–421.
Hawkesworth, J., 1774. *Relation des Voyages Entrepris par Ordre de Sa Majesté Britannique* … Paris.
Hellman, C.D., 1932. John Bird (1709–1776) mathematical instrument-maker in the Strand. *Isis*, 17, 127–153.
Herdendorf, C.E., 1986. Captain James Cook and the transits of Mercury and Venus. *Journal of Pacific History*, 21, 39–55.
Higgitt, R., 2010. Charles Green, Royal Observatory Greenwich Assistant and stand-in Astronomer Royal. London, Royal Museums Greenwich (http://blogs.rmg.co.uk/ontheline/2010/09/03/charles_green_royal_observator/).
Hornsby, T., 1765. On the transit of Venus in 1769. *Philosophical Transactions of the Royal Society*, 55, 326–344.
Hornsby, T., 1771. The quantity of the Sun's parallax ... *Philosophical Transactions of the Royal Society*, 61, 574–579.
Howse, D., 1969a. Captain Cook's minor clocks and watches. In Howse and Hutchinson, 1969a, 138–145.
Howse, D., 1969b. Captain Cook's pendulum clocks. In Howse and Hutchinson, 1969a, 62–76.
Howse, D., and Hutchinson, B., 1969a. *The Clocks and Watches of Captain James Cook 1769–1969*. London, The Antiquarian Horological Society.
Howse, D., and Hutchinson, B., 1969b. The saga of

the Shelton clocks. In Howse and Hutchinson, 1969a, 281–298.
Howse, D., 1979. The principal scientific instruments taken on Captain Cook's voyages of exploration, 1776–80. *Mariner's Mirror*, 65, 119–135.
Howse, D., 1986. The Royal Astronomical Society Instrument Collection: 1827–1985. *Quarterly Journal of the Royal Astronomical Society*, 27, 212–236.
Howse, D., 1989. *Nevil Maskelyne. The Seaman's Astronomer*. Cambridge, Cambridge University Press.
Howse, D., 1993. Charles Green (1734–1771). In *The Dictionary of National Biography: Missing Persons*. Oxford, Oxford University Press. P. 269.
Howse, D., and Murray, A., 1997. Lieutenant Cook and the transit of Venus, 1769. *Astronomy & Geophysics*, 38(4), 27–30.
Johnston, S., 2005. Blast from the past. Measurement and morals in the early transit of Venus. Museum of the History of Science, Oxford University (www.physics.ox.uk/phystat05/Talks/johnston.ppt).
Kaeppler, A., 1972. The use of documents in identifying ethnographic specimens from the voyages of Captain Cook. *Journal of Pacific History*, 7, 195–200.
King, H.C., 1979. *The History of the Telescope*. New York, Dover.
Kippis, A., 1788. *The Life and Voyages of Captain James Cook*. London, George Newnes (the lengthy footnote about Charles Green is in Volume 1, on pages 176–178).
Kurtz, D.W. (ed.), 2005. *Transits of Venus: New Views of the Solar System and the Galaxy*. Cambridge, Cambridge University Press.
Lloyd, C., 1968. *The British Seaman 1200–1860. A Social Survey*. London, Paladin.
Marshall, J.B., 1977. Daniel Solander. In Cook, J. *The Journal of H.M.S. Resolution*. Guildford, Genesis Publications. Pp. 49–60.
Marston, D., 2001. *The Seven Years War.* Oxford, Osprey.
Maskelyne, N., 1764. Astronomical observations made at the island of St. Helena. *Philosophical Transactions of the Royal Society*, 54, 348–349.
Molyneux, R. 1769. Remarks in Port Royal Bay in King George the thirds Island. Original in the Public Record Office (Adm 55/39). Reprinted in Beaglehole, 1968, 551–564.
Moore, P., 1977. Cook, Green and the transit of Venus. In Cook, J. *The Journal of the Endeavour 1768–1771*. Guildford, Genesis Publications. Pp. 61–69.
Morris, M., 1980. Charles Green – man without a face [Part 1]. *Cook's Log*, 3(4), 92.
Morris, M., 1981. Charles Green – man without a face [Part 2]. *Cook's Log*, 4(1), 102.
Orchiston, W., 1972. Maori greenstone pendants in the Australian Museum. *Records of the Australian Museum*, 28(10), 161–213.
Orchiston, W. 1998a. From the South Seas to the Sun. The astronomy of Cook's voyages. In Lincoln, M. (ed.). *Science and Exploration in the Pacific. European Voyages to the Southern Oceans in the 18th Century*. Woodbridge, Boydell Press, in association with the National Maritime Museum. Pp. 55–72.
Orchiston, W., 1998b. *Nautical Astronomy in New Zealand. The Voyages of James Cook*. Wellington, Carter Observatory (Occasional Papers No. 1).
Orchiston, W. 1999. Cook, Banks and the Gregorian telescope in The Museum of New Zealand Te Papa Tongarewa. *Journal of the Antique Telescope Society*, 18, 4–9.
Orchiston, W., 2004a. The astronomical results of Cook's voyages. In Robson, J. (ed.). *The Captain Cook Encyclopaedia*. London, Chatham Publishing. Pp. 31–35.
Orchiston, W., 2004b. The nineteenth century transits of Venus: an Australian and New Zealand overview. *Journal of Astronomical Data*, 10, 219–308.
Orchiston, W., 2005. James Cook's 1769 transit of Venus expedition to Tahiti. In Kurtz, 51–66.
Orchiston, W., 2016. *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits*. Cham, Springer.
Parkinson, S., 1784. *A Journey of a Voyage to the South Seas, in His Majesty's Ship*, The Endeavour. London, printed for Stanfield Parkinson.
Pasachoff, J., Schneider, G., and Golub, L., 2005. The black-drop effect explained. In Kurtz, 242–253.
Paulding, B., 2000. Charles Green astronomer. *Cook's Log*, 23, 1713.
Pickersgill, R., 1769–1770. Journal. MS in the National Archives (Kew): Adm 51/4547/141.
Prowse, D.W., 1896. *A History of Newfoundland from the English, Colonial, and Foreign Records*. *Second Edition*. London, Eyre and Spottiswoode.
Relton, H., 1918. Letter to Major S. Maxwell, F.R.S., London, dated March. Typescript copy in the Archives of the Museum of New Zealand Te Papa Tongarewa (MU000002/067/0002; History: Cook's Relics deposited and presented; 1914-1975; paper).
Ritchie, G.S., 1978. Captain Cook's influence on hydrographic surveying. *Pacific Studies*, 1, 78–95.
Robertson, G., 1948. *The Discovery of Tahiti; A Journal of the Second Voyage of H.M.S. Dolphin Round the World Under the Command of Captain Wallis, R.N., in the Years 1766, 1767, and 1768, Written by her Master*. Edited by Hugh Carrington. London, Haklyut Society.
Schaefer, B.E. 2001. The transit of Venus and the notorious Black Drop Effect. *Journal for the History of Astronomy*, 32, 325–336.
Shelton, J., n.d. Directions to set up the Regulator. Copy, Museum of the History of Science, Oxford University.
Short, J., 1764. Observation of the eclipse of the Sun, the 1st of April 1764, made in Surry Street, in the Strand, London. *Philosophical Transactions of the Royal Society*, 54, *107–*108, 105.
Skelton, R.A., 1954. Captain James Cook as a hydrographer. *Mariner's Mirror*, 40, 92–119.
Sobel, D, 1995. *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time*. New York, Penguin.
Stimson, N., 1985. Some Board of Longitude instruments in the nineteenth century. In de Clercq, P.R. (ed.). *Nineteenth-Century Scientific Instruments and their Makers*. Leiden, Museum Boerhaave. Pp. 93–115.
Turner, G.L'E., 1969. James Short, F.R.S., and his contribution to the construction of reflecting telescopes. *Notes and Records of the Royal Society*, 24, 91–108.

van Gent, R.H., 2005. Observations of the 1761 and 1769 transits of Venus from Batavia (Dutch East Indies). In Kurtz, 67–73.
van Helden, A., 1995. 'Measuring solar parallax: the Venus transits of 1761 and 1769 and their nineteenth century sequels.' In Taton, R., and Wilson, C. (eds.). *The General History of Astronomy. Volume 2. Planetary Astronomy from the Renaissance to the Rise of Astrophysics. Part B: The Eighteenth and Nineteenth Centuries*. Cambridge, Cambridge University Press. Pp.153–168.
Villiers, A., 1971. *Captain Cook, the Seaman's Seaman. A Study of the Great Discoverer*. Harmondsworth, Penguin.
Waldersee, J., 1969. Sic transit: Cook's observations in Tahiti, 3 June 1769. *Journal of the Royal Australian Historical Society*, 55, 113–123.
Wales, W., and Bayly, W., 1777. *The Original Astronomical Observations, Made in the Course of a Voyage towards the South Pole, and Round the World* ... London, Strahan.
Wales, W., 1788. *Astronomical Observations, Made in the Voyages Which were Undertaken by Order of His Present Majesty, for Making Discoveries in the Southern Hemisphere* ... London, Elmsly.
Wales, Wendy, 2008. Researching Charles Green after Kippis. *Cook's Log*, 31(1), 32,
Wallis, R., 2008. Hornsby, Thomas (1733–1810). In *Oxford Dictionary of National Biography*. Oxford, Oxford University Press.
Watt, Sir James, 1979. Medical aspects and consequences of Cook's voyages. In Fisher, R., and Johnston, H. (eds.). *Captain James Cook and His Times*. Canberra, Australian National University Press. Pp. 129–157.
Wood, G.A., 1926. *The Voyage of the Endeavour*. Melbourne, Macmillan and Co. (Gutenburg Australia e-Book).
Woolf, H., 1959. *The Transits of Venus: A Study in the Organization and Practice of Eighteenth-Century Science*. Princeton, Princeton University Press.
Wulf, A., 2012. *Chasing Venus. The Race to Measure the Heavens*. New York, Alfred A. Knopf.
Zuidervaart, H.J., and van Gent, R.H., 2004. "A bare outpost of learned European culture on the edge of the jungles of Java". Johan Maurits Mohr (1716–1775) and the emergence of instrumental and institutional science in Dutch colonial Indonesia. *Isis*, 95, 1–33.

Professor Wayne Orchiston has a Ph.D. from the University of Sydney and is a Senior Researcher at the National Astronomical Research Institute of Thailand and an Adjunct Professor of Astronomy at the University of Southern Queensland (Australia). Wayne has wide-ranging research interests and has published extensively on Cook voyage astronomy



and the 1874 and 1882 transits of Venus, as well as on historic telescopes and observatories, cometary and asteroidal astronomy, solar eclipses and the early development of solar physics, Maori astronomy and the early history of radio astronomy in Australia, France, Japan, New Zealand and the USA. In 1998 Wayne co-founded the *Journal of Astronomical History and Heritage*, and is now the Editor. Currently, Wayne is Vice-President of IAU Commission C3 (History of Astronomy), and he founded the IAU Working Group on Transits of Venus, which ran from 2000 to 2015. In 2013 the IAU named minor planet 48471 Orchiston after him.

Journal of Astronomical History and Heritage, 20(1), 69–94 (2017).

THE PRINCIPAL TIME BALLS OF NEW ZEALAND

Roger Kinns
School of Mechanical and Manufacturing Engineering, University
of New South Wales, Sydney, NSW 2052, Australia.
Email: rogerkinns17@gmail.com

Abstract: Accurate time signals in New Zealand were important for navigation in the Pacific. Time balls at Wellington and Lyttelton were noted in the 1880 Admiralty list of time signals, with later addition of Otago. The time ball service at Wellington started in March 1864 using the first official observatory in New Zealand, but there was no Wellington time ball service during a long period of waterfront redevelopment during the 1880s. The time ball service restarted in November 1888 at a different harbour location. The original mechanical apparatus was used with a new ball, but the system was destroyed by fire in March 1909 and was never replaced. Instead, a time light service was inaugurated in 1912.

The service at Lyttelton, near Christchurch, began in December 1876 after construction of the signal station there. It used telegraph signals from Wellington to regulate the time ball. By the end of 1909, it was the only official time ball in New Zealand, providing a service that lasted until 1934. The Lyttelton time ball tower was an iconic landmark in New Zealand that had been carefully restored. Tragically, the tower collapsed in the 2011 earthquakes and aftershocks that devastated Christchurch.

An Otago daily time ball service at Port Chalmers, near Dunedin, started in June 1867, initially using local observatory facilities. The service appears to have been discontinued in October 1877, but was re-established in April 1882 as a weekly service, with control by telegraph from Wellington. The service had been withdrawn altogether by the end of 1909.

Auckland never established a reliable time ball service, despite provision of a weekly service for mariners by a public-spirited citizen between August 1864 and June 1866. A time ball was finally installed on the Harbour Board building in 1901, but the signal was unreliable and it ceased in 1902. Complaints from ships' masters led to various proposals to re-establish a service. These concluded with erection of a time ball on the new Ferry Building in 1912. The service was finally announced in April 1915, but it was again unreliable and the time ball had been replaced by time lights before the end of that year.

The provision of time balls at Wellington, Lyttelton, Port Chalmers and Auckland is described in this paper with particular reference to newspaper announcements.

Keywords: Time ball, New Zealand

1 INTRODUCTION

Accurate determination of longitude by a ship at sea was one of the great technical challenges of the eighteenth century. All too often, errors in navigation and inaccuracies on charts had resulted in loss of life from shipwrecks on rocks. The Longitude Prize, established in 1714 during the reign of Queen Anne, was designed to encourage development of solutions. The observatory at Greenwich had been founded in 1688 specifically to improve accuracy in navigation via provision of precise astronomical observations. The key was that the Earth rotated at an almost exactly constant rate, so that remote stars appeared to rotate about the axis of the Earth's rotation while the Moon revolved about the Earth and changed position relative to the stellar background. In principle, a navigator could measure the time when the Sun was at its zenith, measure the relative positions of the Moon and a chosen set of stars, and then use a nautical almanac to compute longitude, with Greenwich as the reference meridian.

An alternative approach was to use measurement of the time at Greenwich in place of stellar observations, but clocks and watches in the eighteenth century generally had poor accuracy, made even poorer by the effects of seaway motion and temperature changes. The achievement of John Harrison, in constructing a timekeeper that would be accurate to a few seconds over many weeks in those conditions, is almost incredible. It took him many decades and it required reluctant recognition by the great intellects of the day that a skilled artisan could possibly win the Longitude Prize. It was not until the 1830s that chronometers, as they were by then called, became available in sufficient numbers at sufficiently low cost to be carried by all major ocean-going vessels (Rooney, 2009).

1.1 The Need for Time Signals in Harbour

Although chronometers were much more accurate than ordinary clocks and watches, there could be significant cumulative errors after a long period at sea. The method of lunar distances, for example, was still needed to verify the location of land-based signals that could be used to check chronometers. These land-based signals took many different forms, including guns and flags, but the option preferred by the Admiralty was a time ball, dropped at a prominent position at the same time each day within sight of ships in harbour. It had been invented by Robert Wauchope, a distinguished RN officer, with a first trial implementation at Portsmouth in 1829, followed by the first public time ball at Greenwich in 1833 (Bartky and Dick, 1981). The ball would usually be raised to cross-trees in two stages, so that an observer would know that a signal was imminent. The time to be recorded was the moment a gap first appeared between the top of the ball and the cross-trees, as the ball was released by triggers to descend in initial free fall.

To be of value to navigators, the time had to be precise and the signal had to be repeated at regular intervals. Then, the rate at which a chronometer was gaining or losing time, as well as the absolute error on a particular day, could be determined. That calibration would be repeated at other ports. Any adjustment was deferred until return to a chronometer maker.

Figure 1: New Zealand localities mentioned in the text; those with time balls are shown in red (Map: Wayne Orchiston).

New Zealand is almost as far away from Greenwich on the Earth's surface as it is possible to be, so it was particularly difficult to establish the exact longitudes of time signal locations and associated drop times for Pacific navigators. That was a particular challenge for the observatory at Wellington in North Island. The time ball at Lyttelton was the principal signal in South Island and was controlled by telegraph from Wellington, so did not require a nearby observatory. For New Zealand localities mentioned in the text see Figure 1.

The basic problems of chronometer calibration are well-described in a letter to an Auckland newspaper in 1911, when there was no time-ball service in Auckland. Extracts from that letter are transcribed below.

> For instance, a captain is loading here and leaving in a few days for 'Frisco or Europe, via Cape Horn, and is not sure of his chronometer error or daily rate. He has to go and make arrangements with the Post Office for a signal at a certain time from the Wellington Observatory, and take this on a watch previously compared with the chronometer, then go back on board and compare with chronometer again. Only by doing this can he obtain the error of his chronometer on Greenwich mean time, and this error compared with that of his last error either here or in Wellington gives the daily rate, that is, the amount the chronometer is gaining or losing per day. The error shown will be used to keep the chronometer correct until the next check is taken.
>
> Sometimes, in fact very often, the chronometer itself is taken up to the P.O. so as to get a direct check and not trust to a watch. This is a very bad plan, as the movement of the chronometer in transit, no matter how careful one may be, as well as the difference of temperature, all combine to upset the daily rate sometimes for days afterwards.
>
> On the other hand with a time ball the chronometer is not touched an officer watches the ball, sings out 'stop' when it drops, and another officer watching the chronometer records the time and obtains the error, etc., and the whole performance is finished in a few moments, and without disturbing the instrument. (Chudley, 1911)

Similar arguments had been used in 1853 to support erection of a time ball in Edinburgh (Kinns, 2011).

2 ADMIRALTY LISTS OF TIME SIGNALS

The Admiralty in London published five editions of time signals for mariners between 1880 and 1898. The first and last of these show the growth of time signal provision worldwide towards the end of the nineteenth century (*Lists of Time Signals*, 1880 and 1898). The number of distinct entries increased from 71 to 154 during that period, some having more than one type of signal. The number of listed time balls had increased from 52 to 94 while the number of listed time guns had grown from 9 to 30. Many others are known to have existed worldwide. There were no time gun entries for New Zealand, so the time gun at Nelson, for example, was not regarded by the Admiralty as an official signal. The 1898 list formed the basis of a study by the

New Zealand Historic Places Trust to show the recent status of time signals and to provide additional information about their origin (Wright, 2007).

2.1 The Entries for New Zealand

Tables 1 and 2 show the entries for New Zealand in the 1880 and 1898 Admiralty lists. Dimensions are given in the original Imperial units. Time balls at Wellington and Lyttelton are included in both lists, but details change between them. Some are incorrect, although stated latitudes and longitudes were subject to adjustment when more accurate astronomical data became available.

The Otago time ball at Port Chalmers, near Dunedin, had been established in 1867, initially as a daily signal using local astronomical observations, but appears to have been discontinued in 1877 for some years. That explains its omission from the 1880 list. The signal was re-established and controlled by telegraph from Wellington, but was downgraded in April 1882 to the weekly signal shown in the 1898 list.

Table 1: The entries for New Zealand in the 1880 Admiralty list

Signal Station Latitude and Longitude	Place	Signal adopted	Situation of Time Signal	Time of Signal being made		Additional Details
				Greenwich Mean Time	Local Mean Time	
41° 17′ 15″ S. 174° 47′ 45″ E.	Wellington	Red and White Ball	The Custom house – 60 feet above high water. 50 feet above ground. (Drop 12 feet.)	h.m.s. 12 30 0	h. m. s. 0 0 0	Ball two thirds up at $11^h 50^m$. Ball hoisted close up as at $11^h 55^m$. Ball dropped by electricity from Wellington Observatory clock at noon, New Zealand mean time* [*Note*: The days on which the signal may be relied on to one-tenth of a second are advertised in the daily newspaper. Ordinarily, the signal is never more than one second out.]
43° 36′ 40″ S. 172° 44′ 17″ E.	Lyttelton	Ball	Custom House 247 feet above high water. 56 feet above ground (Drop 16 feet.)	13 30 0	1 0 0	Ball hoisted close up as preparatory signal at $12^h 55^m$ p.m. Ball dropped at 1 p.m. New Zealand mean time.

* Throughout the Colony of New Zealand one uniform time is kept, called 'New Zealand Mean Time', computed for 172° 30′ E. long., or 11h 30m 00s from the meridian of Greenwich.

Table 2: The entries for New Zealand in the 1898 Admiralty list

Signal Station Latitude and Longitude	Place	Signal adopted	Situation of Time Signal	Time of Signal being made		Additional Details
				Greenwich Mean Time	Local Mean Time	
41° 16′ 50″ S. 174° 46′ 55″ E.	Wellington	Ball	Staff on square tower at inner end of Railway Wharf	h.m.s. 12 30 00	h. m. s. 0 09 7.6	Ball dropped automatically at noon New Zealand standard mean time. (*See* page 2.) Signal only made when satisfactory observations have been obtained. The days the ball will drop are advertised in the local morning newspaper. Masters of vessels are also informed that in the public room of the Telegraph Office, near the Queen's Wharf, is a galvanometer which is deflected every hour.
43° 36′ 42″ S. 172° 44′ 50″ E.	Lyttelton	Ball	The Observatory	13 30 00	1 00 59.2	Ball hoisted up as preparatory signal at $0^h 55^m 00^s$ p.m. Ball dropped at $1^h 00^m 00^s$ p.m. New Zealand standard mean time (*See* page 2.)
45° 49′ 0″ S. 170° 39′ 0″ E.	Otago	Ball	Signal Staff at Port Chalmers	12 30 00	11 52 36	Ball dropped about once a week at noon, New Zealand standard mean time. (*See* page 2.) When ball is to be dropped a blue flag is hoisted on the flagstaff at 10h 00m 00s a.m. New Zealand mean time.

2.2 Errors in New Zealand Entries

The time ball extant at Wellington in 1880 had a drop of 18, not 12, feet. It had been procured from England in 1863. The ball colour is described as red and white, but available photographs suggest that it was a dark colour. A red ball with a white central band had been supplied for the Strand, London by the same manufacturer (The electric time ball ..., 1852, see Kinns, 2014). The colours may have been changed after arrival in New Zealand, to suit the ball location. The Wellington apparatus was relocated in 1888, so the locations in 1880 and 1898 were different. The changes at Wellington are due partly to a change in time signal location and partly to correction of co-ordinates. The later ball colour was not stated in the 1898 list, but it appears from photographic evidence to have been black with a central band, probably painted red.

There was never an observatory at Lyttelton; the time ball was actually located at the signal station and the same apparatus was used from 1876 onwards. The time signal was communicated by telegraph from Wellington. The Lyttelton apparatus had been shipped from England in 1874. It was a replica of that built for Sydney in 1855 and first used there in 1858. The drop was 10, not 16, ft. It is noteworthy that the stated longitude at Lyttelton changed by 33 seconds of arc between the 1880 and 1898 lists, with a much smaller 2 second adjustment in latitude. The signal location remained the same. The ball colour was not stated in the Admiralty lists; the present colour of the 5 ft. diameter ball is black with a central red band.

2.3 Mean Time and Apparent Time

Mean time establishes noon at regular 24-hour intervals. This eliminates any daily variations caused by the Earth's elliptical path around the Sun. Local mean time changes by one hour for each 15° change in longitude. A single mean time for the whole of New Zealand had been established on 2 November 1868. This time (*New Zealand Mean Time*, n.d.) was exactly 11½ hours in advance of Greenwich Mean Time.

A notable difference between the 1880 and 1898 lists is definition of "Local Mean Time" in New Zealand. Confusingly in the 1880 list, the Local Mean Time is specified as New Zealand Standard Mean Time. In the 1898 list, the Local Mean Time shows the expected variation with longitude.

2.4 Drop Times in New Zealand

The time balls at Wellington and Port Chalmers were dropped at noon, while the time ball at Lyttelton was dropped at 1 p.m. The delay of one hour was common at many locations, including Greenwich; it allowed astronomers to concentrate on solar observations at noon, rather than signal transmission.

2.5 The Lack of an Entry for Auckland

Perhaps surprisingly, there is no entry for Auckland in either the 1880 or 1898 lists. Many newspaper articles chronicle the various attempts to establish an official service, with frequent letters from ships' masters about the lack of a time ball service in such an important port. The underlying problem was lack of budgetary commitment over an extended period. There was great reluctance to buy the high quality, reliable apparatus and instruments that had allowed Wellington and Lyttelton to establish a credible service, and to provide the funds for maintenance and operation by skilled staff. An accuracy of a few seconds might be satisfactory for railway operation and workplace signals, but it was certainly not adequate for calibrating marine chronometers.

3 *NEW ZEALAND NAUTICAL ALMANACS*

The later history of time balls and other time signals can be traced through successive editions of the *New Zealand Nautical Almanac and Tide Tables*, which was first published in November 1902 for the following year. It was then published annually, but copies tend to be elusive, because the usual policy was to destroy the preceding edition when a new one was issued. The first edition has an introduction that included the following statements:

> The want of an authoritative publication containing tide-tables and up-to-date information about the principal ports of New Zealand made use of by large foreign-going steamers has long been felt, and the Hon. Mr. Hall-Jones, Minister of Marine, has authorized the publication of this book, which will supply the want ... The various Harbour Boards supplied the latest information concerning their ports; but in most cases such information has been supplemented by particulars taken from the "New Zealand Pilot" and the latest New Zealand Yearbook, &c.
>
> The various Notices to Mariners regarding the colony issued since the publication of the last edition of the "New Zealand Pilot" have been collated and published herein, and the General Notices to Mariners and special warnings which are issued monthly by the Board of Trade also appear.

Each *Almanac* includes statements about time signals that were expected to be available during the year. The only entries concerning time balls are for Wellington, Auckland, Lyttelton and Otago, many indicating that the signal had been withdrawn either temporarily or permanently. Extracts from almanacs for particular years will be given for each time signal location.

By 1928, the entries in the *Almanac* had changed to include a section entitled "Dominion Time-service Arrangements for Chronometer-rating Purposes", as well as entries for individual ports. This included a list of the different types of signal that were then available throughout New Zealand and the means available for rating chronometers. The following sub-headings were used.

1. Day wireless time-signals;
2. Night wireless time-signals;
3. Chronometer-rating time-signals by lights;
4. Chronometer-rating time-signals by time-ball;
5. Charging for telegraphing time-signals;
6. Rating chronometers at Wellington;
7. Dominion Standard Mean Time.

The following note in the 1928 *Almanac* indicates that no manual intervention was required for signal transmission:

> Transmission of the time-signals is free of manual interference. The lights are extinguished, galvanometer deflected, wireless signals transmitted, and time-ball dropped automatically by direct communication from the Observatory clock at Wellington.

The complete entry under "Chronometer-rating time-signals by time-ball" (1928 *Almanac*: 132) was

> Lyttelton. – From the signal-station. A time-ball is dropped at 3.30 pm N.Z.T. (04 00 00 G.M.T.) Supplied every Tuesday and Friday evening. (This time-signal is considered unreliable.)

The reason for the last statement is unclear, but it may stem from the need for manual intervention. The time ball had to be raised manually, so that triggers could be set prior to the drop. Thus, the process was not fully automatic and relied on the availability and skill of the operator. The specific entry for Lyttelton (1928 *Almanac*: 254) was "Time-ball for chronometer-rating purposes is directly connected with the Dominion Time Observatory at Wellington." The drop time of 0400 GMT reflects the re-basing of GMT from noon to midnight on 1 January 1925.

4 THE WELLINGTON TIME BALL

The first time ball in New Zealand was at Wellington and became operational on 9 March 1864. Its origin is known from correspondence relating to a time ball at the Cape of Good Hope.

4.1 The First Wellington Time Ball

A new time ball apparatus was described in a notice published by Sir Thomas Maclear, Astronomer Royal at the Cape (New time-ball at the Royal Observatory ..., 1863; reproduced in Kinns, 2014: 171). It featured in two letters to George Airy, the Astronomer Royal at Greenwich, which show that a similar apparatus had been ordered for New Zealand (Maclear, 1863a; 1863b). The mechanism was provided by Sandys & Co. of 158 Aldersgate Street, London.

Maclear was told by Sandys that they been awarded a contract for a New Zealand time ball. Maclear wanted Airy to check its design and operation before it was shipped, having found defects in the machinery delivered to the Cape. The letters were uncertain about the precise destination in New Zealand, but it must have been Wellington. Maclear wrote in the first letter:

> I suspect that our late excellent Governor – Sir Geo[e] Grey, now Governor of New Zealand, originated the order, & am exceedingly anxious both on private & public grounds, that the machine should be sent out complete – in a state as perfect as the construction will admit of. My reasons for caution will appear presently ...
>
> My reason for the precaution is the fact that he sent out the Cape machine unfinished. Because of the great fall (18 feet) & the danger of the wood of the upper or slotted shaft twisting in this climate, it is covered outside with plate iron, & inside knee bent plate iron in the corners …
>
> As the New Zealand Machine is to be on the plan of the Cape one, it will be found a heavy concern to manage. The weight of the Time Ball, gun metal rack rod & wood behind it, & metallic piston, come to about 350 or 360 pounds. 160 turns of the windlass are required to raise the ball, which on the average occupies 3 minutes. But the fault if any is my own. I wanted a great fall because of the low position & distance from the Anchorage. (Maclear, 1863a).

The second letter (Maclear, 1863b), written two days later, was concerned with the lack of telegraph and observatory facilities in New Zealand. Although Airy was willing to inspect the apparatus and Sandys would have agreed, the Maclear letters arrived too late; the apparatus had already been shipped to New Zealand by the time Airy made contact with the manufacturer (Sandys & Co., 1863). If the Wellington apparatus was indeed identical to that at the Cape, the ball would have had a diameter of 1.65m and a drop of 5.5m.

4.2 Announcement in Wellington

The time ball apparatus had arrived in Wellington by January 1864. The following brief account was published soon afterwards:

> Many improvements have of late been made in the way of buildings, &c. and one of the chief objects that catches the eye from the wharf, is a time ball erected on the top of the Custom House, the pole passing through the centre of the building. It is on the same prin-

> ciple as the Greenwich time ball, and will fall every day at 12 o'clock. The clocks in connection with the works will be under the management of S. Carkeek, Esq., Collector of Customs … (*The Nelson Examiner and New Zealand Chronicle*, 1864)

The location of the new time ball is shown in Figure 2. The large drop of the ball is consistent with Maclear's description of the apparatus at the Cape. A fulsome description of the new time ball apparatus was published in the *New Zealand Spectator and Cook's Strait Guardian* (The time ball, 1864). Extracts from that notice are reproduced below. The article gives due credit to Stephen Carkeek, the leading astronomer in New Zealand. Orchiston (2016: Chapter 8) has described Carkeek's work in depth.

> Saturday last ought to be marked as a red letter day in all future editions of New Zealand almanacks, for at 3 o'clock the Wellington Time Ball was dropped by electricity ...
>
> To Mr. Carkeek belongs the chief credit of this work; as most certainly it would never have been thought of had we not possessed one so thoroughly capable of directing the setting up of the somewhat complicated gear which carries and works the ball. Saturday's experiment proved that all the machinery was in working order, but the ball will not, we understand, be dropped regularly each day for at least a month. The observatory has yet to be built at the side of the Custom house; the transit instrument to be set up; the two clocks to be fixed and rated; all this done, each day at 12 o'clock the ball will drop, shewing with perfect accuracy true time ...
>
> The necessity of thus checking the chronometers of ships is so well known in England, that a ball is dropped at Greenwich, at Deal, and at another point of the Channel. All three balls are dropped by the same current of electricity, and all at the same instant precisely, although so far distant from one another ...
>
> The time ball is of zinc, weighing about two hundredweight. It is carried by an iron rod, which rod at its lower end is attached to a piston. The rod and piston are fitted into an iron cylinder resting on a foundation built up carefully from the rock below the Customhouse. The cylinder is packed at the bottom with India-rubber, forming an elastic cushion to deaden the blow of the piston when the ball is dropped ...
>
> When the ball is wound up by the rack work the bottom of the piston is caught by a small piece of steel, which locks it securely. This trigger forms part of a most beautiful and delicate system of levers, which work one upon the other. The last of these, when the whole are set, needs but the slightest touch to release the trigger supporting the piston, and to drop the ball. Each day, when the ball is wound up to the top of the mast, these levers must be set by the assistant ...

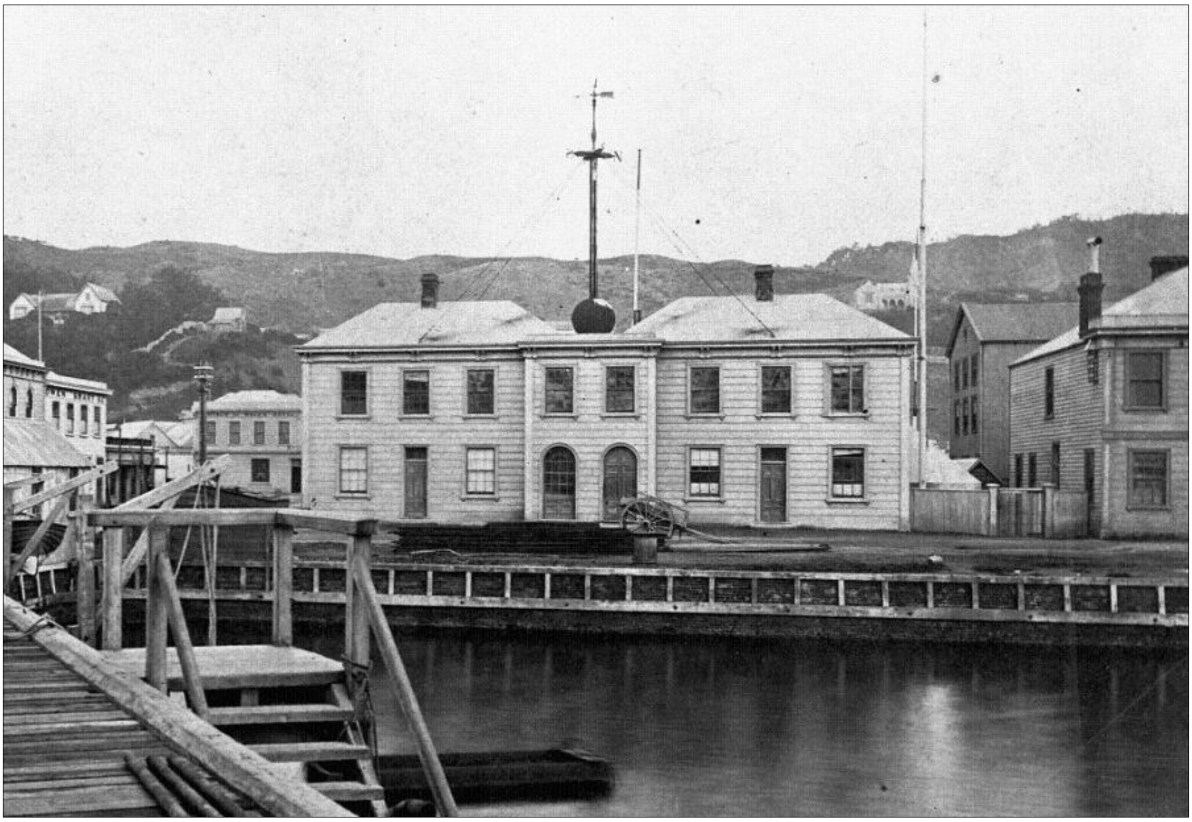


Figure 2: View of the Wellington waterfront showing the Customs House and time ball (courtesy: Alexander Turnbull Library, H.N. Murray Collection, Ref: PAColl-0824-1).

> The second clock is the Astronomical clock, required to give true time, in order to set, and to occasionally correct the going of the clock attached to the battery. The rate of this clock is ascertained by observations of the stars. When the observatory is fixed we purpose to give a description of the telescope and of the method of using it. We hope that the Provincial Council will supplement the work of the ball, by voting funds for powder, &c, for a cannon, which, when fired, will carry the tidings, it is 12 o'clock, to the Hutt and to those parts of the town where the fall of the Time Ball is not visible.

The time ball dropped for the first time as an official signal on 9 March 1864, as indicated by the following notice in the *New Zealand Spectator and Cook's Strait Guardian*:

> Notice is hereby given, that on and after Wednesday next, the 9th instant, the Time-ball at the Custom House will be dropped on each and every day, Sunday's excepted. The Ball will be hoisted half-mast high at ten minutes before 12, to the mast head at five minutes before 12, and will fall precisely at 12 o'clock at noon, Wellington mean time. (Monthly Summary, 1864).

Notices about the time ball location and drop time were published regularly in newspapers. The following notice is typical:

> The Time Ball at Wellington is situated in latitude 41 17′ 01″ S., and longitude 174 49′ 15″ E. It is dropped at noon every day (Sunday's excepted), or at 12h. 20m. 43s. past noon at Greenwich of the previous day. (*Wellington Independent*, 1864).

Carkeek carried out the appropriate astronomical observations to determine its latitude and longitude (Thomson and Jackson, 1871). Amateur astronomer and minister of religion, Archdeacon Arthur Henry Stock (Orchiston, 2016b), was responsible for the day-to-day operation of the time ball. He published a letter to the editor of the *Wellington Independent*, explaining the change that would occur on 2 November 1868 when New Zealand mean time was introduced:

> Sir, The Time Ball will drop on Monday at 12 o'clock New Zealand mean time. This time is 9 minutes 17 seconds slower than Wellington mean time, as the longitude of the Time Ball is 174° 49′ 15″. This longitude differs from that generally given, but it was calculated by Mr Carkeek from several observations taken by the transit instrument of the Time Ball observatory. The master of H.M.S. Esk told me that he was aware of this error of the chart longitude. If true time is wanted for setting sundials, or for any other purpose, 9 minutes 17 seconds should be added to the Time Ball time. Clocks and watches should be put back 9½ minutes on Sunday night. (Stock, 1868).

The longitude quoted in the letter is precisely that given in 1865 notices about time ball operation, which appears to have differed from contemporary Admiralty charts. The letter stated the need to readjust clocks and watches to take account of the introduction of New Zealand mean time. In the 1880 Admiralty list (see Table 1), the longitude was given as 174° 47′ 45″, a reduction of 1′ 30″ from the value determined by Carkeek.

The reliability of the time ball apparatus started to become a problem in the early 1870s. A notice in April 1871 stated that the time ball must not be used for rating chronometers until further notice (Stock, 1871). The problems had become more serious by November 1873:

> Sir – The cause of the time ball's not falling is that some of the gear for raising it has from long use become worn. When application was made to the General Government for repairs, the answer was that, although the General Government had bought the needful apparatus for giving true time to the Telegraph Office, they had not bought the time ball. The Provincial Government were under the impression that they had sold everything. It is now settled that the time ball belongs to the Provincial Government. They have given orders for the needful repairs, and the time ball will drop as usual when these are completed. The same magnetic current that gives time to the Telegraph Office will drop the ball. (Stock, 1873).

The service was re-established about three weeks later (The time ball, 1873). There was still controversy about the longitude of the time ball and further calculations led to a time signal correction on 1 April 1874 (Longitude of Wellington, 1874). It was stated that the drop had previously been 6.15 seconds too early, corresponding to a longitude error of 1 minute, 33 seconds of arc too far east. The revised longitude was therefore estimated to be 174° 47′ 42″, almost exactly that appearing in the 1880 Admiralty list.

Problems with decay in the time ball mast had become significant by September 1874, and the ball had ceased to operate regularly (*Evening Post*, 1874). The winding mechanism was again faulty in the following year:

> We are requested to give notice that in consequence of a defect in the winding-up gear of the Time Ball, it was not hoisted this morning. The ball will not fall until the defect is repaired. (*Evening Post*, 1875).

Controversy about the longitude of Wellington was further exposed in correspondence published on 16 December 1875 (Dr Hector ..., 1875). Newspaper announcements petered out in 1875, but the service may have continued until 1882, when major waterfront development required relocation of the time ball. Its appearance in the 1880 Admiralty list suggests that it was still operational in 1879.

4.3 Relocation of the Wellington Time Ball

The Harbour Master (1882) at Wellington offered his views about future time ball location to the Harbour Board. He referred to the poor visibility of the time ball against the background of houses and hills at its former location and argued that it should be positioned on Mount Victoria. His letter gives the impression that the first time ball had long since ceased to operate. Discussion continued for years afterwards. The Engineer concluded in a memorandum that the best location would be on the brow of Mount Wellington, next to an existing telegraph line. He noted:

> ... as the time ball is completely smashed, the question of size is not an element to be considered as the new ball could be made as large as might be deemed necessary ... (Engineer's memo …, 1885).

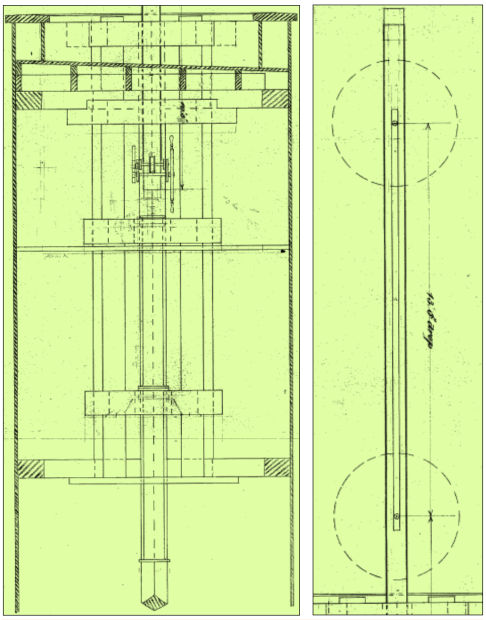


Figure 3: Extracts from 1888 installation drawing for the Wellington time ball apparatus (Wellington Harbour Board archive, Drawing Office No. 3511)

The matter was referred to Dr James Hector, Director of the Colonial Museum of New Zealand and the Colonial Observatory (Orchiston, 2016b), for his opinion. Hector (1886) indicated that he had received various papers about the time ball and that the favoured location was by then "… one of the tees of the wharf." He also noted that:

> ... I think it rather absurd that we should have the time observatory in Wellington and no time ball, nor any means by which the public can check the time that is distributed through the telegraph and railway clocks, while the time ball apparatus is lying idle.

It appears that the original time ball apparatus had been saved and that a new mast and ball would allow it to be re-used. It was to be another two years before a Wellington time ball was again in operation.

4.4 The Second Wellington Time Ball

Notice of a new Wellington time ball service appeared in newspapers with the statement that "The time ball is to be erected once more for the benefit of shipping." (Wellington, 1888). The 1898 Admiralty list (Table 2) shows that the new ball was located on "Staff on square tower at inner end of Railway Wharf" whereas it had been located previously at "The Custom House" shown in Figure 2. The title of the drawing of a square tower issued to potential contractors by the Wellington Harbour Board was "Hydraulic Accumulator House at Waterloo Quay Woolshed (Wool Store J)". (Hydraulic Accumulator House ..., 1888).

A contract to erect the new building was signed by James Lockie (Wellington Harbour Board Contract No 43, 1888). The specification, signed by the Engineer to the Board on 18 January 1888, includes the statement "At the eastern corner provision is to be made as shown on Sheet No 2 and in detail on Sheet No 4 for the subsequent erection of a time ball mast and apparatus". Two elements of Sheet No 4 are shown in Figure 3 (Details for timeball, n.d.). The outline drawing for the time ball and mast indicate that the ball drop would be 13 ft. (4.0m), with a ball diameter of 4 ft (1.2m). Both dimensions had changed from the first Wellington time ball in Figure 2 and changed again in the final installation. An arrangement of gears and a capstan can be seen in the left-hand drawing. An offer to supply a new time ball for £5 10s was made on 31 August 1888, using a design supplied by the Harbour Board (Luke & Sons, 1888). A later report (*Wellington Harbour Board Report* ...,1910) stated that the ball diameter was 5 ft. (1.5m). No evidence has been found that tenders were sought for a replacement apparatus, so it appears that the original 1863 apparatus was re-used with a new ball.

The photograph in Figure 4 shows the time ball at its new location on the tower next to 'J' shed. Figure 5 shows a close up of the ball and mast. Comparison of the photographs with the drawing of the building indicates that the ball diameter was 1.5m and that the drop height was about 5.2m, close to the original drop height. Figure 5 suggests that the second ball was painted black with a coloured central band, similar to the colour scheme used at Lyttelton (see later). A drawing of the Lyttelton ball, which had the same 1.5m diameter, was probably given to the ball manufacturer.

Captain Edwin was responsible for time ball operation and weather forecasts, but public announcements concerning the time ball drop time

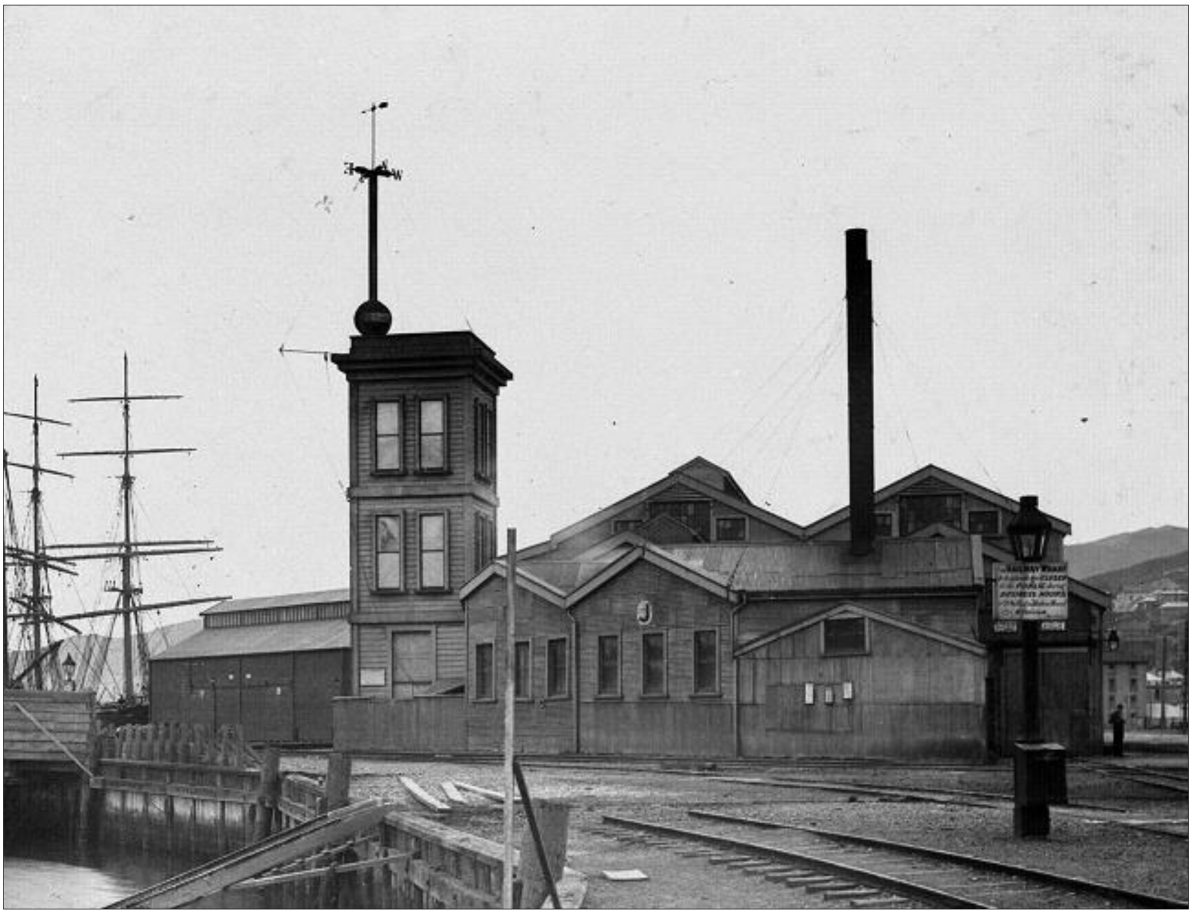


Figure 4: The time ball at its second location in Wellington (courtesy: Wellington City Archives 2012/2:6725).

and longitude have not been found. The absence of these was noted:

> That Mr Dacre wants the Harbour Board to advertise the hour at which the “time ball” will drop. Wouldn’t it be better to get Captain Edwin to include the event in his daily prophecies? (They Say, 1902).

The Railway Wharf tower burnt down in March 1909 and the outline of the time ball apparatus can be seen in Figure 6. Subsequently, calibration had to be carried out by taking chronometers ashore:

> In this week’s Gazette it is notified that, owing to the destruction by fire of the "J” Shed, Waterloo Quay, the time ball which was situated on the tower of the said shed is no longer available for the information of masters of vessels frequenting the port. Correct mean time may be obtained in the public room of the telegraph office, close to the Queen’s Wharf, where a galvanometer, controlled by the observatory clock, is deflected every hour. (Shipping News, 1909).

4.5 Possible Replacement in 1910

Enquiries about a replacement time ball apparatus were made in London:

> I am directed by the High Commissioner to inform you that he has been requested by his Government to obtain quotations for the supply of a Time Ball Apparatus for Wellington, in place of one burnt by fire a short time ago. The Time Ball will be dropped by electric cur-

Figure 5: The ball and mast at their second location in Wellington (courtesy: Wellington City Archives 2012/2:6725).

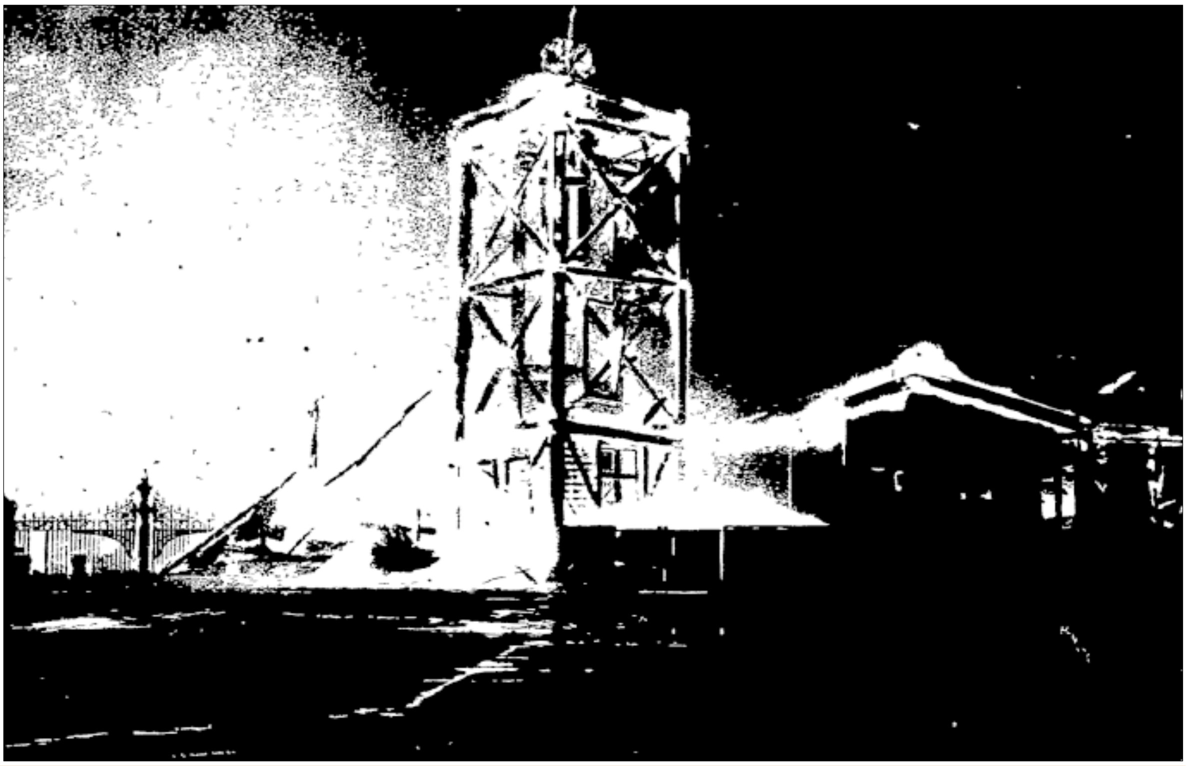


Figure 6: Wellington's Latest Conflagration – The Last of Capt. Edwin's Tower and Time Ball (*New Zealand Free Lance*, 13 March 1909).

rent from the Hector Observatory.

> I am also directed to state that the High Commissioner will be very pleased if you could kindly furnish him with the names of the best Manufacturers from whom Tenders should be invited for the supply of this Apparatus. (NZ High Commission, 1910a).

W.H.M. Christie, the Astronomer Royal at Greenwich, arranged for a reply to be drafted by a member of his staff (Lewis, 1910a). His notes also included estimates of cost:

> It is presumed that the Time-Ball installation is to be similar to those at Singapore, Portsmouth, Brisbane, Cairo, Port Said, Alexandria, &c. ...
>
> The stays and hoisting gear for Singapore were made by Messrs Saxby and Farmer, 50 Victoria Street Westminster, who make Railway Signals. Capt. Lyons, when erecting the Egyptian Time balls, was unable to trace this firm.
>
> The other portions were made by E. Dent & Co 61 Strand, W. C. who also make the whole apparatus complete. This firm supplied the whole apparatus for Genoa.
>
> I would recommend that the High Commission communicates with these firms.

These notes were summarised in the official reply from the Astronomer Royal (1910a):

> In reply to your letter of April 21, R. B 21/58, relative to the supply of a Time Ball and apparatus for Wellington, New Zealand, I have to inform you that the Time Ball and hoisting apparatus can be supplied by Messrs Saxby and Farmer Ltd., Railway Signal Engineers, 53 Victoria Street, Westminster, and the Clock and Electrical appliances by Messrs E Dent & Co., Ltd., 61 Strand, W. C., or doubtless the latter firm would undertake the complete contract.
>
> These firms have satisfactorily carried out the fitting up of Time Balls and apparatus in various parts of the world.

Tenders were sought by the NZ High Commission (1910a; 1910b) from the two firms. A subsequent report confirmed that offers were received from both, with additional offers from Messrs Smith & Sons and Messrs Gibett & Johnson, who stated that their time ball would be similar to those supplied for Port Said and Cape Town (*Wellington Harbour Board Reports ...*, 1910). Despite protests from shipping companies on 21 July 1911 (see Wellington Harbour Board, 1911), it appears that no order was ever placed for a new time ball apparatus.

4.6 Entries for Wellington in the *New Zealand Nautical Almanacs*

The entry for Wellington in the *New Zealand Nautical Almanac* for 1903 is particularly informative, including notification that the assumed longitude of the observatory was about to be changed and that the time ball would be dropped 3.8 seconds later than before. There was also a clear distinction between days when the exact time could be confirmed by astronomical observations and other days where there had to be reliance on the astronomical clock for interpolation:

> There is an astronomical observatory at Wellington, and approximately correct time may be obtained from daily signals which are given by a time ball situated on the tower of "J" Shed, Waterloo Quay, at the root of Railway Wharf. The time may be taken as absolutely correct for chronometer-rating purposes on the days when a flag is flown on the flagstaff close alongside the time ball; also, on these close-rating days a notice is inserted in the *New Zealand Times* to this effect. The ball falls at 12.30 Greenwich mean time, which is equivalent to noon in New Zealand, and this is the time which is kept throughout the colony. There is also a galvanometer, deflecting every hour, in the Public Room of the Telegraph-office, close to the Queen's Wharf, which is controlled by the same clock which drops the time ball.
>
> [NOTE. – The longitude assumed for the Observatory in calculating time is 11h. 39m. 9.13s., which corresponds to that of the coastal charts. The accepted longitude of the Observatory is 11h. 39m. 5.31s., based on the longitude of Sydney. It is probable that this longitude will very shortly be adopted in giving Greenwich time by the time ball.]

The 1905 and 1906 entries confirmed the change in assumed longitude. The entry for 1907 contained an important announcement about relocation and development of the observatory at Wellington. A temporary observatory and a reduced time signal service, including suspension of the Wellington time ball service, would be available in that year:

> The time ball has been temporarily discontinued owing to the observatory having been demolished. A new observatory is about to be erected on another site. Meanwhile the time for the colony is kept by chronometers which are checked by theodolite observations taken from a temporary observatory in the grounds of the Government Buildings by the Lands and Survey Department. Approximately correct time is given daily by galvanometer to the Telegraphic and Railway Offices, and once a week the correct time from observation is telegraphed to Auckland, Lyttelton and Dunedin. Any shipmaster in Wellington wishing to correct his chronometer should apply at the Museum to the Permanent Observer (Mr. King), who has charge of the chronometers, and gives the time to the colony.

The 1908 entry was the same as the 1906 edition, but there was a major change in the 1910 edition, owing to the fire which destroyed the time ball in March 1909. Apart from the note concerning longitude, the entry was reduced to:

> There is an astronomical observatory at Wellington, and correct mean time may be obtained in the public room of the telegraph-office, close to the Queen's Wharf, where a galvanometer controlled by the observatory clock is deflected every hour.

The entry in the 1912 edition (the 1911 and 1913 editions have not been seen by the author) heralded the introduction of time lights at Wellington observatory, as well as final discontinuance of the time ball service in Wellington:

> There is an astronomical observatory at Wellington on Battery Hill, in the Botanical Gardens, in latitude 41° 17′ 3.76″ S. and longitude 174° 46′ 7.2″ E. = 11h. 39m. 4.48s. From the tower of this observatory a time-signal by electric lights is being inaugurated (See further page 328.) The time-ball which was situated on the tower of J. Shed, Waterloo Quay, has been discontinued since the destruction of this shed by fire. Correct mean time may be obtained in the public room of the telegraph-office, close to the Queen's Wharf, where a galvanometer controlled by the observatory clock is deflected every hour.

Later editions include details of the telegraph, time light and eventually radio signals that were provided by Wellington. The sequence of time lights changed over the years, but a similar time light service was provided in Auckland after 1915.

5 THE LYTTELTON TIME BALL

An informative booklet was published by the New Zealand Historic Places Trust (Bremner and Wood, 1979). According to that booklet, Siemens Brothers shipped the apparatus for Lyttelton from London in July 1874, following an order in March 1873. Siemens had become a principal supplier of telegraphic equipment, with heavy commitments to supply and installation of telegraph cables at the time. Lyttelton time ball operation had to await completion of the necessary tower and it became operational on 23 December 1876. It was restored faithfully during the 1970s and was a much-admired New Zealand landmark.

5.1 Design of the Lyttelton Apparatus

It has been demonstrated that the apparatus for Lyttelton is actually a replica of the 1855 design for Sydney, NSW, despite a long interval between their dates of supply (Kinns, 2009). Maudslay, Sons & Field of Lambeth, London built the time ball apparatus for Sydney in 1855, using a rack and pinion mechanism to hoist the ball that had been developed from the design for Edinburgh and Deal (Kinns and Abell, 2009). It became operational in 1858, following completion of Sydney Observatory and the time ball tower. Henry Russell, the NSW Government Astronomer, modified this apparatus during the 1870s, but most principal features were retained.

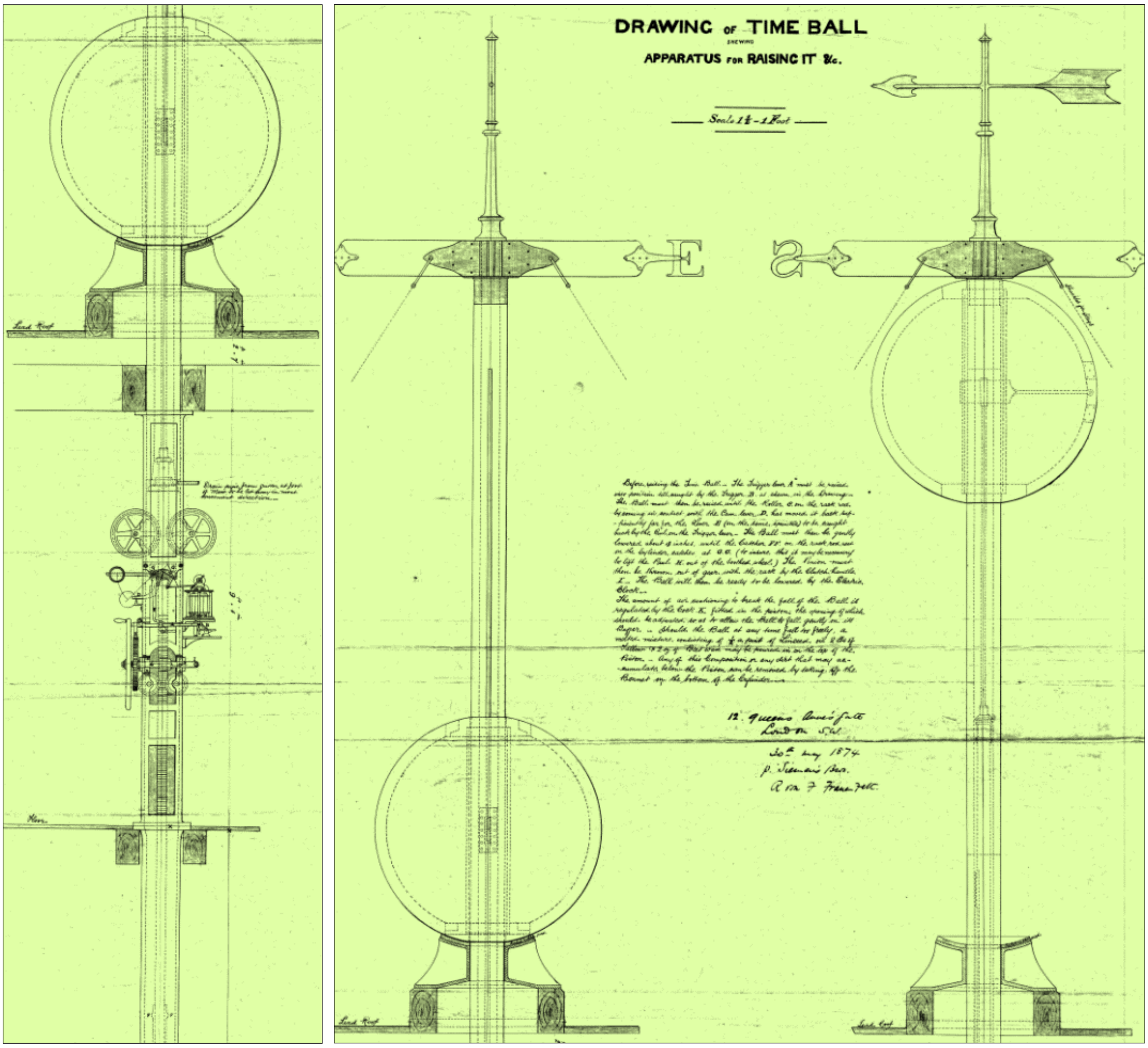


Figure 7: Extracts from Siemens 1874 drawing of the Lyttelton time ball apparatus (courtesy: Wellington Harbour Board archive, Drawing Office No. 3510)

He identified many of his changes in a letter to Sir Charles Todd in Adelaide. Detailed comparison of the two time ball systems in 2009 confirmed that Lyttelton used the unmodified 1855 design (Kinns, 2009). The only surviving note in Maudslay records about an 1873 order for a time ball indicates provision for the Cape of Good Hope and an association with Siemens (Sells, 1842–1883). No evidence has been found that an apparatus built by Maudslay, Sons & Field was ever delivered to Cape Colony. Also, no Siemens records showing supply of time ball apparatus to a location other than Lyttelton have been found. It was deduced that a single 1873 apparatus was built for Siemens Brothers who added electrical equipment and shipped the complete system to Lyttelton, not the Cape, in 1874.

Extracts from the drawing supplied by Siemens Brothers are shown in Figure 7 (Drawing of Timeball, 1874). The drawing of the Lyttelton ball was probably used for the 1888 replacement ball at Wellington.

5.2 Entries for Lyttelton in the *New Zealand Nautical Almanacs*

The entry for Lyttelton in the *New Zealand Nautical Almanac* for 1903 continued to define the time ball location as “The Observatory”, perpetuating the anomalous description given in the 1898 Admiralty list:

> At the Observatory, on the east side of Lyttelton, a ball is dropped at 1h. 0m. 0s. p.m., New Zealand standard mean time, or 13. 30m. 0s. Greenwich mean time. The ball is hoisted five minutes before the signal.

The entry for 1918 showed a change of drop time, but still referred to the Observatory. The time ball drop was delayed from 1330 to 1600 GMT, then still based by astronomers on noon at Greenwich, rather than midnight. GMT was rebased to midnight for all purposes on 1 January

1925:

> At the Observatory, on the east side of Lyttelton, on days when accurate time signals are given a ball is dropped at 3h. 30m. p.m. New Zealand standard mean time, or 16h. 0m, Greenwich mean time. The ball is hoisted five minutes before the signal. The time signals will be sent on Tuesdays and Fridays, provided satisfactory observations have been obtained. If time signals are required on other days or at other exact hours of Greenwich mean time, application for them should be made to the Observatory, Wellington.

The service continued as the only official time ball in New Zealand until it was rendered obsolete by radio time signals and ceased at the end of 1934. At some time between 1918 and 1928, the location description given in almanacs had been changed to the 'signal-station'.

5.3 Damage in 2011

Tragically, the tower collapsed during the earthquakes and aftershocks in 2011 that devastated Christchurch. The extent of the damage is shown in Figures 8 and 9.

The photograph in Figure 8 was taken following an aftershock which had caused major structural damage to the tower, but had left the time ball apparatus largely intact. The tower was being dismantled and the photograph was taken from a crane only one hour before the second major aftershock that caused the tower to collapse completely.

The effect of that second after-shock is shown in Figure 9. The time ball itself can be seen in the lower left hand corner of Figure 9. The mechanism was badly damaged, but most key components have survived and it may be possible to restore it to working order.

5.4 Importance of the Lyttelton Ball

Although the Lyttelton ball was damaged in 2011, it is an important artefact, and is likely to be the only original time ball from the period before 1875 that is still in existence. The Maudslay time balls at Greenwich, Edinburgh, Deal and Sydney have all been replaced or modified since original supply. That at Edinburgh was restored in 2009, but its frame had been extensively reinforced during the nineteenth and twentieth centuries and the ball is now significantly heavier than the original. Time balls supplied by other manufacturers during the nineteenth century all appear to have been lost.

Figure 10 shows the Lyttelton ball in its present state. Figure 11 shows the internal framing of the top half of the ball, which escaped damage. This may be compared with photographs of the Edinburgh ball, before restoration, shown in Kinns (2014).

Figure 8: A photograph taken on 13 June 2011 just before the collapse of the Lyttelton Time Ball Tower (www.stuff.co.nz/the-press/news/8794428//Timeballs-last-known-photo).

6 THE OTAGO TIME BALL

The prospect of a time gun for Otago, in preference to a time ball, was introduced in March 1864 (Harbor Department, 1864). The report was published in the *Otago Daily Times* on 9 April. Extracts are transcribed below:

> A flagstaff has been erected at Port Chalmers, and a signal master appointed, who will enter upon the duties of his office immediately ... I would now recommend that an astronomical clock be procured for this station, to assist in keeping accurate time, which will also be computed every clear day by observation; and that a small signal gun be got to be fired at eight p.m., to enable ship masters to correct their chronometers – an accommodation much prized by them. A gun would be much preferable to a time ball, as in the case of the latter

Figure 9: A photograph taken on 18 June 2011, five days after the collapse of the Lyttelton Time Ball Tower (www.stuff.co.nz/national/christchurch-earthquake/5145289/June-13-earthquakes-Morale-costs-get-a-shake-up).

Figure 10: The damaged Lyttleton ball (courtesy: Bruce Carr).

the time would necessarily have to be signalled at noon, an hour when ship masters are frequently on shore, and when the duties of the day would much prevent their giving attention to it. The gun would also indicate the time to the inhabitants of the town, many of whom are not within sight of the signal station, and to the river steamboat masters, who are desirous of keeping correct time with a view to secure punctuality in arriving and departing.

The idea of a time ball for Dunedin was raised again in a Letter to the Editor of the *Otago Daily Times*, with an emphasis on the need for improved clock accuracy in the City:

Sir – Now that the telegraph has been established throughout the Provinces, a very great addition, and one of much value to the public in Dunedin, would be the erection of a ball over the Telegraph Office, and some regular time adopted for the town ... (Time ball for Dunedin, 1865).

6.1 Introduction of a Daily Service

The imminent provision of a time ball for Port Chalmers, near Dunedin, was announced in the *Otago Daily Times*:

Active preparations are being made for the working of the long needed time ball at the Flagstaff, Port Chalmers. A conductor has been

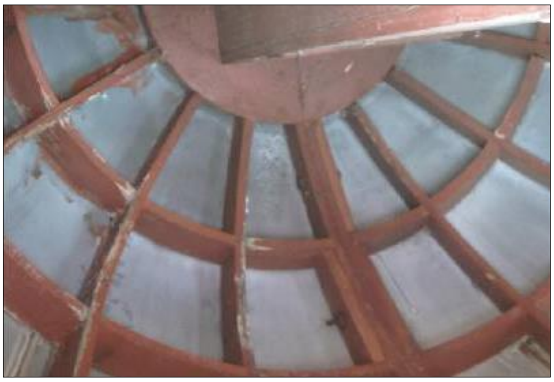


Figure 11: Internal framing of the Lyttelton time ball (courtesy: Bruce Carr).

laid from the Observatory to the Flagstaff, which being attached to the haulyards by a simple arrangement, the ball is dropped instantaneously by the signal master. The whole of the arrangements are expected to be completed in a week, when the great want of a time ball to the shipping community will be numbered with the things of the past. (Shipping, 1867).

The service actually started on Saturday, 1 June 1867, two months later. This still preceded establishment of New Zealand Mean Time. The time ball was dropped every day, except Sundays:

The time ball at the Port was dropped, for the first time, on Saturday, and it will in future be dropped daily (Sundays excepted) at 1 p.m., Port Chalmers mean time or 1h 37m. 23.5s a.m., Greenwich mean time. (Customs entry, 1867).

Figure 12 is a photograph of the time ball, taken from a vessel that was anchored in Port Chalmers (cf. Hargreaves and Hearn, 1980: 47).

The following notice is typical of newspaper entries that appeared regularly in the *Otago Daily Times* until 5 October 1877

PORT CHALMERS OBSERVATORY. Latitude, 45.48.55 south; longitude, 11h. 22m. 37s. east. Time ball drops daily (Sundays excepted) at 1 p.m. Port Chalmers mean time, or 1h. 37m. 23s. a.m., Greenwich mean time. (Port Chalmers Observatory, 1877).

Curiously, the stated drop time after 1868 continued to be 1 p.m. Port Chalmers mean time, not 1 p.m. New Zealand mean time.

The time ball service may have been discontinued from then until 1882. The need for vigilance concerning the accuracy of time signals and measurements of longitude is emphasised in the following letter from the Captain of *SS Zealandia* to the *Otago Daily Times*.

Captain Chevalier, of the Pacific Mail Company's S.S. Zealandia, publishes the following interesting notice to mariners: – The Union group, being in a direct line from Auckland to the Sandwich Islands, caution is necessary in passing them, they being low, dangerous islands, and have been found to be placed 11 miles to the east of their true position on Admiralty charts. The Zealandia's chronometers were carefully rated by observations in San Francisco, assuming the Pacific Mall Company's wharf to be in latitude 37 deg. 40 min. 45 sec. N., and longitude 8 deg. 9 min. 32 sec. W [*sic*]. On arrival in Sydney on October 12th, after a lapse of 30 days, the chronometers by Observatory time ball were three seconds, or three-quarters of a mile to the east of true. The ship's position when off the Duke of Clarence Island, Union Group, was ascertained at time of observation by a series of angles. These islands have been sighted on two different voyages, and found each time to

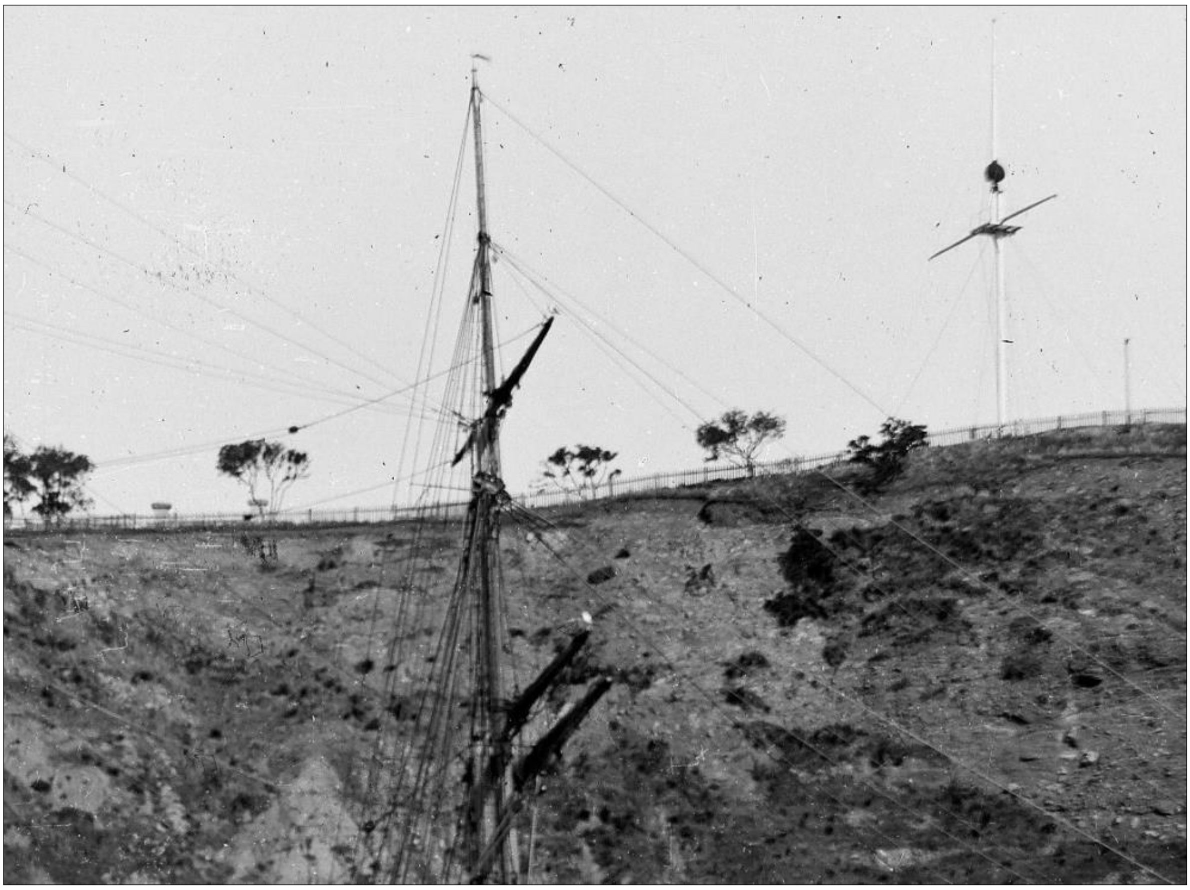


Figure 12: A close-up from a photograph of the sailing ship *Waipa* which shows the time ball at Port Chalmers some time prior to 1895 (courtesy: Alexander Turnbull Library, Ref: 1/1-002534-G).

> be eleven miles out of position. (Shipping, 1877).

Published records of a meeting of the Harbour Board in January 1881 indicate that the time ball had been discontinued for some time, but that action was required in response to protests from shipmasters:

> The following petition, which was signed by eleven shipmasters, was received: Port Chalmers, January 26, 1881. To the Chairman and Members of the Otago Harbor Board. Gentlemen, We, the undersigned, masters of vessels at present in port of Otago, respectfully desire to draw your attention to the great disadvantages under which we labor in consequence of the disuse of the time-ball at Port Chalmers, and desire to urge upon you the great necessity which exists for the appointment of some competent person to work the ball and otherwise attend to the duties of the signal station at this port. We trust our application will meet your favorable consideration. (Time ball, 1881).

After considerable discussion concerning previous inaccuracies, location of the time ball and methods for its control, "... it was resolved to inform the memorialists that a time-ball would be erected shortly."

6.2 Control from Wellington

On 15 March 1881 it was announced that the time ball was to be regulated in future by telegraph signal from Wellington:

> On receipt this morning of intimation from the Wellington Telegraph Office that the time ball at Port Chalmers would in future be worked in connection with the telegraph, notice thereof was sent round to the masters of vessels by the harbor authorities. The time ball was dropped at the instant the current moved the needle of the galvanometer. The time given is mean time at longitude 11h 30min 00.3 [*sic*] sec east. (*Evening Star*, 1881).

6.3 Change to a Weekly Service

The lack of announcements during the following year suggests that the new service was only introduced in April 1882, when the signal was offered once per week :

> TIME BALL AT PORT CHALMERS. New Zealand mean time at noon, calculated for the meridian of longitude, in time 11 hours 30 minutes east of Greenwich, will be signalled once a week by the time-ball dropping at the instant of mean noon. A blue flag will be hoisted at the mast-head, Port Chalmers signal-station, on the forenoon of the day when the time-signal will be given. (Shipping, 1882).

Regular time ball announcements in the *Otago Daily Times* re-appeared in April 1882 after the change to a weekly service. The last newspaper notice appears to have been in 1906 (Time ball at Port Chalmers, 1906), although New Zealand nautical almanacs indicated that the service was operating in 1908 and 1909 after development of the new Wellington observatory during 1907.

The latitude and longitude of the time ball are given in the 1898 Admiralty list (see Table 2) as 45° 49′ 0″ S. and 170° 39′ 0″ E (corresponding to 11h. 22m 36s E), almost exactly those stated in early announcements. This confirms that the time ball was not relocated. Rounding to the nearest minute of arc is likely to indicate the perceived accuracy.

6.4 Entries for Otago in the *New Zealand Nautical Almanacs*

The entry in the 1903 *New Zealand Nautical Almanac* was similar to those published in the late nineteenth century:

> A time ball is dropped about once a week from the flagstaff at Port Chalmers at noon New Zealand standard mean time, or 12. 30m. 0s. Greenwich time. When the ball is to be dropped a blue flag is hoisted on the signal-staff at about 10h. 0m. 0s. a.m. *New Zealand mean time*.

The same notice was repeated up to 1906, but the entry for 1907 was changed to "The time ball has been temporarily discontinued." This is likely to have been caused by construction of the new observatory at Wellington during 1907, when only a temporary observatory was available. The original notice reappeared in the 1908 and 1909 editions. That changed in 1910 to "The time-signal ball dropped from Port Chalmers Signal-station has been discontinued." The same notice appeared in editions up to at least 1918.

The Otago time ball service had long ceased by 1919, but the demand for an accurate signal was still present:

> At the termination of the meeting of the Harbour Board yesterday the chairman (Mr H. L. Tapley) introduced Captain Sebourne, who has distinguished himself in connection with submarine Warfare ...
>
> The second matter was that means for rating chronometers were not provided at the Port – there was no time ball to correct them. That could be done by going to Lyttelton, but he thought that there should be a time ball here. Mr Galbraith asked if wireless time would not supply the deficiency, and take the place of a time ball. Captain Sebourne replied in the affirmative. Mr Galbraith then remarked that the Government had that matter in hand. (*Otago Daily Times*, 1919).

The Port Chalmers time ball service was never re-established after 1909.

7 THE AUCKLAND TIME BALL

7.1 The First Auckland Time Ball in 1864

The first time ball at Auckland was established by Captain Williams at Smale's Point. He offered a Sunday service only at 9 am, Auckland time, with a newspaper notice on the following Monday to state the time of the drop. The new service started on Sunday, 7 August (*New Zealand Herald*, 1864). Its announcement was republished fifty years later:

> To the Editor of the NEW ZEALAND HERALD.
> A time ball for the benefit of the city and shipping will be dropped every Sunday morning about 9 a.m., and will be hoisted at the mast head, Smale's Point, some five minutes before it is let fall. The corresponding Auckland, as also Greenwich mean time, at which the ball was dropped, will be published in this journal on the Monday morning.
> S.J. WILLIAMS Smale's Point (*New Zealand Herald*, 1914).

A typical Monday notice is transcribed below:

> The mean time when the Ball dropped yesterday morning
> Auckland 8h. 59m. 48s.
> Greenwich 9h. 20m. 37s.
> S.J. WILLIAMS Smale's Point (*New Zealand Herald*, 1865).

The local mean time was estimated to be 11 hours, 39 minutes and 11 seconds ahead of Greenwich. The longitude may have been calculated using data obtained by Wellington observatory. There is no known photograph of the time ball at Smale's point, but Figure 13 shows the view in January 1864 from close to its probable location later that year.

The service appears to have ceased on Sunday 10 June 1866, less than two years after it started, with a final published notice on the following day (*New Zealand Herald*, 1866a).

In practice, this time service would have been of limited value to navigators, who really required a daily service for rating chronometers while in port. It is not known how Captain Williams determined mean time or how he designed and constructed a time ball apparatus. He may have possessed a high quality astronomical clock and chronometer which he could calibrate in the City. The Wellington time ball service started in March 1864, a few months before his, using a heavy-duty apparatus provided by Sandys and Co. in England (Kinns, 2014). Williams' apparatus was probably much simpler with a light wickerwork ball and manual release.

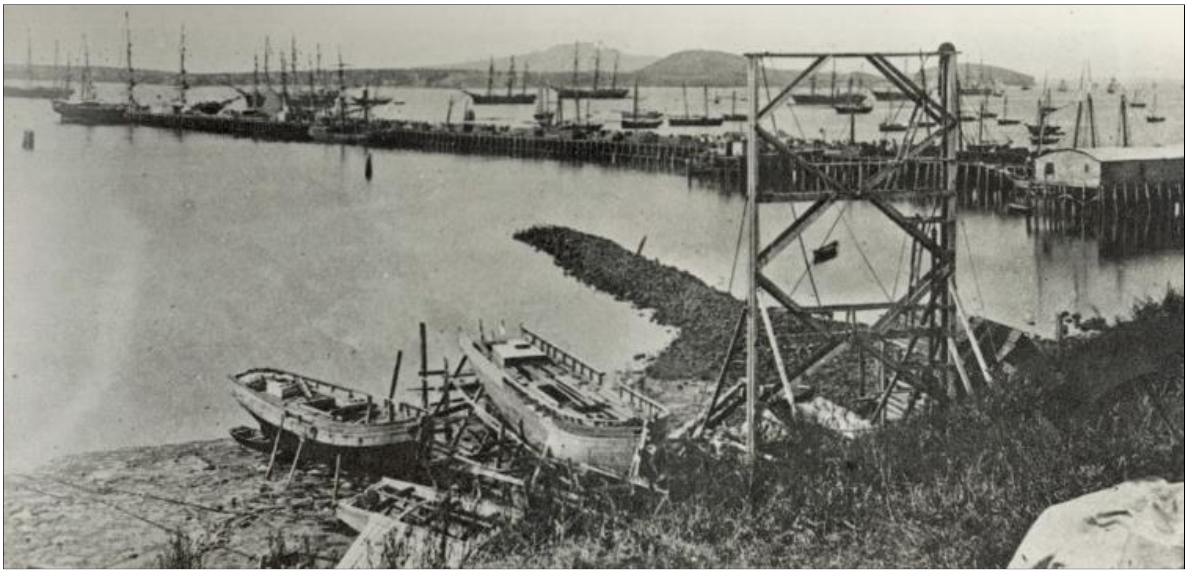


Figure 13: A photograph of Auckland Harbour taken from Smale's Point on 29 January 1864 (courtesy: Auckland Libraries, Sir George Grey Special Collections, 4-1166).

7.2 Bartlett's Time Ball in 1866

The apparent demise of Williams' time ball may have been associated with the provision of a time ball by Mr A.G. Bartlett. He described himself in advertisements as a "Chronometer, Watch and Clock Maker" with a business on the corner of Shortland-street and High-street. He gave his credentials as "23 years Examiner to Messrs. Crockland & Atkins of 7 Cowper's Court, Cornhill, London" (*New Zealand Herald*, 1866b). Cornhill was the location of many chronometer-makers in England.

The new service was announced in the *New Zealand Herald*:

> Mr. Bartlett has caused his time ball to be erected at his residence, a high situation in Coburg-street. This cannot fail to be of great convenience, and the unfailing correctness with which, by the aid of the transit instrument, time is kept, is a boon to men of business. It is commendable to the enterprise of this scientific chronometer maker, that "Bartlett's time" has become familiar in our mouths as household words. (Bartlett's time ball, 1866).

Although Bartlett's time ball may have been useful to local businesses, it fell short of providing a viable service to mariners.

Published correspondence in 1874 showed further interest in erection of a new time ball for mariners.

7.3 Proposal for a Time Ball in 1874

The Telegraph and Post Office had burned down in 1874 and there were suggestions that it should be rebuilt with a time ball. Extracts from an editorial in the 6 October 1874 issue of the *Auckland Star* are shown below:

> The renovation of the lately burnt down Post-cum-Telegraph office is approaching completion, and the freshened aspect or its facade is quite imposing ...
>
> As the support for a time ball, which is surely a necessity in every commercial port, as a means of signalling any approaching gales to the shipping in harbour, in accordance with the new system inaugurated, and as an embellishment to a city that has but few objects of architectural pretension, the tower once intended and since neglected is deserving of an effort on the part of our citizens. (Editorial, 1874).

The response was ambivalent and no action appears to have been taken:

> The Mayor wished first to direct the Commissioner of Customs' attention to the desirability of completing the Post-office building, which had been handed over to the General Government, by the erection of a tower with the addition of a time-ball, which was of very great use to an important shipping port like Auckland. The tower could be utilized for many purposes, and the clock would not only be useful but ornamental.
>
> Mr Reynolds said that the matter was one which came within the Department of the Minister of Public Works … He should certainly not be in favour of erecting a time-ball there, as it would not be of any use; it would be better to erect it in a position nearer the harbour …
>
> Captain Daldy said if the Government intended to carry out the system of storm signals the time-ball would be required in connection with the telegraph. It was desirable that the time-ball should be connected with the Telegraph Department, which he believed would occupy that building. (Public Works in Auckland, 1874).

No evidence of further activity has been found before 1883. Possible provision of a time ball was discussed on several occasions in the years up to 1900.

7.4 Public Discussion between 1883 and 1900

The possibility of progress was noted in 1883:

> We have been favoured with a glance at the conditions for the guidance of architects sending in competitive designs for the new Harbour Board offices. The building is to be situated on the reserve bounded by Little Queen, Quay, and Albert-streets, and Mr Goldie's property, and is to be three stories high, and provision is to be made for a time ball tower. (*Auckland Star*, 1883).

Still nothing happened and a discouraging note appeared in 1885:

> The Works and Tariffs Committee's recommendations were: – (1) That the Board decline to expend £700 or £800 in providing a reliable time ball apparatus. (Harbour Board, 1885).

Another editorial in support of time ball procurement and the required operational budget was published in 1886 (*New Zealand Herald*, 1886). It was in support of a correspondent and showed that the design of the Victoria Arcade building had made provision for a time ball apparatus:

> When the Victoria Arcade was in course of erection, representations were made to the directors of the New Zealand Insurance Company of the suitability of the projected clock tower of their new building for the purposes of a time ball, and urging the importance of one being fixed on it. On these representations, the directors caused the plans of the building to be altered, and the tower strengthened in order to render it available for the proposed object. After this expense has been incurred, we learn that the Government refuses to sanction the very small expenditure that would be involved in placing and maintaining the tower in electric contact with the telegraph office, and thence with Wellington, in order to secure the desired end. This is, we think, a matter on which strong representations might be made by the Chamber of Commerce and the Harbour Board.

Again, nothing happened. Another attempt to establish a time ball was made in 1893:

> ... Mr Crowther will move (1) "That the next ordinary meeting of the Board be held on Tuesday the 9th January, 1894, at 2.30 p.m." Mr Porter will move (2) "That the Secretary be instructed to communicate with Sir J. Hector, Colonial Museum, Wellington, with the view of obtaining information as to time ball for harbour purposes, and estimated cost of fitting and erecting same on the offices of this Board; time ball to be of a similar description to those in use at Lyttelton and Wellington." (*Auckland Star*, 1893).

It was at least recognised that the apparatus would have to be of similar quality to those at Wellington and Lyttelton, to be of value to mariners. Progress was still snail-like and there was no time ball during the last twenty years of the nineteenth century. That certainly explains the lack of an entry for Auckland in the 1880 and 1898 Admiralty lists.

Another strongly worded petition for a time ball was published in 1900:

> Time Ball: A petition signed by over 60 shipowners, agents, and shipmasters, was read, drawing attention to the great inconvenience caused by the absence of a time ball at the port. Auckland, said the petition, was the only port in Australasia where such a necessary adjunct to navigation was absent. The petition was referred to the Works and Tariff Committee. (Auckland Harbour Board, 1900).

The lack of a time ball was an embarrassment to such an important port.

7.5 The Time Ball on The Harbour Board Building

A time ball for Auckland was finally under detailed discussion in 1900, with support from the Admiralty:

> Machinery, Time Balls, etc. – Messrs. W. and A. McArthur wrote that the Admiralty considered it better that shop tools and iron ladders should be made in Auckland, and enclosing sketch thereof. Information with regard to the time ball, core former, sheer legs, etc., was also forwarded. – Referred to the Works and Tariff Committee to report. – The Acting-Chairman said the work could be done here for a small sum of money. It was at first thought it would cost a lot. (Harbour Board, 1900).

Tenders for construction of the time ball were invited with a closing date of 30 April (Tenders, 1901). Meanwhile, the possibility of a time gun also was debated:

> TIME BALL: Sir, – I see by your paper that, we have got a time ball for Auckland, by which to regulate our clocks and watches, but like many others I have no opportunity of seeing such a thing from my point of view, and without undervaluing the time ball I think that (if practicable) the electric wire might be extended to the Albert Park and connected with one of the guns there, and at the same moment that the current frees the ball it will also discharge the gun, which could be heard all over the city, and so greatly extend its usefulness, a plan adopted in Edinburgh. (Auld Reekie, 1901).

The proposed system would be like that used in Edinburgh since 1861, when the gun was introduced to complement the time ball that had become operational in 1854 (Kinns, 2011). Bart-

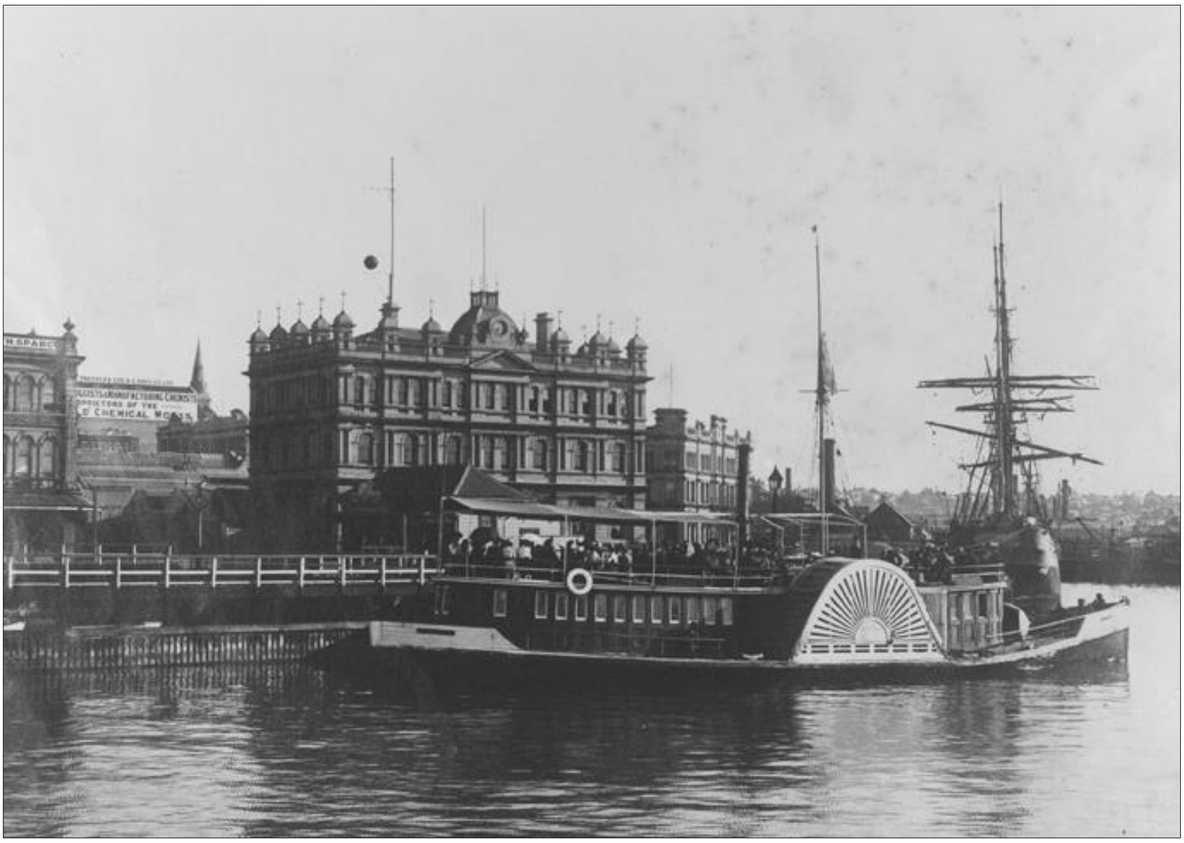


Figure 14: Harbour Board Building, pre-1911 (courtesy: Auckland Libraries, Sir George Grey Special Collections, 4-2938).

lett was given a budget of only £30 per annum to operate the time ball:

> Works and Tariff Committee. – The report of this committee was adopted … that Mr A. Bartlett be requested to take the necessary steps to cause the time ball to be dropped at 12 noon every day, excepting Sundays and holidays, payment not to exceed £30 per annum … (*Auckland Star*, 1901).

It was 35 years since he had operated a time ball at his own premises.

7.6 Design of the Auckland Apparatus

The time ball can be seen on top of the Harbour Board Building in Figure 14. The photograph has uncertain date. As shown in the Figure 15 close-up, the time ball is clearly off-set from a tall mast. This suggests that the apparatus was dissimilar to those used at Lyttelton or Wellington and may have used the 'Devonport Principle'. This type of design was outlined in correspondence relating to a new time ball for Portsmouth:

> In the more recent form of apparatus, there are two vertical guides (wire) and when once the ball is hoisted it is held by a small rope. Everything else being loose, the ball drops about a foot before the thick rope used in hoisting comes into real action. (Astronomer Royal, 1910c).

Figure 15: A close-up of the time ball shown in Figure 14 (courtesy: Auckland Libraries, Sir George Grey Special Collections, 4-2938).

The design had been developed by William Wharton, Hydrographer of the Navy, and was first used at Devonport, England. It was much cheaper than the designs using rack and pinion mechanisms for hoisting the ball, gave a larger drop distance and was used almost universally for installations after 1885:

> The principle of our Time Ball [*at Greenwich*] is not so suitable as the later pattern which was adopted at Devonport about 1884-5 and has been so successful that it has been copied at Ports all over the world. Moreover it is doubtful whether the firms that originally installed our apparatus are now in existence. (Astronomer Royal, 1910b).

The dominance of the design was emphasised in an internal note to the Astronomer Royal:

> 90% of recent Time-Balls are on the Devonport Principle. This gives a drop of 18 to 20 ft. The Greenwich type [*supplied by Maudslay, Sons & Field*] can scarcely be expected to give anything like this – Ours is 10 ft. (Lewis, 1910b).

The Auckland time ball finally became operational in September 1901:

> Harbour Board Offices, September 6th, 1901. Notice is hereby given that the Time Ball erected at the Offices of the Board, Quay-street, will be Hoisted every day (Sundays and holidays excepted) at 11.50 a.m. and Dropped at 12 Noon, Colonial Mean Time (same time as observed in the town). By order of the Board. J. M. BRIGHAM, Secretary. (Time ball, 1901).

So far, so good, but other expenditure was needed:

> Mr A.G. Bartlett wrote asking for a clock, cost £50, to assist in keeping the time ball correct – The letter was referred to the Works and Tariff Committee. (Harbour Board ..., 1901).

Regular notices about the time ball drop appeared in the *Auckland Star* and continued up to August 1902 in one of two forms:

> TIME BALL: The time ball drops at the Harbour Board Buildings at noon daily. New Zealand mean time, equivalent to 12 hours 30 minutes Greenwich mean time. (*Auckland Star*, 1902a).

> TIME BALL: Harbour Board Offices, August 2nd, 1902. Notice is hereby given that the TIME BALL erected at the Offices of the Board will be hoisted every day (Sundays and Holidays excepted) at 11.50 a.m., and dropped at 12 noon, Colonial mean time (same time as observed in the town). By order of the Board. M. H. LAIRD, Acting Secretary. (*Auckland Star*, 1902b).

The service did not last long and appeared to have stopped on 5 August 1902. Not long afterwards, it appears to have been abandoned altogether:

> The Harbour Board, at its meeting yesterday, decided on the recommendation of the Works and Finance Committee to incur no further expenditure in regard to the time ball over the Board's buildings. The chairman (Mr. J.T. Julian) said the time-ball had become the laughing stock of the port on account of its unreliableness, and Mr. J.A. Walker said that the visiting naval officers, as well as shipping masters, had ceased to take any notice of the thing for the reason stated by the chairman. Mr. W.J. Philson said he thought a correct timeball was essential for any sub-naval station, but other members regarded the matter of adjusting the present instrument as apparently hopeless, and adopted the committee's report. (Local and General News, 1903).

The following letter was published in the *New Zealand Herald*:

> Sir, – A few years ago the Harbour Board, at some considerable expense, imported and erected a time ball for the benefit of vessels frequenting this port, but, as the antics of the said ball became very erratic, further expense was incurred by an additional pole. An astronomical clock was next to arrive, followed by an individual with electrical knowledge: still the ball remains a fixture ...
> – I am, etc. Correct Time. (Time ball, 1904).

There were further attempts to re-establish the service, still involving Mr. Bartlett, and the following statement was published in 1905:

> Time Ball Wanted. – Mr Dacre moved. "That it is in the interest of the port that a correct, time ball be kept in use." He found there was a great need of this, and it was a necessity for any up-to-date port. – Mr Napier, seconding, asked why it was not gone on with. – The Chairman said it was because of complaints that it was inaccurate. It cost £50 a year to maintain, and he thought it was unnecessary expense. When the matter was gone into two years ago Mr Bartlett told them that to ensure correct time it would be necessary to erect an observatory in the Albert Park – The matter was referred to the Works and Tariff Committee. (Harbour Board, 1905).

This was followed by another announcement:

> The Harbour Board has instructed its engineer to submit an estimate of the cost of putting an observatory into the Albert Park, and requested Mr A. G. Bartlett to quote the cost of maintaining the time ball at accurate time. (Advertisement, 1905).

Yet another plan was published in the following year, whereby electro-magnetic triggering was to be used, with control from Wellington:

> Mr. J. Hamilton, director of the Colonial Museum, Wellington, has written to the Harbour Board stating that the Superintendent of Telegraphs is willing to arrange for the Auckland Harbour Board's time ball to be dropped by the Wellington standard signalling clock each weekly rating day provided that the ball has an electro-magnetic trigger. Mr. Logan was will-

> ing to lay on a special wire from the Auckland Telegraph Office to the ball tower. The Wellington clock would then be connected with the main line to Auckland and the ball, being properly set, could be made to drop exactly when the clock makes contact with its chronograph. That referred to the weekly signal, but if desired any other day, that could also be arranged. The balls at Port Chalmers and Lyttelton are similarly dropped at one p.m. (Advertisement, 1906).

Progress appeared to have been made with a decision by the Harbour Board to erect a new time ball:

> The fortnightly committee meeting of the Auckland Harbour Board was held yesterday afternoon. In reply to requests from Captain McNellar, of the SS Kaikoura, it was decided to state that a time ball would be erected on top of the proposed offices in the corner of Queen-street as soon as convenient. (*Auckland Star*, 1907).

Inclusion of an observatory was suggested after another year had elapsed:

> Time Ball. – In answer to a letter from J. Hamilton, of Wellington, re a time ball, it was decided on the motion of the Chairman to inform the writer that the Board contemplated erecting a building on the water front, which would be fitted with an observatory. (Harbour Board Committee, 1908).

A photograph of new breastwork shows that the ball was still in place on the Harbour Board building in 1909 (Improvements ..., 1909). It was probably removed at some time before 1913, when a time ball should have become operational on the new Ferry Building.

7.7 The Time Ball on the Ferry Building

There was still no time ball in 1911 (A time ball for Auckland, 1911). A time ball on the new Ferry Building should have been operational in the following year, but the excuse was that there had been a problem in connecting the time ball to the Post Office (The time ball, 1912). The unfortunate saga was exposed in the *Auckland Star*:

> The Harbour Board engineer reported to the Board this afternoon that although the time-ball had been ready for many months and connection with the post office had been promised in April last, nothing whatever had been done by the Department, and the gear was simply rusting from inaction. In connection with this matter a "Star" reporter, who made inquiries in official circles, was informed that the Department had never been made aware that the time-ball was ready for connection. The Department would fix it up at once when the Board was ready, but no intimation of any kind had been received, nor any suggestion of a conference made. When the connection is made it is understood that the exact mean time will he made available from Wellington at certain defined periods, possibly twice a week. (Time ball: a Department's inaction, 1913).

Figure 16 shows a photograph of the Ferry Building in April 1913, taken before the clock had been installed. A small diameter ball can be seen on the mast above the tower. A notice published two years later suggested that a new time ball service was at last imminent:

> The time ball on the Ferry Buildings will in future be dropped daily at l. p.m., while on the day of the week on which a time signal is flashed from Wellington a red flag will be displayed from the building. (*Auckland Star*, 1915a).

The plan was changed in August 1915 to the use of night-time signals (*Auckland Star*, 1915b), the time ball having proved to be unreliable yet again:

> Another attempt probably will be made by the Auckland Harbour Board to provide time signals for the harbour. At to-day's meeting of the Board a letter was received from the acting Government astronomer approving of the proposal for two time signals per week at 9 p.m. Usually signals of guaranteed accuracy were provided on three nights a week at Wellington, and he felt fairly safe in promising two for Auckland.
>
> The harbourmaster (Captain Sergeant) recommended that the signals should be given only on those nights when the observatory could guarantee them. The Government Astronomer should notify the Board by telegram at 2 p.m. on the days when he could guarantee the signals. When such telegram was received a red flag should be hoisted on the tower of the Ferry Buildings from 4 p.m. to 4.30 pm., notifying shipping that a guaranteed time signal would be given that night. At least two guaranteed signals per week should be given at 9 p.m. and the following lights shown from the flagstaff of the Ferry Buildings. – Green light switched on at 8.l0 p.m., red light at 8.50 p.m., white light at 8.55 p.m. All lights switched off at 9 p.m.
>
> The Harbourmaster further recommended, that the present time ball-signals should be discontinued at once owing to their irregularity, and the night signals commenced as soon as the mechanism had been installed. (Time signals: a new proposal, 1915).

The Auckland time lights were operating by the end of 1915.

7.8 Entries for Auckland in the *New Zealand Nautical Almanacs*

There was no mention of an Auckland time ball in the first (1903) edition of the *New Zealand Nautical Almanac*, but the statement “The time ball has been temporarily discontinued ... ” app-

Figure 16: The Auckland Ferry Building on 8 April 1913 showing the time ball on the mast (courtesy: Auckland Libraries, Sir George Grey Special Collections, 1-W1555).

eared in the editions for 1905 to 1910 (the 1904 and 1911 editions have not been seen by the author). In the 1912 edition, this was expanded to 1.1

> The time ball has been temporarily discontinued. When the Ferry Buildings, now in the course of erection, are completed the time-ball will be placed at the summit of the tower.

The statement in the 1914 edition was

> The time ball has been erected on the tower of the Ferry Building and will shortly be ready for use. It will be dropped at noon each day, except Sundays.

That was changed again in the 1915 edition to

> The time ball has been erected on the tower of the Ferry Building, and is now awaiting satisfactory connections with the Government Observatory at Wellington.

The 1916 edition confirmed the final demise of the Auckland time ball:

> The time ball has been discontinued and a system of night signals has been adopted. Not less than two guaranteed time signals per week will be given at 9 p.m.

8 OTHER NEW ZEALAND TIME SIGNALS

8.1 Time Balls

Time balls existed at various other places in New Zealand, but they appear to have been used mainly to provide time signals for local inhabitants, rather than a calibration service for chronometers on ocean-going vessels. Wright (2007) noted those at Wanganui and Timaru.

8.2 The Wanganui Time Ball

A Wanganui newspaper editorial on 16 October 1874 expressed the frustration that occurred when a local time ball was not maintained or operated properly:

> The irregular manner in which the time ball has been attended to of late has been the cause of great complaints being made by the public, especially the working men. On Wednesday it was not put up until 0.55 p.m., and dropped at 1 p.m. Yesterday (Thursday) it went up about noon and fell at 0.45, going up again a little before 1 p.m. and dropping at the full hour. If Wanganui has a time ball, we do not see why it should not be attended to properly, and if anything goes wrong, the cause should be ascertained and remedied. As at present

> attended to, it is quite useless, as it misleads some, while others take no notice whatever of it. (*Wanganui Herald*, 1874).

Most references to a time ball at Wanganui are in 1886 or later, when a time ball was located on a mast at the Harbour Board's signal station on Durie Hill. There appear to have been persistent difficulties in operating the station with limited staff and budgets (The signal station, 1899). It was reported that the ball had once blown down in a gale:

> A heavy nor'-westerly gale was experienced to-day, and a big sea was running, in the roadstead. The gale blew with great force on Durie Hill, and about 12.5 o'clock brought down the time ball from the flagstaff, a passer-by having a very narrow escape, as the ball fell with a crash within a couple of feet of him. (Local and General, 1914).

The Wanganui time ball was not mentioned in any edition of the *New Zealand Nautical Almanac* from the first in 1903, so it was not regarded as an official signal for mariners.

8.3 Time Guns

A time gun at Nelson fired for the first time on 11 September 1858 (Nelson town improvements, 1858), almost three years earlier than the time gun in Edinburgh (Kinns, 2011). It was fired at noon on Saturdays, but did not feature in the Admiralty lists as an official signal for mariners. There were occasional minor incidents concerning safety (*New Zealand Herald* , 1878).

Time guns were used at other locations, including Dunedin and Auckland, but were often controversial because of disturbance, concerns about safety and the cost of maintaining the service. A gun was installed on Mount Victoria in Wellington at the end of 1877, but ceased to operate in 1880 when the supply of cartridges was discontinued on grounds of cost (News and Notes, 1880). No time gun in New Zealand was included as an official signal in either Admiralty lists or *Nautical Almanacs*.

9 CONCLUDING REMARKS

Accurate time signals in New Zealand were important for navigation in the Pacific. The provision of time balls at Wellington, Lyttelton, Port Chalmers and Auckland has been described. Time balls at Wellington and Lyttelton were noted in the 1880 Admiralty list of time signals, with the addition of the Port Chalmers (Otago) time ball in the 1898 edition. Time balls were operated in Auckland for short periods during 1901–1902 and 1915, but failed to provide a reliable service and were soon abandoned. The later history of time balls has been traced through successive editions of the *New Zealand Nautical Almanac* from 1903 onwards.

9.1 Wellington

The time ball service at Wellington started in March 1864 using the first official observatory in New Zealand. The apparatus was supplied by Sandys & Co of London and used a rack and pinion system for hoisting. The ball diameter was 1.65 metres with an unusually large drop height of 5.5 metres. It was installed at the Customs House on the Wellington waterfront. Accurate determination of longitude at the time ball location was a particular challenge; the drop time was adjusted when improved estimates of longitude became available. Newspaper notices about the time ball petered out in 1875. It is likely that the time ball service was still operating in 1879, but it had ceased in 1882 at the start of long period of waterfront redevelopment. After prolonged discussion that included the possibility of a time ball on Mount Victoria, a second time ball service started in November 1888 at a different harbour-side location. The original time ball had been destroyed, but the mechanical apparatus had been saved. A new ball was manufactured, apparently using the design for Lyttelton, and had a diameter of 1.5 metres. The ball drop was over 5 metres. The system was destroyed by fire in March 1909 and was never replaced. Instead, a sequence of time lights was inaugurated in 1912.

9.2 Lyttelton

The service at Lyttelton, near Christchurch, began in December 1876 after construction of the signal station there. It used telegraph signals from Wellington to regulate the time ball. By the end of 1909, Lyttelton had the only official time ball in New Zealand, those at Wellington, Auckland and Port Chalmers having been discontinued. The Lyttelton time ball service continued until it was finally rendered obsolete in 1934 by the wide-spread availability of radio time signals.

The Lyttelton time ball apparatus was shipped by Siemens Brothers of London in 1874, but the mechanical apparatus replicated the original 1855 design for Sydney, New South Wales, which had been supplied by Maudslay, Sons & Field. It is known that Maudslays received an order for another apparatus in 1873 and that there was an association with Siemens. The ball had a drop of 3 metres and a diameter of 1.5 metres. The differences between the Sydney and Lyttelton systems in 2009 reflected the changes made in Sydney since original manufacture.

The Lyttelton time ball tower was an iconic landmark in New Zealand that had been carefully restored. Tragically, the tower collapsed during the 2011 earthquakes and aftershocks that devastated Christchurch.

9.3 Port Chalmers

A daily time ball service at Port Chalmers, near Dunedin, started in June 1867, initially using local observatory facilities. It appears to have been discontinued in 1877 and therefore was excluded from the 1880 Admiralty List. The intention to use telegraph signals from Wellington for future time ball operation was announced in March 1881, but the service was reduced to weekly in April 1882. It was suspended in 1907 and terminated by the end of 1909.

9.4 Auckland

Auckland never established a reliable time ball service, despite provision of a weekly service for mariners by a public-spirited citizen between August 1864 and June 1866. A time ball was finally installed on the Harbour Board building in 1901, but the signal had poor accuracy and the service was soon withdrawn. Complaints from ships' masters led to various attempts to re-establish a service. These concluded with erection of another time ball on the new Ferry Building in 1912, but the service only started in April 1915, proved to be unreliable and was soon discontinued. It had been replaced by time lights before the end of 1915.

10 ACKNOWLEDGEMENTS

The stimulus for a paper about New Zealand Time Balls came from Professor Wayne Orchiston at the National Astronomical Research Institute of Thailand.

The work was based initially on notices, articles and correspondence that appeared in New Zealand newspapers from the 1860s onwards. This material was accessed on-line using 'Papers Past', a free service provided by the National Library of New Zealand. This was complemented by research in Cambridge and I thank the Science and Technology Facilities Council and the Syndics of Cambridge University Library for permission to use material from the Royal Greenwich Observatory archives in this paper.

I am grateful to Ayla Koning-Thornton of Wellington City Council for her support in accessing archives of the Wellington Harbour Board, which helped to clarify the complicated history of Wellington time ball provision. I also thank Marleene Boyd and Daryll Pike at the Auckland Maritime Museum for their help in providing access to the extensive collection of *New Zealand Almanacs* in the Bill Laxon Library. Staff at the Macmillan Brown Library at the University of Canterbury helped me to access *Almanacs* held there. Jan Titus of Heritage New Zealand Pouhere Taonga in Christchurch has continued to provide encouragement for this research.

10.1 Dedication

This paper is dedicated to the memory of Alice McElroy (1917–2014), a family friend in Christchurch who inspired the first of many visits to New Zealand from my home in Scotland. The first visit in February 2000 included a demonstration of the Lyttelton time ball by Bruce Carr of the NZ Historic Places Trust, which led to my enduring interest in the history of time signals worldwide.

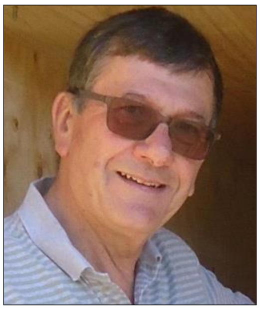
11 REFERENCES

A time ball for Auckland. *Auckland Star*, 7 July, page 2 (1911).
Advertisement. *Auckland Star*, 12 July, page 6 (1905).
Advertisement. *Auckland Star*, 21 February, page 10 (1906).
Astronomer Royal, 1910a. Letter to the NZ High Commissioner, dated 25 April. Royal Greenwich Observatory Archives: RGO 7-257.
Astronomer Royal, 1910b. Letter to the Admiral Superintendent, Portsmouth, dated 15 November. Royal Greenwich Observatory Archives: RGO 7-257.
Astronomer Royal, 1910c. Letter to the Admiral Superintendent, Portsmouth, dated 7 December. Royal Greenwich Observatory Archives: RGO 7-257.
Auckland Harbour Board. *New Zealand Herald*, 4 April, page 3 (1900).
Auckland Star, 4 May, page 2 (1883).
Auckland Star, 16 December, page 5 (1893).
Auckland Star, 4 September, page 2 (1901).
Auckland Star, 15 February, page 4 (1902a).
Auckland Star, 2 August, page 8 (1902b).
Auckland Star, 8 June, page 4 (1907).
Auckland Star, 21 April, page 4 (1915a).
Auckland Star, 5 August, page 4 (1915b).
Auld Reekie, 1901. Letter to the Editor of the *Auckland Star*, 5 July, page 8.
Bartky, I.R., and Dick, S.J., 1981. The first time balls. *Journal for the History of Astronomy*, 12, 155–164.
Bartlett's time ball. *New Zealand Herald*, 28 June, page 3 (1866).
Bremner, J., and Wood, F.L.W., 1979. *The Lyttelton Time-Ball Station. An Account of its History, Operation and Restoration.* Wellington, New Zealand Historic Places Trust.
Chudley, Captain, 1911. Correct times: timeball required locally. *Auckland Star*, 9 June.
Customs Entries. *Otago Daily Times*, 3 June, page 4. (1867).
Details for Timeball. Wellington City Archives, AC046:3511 (n.d.).
Dr Hector and the longitude of Wellington Observatory. *Otago Daily Times*, 16 December, page 1 (1875).
Drawing of Timeball Showing Apparatus for Raising It, &c., 1874. Wellington Harbour Board Plans, Wellington City Council WHB plan series reference number 1/75.
Editorial. *Auckland Star*, 6 October, page 2 (1874).
Engineer's memo re time ball, dated 11 June 1885. Wellington City Archives, AC020:1956.
Evening Post, 10 September, page 2 (1874).
Evening Post, 2 March, page 2 (1875).
Evening Star, 15 March, page 2 (1881).

Harbor [*sic*] Department, No.III report to the Provincial Council, dated 14 March 1864. *Otago Daily Times*, 9 April, page 4 (1864).
Harbour Board. *Auckland Star*, 4 March, page 2 (1885).
Harbour Board. *Auckland Star*, 22 August, page 6 (1900).
Harbour Board: Time Ball. *Auckland Star*, 27 November, page 3 (1901).
Harbour Board. *Auckland Star*, 14 June, page 6 (1905).
Harbour Board Committee. *Auckland Star*, 5 June, page 2 (1908).
Harbour Master, 1882. Letter to Wellington Harbour Board, dated October 18. Wellington City Archives, AC020:559.
Hargreaves, R.P., and Hearn, T.J., 1980. *Colonial New Zealand: Engravings of the Victorian Period*. Dunedin, John McIndoe Ltd.
Hector, J., 1886. Letter to Wellington Harbour Board, dated 9 September. Wellington City Archives, AC020:3098.
Hydraulic Accumulator House at Waterloo Quay Woolshed (Wool Store J), 1888. [Drawing]. Wellington City Archives, AC016:43.
Improvements to the Port of Auckland: the new breastwork facing the Harbour Board Building at the foot of Albert Street. Photograph by F.W. Birch for *Auckland Weekly News*, 19 August 1909, Sir George Grey Special Collections, Auckland Libraries, AWNS-19090819-16-1.
Kinns, R., 2009. Time-keeping in the Antipodes: a critical comparison of the Sydney and Lyttelton time balls. *Journal of Astronomical History and Heritage*, 12, 97–107.
Kinns, R., 2011. The early history of the Edinburgh time ball and time gun. *International Journal for the History of Engineering & Technology,* 81, 264–290.
Kinns, R., 2014. Did the Edinburgh time ball really weigh 15 cwt? *International Journal for the History of Engineering & Technology,* 84, 160–174.
Kinns, R., and Abell, L., 2009. The contribution of Maudslay, Sons & Field to the development of time balls in Australia. *International Journal for the History of Engineering & Technology,* 79, 59–90.
Lewis, T., 1910a. Notes dated 21–25 April. Royal Greenwich Observatory Archives: RGO 7-257.
Lewis, T., 1910b. Note to W.H.M. Christie, dated November. Royal Greenwich Observatory Archives: RGO 7-257.
List of Time Signals, Established in Various Parts of the World: Compiled for the Use of Seamen, as an Aid for Ascertaining the Errors and Rates of Chronometers, 1880. Printed for the Hydrographic Department, Admiralty (1st edition, 1880).
List of Time Signals, Established in Various Parts of the World: Compiled for the Use of Seamen, as an Aid for Ascertaining the Errors and Rates of Chronometers, 1898. Printed for the Hydrographic Department, Admiralty (5th edition, 1898).
Local and General News. *New Zealand Herald*, 14 October, page 4 (1903).
Local and General. *Wanganui Herald*, 6 October, page 4 (1914).
Longitude of Wellington. *Wellington Independent*, 1 April, page 3 (1874).
Luke & Sons, 1888. Memorandum to Wellington Harbour Board, dated 31 August. Wellington City Archives, AC020:4546.
Maclear, T., 1863a. Letter to G.B. Airy dated 16 June. Royal Greenwich Observatory Archives: RGO 6.615, File 7, Leaves 145-146.
Maclear, T., 1863b. Letter to G.B. Airy dated 18 June. Royal Greenwich Observatory Archives: RGO 6.615, File 7, Leaf 147.
Monthly Summary. *New Zealand Spectator and Cook's Strait Guardian*, 12 March, page 2 (1864).
Nelson town improvements. *Colonist*, 14 September, page 2 (1858).
New Time-Ball at the Royal Observatory, Cape of Good Hope. 1863 notice signed by Thomas Maclear. Royal Greenwich Observatory Archives: RGO 6.615, File 7, Leaf 148. Reproduced in Kinns (2014).
New Zealand Herald, 2 August, page 4 (1864).
New Zealand Herald, 8 May, page 4 (1865).
New Zealand Herald, 11 June, page 3 (1866a).
New Zealand Herald, 22 June, page 1 (1866b).
New Zealand Herald, 17 August, page 4 (1878).
New Zealand Herald, 4 March, page 4 (1886).
New Zealand Herald, 1 August 1, page 11 (1914).
New Zealand Mean Time. Te Ara Encyclopedia on New Zealand, n.d. (www.teara.govt.nz/en/ timekeeping/ page-2).
New Zealand Nautical Almanac and Tide-Tables, and Information concerning the Principal Ports of New Zealand, published annually by the Government Printer, Wellington. Editions seen by the author are for 1903 (1st edition), 1905, 1906, 1907, 1908, 1909, 1910, 1912, 1914, 1915, 1916, 1917, 1918 and 1928 (26th edition).
News and Notes. *The Press*, April 19, page 3 (1880).
NZ High Commission, 1910a. Letter to the Astronomer Royal, dated 21 April. Greenwich Observatory Archives: RGO 7-257.
NZ High Commission, 1910b. Letter to the Astronomer Royal, dated 26 April. Royal Greenwich Observatory Archives: RGO 7-257.
Orchiston, W., 2016a. *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits*. Cham, Springer.
Orchiston, W., 2016b. James Hector, Arthur Stock and early astronomy in Wellington. *Journal of the Royal Society of New Zealand*, on-line (http://dx. Doi.org/10.1080/03036758.2016.1207681) (pp. 1–6).
Otago Daily Times, 12 July, page 8 (1919).
Port Chalmers Observatory. *Otago Daily Times*, 1 August, page 2 (1877).
Public Works in Auckland. *Auckland Star*, 13 October, page 2 (1874).
Rooney, D., 2009. John "Longitude" Harrison, *Links: The Bulletin of the Newcomen Society*, 211, 8–9.
Sandys & Co., 1863. Letter to G.B. Airy, dated 31 August. Royal Greenwich Observatory Archives: RGO 6.615, File 7, Leaves 151-152.
Sells, C., 1842–1883. Notebooks: (1) 1842, also 1847; (2) April 1842 to 1849; (3) January 1849 to June 1856 (*sic*); (4) June 1853 to December 1855; (5) January 1856 to March 1859; (6) March 1859 to November1861; (7) November 1861 to May 1865; (8) May 1865 to December 1867; (9) December 1867 to January 1871; (10) January 1871 to May 1875; (11) May 1875 to April 1878; (12) April 1878 to March 1883.
Shipping. *Otago Daily Times*, 30 March, page 4 (1867).
Shipping. *Otago Daily Times*, 31 October, page 2

(1877).
Shipping. *Otago Daily Times*, April, page 2 (1882).
Shipping News. *Dominion*, 16 July, page 7 (1909).
Stock, A., 1868. The time ball. *Wellington Independent*, 31 October, page 5
Stock, A., 1871. The time ball. *Wellington Independent*, 25 April, page 2.
Stock, A., 1873. The time ball: letter to the Editor. *Evening Post*, 26 November, page 2.
Tenders. *New Zealand Herald*, 27 April, page 3 (1901).
The electric time ball in the Strand. *The Times*, 12 August (1852).
The Nelson Examiner and New Zealand Chronicle, 11 January (1864).
The Signal Station. *Wanganui Herald*, 18 April, page 2 (1899).
The time ball. *New Zealand Spectator and Cook's Strait Guardian*, 10 February (1864).
The time ball. *Wellington Independent*, 12 December, page 3 (1873).
The time ball. *Auckland Star*, 10 September, page 7 (1912).
They Say. *Observer*, 19 April, page 7 (1902).
Thomson, J.T., and Jackson, H., 1871. *Report Relative to Measurement of Longitude Between Wellington and Otago by Means of Electric Telegraph*. Wellington. Government Printer.
Time ball. *Evening Star*, 28 January, page 4 (1881).
Time ball. *Auckland Star*, 7 September, page 8 (1901).
Time ball. Letter to the Editor *New Zealand Herald*, 19 September, page 7 (1904).
Time ball: a Department's inaction. *Auckland Star*, 29 July, page 2 (1913).
Time ball at Port Chalmers. *Otago Daily Times*, 27 September, page 6 (1906).
Time ball for Dunedin. *Otago Daily Times*, 26 June, page 5 (1865).
Time signals: a new proposal. *Auckland Star*, 17 August, page 4 (1915).
Wanganui Herald, 16 October, page 2 (1874).
Wellington Harbour Board, 1911. Letter to Marine Department – Copy of Letter from Shipowners urging that timeball should be re-established, dated 2 August [with enclosures dated 30 November 1910 and 21 July 1911]. Wellington City Archives, AC020:33271.
Wellington Harbour Board Contract No 43, signed 15 March 1888. Hydraulic Accumulator House at Waterloo Quay Woolshed [Wool Store J] – 1888. Wellington City Archives, AC016:43.
Wellington Harbour Board Report on Proposed New Time Ball, dated 30 November 1910. Wellington City Archives, AC020:32094.
Wellington Independent, 19 March, page 2 (1864).
Wellington. *Wanganui Herald*, 6 November, page 2 (1888).
Wright, G., 2007. A Compilation of World Time Signals Past and Present. NZ Historic Places Trust.

Roger Kinns is a Senior Visiting Research Fellow in the School of Mechanical and Manufacturing Engineering at the University of New South Wales in Sydney, Australia. He has worked as an independent consultant since 1999 with principal research interests in underwater noise due to marine propulsion systems. He read Mechanical Sciences as an undergraduate at Gonville and Caius College, Cambridge and then took an MASc degree in control engineering at the University of Waterloo, Ontario, before returning to Cambridge to complete a PhD in unsteady aerodynamics. Roger was the first Maudslay Research Fellow of Pembroke College, Cambridge before moving to Scotland and joining YARD Ltd in Glasgow to develop and apply techniques for the acoustic design of ships and submarines. Roger has lived in Clynder, near Helensburgh, Scotland since 1975. The Maudslay connection led to an enduring fascination with the history of engineering and particularly time signals.



Journal of Astronomical History and Heritage, 20(1), 95–111 (2017).

THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 7: PHILIP HAMILTON, RAYMOND HAYNES AND THE UNIVERSITY OF TASMANIA'S PENNA FIELD STATION NEAR HOBART

Martin George, Wayne Orchiston
National Astronomical Research Institute of Thailand, 191 Huay Kaew Road, Suthep District, Muang, Chiang Mai 50200, Thailand, and University of Southern Queensland, Toowoomba, Queensland, Australia.
Emails: martingeorge3@hotmail.com; wayne.orchiston@narit.or.th

and

Richard Wielebinski
Max-Planck-Institut für Radioastronomie, Bonn, Germany, and University of Southern Queensland, Toowoomba, Queensland, Australia.
Email: rwielebinski@mpifr-bonn.mpg.de

Abstract: Following initial experiments near Hobart by Graeme Ellis, Grote Reber and Gordon Newstead from 1955 to 1957, the University of Tasmania established several sites for the study of low frequency radio astronomy, beginning in 1961. This paper describes the antenna array that was constructed at Penna, to the east northeast of Hobart. Between 1962 and 1967 it was used to produce maps of the southern sky at the frequencies of 4.7 and 10.02 MHz and contributed to an overall study of the low frequency emission from the Galaxy. Because of the proximity of the array to the town of Sorell, it was also referred to the 'Sorell Radio Telescope'.

Keywords: Low frequency radio astronomy, Tasmania, Penna, G. Ellis, R. Green, P. Hamilton, R. Haynes

1 INTRODUCTION

By 1960, researchers in the field of low frequency radio astronomy had enjoyed several successes, making it clear that there was great potential for exploring frequencies below 20 MHz. Significant early work was performed in Australia; beginning in 1946, the CSIR (later CSIRO) Division of Radiophysics maintained many field stations, mostly in the Sydney area (see Orchiston and Slee, 2005; Robertson, 1992). Two of these, Hornsby Valley and Fleurs, specialised in low frequency work (see Orchiston et al., 2015a, 2015b).

Because of absorption of radio waves by the Earth's ionosphere, radio astronomy at low frequencies becomes steadily more difficult as the desired frequencies drop below 10 MHz, with the lowest possible frequency being of the order of 1–2 MHz. The ability to detect such frequencies is strongly dependent on the value of the ionospheric critical frequency foF2, which needs to be below the frequency of observation and is dependent on the observer's location. In general, the lowest values of foF2 occur at locations that are sufficiently distant from both the geographic equator and the magnetic poles—and at sunspot minimum during winter nights. Studies of ionospheric conditions in various parts of the world (e.g. see Reber, 1982) showed that two key locations are north eastern North America (in the vicinity of the Great Lakes), and Tasmania (see Figure 1 for foF2 values obtained in Tasmania in 1962).

The year 1954 saw the arrival of Grote Reber in Tasmania, and his work with Graeme Ellis in the following year near Cambridge (see George et al., 2015b) resulted in the first detection of celestial radiation below 2 MHz.

After being absent from Tasmania between December 1956 and October 1960, Ellis returned to Tasmania to take up the appointment of the University of Tasmania's Chair of Physics, and this marked the beginning of the halcyon years of low frequency Tasmanian radio astronomy. His interest in this field inspired several B.Sc. Honours and Ph.D. projects in the 1960s. At this time, the three major observing sites of interest were Richmond (see George et al., 2016), Llanherne (at Hobart Airport, which will

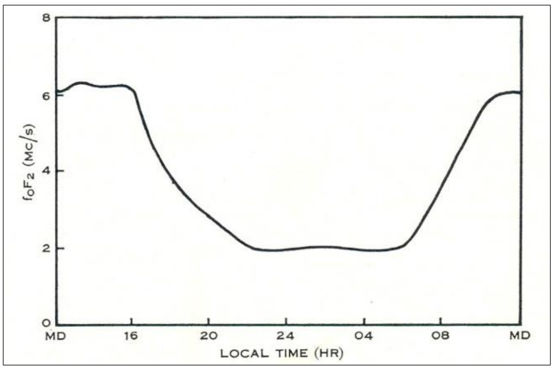


Figure 1: Ionospheric critical frequencies (foF2) for Hobart, measured (most likely at Mount Nelson) in June 1962. At midday, foF2 was ~6 MHz but during the night it dropped to ~2 MHz, easily allowing observations at 4.7 MHz (after Ellis et al., 1963: 548).

be the subject of a future paper in this series) and Penna, the subject of this paper.[1] The University's Penna field station was just north of the township of Midway Point, to the east-north-east of Hobart, between Hobart Airport and the town of Sorell (for Tasmanian localities mentioned in this paper see Figure 2).

2 BIOGRAPHICAL NOTES

2.1 Philip Hamilton

Professor Philip (Pip) Hamilton (Figure 3)[2] completed his B.Sc. at the University of Tasmania in 1961 and commenced a PhD in low frequency radio astronomy there in 1963. Following the establishment of a low frequency array at Penna in 1961–1962 and initial work carried out there by B.Sc. Honours student Robert Green, Hamilton used the array for surveys of the sky at 4.7 MHz and 10.02 MHz right up until it was destroyed by a disastrous bushfire in 1967.

In 1965 Hamilton joined the staff of the Physics Department as a lecturer while still part of the way through his PhD studies, and did not submit his Ph.D. thesis until 1969. He played a role in the design of a major low frequency array at Llanherne (Hobart Airport), and worked with Peter McCulloch to establish a high frequency array, also at Llanherne, which was used mainly for pulsar work.

Hamilton took over as Chair of the Physics Department in the early 1980s and went on to become Pro-Vice Chancellor for Research. He oversaw the transfer to Tasmania of the 26-m antenna from the Orroral Valley Tracking Station near Canberra, and in 1986 this telescope began operation at Mount Pleasant near Hobart.

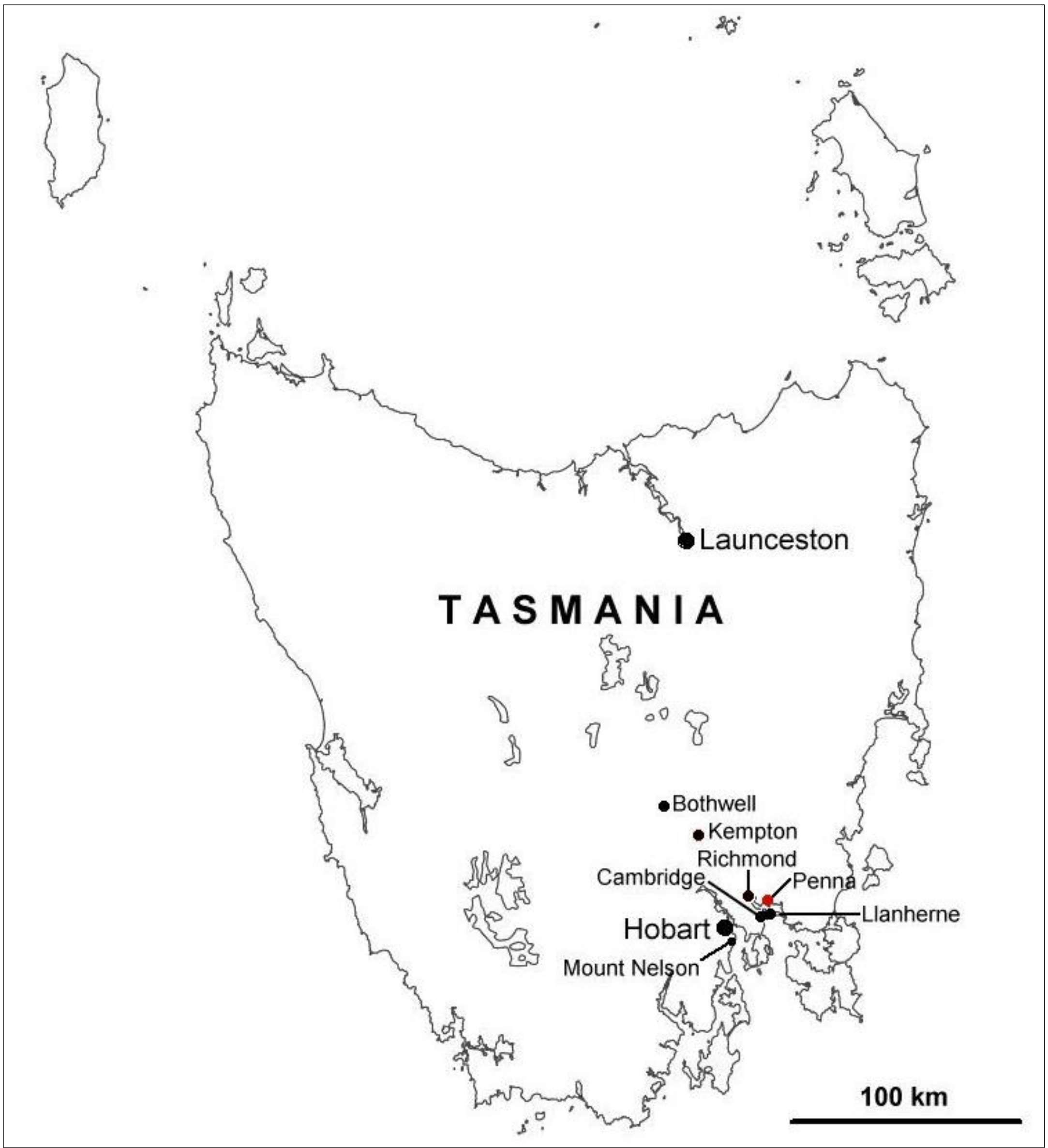


Figure 2: Key radio astronomy sites in Tasmania. This paper discusses the University of Tasmania arrays at Penna, to the east-north-east of Hobart (map: Martin George and Wayne Orchiston).

Hamilton left the University of Tasmania in 1997 to become Pro-Vice Chancellor for Research at Deakin University in Victoria, and later Deputy Vice Chancellor for Research.

In 2006, for his services to science and research, he was awarded an AM in the Queen's Birthday Honours, and in 2007 he received a D.Sc. from Deakin University in recognition of his outstanding scientific achievements, his contribution to the Australian higher education sector and his outstanding contribution to research (Deakin University, 2007). He is now retired.

2.2 Raymond Haynes

Dr Raymond Haynes (Figure 4) completed a B.Sc. at the University of Tasmania in 1964. During his Honours year in 1965 he was supervised by Grote Reber, who was then using an array near Bothwell in southern central Tasmania to make observations at 2.1 MHz.

Haynes began his Ph.D. degree in early 1966, with Graeme Ellis as his supervisor. He used the Penna array during his Ph.D. candidature, working together with Philip Hamilton, and they produced a radio map of the sky at 10.02 MHz.

Following this, Haynes was awarded a Postdoctoral Fellowship by the CSIRO and went to the University of Cambridge. In 1972 he became a CSIRO scientist and performed extensive research work over three decades. His topics included Milky Way molecules, supernova remnants and Galactic magnetic fields.

Haynes was chief author of the authoritative book *Explorers of the Southern Sky: The History of Australian Astronomy*. Although now officially retired, he likes to comment on scientific topics and present lectures on astronomy, and he has a variety of other interests.

3 INSTRUMENTATION

3.1 Location and Planning of the Site

After his 1960 return to Tasmania, Graeme Ellis lost little time in seeking out potential sites for the establishment of low frequency radio astronomy arrays in the Hobart area. One site was selected just north of Richmond (George et al., 2016), where three small non-phased arrays were set up on land owned by a personal friend. However, the desire to establish a more significant array for mapping of the sky led to Ellis seeking out a second large, flat area of land. Having noticed a suitable location at Penna, Ellis approached the landowners of three properties—William and James Reynolds, Rupert Jones and Gerald Barwick—and obtained permission to use the land for the construction of an array, with the agreement that sheep be allowed to continue grazing on the land (see Figure 5). The University paid rent for the Barwick property (K. Barwick, pers. comm., 2016) but not for the Reynolds property (D. Reynolds, pers. comm., 2016); it is not known if there was any financial arrangement made with regard to the Jones property (ibid.).

Figure 3. Philip Hamilton in 2007 (photograph: M. George).

Figure 4: Raymond Haynes in 2017 (courtesy: Raymond Haynes).

Figure 5: The site of the Penna Array outlined in red on a recent aerial image. The rectangle measures 4000 feet × 1000 feet and corresponds to the rectangular area of poles shown in Figure 13. North is towards the top (Map Data Google, DigitalGlobe, 2016).

Graeme Ellis' daughter Elizabeth Ellis (pers. comm., 2008) recalls:

> I remember clearly going out on drives to the property at Penna, pacing it out [i.e. to measure the property]. This was done at weekends and he (Graeme Ellis) would take us along for the drive.

The area of land that was chosen for the array was centred on longitude 147° 31′ 37.8″ E, latitude 42° 46′ 15.5″ S,[3] the position of the hut (see Section 3.3) near the centre of the array having been measured accurately using a February 1966 aerial photograph.

3.2 Site Testing and Early Results

In a radio astronomy equivalent of site testing,[4] which doubtless included an assessment of interference from terrestrial transmissions, Graeme Ellis set up two sets of dipoles near the extreme eastern and western ends of what was to become the Penna Array. Michael Waterworth and Gordon Gowland did the initial surveys:

> Mike Waterworth and I surveyed the scene, with a strange instrument called a theodolite. It was an ancient theodolite—it was a big brass one, an antique. (G. Gowland, pers. comm., 2008.)

Peter McCulloch, who was an undergraduate student at the time, recalls that

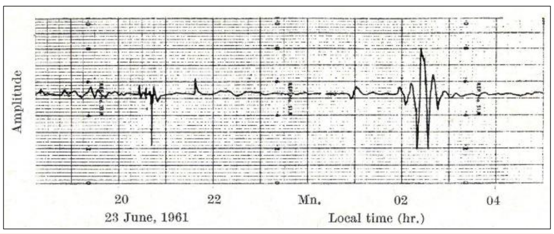


Figure 6. Record of the interferometer observation of Jupiter at 4.8 MHz on 23 June 1961.[6] Jupiter's transit time at Penna was 02h 41m local time (after Ellis, 1962b: 667).

> In 1961 when I was doing third year [i.e. third year of the B.Sc. degree], Ellis built an interferometer at Penna. There were maybe 8 dipoles at each end … [with the two ends being] about 1 km apart. He detected some background emission, and detected Jupiter. At that stage it wasn't an array; it was a test to 'see' things at 4.7 MHz. (P. McCulloch, pers. comm., 2008.)

This initial set up at Penna formed a phase-switching interferometer,[5] with the two sets of dipoles 4,000 ft (~1,219 m) apart. It had a primary beamwidth of 45° (N-S) and 12° (E-W) with the centre of the antenna pattern directed to declination −43°, i.e. to the zenith (Ellis, 1962a, 1962b; University of Tasmania, 1962).

Although there is no record of students being used as part of this very early work at Penna, Kevin Parker and Gordon Gowland—who both commenced work in the Physics Department in 1961—assisted in this initial setup. In particular, Kevin Parker (pers. comm., 2009) recalls that he and Gordon Gowland were involved in the surveying.

Clearly the detection of radio emission from Jupiter (see Figure 6) was unexpected,[7] and was later described as accidental (University of Tasmania, 1963). Even so, Jovian bursts were detected on 29 out of 40 observing nights (Ellis, 1962b), and Ellis assumed that the radiation probably would have been observed on most nights were it not for terrestrial interference.

Two well-known radio galaxies, Centaurus A and Fornax A, also were detected. Ellis (1962a) presented an interferometer record showing Centaurus A and other objects at 4.8 MHz, with a clear maximum amplitude at 20h 29m local time, with an uncertainty of at most a few minutes (see Figure 7). This corresponds precisely to the transit time of Centaurus A, which occurred at 20h 28m local time on that date.

The observations of Fornax A were compared with those of Centaurus A, with the former radio galaxy showing a notably less steep cut off at 4.8 MHz. Ellis (ibid.) interpreted this as indicating a low electron density in the intergalactic medium.

3.3 Construction and Layout of the Main 4.7 MHz array

Construction of the Penna Array began in 1961. It involved physics staff Gordon Gowland, Kevin Parker and Tony Harris. Several Honours students also were involved, with one of the earliest being Michael Waterworth, who recalled working at the site in 1961 as the poles were being inserted into the ground (M. Waterworth, pers. comm., 2011).

The exact period over which the main set of poles were placed into the ground is not specifically recorded, but it would have most likely been over the spring and/or summer of 1961–1962.

Working at Penna was a very early activity in the Physics Department for Kevin Parker:

> The Hydro were in the process of putting the poles in ... they were standard power poles.[8] My first role was to start with Gordon [Gowland], and Tony Harris later on, climbing the poles and erecting the aerials. We made the aerials up, and they were using aluminium conductors, which was a bit radical at that time. They were seven-strand and with a bit of a pulley system to tighten them up. (K. Parker, pers. comm., 2009).

More Honours students assisted in the establishment of the array during early 1962. Peter McCulloch, an honours student at the time, recalled:

> Lectures would go from nine o'clock until morning tea time, and the three Honours students, [together with] Kevin [Parker] and Gordon [Gowland] would work together to string up all the lines. The poles were already put in. (P. McCulloch, pers. comm., 2008.)

These 'Hydro' poles to which the dipoles were attached stood 30 ft (9.1 m) above the ground (Green, 1963; K. Bolton, pers. comm., 2007). One of the problems that had to be faced was access to the tops of the poles. Initially, a 30-ft oregon ladder was used (K. Parker, pers. comm., 2009) but it proved to be a difficult task to access the poles this way, especially in the wind (G. Gowland, pers. comm., 2008). Later, the University had the use of an ex-army 'Blitz' truck.[9] This was fitted with a tower (Figure 8), and equipped with a short ladder to enable people to work at a height of 30 feet. While not a perfect solution, it was a great improvement. Indeed, In McCulloch's opinion (pers. comm., 2009), "… the array wouldn't have been built without it." However, Gerald Barwick, on whose property a small part of the array was located, forbade the use of the truck on his land, so only the 30-foot ladder was used there.

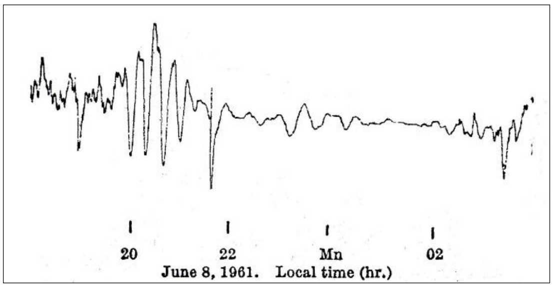


Figure 7: An interferometer record from the night of 8–9 June 1961 at 4.8 MHz that included Centaurus A; this source transited at 20h 28m local time (after Ellis, 1962a: 258).

The Blitz truck was used for several radio astronomy purposes in the 1960s, and is well remembered by everyone involved in the various projects. However, it was in far from perfect condition:

> The Blitz truck was used at Penna. It had been in the possession of the Uni for a long time, possibly by the Cosmic Ray people. One day it got stuck in two gears at once. The mechanic was called from the Uni—Col Matthews—and he got it back to Uni by changing gears with a screwdriver. The gearbox was next to the driver. (P. Hamilton, pers. comm. 2007).

Figure 8: The ex-army 'Blitz' truck used by the University of Tasmania for various purposes in the 1960s (after Green, 1963).

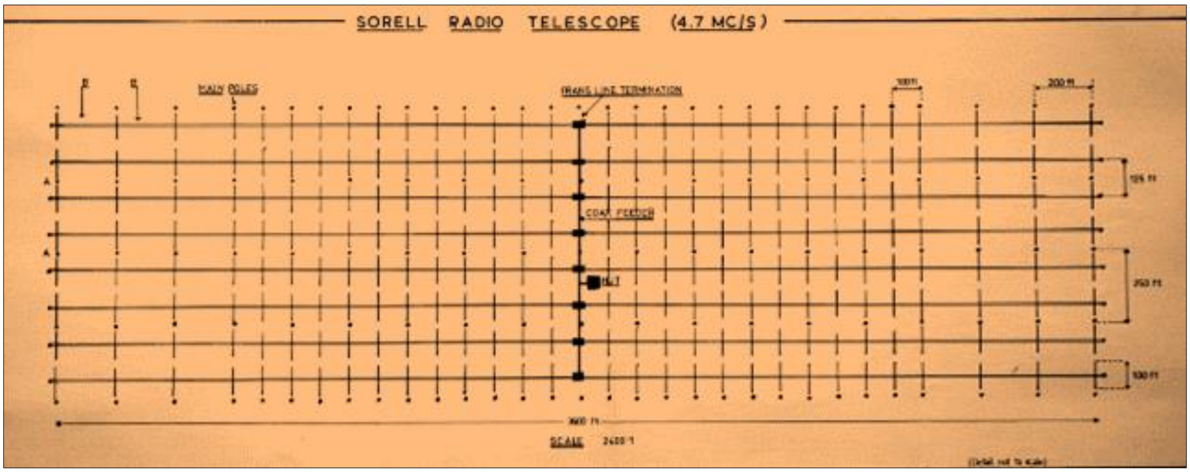


Figure 9: The overall layout of the 4.7 MHz array at Penna (after Green, 1963).

Gordon Gowland (pers. comm., 2008) recalls that the vehicle was used to drive between Penna and Richmond, and

> One very frosty morning, the vehicle was stripped down so that there was a 'naked engine' between the driver and the passenger. It backfired through the carburettor and blew the air filter off. It went up in the air, and Kevin [Parker] quickly pushed it back down onto the carb and we continued our journey.

Another problem encountered in setting up the array was the presence of a creek known as Frogmore Creek at its western end (see Section 4.3).

Green (1963) commented that the completed array consisted of eight E-W rows of dipoles, with 32 dipoles in each row. However, Green's diagram of the layout (Figure 9) shows only 31 north-south lines of dipoles, or 30 if there were no dipoles along the central north-south axis (this is not clear from the diagram). Also, Green's diagram shows the E-W dimension of the array as 3,600 ft, but dimensions are generally quoted as 4,000 × 1,000 ft (e.g. see Green, 1963). This apparent discrepancy is explained in a later diagram (Figure 10), which shows a 200-ft extension at each end in four of the rows (Ellis, Green and Hamilton, 1963). That it was mentioned that there were 32 E-W rows of dipoles may therefore be explained if allowance is made for two extra dipoles in the four middle rows but no central dipoles.

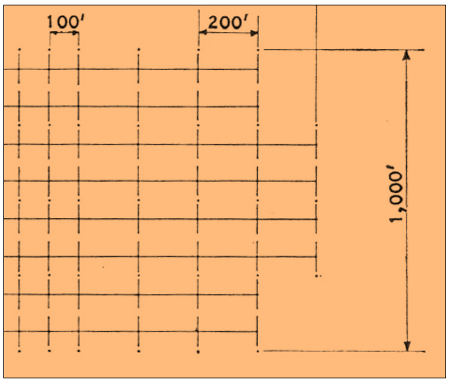


Figure 10: Detail of the layout at the eastern end of the 4.7 MHz array at Penna (after Ellis, Green and Hamilton, 1963).

Another discrepancy is apparent in that it was later reported that there were 272 half-wave dipoles (Ellis and Hamilton, 1966a; Hamilton, 1969). Even with the extensions to four rows, containing eight dipoles, it seems that number should have been 264 (8 × 32 + 8).

Most of the dipoles were separated by 100 feet (half a wavelength) in an E-W direction but three (or four, in the middle rows—see Figure 9) were separated by twice this amount, in order to reduce the effect of lobes at 90° to the main lobe (Green, 1963). Fewer poles also facilitated construction at the western end of the array, where the aforementioned problems were encountered with Frogmore Creek.

Interestingly, Gowland (pers. comm., 2008) recalled that initially, the array had an area of only 1,000 × 1,000 ft, suggesting that this was at the first stage of construction. Green (1963) commented that at first, only half of the aerials were connected. There may therefore be a connection between these two comments and the possibility of no dipoles down the central axis, effectively 'splitting' the dipoles into eastern and western halves. However, no other evidence has been found to support a two-phase construction process, and indeed, each half would have been 2,000 × 1,000 ft, twice the size recalled by Gowland.[10]

The separation in the centre of each dipole, effected by a spacer, was 4 inches (10 cm) in length. An open-wire transmission line connected each dipole to the main E-W transmission line, which ran underneath the centres of all the dipoles. This open-wire line was aluminium wire and acted as a transformer from the 70-ohm aerial impedance to the 500-ohm characteristic im-

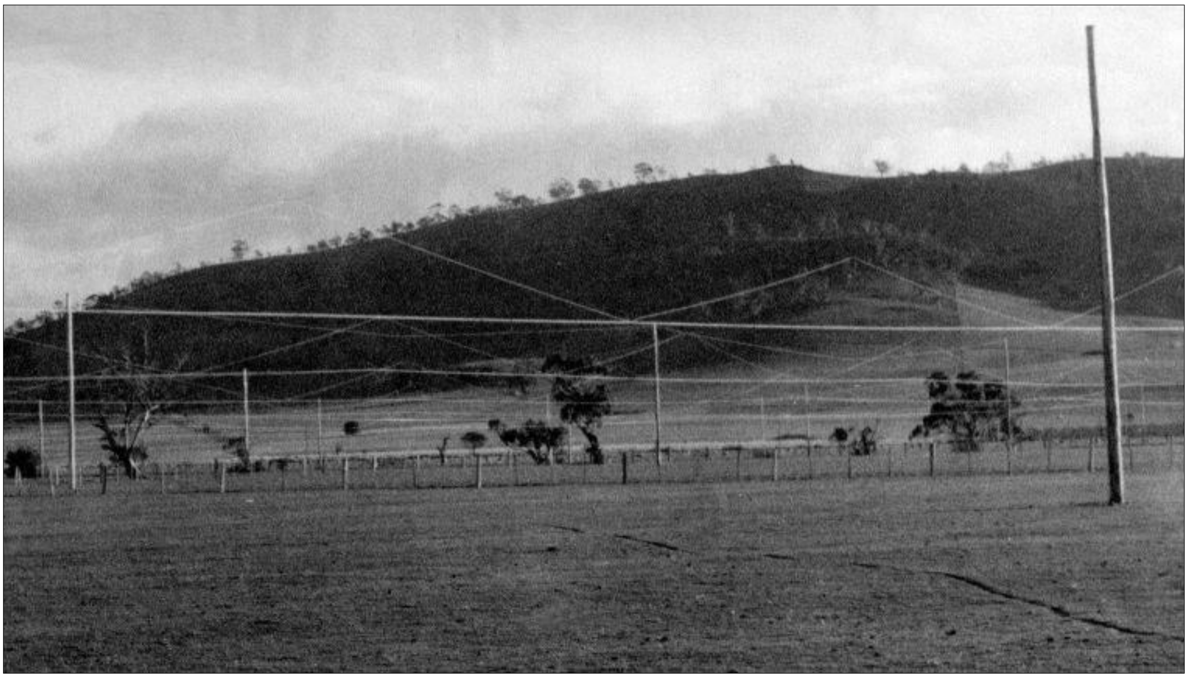


Figure 11: Part of the Penna Array (after Green, 1963).

pedance of the main transmission line (Figures 11 and 12) (Green, 1963). Figure 13 shows the 'footprint' of the array on a 1966 aerial photograph, while Figure 14 gives a view of most of the array.

Near the centre of the array was a hut, which contained the receiving equipment (see Figure 15). Kevin Parker (pers. comm., 2008) recalled:

> The hut was almost exactly in the middle of the array. It was a weatherboard structure that was built in the carpenters' workshop [at the University]. They transported it out there and set it up on concrete blocks. I'd say at a guess it was about 12 foot by 10 foot. It wasn't very big.

The Hydro-Electric Commission connected a 240 volt power supply, with a main switch in a box that included a meter. The box was in a paddock that contained a bull, which was sometimes a hazard! However, once the array was in

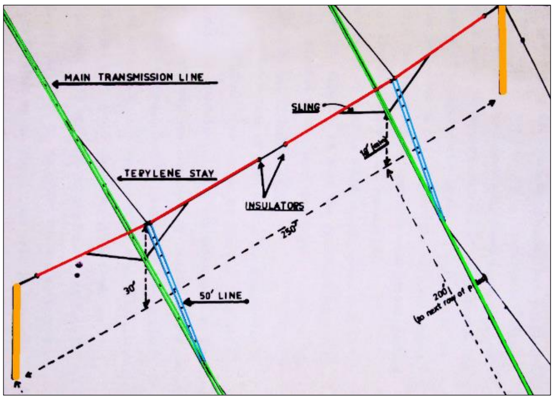


Figure 12: A diagram showing the relationship between the dipoles (red) and main transmission lines (green) (adapted from Green, 1963).

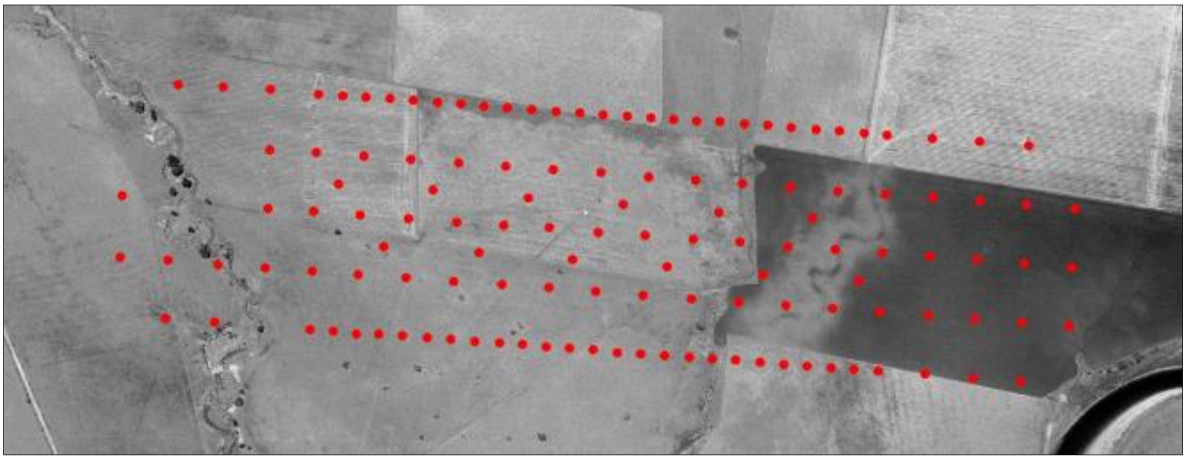


Figure 13: Locations of identifiable poles (red dots) shown on an aerial photograph taken in February 1966, based on the poles' shadows. The structure of the array can easily be seen (base data from the LIST (www.thelist.tas.gov.au), © State of Tasmania).

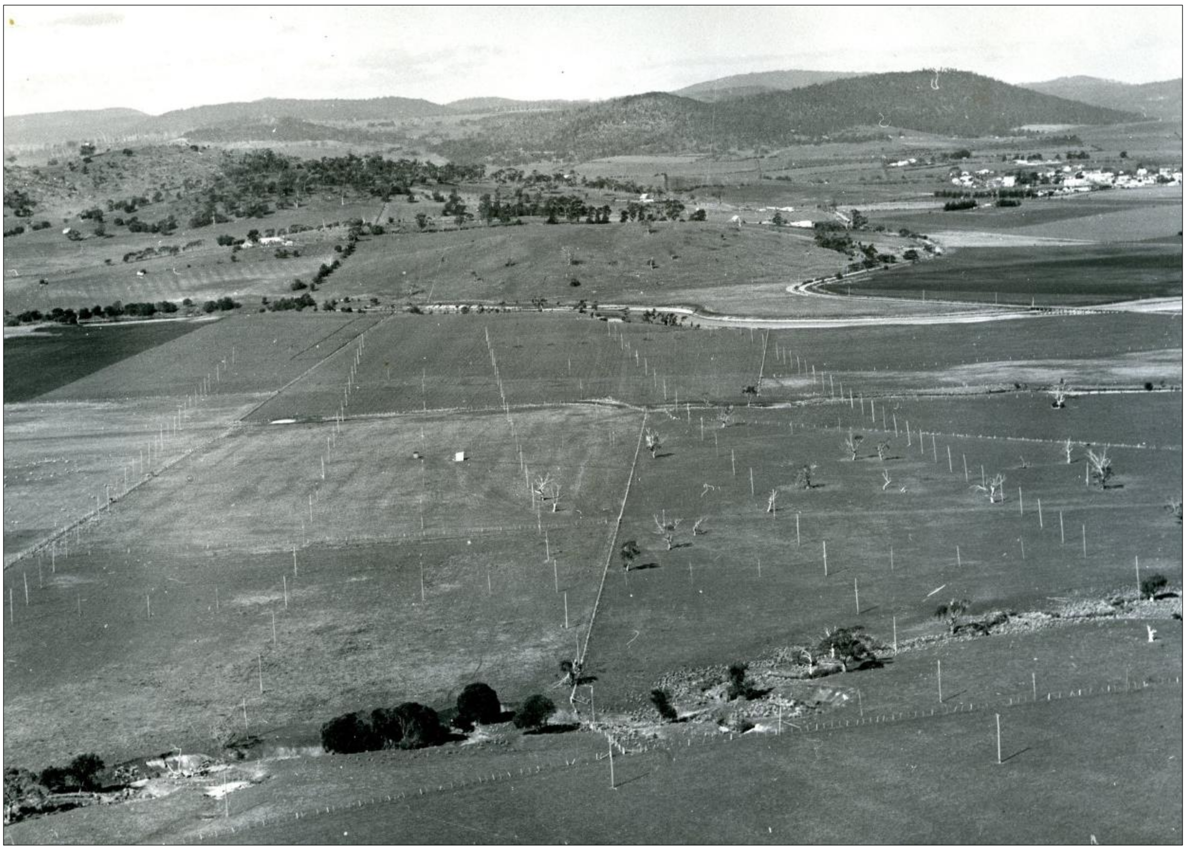


Figure 14: An undated aerial photograph of the Penna Array (courtesy: University of Tasmania).

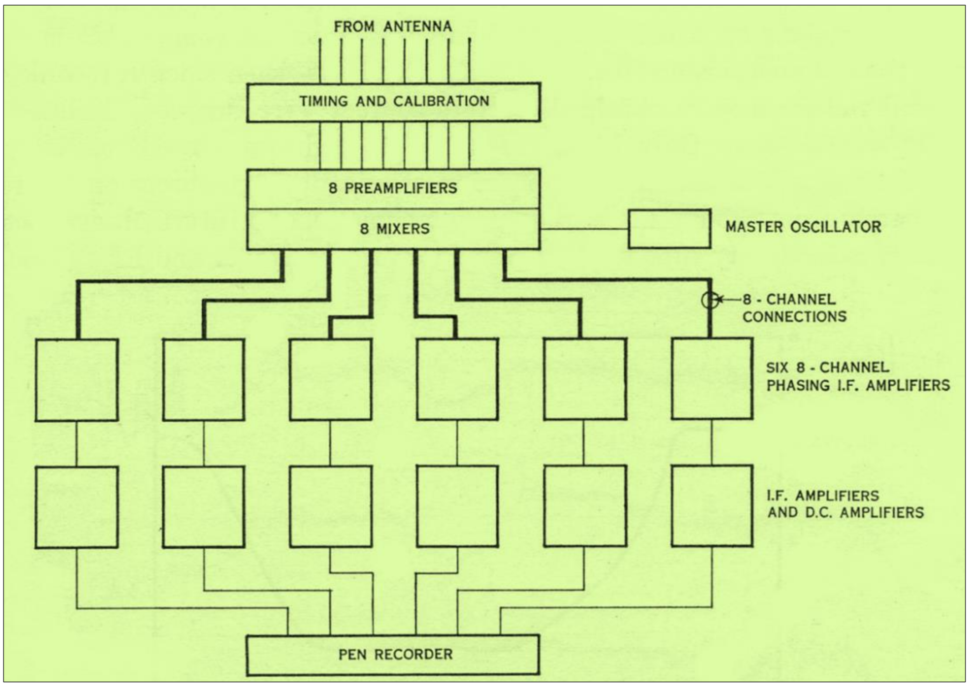


Figure 15: Block diagram of the receiving equipment for the 4.7 MHz observations (Ellis et al., 1963: 547).

operation, there was no need to switch it off (G. Gowland, pers. comm., 2008). The power supply to the hut ran underground and the connection came from Penna Road (K. Parker, pers. comm., 2009).

Contained within the hut was the receiving equipment:

> It was all valve radio equipment. A lot of it was built out of ex-army equipment. There were truckloads of ex-army equipment we got from

> somewhere; Prof Ellis had organised it. A lot of it we cannibalised for things like transformers … I remember building a power supply to drive all the heaters on the values and that put out 60 amps, so there was a lot of heat in there (K. Parker, pers. comm., 2008).

Indeed, Keith Bolton, who first was employed by the Physics Department in 1965 and worked on the maintenance of the array, recalled how pleasant it was in winter to be inside the hut, because of this heat (K. Bolton, pers. comm., 2011).

The receiving arrangement allowed simultaneous observation of the sky at six different declinations, by introducing a phase difference in the amplifiers between successive rows, even though significant mismatching of impedances resulted in only a small amount of signal arriving at the receivers (Hamilton, 1969).

It was decided that this electronic method of introducing phase differences method was preferable to using mechanical delays (which are effected by inserting lengths of cable). However, Hamilton (1969) comments that delay cables were indeed used at least partly to effect the phasing, although this may have been only during the second series of observations (see Section 4.1).

The final output was recorded by a 6-channel chart recorder (see Figure 16). Keith Bolton (pers. comm., 2011) commented that all chart recorders used for radio astronomy work were

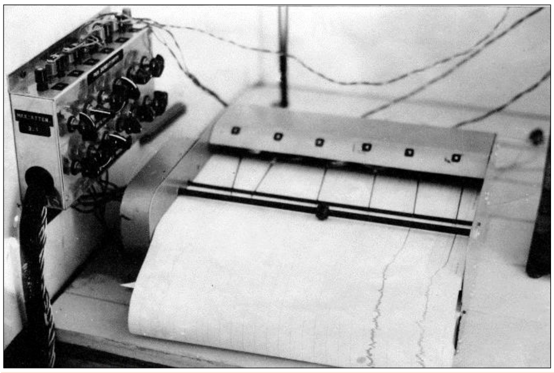


Figure 16: The chart recorder used at Penna, clearly showing the six pens (after Green, 1963).

built at the University.

Later, the array was converted for use at 10.02 MHz and was operated at this frequency in 1965 and 1966. For this purpose, an array of 15 rows each of 25 dipoles was used (Figure 17). The beamwidth was 4° × 5° and based on Hamilton's information and the figure, the array area used for these observations was 932 × 1,250 feet. Phasing was achieved through the use of delay lines (Hamilton 1969; Hamilton and Haynes 1968).

Relatively little information is recorded about the conversion of the array. However, Pip Hamilton (pers. comm., 2007) recalled:

> I did a more detailed survey at 4.7 MHz then restrung it to 10 MHz, then did another survey. The restringing wasn't easy; it took some time.

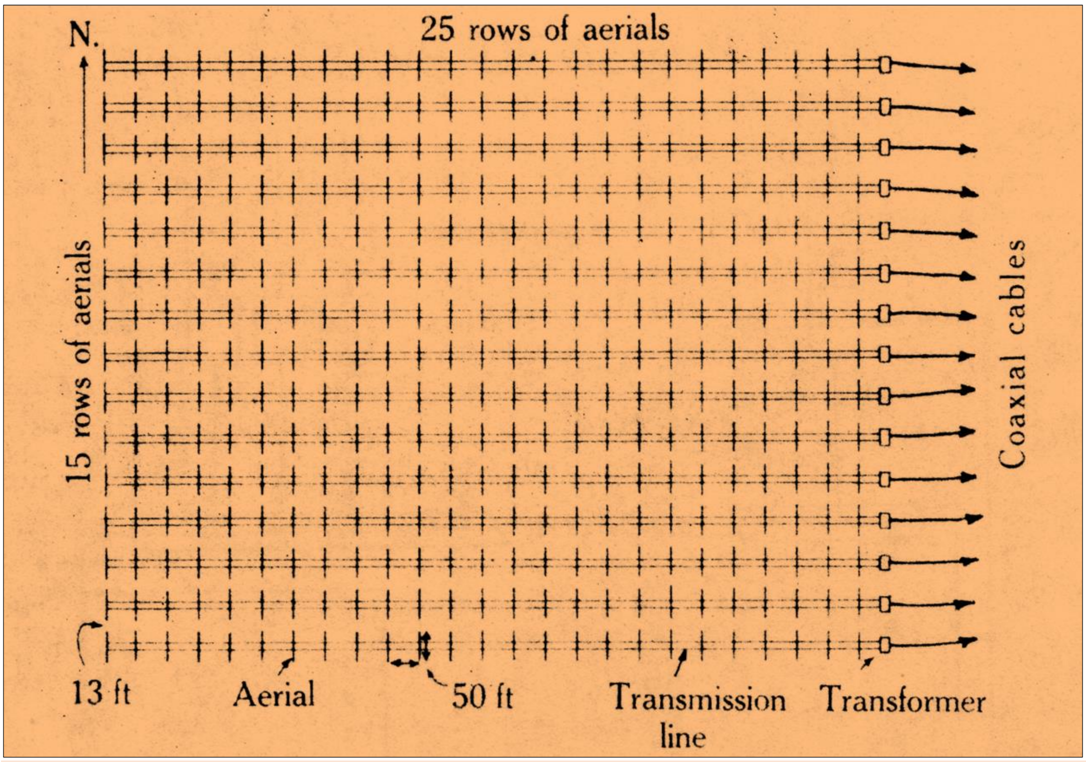


Figure 17: The antenna arrangement used for observations at 10.02 MHz in 1965 and 1966 (after Hamilton and Haynes, 1968: 896).

> Effectively, the whole thing was rebuilt. It was not too expensive. Bill Ellis had organised the staffing appropriately—Gordon Gowland and Kevin Parker were helpful.

4 THE MAIN OBSERVATIONS

Section 3.2 described observations made as a result of the original basic interferometer setup at Penna, where the Jupiter results, especially, were incidental to the site testing. However, the main work at this site was to map the radio sky at 4.7 MHz, and later, at 10.02 MHz. With the solar minimum approaching, it was a good time to be planning these observations: at times of minimum solar activity, the lower degree of ionisation of the ionosphere improves the transmission of the lower radio frequencies. The solar minimum occurred in mid-1964 (see Meeus, 1983).

During the period from March to mid May 1962, the array was used; this would have been largely for testing purposes. However, this took place with only half of the aerials connected. It was found that a 'systematic error' had been introduced in setting up the array (Green, 1963). Green (ibid.) also commented that

> … the array was designed to operate at 4.86 Mc/s but 4.7 Mc/s was finally used. This difference introduced a small phasing error, which was, however, corrected by July 2.

4.1 The 4.7 MHz Observations

The first reliable results from the Penna array, which were at 4.7 MHz, were obtained on 10 June 1962, although on that date the aerials were still being connected to the transmission lines. By 12 June the array was regarded as complete.

Observations at 4.7 MHz were made over two main periods: June 1962 to January 1963, and May to December 1963 (Ellis and Hamilton 1966a; Ellis, Green and Hamilton, 1963). Green (1963) records that the equipment was shut down in January 1963 to enable some modifications to be carried out, and although the specific work was not recorded, this was likely to have been in preparation for the second series of 4.7 MHz observations.

The array formed a transit instrument with 3° (E-W) × 11° (N-S) resolution at 4.7 MHz. The observing method was therefore to use the rotation of the Earth to record different right ascensions. The receiver frequency was swept over a range of 12 kHz each 0.2 second to find frequencies that were not affected by terrestrial transmissions. The pen recorder would chart the signal strength from six different declinations (Figure 18). In some cases, a camera was used to record the display of a cathode ray oscilloscope (Ellis and Hamilton, 1966a).

The most important paper detailing the overall results of the 4.7 MHz survey was that of Ellis and Hamilton (ibid). They comment that reproducible results were obtained on about 60% of nights, the main impediment being transmitting stations. The selected records were the ones least affected by the terrestrial transmissions, or, in the case of records in the region of the Galactic Centre, those that displayed the greatest contrast and were therefore least affected by scattered radiation. The resulting isophote plot of Galactic radiation is shown in Figure 19.

The significant results mentioned in that paper, making use of observations at other frequencies, were that

(1) The emission at the South Galactic Pole (declination –27°) reached a maximum at around 5 MHz, and dropped off rapidly at lower frequencies; this drop off was interpreted as absorption of radiation by ionised hydrogen.
(2) The Milky Way Galaxy had a "… general ionised atmosphere …" with a density of about 0.1 ions/cm^3.
(3) At 4.7 MHz, an absorption 'trough' was observed in the plane of the Galaxy, but the significant trough between about 16^h and 19^h right ascension—straddling the Galactic Centre, which is at 17^h 42^m (epoch 1950)—appeared to have a variable depth which was interpreted as at least partly due to scattered radiation from outside the trough direction; this was attributed to disturbed ionospheric conditions (Hamilton, 1969: 116). This is shown in Figure 20.
(4) Apart from the Jupiter emission mentioned earlier, several discrete sources were recorded. The strongest ones were Centaurus A, Fornax A and Pictor A, in descending order of flux density (Ellis, Green and Hamilton, 1963).

4.2 The 10.02 MHz Observations

The 10.02 MHz observations were made in 1965 and 1966, after the array was modified. Once again, the receiving setup was organised so as to produce simultaneous results at six different declinations, and a radio map was produced of the sky (see Figure 21).

As with the 4.7 MHz observations, there was hindrance from transmitting stations. The receiver's centre frequency was swept over a range of 10 kHz each 0.2 second, with an interesting minimum reading method being chosen. Because a transmitting station would appear as a periodic impulse, the receiving equipment 'learned' to ignore the signal. In this way, even a station appearing where none previously caused a problem would be ignored.

Figure 18: An original chart record from 6 July 1962. On this occasion traces are shown on just five of the six channels (courtesy: University of Tasmania).

At very low radio frequencies, maps of the sky show obvious absorption features along the Galactic Plane. It had already been understood that the absorption was caused by ionisation in the Galactic Plane (see Ellis and Hamilton, 1964; Hoyle and Ellis, 1963).

The researchers noticed a significant difference between the 4.7 MHz and 10.02 MHz surveys: at the higher frequency, the absorption was less obvious, resulting in lower contrast between the Galactic Plane and its surroundings. This was to be expected, as it was already clear (Hoyle and Ellis, 1963) that the intensity of the radiation reached a maximum around 5 MHz, with the decreasing intensity below that frequency needing an ionisation explanation: that is, absorption of radio frequencies because of ionisation became dominant at frequencies below about 5 MHz.

As in the 4.7 MHz survey, several discrete sources were observed. In particular, Centaurus A (NGC 5128) was obvious. Hercules A (the elliptical galaxy 3C 348, just north of the Celestial Equator) and Puppis A (a supernova remnant) also were noted.

A chart recorder was used to record the observations, just as it was with the 4.7 MHz work. Initially the intention was to record images on the cathode ray oscilloscope, but this technique was used only toward the end of the 10.02 MHz observations, and even then it merely supplemented the chart records (Ellis, Green and Hamilton, 1963).

Although two surveys had been carried out, there was still further research to be done (P. Hamilton, pers. comm. 2007). Hamilton and Haynes had a considerable amount of data for the

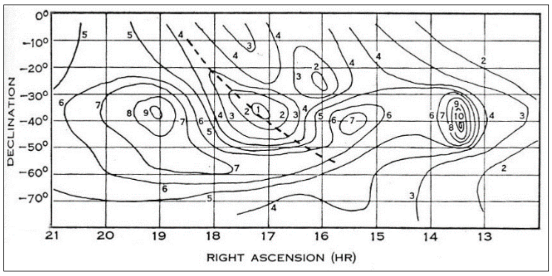


Figure 19: Part of the map of the southern sky at 4.7 MHz. The bright source between 13 and 14 hours right ascension is Centaurus A (adapted from Ellis et al., 1963: 549).

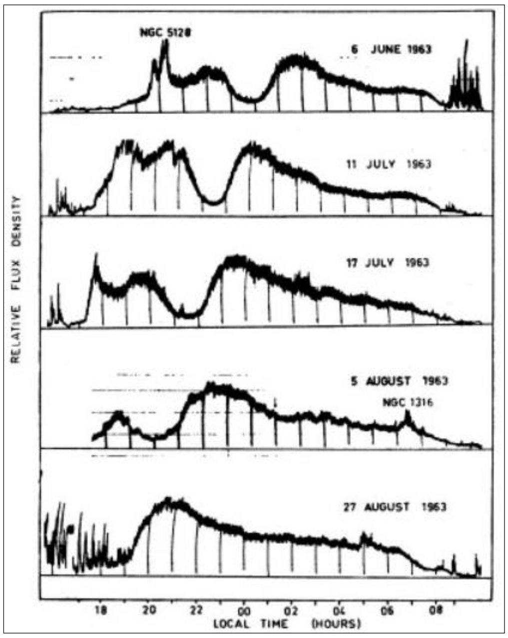


Figure 20: Observations on several different dates in 1963, showing the sidereal effect causing the 'trough' between about 16 and 19 hours right ascension to transit at progressively earlier local times (after Ellis and Hamilton, 1966a: 230).

higher frequency survey (10.02 MHz), but the pair agreed that another set of observations would be highly desirable, as there was still some uncertainty over whether every declination profile was correct. There was therefore a plan to observe over the winter of 1967 and combine these observations with the earlier ones (R. Haynes, pers. comm., 2017). However, because of the untimely destruction of the array in February 1967 (see Section 4.4), these observations were never made.

Hamilton and Haynes therefore needed to make do with what they had in order to produce the 10.02 MHz map. At around this time, the University began operating a new computer—an Elliott 503—and theirs was the first project for which the computer was used. Hamilton and Haynes wrote software in machine code and Algol, respectively, and spent hundreds of hours (often working at night) with paper tape and later with punched cards. Finally, by August 1968 they were able to submit the manuscript of their research paper (Hamilton and Haynes, 1968) to the *Australian Journal of Physics* (R. Haynes, pers. comm., 2017). Figure 21 shows their isophote plot of Galactic radiation at 10.02 MHz.

4.3 Difficulties

Construction of the array was hampered by the presence of Frogmore Creek near the array's western end. The lower altitude of the depression in the land carved out by the creek resulted in the poles being of insufficient height, and short lengths of 4-inch × 4-inch oregon timber were added to the tops of the 'Hydro' poles so that these poles were level with those in the rest of the array (G. Gowland, pers. comm., 2008).

The creek bed also posed a problem for the use of the Blitz truck, which sometimes got bogged (ibid.). On each occasion the radio astronomers were able to retrieve it, but this did slow down their observing programs.

Gordon Gowland (ibid.) also recalls that at one time there was a problem involving an illegal transmitter:

> There was some transmitter that sprung up somewhere and was being a bit of a pain, and we'd never had this before ... On that range of hills towards Cambridge, there was this station that was a monitoring station looking for illegal transmitters ... We must have enlisted their aid, because they tracked it down. I think it was some guy in Richmond who had a scanner, and … he was scanning the police radio, but he was coming up loud and clear on the array. I'm not sure what happened to him.

Several of the physics staff recall that maintenance often was necessary. Gordon Gowland (ibid.) and Raymond Haynes (pers. comm., 2017) especially remember problems with the chart recorder, with the ink "… going everywhere."

Damage caused by weather was also a problem:

> After a storm, you'd find 2 or 3 aerials down. There wasn't a *lot* of maintenance. Most of the problems were valve replacements—they'd wear out. (K. Parker, pers. comm., 2009).

4.4 Destruction of the Array

The Penna Array came to an end on 7 February 1967, at the peak of highly destructive fires which engulfed many parts of southern Tasmania, even encroaching into Hobart suburbs. It was responsible for the loss of 62 lives (Wetten-

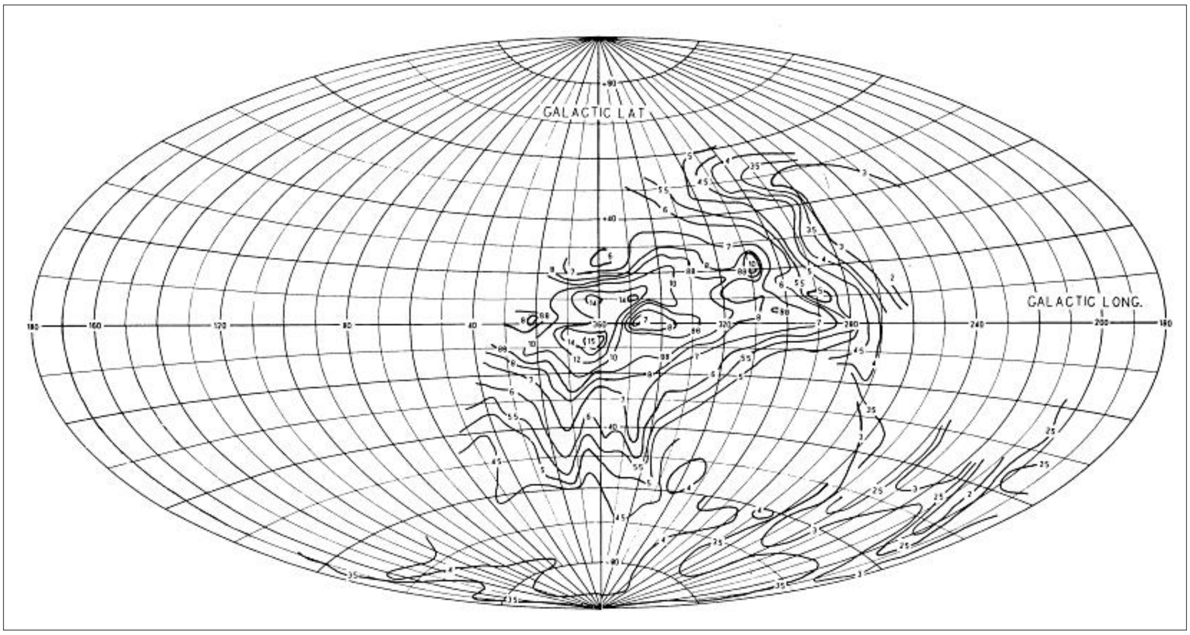


Figure 21: The 10.02 MHz map produced using the modified Penna array, plotted using galactic coordinates (after Hamilton and Haynes, 1968: 898).

Figure 22: The site of the Penna Array after the fire of February 1967. Two poles (one fallen) are seen to have burned bases (photograph by Des McLean, provided courtesy William and Dorothy Reynolds).

hall, 2006). Considerable damage was caused in the Penna area, and there was no attempt made to save the array (D. and W. Reynolds, pers. comm., 2015). Two photographs taken soon after the fire are shown in Figures 22 and 23.

Kevin Parker (pers. comm., 2009) recalled that most of the aluminium had simply disappeared, because it had melted. However, the hut was found to be still standing after the fire:

> The only part of the whole array that was insured was the hut and the equipment—but the grass was so trodden down around the hut that the hut survived (K. Bolton, pers. comm., 2011).

Although Hamilton and Haynes had wished to observe over one more winter (see Section 4.2), Keith Bolton (ibid.) recalled that there were no significant plans for further use and the fire "… saved us pulling it down." The implication is therefore very strong that the array would in any case have fallen into disuse after 1967.

After the fire, there was some urgent clearing work to do. Hamilton and Haynes went out to the array not long after the fire—Haynes is almost certain that it was the next day—to find that some poles had been completely burned and had fallen, with nothing left but a line of ash on the ground. Only a few poles were still standing, and many were still smoking from the fire (R. Haynes, pers. comm., 2017).

The Blitz truck was singed by the fire but still usable:

> We used it [the truck] the whole of that day. We brought some chains and hooks. We dragged the poles so we could move up and down the rows to grab all the wires together. We chopped the wires off. It took us about two days to clean the place up. We assume it was the farmer who cleared the poles. (ibid.).

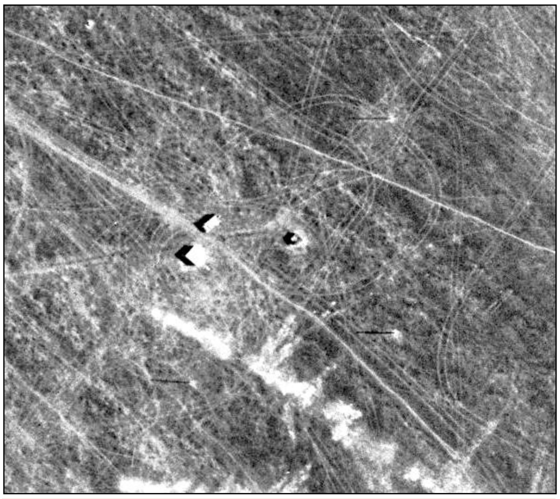


Figure 23: An aerial photograph of the Penna Array site taken in February 1967, shortly after its destruction by fire. The Blitz truck can be seen next to the hut, and clearly visible are its wheel tracks made during the cleaning up of the site (base data from the LIST (www.thelist.tas.gov.au), © State of Tasmania).

Indeed, Keith Barwick (pers. comm., 2016), whose father in late 1966 or early 1967 purchased the property owned by Rupert Jones, recalled that as a young man he assisted in removing some of the poles from that ground.

5 DISCUSSION

The establishment of the Penna Array was the brainchild of Graeme Ellis. The push for low frequency radio astronomy studies in the early 1960s by the University of Tasmania was undoubtedly largely inspired by the initial work done by Ellis and Grote Reber at Cambridge, near Hobart, in 1955 and the follow-up by Ellis and Gordon Newstead (see Ellis and Newstead, 1957; George et al., 2015b; Reber and Ellis, 1956).

It is interesting to contemplate what would have happened in the absence of the mid-to-late-1950s work being performed. Certainly, it would have been known that Tasmania was an excellent place for low frequency radio astronomy, and Ellis had a detailed understanding of the ionosphere (e.g. see Ellis, 1954). However, the search for suitable array sites began very soon after Ellis' 1960 return to Tasmania, indicating his eagerness to proceed quickly with the work and suggesting that he remained mindful of the successes of the earlier Tasmanian efforts.

Interestingly, the construction of the Penna Array coincided very closely with that of one built independently by Grote Reber near the Tasmanian town of Bothwell, which will be described in a future paper in this series. That array, however, was designed to work at 2.085 MHz.

In preparing this paper, attempts were made to locate the researcher who was the first person to officially use the array for research, Robert Green, the 1962 B.Sc. Honours student whose thesis (Green, 1963) was an important reference for this paper. Unfortunately, up to the time of writing, Green had not been located. There is little doubt that he could have provided even more insight into the operation of the array in the very early days.

An interesting question, of course, is the degree to which the fiery end of the array in February 1967 was a setback. Certainly, it was for Hamilton and Haynes, who has hoped to observe over another winter—a 'frustrating' situation (R. Haynes, ibid.). It also cannot be stated with any certainty that no other use would have been found—for example, 'restringing' the array to investigate other wavelengths.

6 CONCLUDING REMARKS

The Penna Array was a major instrument used by the University of Tasmania. Even though plans were in progress for the work to be concentrated at Hobart airport (Llanherne), there was still further work to be done at the time of its destruction in 1967.

During the period when the Penna Array was in use it became increasingly clear that the there was evidence of ionised hydrogen along the plane of our Galaxy (Ellis and Hamilton, 1964, 1966b; Hoyle and Ellis, 1963). The results showed that the ionisation became increasingly apparent at lower frequencies. The Penna Array provided valuable data points for this work, and more generally, contributed to other surveys of the sky that were conducted at low frequencies in the 1960s and 1970s.

Despite being quite sizeable, the existence of the Penna Array was little known by the public, primarily because it was not near a major road. It was the subsequent construction of an array adjacent to Holyman Drive near Hobart Airport that brought considerable public attention to the low frequency radio astronomy research carried out by staff from the University of Tasmania, and this array will be discussed in a future paper in this series.

7 NOTES

1. This is the seventh paper in a series that aims to document pre-1980 low frequency (<30 MHz) radio astronomy in Australia. The first two papers overviewed the research by staff from the CSIRO Division of Radiophysics near Sydney (Orchiston et al., 2015a) and the efforts in Tasmania by Grote Reber and staff from the Physics Department at the University of Tasmania (George et al., 2015a). Subsequent papers looked in depth at individual field stations in Tasmania (see George et al., 2015a, b, c, 2016) and at Hornsby Valley near Sydney (Orchiston et al., 2015b).
2. The following biographical sketch is based on personal communications from Pip Hamilton (2007) and Robert Delbourgo (2017), and Deakin University (2007).
3. This location is five kilometres north of the township of Midway Point. William Reynolds (pers. comm., 2015) commented that the house on the property currently known as Socoma, which was not present in the 1960s, is close to the location of the hut that stood near the centre of the array. Examination of a current aerial image shows that Socoma is approximately 55 metres west of the hut's location.
4. In optical astronomy, major considerations are the quality of the seeing conditions, the presence of artificial light and a study of cloud cover records. The major consideration in radio astronomy is testing for terrestrial radio interference.

5. The phase-switching interferometer was invented by Martin Ryle at Cambridge, and it correlated the signals from two antennas to remove uncorrelated noise.
6. On 23 June 1961 Jupiter's declination was –19°18′, so its maximum altitude as seen from Penna was 66°32′. The planet reached opposition on 25 July, at a declination of –20°15′.
7. The detection of Jovian bursts was described as "unexpected" because it was not anticipated. Although Burke and Franklin reported the detection of Jovian decametric burst emission in 1955, their observations and most other confirmatory observations were made in the 18–20 MHz range. In 1961, when Ellis was setting up the Penna field station, no-one would have anticipated detecting Jovian bursts at 4.8 MHz.
8. The Hydro-Electric Commission, commonly called simply 'The Hydro', was the name given in 1929 to the former Hydro-Electric Department. It was a Government Commission charged with the operation of the State of Tasmania's hydro-electric power stations and the construction of their dams. It is now called Hydro Tasmania. The 30-ft (9.14-m) height of the poles was not ideal for observations at 4.7 MHz for which the ideal height—one quarter of a wavelength—would have been 15.96 metres. However, use was made of them because of their ready availability, and the relative ease of reaching the tops of the poles. Moreover, the pole height was almost ideal for the later observations made at 10.02 MHz.
9. Such trucks were made in large numbers during WWII. The vehicle used by the University appears to be a Ford model (Hervey Bay Museum, 2017).
10. There exists a curious 1963 note about a 3.35 MHz array at Richmond (University of Tasmania, 1963: 52–53). Nowhere are observations with it described in great detail, and nobody interviewed for this paper or the paper about the Richmond arrays (George et al., 2016) recalls such an array at Richmond. A comment from Gordon Gowland (pers. comm., 2008) offers a clue: he made a brief mention of a smaller array at Penna (see Section 3.3). Whether he was referring to the partly-built 4.7 MHz array or to another array is unclear, although a small section of a 3.3 MHz curve was included in a paper published by Ellis and Hamilton (1966b). The history of that particular array requires further investigation.

8 ACKNOWLEDGEMENTS

We wish to thank the following for their assistance: Keith Barwick, Susan Blackburn, Keith Bolton, Simon Ellingsen, Elizabeth Ellis, Gordon Gowland, Philip Hamilton, Raymond Haynes, Julian Isles, Peter McCulloch, Kevin Parker, Dorothy and William Reynolds, the late Michael Waterworth, and the Department of Primary Industries, Parks, Water and Environment (Tasmania). Finally, we are grateful to William and Dorothy Reynolds and the University of Tasmania for kindly supplying Figures 14, 18 and 22.

9 REFERENCES

Deakin University, 2007. http://www.deakin.edu.au/research/research-news/articles/honorary-doctorate-for-professor-pip-hamilton. Retrieved October 2016.

Ellis, G.R.A., 1954. The Magneto-Ionic Triple Splitting of Ionospheric Echoes. Ph.D. thesis, Physics Department, University of Tasmania.

Ellis, G.R.A., 1962a. Extra-galactic radio emission at 4.8 Mc./s. *Nature*, 193, 258–259.

Ellis, G.R.A., 1962b. Radiation from Jupiter at 4.8 Mc./s. *Nature*, 194, 667–668.

Ellis, G.R.A., and Hamilton, P., 1964. Absorption of radio waves in the Galaxy. *Nature*, 204, 272.

Ellis, G.R.A., and Hamilton, P, 1966a. Cosmic noise survey at 4.7 Mc/s. *Astrophysical Journal*, 143, 227–235.

Ellis, G.R.A., and Hamilton, P., 1966b. Ionised hydrogen in the plane of the Galaxy. *Astrophysical Journal*, 146, 78–87.

Ellis, G.R.A., and Newstead, G., 1957. Discrete sources of cosmic radio noise at 18.3 and 10.5 Mc/s. *Journal of Atmospheric and Terrestrial Physics*, 10, 185–189.

Ellis, G.R.A., Green, R.J., and Hamilton, P.A., 1963. Observations of galactic radiation at 4.7 Mc/s. *Australian Journal of Physics*, 16, 545–551.

George, M., Orchiston, W., Slee, B., and Wielebinski, R., 2015a. The history of early low frequency radio astronomy in Australia. 2: Tasmania. *Journal of Astronomical History and Heritage*, 18, 14–22.

George, M., Orchiston, W., Slee, B., and Wielebinski, R., 2015b. The history of early low frequency radio astronomy in Australia. 3: Ellis, Reber and the Cambridge Field Station near Hobart. *Journal of Astronomical History and Heritage*, 18, 177–189.

George, M., Orchiston, W., Slee, B., and Wielebinski, R., 2016. The history of early low frequency radio astronomy in Australia. 6: Michael Bessell and the University of Tasmania's Richmond Field Station near Hobart. *Journal of Astronomical History and Heritage*, 19, 185–194.

George, M., Orchiston, W., Wielebinski, R., and Slee, B., 2015c. The history of early low frequency radio astronomy in Australia. 5: Reber and the Kempton Field Station in Tasmania. *Journal of Astronomical History and Heritage*, 18, 312–324.

Green, R., 1963. A High Resolution Galactic Survey at 4.7 Mc/s. B.Sc. Honours Thesis, Physics Department, University of Tasmania.

Hamilton, P. A., 1969. Low Frequency Radio Emissions from the Galaxy. Ph.D. Thesis, Physics Department, University of Tasmania.

Hamilton, P.A., and Haynes, R., 1968. Observations of the Southern Sky at 10.02 MHz. *Australian Journal of Physics*, 21, 895–902.

Hervey Bay Museum (Australia), 2017. Ford Blitz 1942. http://herveybaymuseum.com.au/ford-blitz-1942. Retrieved 5 February 2017.

Hoyle, F., and Ellis, G.R.A., 1963. On the existence of an ionized layer about the Galactic Plane. *Australian Journal of Physics*, 16, 1–7.

Meeus, J., 1983. *Astronomical Tables of the Sun, Moon and Planets*. Richmond, Willman-Bell.

Orchiston, W., and Slee, B., 2005. The Radiophysics field stations and the early development of radio astronomy. In Orchiston, W. (Ed.). *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth. A Meeting to Honor Woody Sullivan on His 60th Birthday.* Dordrecht, Springer. Pp. 119–168.

Orchiston, W., George, M., Slee, B., and Wielebinski, R., 2015a. The history of early low frequency radio astronomy in Australia. 1: The CSIRO Division of Radiophysics. *Journal of Astronomical History and Heritage*, 18, 3–13.

Orchiston, W., Slee, B., George, M., and Wielebinski, R., 2015b. The history of early low frequency radio astronomy in Australia. 4: Kerr, Shain, Higgins and the Hornsby Valley Field Station near Sydney. *Journal of Astronomical History and Heritage*, 18, 285–311.

Reber, G., 1982. My Adventures in Tasmania. *Tasmanian Tramp*, 24, 148–151.

Reber, G., and Ellis, G.R.A., 1956. Cosmic radio-frequency radiation near one megacycle. *Journal of Geophysical Research*, 61, 1–10.

Robertson, P., 1992. *Beyond Southern Skies. Radio Astronomy and the Parkes Telescope*. Cambridge, Cambridge University Press.

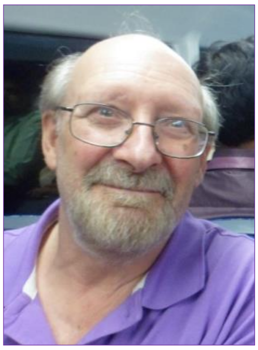
University of Tasmania, 1962. *Research Report for 1961*. Hobart, University of Tasmania.

University of Tasmania, 1963. *Research Report for 1962*. Hobart, University of Tasmania.

Wettenhall, R., 2006. Bushfires 1967. Centre for Tasmanian Historical Studies. http://www.utas.edu.au/library/companion_to_tasmanian_history/B/Bushfires%201967.htm. Retrieved October 2016.

Martin George is the Collections and Research Manager at the Queen Victoria Museum and Art Gallery in Launceston, Tasmania, and also is responsible for the Museum's planetarium and astronomy collections. He is a former President of the International Planetarium Society. Martin has a special research interest in the history of radio astronomy, and is completing a part-time Ph.D. on the development of low frequency radio astronomy in Tasmania through the University of Southern Queensland, supervised by Professors Wayne Orchiston and Richard Wielebinski (and originally also by the late Professor Bruce Slee). Martin is the Administrator of the Grote Reber Medal for Radio Astronomy, and is a member of the IAU Working Group on Historic Radio Astronomy.

Professor Wayne Orchiston was born in New Zealand in 1943 and works as a Senior Researcher at the National Astronomical Research Institute of Thailand and is an Adjunct Professor of Astronomy at the University of Southern Queensland in Toowoomba, Australia. In the 1960s Wayne worked as a Technical Assistant in the CSIRO's Division of Radiophysics in Sydney, and forty years later joined its successor, the Australia Telescope National Facility, as its Archivist and Historian. He has a special interest in the history of radio astronomy, and in 2003 was founding Chairman of the IAU Working Group on Historic Radio Astronomy. He has supervised six Ph.D. or Masters theses on historic radio astronomy, and has published papers on early radio astronomy in Australia, England, France, Japan, New Zealand and the USA. He also has published extensively on the history of meteoritics, historic transits of Venus and solar eclipses, historic telescopes and observatories, and the history of cometary and asteroidal astronomy. In 2016 and 2017 Springer published his two latest books, *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits* (733 pp.), and *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy* (603 pp.). Wayne's next book, co-edited by Tsuko Nakamura, is on *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*, and will be published, also by Springer, in 2017. Currently, Wayne is the Vice-President of IAU Commission C3 (History of Astronomy), and he is a co-founder and the current Editor of the *Journal of Astronomical History and Heritage*. In 2013 the IAU named minor planet 48471 Orchiston after him.



Professor Richard Wielebinski was born in Poland in 1936, and moved with his parents to Hobart, Tasmania, while still a teenager. Richard completed B.E. (Hons.) and M.Eng.Sc. degrees at the University of Tasmania. In his student days he met Grote Reber and was involved in the construction of a low frequency array at Kempton. After working for the Postmaster General's Department in Hobart he joined Ryle's radio astronomy group at the Cavendish Laboratory, Cambridge, and completed a Ph.D. in 1963 on polarised galactic radio emission. From 1963 to 1969 Richard worked with Professor W.N. (Chris) Christiansen in the Department of Electrical Engineering at the University of Sydney, studying galactic emission with the Fleurs Synthesis Telescope and the 64-m Parkes Radio Telescope. He also was involved in early Australian pulsar research using the Molonglo Cross. In 1970 Richard was appointed Director of the Max-Planck-Institute für Radiostronomie in Bonn, where he was responsible for the instrumentation of the 100-m radio telescope at Effelsberg. In addition,

he built up a research group that became involved in mapping the sky in the radio continuum, studying the magnetic fields of galaxies, and pulsar research. Further developments were the French-German-Spanish institute for mm-wave astronomy (IRAM), and co-operation with the Steward Observatory, University of Arizona, on the Heinrich-Hertz Telescope Project. Richard holds Honorary Professorships in Bonn, Beijing and at the University of Southern Queensland. He is a member of several academies, and has been awarded honorary doctorates by three universities. After retiring in 2004 he became involved in history of radio astronomy research, and is currently the Chair of the IAU Working Group on Historic Radio Astronomy.

Journal of Astronomical History and Heritage, 20(1), 112–118 (2017).

HIGHLIGHTING THE HISTORY OF JAPANESE RADIO ASTRONOMY. 5: THE 1950 OSAKA SOLAR GRATING ARRAY PROPOSAL

Harry Wendt
National Astronomical Research Institute of Thailand, 191 Huay Kaew Road, Suthep District, Muang, Chiang Mai 502000, Thailand.
Email: harry.wendt@gmail.com

Wayne Orchiston
National Astronomical Research Institute of Thailand, 191 Huay Kaew Road, Suthep District, Muang, Chiang Mai 502000, Thailand.
Email: wayne.orchiston@narit.or.th

Masato Ishiguro
National Astronomical Observatory of Japan, 2-21-1, Osawa, Mitaka, Tokyo 181-8588, Japan.
Email: masato.ishiguro@nao.ac.jp

and

Tsuko Nakamura
Institute for Asian Studies, Daito-bunka University, 2-19-10 Tokumaru, Itabashi-ku, Tokyo 175-0083, Japan.
Email: tsukonk@yahoo.co.jp

Abstract: In November 1950, a paper was presented at the 5th Annual Assembly of the Physical Society of Japan that outlined the plan for a radio frequency grating array, designed to provide high-resolution observations of solar radio emission at 3.3 GHz. In this short paper we provide details of the invention of this array, which occurred independently of W.N. Christiansen's invention of the solar grating array in Australia at almost the same time.

Keywords: Japan, solar radio astronomy, Osaka City University, solar grating array, Takanori Oshio, Tatsuo Takakura, Shinichi Kaneko, W.N. Christiansen, Minoru Oda

1 INTRODUCTION

The first Japanese radio astronomy observations occurred on 9 May 1948 when Koichi Shimoda observed a partial solar eclipse from Tokyo (Shimoda, 1982; Shimoda et al., 2013). By 1952 there were four different groups of Japanese researchers actively pursuing solar radio astronomy (Ishiguro et al., 2012; Orchiston and Ishiguro, 2017). One of these was based in Osaka, and this short paper deals with that group and specifically with the independent invention of a solar grating array in 1950.[1]

2 THE SOLAR GRATING ARRAY

2.1 Introduction

An earlier paper in this series (Orchiston et al., 2016) dealt with the background to the first solar radio astronomy observations at Osaka University during 1949 using a single horn radio telescope operating at 3.3 GHz and mounted on an ex-military searchlight mounting. That paper also described the transfer *en masse* of the Physics staff to the newly formed Faculty of Science and Technology at Osaka City University in early 1950.

On 5 November 1950, a paper (5C7) was presented at the 5th Annual Assembly of the Physical Society of Japan. Thanks to Professor Woody Sullivan we have obtained a copy of the handwritten 8-page paper and an English translation that was prepared by Professor Haruo Tanaka in December 1982.

The paper was titled, "A plan for the localization of noise source on the solar surface by 5-column 5-row electro-magnetic horns". The lead author was Takanori Oshio,[2] with Tatsuo Takakura and Shinichi Kaneko as co-authors; all were affiliated with Osaka City University and were part of Minoru Oda's group, but only Takakura would go on to make a career in radio astronomy (see Nakajima et al., 2014; Orchiston et al., 2016). The lead author, Takanori Oshio (1920–2002) had been appointed a Lecturer in Physics the previous year, and became a Professor at Osaka City University in 1963. He was interested in the calibration of soft X-ray observations using the X-ray emission from synchrotron radiation as a standard light source for the calibration. Ultimately, Oshio's research led to a collaboration with Professor Minoru Oda who also was interested in research on cosmic ray physics and later X-ray astronomy (Sasaki, 2003). Apparently Shinichi Kaneko, the third author of the 1950 paper, initially conducted cosmic ray research at Osaka City University, but we have not been able to source biographical material about him that post-dates 1955.

This paper discusses the independent invention of a radio-frequency solar grating array design made almost in parallel with that of W.N. Christiansen at the CSIRO Division of Radiophysics (RP) in Australia. Christiansen presented the first version of his design to RP's Radio Astronomy Committee on 14 March 1950 (see Wendt et al., 2008). This is perhaps another very good example of multiple discoveries, or simultaneous invention, as described by sociologists of science (e.g. see Merton, 1963).

2.2 Influences

In their paper, Oshio et al. (1950) made reference to two prior areas of research. They referred to the Australian observations of

> Bolton and Stanley [who] observed the radiating sources of cosmic noise with an accuracy of 0.15 degrees using the interference of direct waves and reflected waves from the sea...

They did not reference a specific publication, but presumably they had read the paper by Bolton and Stanley (1948) that appeared in *Nature*. This reported on the observations at Dover Heights of the Cygnus-A discrete radio source using the technique of sea (or cliff) interferometry. Oshio et al. also noted a paper by Stanier (1950) that also appeared in *Nature* and described the two-element solar interferometry work being carried out at Cambridge. It is surprising that these were the only two papers mentioned from the period that dealt with interferometry.

In a similar manner to Christiansen (1984: 118), Oshio et al. appear to have made the design connection with the optical grating array first proposed by Bernard Lyot (1945). They mention their arrangement of antennas, "…corresponding to a grating or lattice as inferred from optics."

2.3 The Design

The paper by Oshio et al. described how a grating type antenna response could be produced by summing the outputs of a row of identical aerials arranged at integer intervals of their operating wavelength (see Figure 1). They also noted that for observations of the Sun it was important to design the array in such a way that only one response lobe would be located on the Sun at any time and that a drift scan technique could be used to produce a one-dimensional profile of emission across the solar disk by relying on the Earth's rotation. They also considered the effect of a reduction in resolution as the Sun moved away from the perpendicular to the array axis. This was virtually identical to the design principles described by Christiansen (1953) and Christiansen and Warburton (1953). Figure 2 shows the approximate power response of a single 5-element row of the array proposed by Oshio et al. and based on equation [1] from Christiansen and Warburton (1953: 192).

Although the principles were largely the same, there were a number of key differences between the proposed Japanese array design and Christiansen's earliest grating interferometer. The first of these was that Oshio et al. proposed using equatorially mounted circular horns 50 cm in diameter and 130 cm long rather than dishes (see Figure 3).[4] Further, the operating frequency they chose was 3.3 GHz rather than the 1.42 GHz used by Christiansen, and was selected mainly due to the availability of ex-WWII equipment.

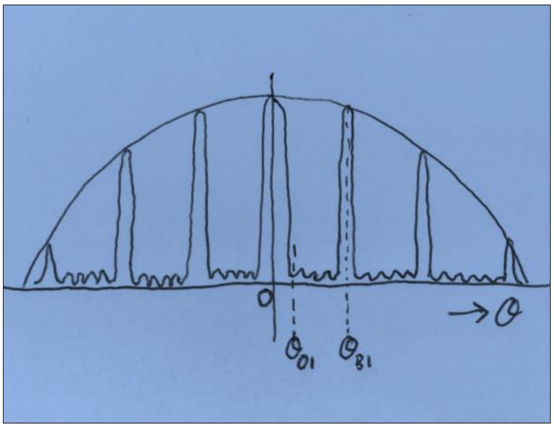


Figure 1: The directivity pattern of the array. Originally Figure 3 of Oshio et al. (1950).[3]

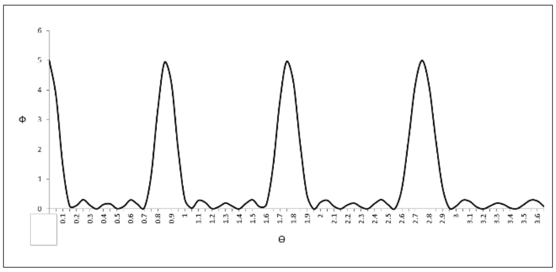


Figure 2: The calculated response of a 5-element grating array operating at a wavelength of 7.5 cm and with an element spacing of 5 m. The *y*-axis: ϕ = the power received by the array from a point source relative to the power received from a single element of the array. The *x*-axis: θ = the angle perpendicular to the array baseline and the direction of the source.

Perhaps the most ambitious aspect of the proposed design was that rather than having a single east-west baseline, they proposed using a 5 × 5 grid of 25 equatorially mounted horns arranged in a 25 × 25 m square with spacing of 5 m between aerials (see Figure 4). While an E-W row of aerials would produce the familiar sharp

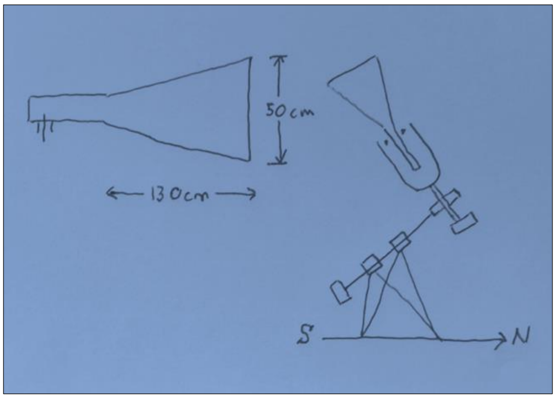


Figure 3: The proposed dimensions of the horn aerial design and its equatorial mounting to allow tracking of the Sun. Originally Figure 9 of Oshio et al. (1950).

fan-beam response, the combination of the 25 elements of the grid would produce a complex two-dimensional grid response, not dissimilar to that produced by the later development of Christiansen's crossed grating array at Fleurs (Christiansen and Mathewson, 1958; Orchiston and Mathewson, 2009). Oshio et al. describe

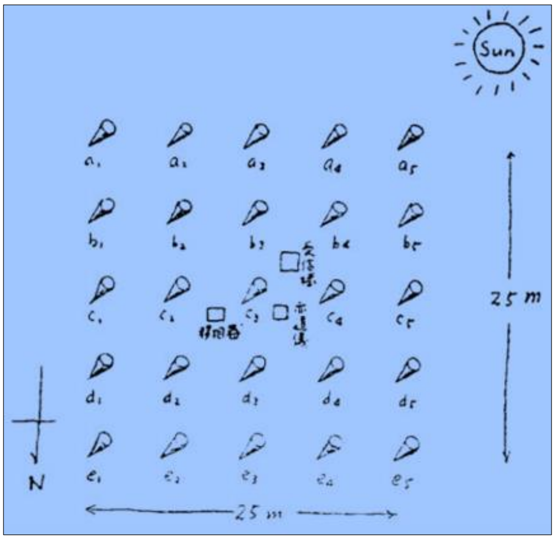


Figure 4: The grid array layout proposed for the array. Originally Figure 7 in Oshio et al. (1950). The three boxes annotated by Japanese characters are the receiver, phase shifter and the master equatorial mount intended to drive the 25 horn aerials for the purpose of tracking the Sun.

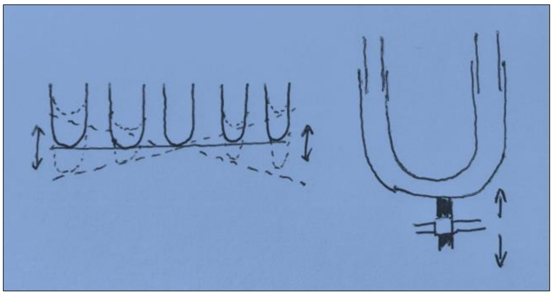


Figure 5: The diagram on the left illustrates the five u-shaped wave guides mounted on a see-saw bench which is rocked to vary the path lengths. The diagram on the right shows the sliding wave guide connected to a flexible coaxial cable. Originally Figure 12 in Oshio et al. (1950).

how

> ... for a multi-column, multi-row system, the directivity becomes two-dimensional, but the above theory [of a single grating array] can be applied precisely regarding the main axes (in two directions parallel to the antenna arrays).[5]

To further complicate the design, Oshio et al. also proposed dynamically varying the path length of the transmission lines for each row so as to produce a vertical sweeping of the beam response, which they called "... shaking the beam." They proposed doing this by using a series of five u-shaped wave guides mounted on a rocking see-saw arrangement (see Figure 5). The rocking motion varied the relative path lengths of each array column, and hence the phase, so that the beam pattern was swept in a north-south direction completing a cycle every 17 seconds. The technique of changing the phase of the N-S arm of the Fleurs Crossed Grating Array also was used by Christiansen so that over the course of a day multiple drift scans across the solar disk could be used to create a two-dimensional radio picture of the Sun. However, this was done by a static change to the N-S transmission line path length rather than trying to dynamically sweep the response over the solar disk during an individual drift scan.

Allowing for the slightly larger disk size of the Sun at radio frequencies (presumably on the basis of the reports of others), Oshio et al. assumed a disk of 41.3 minutes of arc, which meant that it would take approximately 2.8 minutes for the Earth's rotation to move the Sun's disk horizontally through the maximum beam response, with ten vertical scans completed in the same period. To produce an image, they proposed using an oscilloscope and camera. On the oscilloscope screen a spot, whose brightness was modulated by the signal intensity, would be swept in the vertical axis synchronised to the phase shifter.[6] The camera's shutter would then be open for 2.8 minutes to produce a single image. A block diagram of the proposed system design is shown in Figure 6.

3 CONCLUDING REMARKS

It is very likely that this ambitious design, which aimed to produce a single high-resolution image of the radio emission across the solar disk in 2.8 minutes, would have presented a very considerable engineering challenge for any group in the 1950s. Actually achieving accurate transmission pathlengths to maintain phase accuracy through the phase-shifting device would have been extremely difficult.[7] In many ways, the design was ahead of its time. However, the theory behind the design is sound and could easily have led to the construction of a less ambitious, but more practically achievable one-dimensional grating array similar to that constructed in the

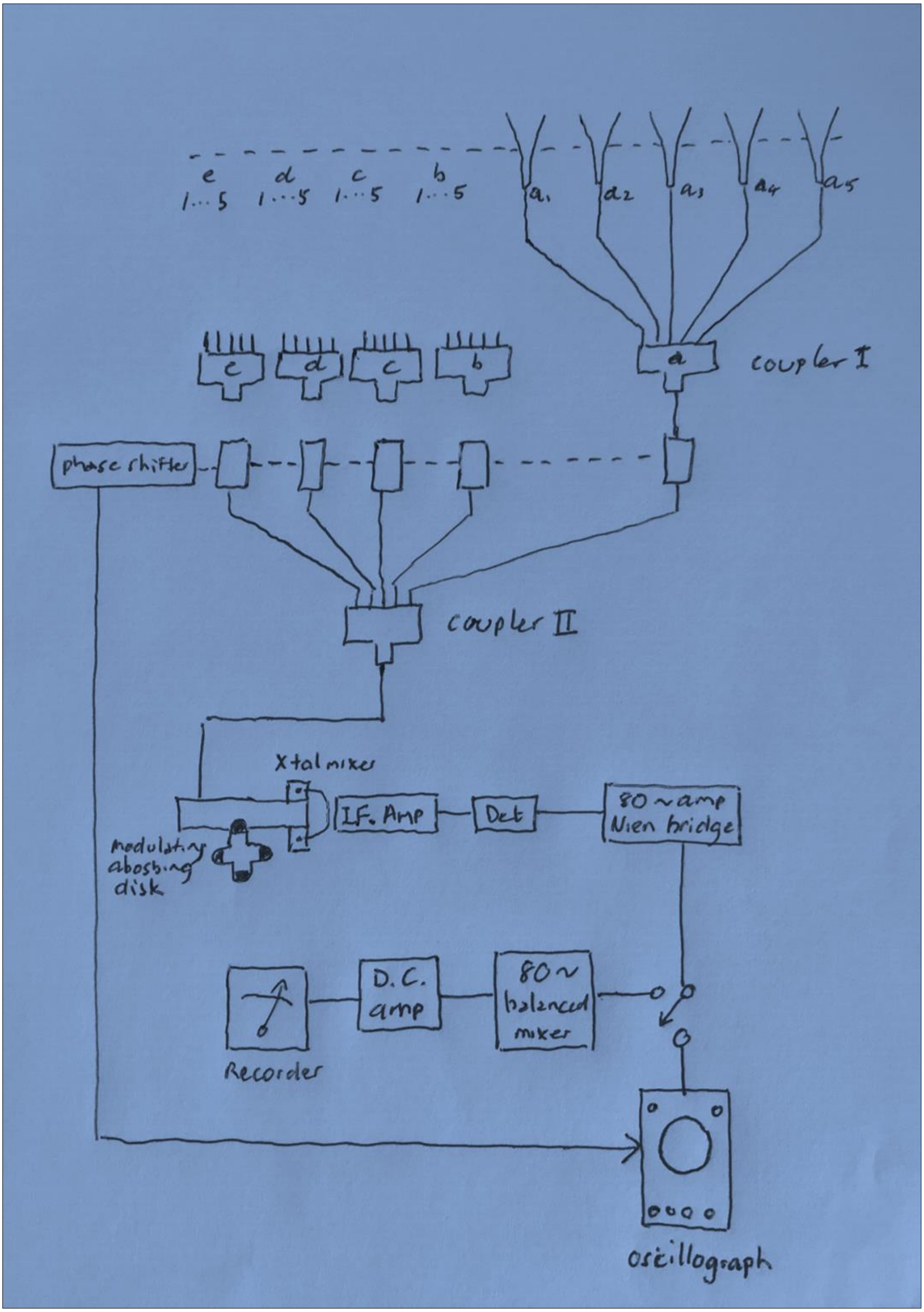


Figure 6: A block diagram of the proposed system. The outputs of each array row are first summed (coupler I) and then passed through the phase shifter before being again summed (coupler II). The output then passes to the receiver where it goes through a modulator (80 Hz) – crystal-balanced mixer – I.F. amplifier – detector – 80 Hz narrowband amplifier and then to the ‘Braun tube’ (oscilloscope), or is switched to a 80 Hz balanced mixer and the D.C. amplifier and then to a recorder. Originally Figure 8 in Oshio et al. (1950).

period 1951–1952 at Potts Hill in Sydney (Australia) by W.N. Christiansen (1953; cf. Wendt et al., 2008). In fact, Professor Haruo Tanaka of Nagoya University did later construct such an array at Toyokawa, in 1953, and this will be the subject of a later paper in this series that will deal with the radio telescopes designed and constructed by the Toyokawa researchers.

Although Minoru Oda, who headed the group at Osaka City University, did not apply this design in radio astronomy, later he successfully applied similar principles to the invention of a modulation collimator (Oda, 1965) which is now known as an 'Oda Collimator' and is used in high energy X-ray observations (Tanaka, 1984: 339).

As discussed by Orchiston et al. (2016), the design outlined by Oshio et al. in their 1950 conference paper was never published and, apart from the construction of a single horn aerial and receiver, the array itself was never constructed.

4 NOTES

1. This is the fifth paper in a series initiated by the IAU Working Group on Historic Radio Astronomy that aims to document, in English, the early development of Japanese radio astronomy. The first paper (Ishiguro et al., 2012) provided a chronological overview, while papers 2–4 dealt respectively with Koichi Shimoda's observation of the 9 May 1948 partial solar eclipse (Shimoda et al., 2013); early solar radio astronomy at Tokyo Astronomical Observatory (Nakajima et al., 2014) and early solar research at Osaka University and Osaka City University (Orchiston et al., 2016).
2. In the course of researching this paper we discovered that Takanori Oshio's name originally was erroneously written as 'Takabumi Ojio' in some of the papers listed above in Note 1, and in Tanaka (1984).
3. Note that all figures from the 1950 paper that appear in this paper are tracings of a copy of the original paper which was of too poor a quality to reproduce for publication.
4. Orchiston et al. (2016) note that the horn design which was used with the first single 3.3 GHz receiver was later replaced by a 1-m dish when the horn proved less than ideal.
5. A crossed grating array is a much more economical way of producing this type of beam pattern, but this would have required the conceptual design leap of multiplying the array responses. This innovation would only come later when made by Bernard Mills with the invention of the cross-type array (Mills and Little, 1953) and Christiansen's subsequent application of it to a grating interferometer (Christiansen and Mathewson, 1958; cf. Orchiston and Mathewson, 2009).
6. It is interesting to note that Little and Payne-Scott (1951) used a similar recording method for capturing images from their swept-lobe interferometer at 97 MHz which was used for capturing the position, motion and polarisation of short duration solar bursts.
7. Little and Payne-Scott (1951) used a rotating metal arm within a drum to achieve the variable path length change for their swept-lobe interferometer. In their case, they were only using a two-element interferometer and they changed the phase of the local oscillator rather than attempting to change the phase of the actual signal. Fortunately, sensitivity was not a major issue for solar observations as this type of mechanical phase change created significant losses.

5 ACKNOWLEDGEMENTS

We wish to thank Professor Woody Sullivan for kindly supplying a copy of the original Oshio et al. paper *and* an English translation of it that were in the archives that he assembled when researching his comprehensive history of early radio astronomy (see Sullivan, 2009). One of the authors (HW) also would like to thank Professor Bob Frater for his discussions on beam forming in arrays, although any misinterpretation of aspects of electrical engineering is solely that of the author.

6 REFERENCES

Bolton, J.G., and Stanley, G.J., 1948. Variable source of radio frequency radiation in the constellation of Cygnus. *Nature*, 161, 312–313.
Christiansen, W.N., 1953. A high-resolution aerial for radio astronomy. *Nature*, 171, 831–833.
Christiansen, W.N., 1984. The first decade of solar radio astronomy in Australia. In Sullivan, 113–131.
Christiansen, W.N., and Mathewson, D.S., 1958. Scanning the Sun with a highly directional array. *Proceedings of the Institute of Radio Engineers*, 46, 127–131.
Christiansen, W.N., and Warburton, J.A., 1953. The distribution of radio brightness over the solar disk at a wavelength of 21 cm. Part I. A new highly directional aerial system. *Australian Journal of Physics*, 6, 190–202.
Ishiguro, M., Orchiston, W., Akabane, K., Kaifu, N., Hayashi, M., Nakamura, T., Stewart, R., and Yokoo, H., 2012. Highlighting the history of Japanese radio astronomy. 1: An introduction. *Journal of Astronomical History and Heritage*, 15, 213-231.
Little, A.G., and Payne-Scott, R., 1951. The position and movement on the solar disk of sources of radiation at a frequency of 97 Mc/s. *Australian Journal of Scientific Research*, 4, 489–507.
Lyot, B., 1945. A monochromatic polarising filter and its applications in solar physics. *Annales d'Astrophysique*, 7, 31–79 (in French).
Merton, R.K., 1963. Resistance to the systematic study

of multiple discoveries in science. *European Journal of Sociology*, 4, 237–282.

Mills, B.Y., and Little, A.G., 1953. A high-resolution aerial system of a new type. *Australian Journal of Physics*, 6, 272–278.

Nakajima, H., Ishiguro, M., Orchiston, W., Akabane, K., Enome, S., Hayashi, M., Kaifu, N., Nakamura, T., and Tsuchiya, A., 2014. Highlighting the history of Japanese radio astronomy. 3: Early solar radio research at the Tokyo Astronomical Observatory. *Journal of Astronomical History and Heritage*, 17, 2–28.

Oda, M., 1965. High-resolution X-ray collimator with broad field of view for astronomical use. *Applied Optics*, 4, 143.

Orchiston, W., and Ishiguro, M., 2017. The early development of radio astronomy in Japan. In Nakamura, T., and Orchiston, W. (eds.). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe.* Cham, Springer.

Orchiston, W., and Mathewson, D.S., 2009. Chris Christiansen and the Chris Cross. *Journal of Astronomical History and Heritage*, 12, 11–32.

Orchiston, W., Nakamura, T., and Ishiguro, M., 2016. Highlighting the history of Japanese radio astronomy. 4: Early solar research in Osaka. *Journal of Astronomical History and Heritage*, 19, 240–246.

Oshio, T., Takakura, T., and Kaneko, S., 1950. A plan for the localization of solar sources on the solar surface by 5-column 5-row electromagnetic horns. Paper 5C7 presented at the 5th Annual Assembly of the Physical Society of Japan, November 5. Pp. 8 (in Japanese).

Sasaki, T., 2003. Obituary: Takanori Oshio (1920–2002). *Journal of JSSRR*, 16, 44–45.

Shimoda, K., 1982. After Dinner Talk: two reflectors made in 1930. In 13th Okazaki Conference, 1982 Tokyo, Institute for Molecular Science. Pp. 31–35.

Shimoda, K., Orchiston, W., Akabane, K., and Ishiguro, M., 2013. Highlighting the history of Japanese radio astronomy. 2: Koichi Shimoda and the 1948 solar eclipse. *Journal of Astronomical History and Heritage*, 16, 98–106.

Stanier, H.M., 1950. Distribution of radiation from the undisturbed Sun at a wave-length of 60 cm. *Nature*, 165, 354.

Sullivan, W.T. (ed.), 1984. *The Early Years of Radio Astronomy: Reflections Fifty Years after Jansky's Discovery.* Cambridge, Cambridge University Press.

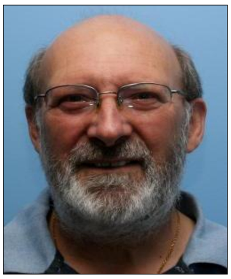
Sullivan, W.T., 2009. *Cosmic Noise: A History of Early Radio Astronomy.* Cambridge, Cambridge University Press.

Tanaka, H., 1984. Development of solar radio astronomy in Japan up until 1960. In Sullivan, 335–348.

Wendt, H.W., Orchiston, W., and Slee, B., 2008. W.N. Christiansen and the development of the solar grating array. *Journal of Astronomical History and Heritage*, 11, 173–184.

Dr Harry Wendt is an independent researcher based in Sydney, but is affiliated with the History of Astronomy group at the National Astronomical Research Institute of Thailand. He has a long-standing interest in early Australian radio astronomy and in 2009 completed a Ph.D. thesis on "The Contribution of the CSIRO Division of Radiophysics Potts Hill and Murraybank Field Stations to International Radio Astronomy" through James Cook University (Townsville, Australia), supervised by Professor Wayne Orchiston and the late Professor Bruce Slee. Harry has since published a series of papers based upon his thesis research. He is a member of the IAU Working Group on Historic Radio Astronomy.

Professor Wayne Orchiston is a Senior Researcher at the National Astronomical Research Institute of Thailand in Chiang Mai and an Adjunct Professor of Astronomy at the University of Southern Queensland. In his earlier years Wayne worked at the CSIRO's Division of Radiophysics in Sydney and later at its successor, the Australia Telescope National Facility. He has published on the history of radio astronomy in Australia, France, Japan, New Zealand and the USA. In 2011 Wayne co-edited the book *Highlighting the History of Astronomy in the Asia-Pacific Region*, more than 250 pages of which deal with the early history of Australian radio astronomy. Wayne was the founding Chairman of the IAU's Working Group on Historic Radio Astronomy. He has supervised five Ph.D. theses on the history of radio astronomy. Currently he is the Vice-President of IAU Commission C3 (History of Astronomy). In 2013 he was honoured when minor planet 48471 Orchiston was named after him.



Dr Masato Ishiguro is an Emeritus Professor at the National Astronomical Observatory of Japan (NAOJ). He started his research in radio astronomy at Nagoya University in 1970 where he investigated radio interferometry techniques. In 1980, he moved to the Tokyo Astronomical Observatory of the University of Tokyo to join the project to construct large millimeter-wave telescopes at the Nobeyama Radio Observatory (NRO) where he was in charge of constructing the Nobeyama Millimeter Array. He was the Director of the NRO from 1990 to 1996 and contributed to the open use of the telescopes. While doing research at the NRO, he worked on a plan for a large array at millimeter and submillimeter wavelengths. From 1998, he led the Japanese involvement in the construction of the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. Masato was a Professor at the NAOJ from 1988 until he retired in 2009. He is now the Japanese representative on the Committee of the IAU Working Group on Historic Radio Astronomy.

Dr Tsuko Nakamura was until very recently a Professor at the Teikyo-Heisei University in Tokyo, where he taught Information Sciences since 2008. Prior to that, he worked at the National Astronomical Observatory of Japan for many years. His research interests lie in observational statistics of very small

asteroids and in the history of Japanese astronomy, and he has published more than fifty papers in this latter field. His books include *Five Thousand Years of Cosmic Visions* (2011, in Japanese, co-authored by S. Okamura), *Mapping the Oriental Sky*, *Proceedings of the ICOA-7 Conference* (2011, co-edited by W. Orchiston, M. Sôma and R. Strom) and *Highlighting the History of Astronomy in the Asia-Pacific Region*, *Proceedings of the ICOA-6 Conference* (2011, co-edited by W. Orchiston and R. Strom). Tsuko is the Chairman of the Executive Committee of the International Conference on Oriental Astronomy.

Journal of Astronomical History and Heritage, 20(1), 119–125 (2017).

ON THE HISTORY OF THE ARGUMENT FROM DESIGN IN ASTRONOMY[1]

Alan H. Batten
2594 Sinclair Rd, Victoria, B.C., Canada, V8N 1B9.
E-mail: ahbatten@telus.net

Abstract: The Argument from Design is possibly the oldest attempt to 'prove' the existence of a deity, or, at least, to persuade people that it is reasonable to believe in one. Although the Argument has often been used in the context of biology, its use in the context of astronomy is arguably earlier. In this paper, its history in astronomical contexts is traced from ancient times to modern discussions of the 'fine tuning' of the Universe.

Keywords: design, deity, Anthropic Principle

1 INTRODUCTION

Simply stated, the Argument from Design is that the natural world shows evidence of having been designed and that, therefore, there must be a designer. The Argument is ancient and seductive, even if it falls short of being a completely convincing proof. Indeed, there are obvious objections to so simple a statement of the Argument as has just been given. Design has been perceived at various times in both the astronomical Universe and in the biosphere. Of course, arguments in the two sciences concerned with those regions are closely related and even, as we shall see, intertwined. Yet they are distinct enough for each to stand or fall alone: a refutation of either one does not necessarily entail the refutation of the other. This is important because Charles Darwin (1809–1882; Figure 1) is often considered to have dealt the Argument a mortal blow with the publication of the *Origin of Species* (Darwin, 1859). The theory of natural selection undoubtedly made much less plausible the argument, advanced by many eighteenth-century writers, that the adaptations of plants and animals were evidence of a powerful intelligence having designed each individual creature. Whether or not it totally invalidated the Argument even within biology is perhaps less obvious. Clearly, however, Darwin's theory left untouched astronomical versions of the Argument, which may well be older than the biological versions, since the former can be found in classical antiquity.

2 THE ARGUMENT IN ANTIQUITY

One of the earliest expressions of the Argument, if only in poetic form, is the opening verse of the nineteenth psalm: "The heavens declare the glory of God and the firmament sheweth his handiwork." That probably precedes even Plato's (c.427–c.347 B.C.E.; Figure 2) reference to the Argument in the tenth book of *The Laws.* The nineteenth psalm is certainly concerned with the heavens and they seem to have been the principal concern of Plato who introduces the subject by making Cleinias, one of the participants in his dialogue, say that it is easy to explain the existence of the gods:

> … just look at the earth and the sun and the stars and the universe in general: look at the wonderful procession of the seasons and its articulation into years and months! (Saunders, 1970: 412).

Plato, in the person of the Athenian Stranger, appears unimpressed by this argument but, nevertheless, goes on to argue strongly against the notion that the Universe could have appeared by chance. There is little or no reference to biological adaptations in these two sources.

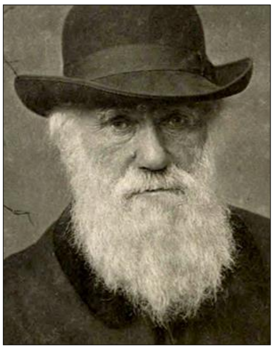
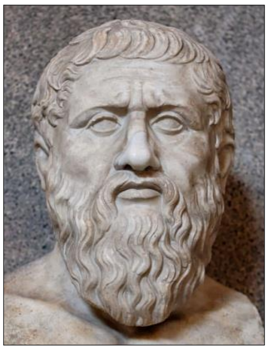



Figure 1 (left): Charles Darwin in 1881 (www,wikiwand.com). Figure 2 (right): A Roman marble bust of Plato after a Greek original from the last quarter of the fourth century (www.wikiwand.com).

Marcus Tullius Cicero (106–43 B.C.E.; Figure 3) took up the Argument in his work, *De Natura Deorum*, introducing it in the same way as Plato had by pointing to the regularity of the seasons. This regularity reflected the apparent motions (which Cicero, of course, assumed to be real) of the Sun, Moon, and the other stars. He likened the Universe first to a house that had been designed, and then to an organism which, he maintained, must itself be divine. He went on to argue that the Sun, Moon, planets and stars, which moved themselves, were also divinities (McGregor, 1972: esp. 123–144). This illustrates the weakness of the Argument from the point of view of Christian theologians. It may persuade people to believe in a divinity, but it is as likely to persuade them to be pantheists or polytheists as

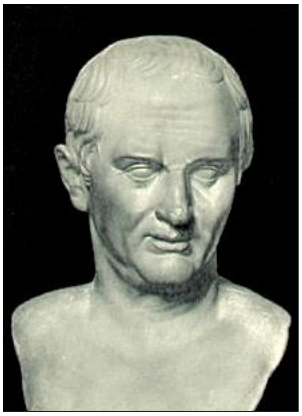


Figure 3: A photograph published in an unidentified book dated 1900 of a marble bust of Cicero at the age of about 60. This bust is presumed to now be in Madrid's Museum of Archaeology (en.wikipedia.org).

to believe in the Christian God. Similar objections to the Argument have been made by both Kant (1781) and Bertrand Russell (1946). As we shall see, Cicero's discussion was to have considerable influence on David Hume.

Of course, the contrary view was also advanced in antiquity, particularly by the Greek atomists, Leucippus and Democritus. Their ideas were communicated to the Roman world through the writings of Epicurus and the famous poem of Lucretius, *De Rerum Natura*. For a thorough discussion of the Greek atomists, including the original texts of the surviving fragments of their work, see Kirk and Raven (1957: Chapter XVII).

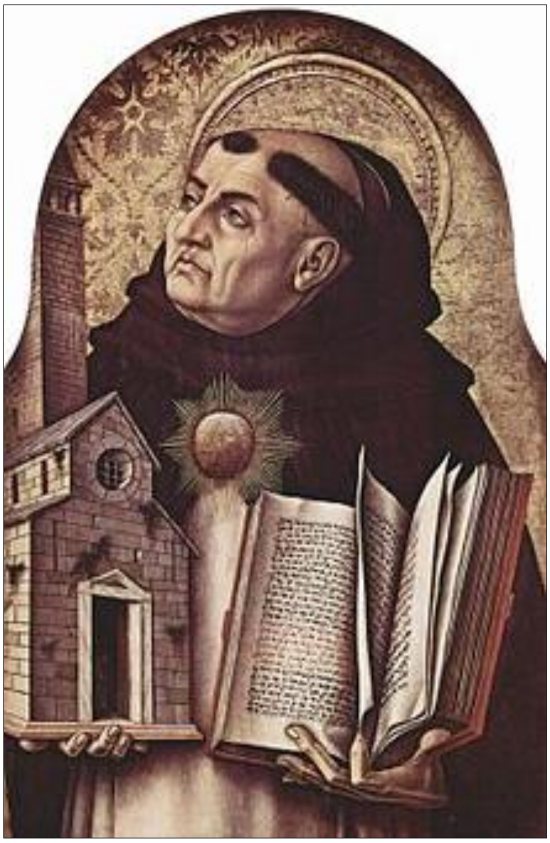


Figure 4: Saint Thomas Aquinas on a 15th century altarpiece by Carlo Crivelli in Ascoli Piceno. Italy (en.wikipedia.org).

3 A MEDIEVAL VERSION

In the Christian era St Thomas Aquinas (1225–1274; Figure 4) gave us the classical form of the Argument in the last of his five ways of 'proving' the existence of God. His is a very general argument and contains no specific reference either to astronomical phenomena or to biological adaptation. While it obviously does not exclude either, the emphasis seems to be on inanimate objects, presumably the planets. As translated in Burrill (1967: 55), Aquinas wrote:

> The fifth way is taken from the governance of the world. We see that things which lack knowledge, such as natural bodies, act for an end, and this is evident from their acting always, or nearly always, in the same way, so as to obtain the best result. Hence it is plain that they achieve their end, not fortuitously but designedly. Now whatever lacks knowledge cannot move towards an end, unless it be directed by some being endowed with knowledge and intelligence; as the arrow is directed by the archer. Therefore some intelligent being exists by whom all natural things are directed to their end; and this being we call God.

4 THE EARLY MODERN PERIOD

In the English-speaking world, John Ray (1627–1705; Figure 5), an older contemporary of Isaac Newton (1642–1727) and, like him, a fellow of Trinity College, Cambridge, was one of the earliest to elaborate the Argument in his book *The Wisdom of God Manifested in the Works of Creation* (Ray, 1691). Although his primary interest was in botany, his book was wide-ranging and included a discussion of the astronomical versions of the Argument. He wrote (*op. cit.*: 63):

> First, for the Celestial or Heavenly bodies, the Equability and Constancy of their Motions, the Certainty of their Periods and Revolutions, the Conveniency of their Order and Situations, argue for them to be ordain'd and govern'd by Wisdom and Understanding; yea, by so much Wisdom as Man cannot easily fathom or comprehend: For we see by how much the hypotheses of astronomers are more simple and conformable to reason, by so much do they give a better Account of the Heavenly Motions.

Thus, like Plato, Cicero and Aquinas, with whose works he would, of course, have been familiar, Ray saw design primarily in the regularity of the motions of the heavenly bodies, but he introduced a new element. He was clearly also familiar with the astronomical science of his day and recognized that the Copernican system (or perhaps we should say at this point, the

Newtonian system) was simpler than the Ptolemaic, and he saw that simplicity as further evidence for design. Ray's book was extremely popular and ran to several editions, some of which were published posthumously. It was the inspiration for many writers throughout the eighteenth and early nineteenth centuries, who argued that the adaptations of plants and animals to their environments was evidence of Divine Providence (see e.g., Turner, 1833). Some writers carried the Argument to implausible extremes. Bertrand Russell (1872–1970) asserts (without citation) that some even argued that it was providential that rabbits had white tails that provided good marks for sportsmen (Russell, 1943: 81)! Darwin's theory was a good antidote to such nonsense.

A much younger contemporary of Ray, Joseph Addison (1672–1719), published a famous poem "The spacious firmament on high", which paraphrased the nineteenth psalm and was a summary of a long essay on the Argument from Design (Addison, 1712). Unlike Ray, he appears less familiar with Newtonian physics, or, at least, he chose to ignore it. In the third verse of his poem, he resorted to pre-Copernican imagery:

> What though in solemn silence all
> Move round the dark terrestrial ball?
> What though no real voice or sound
> Amid the radiant orbs be found?
> In reason's ear they all rejoice,
> And utter forth a glorious voice,
> Forever singing as they shine,
> "The hand that made us is Divine!"

The year after Addison's poem appeared, Isaac Newton (Figure 6) published the second edition of the *Principia*, which contained the famous *General Scholium.* Newton had been stung by criticisms of the first edition of his great work to the effect that it presented a godless Universe. One purpose of the *General Scholium* was to refute those criticisms. Unlike Plato, Cicero, and Ray, Newton did not rely simply on the regularity of motions; that followed, after all, from the inverse-square law of gravity and the three laws of motion, once the system had been set in motion. Instead, Newton pointed to the fact that all the planets and all their satellites then known revolved around the Sun in the same sense and in almost the same plane. He wrote:

> This most beautiful System of the Sun, Planets, and Comets, could only proceed from the counsel and dominion of an intelligent and powerful being. And if the fixed Stars are centres of other like systems, these being formed by the like wise counsel, must all be subject to the Dominion of One; especially since the light of the fixed Stars is of the same nature with the light of the Sun, and from every system light passes into all the other systems. And lest the system of the fixed Stars should, by their gravity, fall on each other mutually, he hath placed those Systems at immense distances from one another. (Newton, 1713: 1–2).

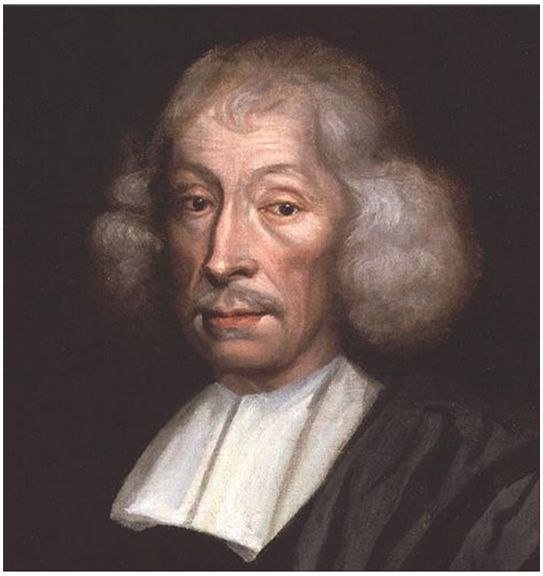


Figure 5: A painting of John Ray (by an unknown artist) now in the National Portrait Gallery, London (en.wikipedia.org).

As we have seen, Ray's book inspired many writers during the eighteenth and early nineteenth centuries to elaborate the biological version of the Argument from Design. The eighteenth century, however, was dominated by the figure of David Hume (1711–1776; Figure 7). In his posthumously published *Dialogues Concerning Natural Religion*, Hume (1779) concentrated mainly on the analogy between the Universe, on the one hand, and a machine or a house (*cf.* Cicero), on the other. The matter of biological adaptation is raised, but not dwelt upon to any

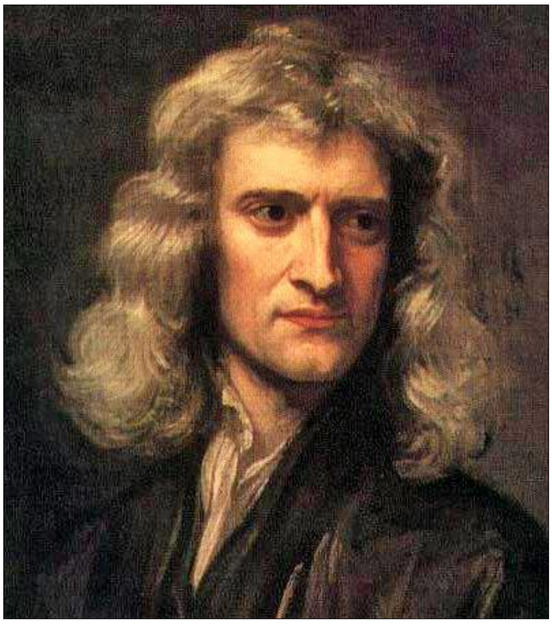


Figure 6: A copy of a painting of Isaac Newton by Sir Godfrey Kneller (en.wikipedia,org).

Figure 7: Painting of David Hume (en.wikipedia.org).

Figure 8: An 1842 posthumous painting of Simon Laplace by Madame Feytaud in the Académie des Sciences, Paris (en.wikiquote.org).

great extent. Hume, indeed, presents both the Argument and the objections to it very forcefully. If the *Dialogues* had been the only one of his writings to survive, we should be hard put to decide which side of the controversy he favoured! Although in many ways Hume echoes Cicero's arguments, there are some surprisingly modern ideas in the *Dialogues.* For example, the famous sentence "Many worlds might have been botched and bungled ere this system was struck out." anticipates by about three centuries modern scientific arguments for "many worlds"! Again, at one point, one of the speakers, following Cicero, likens the Universe to an organism rather than a machine, anticipating, perhaps, some versions of the many-worlds hypothesis which speak of 'baby universes' and a kind of natural selection among universes. Hume would have taken such ideas in his stride.

The eighteenth century ended with the publication of Laplace's *Exposition du Système du Monde* (Laplace, 1796). Sometimes known as 'the French Newton', Pierre Simon Laplace (1749–1827; Figure 8) was anxious to show that he could do what Newton himself had been unable to do, namely, to explain the properties of the Solar System without recourse to Divine intervention. This, rather than an uncompromising statement of atheism, is probably the significance of the remark that Laplace is supposed to have made in reply to Napoleon's question about the role of God in the formation of the Solar System: "*Je n'ai pas besoin de cette hypothèse-la*."[2] Laplace may well have thought that he had dealt a blow to the astronomical argument from design as mortal as that which Darwin is commonly believed to have dealt to the biological argument some half a century later. That was not the opinion of many of his contemporaries, however, as has been shown by R.L. Numbers (1977). Numbers was primarily concerned with the reception of Laplace's hypothesis in the United States, but the reaction of British scholars was similar, as we shall see.

Early in the nineteenth century William Paley's (1743–1805; Figure 9) famous book, *Natural Theology or Evidences for the Existence and Attributes of the Deity*, appeared (Paley 1802). Despite its opening illustration of the watch found on the heath—the part that everyone quotes and, I suspect, the only part most people have read—which clearly suggests a mechanical analogy, the book is mainly concerned with biological adaptations. There is one, relatively short, chapter on astronomy. Paley writes that he does not consider astronomy to be the best science to illustrate design and thus to lead to belief in a Creator, but that, given the existence of a Deity, astronomy shows us the most magnificent works of the Creator. His astronomical arguments are very weak, however, and would not convince any modern astronomer. For example, he argues that the law of gravitation could have been different, or that the Sun need not have been in the centre of the Solar System. The central body could have been dark and opaque and one of the planets might have been the source of heat and light. With our understanding of modern physics, we would rule these ideas out of consideration.[3] Paley seems to have believed that God was free to make quite arbitrary choices of this kind. Einstein's famous question about whether God was free to create the Universe however he wished or was constrained by logical necessity seems never to have crossed his mind.

Somewhat later in the century we encounter the *Bridgewater Treatises* which again are mainly concerned with biological adaptation, still from a pre-Darwinian point of view. The famous Victorian polymath and Master of Trinity College, Cambridge, William Whewell (1794–1841; Figure 10), was assigned to write the treatise on *Astronomy and General Physics, Considered with Reference to Natural Theology*, but even quite a large portion of this is devoted to biological matters. To Whewell (1833) it was evidence of design that plants and animals had annual and diurnal cycles in their behavior and that the periods of these cycles coincided so closely with the astronomical year and day. It was also a cause of amazement to him that the sap in trees could rise against gravity, indicating a fine balance between the properties of sap and capillary action and the strength of gravity at the Earth's surface. He argued that the Earth could have had different periods of revolution and rotation so the cycles of living things would no longer have matched, or that the Earth could have been more or less massive, so that the force of gravity would have had a different strength and the sap would have been unable to rise in the tree to the proper height. He does not seem to have thought of the possibility that biological cycles developed to match the astronomical periods, and he dismisses the notion that the coincidence of the properties of sap was an inevitable consequence of the actual value of the force of gravity on this planet. He also sees design in the constancy of the Earth's climate – he was writing not only before Darwin, but before the recognition of ice ages in the distant past. Reading Whewell's treatise brings home the great revolution in thinking that Darwin produced. Whewell's perception of God seems to have been of an omnipotent Creator of a giant jig-saw puzzle, who painstakingly and lovingly carved out each individual piece so that they would all fit together. In this respect, he resembles his eighteenth-century predecessors. Our post-Darwinian thinking is more like the way in which jig-saw puzzles are actually made: the

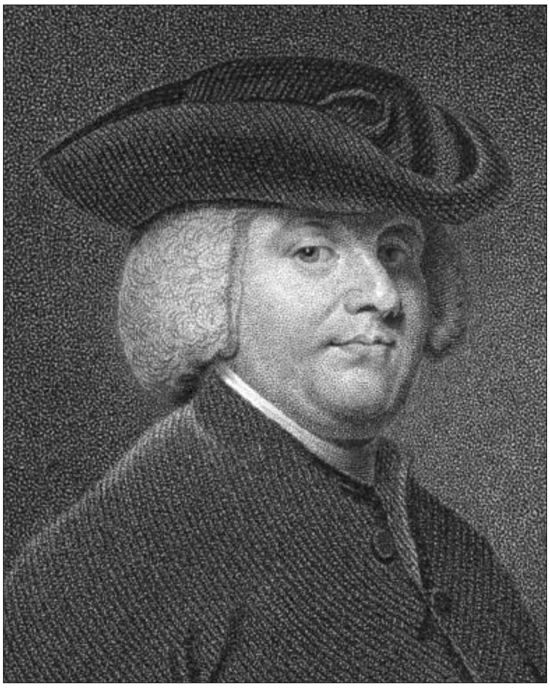


Figure 9: An undated woodcut of William Paley (Wikimedia Commons).

picture is cut into tiny pieces that inevitably fit together because they were cut from the original picture.

Whewell also discusses Laplace's hypothesis of the origin of the Solar System, which, he believed, his contemporaries among astronomers were by no means united in accepting. He argues that it does not rule out the possibility of intelligence and design in the formation of the Universe. He writes:

> If we grant, for a moment, the hypothesis, it by no means proves that the solar system was

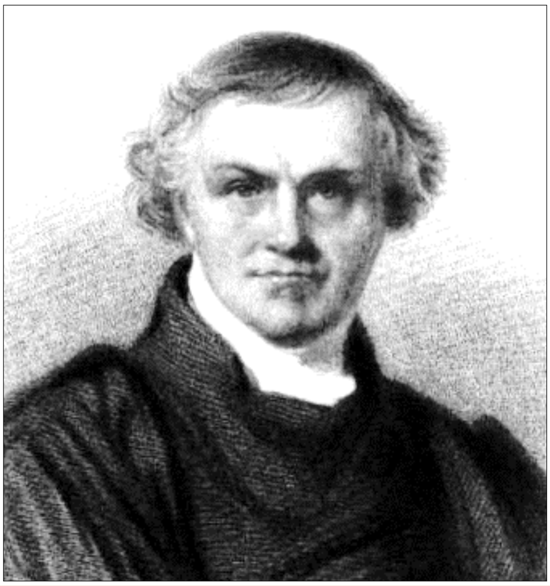


Figure 10: An engraving of William Whewell (after Whewell, 1881: Frontispiece).

> formed without the intervention of intelligence and design. It only transfers our view of the skill exercised, and the means employed, to another part of the work. For how came the sun and its atmosphere to have such materials, such motions, such a constitution, that these consequences followed from their primordial condition? (Whewell, 1833: 145).

This attitude is consistent with that of American scholars at the time, as is shown in the work by Numbers, already cited. It is of interest that, contrary to what many scientists suppose, the contradiction between Laplace's hypothesis and any literal interpretation of the early chapters of *Genesis* seems not to have been of concern to most theologians, even in the early nineteenth century. Although Whewell was discussing the origin of the Solar System, rather than that of the Universe as a whole, he comes close to imagining something like the Big Bang, with light being the first created thing. His reaction is rather similar to that of Pope Pius XII over a century later, almost claiming that science had proved the existence of God.

5 THE TWENTIETH CENTURY

Although neither Paley's nor Whewell's arguments carry much conviction to us, there is an interesting parallel between them and modern reasoning along the lines of the so-called "Anthropic Principle". Paley and Whewell argued from coincidences between astronomical and biological phenomena that seemed to them evidence for design. Anthropic reasoning also points to coincidences, in particular to the precise values of the four major forces currently recognized as ruling the material Universe. Some of us find it very difficult to avoid the conclusion that the Universe was created with the deliberate intention of making possible the kind of life forms that are capable of evolving into morally self-aware beings such as ourselves, but not necessarily limited to those we find on this planet. Are we making the same mistake as Newton, Paley and Whewell made? Will some perfectly natural explanation be found for these coincidences? From my reading of the history of science, I cannot rule that possibility out. Indeed, many, but not all, cosmologists believe that they have already found the natural explanation in the hypothesis that this 'Universe' is but one of many and that we are bound to find ourselves in a Universe in which we can exist. The 'multiverse', as it is sometimes termed, is, however, still a hypothetical entity and, even if we eventually find convincing evidence for it, that would not disprove that the entire system was deliberately created. In Whewell's words (quoted above): "It only transfers our view of the skill exercised, and the means employed, to another part of the work."

Meanwhile, there seem to me to be three differences between our modern arguments and those of our predecessors. First, the coincidences we talk of are found in inanimate matter, were necessary for the appearance of life as we know it, and must have been fixed long before any form of life could have appeared in this Universe. As Freeman Dyson (1979: 250) has put it: "… in some sense the universe must have known that we were coming." Second, the coincidences have very tight limits. That was not so for the kinds of coincidences that Paley and Whewell were discussing. We could easily imagine a planet about half as massive again as the Earth, revolving around a star, perhaps a little hotter than our Sun, with a period of, say, eighteen of our months. Such a planet might well be life-supporting. The life forms on it would be different from ours but, provided they were based on DNA, would probably be recognizable as kindred beings. In our modern understanding, the ratios of the four forces need to be only a very little different to make the evolution of life as we know it (i.e. based on DNA) impossible. As Leslie (1989: 3–6) has emphasized, we require a vast number of other universes if we are to explain this one as simply a product of chance. Third, the importance of these coincidences has impressed itself on many people who would like to be able to explain them away. We may compare this with the situation in modern biology where design arguments have re-appeared in the guise of 'Intelligent Design'. The chief protagonists of this movement, Michael Behe and William Dembski, are both men of strong religious faith who very much want to find evidence for design in living creatures.

I began by describing the argument from design as seductive and many of you may have, quite correctly, assumed that I am myself attracted to it. My understanding is that most modern theologians are wary of it. Perhaps they are wise to be so.

6 NOTES

1. This is a modified version of a paper presented at a conference on *Theology and the Philosophy of Science: Analytic, Scholastic, and Historical Perspectives*, at Concordia University of Edmonton, 14–15 October 2016.
2. I have tried to find if Laplace ever did make that remark. We know that there was a meeting between Napoleon and Laplace at which the role of God in the creation of the Solar System was discussed, because the British astronomer, Sir William Herschel (1738–1822), was present and kept a diary, but the famous reply is not recorded there (Lubbock, 1933: 312). I rather like the suggestion at which the late Stephen Jay Gould hinted: that the reply was the one Laplace

wished he had made when he got home! (Gould, 1995: 25).

3. I assume that when Paley wrote that the law of gravitation might have been different, he was imagining some form different from the inverse-square law. Of course, we can conceive of the *strength* of the force of gravity being different, as will become clear in the discussion of anthropic reasoning in the next section.

7 REFERENCES

Addison, J., 1712. *The Spectator*, 23 August.

Burrill, D.R., 1967. *The Cosmological Argument*. New York, Anchor Books, Doubleday & Co.

Darwin, C.R., 1859. *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life*. London, John Murray.

Dyson, F.W., 1979. *Disturbing the Universe*. New York, Harper and Row.

Gould, S.J., 1995. *Dinosaur in a Haystack*. New York, Harmony Books.

Hume, D., 1779. *Dialogues Concerning Natural Religion*. This work was published posthumously; I have used the text in Wolheim, R., 1963. *Hume on Religion*. London, Collins.

Kant, I., 1781. *Kritik der Reinun Vernunſt*. Riga, J.F. Hartknoch.

Kirk, G.S., and Raven, J.E., 1957. *The Presocratic Philosophers*. Cambridge, Cambridge University Press.

Laplace, P.-S., 1796. *Exposition du Système du Monde*. Paris, l'Imprimerie du Cercle-Social.

Leslie, J., 1989. *Universes*. London, Routledge.

Lubbock, C.A. (ed.), 1933. *The Herschel Chronicle: The Life-Story of William Herschel and His Sister Caroline Herschel*. Cambridge, Cambridge University Press.

McGregor, C.P. (trans.), 1972. *Cicero: The Nature of the Gods*. Harmondsworth, Penguin Books.

Newton, I., 1713. *Philosophiae Naturalis Principia Mathematica*, Second Edition. London, The Royal Society. The *General Scholium* is appended at the end of the text and the English translation is by A. Motte in 1729 (newtonprojectca.files.workdpress.com/2013/06/newton-general-scholium-1729-english-text-by-motte-letter-size.pdf). The page numbers listed in the text refer to this web version.

Numbers, R.L., 1977. *Creation by Natural Law*. Seattle, University of Washington Press.

Paley, W., 1802. *Natural Theology or Evidences for the Existence and Attributes of the Deity*. London, John Murray.

Ray, J., 1691. *The Wisdom of God manifested in the Works of Creation*. London, William Innys.

Russell, B., 1943. *An Outline of Intellectual Rubbish*. Reprinted in Egner, R.E., and Denonn, L.E. (eds.). *The Basic Writings of Bertrand Russell*. New York, Simon and Schuster.

Russell, B., 1946. *History of Western Philosophy*. London, Allen and Unwin.

Saunders, T.J. (trans.), 1970. *Plato: The Laws*. Penguin Books, Harmondsworth.

Turner, S., 1833. *The Sacred History of the World: As Displayed in the Creation and Subsequent Events to the Deluge*. New York, J. and J. Harper.

Whewell, W., 1833. *Astronomy and General Physics, Considered with Reference to Natural Theology*. London, Pickering.

Alan H. Batten spent his active career at the Dominion Astrophysical Observatory in Victoria, B.C.,

Canada, where he studied spectroscopic binary systems. He served as a Vice-President of the International Astronomical Union from 1985 to 1991 and is a member of the Editorial Board of this *Journal*. His latest book, *Our Enigmatic Universe*, was published in 2011, and since then he has published several papers in this journal and essays by him have appeared in the *Biographical Encyclopedia of Astronomers*.

Journal of Astronomical History and Heritage, 20(1), 126–135 (2017).

RECEPTION AND DISSEMINATION OF AMERICAN AMATEUR TELESCOPE MAKING IN SWEDEN

Johan Kärnfelt
Department of Literature, History of Ideas, and Religion, University of Gothenburg, Box 200, SE-405 30 Gothenburg, Sweden.
johan.karnfelt@lir.gu.se

Abstract: This paper discusses the appropriation of the American Amateur Telescope Making (ATM) movement in Sweden in the 1940s and 1950s. A key player was the Swedish Astronomical Society, which in 1943, and inspired by the American example, launched a campaign to raise interest in ATM and disseminate the necessary knowledge amongst potential amateur astronomers. The campaign was successful and in just a few years it quadrupled the number of amateurs with access to telescopes. Swedish amateurs kept on building telescopes through the 1950s, but the activities then stalled with the introduction of cheap mass-market telescopes. The appropriation of ATM in Sweden is an important example of how technical innovations have shaped the course of amateur astronomy.

Keywords: Sweden, amateur astronomy, ATM, Swedish Astronomical Society

1 INTRODUCTION

Amateur astronomers spend a lot of time with their instruments.[1] They make their observations, tweak and tinker with them, build and rebuild them, even collect them. Many amateurs have several specialized instruments for particular uses, including large-aperture Dobsonians for deep sky observing, high-end refractors for planets and astrophotography, and astronomical binoculars for comets. Without these instruments, there would be no amateur astronomy. One result of the central role played by these instruments is that innovations in optics, mechanics, electronics and manufacturing techniques have the potential to change the course of amateur astronomy. Cheap mass market telescopes made available after WWII put the heavens within reach of new demographic groups. Deep sky observing took off with the introduction of the large-aperture Dobsonian in the 1970s. Starting in the early 1990s, commercial CCD cameras gave rise to modern astrophotography, and so on.[2]

One early and particularly important development was the rise of the Amateur Telescope Making (ATM) movement. ATM developed in many countries, but the American tradition was arguably the most important (Cameron, 2010). Launched in the 1920s, and in close association with *Scientific American*, it had a profound impact on amateur astronomy. But its reach went far beyond the borders of the United States. Borne by magazine articles, handbooks and letters, the ideas and techniques of the American ATM movement travelled far and was eventually appropriated by many other amateur cultures.

In this paper I will discuss one example, the reception and dissemination of the American ATM tradition in Sweden during the early 1940s and later.

2 THE NORTH-AMERICAN ATM MOVEMENT

Early twentieth century amateur astronomy was defined by the refractor. The 80-mm achromatic model was a typical instrument of the time. It was often manufactured by the same optical companies—e.g. Alvan Clark & Sons in the United States, Carl Zeiss in Europe—that supplied professional astronomers. It was also quite expensive, which tended to leave amateur astronomy to wealthy practitioners (Cameron, 2010). These circumstances give context to a seminal article titled "The Poor Man's Telescope", which was written by American optician Russell W. Porter (1871–1949) in 1921 and published in *Popular Astronomy* (Porter, 1921). It was this article that launched the American ATM movement.

According to Porter, the poor man's telescope was not a refractor, but a reflector. The mirror was ground by hand from a disk of raw glass into a spherical or parabolic shape (Figure 1), polished, silvered to make it reflective, installed in a simple wooden tube and supported by a mounting. The article details the mirror-grinding process. It also describes the bait that readers were supposed to rise to:

> It is really remarkable, considering the prices asked for telescopes today, that one possessed with patience and a little time can produce a very powerful and efficient instrument at so small a cost. (Porter, 1921: 527).

The article had no immediate impact, but a small group formed around Porter and started to build telescopes. Some years later, the group was formally organized as the Springfield Telescope Makers. Later it became the *avant-garde* of the ATM movement, particularly through the Stellafane Conventions that began in 1923 and have been attracting participants from all over the United States ever since (Cameron, 2010: 168; Stellafane).

A couple of years later, Albert G. Ingalls (1888–1958), the newly appointed Editor of *Scientific American*, came across Porter's article. Ingalls realized that amateur telescope making fitted perfectly with the journal's goal of offering more space to various kinds of do-it-yourself projects. He contacted Porter (Figure 2), and embarked on a long and successful series of articles concerning every aspect of telescope making. Readers were highly receptive. After just a couple of years, the journal estimated the number of active telescope makers at 3,000, some of whom constructed 200-mm reflectors for as little as $12—compared to the several hundred dollars for commercial equivalents (Cameron, 2010: 178). The success convinced Ingalls to edit the articles for a book, including an out-of-print ATM manual by Irish astronomer William F.A. Ellison (1864–1937). The first edition of *Amateur Telescope Making* was published in 1926 (Ingalls, 1926). By 1932, close to 10,000 copies had sold. Ten years later, there were over 60 ATM clubs in the United States (Cameron, 2010: 190). The book is still regarded as the 'bible' of ATM.[3]

ATM kick-started American amateur astronomy. Although the materials and methods of telescope making had been around for a long time—the invention of glass mirror silvering by Léon Foucault (1819–1868) in 1857 was the starting point of the modern tradition (Tobin, 1987)—Ingalls and Porter managed to make an attractive package out of it and sell it to the American public. The key concept was that virtually anyone could build a telescope. You did not need an optician's workshop or specialized training. It could be done in a garage or basement. Besides very affordable raw materials, it required only time, endurance and thoroughness. Many Americans took up the challenge. The number of active amateurs grew exponentially in the decades to come, reaching the tens of thousands by mid-century. At the same time, amateur astronomy was no longer limited to the educated and wealthy but encompassed ordinary people as well (Cameron, 2010; cf. Williams, 2000).

The ATM movement extended far beyond the borders of the United States. The articles in *Scientific American*, as well as the book Ingalls put together, brought both the theory and methods to other cultures. In the 1940s amateur astronomy got off to a flying start in Sweden as a result.

3 EARLY TWENTIETH CENTURY AMATEUR ASTRONOMY IN SWEDEN

The Swedish Astronomical Society was founded in 1919. There were no other astronomical associations in Sweden at the time at either the national or local level. Inspired by both the professionally oriented Royal Astronomical Society in England and the British Astronomical Association (with its emphasis on amateurs), the new Swedish organization adopted a number of goals. It wanted to serve the needs of professional astronomers while providing a forum where amateurs and members of the general

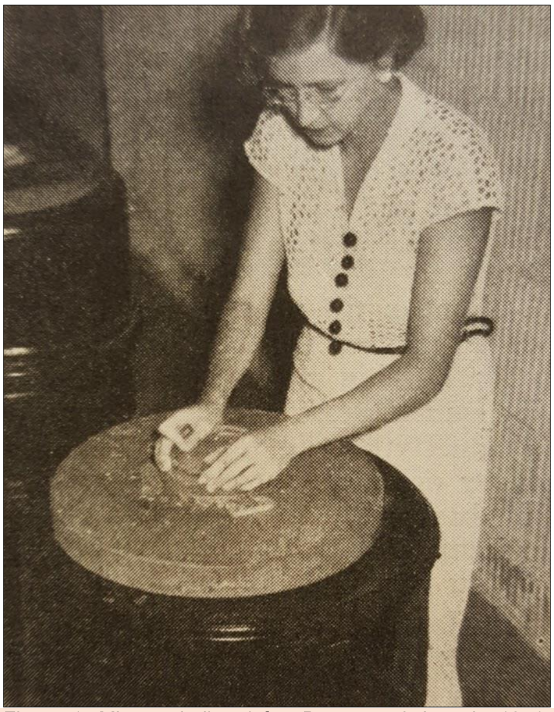


Figure 1: Mirror grinding (after Barton and Joseph, 1951: 171).

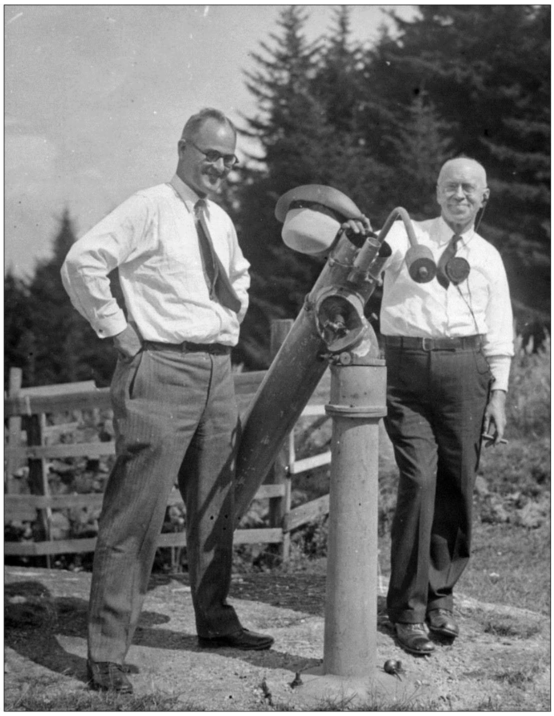


Figure 2: Albert G. Ingalls (left) and Russell W. Porter (after Beaty, 2015).

public could interact with astronomers (Kärnfelt, 2004: Chapter 5; 2015).

During the first few years, the Society focused largely on amateur astronomy. Sweden could muster only a handful of amateur astronomers, so one of the main objectives was to recruit a large group of amateurs and train them in the service of professional astronomy (Kärnfelt, 2004: 188). A key tool was the Society's mouthpiece, the ambitious *Populär Astronomisk Tidskrift* (*Journal of Popular Astronomy),* a biannual that was first published in 1920. The journal included a number of long, popular articles about academic astronomy, as well as some material on amateur astronomy. Guides for performing various types of observations, information about amateur observatories, discussions of astrophotography, etc., were among the features. For a number of years, the Society had a small public observatory in Stockholm—the first of its kind in Sweden—for the purpose of general enlightenment and the opportunity for amateurs to use the 130-mm Carl Zeiss refractor. But these and similar initiatives ultimately failed to

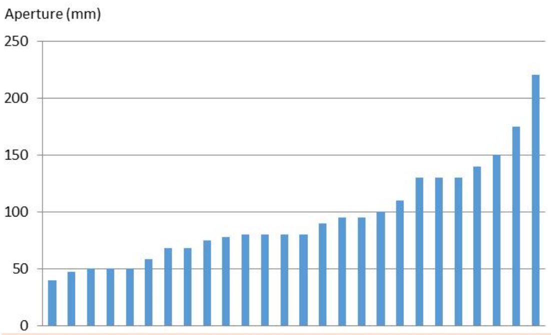


Figure 3: Telescopes, sorted by aperture, known to have been used by Swedish amateurs between 1900 and 1940 (plot: Johan Kärnfelt).

pay off. Contrary to expectations, amateurs were conspicuous by their absence. Neither the journal nor the Minutes of the Board of Directors has anything to say about the matter. It seems that the initiative simply ran out of steam. By the later 1920s, the Society had turned to other goals and abandoned amateur astronomy altogether.

Why did amateur astronomy not take off? The eight-hour workday had become the law of the land in 1919, leaving plenty of time for people to engage in all kinds of recreational activities. Representatives of the public sector encouraged everyone to engage in hobbies of their choice. Instead of squandering their leisure hours on alcohol or gambling, they should collect stamps, building model railroads or get into ham radio. Such admonitions appeared in newspaper editorials, a plethora of periodicals devoted to various hobbies, the adult education movement and the political establishment (Stattin, 2007). The stage seemed to have been set for activities like amateur astronomy. But something was missing.

Figure 3 contains information about all telescopes known to be used by Swedish amateurs between 1900 and 1940.[4] The data include 26 telescopes. Two of these were housed in public observatories and used by some amateurs; the rest were owned by 16 different amateurs (among them August Strindberg). All but one were refractors, most of them imported from Germany, mainly through the Carl Zeiss Company. The smallest, the 40-mm or 50-mm aperture refractors, were homemade and built in accordance with instructions that now and then appeared in weekly magazines and required mounting a glass lens and eyepiece in paper tubing. Although they could be used to gaze at the Moon and the brighter planets, they were generally regarded as toys rather than tools for astronomical observation. The largest telescopes, from 130-mm up, were semi-professional in quality and at the disposal of the country's few advanced amateurs. For example, Bertil Berggren (1884–1970) used his 500 kg 215–mm refractor by C.A. Steinheil & Söhne for sophisticated lunar studies.

An achromatic refractor in the 70–90 mm range seems to have been the standard among Swedish amateurs during this era, and we can use that as a basis for determining the kind of investment required. Including a wooden tripod, alt-azimuthal mount, four eyepieces and a finder, an 80-mm refractor (Figure 4) was available from Carl Zeiss in Germany for about SEK 2,000 in 1928.[5] At the time, the median annual income was SEK 3,500 for a working-class family and SEK 6,000 for a middle-class family (Statistiska Centralbyrån, 1925). Clearly, that kind of investment was beyond the wildest dreams of most Swedes. The Society's ambitions foundered on lack of affordability. Action was required to put the heavens within reach of a bigger slice of the population.

4 THE INTRODUCTION OF ATM IN SWEDEN

A short notice in the review section of *Journal for Popular Astronomy* (1936) called attention to the fourth edition of Ingalls' *Amateur Telescope Making*, apparently the first Swedish reference to the American ATM movement. Other than bibliographical information, the notice consisted of one sentence to the effect that this was the source of information for people who wanted to build a telescope (Anonymous, 1936). We know that at least one member of the Society read the book thoroughly. Alf Grabe (1880–1966), a mining engineer, Director of the Mint and Chairman of the Swedish Association of Engineers and Architects, was inspired (Figure 5). There are no indications that he actually built a telescope for himself, or even bought one for that matter, but he was clearly among the first influential members of the Society to realize the potential of ATM.

Grabe spoke on the subject at the Society's 1943 annual meeting. Drawing on Ingalls' book, he explained the basics of telescope making, asserting that even a "… handy boy …" could do it (Grabe, 1943: 15). He urged the Society to actively

> … encourage amateur telescope making, which, especially in the United States, is pursued with great intensity in therefore especially formed club and in close association with *Scientific American* … (ibid.).

This was the start of the Swedish ATM movement. Buttressed by a positive response to his talk, Grabe teamed up with optical engineer Ragnar Schöldström (1889–1981) to promote ATM in Sweden. A summary of Grabe's talk was published in the journal (Grabe, 1943). In the next issue, Schöldström—later to become the Russell W. Porter of the Swedish tradition—wrote a rather technical article on the knife-edge test to determine the correct shape of the mirror during the grinding process (Schöldström, 1943a). He also produced a more extensive ATM manual. He subsequently wrote more general articles for various magazines about his experience building telescopes (Schöldström, 1943b, 1943c and 1944).[6] The purpose of the articles was not so much to provide instructions as to promote the idea that realizing the dream of having a telescope was possible even with limited resources. Or as Grabe (1943, 15) put it: mastery of mirror-grinding required only three qualities: "… patience, cleanliness and accuracy …"

Meanwhile, these and similar publications were followed up at the organizational level. At Grabe's initiative, the Board of Directors of the Society appointed a Committee to promote ATM. In addition to Grabe, the Committee consisted of astronomers Bertil Lindblad (1895–1965), Gunnar Malmquist (1893–1982) and Yngve Öhman (1903–1988), as well as engineer Erik Forsberg (1875–1946) (Protokoll, 26 February 1943). Öhman, who at the time worked at Stockholm Observatory, was the only Committee member who had previous first-hand experience as an amateur astronomer. Among the first events arranged by the Committee was a meeting at an optical workshop in Stockholm, at which Schöldström talked about his ATM experiences (Anonymous, 1943). In connection to the Society's 25th Anniversary the following year, they put together a small exhibit of amateur-made telescopes. The exhibit was reported in the press. One of the items was Schöldström's masterpiece, a 210-mm reflector,

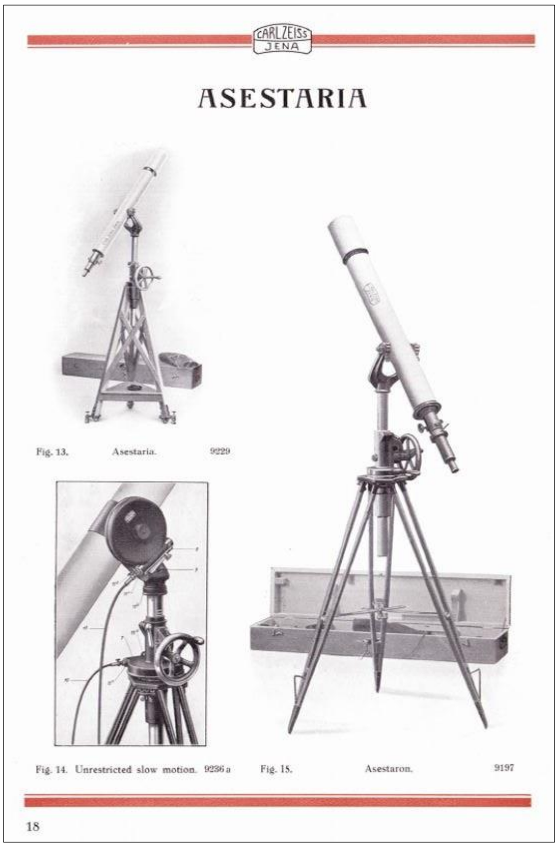


Figure 4: The "Asestaria" manufactured by Carl Zeiss in Jena. This 80-mm refractor could be bought with an achromatic or a more expensive apochromatic objective. The slow motion cables shown in the image at the bottom left was an extra and is not included in the price cited above (after Carl Zeiss Jena, 1928: 19).

as well as a simpler 135-mm reflector that was built according to Schöldström's instructions by Air Force Officer Per Anders Kinnman (b. 1913) (Figure 6) (Anonymous, 1944; Öhman, 1944a).

While the Society had failed to attract the attention of amateur astronomers in the 1920s, it fared better this time around. Many people, both inside and outside of the Society, responded positively. But awaking interest was not enough to persuade amateurs to build telescopes. Although the technique of mirror-grinding was avail-

Figure 5: Alf Grabe (after *Svenskt Biografiskt Lexikon*).

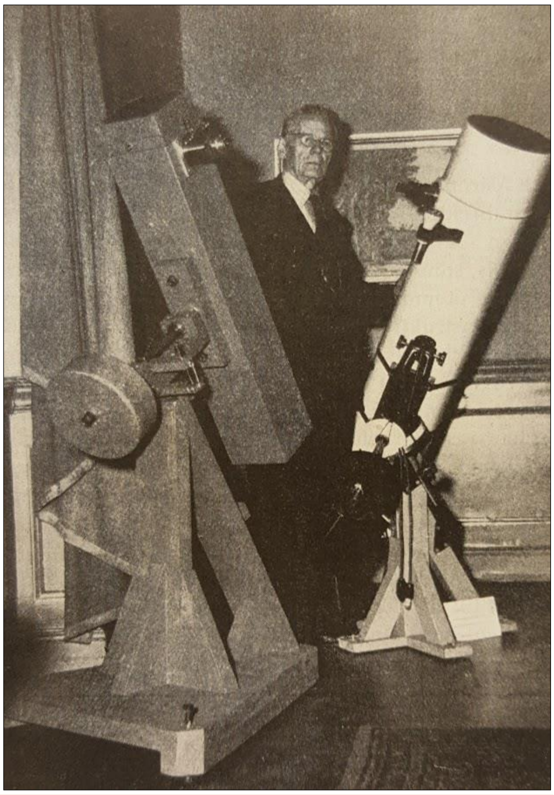


Figure 6: Nils Nordenmark, Secretary of the Swedish Astronomical Society, poses with two homebuilt telescopes at the Society's ATM exhibition. The white instrument to the right is Schöldström's; the bulky one to the left is Kinnman's (after Öhman, 1944: 100).

able to virtually anyone, ATM also demanded access to a great deal of information and raw materials (Figure 7). First of all, you needed detailed instructions on how to go about performing the various steps of mirror grinding, not to mention some basic ideas about building the tube and mount. Then you needed to get your hands on glass blanks, grinding and polishing powder, a plane mirror for the secondary, chemicals for silvering, and wood and fittings for the telescope. Before grinding, you also had to build a device for the knife edge test. Finally, a suitable eyepiece was required once the telescope was complete. You could not make one yourself, but had to buy it from an optician or salvage it from a trashed microscope. All of this had been available long before the Society started to promote ATM, but only to those who knew what they were looking for and where to find it.[7]

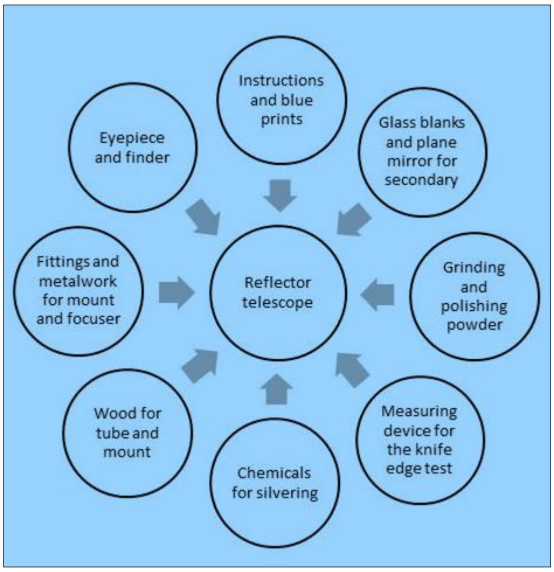


Figure 7: Information and material needed to build a telescope (diagram: Johan Kärnfelt).

The Society's most important achievement when it came to ATM, besides promoting the idea itself, was to create the needed infrastructure for telescope makers. To begin with, Ragnar Schöldström wrote a lengthy compendium on telescope making (Schöldström, 1943d). It was clearly inspired by Ingalls' book, as well as his own experience as an optician. The project described in the compendium targeted a 150-mm reflector, which could easily be upgraded for more experienced telescope makers. Schöldström also arranged for the compendium to be distributed by Clas Ohlson & Co., a mail order firm specializing in technical manuals and hobby products. The compendium was advertised for the first time in the 1944-45 Clas Ohlson catalog (Figure 8). Based on an agreement with Schöldström, the company also started to sell mirror grinding materials. A subsequent announcement stated that a telescope could be built for less than SEK 100, a fraction of the price of a commercial counterpart (Advertisement, 1944/45).

Still you needed an eyepiece and a finder, which could not be bought from Clas Ohlson & Co. Schöldström's compendium is rather vague in this regard, suggesting only that amateurs try to find a suitable loupe or microscope eyepiece (Schöldström, 1943: 25). Had it not been for yet another arrangement by the Society's ATM Committee, this might have been the stumbling block for Swedish ATM. Astronomer Yngve Öhman negotiated a deal with an optical company to supply the Society's members with lens kits for a 17-mm orthoscopic eyepiece and a 7.5× finder.[8] Sockets for the lenses were not included but could be ordered from a mechanical firm in accordance with another agreement set up by Öhman. The package was first advertised in the Society's journal in 1944. Members could buy it for SEK 15. Since the supply was limited, however, they were allowed to do so only if they submitted a certificate stating that they had actually completed a telescope of their own (Öhman, 1944b).

Figure 8: Advertisement for Schöldström's ATM compendium in the Clas Ohlson catalogue of 1944/45. The 150-mm reflector displayed is the end result following the instructions. Cf. Figure 6 above (after Advertisement, 1944/45: 90).

5 IMPACT

The impact of the Society's ATM initiative is difficult to gauge. But a few indications permit an assessment of the outcome.

As the Society sold off its inventory of lens kits, Öhman made sure to report its progress in the journal. In 1948, once the inventory had been depleted, Öhman could name over 60 amateurs who had bought the kit and completed their telescopes (Öhman, 1948). This is not much in absolute numbers, but if we assume that the telescopes listed in Figure 3 were still in use, it actually means that the number of amateur telescopes had quadrupled in just a couple of years.

Amateurs continued to build telescopes in the years to come (Figure 9). A definitive indicator of ATM activity—at least until 1960 when others entered the market—would have been the sales figures for the glass blanks from Clas Ohlson & Co. Unfortunately, they are no longer available. But we do know that the company's mimeographed pricelist for mirror grinding materials was issued in about 500 copies yearly well into the 1960s.[9] Since the number of copies was stable for many years, it permits a reasonable estimate of the circulation of the lists. Assume that one out of 20 of those who consulted the list actually bought glass blanks and built a telescope. Then about 25 new telescopes were built every year. This simple calculation suggests that the Swedish ATM movement, from its launch in 1943 until 1960, produced somewhere in the neighborhood of 400 new instruments and potentially as many new amateurs.

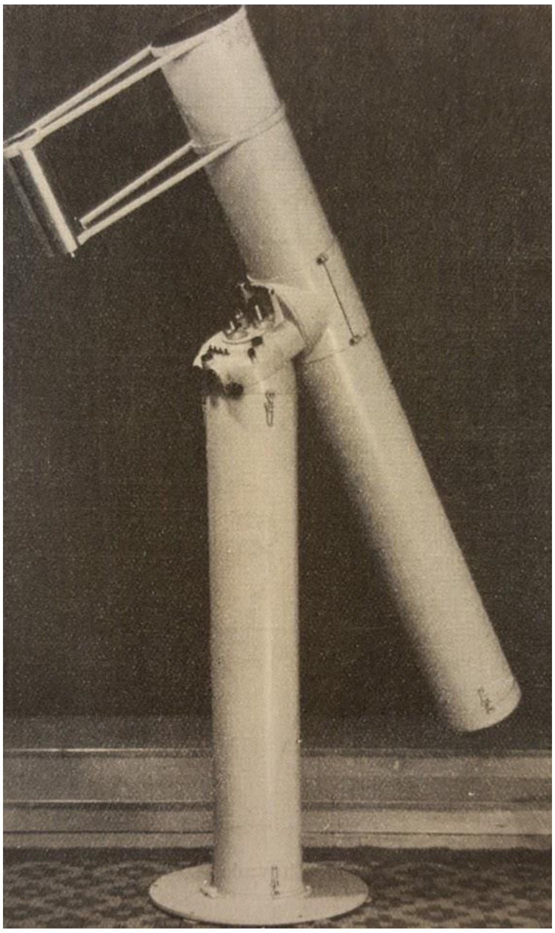


Figure 9: The Springfield-mounted telescope built from steel pipes by engineering teacher David Lindhed in 1945, following an instruction in *Amateur Telescope Making*. The mount, allegedly invented by Russell W. Porter, uses two secondary mirrors to lead the light cone through the polar axis and then to the eyepiece on top of the pier. The construction allows the observer to observe in the same position regardless of how the telescope is pointing (Lindhed, 1946: 56).

Swedish ATM took a new turn in the late 1950s. A sudden inflow of cheap mass-market instruments changed the world of amateur astronomy forever. New manufacturing techniques had enabled Goto Optical Manufacturing in Japan and others to produce telescopes for a fraction of the previous cost. These telescopes found their way into Sweden when Clas Ohlson & Co. started selling them in 1956. Suddenly you could buy a simple 62-mm refractor with a tripod, eyepiece and finder for less than SEK 400 (Figure 10), one-fifth of the monthly income of a typical office worker (Swedish National Board of Health and Welfare, 1965: 3). Under these circumstances there was no longer a financial incentive for mirror grinding and telescope making—at least among entry-level amateurs who were satisfied with smaller apertures. ATM became the domain of advanced amateurs in search of larger apertures, specialized instruments or optical perfection.

Figure 10: The cover of the *Clas Ohlson catalogue* for 1956-57. The telescope displayed is the 62-mm refractor mentioned in the text.

6 CONCLUDING REMARKS

ATM had a definite impact on Swedish amateur astronomy of the 1940s and 1950s. In a country that was barely aware of amateur astronomy before 1940, the ATM movement increased the number of practitioners from a few dozen to hundreds. This was arguably the Swedish Astronomical Society's most important contribution to amateur astronomy in the first half of the twentieth century.

The introduction of ATM also opened Swedish amateur astronomy up to other developments. With several hundred participants, the community reached a critical mass. The Swedish Astronomical Society tried its best to handle the newborn interest, but local clubs did most of the organizing. Beginning in the mid-1950s, amateur clubs were formed in most big cities, often with first-generation ATM enthusiasts in leading positions. All the accoutrements of modern amateur astronomy followed: club observatories, bulletins, workshops, star parties, observing projects, etc. It is safe to say that the ATM movement, as imported from the United States in the 1940s, laid the foundation for the later development of Swedish amateur astronomy.

ATM proved to be of great importance in both the United States and in Sweden. For several decades, it was the poor man's route to the stars, a means of circumventing the price tags for commercial telescopes. More research needs to be conducted, but similar patterns are sure to emerge for other countries. The role that the specific American tradition has played in these cultures is, however, another question. Germany and the UK had their own ATM traditions, probably making them less receptive to American influence (for the British tradition, see Chapman, 1998). How about Greek, Italian and Russian amateur astronomy? Another issue is the nature of these influences. Swedish amateurs were inspired by and learned a great deal from American ATM, although appropriating it to a pre-existing optical tradition. Several leading Swedish ATM enthusiasts, including Ragnar Schöldström, had acquired professional know-how as opticians. The various ATM traditions have certainly had their own particular flavors depending on local optical traditions, the point at which they emerged and socio-economic factors.[10]

7 NOTES

1 This paper is an offshoot of a recent research project concerning the history of Swedish amateur astronomy. This three-year project, directed by the author and Gustav Holmberg from Gothenburg University, was launched in 2013 and funded by the Bank of Sweden's Tercentenary Foundation. The paper draws on a longer chapter in Swedish for a forthcoming monograph (Holmberg and Kärnfelt, n.d.).

2 Scientific instruments have received renewed attention from historians of science during the last few decades (e.g., see Taub, 2011; van Helden and Hankings, 1994). From an American point of view, the instruments of amateur astronomers have been studied by Cameron (2010). Australian and New Zealand ATM is discussed by Orchiston (2003; 2016: Chapter 12) and Orchiston and Bembrick (1995). Finally, the Spanish ATM tradition recently has been discussed by Ruiz-Castell (2016).

3 A second expanded edition appeared in 1928, followed by several others. The current edition contains three volumes totaling more than 1,500 pages (cf. Willmann-Bell Inc.: www.willbell.com/tm/tm7.htm).

4 The sources are too many to cite here, but they include articles about amateur observatories published in journals, correspondence with astronomers, recollections, biographical notes, etc. Even though additional telescopes were probably in use, especially in the lower aperture range, the graph represents a good estimate of the scene among Swedish amateurs in the early twentieth century.

5 As far as I know, no Swedish pricelists have been preserved, so this estimate is based on a British counterpart for the 1928 Carl Zeiss catalog and historical exchange rates. The instrument in question, the "Asestaria," can be found in Carl Zeiss (Jena) (1928: 19). Prices are from Carl Zeiss (London) (1928). Historical exchange rates are from the Bank of Sweden (2016).

6 Schöldström's piece in *Teknik för alla* was followed by three do-it-yourself articles by Olle Norelius (1943).

7 To my knowledge, Swedish amateurs made only two attempts to build telescopes before the 1940s (not counting the above-mentioned glass lens telescopes). One was an utter failure. In the early 1910s, artist Hans Erlandsson, inspired by the Herschels, tried to cast and grind a 370-mm speculum mirror (Erlandsson, 1941). Once finished and tested, Erlandsson notes, the mirror was powerful enough to light a cigar at the focal point while the mirror was aimed at the Sun, but unfortunately the optical quality made it useless under the stars. He later sold the mirror to a scrapyard. A more successful attempt was made by police officer, Tore Sjögren, in the early 1930s. Using a German ATM manual and hunting down all necessary material himself, he managed to grind a small mirror and build a fully operational reflector telescope (Sjögren, 1941). Later Sjögren became an important promoter of ATM within the Gothenburg circle of amateur astronomers.

8 With regard to Öhman, see Holmberg (2008). A journal kept while he was a youthful amateur has been preserved in the Yngve Öhman archives, Center for the History of Science, Royal Swedish Academy of Science, Stockholm.

9 Editions from written remarks on pricelists for mirror grinding materials in Clas Ohlson archive, Insjön (Pricelists, 1955, 1957, 1965, 1966 and 1967).

10 A recent paper on Spanish amateur astronomy during Franco's rule indicates that ATM became integral to the goal of creating spaces for instruction and socialization that were not directly controlled by the regime (Ruiz-Castell, 2016). Previous and yet un-published research has demonstrated that ATM also played a vital role on the Portuguese scene when naval officer and advanced amateur astronomer Conceição Silva (1903–1969) took charge of the Gulbenkian Planetarium and started to use it as a platform to promote amateur astronomy (Raposo, 2014, cf. Ré, 2007). Lastly, a study of the Australian ATM tradition has shown how some advanced

amateurs chose to appropriate and develop more complex telescope designs popularized in the USA, including Buckroeders, Maksutovs, Schiefspeiglers and Wrights (see Orchiston, 2003).

8 ACKNOWLEDGEMENTS

The author wishes to express his gratitude to the anonymous referees for their many useful comments, and to Gustav Holmberg and the participants in a session he arranged with the author at the Science and Technology in the European Periphery (STEP) conference in Lisbon in September 2014. Finally, the author would like to thank English language editor Ken Schubert, whose painstaking efforts have greatly contributed to the international viability of this paper.

9 REFERENCES

Advertisement, 1944/45. Teleskop: Bygg själv en stjärnkikare [Telescope: Build Your own Telescope]. *Clas Ohlson Catalogue*.

Anonymous, 1936. Review of Albert Ingalls (ed.), *Amateur Telescope Making* (4th edition, 1935). *Populär Astronomisk Tidskrift*, 17, 79.

Anonymous, 1943. Bygga teleskop, en förnämlig hobby [Building Telescopes, a Distinguished Hobby]. *Svenska Dagbladet*, 1 October.

Anonymous, 1944. Intressant utställning av hemmagjorda speglar och linser [Interesting Exhibition of Homemade Mirrors and Lenses]. *Svenska Dagbladet*, 7 October.

Bank of Sweden 2016. homepage: www.riksbank.se/sv/Rantor-och-valutakurser/Aldre-valutakurser-forskningsprojekt/Manatliga-valutakurser-1913-2006/.

Barton, W.H., and Maron, J., 1951. *Rolig Astronomi*, Stockholm, Natur & Kultur.

Beaty, J., 2015. Odyssey of a Wayward Telescope Nut: Memories of my First Stellafane Convention Half a Century Ago. Stellafane homepage, https://stellafane.org/stellafane-main/history/early/beaty.html.

Cameron, G., 2010. *Public Skies: Telescopes and the Popularization of Astronomy in the Twentieth Century*. Ph.D. Thesis, Iowa State University.

Carl Zeiss (Jena), 1928. *Zeiss telescopes* (Astro 80) (www.geogdata.csun.edu/~voltaire/classics/zeiss/zeiss_1928_catalog.pdf).

Carl Zeiss (London), 1928. Zeiss Telescope Price Sheet (www.geogdata.csun.edu/~voltaire/classics/zeiss/zeiss_price_list_28.pdf

Chapman, A. 1998. *The Victorian Amateur Astronomer: Independent Astronomical Research in Britain, 1820–1920.* Chichester, Praxis Publishing.

Clas Ohlson Catalogue, 1956-57. Clas Ohlson Inc.

Erlandsson, H., 1941. Några upplevelser som amatörastronom [Some Experiences as an Amateur Astronomer]. Lund, *Tycho Brahe-sällskapets årsbok*. Pp. 125–134.

Grabe, A., 1943. Något om amatörmässig framställning av speglar för spegelteleskop [Something on Amateurs Making Mirrors for Mirror Telescopes]. *Populär Astronomisk Tidskrift*, 24, 15.

Holmberg, G., 2008. Yngve Öhman, utbyteszonerna och svensk solforskning under efterkrigstiden [Yngve Öhman, Trading Zones and Swedish Solar Research During the Post War Period]. In Widmalm, S. (ed.), *Vetenskapens Sociala Strukturer: Sju Historiska Fallstudier om Konflikt, Samverkan och Makt*. Lund, Nordic Academic Press.. Pp. 167–190.

Holmberg, G., and Kärnfelt, J., n.d. *Kärlek till stjärnorna: Den svenska amatörastronomins historia 1900 till idag* [*Love for the Stars: The History of Swedish Amateur Astronomy 1900 until Today*]. In preparation.

Ingalls, A.G., 1926. *Amateur Telescope Making*. New York, Scientific American Publishing Co.

Kärnfelt, J., 2004. *Till Stjärnorna: Studier i Populärastronomins Vetenskapshistoria under Tidigt 1900-tal* [*To the Stars: Studies in the History of Popular Astronomy During the Early Twentieth Century*]. Gothenburg, Folkuniversitetets Akademiska Press.

Kärnfelt, J., 2015. Follow the information: comets, communicative practices and Swedish amateur astronomers in the twentieth century. *Journal of Astronomical History and Heritage*, 18, 161–176.

Lindhed, D., 1946. Ett Bekvämt Spegelteleskop, del 2 [A Confortable Reflector Telescope, part 2]. *Populär Astronomisk Tidskrift*, 27, 54–57.

Norelius, O., 1943. Nu bygger vi ett spegelteleskop, del 1-3 [Let's build a Reflector Telescope, Part 1-3]. *Teknik för alla*, nr 26, 28 and 30.

Öhman, Y., 1944a. En utställning av amatörtillverkade teleskop [An Exhibition of Amateur Made Telescopes]. *Populär Astronomisk Tdskrift*, 25, 99.

Öhman, Y., 1944b. Okular, planspegel och sökare för amatörtillverkade teleskop [Eyepiece, Plane Mirror and Finder for Amateur Made Telescopes]. *Populär Astronomisk Tidskrift*, 25, 59.

Öhman, Y., 1948. Amatörtillverkade teleskop [Amateur Made Telescopes]. *Populär Astronomisk Tidskrift*, 29, 175.

Orchiston, W., 2003. Amateur telescope making in Australia: an historical perspective. In Cook, W.J. (ed.), *The Best of Amateur Telescope Making Journal*, *Volume 2*. Richmond, Willmann-Bell. Pp. 208–239.

Orchiston, W., 2016. *Exploring the History of New Zealand Astronomy; Trials, Tribulations, Telescopes and Transits*. Cham, Springer.

Orchiston, W., and Bembrick, C., 1995. The role of the large reflecting telescope in amateur astronomy: an Australian case study. *Australian Journal of Astronomy*, 6, 53–74.

Porter, R.W., 1921. The poor man's telescope. *Popular Astronomy*, 29, 527–536.

Pricelists, 1955, 1957, 1965, 1966 and 1967, Clas Ohlson archive, Insjön.

Ré, P., 2007. Eugénio Conceição Silva (1903–1969), pai da Astronomia de Amadores em Portugal. *Astronomia de Amadores, revista da Associação Portuguesa de Astrónomos Amadores*, nr 32. (http://www.astrosurf.com/re/e.c.silva_1903_1969_bw.pdf)

Protokoll, Svenska astronomiska sällskapet [Minutes of the Swedish Astronomical Society], 26 February 1943. § 7, Swedish Astronomical Society's Archive, Secretary, Stockholm.

Raposo, P., 2014. Artificial Skies and Real Telescopes: Conceição Silva (1903–1969). The Gulbenkian Planetarium, and the ATM movement in Port-

ugal, conference presentation, 9th STEP Meeting: Science and Technology in the European Periphery, Lisbon, Portugal.
Ruiz-Castell, P., 2016. Making telescopes and partying with the stars: amateur astronomy in Spain during Franco's dictatorship. *Journal for the History of Astronomy*, 47, 194–209.
Schöldström, R., 1943a. Kniveggsprovet och dess tillämpning vid tillverkning av teleskopspeglar [The Knife Edge Test and its Use at the Manufacturing of Telescope Mirrors]. *Populär Astronomisk Tdskrift*, 24, 109.
Schöldström, R., 1943b. Ett amatörtillverkat spegelteleskop [A Reflector Telescope Made by Amateurs], *Populär Astronomisk Tidskrift*, 24, 119.
Schöldström, R., 1943c. Amatörtillverkade teleskop [Amateur Made Telescopes]. *Teknik för alla*, 23, 15.
Schöldström, R., 1943d. *Hur gör man ett spegelteleskop: Handledning och ritningar* [How to Make a Reflector Telescope: Instructions and Drawings]. Insjön.
Schöldström, R., 1944. En stjärnkikare för en spottstyver [A Telescope for a Mere Trifle]. *Levande livet*, 5, 11.
Sjögren, T., 1941. Observatoriet i Hovås ved Göteborg [The Hovås Observatory in Gothenburg]. *Nordisk Astronomisk Tidsskrift*, 22, 4.
Swedish National Board of Health and Welfare, (1965), *Löner 1962, del 1: Industritjänstemän, handelsanställda m.fl*. [Wages 1962, part 1: Industry officials, commercial workers and others], Stockholm.
Statistiska centralbyrån, (1935), *Statistisk årsbok för Sverige 1935* [Statistical Yearbook for 1935].
Stattin, J., 2007. *Hobbyentusiaster och folkhemsbyggare* [*Hobby Enthusiasts and Social Engineers*]. Stockholm, Carlsson.
Stellafane convention's homepage: www.stellafane.org/history/index.html.
Svenskt Biografiskt Lexikon, 1969. Alf Grabe https://sok.riksarkivet.se/sbl/Presentation.aspx?id=13119.
Taub, L., 2011. Introduction: Reengaging with instruments. *Isis*, 102, 689–696.
Tobin, W., 1987. Foucault's invention of the silvered-glass reflecting telescope and the history of his 80-cm reflector at the Observatoire de Marseille. *Vistas in Astronomy*, 30, 153–184.
van Helden, A., and Hankings, T.L., 1994. Introduction: instruments in the history of science. *Osiris*, 9, 1–6.
Williams, T., 2000. *Getting Organized: A History of Amateur Astronomy in the United States*. Ph.D. Thesis, Rice University (http://hdl.handle.net/1911/19569).
Willmann-Bell Inc.: www.willbell.com/tm/tm7.htm

Johan Kärnfelt is Associate Professor (docent) in History of Ideas and Learning in the Department of Literature, History of Ideas and Religion, at Gothenburg University. His research is at the cross-roads between history of science (and especially history of astronomy) and science communication studies and public understanding of science. His focus has been mainly on the nineteenth and twentieth centuries and on Swedish material. Currently he and Gustav Holmberg, Gothenburg University, are researching the history of Swedish amateur astronomy. Through the Center for History of Science of the Royal Swedish Academy of Sciences in Stockholm, Kärnfelt also is coordinating a larger research programme that studies the history of Swedish science during the modern era (the eighteenth to twentieth centuries), and focuses on the Royal Swedish Academy of Sciences.

Journal of Astronomical History and Heritage, 20(1): 136–142 (2017).

BOOK REVIEWS

***Sternbilder des Mittelalters und der Renaissance: Der gemalte Himmel zwischen Wissenschaft und Phantasie*, Volume 2, three books by Dieter Blume, Mechthild Haffner and Wolfgang Metzger. (Berlin, Walter De Gruyter GmbH, 2016). Pp. 1,660. ISBN 978-3-11-037601-2 (hardback), 220 x 290 mm, €298.**

The second segment of this enormous contribution to art historical scholarship encompassing illustrated astronomical manuscripts from the start of the thirteenth through the fifteenth centuries has arrived. It is even more comprehensive than the first set of two volumes produced by the same three art historians in 2012; both works are in German. The initial volumes included illustrated astronomical manuscripts created between the ninth and twelfth centuries. Each set provides full details of pertinent information, including commentaries, related essays and a small selection of illuminations from each manuscript.

The most recent publication consists of a voluminous three-volume set; just lifting them is almost a herculean task. The most recent volumes follow the same organizational pattern as the original two-volume set and are printed on high quality paper. All material in the three volumes is collaborative, credited to the trio of authors; none is given individual credit for any of the commentaries or detail work.

The first two books, consisting of 1,031 pages numbered consecutively, begin with eight substantial essays that discuss several key illustrated astronomical manuscript traditions such as Michael Scotus, al-Ṣūfī, and the Germanicus Aratea. The authors' commentaries most conveniently include the illustration numbers in the margin next to the images they are discussing. These initial essays are followed by a listing of surviving astronomical manuscripts, all produced between the start of the thirteenth and the end of the fifteenth centuries; these are held in libraries throughout Europe, the United States, and one in Turkey. Each individual manuscript receives a thorough description including codicology (the study of medieval manuscripts and their place in history and culture), the author of the astronomical text on each folio, a commentary, a complete listing of the miniatures, the provenance, and relevant scholarly literature. The initial volume of this massive work covers 67 different manuscripts; the second volume picks up with number 68 and continues to number 143 and adds a celestial globe produced in the fourteenth century and a celestial ceiling in the Old Sacristy of San Lorenzo, Florence created in the mid-fifteenth century. The third volume of the set contains a selection of illuminations from each described manuscript; the initial illuminations are in color, 38 pages in all; the total comprises 1,237 manuscript illustrations and 22 images of the astronomical globe and frescoed ceiling for an enormous total of 1,259 photographic images. The comprehensive bibliography of pertinent scholarly literature itself it a valuable resource as it covers 38 pages.

These three volumes, in addition to the earlier publications covering astronomical manuscripts from the Carolingian era to the start of the Gothic, obviate the need previously required to visit a large number of libraries to consult astronomical or astrological texts and view the images. This second set of books includes the especially creative and expansive period of astronomical advances that became available to the Latin West after the translation period of the twelfth century in Spain and Sicily. At that time, European scholars acquired an entirely new assemblage of texts thought entirely lost, including Ptolemy, Plato, Aristotle and the Hellenistic astrologers. This convenient and invaluable resource provided a prodigious contribution of ancient and Islamic knowledge and opened a whole new world of research opportunities for those studying scientific data and research. By organizing and cataloging a large quantity of information from the most prominent authors of fundamental astronomical data, the authors have created a new resource tool of great erudition.

Due to the increased interest in astronomical and astrological topics and a wider distribution of wealth at the time, the numbers of illuminated manuscripts that were produced and survive from the later Middle Ages and early Renaissance is shown to be enormously greater than those extant from the earlier Medieval period. These manuscripts are more varied in their textual compositions and much more experimental and creative in their illustrative iconography. The fascination with the Classical past that develops during the Renaissance can now be easily accessed by viewing the evolution and expansion of various authors' writings and illustrations. One can witness why the long-held viewpoint of Fritz Saxl (1890–1948) and others, that the artistic interest during the Renaissance was strictly to recreate images and artworks of the Classical past, has been challenged. The images gathered for this edition prove that patrons and artists commissioning and creating manuscripts in the fifteenth century were extremely creative in designing and implementing entirely new constellation and astrological illuminations.

Some constellation cycles, such as the Aratea of Cicero and Germanicus retained their very traditional images based on Late Antique prototypes and the astronomy of Aratus, derived from Eudoxus, but their poetic text describing the rising and setting of the forty-two to forty-six Ptolemaic constellations became corrupted through the centuries, augmented with myths from Hyginus and overwhelmed with commentaries and scholia.

Other traditions, for example the al-Ṣūfī (903–986) *Kitāb Ṣuwar al-Kawākib al-Thābita* (*Book of Pictures of Fixed Stars*), and its Latin translations, the al-Ṣūfī Latinus manuscripts can be traced through this resource, as the precisely-placed stars of each constellation are carefully recorded. In the original manuscript of al-Ṣūfī (although only early copies survive—see Hafez et al., for details), he plotted the individual stars by name and even devised his own system for indicating their magnitudes (Hafez et al., 2015a, 2015b); he also noted their colors. His writings combined native Bedouin astronomy with his Persian sources that consisted of a consolidation of Babylonian, Indian and Greek astronomical knowledge. The Ṣūfī Latinus copies circulating in the West retained that stellar accuracy, so that by studying these, one could actually locate and identify a constellation in the night sky. By following the series of copies published in these volumes, it is possible to witness the attention continually paid to positioning each star accurately. Identifying a constellation from a manuscript drawing was not possible before al-Ṣūfī's masterpiece became known, for in Latin constellation images, the stars were simply sprinkled at random (except for the Leiden Aratea, c. 820) which had the correct number of stars as per Ptolemy, but not their accurate positioning (see Dekker, 2010). These reference books provide a rich resource to locate numerous diverse astronomical works from the Middle Ages.

Another important group of manuscripts discussed is that of Muhammad Abū Maʿshar al-Balkhī (787–886), who according to John North (2008: 195 traditions – the Greek, the Indian, the Iranian and the Syrian." Abū Maʿshar (Latinized to Albumasar) worked in Baghdad under the Abbasid Caliphate al-Maʾmūn (813–833), as court astronomer and astrologer. His writings on astronomy and especially on astrology reintroduced the 'wretched' topic into Western science and became enormously influential. A mysterious author Georgius Zothorus Zaparus Fendulus is credited with writing an abridged and illustrated version of a Latin translation of *Introductorium maius in astronomiam*, by Abū Maʿshar, completed by Hermann of Carinthia in Toledo about 1140. This translation and interpretation was inspired by Hermann's work, commonly called the *Greater Introduction.* Illuminations from a thirteenth-century manuscript, Paris BN Ms. lat. 7330, are pictured in color in *Sternbilder des Mittelalters* …, including a full-page image of Fendulus on folio 1 wearing the garb of a Muslim potentate; these images and their text help to explain the astrological sources and various aspects of the paranatellonta (stars or asterisms on either side of a constellation that help to identify the zodiacal signs when the constellations are not clearly visible) and decans (used by Egyptians to represent each ten degrees of the zodiacal circle amounting to thirty six).

By the mid-twelfth century manuscript production had expanded far beyond the work of lone monks or scriptoria behind thick monastic walls, to the domain of lay scribes and artists in dynamic urban workshops creating texts for the wealthy and for new urban schools and universities. Each illuminated astronomical manuscript, as a condensed cultural and educative object, tells a fascinating story all its own, constituted by its patron, designer, scribe and artist. Each has complex historical roots with associations that continually change according to time, place and other factors. Every codex requires design choices in organizing text, decoration and illustration—no two are alike. Surprisingly, even when looking at what appears to be an exact copy, there are always slight differences that reveal pertinent information. Because of these complex interactions, medieval illustrated manuscripts provide a window into the beliefs, practical knowledge and particular interests of their patrons and users.

Other than Ptolemy, most authors of astronomical treatises in the Middle Ages included a full cycle of constellation illustrations as well as a celestial map and planetary diagrams. Most illuminated manuscripts were quite labor-intensive and extremely costly to produce when considering the cost of parchment, precious minerals and plant substance for paints, and sheets of gold for enhancements. Of course, the more elaborate the manuscript presentation, the better were its chances for survival. In contrast astronomical manuscripts did not require precious minerals or costly pigments but were still a product requiring significant material and human resources.

Although by far the most popular astronomical treatise in the later Middle Ages, the *de Sphaera* of Sacrobosco (ca. 1195–1244), the English monk, scholar and astronomer, does not appear in this work. His composition was one of the most influential and widely-used textbooks throughout Europe for almost 500 years, remaining popular until its astronomical information became outmoded at the start of the scientific revolution in the seventeenth century, but his manuscripts do not include an illustrated constellation cycle. Sacrobosco's surviving texts are often embellished with astronomical diagrams that helped to clarify his descriptions of solar, lunar and planetary motions; hundreds of medieval manuscripts of Sacrobosco's *de Sphaera* survive, but they are not included.

Among the essays published in this book is a discussion and partial explanation of an outburst of production of illuminated manuscripts containing the Aratea of Germanicus in the fifteenth century. They reveal a fascinating story of an early Germanicus manuscript that had been discovered in Sicily between 1465 and 1467 which was transferred directly to the Kingdom of Naples where King Ferdinand d'Aragon (or Ferrante) then reigned after a contentious takeover by his father Alfonso d'Aragon. A document survives that demonstrates that the ancient astronomical manuscript was copied there almost immediately, in either 1467 or 1468; it was copied at least three more times by humanist scholars and scribes at the court of Naples. A copy of this Germanicus manuscript was then taken to Florence where it was reproduced for the Medici court, Francesco Sasetti and for Frederico da Montefeltro. Unfortunately the original 'newly discovered' manuscript is now lost, but text scholars have determined that it was based on a manuscript now in Madrid, which itself had an earlier exemplar. Thus the twelfth century manuscript was regarded as an extraordinary find, leading to antiquity; it was reproduced multiple times, accounting for many of the twenty-six Germanicus Aratea surviving from the fifteenth century. The explosion of illuminated astronomical manuscripts during the fifteenth century Italian Renaissance was also inspired in part by the rise of humanism.

This set of volumes encompasses the highest peak of medieval manuscript production as well as its conclusion, for the appearance of less-expensive printed books initiated the elimination of those handmade. *Sternbilder des Mittelalters* … provides new and invaluable research assistance for scholars investigating not only the transmission of medieval astronomy and astrology, but also mythology, classicism, history, historiography, education, science and medicine. The authors will be greatly thanked for their efforts many times over.

References

Dekker, E., 2010. The provenance of the stars. In the Leiden Aratea picture book. *Journal of the Warburg and Courtauld Institutes*, 73, 1-37.

Hafez, I., Stephenson, R.F., and Orchiston, W., 2011. ʹAbdul-Raḥmān al-Ṣūfī and his *Book of the Fixed Stars*: a journey of re-discovery. In Orchiston, W., Nakamura, T., and Strom, R. (eds.). *Highlighting the History of Astronomy in the Asia-Pacific Region. Proceedings of the ICOA-6 Conference*. New York, Springer. Pp. 121–138.

Hafez, I., Stephenson, R.F., and Orchiston, W., 2015a. The investigation of stars, star clusters and nebulae in ʹAbd al-Raḥmān al-Ṣūfī's *Book of the Fixed Stars*. In Orchiston, Green and Strom: 143–168.

Hafez, I., Stephenson, R.F., and Orchiston, W., 2015b. ʹAbd al-Raḥmān al-Ṣūfī's 3-step magnitude system. In Orchiston, Green and Strom: 169–177.

North, J., 2008. *An illustrated History of Astronomy and Cosmology*. Chicago, University of Chicago Press.

Orchiston, W., Green, D.A., and Strom, R. (eds.), 2015. *New Insights from Recent Studies in Historical Astronomy: Following in the Footsteps of F. Richard Stephenson. A Meeting to Honor F. Richard Stephenson on His 70th Birthday*. Cham, Springer.

Dr Marion Dolan
Independent scholar, Deerfield Beach, Florida, USA.
Email: mdolan79@hotmail.com

***The Complex Itinerary of Leibniz's Planetary Theory* by Paulo Bussotti (Birkhauser/ Springer, 2015; Science Networks Historical Studies 52). Pp. x + 188. ISBN 978-3-319-21236-4 (hardback), 240 x 163 mm, €103.99.**

This informative study provides illuminating new insight into an otherwise somewhat dark corner of Leibniz's physical theory.

Leibniz had no problem with the mathematics of Newtonian planetary theory. But he was dissatisfied with its metaphysics. For Newtonian gravitation was at odds with his own conception of the fundamentals of natural philosophy. And so Leibniz wanted a planetary theory very different from Newton's. Along with many other contemporaries he was committed to the idea that all explanation of the processes of physical nature must proceed on mechanical principles. He rejected gravitation and action at a distance because he saw it as fundamentally at odds with his Law of continuity. Accordingly he, like Descartes and others before him, wanted to explain the phenomena of planetary theory by means of vortex theory. This led him to a Kepler-inspired process of 'harmonic circulation' (*circulatio harmonica*). As Leibniz worked out the mathematics needed to implement these physical interactions he developed a neo-Keplerian planetary physics whose 'complex itinerary' is set out by Bussotti with great detail and in close coordination with the Leibnizian texts and with extensive heed of the relevant literature.

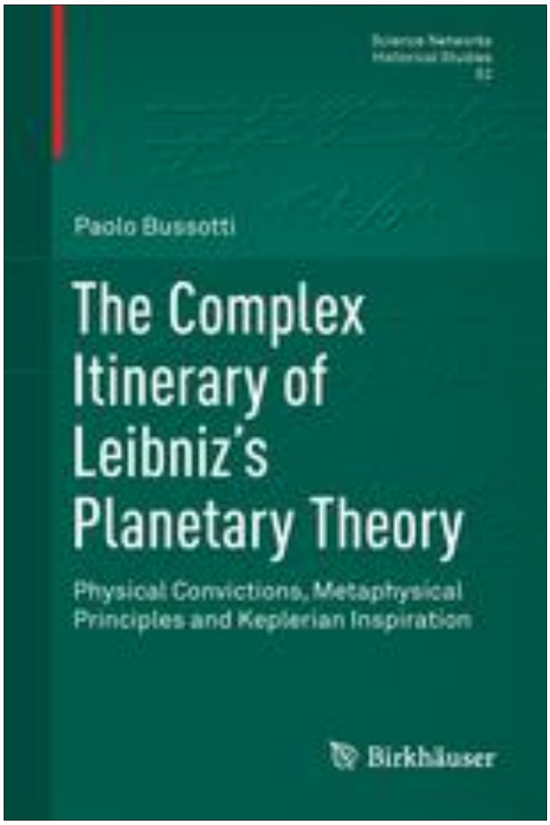
As Bussotti sees it, when Leibniz worked out his theory of planetary motion in the so-called *zweite Bearbeitung*, this led him to maintain: "(1) that 'harmonic circulation' is due to a [global] aether spread throughout the whole solar system; (2) Gravity on earth is due to the [local] aether surrounding our planet. And there are two possible hypotheses as to how gravity acts [viz. either by a 'radiation' due to an expansive impetus (*conatus explosivus*) or by a centrifugal force of an aetherial fluid]; (3) the difference between the specific weights of materials is due to yet a third aetherial fluid, more tenuous than the second [local] one, which, in its turn; is yet more tenuous than that [global] aetherial fluid responsible for harmonic circulation." (Bussotti, p. 98).

The cogency of its mathematical articulation does not altogether compensate for the physical cumbersomeness of Leibniz's planetary mechanics. Why was Leibniz willing to pay this price?

As Bussotti sees it, "… if action at a distance were true, the whole metaphysics of Leibniz would collapse, and not only his physics." (p. 152). Bussotti's reasoning to this conclusion is left somewhere between obscure and missing. But I think it can be supplied. Leibniz and Kepler alike were both influenced by and deeply sympathetic to a neo-Platonic view of cosmic order and harmony which included a commitment to principles like harmony, continuity, and economy. Now contact interaction can be accounted for lawfully via action/reaction, continuity conservation of energy etc. But if there were action at a distance, no reason could be given why it should take this form or that (inverse square rather than inverse cube). And this would violate the most fundamental principle of Leibnizian metaphysics: the Principle of Sufficient Reason.

In the end, Leibniz is prepared to accept the cumbersomeness of his aether-based cosmology because for him the complexity of nature's phenomena (of process) can be more than offset by the elegance of nature's laws (of processuality).

What Bussotti has given us is a highly instructive example of the interplay of technical science and theoretical metaphysics in the rare case of a thinker who was a master-mind in both domains.



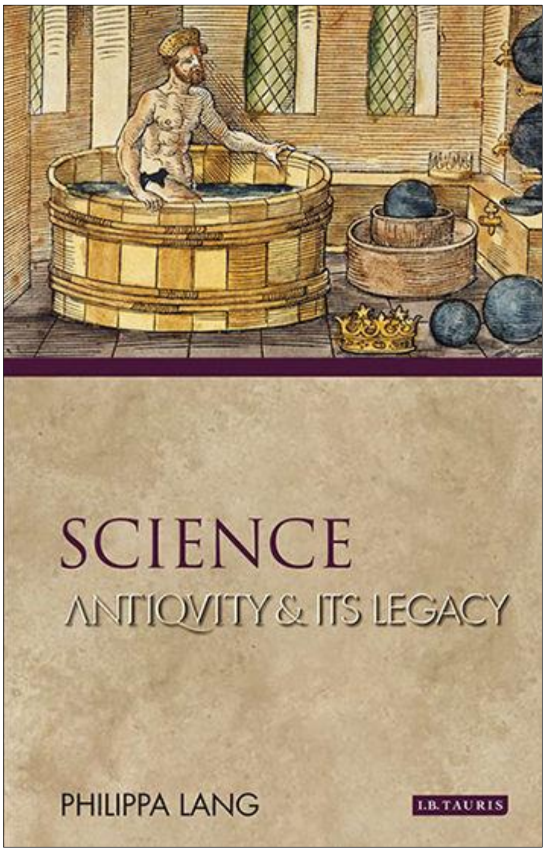
In concluding, I give reluctant voice to one minor caveat. It would have been good to have a native English speaker go over the text. Such a helper would have revised such passages as "… the inertia principle in his theory is a significant subject to catch the features of Leibniz's physics, inside which planetary theory is inscribed." (p 32). It is regrettable to have such avoidable infelicities mar so excellent a work of scholarship.

Professor Nicholas Rescher
Center for Philosophy of Science,
University of Pittsburgh,
Pittsburgh, USA.
Email: rescher@pitt.edu

***Science: Antiquity & Its Legacy* by Philippa Lang. (I.B. Tauris, London and New York, 2016). Pp. xiv + 226. ISBN 978 1 78076 171 8 (hardback), 143 x 233 mm, US $95.**

This is part of a series of books in the Ancients and Moderns Series by I.B. Tauris. Other titles have explored such varied topics as Medicine, Gender, Slavery, War and Religion. This volume is written by Philippa Lang, who was Professor of Classics at Emory University from 2004 to 2013.

Her Masters and Doctoral dissertations both focused on medicine in the ancient world, especially Ptolemaic Egypt. That is reflected in this book, where she devotes forty pages to the topic of illness and disease.



She engages with astronomical issues in various places. One is calendar reform. After a rather perfunctory survey of the development of the Julian and Gregorian systems, she offers an important observation on Julius Caesar's reliance on advice from Sosigenes of Alexandria:

> Authority had shifted from religious authority and civic officialdom to the astronomer ... Astronomical and mathematical expertise had created a new international technocracy ... The Julian calendar marks the first moment in Western history in which astronomy superseded other kinds of expertise in defining time (and place). (p. 138).

Lang also does a fine job at relating analog computers to the ancient Greek Antikythera mechanism (which I recently saw on display in Athens). Its 32 bronze gears, and others that may have existed, were able to show the motions of the planets, the phase of the Moon and the rising/setting of certain stars. “A slide rule is an analog computer of a mechanical kind,” she explains. “The Antikythera mechanism is much more like a very complicated slide rule than a Mac or PC or a smartphone.” (p. 161). She uses the chance discovery of this mechanism to remind us of how we might either underestimate or misrepresent ancient science and technology.

The author identifies attempts to explain the motion of the planets in the sky, both eastwards and westwards, as a prime “… impetus of Greek astronomy.” (p. 182). This leads Lang into a discussion of the role of Ptolemy in the development in meteorology and astrology. She argues it “… was the movement of the planets in relation to the fixed stars …” (p. 184) that led Ptolemy to link these to weather and climate. These varying environments, in turn, partially formed a person's character. Ptolemy's version of astrology, says Lang, was a weak one. Even Ptolemy conceded many astrologers were charlatans.

Lang notes that

> It is ironic that Ptolemy, a leading and influential mathematician and theorist of the ancient world, would be hopelessly adrift in cosmology if transported into the present, but could still make a perfectly good living as an astrologer. (p. 188).

This quote offers a good idea of how this book is being pitched. Professional historians of astronomy will find nothing new here; rather, it is a very fine overview of ancient science and how modern culture can relate to it, and vice versa. It could be used as a supplementary text in an advanced high school or introductory university class, to provide an easily readable way for students to put broad scientific concepts in context.

Dr Clifford J. Cunningham
National Astronomical Research Institute
of Thailand, Chiang Mai, Thailand.
Email: Cliff.Cunningham@usq.edu.au

***The Invention of the Achromatic and Aplanatic Lens With Special Regard to the Role Played by Samuel Klingenstierna*, by N.V.E. Nordenmark and Johan Nordström. Edited by Roger C. Ceragioli; translated into English by Elisabeth Goodwin. (A Special Publication of the Antique Telescope Society: *Journal of the Antique Telescope Society*, Issues 39-40, 2016). Pp. [ii] + 142. No ISBN or ISSN (hardback), 220 x 288 mm, no price.**

For those of us with an interest in the history of the telescope, an important publication was the 2-part paper by N.V.E. Nordenmark and J. Nordström on the invention of the achromatic and aplanatic lens, but this was published in Swedish in the 1930s and in a journal that was not easily available world-wide.

Dr Roger Ceragioli and Elisabeth Goodwin have now solved this problem for us by translating the Swedish paper into English, but they have done more: they have combined the original two-part paper into a single attractive hardcover publication; brought all of the references together as a single listing; and introduced three new appendices. Ceragioli and Goodwin state:

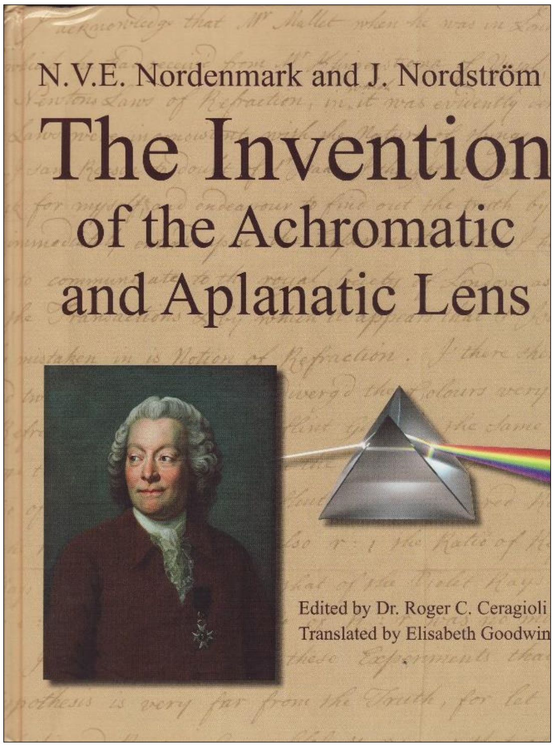
> By performing this labor, we hope at long last to bring Nordenmark and Nordström's paper before a wider audience, so that it will have the impact that it deserves on the scholarship of the telescope. (p. 3).

The 'blurb' on the back cover nicely summarises the contents for this book:

> The invention of the achromatic lens in the 18th century was a watershed event in the history of optical technology, revolutionizing enquiry into the sciences. The invention was, however, long shrouded in confusion, with conflicting claims concerning who did (or knew) what and when.
>
> The present work … presents the first systematic attempt to clear away the confusion. It focuses on the central role of the mathematician Samuel Klingenstierna in the invention. It brings to bear a wealth of documents in the Swedish language – never before available in English translation – stemming from Klingenstierna's network of informants who travelled or were resident in the London area (where the device was invented) and Paris (where it was extensively developed).

The translation of Nordenmark and Nordström's two papers fill pages 8 to 79, and include numerous lengthy quotations drawn from letters and diaries. Along the way we encounter many familiar figures, including Isaac Newton (1643–1727), Chester Moor Hall (1703–1771), John Dollond (1707–1761), Jesse Ramsden (1735–1800), Leonard Euler (1707–1783), Alexis-Claude Clairaut (1713–1765), and of course Samuel Klingenstierna (1698–1765). We learn a great deal about the relationships between John Dollond and Jesse Ramsden and between Dollond and Samuel Klingenstierna. We also find Dollond curiously silent about the fact that Chester Moore Hall invented the achromatic telescope years before Dollond claimed to have done so.

Dollond and Klingenstierna both published hall-mark papers in the *Philosophical Transactions of the Royal Society*, in 1759 and 1761, respectively, and in 1760 Klingenstierna had published an earlier account, in Swedish, in the *Transactions of the Royal Swedish Academy of Sciences*. Yet in 1760, the astronomers of Paris were unfamiliar with the work of either scientist, primarily because the Seven Year's War had prevented regular communication between France and England. Once apprised of these international developments, Clairaut began his own research on refracting telescope optics, and in 1762 and 1764 he published two important papers in the *Historie de l'académie royale des sciences*.



One name that surprised me because it cropped up so often was that of the Swedish Professor of Astronomy, Bengt Ferner (1724–1802) who spent much time in England and in France, and very effectively communicated de-tails of Klingenstierna's work to Dollond and Klingenstierna and Dollond's achievements to the French (and arranged for them to purchase Dollond achromatic refractors). Ferner was an astronomical advocate *par excellence*, and was responsible for prodding Clairaut into action. Although he was not directly involved in optical design, Ferner served as a catalyst, and he deserves a place in the history of the refracting telescope.

Between pages 80 and 126 (inclusive), the book contains twelve Appendices. Most of these are letters that Nordenmark and Nordström included in their original publications, but there are three new ones. Two are letters from the archives of the Royal Society that relate to John Dollond and have never been published before. The third new Appendix is an English translation of a speech about recent improvement in the optics of refracting telescopes that Carl Lehnberg gave at the 17 October 1762 meeting of the Royal Swedish Academy of Sciences. The text of this speech has never before been published in English.

Finally, for those wishing to pursue this topic further, there are nearly 20 pages of References, many in the form of detailed and informative end-notes.

This 142-page book is well laid out and well illustrated. It is an invaluable resource for those with a research interest in the history of the refracting telescope, and is also an enjoyable read for those with a passing interest in the subject. The Antique Telescope Society is to be applauded for taking the trouble to publish this fine book. Copies can be obtained through the Society (http://antiquetelescopesociety.org).

Professor Wayne Orchiston
National Astronomical Research Institute
of Thailand, Chiang Mai, Thailand.
Email: wayne.orchiston@narit.or th