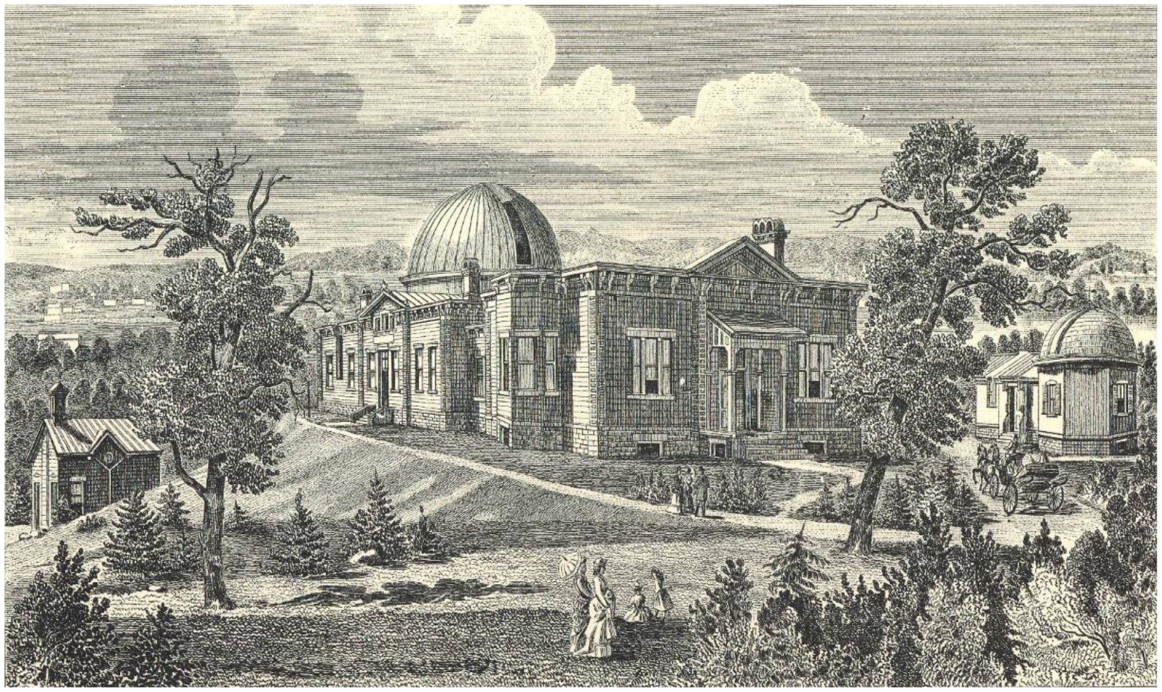
JOURNAL OF ASTRONOMICAL HISTORY AND HERITAGE



Vol. 20 No. 2 July/August 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
260 Moo 4
T. Donkaew
A. Maerim
Chiang Mai 50180
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

Two different images of the University of Wisconsin's Washburn Observatory in Madison (USA), which in 1882 purchased the 6-in (15.2-cm) Alvan Clark refractor from Sherburne W. Burnham that had already achieved a degree of fame through his double star discoveries. Initially, the 'Burnham Telescope' was housed in the Student Observatory shown in the lithograph to the right of the main building, but later it was installed in the Solar Observatory that is in the foreground in the photograph of the Washburn Observatory. The contribution that this historic telescope made to research is recounted by James Lattis on pages 177–194 in this issue of *JAHH*.

JOURNAL OF ASTRONOMICAL HISTORY AND HERITAGE

ISSN 1440-2807

VOLUME 20 NUMBER 2 JULY/AUGUST 2017

CONTENTS

Papers

Book Reviews

Published by the National Astronomical Research Institute of Thailand, 260 Moo 4,
T. Donkaew, A. Maerim, Chiang Mai 50180, Thailand.

Journal of Astronomical History and Heritage, 20(2), 144 (2017).

EDITORIAL

With this issue I would like to announce a change in the Editorial team: the appointment of a new Associate Editor, James Lequeux. James will be well known to many readers of *JAHH* through the various papers he has published in the journal over the past decade. Initially these dealt with aspects of early French radio astronomy (which is how I first came to meet him, through this IAU project), but later I enjoyed reading papers by him on a range of other topics, including one on the pioneering stellar photometry carried out by Charles Nordmann (Lequeux, 2010), whom James and I had met earlier because in 1901 Nordmann had attempted to detect solar radio emission (see Débarbat et al., 2006). Now, here is a little about James Lequeux.

> Dr James Lequeux was born in France and started radio astronomy in 1954 as a student. After a long military service, he observed discrete radio sources with a two-element interferometer using Würzburg antennas at Nançay (see Orchiston et al., 2007), and obtained his Ph.D. in 1962. Then he worked on the construction of Le Grand Radiotelescope at Nançay (Lequeux et al., 2010), before becoming very involved in the formation of the multi-national Institute of Radioastronomie at Millimeter Wavelengths, IRAM (Encrenaz et al., 2011).
>
> In 1966 James founded the first infrared astronomy group at Meudon campus of Paris Observatory, and was involved in the scientific programs associated with the Infrared Space Observatory (ISO) as an Associate Scientist. He was an Invited Scientist at CalTech in 1968–1969. Later, from 1983 to 1988 he was the Director of Marseilles Observatory.
>
> After a career in various fields of astrophysics, involving mainly research on interstellar matter and the evolution of galaxies, James retired in 1999 and his interests turned to the history of astronomy.
>
> James is currently affiliated with the LERMA group at Paris Observatory. He has more than 400 publications, including several books on aspects of astronomical history (e.g. see Lequeux, 2007, 2013; Lequeux and Bobis, 2010).
>
> For fifteen years James was one of the two Editors-in-Chief of the journal *Astronomy & Astrophysics*, so he brings to *JAHH* a world of experience in journal editing.

References

Débarbat, S., Lequeux, J., and Orchiston, W., 2007. Highlighting the history of French radio astronomy. 1: Nordmann's attempt to observe solar radio emission in 1901. *Journal of Astronomical History and Heritage*, 10, 3–10.

Encrenaz, P., Gómez-González, J., Lequeux, J., and Orchiston, W., 2011. Highlighting the history of French radio astronomy. 7: The genesis of the Institute of Radioastronomie at Millimeter Wavelengths (IRAM). *Journal of Astronomical History and Heritage*, 14, 83–92.

Lequeux, J., 2010. Charles Nordmann and multicolour stellar photometry. *Journal of Astronomical History and Heritage*, 13, 207–219.

Lequeux, J., 2013. *Le Verrier—Magnificent and Detestable Astronomer.* Springer International Publishing.

Lequeux, J., 2015. *Francois Arago: A 19th Century French Humanist and Pioneer in Astrophysics.* Springer International Publishing.

Lequeux, J., and Bobis, L., (eds.), 2010. *L'Observatoire de Paris, 350 Ans de Science*. Paris, Gallimard and Observatoire de Paris.

Lequeux, J., Steinberg, J.-L., and Orchiston, W., 2010. Highlighting the history of French radio astronomy. 5: The Nancy Large Radio Telescope. *Journal of Astronomical History and Heritage*, 13, 191–202.

Orchiston, W., Lequeux, J., Steinberg, J.-L., and Delannoy, J., 2007. Highlighting the history of French radio astronomy. 3: The Würzburg antennas at Marcoussis, Meudon and Nançay. *Journal of Astronomical History and Heritage*, 10, 221–245.

I know you will join me in welcoming Dr James Lequeux to the Editorial Team at *JAHH*.

We now receive enough copy to fill each issue of *JAHH*, but we always are happy to receive further unsolicited papers, especially about the astronomical history of nations that rarely feature in this journal or in others that publish on the history of astronomy. Our charter is to provide a truly-international perspective on astronomical history (including ethnoastronomy and archaeoastronomy). When preparing your MSS, please refer to the 'Guide for Authors' on our web site (www.http://www.narit.or.th/en/files/GuideforAuthors.pdf) for editorial guidelines. Note that we now make extensive use of colour throughout the journal.

Finally, I hope that you all have enjoyed the wider range of book reviews that now appear in *JAHH*. If you would like to prepare a review, or know of a new book someone else can review, please contact our Associate Editor, Dr Cliff Cunningham (asteroid4276@comcast.net).

Professor Wayne Orchiston
National Astronomical Research Institute of Thailand
Editor

Journal of Astronomical History and Heritage, 20(2), 145–154 (2017).

STUDYING THE HISTORY OF INDONESIAN ASTRONOMY: FUTURE PROSPECTS AND POSSIBILITIES

Wayne Orchiston
National Astronomical Research Institute of Thailand, 260 Moo 4,
T. Donkaew, A. Maerim, Chiang Mai 50180, Thailand.
E-mail: wayne.orchiston@narit.or.th

Abstract: In this paper I identify a number of research topics relating to Indonesian astronomical history that I feel are of international importance. Through these studies, Indonesia can make a valuable contribution to international history of astronomy.

I also will discuss the role of SEAAN's new Working Group on Astronomical History and Heritage, and the value of the *Journal of Astronomical History and Heritage* and proceedings of the ICOA conferences as outlets for papers about Indonesian astronomical history. Finally, I mention chapters about Indonesia that will appear in a forthcoming book on the early development of astrophysics in Asia.

Keywords: rice cultivation astronomy, temple alignments, de Houtman, 1868 and 1871 total solar eclipses; 1874 transit of Venus, *orang asli* astronomy, Macassan astronomy, Indonesian tektites, Bosscha Observatory variable star studies, SEAAN, *Journal of Astronomical History and Heritage*, ICOA-10, *The Emergence of Astrophysics in Asia*

1 INTRODUCTION

If we follow the lead of the International Astronomical Union we see that History of Astronomy covers many different niche areas, including ethnoastronomy, archaeoastronomy, 'Applied Historical Astronomy' and even the history of meteoritics. Some of these niche areas relate to Indonesia and its astronomical history and heritage.

In this paper[1] I will identify a number of research topics relating to Indonesian astronomical history that are of international importance. These include: *orang asli* astronomy, temple alignments, de Houtman and his star map, the 1868 and 1871 total solar eclipses, the 1874 transit of Venus, the history of Indonesian tektite and meteorite studies, and early variable star research at Bosscha Observatory and Riverview Observatory (in Australia).

2 INDONESIAN RESEARCH TOPICS

2.1 Astronomy and Lowland Wet Rice Cultivation

Hidayat (2011; see also Daldjoeni and Hidayat 1987) has published several very interesting papers in English on the astronomy associated with low-land wet rice cultivation in Central Java, and emphasized the importance of *pranotomangsa*. But how typical is this astronomical knowledge base of other parts of Java, let alone other islands within the Indonesian archipelago (cf. Ammarell, 1991)? Furthermore, Islam is the predominant religion in Indonesia, but most of those living in rural Bali are Hindus while many of those in rural Manado are Christians. Have these different religions imprinted themselves on the astronomical systems in these two localized regions of Indonesia?

Here we have an opportunity to carry out a succession of localised studies of the astronomical systems associated with low-land wet rice (*padi*) cultivation, by selecting, for example, from the various locations indicated by the red dots in Figure 1. Such studies are ideal small-scale projects for university students. Meanwhile, it is heartening to know that Sawitar (2015) has already examined the astronomical system of Balinese farmers, and Hose (1905) has examined rice-farming in Kalimantan, which are excellent steps in the right direction. I particularly look forward to reading a full account of Sawitar's study when he publishes it.

Lowland wet rice cultivation is found throughout Southeas Asia. In reference to Figure 1 and the black dots shown there, how do the various Indonesian astronomical systems compare and contrast with those found in rural Philippines (where Christianity is the principal religion), Malaysia (where Islam predominates) and Vietnam, Cambodia, Thailand and Myanmar (which are Buddhist countries)? Some comparative data already exist: Ammarell (1988; 2008) and Maass (1924) have published on the 'Indo-Malaysian archipelago', while Jaafar et al. (2015) recently studied the astronomical and ecological systems associated with rice cultivation in north-western Malaysia.

2.2 Temple Alignments

Central Java in particular it is well endowed with Hindu and Buddhist *candi*, and we can assume that most (if not all) of these had astronomical associations. Irma Hariawang and her collaborators (2011) have already written about the orientation of the eastern gateway at Borobudur (Figure 2), and other Javanese temples warrant similar analysis. Meanwhile, in India and Thailand for instance, Kameswara Rao and Thakur (2011) and Komonjinda (2010) have respectively examined the interior illumination of Hindu temples at different critical times of the year, while Stencil et al. (1976) have written about the astronomical parameters of Angkor Wat in Cambodia. Javanese *candi* also could be subjected to similar scrutiny.

Figure 1: Lowland wet rice astronomical systems in Indonesia and Southeast Asia (map modifications: Wayne Orchiston).

Figure 2: Candi Borobudur (en.wikipedia.org).

This raises the issue of the somewhat later, architecturally-distinct Hindu temples in Bali (e.g. see Figure 3). What astronomical associations and orientations occur there? This would make an interesting archaeoastronomical study, and the broad topic of Indonesian temple alignments, illumination and astronomical symbolism offers an ideal opportunity for astronomers to work closely with Drs Bambang Budi Utomo and his staff from the Pusat Penelitian Arkeologi Nasional.

2.3 de Houtman and his Star Map

Frederik de Houtman (1571–1627; Figure 4) was a Dutchman who between 1595 and 1599 made two voyages to the Dutch East Indies (as Indonesia was then known), and plotted stars visible in the southern sky. Subsequently, he was imprisoned in Aceh, and was able to make further astronomical observations. In 1603 he published his southern star catalog as an appendix to a dictionary of local languages. Hidayat (2000: 46) records how

> The catalogue of stars published by Frederick de Houtman in 1603 provided the basis for the renaming of many of the southern constellations. In a publication that was brought to the attention of European astronomers, de Houtman listed 303 stars in the southern sky and provided names for the major constellations.

In 1917 the distinguished British amateur astronomer, Edward Ball Knobel (1841–1930, Figure 5; F.W.D., 1931) published a paper on de Houtman and his star catalog in *Monthly Notices of the Royal Astronomical* Society (Knobel, 1917), but since then no-one has made an in-depth study of this important astronomer and his pioneering star catalog (though see Dekker, 1987).

Here is an exciting project for an Indonesian astronomer: the relevant records are in Holland patiently awaiting your attention!

2.4 The 1868 and 1871 Total Solar Eclipses

The 1868 total solar eclipse was visible across India and Siam (Thailand), and was a watershed event in astronomical history as it revealed the chemical composition of prominences, the chromosphere and the solar corona, and led —eventually—to the discovery of a new element, helium (see Launay, 2012; Nath, 2013; Orchiston et al., 2017). Note that the path of totality of this eclipse also passed over Kalimantan and Sulawesi (Figure 6, and the surveyor and astronomer Dr Jean Abraham Chrétien Oudemans (1827–1906) published two different report on this eclipse, in German, in *Astronomische Nachrichten* (Oudemans, 1869a; 1869b).

The 1868 eclipse was followed just three years later by another total solar eclipse that offered astronomers a further opportunity to investigate the structure and elemental compo-

Figure 3: The Taman Ayun temple in Bali (www. balitourismboard. org/temples.html).

Figure 4: Frederik de Houtman (jv.wikipedia. org).

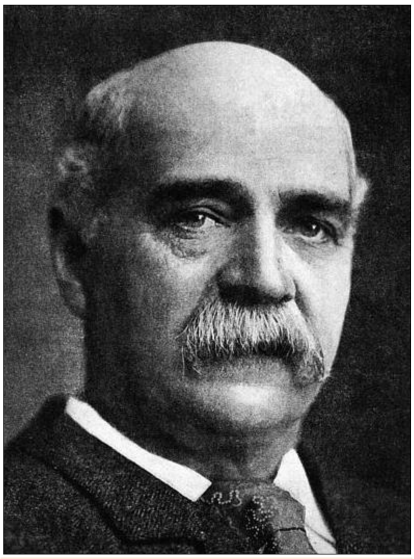


Figure 5: E.B. Knobel (en.wikipedia.org).

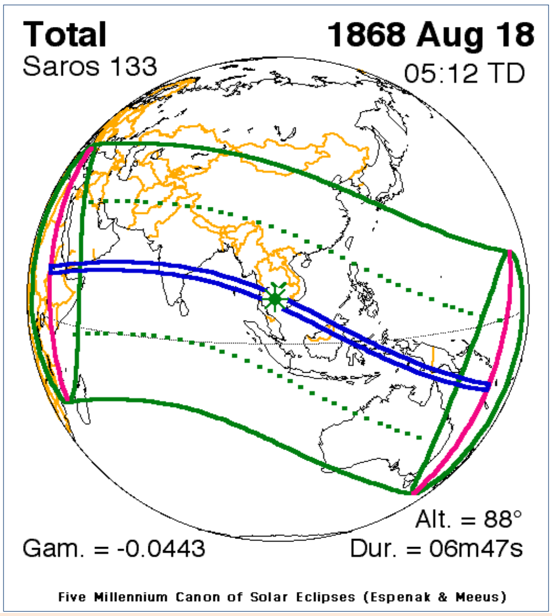


Figure 6: The path of totality of the total solar eclipse of 1868 (after Espenak and Meeus, 2006).

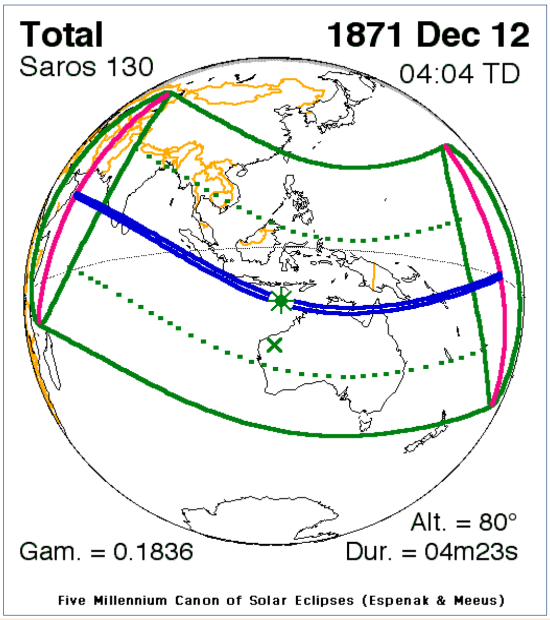


Figure 7: The path of totality of the total solar eclipse of 1871 (after Espenak and Meeus, 2006).

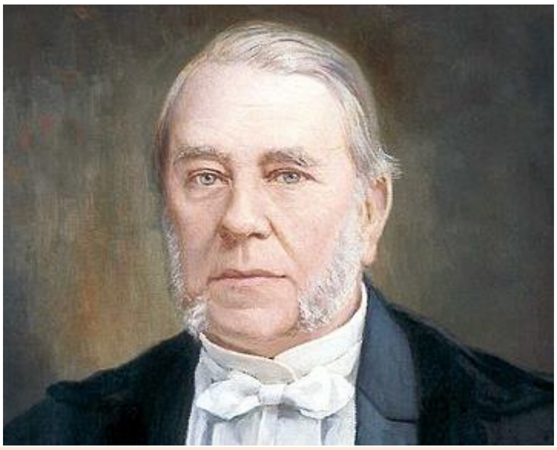


Figure 8: Dr J.A.C. Oudemans in 1898 (en.wikipedia.org).

sition of the corona, and this eclipse also was visible from India (Orchiston and Pearson, 2017) and the Dutch East Indies (see Figure 7). On this occasion the path of totality conveniently passed across Java, and Oudemans (Figure 8) was able to carry out observations and publish a long report, again in German and in *Astronomische Nachrichten* (Oudemans, 1873). Recently, Mumpuni et al. (2017) analysed Oudemans; observations of the 1868 and 1871 eclipses, and in a separate study Orchiston et al. (2018) reviewed Oudemans; overall contribution to nineteenth century Dutch East Indies astronomy.[2]

2.5 The 1874 Transit of Venus

The 1874 transit of Venus was one of the most important events in world astronomy as it offered the ideal opportunity to finally pin down the solar parallax and assign a value to the Astronomical Unit—the distance from the Earth to the Sun (see Dick et al., 1998). Consequently, a number of nations mounted expeditions to northern Asia and to the Australia-New Zealand region (Orchiston 2004) where the whole of the 7-hr transit would be visible.

Figure 9 shows that the Dutch East Indies also lay wholly within the pale blue region where the entire transit would be visible (weather permitting), and although Oudemans journeyed to Réunion to observe the event, it is reasonable to assume that other scientists with an interest in astronomy who remained on home soil would have attempted to view this once-in-a-lifetime even—and even time the ingress and egress contacts. A search, therefore, should be made in Jakarata and Bandung, and perhaps in other cities, for relevant records.

Because of its research importance the 1874 transit also received enormous media coverage worldwide, not just in nations involved in astronomical research (e.g. see Cottam and Orchiston, 2014), but also in those where it was used as a vehicle to promote scientific astronomy and ally fears derived from myth and superstition (e.g. see Lu and Li (2013), which specifically deals with China). Was the 1874 transit portrayed in this way in Java? A survey of local newspapers and magazines should provide the answer.

3 REGIONAL STUDIES

3.1 *Orang Asli* Astronomy

The term *orang asli* is common to Indonesia and Malaysia and refers to the original (*asli*) people (*orang*) who were thought to have occupied the Southeast region prior to the arrival of the current populations (e.g. see Aghakhanian et al., 2015; Bellwood, 2007). On the Andaman and Nicobar Islands and in isolated areas of southern Thailand, Malaysia, Indonesia and the Philippines the *orang asli* stand out physically, ecologically, culturally and linguistically from later occupants of mainland and island southeast Asia.

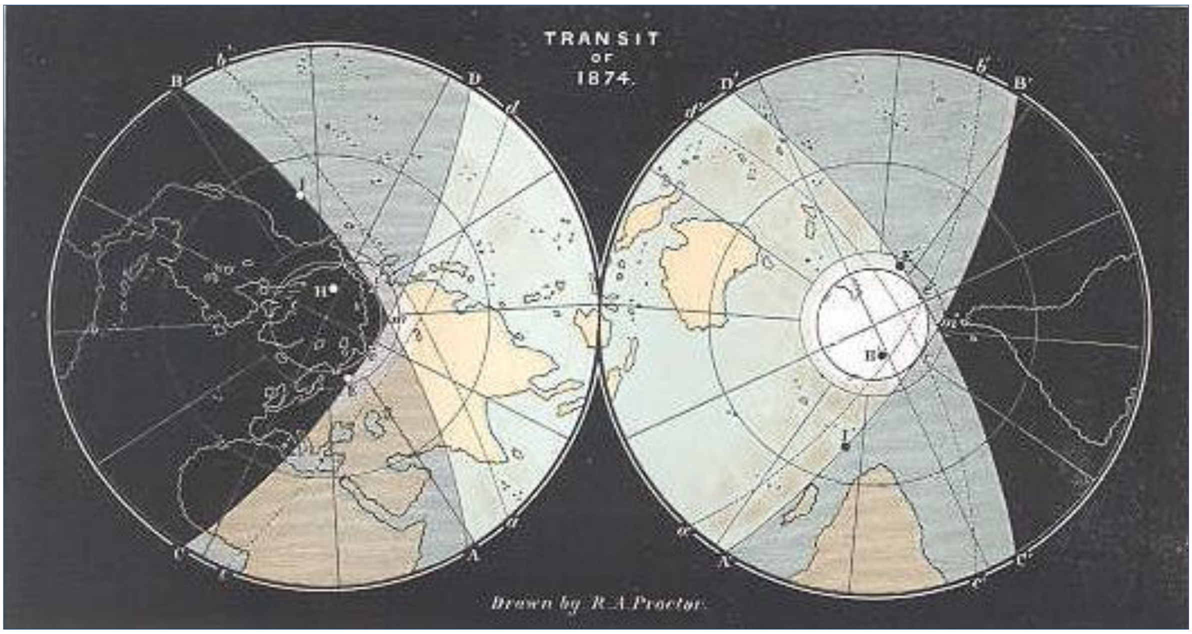


Figure 9: A map showing the visibility of the 9 December 1874 transit of Venus. The entire transit was visible, weather permitting, from the Dutch East Indies, and other nations lying within the pale blue area (after Proctor, 1874).

If the Andaman and Nicobar Islanders and the *orang asli* are indeed remnants of an ancestral relic population, as the archaeological and anthropological evidence suggests, then do their astronomical systems exhibit any 'common denominators', despite the passing of the millenia? Vahia and his collaborators (2013, 2014, 2015) recently studied the astronomical systems of what are reputed to be India's most ancient tribes, and comparative studies now need to be carried out in the Andaman and Nicobar Islands and among the *orang asli* of mainland and island southeast Asia.

This whole topic lends itself to an exciting field experiment, and has the potential to encourage collaboration between anthropologists and astronomers and produce important results for Asian and Southeast Asian astronomy. While thus far very little has been published in English on the Indonesian *orang asli*, which were found in Kalimantan, potentially Indonesia has an important role to play in this research.

3.2 Astronomy and the Macassans

Another Indonesian-related project with exciting research potential and regional implications relates to the astronomy of the Macassans.

Since the mid-seventeenth century (Ganter, 2008) each year, starting in December (the wet season) groups of up to 1,000 Macassan fishermen in fleets of *praus* would voyage to northern Australia and establish coastal settlements in the western Gulf of Carpentaria, eastern Arnhem Land and the Kimberleys region (Figure 10), where they would live for the next 4–5 months, interacting with the local Aboriginal populations and even marrying Aboriginal women (see Macknight, 1976, 1986). The incentive for these trips was the sea cucumber or *trepang* (Figure 10 inset), which they harvested, boiled and then dried in the Sun and smoked. The processed *trepang* were taken back to Macassar, in southern Sulawesi, and from there shipped to China where they were a delicacy in cooking and also were viewed medicinally as a stimulant and an aphrodisiac. Because of the economic success of these early Macassan ventures other Indonesian fishermen from islands closer to Australia (see Figure 10) subsequently began to replicate the exploits of their Sulawesi compatriots.

These expeditions only ceased in 1907 when taxes and licence fees imposed by the Australian government made *trepang* fishing uneconomical, but by that time large numbers of fishermen from at least five different Indonesian islands had lived (and occasionally died) on the Australian coast (see Theden-Ringl et al., 2011), in the process learning about Australian Aboriginal culture, and at the same time drastically changing Aboriginal culture and leaving their mark on the local languages (Evans, 1992) and in rock art (Chaloupka, 1996). In addition, Aboriginal men sometimes joined these expeditions when the Indonesians returned to their home ports (Macknight, 2011).

So, if we survey the astronomical knowledge systems associated with Indonesian fishermen from these different islands (e.g. see Ammarell, 1995; 1999) will we discover that they also include elements of Aboriginal astronomy? Conversely, do any the astronomical knowledge systems of coastal northern Australia include aspects of Indonesian astronomy? Here is a fascinating ethnoastronomical project crying out for attention in both Indonesia and Australia.

Figure 10: Map showing the Gulf of Carpentaria, Arnhem Land and Kimberleys coast of Australia and Indonesian islands known to have been involved in harvesting the *trepang*. The insert shows one of these sea cucumbers (map modifications: Wayne Orchiston).

3.3 The History of Indonesian Tektite Studies

Tektites are glass-like objects that sometimes look like obsidian, or volcanic glass, so originally they were referred to as ‘obsidianites’. We now know these tektites have nothing to do with volcanoes, but were formed during major meteorite impacts. They are found around the world in a limited number of ‘strewn fields’, most of which are associated with known meteorite craters.

By far the largest tektite strewn field is the Asian-Australian strewn field which extends from mainland Southeast Asia through to Australia (Figure 11) and is also represented by microtektites recovered during deep-sea drilling over much of the floor of the Indian Ocean (see Glass et al., 1996: Figure 1) and recently from the Trans-Antarctic Mountains in Antarctica (Howard, 2011). ^{40}A/^{39}A, and fission track dating indicates that this extensive strewn field derives from a single major meteorite impact that occurred between 770,000 and 780,000 years ago (McCall, 2001) somewhere near the Laos-Thai border (Schnetzler, 1992; Schnetzler and McHone, 1996).

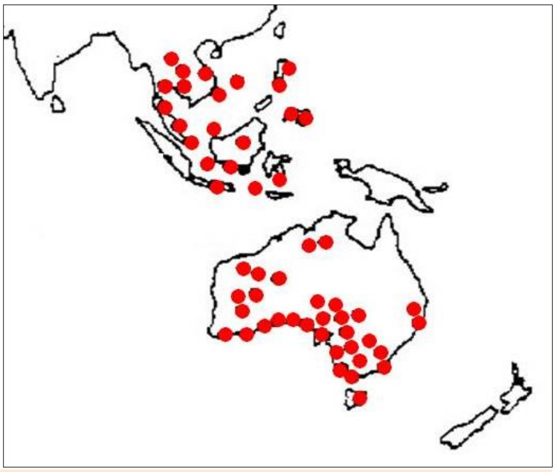


Figure 11: A map showing the general distribution of tektites belonging to the Asian-Australian strewn field (map: Wayne Orchiston).

As Figure 11 indicates, tektites are known from Indonesia, and their typical chemical composition is shown in Table 1. The first Indonesian tektite described was from Pelaihari (Kalimantan) in 1836, followed by ‘Billitonites’ from the island of Bilitung, recovered during tin-mining operations, but they also have been recovered from several other sites in Kalimantan, from Natuna and Gourd Islands, from Java and from Flores. Those from Java, sometimes referred to as ‘Javanites’, are mainly from Sangiran, and in the course of researching *Homo erectus* (‘Java Man’) geologists recovered more than 10,000 specimens (von Koenigswald, 1960). Despite certain problems (see Orchiston and Seisser, 1982), these Sangiran tektites have even been used to try and date *Homo erectus* (Ninkovich and Burkle, 1978; von Koenigsvald, 1968).

Indonesian tektite studies have been carried out mainly by geologists and little has been published by astronomers, even though tektite studies are an important part of meteoritics (which is about meteorites, tektites, meteorite craters and the impact cratering processes).

Given the recent interest shown in the Asian-

Table 1: The mean chemical composition of tektites from Java (adapted from McCall, 2001: Table 2.4).

Element	SiO_2	Al_2O	Fe_2O_3	FeO	MgO	CaO	Na_2O	Ka_2O	TiO_2
%	72.32	11.68	0.85	4.81	2.75	2.89	1.78	2.35	0.75

Australian tektites (e.g. see Howard, 2011 and references therein), now is a good time to survey the relevant literature and produce a research paper documenting the history of tektite studies in Indonesia. This will not only be a valuable contribution to the history of astronomy but undoubtedly also will be appreciated by geologists, geochemists and other scientists involved in tektite studies.

3.4 Bosscha Observatory Variable Star Studies

Thanks to the 1901 total solar eclipse, Indonesia was able to make a valuable contribution to solar physics (see Pearson and Orchiston, 2017), but astrophysics only emerged in Indonesia during the 1920s with the founding of the Bosscha Observatory at Lembang, on the southern slopes of a volcano and at an altitude of ~1300 m (Voûte, 1933: A14). The initial suite of instruments there included a twin Zeiss refractor with an aperture of 64 cm; a 37-cm Schmidt refractor; the Bamberg Astrographic Refractor; a Secretan 16-cm refractor; a Zeiss 13-cm refractor; a Zeiss 11-cm comet-seeker and an assortment of astrocameras. From the start, these were mainly devoted to variable star studies (see Hidayat, 2000).

The founding Director of the Bosscha Observatory was Joan George Erardus Gijsbertus Voûte (1879–1963; Figure 12; O'Connell, 1964), and one of his friends was the Jesuit astronomer Father Edward Francis Pigot (1858–1929; Figure 13; Drake, 1988), who had set up the Riverview Observatory in Sydney (Australia) in 1907. Initially Riverview Observatory was devoted to seismology and meteorology, but when it acquired an equatorially-mounted 17.8-cm (7-in) refractor in 1922 Pigot was motivated to initiate an astronomical research program. While returning from the Pan-Pacific Science Congress in Tokyo in 1926 he visited Bosscha Observatory and after discussions with Voûte decided that Riverview also would investigate variable stars, using photographic photometry. Unfortunately Pigot died before this plan could be actioned, and it was left to his successor, Fr William O'Leary, to bring it to fruition. In order to achieve this, Bosscha Observatory kindly donated what was referred to as the 'Voûte Telescope', which comprised

> … two separate astrocameras, and a 10-cm guide scope, the latter being mounted within the polar axis Northumberland style (this is simply a variant of the English equatorial mounting). For the remaining years of the 1930's, through the 40's and into the early 50's O'Leary and O'Connell (the next director) … succeeded in discovering hundreds of new [variable] stars … Some of these were written up in the *Riverview College Observatory Publications*, which began in 1935. Through this work Riverview Observatory achieved an international reputation … (Orchiston, 1985: 72–73).

It would be interesting to carry out a comparative study of the variable star research programs of the Bosscha and Riverview Observatories during the period 1930–1950 to see the ways in which the Sydney programs were influenced and guided by those initiated earlier at the Lembang observatory.

4 DISCUSSION

The Southeast Asian Astronomy Network (SEAAN) is the primary 'association' of professional astronomers in the ASEAN nations and meets annually in a different city in one of the member countries. The next SEAAN conference will be held in Myanmar in December 2017, and it is planned to hold a separate meeting there of the SEAAN History and Heritage Working Group. Papers presented at this historical meeting will be combined those that were presented in Ao Nang at the 30 November–1 December 2015 meeting of the Working Group and published by Springer (see Orchiston and Vahia, 2018).

In order to reach an international audience, increasing numbers of research papers on Indonesian history of astronomy need to be published, *in English*, in reputable astronomical books and journals. The obvious choice of journals for Indonesian scholars is this Journal, which is produced by the National Astronomical Research Institute of Thailand and, amongst other topics, actively promotes research on Asian astronomical history. Undoubtedly the most useful book to publish in is the ICOA proceedings. The International Conference on Oriental Astronomy (ICOA) conferences are held every three years in a different Asian city. The next meeting, ICOA-10, will be held in Uzbekistan in 2019.

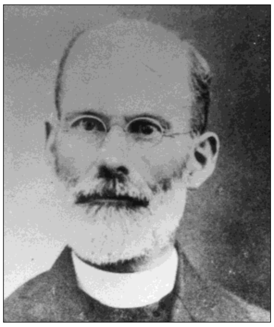


Figure 12 (left): J.G.E.G. Voûte (en.wikipedia.org).
Figure 13 (right): Father Pigot (courtesy: Riverview College Archives).

Finally, I should mention a book titled *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*, edited by Tsuko Nakaura (Japan) and myself, which will be published by Springer in 2017. This includes an Indonesian section, which begins with an overview paper by Hidayat, Malasan and Mumpuni (2017)—see Figure 14—and is followed by two case studies that detail specific research projects undertaken in the Dutch East Indies during the nineteenth century that contributed to the early international development of solar physics (Mumpuni et al., 2017; Pearson and Orchiston, 2017).

5 CONCLUDING REMARKS

In this paper we have discussed a number of research topics relating to Indonesian ethnoastronomy, ancient astronomy, positional astronomy, astrophysics and the history of meteoriticis that I believe have local or regional importance. Five of these are specific to Indonesia:

- Astronomy and lowland wet rice cultivation
- Temple alignments
- de Houtman and his star map
- The 1868 and 1871 total solar eclipses
- The 1874 transit of Venus

I also discussed five research topics where Indonesian astronomy should be studied in a regional context, namely:

- Astronomy and lowland wet rice cultivation (Indonesia and Southeast Asia)
- *Orang asli* astronomy (Indonesia and Philippines, Malaysia, Thailand, Andaman and Nicobar Islands)
- Astronomy and the Macassans (Indonesia and Australia)
- The history of Indonesian tektite studies (Indonesia, Southeast Asia, Australia)
- Bosscha Observatory variable star studies (Indonesia and Australia)

Figure 14: One of the figures included in the paper by Hidayat et al. (2017) in the forthcoming book on *The Emergence of Astrophysics in Asia* … (courtesy: Emanuel Sungging Mumpuni).

Some of these topics can be studied by individuals or small groups of collaborators and would even make excellent student projects, but major studies that examine the relationship between Indonesia and regions to the north, northwest and/or the southeast ideally call for international collaborations. Through these studies, Indonesia can make an important contribution to international history of astronomy.

6 NOTES

1. This is a revised version of a paper presented at *Seminar Astronomi Dalam Budaya Nusantara*, Universitas Ahmad Dahlan Yogyakarta, Yogyakarta, in 2015.
2. Note that these studies by Mumpuni, Orchiston and Steinicke were carried out following the Yogyakarta conference and in response to discussions that occurred during that conference.

7 ACKNOWLEDGEMENTS

I am grateful to Professor Mayank Vahia for reading and commenting on the manuscript, and the Riverview College Archives (Sydney) and Emanuel Sungging Mumpuni for kindly providing Figures 13 and 14 respectively.

8 REFERENCES

Aghakhanian, F., Yunus, Y., Naidu, R., Jinam, T., Manica, A., Boon Peng Hoh, and Phipps, M.E., 2015. Unravelling the genetic history of Negritos and indigenous populations of Southeast Asia. *Genome Biology and Evolution*, 7, 1206–1215.

Ammarell, G., 1988. Sky calendars of the Indo-Malay archipelago: regional diversity, local knowledge. *Indonesia*, 45, 85–104.

Ammarell, G., 1991. The planetarium and the plough: interpreting star calendars of rural Java. *Yale Graduate Journal of Anthropology*, 3, 11–25.

Ammarell, G., 1995. Navigation practices of the Bugis of South Sulawesi, Indonesia. In Feinberg, R. (ed.). *Seafaring in the Contemporary Pacific Islands*. DeKalb, Northern Illinois University Press. Pp. 196–218.

Ammarell, G., 1999. *Bugis Navigation*. New Haven, Yale University Press.

Ammarell, G., 2008. Astronomy in the Indo-Malay archipelago. In Selin, H. (ed.). *Encyclopedia of History of Science, Technology and Medicine in Non-Western Cultures*. *Second Edition*. Dordrecht, Kluwer. Pp. 324–333.

Bellwood, P., 2007. *Prehistory of the Indo-Malaysian Archipelago*. Canberra, ANU Press.

Chaloupka, G., 1996. Praus in Marege: Makassan subjects in Aboriginal rock art in east Arnhem Land, Northern Territory, Australia. *Anthropologie*, 34, 131–142.

Cottam, S., and Orchiston, W., 2014. *Eclipses, Transits, and Comets of the Nineteenth Century: How America's Perception of the Skies Changed*. New York, Springer.

Daldjoeni, N., and Hidayat, B, 1987. Astronomical aspects of pranotomangsa of the 19th century Central Java. In Swarup, G., Bag, A.K.., and Shukla, K.S. (eds.). *History of Oriental Astronomy.* Cambridge, Cambridge University Press. Pp. 249–253.

Dekker, E., 1987. Early explorations of the southern celestial sky. *Annals of Science*, 44, 439–470.

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.

Drake, L.A., 1988. Pigot, Edward Francis (1858–1929). In *Australian Dictionary of Biography. Volume 11*. Melbourne, Melbourne University Press.

Espenak, F., and Meeus, J., 2006. *Five Millennia Canon of Solar Eclipses: -1999 to + 3000 (000 BCE to 3000CE)*. Greenbelt, NASA (TP-2006-214141).

Evans, N., 1992. Macassan loanwords in Top End languages. *Australian Journal of Linguistics*, 12, 45–91.

F.W.D., 1931. Obituary: Edward Ball Knobel. *Monthly Notices of the Royal Astronomical Society*, 91, 318–321.

Ganter, R., 2008. Muslim Australians: the deep histories of contact. *Journal of Australian Studies*, 32, 481–492.

Glass, B.P., Chapman, D.R., and Prasad, M.S., 1996. Ablated tektite from the central Indian Ocean. *Meteoritics & Planetary Science*, 31, 365–369.

Hariawang, I.I., Simatupang, F.M., Radiman, I., and Mumpuni, E.S., 2011. Orientation of Borobudur's east gate measured against the sunrise positon during the vernal equinox. In Nakamura et al., 37–42.

Hidayat, B., 2000. Under a tropical sky: a history of astronomy in Indonesia. *Journal of Astronomical History and Heritage*, 3, 45–58.

Hidayat, B., 2011. The sky and agro-bio-climatology of Java. Is there a need for a critical reevaluation due to environmental changes? In Nakamura et al., 43–46.

Hidayat, B., Malasan, H., and Mumpuni, E.S, 2017. The development of astronomy and emergence of astrophysics in Indonesia. In Nakamura and Orchiston.

Hose, C., 1905. Various methods of computing the time for planting among the races of Borneo. *Journal of the Straits Branch of the Royal Asiatic Society*, 42, 1–5.

Howard, K.T., 2011. Tektites. In Ridd, M.F., Barber, A.J., and Crow, M.J. (eds.). *The Geology of Thailand*. Bath, The Geological Society. Pp. 573–591.

Jaafar, N., Yahaya, F.H., and Yew, C.H., 2015. Piama, the wetland paddy calendar of Kedah, peninsular Malaysia. Paper presented at *Seminar Astronomi Dalam Budaya Nusantara*, Universitas Ahmad Dahlan Yogyakarta, Yogyakarta.

Kameswara Rao, N., and Thakur, P., 2011. Aspects of observational astronomy in India: the Vidyasankara Temple at Sringeri̱. *Journal of Astronomical History and Heritage*, 14, 136–144.

Knobel, E.B., 1917. On Frederick de Houtman's catalogue of southern stars, and the origin of the southern constellations. *Monthly Notices of the Royal Astronomical* Society, 77, 414–432.

Komonjinda, S., 2010. The Sun and fifteen doorways of Phnom Rung. *Proceedings of the International Astronomical Union 12*, 7, 325–330.

Launay, F., 2012. *The Astronomer Jules Janssen: A Globetrotter of Celestial Physics.* New York, Springer.

Lu, L., and Li., H., 2013. Chinese records of the 1874 transit of Venus. *Journal of Astronomical History and Heritage*, 16, 45–54.

McCall, J., 2001. *Tektites in the Geological Record: Showers of Glass from the Sky*. Bath, The Geological Society.

Macknight, C., 1976. *The Voyage to Marege': Mac-*

assan Trepangers in Northern Australia. Melbourne, Melbourne University Press.

Macknight, C., 1986. Macassans and the Aboriginal past. *Archaeology in Oceania*, 21, 69–75.

Macknight, C., 2011. The view from Marege': Australian knowledge of Makassar and the impact of the trepang industry across two centuries. *Aboriginal History*, 35, 121–143.

Maass, A., 1924. *Sternkunde und sterndeuterei im Malaiischen Archipel*. *Two Volumes.* Batavia, Koninklijke Bataviaasch Genootschap van Kunsten en Wetenschappen (Tijdschrift voor Indische Taal-, Land- en Volkenkunde Deel 64).

Mumpuni, E.S, Orchiston, W., and Steinicke, W., 2017. Dr J.A.C. Oudemans' observations of the 18 August 1868 and 12 December 1871 total solar eclipses from the Dutch East Indies. In Nakamura and Orchiston.

Nakamura, T., and Orchiston, W., (eds.), 2017. *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. New York, Springer.

Nakamura, T., Orchiston, W., Sôma, M., and Strom, R. (eds.), 2011. *Mapping the Oriental Sky. Proceedings of the Seventh International Conference on Oriental Astronomy (ICOA-7)*. Tokyo, National Astronomical Observatory of Japan.

Nath, B.B., 2013. *The Story of Helium and the Birth of Astrophysics*. New York, Springer.

Ninkovich, D., and Burkle, L.H., 1987. Absolute age of the base of the hominid-bearing beds of eastern Java. *Nature*, 275, 306–308.

O'Connell, J.K., 1964. Obituary: Joan George Erardus Gijsbertus Voûte. *Quarterly Journal of the Royal Astronomical Society*, 5, 296–297.

Orchiston, W., 1985. Life-history of a telescope: the 17.8-cm refractor at the Riverview Observatory in Sydney. *Australian Journal of Astronomy*, 1, 57–80.

Orchiston, W., 2004. The nineteenth century transits of Venus: an Australian and New Zealand overview. *Journal of Astronomical Data*, 10(7), 219–308.

Orchiston, W., and Pearson, J., 2017. American observations of the 22 January total solar eclipse expedition from Jeur, India. In Nakamura and Orchiston.

Orchiston, D.W., and Siesser, W.G., 1982. Chronostratigraphy of the Plio-Pleistocene fossil hominids of Java. *Modern Quaternary Research in Southeast Asia*, 7, 131–149.

Orchiston, W., Lee, E.-H., and Ahn, Y.-S., 2017. British observations of the 18 August 1868 total solar eclipse from Guntoor, India. In Nakamura and Orchiston.

Orchiston, W., Steinicke, W., and Mumpuni, E.S., 2018. J.A.C. Oudemans and nineteenth century astronomy in the Dutch East Indies. In Orchiston, W., and Vahia, M. (eds.). *Exploring the History of SE Asian Astronomy: A Review of Current Projects and Future Prospects and Possibilities*. Cham, Springer.

Oudemans, J.A.C., 1869a. Beobachtung der totalen Sonnenfinsterniss vom 18. August 1868, auf der Insel Klein-Mantawalu, in der Tomini-Bucht (Ostküste Celebes). *Astronomische 'Nachrichten*, 74, 1–8.

Oudemans, J.A.C., 1869b. Nachschrift zu meiner Mitteilung über die Beobachtung der totalen Sonnenfinsterniss am 18. Aug. 1868. *Astronomische 'Nachrichten*, 74, 161–176.

Oudemans, J.A.C., 1873. Bericht über die Beobachtungen, bei Gelegenheit der totalen Sonnenfinsterniss am 12. December 1871 im niederländischen Ostindien angestellt. *Astronomische 'Nachrichten*, 81, 1–36.

Pearson, J., and Orchiston, W., 2017. American observations of the 16 May 1901 total solar eclipse from Dutch East Indies. In Nakamura and Orchiston.

Proctor, R., 1874. *The Transits of Venus. A Popular Account of Past and Coming Transits*. London, Longmans, Green & Co.

Sawitar, W., 2015. Astronomi dalam cerita rakyat Nusantara. In Pramadya, Y. (ed.). *Seminar Astronomi Dalam Budaya Nusantara*. Yogyakarta, Universitas Ahmad Dahlan Yogyakarta.

Schnetzler, C.C., 1992. Mechanism of Muong Nong-type tektite formation and speculation on the source of Australasian tektites. *Meteoritics*, 27, 154–165.

Schnetzler, C.C., and McHone, J.F., 1996. Source of Australasian tektites: investigating possible sites in Laos. *Meteoritics and Planetary Science*, 31, 73–76.

Stencil, R., Gifford, F., and Moron, E., 1976. Archaeology and cosmology of Angkor Wat. *Science*, 193, 281–287.

Theden-Ringl, F., Fenner, J., Wesley, D., and Lamilami, R., 2011. Buried on foreign shores: isotope analysis of the origin of human remains recovered from a Macassan site in Arnhem Land. *Australian Archaeology*, 73, 41–48.

Vahia, M.N., and Halkare, G., 2013. Aspects of Gond astronomy. *Journal of Astronomical History and Heritage*, 16, 29–44.

Vahia, M.N., Halkare, G., Menon, K., and Calamur, H., 2014. The astronomy of two Indian tribes: the Banjaras and the Kolems. *Journal of Astronomical History and Heritage*, 17, 65–84.

Vahia, M.N., Ramachandran,V.S., Gangopadhyay, J., and Joseph, J., 2017. Astronomy of Cholanaikkan tribe of Kerala. arXiv: 1702.04149.

von Koenigswald, G.H.R., 1960. Tektite studies. I: The age of the Indo-Australian tektites. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen B*, 63, 135–141.

von Koenigswald, G.H.R., 1968. Das absolute alter des *Pithecanthropus erectus* Dubois. In Kurth, G. (ed.). *Evolution und Hominization*. Stuttgart, Gustav Fischer. Pp. 195–203.

Voûte, J., 1933. Description of the Observatory (with a Dutch Introduction). *Annalen v.d. Bosscha-Sterrenwacht Lembang (Java)*, 1, A1–A27.

Professor Wayne Orchiston 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). He has wide-ranging research interests and has published extensively on cometary and asteroidal astronomy, Cook voyage astronomy, historic telescopes and observatories, historic transits of Venus, Maori astronomy, solar eclipses and the early development of solar physics, 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. In 2013 the IAU named minor planet 48471 Orchiston after him.

Journal of Astronomical History and Heritage, 20(2), 155–160 (2017).

THE SYZYGY VOLVELLE IN *ASTRONOMICUM CAESAREUM*

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

Abstract: The theory and parameters behind a volvelle in Peter Apianus' *Astronomicum Caesareum* are investigated. It is found that he used the full Ptolemaic model of the Moon and also that he improved the layout of the volvelle by a clever trick.

Keywords: volvelle, Petrus Apianus, solar model, lunar model, syzygy

1 INTRODUCTION

In two earlier papers (Gislén, 2016; 2017) I studied Petrus Apianus' volvelles for eclipse duration and for planetary latitudes from his magnificent *Astronomicum Caesareum* (1540). Here I will study his volvelle for finding the true time of a syzygy (Figure 1). As it turns out it is possible to extract several pieces of interesting information from the volvelle.

2 THE VOLVELLE

In order to use the volvelle you need two input quantities, the solar anomaly (*argumentum solis*), γ_S, and the lunar anomaly (*argumentum lunae*), γ_M.

The volvelle has a circular rim with two graduations from 0° to 360°, one counter-clockwise and one clockwise, the first one with Arabic numbers and is to be used for lunar anomalies less

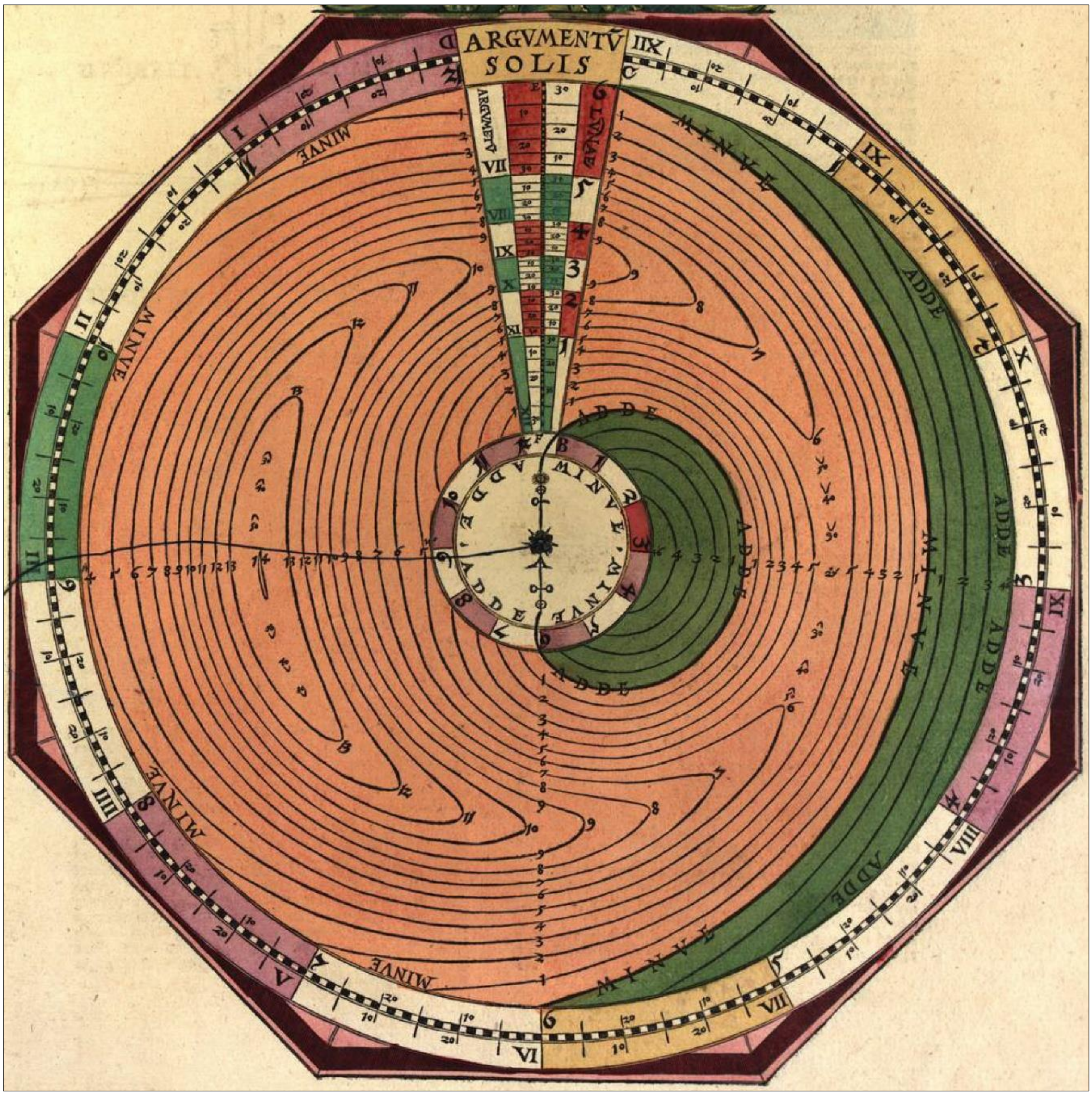


Figure 1: The volvelle.

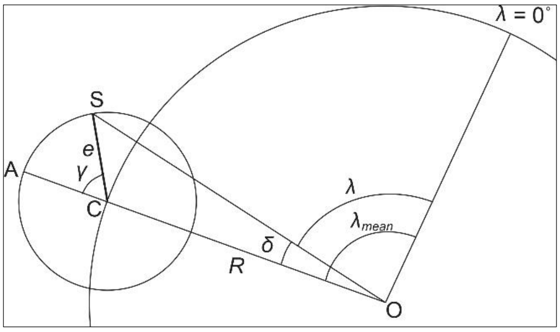


Figure 2: The solar model.

than 180°, the other one with Latin Numbers for anomalies larger than 180°. At the top of the volvelle there is a wedge-shaped area for setting the lunar anomaly. There is a thread coming from the centre of the volvelle with a small bead that can slide along the thread. You set the bead on the thread using the lunar anomaly scale, then align the thread against the solar anomaly on the rim and read off the correction in hours to the mean syzygy from the grid of isochronal lines below the bead. The reddish areas of the volvelle mean that the mean syzygy comes before the true one if the lunar anomaly is less than 180°, i.e. you have to add the correction to the mean syzygy time, for the greenish areas you have to subtract it. If the lunar anomaly is larger than 180° the colours have the opposite meaning.

3 THEORY

In the discussion below I use 'velocity' for 'change in angle per time'. The unit of velocity will be arc minutes per hour.

In the Ptolemaic models (Neugebauer, 1975; Pedersen, 1974) used by Apianus, the true longitudes of the Sun and the Moon are given by

$$\lambda = \lambda_{mean} - \delta(\gamma) \qquad (1)$$

where λ is the true longitude, λ_{mean} is the mean longitude, $\delta(\gamma)$ the equation of centre, and γ the anomaly. At a mean syzygy, the mean longitudes are equal and the difference in longitude between the Moon and the Sun is then

$$\Delta\lambda = -\delta_M(\gamma_M) + \delta_S(\gamma_S) \qquad (2)$$

where the indices M and S stand for Moon and Sun respectively.

Table 1: Solar Velocity.

Anomaly (°)	Solar Velocity (arcmins/hour)
0	2.37
10	2.38
20	2.38
30	2.38
40	2.39
50	2.40
60	2.42
70	2.43
80	2.44
90	2.46
100	2.48
110	2.49
120	2.51
130	2.52
140	2.54
150	2.55
160	2.55
170	2.56
180	2.56

If we divide this longitude difference by the difference in longitudinal velocities of the Moon and the Sun, the elongation velocity, we will get the time difference, ΔT, between the true and mean syzygy. Thus

$$\Delta T = \Delta\lambda / (v_M - v_S) = (\delta_S(\gamma_S) - \delta_M(\gamma_M)) / (v_M(\gamma_M) - v_S(\gamma_S)) \qquad (3)$$

The equations of centre and the velocities are given as tables in the Alfonsine Tables. However, it turns out that if one uses the velocity tables there, it is not possible to reproduce the volvelle. Below I will prove that Apianus used a more complicated model for the velocity of the Moon than that used for these tables.

3.1 The Solar Model

For the Sun (Figure 2) the equation of centre is given by

$$\delta(\gamma) = \arctan(e \sin\gamma / (R + e\cos\gamma)) \qquad (4)$$

This function is given as a table, *Equatio solis*, in the Alfonsine tables. γ is the anomaly of the Sun, R = 60 and the Ptolemaic value of e is 2.5, but a least square fit to the data in that table gives e = 2.268.

We get longitudinal velocity of the Sun by taking the time derivative of (1):

$$v(\gamma) = v_{mean} - \frac{e(R\cos\gamma + e)}{R^2 + 2Re\cos\gamma + e^2} v_\gamma \qquad (5)$$

where v_γ is the mean velocity in anomaly. For the Sun, this velocity is the same as the mean solar velocity in longitude v_{mean} = 2.464′/hour. If we insert numbers in (5) we generate Table 1.

This table agrees within rounding errors with the corresponding table in the Alfonsine Tables.

3.2 The Lunar Model

The Moon requires a considerably more complicated model (Figure 3), Ptolemy's final lunar model.

O is the observer, M the Moon, C the mean centre attached to F by CF with fixed length $R - s$. A is the mean apogee, A' the true apogee. The angle η is the elongation between the mean Moon and the mean Sun, the angle FOC being 2η. The distance to the Moon is varied by a crank mechanism with F moving around the centre O with twice the elongation velocity. This complication was invented by Ptolemy to describe the lunar longitude at the quadrants. However, it causes the distances between the Moon and the Earth to vary too much, the closest distance being ⅔ of the largest distance, something that could easily be detected by the naked eye by looking at the apparent size of the Moon. The red line OC points towards the mean Moon, OM points to the true Moon.

From the triangle OCN we get by standard trigonometry

$c_3(2\eta) = \arctan (s \sin 2\eta \,/\, (\rho + s \cos 2\eta))$ (6a)

$\rho(2\eta) = s \cos 2\eta + \sqrt{(R^2 - 2Rs + s^2 \cos^2 2\eta)}$ (6b)

The function c_3 is given in the Alfonsine Tables as *Equatio centri.*

The true anomaly γ' is given as a correction to the mean anomaly γ by $\gamma' = \gamma + c_3$.

The equation of centre is then

$\delta(\gamma') = \arctan (r \sin \gamma' \,/\, (\rho + r \cos \gamma'))$ (7)

This function is given in the Alfonsine Tables as *Equatio argumenti* with $\rho = R = 60$.

A least square fit to the data in the Alfonsine Tables gives $r = 5.16$ and $s = 10.317$. The first quantity is different from the Ptolemaic value $r = 5;25 = 5.417$.

At syzygy ($\eta = 0$) the change of ρ is zero and we can set $\rho = R = 60$ in (6a).

We take the time derivative of (1) with the relations (6a) and (7) inserted and get, using the chain rule for derivation,

$$v(\gamma,\eta) = v_{mean} - \frac{r\,(R \cos\gamma' + r)}{R^2 + 2R\,r \cos\gamma' + r^2}\left(v_\gamma + 2\frac{dc_3}{d(2\eta)}\,v_\eta\right) \quad (8)$$

Here v_γ is the lunar mean velocity in anomaly and v_η the mean velocity in elongation.

We now consider the situation at syzygy.

Then $\eta = 0$, $c_3 = 0$, $\gamma' = \gamma$, and $\left.\frac{dc_3}{d(2\eta)}\right/_{\eta=0} = \frac{s}{R+s}$ (9)

Using this we finally get

$$v(\gamma) = v_{mean} - \frac{r\,(R \cos\gamma + r)}{R^2 + 2R\,r \cos\gamma + r^2}\left(v_\gamma + 2\frac{s}{R+s}\,v_\eta\right) \quad (10)$$

Inserting numbers, the factor $2s \,/\, (R + s) = 2\cdot 10.317 \,/\, (60 + 10.317) = 0.2934$. For Apianus it would be more natural to find this factor by using the table for c_3 in the Alfonsine tables (*Equatio centri.*). The difference between argument 0° and 1° in this table is 0.1500°, this divided by the difference in angle, 1°, is very nearly the derivative of c_3 for $\eta = 0$, giving the factor above a value of 0.3. I have used this value for the calculations.

For the different velocities we have values derived from *Astronomicum Caesareum*, marginally different from the corresponding values in the *Almagest*:

- Mean lunar velocity in longitude, v_{mean} = 3.17639°/day = 32.941′/hour
- Mean lunar anomaly velocity, v_γ = 13.06499°/day = 32.662′/hour
- Mean elongation velocity, v_η = 12.19074°/day = 30.477′/hour

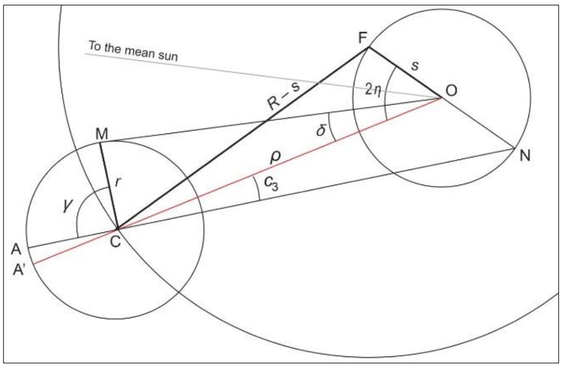


Figure 3: The lunar model.

Inserting these numbers, we can generate a table for the lunar velocity (see Table 2).

These are not the values we find in the Alfonsine Tables, and different editions of the Alfonsine Tables deviate slightly from each other. The values there are those we get if we set $s = 0$ in the model above, i.e. a simpler model without the crank mechanism, equivalent to Ptolemy's first model of the Moon, presumably due to Hipparchos. As we will show in the next section, Apianus used the more complex model.

4 CONFRONTING THE VOLVELLE

A close inspection of the volvelle reveals that at the inner right edge, for solar anomaly 90°, the time correction is written out as 4 hours 46 minutes (4;46 = 4.767). Here the lunar anomaly is 0°. At the outer edge where the lunar anomaly is 180°, the correction is 3;46 = 3.767. In both these cases the lunar equation is zero. In between these extremes, for lunar anomaly 90°, the time correction is 5;27 = 5.45, with the opposite sign. On the left side of the volvelle, for solar anomaly 270°, there is, hardly legible, written a number 14 close to inner and the outer edges. The obvious interpretation is that at the inner edge the time correction is 5 – 0;14 = 4;46, at the outer edge 4

Table 2: Lunar Velocity.

Anomaly(˚)	Lunar velocity(arcmins/hour)
0	29.63
10	29.67
20	29.79
30	29.98
40	30.25
50	30.60
60	31.01
70	31.50
80	32.04
90	32.63
100	33.26
110	33.91
120	34.56
130	35.17
140	35.73
150	36.21
160	36.57
170	36.80
180	36.87

– 0;14 = 3;46, i.e. the same values as for solar anomaly 90° as to be expected from symmetry.

We now apply numerically the models above for these points in the volvelle and compute the time correction ΔT. Along the line with solar anomaly 90°, the solar velocity in anomaly is constant and will be denoted ν_S for reasons that will be apparent later. From the Alfonsine Tables we obtain that $\delta_S(90) = 2.1658$. The factor 60 below is to convert the δ values from degrees to arc minutes.

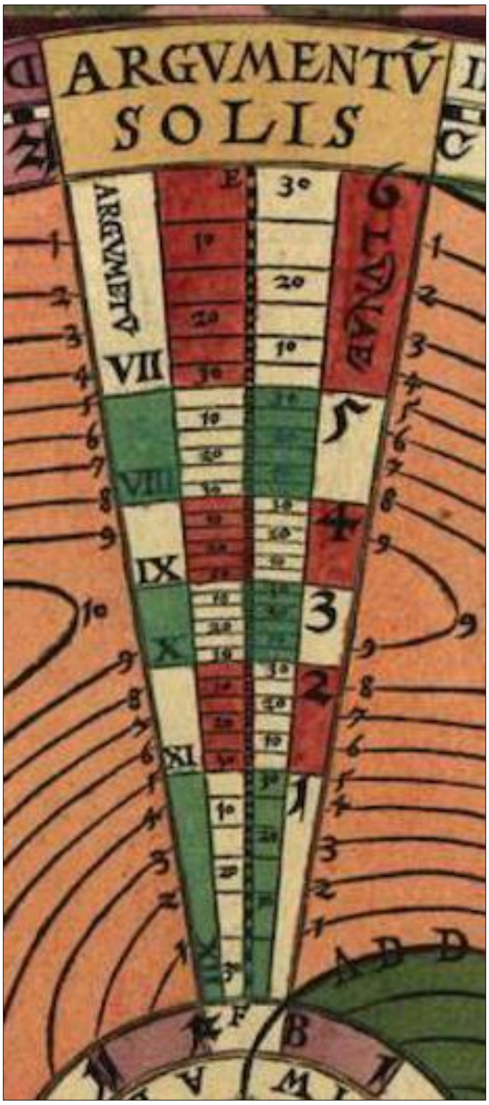


Figure 4: The lunar anomaly scale.

The inner edge:

$$\Delta T = 60\cdot(\delta_S(90) - \delta_M(0))/(\nu_M(0) - \nu_S) = 60\cdot 2.1658/(29.63 - \nu_S) = 4.767 \qquad (11)$$

or $29.63 - \nu_S = 27.26$, thus $\nu_S = 2.37$.

The outer edge:

$$\Delta T = 60\cdot(\delta_S(90) - \delta_M(180))/(\nu_M(180) - \nu_S) = 60\cdot 2.1658/(36.87 - \nu_S) = 3.767 \qquad (12)$$

or $36.87 - \nu_S = 34.50$, thus $\nu_S = 2.37$.

For $\gamma_M = 90°$, we take $\delta_M(90) = 4.9150$ from the Alfonsine Tables (*Equatio argumenti*).

$$\Delta T = 60\cdot(\delta_S(90) - \delta_M(90))/(\nu_M(90) - \nu_S) = 60\cdot(2.1658 - 4.9150)/(32.63 - \nu_S) = -5.45 \qquad (13)$$

or $32.63 - \nu_S = 30.27$, thus $\nu_S = 2.36$.

This is what is to be expected, we should get the same value for the solar velocity if the scheme works. What is not expected is that it is the value for solar anomaly 0°, not 90°. Apianus apparently used 2.36 as a generic constant for the solar velocity for all the points in the volvelle and that would simplify his calculations considerably. As the solar anomaly velocity is almost constant, the error introduced would be small, at most a couple of minutes. However, I think a more natural choice would have been to use the mean anomaly velocity.

It is interesting to note that the three elongation velocities above, 27.26, 30.27, and 34.50, agree quite well with the corresponding (less accurate) velocities derived in my earlier paper (Gislén, 2016) on Apianus' eclipse volvelle: 27.38, 30.32, and 34.43.

If we now use this scheme, it turns out that we can generate time correction values that very precisely correspond to the isochronal lines of the volvelle. Apianus gives two examples of using the volvelle for syzygies that can be used as a further check of the scheme, one New Moon on 14 February 1500, associated with the birth of the Holy Roman Emperor Charles V and a Full Moon on 25 February 1503 associated with the birth of his brother Ferdinand I.

Example 1. New Moon of 14 February 1500.

γ_S = 8 signs 1° 44′ = 241.73°, γ_M = 2 signs 14° 47′ = 74.78°

Apianus gives the time correction as 13;23. This is certainly a calculated value; it is not possible to get a time with this precision using the volvelle. The scheme above gives 13;26.

Example 2. Full Moon of 25 February 1503.

γ_S = 8 signs 13° 42′ = 253.70°, γ_M = 4 signs 16° 34′ = 136.37°

Apianus gives the time correction as 10;19. The scheme above gives 10;21.

For those interesting in experimenting with the model there is a downloadable Java application PASyzygy.jar on my web site; see http://home.thep.lu.se/~larsg/Site/Welcome.html

5 THE DISTORTED LUNAR ANOMALY SCALE

The lunar anomaly scale (Figure 4) in the wedge at the top of the volvelle is distorted such that the central part is contracted and the other parts extended. What is the purpose of this?

I think the reason was to try to make the isochronal lines of the volvelle more equidistant. This would make interpolation in the volvelle much easier both for its construction and for the later use. If we move radially in the volvelle for fixed solar anomaly $\gamma_S = 0$, increasing the lunar anomaly, the time correction is approximately determined by the lunar equation $\delta(\gamma_M)$. Other solar anomalies would essentially only add a constant to this function. A qualitative graph of $\delta(\gamma_M)$ is shown in Figure 5a with the anomaly γ_M on the horizontal axis.

If we now consider this as a picture of a 'hill', a set of altitude curves in a map of the hill would not be equidistant, they would spread out as we approach the top of the hill. In Figure 5a I have mirrored the right part of the black curve from the point where the tangent to the original curve is horizontal, to generate the red curve, i.e. I have reversed the slope of the curve where the slope is negative. Suppose now that we unite the left, black part of the curve and the red right part creating a monotonous rising function and use this curve as a conversion curve from the anomaly coordinate γ_M on the horizontal axis to a plotting scale coordinate *P* on the vertical axis, Figre 5b. If we then replot the original function as a function of *P*, it can be proven mathematically that the graph of original function will be reduced to straight lines, in this case the curves in Figure 5c. This means that if we do this for the volvelle, the isochronal lines for the replotted 'hill' would be equidistant, at least locally.

I measured the position in pixels for each 10′ step of the actual lunar anomaly scale in the picture of the volvelle. I then used the table of the lunar equation to construct a conversion function between lunar anomaly and an ideal plotting scale, using the procedure described above. Finally, I rescaled this ideal scale with a factor such that the largest item, for γ_M =180°, had the same size as the total length of the measured anomaly scale, 668 pixels. Figure 6 shows a comparison between the actual measured (blue) anomaly scale and the constructed ideal plotting scale (red). The agreement is quite good and indicates that the distorted scale really had the intention of making the isochronal curves in the volvelle more equidistant. Actually, this trick is also used in the Venus latitude volvelle, although in that case it does not seem to be quite necessary.

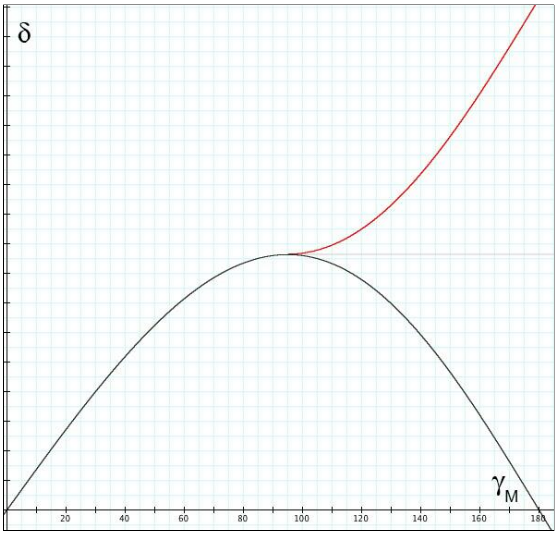


Figure 5a: Scale transformation.

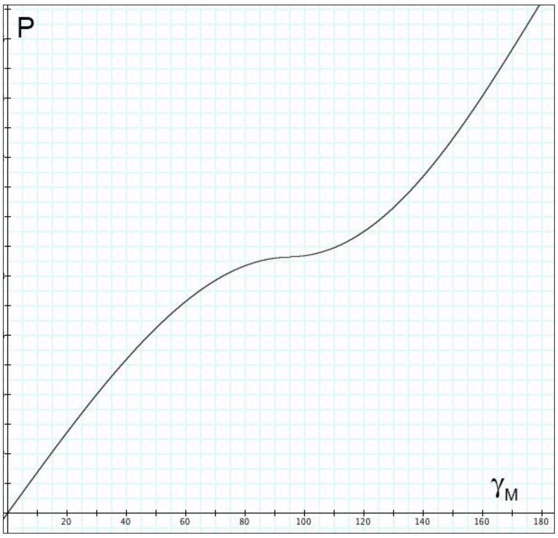


Figure 5b: The conversion function.

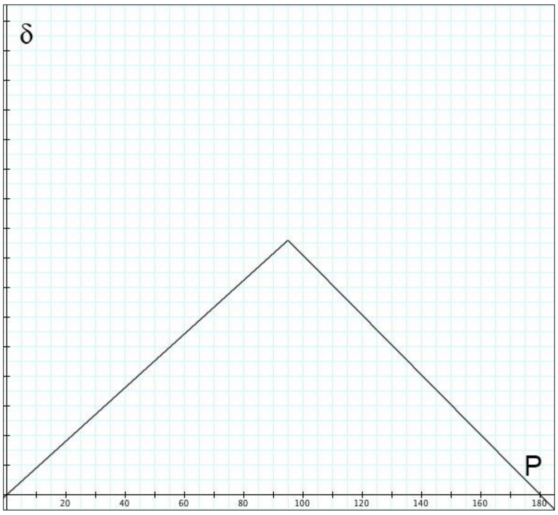


Figure 5c: The replotted curve.

6 CONCLUDING REMARKS

The syzygy volvelle confirms the reputation that Petrus Apianus had as being one of the most famous astronomers of the sixteenth century. He works here with a complicated scheme and makes clever approximations and simplifications where they can be made, in order to produce a pedagogical and elegant instrument. It is ironic that his magnificent *Astronomicum Caesareum*, based on the Ptolemaic model, soon after its publication would become obsolete in the new astronomical era based on the heliocentric model, with Copernicus' *De revolutionibus* (1543), published just three years after *Astronomicum Caesareum.*

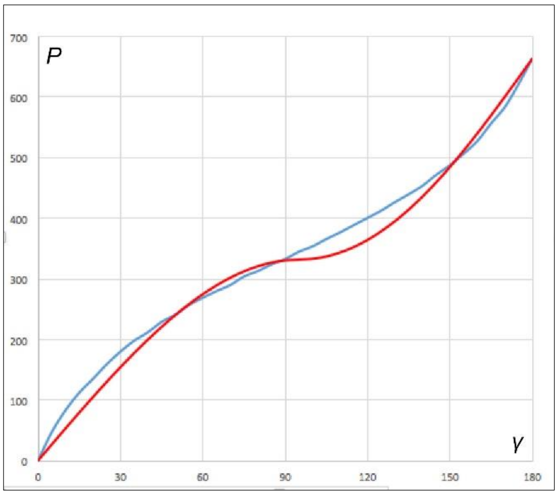


Figure 6: Comparison of the conversion functions.

7 REFERENCES

Alfonsine Tables, 1492. *Tabule Astronomice Alfontii Regis*. Venice, 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

Copernicus, N., 1543. *De Revolutionibus Orbium Coelestium*. Nürnberg, Ioh. Petreium.

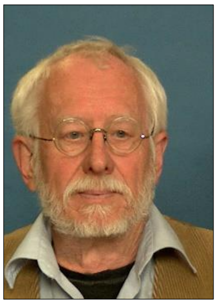
Gislén, L., 2016. A lunar eclipse volvelle in Petrus Apianus' *Astronomicum Caesareum*. *Journal of Astronomical History and Heritage*, 19, 247–254.

Gislén, L., 2017. Apianus' latitude volvelles in *Astronomicum Caesareum*. *Journal of Astronomical History and Heritage*, 20, 13–20.

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

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

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(2), 161–176 (2017).

REVISITING J.M. GILLISS' ASTRONOMICAL EXPEDITION TO CHILE IN 1849–1852

Germán Hidalgo Hermosilla
School of Architecture, Pontificia Universidad Católica de Chile,
El Comendador 1916 Providencia Santiago de Chile, Chile.
ghidalgb@uc.cl

Abstract: Between 1849 and 1852 the U.S. astronomer J.M. Gilliss led an expedition to Santiago, Chile, aimed at improving the accepted value for the solar parallax. Although this particular research project was not a success, the astronomers did make other useful astronomical contributions, and the expedition was the catalyst that led directly to the founding of the Chilean National Observatory. Meanwhile, Gilliss later went on to achieve further prominence as Superintendent of the U.S. Naval Observatory in Washington, D.C.

The results of the Chilean expedition were published by Gilliss in a six-volume work titled *The U.S. Naval Astronomical Expedition to the Southern Hemisphere during the Years 1849-50-51-52* that was issued over a 40-year period. In Volume I (published in 1855) Gilliss presented a 'warts-and-all' account of Chile, its politics and its people, which at the time—and subsequently—created considerable controversy. In this paper, after briefly reviewing Gilliss' Southern Hemisphere expedition we focus on the extensive non-astronomical narrative that Gilliss presents in this first volume.

Keywords: J.M. Gilliss, U.S. expedition, Chile, Astronomical Unit, non-astronomical narrative, controversy

1 INTRODUCTION

In 1848, in order to improve the measurement of the distance between the Earth and the Sun (the Astronomical Unit), Lieutenant James Melville Gilliss (Figure 1; Gould, 1866), a U.S. Navy astronomer, proposed to the United States Congress a scientific mission to Chile. The object of the mission was to complete measurements for the solar parallax at the same time these were carried out in the northern hemisphere (Huffman, 1991; Schrimpf, 2014). Chile was chosen for its location, near coinciding in degrees of latitude and longitude with Washington D.C., the location of the U.S. Naval Observatory. At first, Gilliss thought the island of Chiloé (just off the coast of southern Chile) would be the most appropriate place because it corresponded more closely in latitude to Washington, but the inclement climate there led him to select the city of Santiago, where he chose Cerro Santa Lucía as the site for his observatory (Gould, 1866).

Since others have already discussed Gilliss' scientific achievements while in Chile (e.g. see Dick, 2003; Huffman, 1991; Schrimpf, 2014), in this paper we will focus on the extensive non-astronomical narrative that Gilliss presents in the first volume of *The U.S. Naval Astronomical Expedition to the Southern Hemisphere during the Years 1849-50-51-52*. But first, let us learn about Gillis, the expedition and his six-volume treatise.

1.1 James Melville Gillis: A Biographical Sketch

James Melville Gilliss was born on 6 September 1811 in Washington D.C. His father was George Gilliss, of Scottish descent, who worked as a Government clerk in the city. When he was fifteen years old, the younger Gilliss joined the United States Navy, graduating with honors three years later, as a Passed Midshipman on his way to becoming a Lieutenant after three more years service. At this stage he became interested in scientific studies. In a letter that he wrote to the German mathematician Christian Ludwig Gerling (1788–1864; Figure 2), Gilliss explained that

Figure 1: James Melville Gilliss, 1811–1865 (www.usno.navy.mil/usno.library).

> Very shortly after I came to Washington for duty as a Passed Midshipman, members of Congress were told in my presence, 'There is not an officer of the navy capable to conduct a scientific enterprise.' The charge was intended prejudicially to the service to which I belonged, and was the more humiliating because the speakers were unknown, and defense was not possible. But from that hour no effort has been spared by which the standard of intelligence in the service might be increased and its service enhanced. (Gould, 1866: 138–139).

From that moment on Gilliss felt duty-bound to pursue a scientific education, and he attended the University of Virginia before health problems interrupted his studies. He took up his studies again during six months in Paris, between 1835 and 1836 (Dick, 2003).

Upon returning from Europe, Gilliss was sent to Washington as Assistant to Lieutenant Edward Hitchcock who was in charge of the Naval Depot of Charts and Instruments (see Leslie, 1866). Shortly thereafter, Gilliss was placed in charge of a small observatory supplied with a transit instrument with which he carried out his first astronomical observations. In 1838 Gilliss assumed new duties on a mission of longer duration. He was to carry out complimentary astronomical observations to the many others performed by the U.S. naval officer and explorer Captain Charles Wilkes (1798–1877) during his expedition to the Southern Seas from 1838 to 1842. It was fundamental to his new duties that Gilliss did not leave the Naval Depot observatory for the duration of Wilkes' expedition, and the observations that he carried out at this time marked the beginning of his career as an astronomer (Dick, 2003).

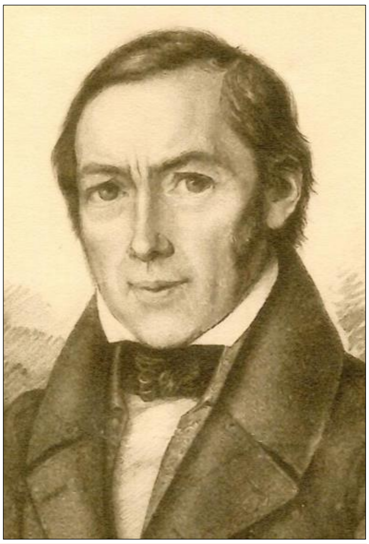


Figure 2: Chrisitan Ludwig Gerling (en.wikipedia.org).

Moreover, his work, continuously and systematically carried out and developed with unflagging energy, laid the groundwork for the founding of the United States Naval Observatory. As Gould (1866: 155) notes, at the time Gilliss "… was the sole working astronomer in the nation". Yet political intrigue prevented his anticipated appointment as the inaugural Superintendent (see Gould, 1866: 155–156 for details), and it was only in 1861 that he was appointed its Superintendent, a post he retained until his death (Dick, 2003). James Melville Gillis died prematurely from a stroke on 9 February 1865, at the age of 53 (ibid.). At the time he arguably was America's foremost astronomer. He was the first to have carried out *systematic* observations in an astronomical observatory, the first to have worked full-time and for four years in that position, the first, also, to publish a monograph containing his astronomical observations (Gilliss, 1846), and the first to prepare a catalog of stars and to plan and build a national astronomical observatory destined for professional use and not simply for instruction (ibid.). He died after an impressive astronomical career in both Chile and the United States.

1.2 Gilliss' United States Astronomical Expedition to the Southern Hemisphere

Gilliss (1856: iii) describes the origin of his expedition to Chile:

> During the summer of 1847 I received a letter from Dr. C.L. Gerling, a distinguished mathematician of the Marburg University in which he says: 'Since the date of my last I have been busy with the volume of astronomical observations, which you have kindly sent me, and it has occurred to me that it might be acceptable to you to receive by letter, in advance of its publication, the content of a brief treatise I shall transmit to M. Schumacher in a few days for its publication in the *Astronomische Nachrichten*'.

The volume to which Dr Gerling referred was the book Gilliss sent him with observations made in Washington between 1838 and 1842. On the other hand, the brief treatise mentioned by Dr Gerling was a manuscript he was about to publish in *Astronomische Nachrichten* about a new method of determining the solar parallax (Gerling, 1847).

As Keenan et al. (1985: 100; my italics) point out, Gerling's proposal was to perfect the established method of parallax, considering that

> … in addition to the observations of Mars near opposition, similar observations of Venus, near its stationary phase, would better provide the best determinations of the solar parallax. In order to measure the distance to the planet *simultaneous observations from two points on the earth separated as widely as possible in longitude would be needed.* Gerling suggested that the observations be made for Venus at its stationary points, in September, 1847, and April and May, 1849, and of Mars at its opposition, in 1849.

Clearly, this new requirement made it necessary that the observations conducted in the Northern Hemisphere be matched by equivalent measurements in the Southern Hemisphere. Therefore, Professor Gerling continued in the same letter:

> … it is much to be desired that the few delicate meridian instruments in the southern hemisphere should be brought to cooperate with us [Gerling and Gilliss]; and this, perhaps, it is in your power, to facilitate. (Gould, 1866: 159).

In his account, Gilliss tells of his reply to Gerling:

> But to prove my interest in the prosecution of the problem to its new solution, I then proposed an expedition to Chile, to observe the planet [Venus] near its stationary terms and opposition, in 1849, should my views receive encouragement from astronomers to justify such an undertaking. (ibid.).

At the beginning of 1848 the proposal that Gillis had presented to the American scientific community was supported by the American Philosophical Society and the American Academy of Arts and Sciences, and a budget of up to $5,000 was approved by the Senate of the United States (Rasmussen, 1954).

Paying tribute to the genre of travel writing, customary even in the middle of the nineteenth century (e.g. see Seed, 2004), Gilliss enjoyed describing with a wealth of detail the long journey that brought him from the Hudson River to the slopes of the Andes, via Panama. He dedicated the first six chapters of the second part of his book to this kind of writing, giving it the character of a logbook or diary. Thanks to these notes we know that at 3 pm on 16 August 1849 Gilliss left New York on board the *S.S. Empire City*, to arrive at the capital of Panama fourteen days later, where after moving around the city by various means of transport he was able to find "… one of the very best beds of Panama—a cot, with one small pillow and two thin sheets." (Gilliss, 1855: 411). From there he left for Callao on 27 September, this time on the *S.S. Nueva Granada*, arriving finally on 9 October at 8 am. He remained in Peru until midday of the 14th of that month, when he set sail, on the same ship that had brought him thus far, for the port of Valparaíso. The ship sailed into Valparaíso on 25 October, "… toward 5 o'clock just seventy days having elapsed since leaving New York…" writes Gilliss in his notes. And then "… in less than four hours since the Nueva Granada anchored, I was seated in a *birlocho*, on the summit of the hills at the back of Valparaiso, on my way to the capital." (Gilliss, 1855: 450).

Gilliss arrived in Santiago on 26 October. There he finally saw Cerro Santa Lucía, that "… little rocky hill in the eastern portion of the city which had been indicated by the ambassador at Washington as suitable for our purposes." (Gilliss, 1855: 453–454). Nevertheless, Cerro Santa Lucía (Figure 3) was chosen only after taking into account several of its shortcomings: its proximity to the Andes, its difficult and steep access, and the need to level the ground close to the summit where the observatory would be sited. After viewing several alternatives, such as Cerro

Figure 3: A chromolithograph of Santa Lucia drawn in about 1850 by staff of the U.S. Naval Astronomical Expedition; lithography by Thomas S. Sinclaire (after Gilliss, 1855: Plate 1).

Blanco, or even locating the observatory outside the capital, the conclusion was reached that Cerro Santa Lucía was the most appropriate site, in spite of the cost involved in leveling a part of its summit. All this was necessary because of this unprecedented event: to install a sophisticated collection of astronomical instruments on the hilltop in order to scrutinize for the first time and in a systematic manner, those southern skies that were not visible from the United States of America.

Thanks to the joint effort made by local authorities and members of the expedition

> … on the morning of the 9th of November our caravan delivered its assorted cargo at the foot of the Santa Lucía, almost uninjured by rough handling and the last eighty miles' journey. (Gilliss, 1855: 454).

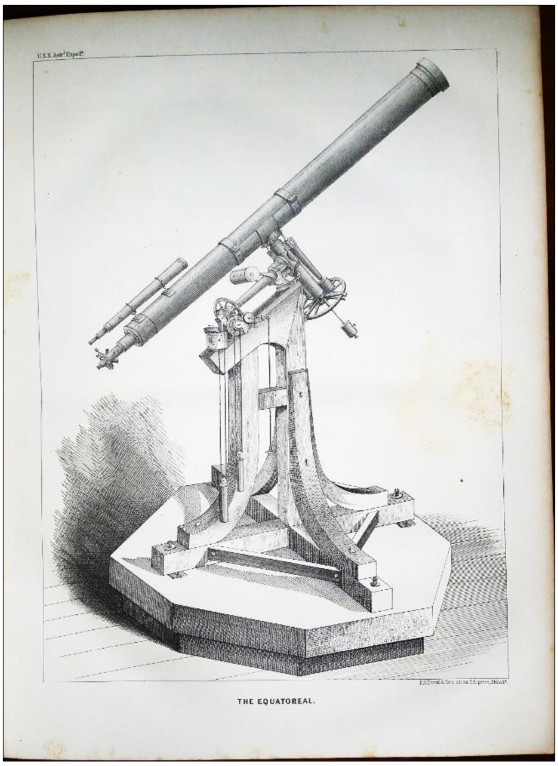


Figure 4: The 6.5-in refractor (after Gillis, 1856).

Then on 6 December 1849 Gilliss wrote with pride: "I had the satisfaction to obtain a first look through the telescope erected on its pier." (Gilliss, 1855: 455). By the last days of January 1850, the set of installations consisting of two observatories[1] and buildings for lodgings became available for the astronomers' use. The telescope referred to above and in Note 1 was a 6.5-in (16.5-cm) refractor shown in Figure 4.

In December and January Gilliss and his staff began a series of observations of Mars using the equatorial telescope. From October 1850 to February 1851 they carried out observations of Venus, followed by a second series of Mars observations from December to March 1952. And finally another series on Venus was undertaken from late May to September 1852, when the observatory was turned over to Chile. The Government of Chile also appointed three Chileans—a Professor of Mathematics and two of his best students, to learn astronomy and how to use the instruments. In addition to those observations undertaken for the original purpose of the expedition—a better determination of the Earth-Sun distance—Gilliss and his staff made thousands of observations of star positions over the four years they were based in Chile.

Gilliss' feelings of pride about these achievements are evident. Neither is it difficult to imagine the stir provoked by these installations among the inhabitants of the capital of Chile. Suffice it to say that the curiosity and wonder caused by the scientific instruments produced a permanent line of local people, old and young, climbing to the top of the hill. Gilliss' words about this situation are illuminating:

> As one of the fruits of our expedition here, I hoped to make it burn brightly, and that we might boast that Santiago through our influence established the first national observatory of South America. (Gilliss, 1855: 455).

The results of the expedition are quite remarkable. It is true the scientific results were a partial failure, for the distance from the Earth to the Sun was not improved on,[2] but this failure was partially offset by the catalogue of southern stars. But of greater importance surely was the fact that Gilliss did indeed, which still thrives today. He also left the earliest description of the culture, geography, meteorology and magnetic observations of Chile.

1.3 Contents of the Six Volume Work

Gilliss' 6-volume work, *The U.S. Naval Astronomical Expedition to the Southern Hemisphere during the Years 1849-50-51-52*, is known to only a few scholars and bibliophiles who specialize in Chilean or astronomical history. Yet apart from its astronomical content it contains his ambitious goal to describe and summarize the vast physical, social, cultural, political and economic reality of Chile in the middle of the nineteenth century.

The first volume (Gillis, 1855; Figure 5) is titled simply, *Chile*. It is organized into two sections and includes three appendices. The first section, *Descriptive*, is made up of fifteen chapters and its objective is to present Chile as a nation, making the country known in its entirety with one general and unique image. The second section, *Narrative*, is composed of twelve chapters and speaks of the various trips of members of the expedition. Gilliss himself travelled alone via Panama, which allowed him to visit Peru before finally reaching port in Valparaiso. His three assistants, Midshipmen Archibald MacRae, Henry C. Hunter, and the young student, Edmond Reuel Smith, travelled via Cape Horn, bringing a large part of the scientific instruments to be set up in Santiago.

Volume II, in contrast to Volume I, has a marked scientific nature; its second half describes minerals, animals and collections of fossils. Furthermore, it contains the narrative of the travels of Midshipman Archibald MacRae in Argentina, where he describes his impressions of the roads and cities visited on his trip back to the United States.

Volume III (Gillis, 1856; Figure 6) is dated 1856 but in fact was not issued until 1858, because of the lengthy calculations required to derive the solar parallax (Huffman, 1991: 213). This volume is devoted entirely to an account of the main objective of the mission. Here astronomical observations to determine solar parallax (and hence the Astronomical Unit) are presented and analyzed; their final scope was to improve the measurement of the distance between the Earth and the Sun and therefore, to improve estimates of the scale of the Solar System. Volume III also offers a detailed explanation of how the expedition came into being, setting out its most important activities. Much of this Volume was written by the U.S. astronomer Benjamin Apthorp Gould (1824–1896; Figure 7; Comstock, 1922), who not only got to know Gilliss well and therefore was ideally placed to write his *Biographical Memoir* (Gould, 1866), but in 1871 was himself appointed founding Director of the National Observatory in neighboring Argentina.

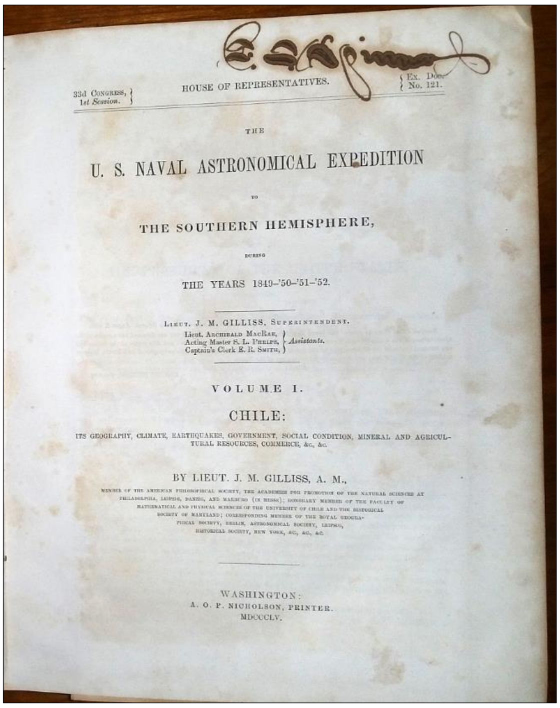
Funding then dried up for a time and the star catalogs, in Volumes IV and V, were not published until much later (in 1871 and 1895, respectively). Part of the reason for the untimely delay in the case of Volume V lay in staffing shortages at the U.S. Naval Observatory and the detailed analysis required to determine star positions.

Finally, Volume VI details the magnetic and meteorological observations carried out in the Cordillera de los Andes, during the return trip of Midshipman Macrae.

In the remainder of this paper we are only concerned with Volume I, and the non-astronomical narrative that Gillis presents there. But first let us 'set the scene', as it were, by briefly reviewing mid-nineteenth century Chile.

2 REPUBLICAN CHILE

Indisputably, one of the values of *The U.S. Naval Astronomical Expedition* lies in the special moment in the history of its writing: the decade between 1850 and 1860 when Chile was a young republic and many of its main cultural and scientific institutions were at the beginning of their development (see Hidalgo, 2010).



33d Congress, } 1st Session. }
HOUSE OF REPRESENTATIVES.
{ Ex. Doc. { No. 121.

THE
U. S. NAVAL ASTRONOMICAL EXPEDITION
TO
THE SOUTHERN HEMISPHERE,
DURING
THE YEARS 1849–'50–'51–'52.

Lieut. J. M. GILLISS, Superintendent.
Lieut. Archibald MacRae, }
Acting Master S. L. Phelps, } Assistants.
Captain's Clerk E. R. Smith, }

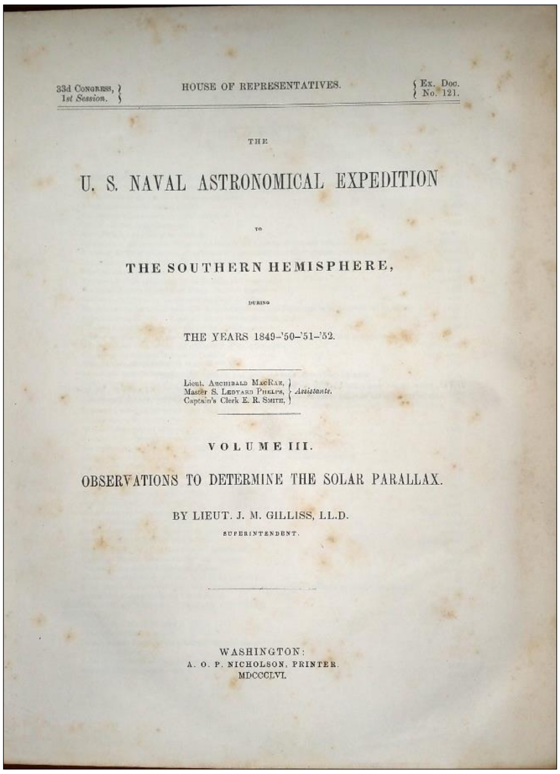
VOLUME I.
CHILE:
ITS GEOGRAPHY, CLIMATE, EARTHQUAKES, GOVERNMENT, SOCIAL CONDITION, MINERAL AND AGRICULTURAL RESOURCES, COMMERCE, &c., &c.

BY LIEUT. J. M. GILLISS, A. M.,
MEMBER OF THE AMERICAN PHILOSOPHICAL SOCIETY, THE ACADEMIES FOR PROMOTION OF THE NATURAL SCIENCES AT PHILADELPHIA, LEIPSIG, DANZIG, AND MARBURG (IN HESSE); HONORARY MEMBER OF THE FACULTY OF MATHEMATICAL AND PHYSICAL SCIENCES OF THE UNIVERSITY OF CHILE AND THE HISTORICAL SOCIETY OF MARYLAND; CORRESPONDING MEMBER OF THE ROYAL GEOGRAPHICAL SOCIETY, BERLIN, ASTRONOMICAL SOCIETY, LEIPSIG, HISTORICAL SOCIETY, NEW YORK, &C., &C., &C.

WASHINGTON:
A. O. P. NICHOLSON, PRINTER.
MDCCCLV.

Figure 5: The Title Page of Volume I (Gilliss, 1855).

Preceded by a period of political and economic consolidation, the end of the 1840s and the beginning of the 1850s were marked by attempts to give cultural identity to the new nation. In this context, the arrival of the United States astronomical expedition became precisely a protagonist of these deeds, confirming the climate of the moment.



33d Congress, } 1st Session. }
HOUSE OF REPRESENTATIVES.
{ Ex. Doc. { No. 121.

THE
U. S. NAVAL ASTRONOMICAL EXPEDITION
TO
THE SOUTHERN HEMISPHERE,
DURING
THE YEARS 1849–'50–'51–'52.

Lieut. Archibald MacRae, }
Master S. Ledyard Phelps, } Assistants.
Captain's Clerk E. R. Smith, }

VOLUME III.
OBSERVATIONS TO DETERMINE THE SOLAR PARALLAX.

BY LIEUT. J. M. GILLISS, LL.D.
SUPERINTENDENT.

WASHINGTON:
A. O. P. NICHOLSON, PRINTER.
MDCCCLVI.

Figure 6: The Title Page of Volume III (Gilliss, 1856).

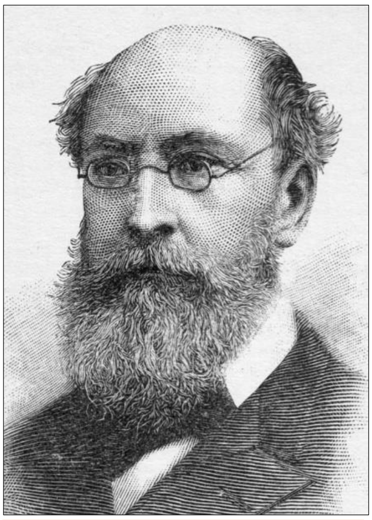


Figure 7: B.A. Gould (after *Harper's Encyclopædia of United States History …*, 1905: 99).

With the arrival of the expedition, toward the end of 1849, the University of Chile had only been extant for seven years, and for six years had been functioning in one of the salons of the old Universidad de San Felipe. The Faculty of Physical Sciences and Mathematics had been created as part of the University. This Faculty was to be fundamental in establishing intellectual networks for the expedition. On the other hand, the creation of the Academy of Painting and the first classes in Architecture are contemporary to the expedition. The importance of these events is confirmed by the visit paid by Gilliss to the Academy of Painting. The first steps for the construction of the Teatro Municipal had been taken the year before, and its inauguration was five years after the members of the expedition had left the country.

Figure 8: Claudio Gay (en.wikipedia.org).

The first volume of the *Atlas de la Historia Física y Política de Chile*, a project that the French scientist Claudio Gay (1800–1873; Figure 8) had worked on for decades, was published in 1854, only one year before Gilliss published the first volume of his own work.[3] This fact is important, because, as can be observed in the first chapters of Gilliss' book, the astronomer made use of information provided by Gay, both in order to write his own reports, and to incorporate unpublished or recently published graphic documents, especially regarding maps of the national territory created by the French sage.

It must also be pointed out that in 1848 the Chilean Government charged the geographer and geologist, Pedro Amado Pissis (1812–1889; Figure 9)—whose works Gilliss also used—with carrying out the titanic labor of mapping the entire national territory, since Gay's mapping was taking too much time (González, et al., 2011).

Meanwhile, other events relevant to the field of knowledge must be mentioned, since they happened at the same time and in some way affected Gilliss' work in Chile. One of these is the publication of the first issue of the *Anales de la Universidad de Chile* in 1844, which from then on and for many years was an exclusive form of communication between Chilean intellectuals. For the same reasons, as we shall see below, these *Anales* contained notes by and about Gilliss, before his arrival and after his departure. A fresh perspective was brought to the Quinta Normal de Agricultura, dating back to 1841, with the arrival of the agronomist, Luigi Sada di Carlo, who became Director in 1849. Rasmussen (1954) has pointed out that Sada di Carlo's efficient management encouraged Gilliss' interest in the possibility of developing an exchange of agricultural practices, as well as of native species, between Chile and the United States. This initiative, successful for many years, depended on the intellectual and scientific relationship between Gilliss and Sada di Carlo, and was kept up even after the American's departure (Rasmussen, 1954: 107). Both men were quite certain this bond would permit the 'Quinta' to contribute much, as Gilliss pointed out. The 'Quinta' was an urban space around which a set of cultural, educational and scientific institutions grew, colonizing the westernmost area of the city together with the new *barrio*, Yungay (Gilliss, 1855: 192).

Gilliss also made contact with the Polish-born geologist Ignacio Domeyko (1802–1889; Figure 10), another of the foreign scholars who had made Chile their home. In 1847 Domeyko was employed as a teacher at the Instituto Nacional and from this position established a relationship of mutual interest with the astronomer. In fact, he accompanied Gilliss in some excursions outside of the city, for scientific reasons (Gilliss, 1855: 111). Later, when Gilliss was about to leave the country, Domeyko was in charge of representing Government authorities in negotiating the conditions of the sale of the instruments and establishment of a new National Observatory (Kennan et al., 1985; Rasmussen, 1954: 108). Years later, as a scientist and expert in geology and mines, the Polish Professor wrote a very critical article about the first volume of Gilliss' work.

One way or another, Gilliss eventually made contact with all the intellectuals and scientists then living in Chile. The American expedition should therefore be considered as another of the cultural and scientific events of the era, confirming that at this time Chile was consolidating its cultural and scientific bases and its identity as a nation.

3 GILLISS' NON-ASTRONOMICAL NARRATIVE

3.1 The Text

In his challenge to reveal Chile as a whole, Gilliss resorted to a narrative writing strategy that consisted of using different voices and registers, which ordered the framework of his discourses. This gave his text a polyphonic character that differentiated it from more traditional travel narratives. In his narrative, Gilliss goes beyond the vision of a traveler, an astronomer, a man of science or a military man. The meticulousness and the breadth of the themes Gilliss attempts to address through his descriptions disclose the ambition of wishing to narrate the entirety of the nation in its formative years. In this work, Gilliss' capacity for collecting documentary evidence is noteworthy, using his intuition to choose pertinent actors and relevant information.

Thus, we observe that sometimes the story of the experience of the trip is transcribed as a personal event as though it were a diary or a logbook (nearly all of the Section II narrative, is organized in this way), while at other times it is more like a newspaper article. On the other hand, the text can be a professional analysis of events of a military sort, impersonally written up; neither is poetical expression absent, inspired by some unusual phenomenon in nature. And certainly, the simple transposition of objective information culled from statistics, is also present. All this is complimented by a few chosen illustrations (e.g. Figures 3, 11 and 12), either produced by the expedition or borrowed from someone.

In collecting his records, Gilliss turned to the most varied sources. In the first place, as we have seen, he made contact with men of science as well as military men and politicians, and although he mingled with local 'high society',[4] he did not ignore the stories provided by the lower classes. He asked questions of everyone, wishing to learn and find answers to the scenes that he saw or the events that he witnessed: in his view, everything merited explanation.

Figure 9: Pedro Amado Pissis (www.wikipedia.org).

Gilliss sought the counsel of other scholars on all subjects of interest to him, openly asking for their opinions and data. For his description of Chile's geography in the first chapter, he went to the scholars Claudio Gay and Ignacio Domeyko, whom he quotes repeatedly. In order to substantiate his report, as we have already mentioned, he used maps made by Gay for his *Atlas de la Historia Física y Política de Chile*.

Figure 10: Ignacio Domeyko (en.wikipedia org).

Figure 11: The Palace, drawn in about 1850 by a member of the U.S. Naval Astronomical Expedition, lithography by P.S. Duval & Cós Steam lith. Press Philadelphia (after Gilliss, 1855: Plate IV).

Figure 12: The Mint, drawn in about 1850 by a member of the U.S. Naval Astronomical Expedition, lithography by P.S. Duval & Cós Steam lith. Press Philadelphia (after Gilliss, 1855: Plate III).

Likewise, he refers to Amado Pissis who, as we remarked above, had been working on a similar assignment since 1848. The plan of the Province of Santiago that Gilliss includes in his report derives from Pissis. We can conclude that cooperation between these men of science was not unusual, and if Amado Pissis was willing to share cartographic information with Gilliss, as the plan indicates, it is very likely that Gilliss in turn supplied him with astronomical data, which were essential for determining the positions of geodetic reference points. All things considered this reflects well on Gilliss, for by including the plan of the province of Santiago in his report, he anticipated by twenty years the publication of Pissis' *Geográfica Física de la República de Chile* which only appeared in 1875 (González and Andrade, 2011). It is also worth noting that Gilliss received assistance from the Academia Military in drawing the plan of Santiago: this plan was achieved with the help of the first Chilean officers trained to draw topographical maps.

On another topics, this time more of a domestic and social nature, Gilliss tells of his encounter with a young country woman surrounded by children, when he was visiting a friend's property in the countryside. He spoke to her to inquire about her situation, and was intrigued to learn that she was not married, and was even more surprised when she recounted her reasons for not marrying (Gilliss, 1855: 344). Gilliss uses this episode to back up his observations about people of the countryside, and then he launches a severe criticism of their beliefs and customs: "It is difficult for one … to realize how his kind can descend so nearly to the level of brutes as they have done in Chile." (ibid.). As regards the organization of farm work, he adds: "Laborers on estates are of two classes: peons (hired men) and *inquilinos* (tenants) veritable remnants of the feudal system." (Gilliss, 1855: 345). Yet at the same time Gilliss described the harsh reality prevailing in his own country, which in many aspects was equally precarious and horrifying: "Indolence and improvidence render the peons of Chile quite as thoroughly slaves as are the negroes of Cuba or of the Southern States of America." (ibid.).

In relation to medical practices, Gilliss' observations are equally scathing. However, in this case the source from which he chooses to build up his arguments have a sparkle that permits the use of nuance and wit: these writings have irony and sarcastic humor. To analyze and present the subject Gilliss relies on a text written two decades earlier by the cleric José Javier Guzmán y Lecaros (1836). In one of these chapters Guzmán speaks of the gifts of Pablo Cuevas, "… an unlettered disciple of Esculapius … so famous in his time that Padre Guzmán devotes an entire chapter to an account of his skill and charity." (Gilliss, 1855: 347). All things considered, however, beyond Gilliss' criticisms of a society which in various ways he considered pre-modern, what we are interested in pointing out are the formal gradations that permeate Gilliss' text, producing transitions in judgment ranging from greater severity, to others of a more playful character, as shown here concerning Padre Guzmán.

Gilliss also was a military man, and as such he had broad knowledge in this area. Thus, he spoke with authority on weapons and strategy, and analyzed and offered opinions about political events. We therefore see in him an observer who thinks in geopolitical terms, even as he visits a fledgling and promising nation, situated at the extreme end of the continent. Plenty of examples of this may be found in his remarks about the revolutionary events in Santiago that occurred on 20 April 1851. These were perhaps the most noteworthy political events while he was in Chile and so he wrote of them extensively. He was not in Santiago that day, since he had gone to Valparaíso to pick up his son who had come to visit him. He therefore collected a series of different versions of that fateful morning's events in order to make up his own mind about them. So even though he was not a direct witness to the armed uprising of Coronel Pedro Urriola Balbontín and his Chacabuco Battalion, this is, nonetheless, one of the events most closely described by Gilliss in his memoirs (Gilliss, 1855: 495–505). Gilliss went directly to the different sources, in effect, the notes brought by the official emissaries to the port, as also the official reports made by the press, which backed the Government. Moreover, upon returning to Santiago he also obtained information from his own men who had remained at the Observatory. But he also gathered news from the opposition press, which he tells us had been silenced, and he even interviewed some of the uprising's leaders. All this information, together with his military knowledge, finally allowed him to make his own judgment at to what actually happened. Beyond the objectivity Gilliss achieved in his account, interestingly, he clearly had detailed knowledge of the military quarters situated at the foot of Cerro Santa Lucía. As he was installed near the summit he could easily observe its functioning and was aware of its weaknesses as well as its strengths. One can deduce from the text also, the knowledge he had of the arms stored there and of the possible ways to access them. He knew the role Cerro Santa Lucía had always played in the city's defense. He knew of the strengths and weaknesses of its two terraces, Hidalgo and González, the one looking north and the other, with less strategic advantages, looking south (see Figure 3). After all, the hill had been home to him for nearly two years. Gilliss' information clearly shows the excesses, achievements and errors of a day marked in blood, whose im-

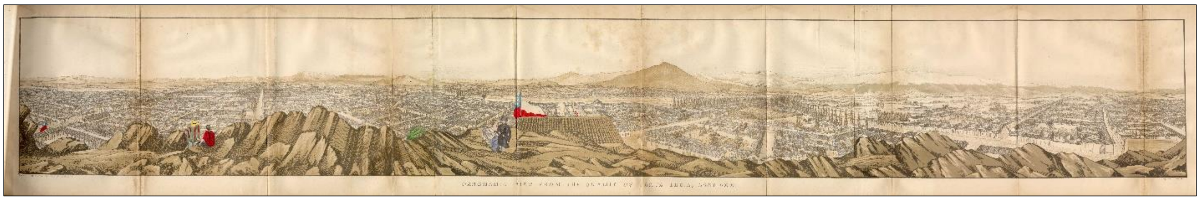


Figure 11: A panoramic view from the summit of Santa Lucia, Santiago, drawn in about 1850 by Edmond Reuel Smith, lithography by Thomas S. Sinclaire (after Gilliss, 1855: Plate 5, Frontispiece).

portance had been played down by official reports. In the end, his report is neither a defense of the rebels nor much less a celebration of order restored. It is, on the other hand, a reflection of the danger the city found itself in, under threat of the possible explosion of the ammunitions depot located at the foot of the hill, and of the risk to the population and also of course to his own assistants and scientific instruments had the rebels achieved their goal.

Gilliss was a liberal, moved by the daily conditions of people at large, to which the locals largely were insensible, since they were not alive to any reaction or surprise. Nevertheless, at other moments he tried to be a mere observer, a person who scrupulously reflected only what he saw and felt. This was the case when he addressed the fearsome and frightening subject of earthquakes:

> There was yet one other subject for whose intelligent discussion it was hoped we might collect interesting materials, and for which a rude instrument had been brought to assist us, I mean that startling terrestrial phenomenon of whose coming no man knows—the earthquake. (Gilliss, 1855: 508).

For this, he measured the duration of earthquakes, and noted his own and his assistants’ reactions as well as those of his neighbors—the latter supposedly being more accustomed to these natural events (Gilliss, 1855: 461–462). He kept records of the phenomena, once he grew used to them. At other times his open sensibility was obvious, as when he admired the landscape and nature in all its breadth and diversity, as when he described the Santiago Valley seen from the Cuesta de lo Prado (e.g. see Gilliiss, 1855: 142). Perhaps all of this was simply a reaction to what, on the contrary, human nature provoked in him, which most times was irritation and cause for distress. Such was the case during the visit to the countryside by Laguna Aculeo, where he witnessed the difficult lives of the inhabitants.

The text, then, is presented as a series of voices, through which Gilliss essayed different ways of thoroughly tackling a diverse range of material. Through his carefully planned narrative, Gilliss stressed the fragmentary nature of the reality before him. His approach was critical, and we know that behind each text there was a choice, and therefore partiality, and in spite of this, there was willingness to show reality in its completeness. No doubt, in this way of seeing and narrating facts, there are also clear symptoms of a change of era and of sensibility. Framed in this way, images play an important role in this work.

3.2 The Role Played by Images

The role played by images in the Gilliss’ publications is limited, as was the case for many of the texts dating to this period. Nevertheless, considered individually, images contributed significantly to the work. Each image was of specific interest, but taken together their importance was diluted due in part to their scarcity, and in part to the diversity of their subjects and quality. Furthermore, it must be pointed out that how they were actually produced is an enigma to us, their success or relative achievements notwithstanding.

Considering how responsibilities were initially distributed among the members of the expedition, it is very likely that the task of producing images fell on the young assistant, Edmund Reuel Smith, a recent graduate of Georgetown College who was appointed to join the expedition as an artist (Gilliss, 1856). However, and with the noteworthy exception of the panoramic view of Santiago (Figure 11), where he is clearly identified as the artist of the drawing,[5] his authorship cannot be guaranteed in any other cases.

Regarding the image of the capital, it is invaluable for its descriptive rigor and verisimilitude. The latter characteristic is proof that it was attained using records captured by some kind of optical instrument. Nonetheless, it is interesting to ask about the original records made by Smith. From which illustrations were the engravings based? How was this high degree of precision achieved regarding observed reality? The answer to this question would be much simpler if we had access to these records, which unfortunately have not come down to us from Gilliss, unlike his maps and notes of astronomical data.[6]

For the most part, the plates show us unique events, many of them experienced by members of the expedition, such as the visit to Laguna Aculeo and a trip to the port of Caldera. Illustrations of noteworthy places in the capital are included, such as the buildings on the north side of the Plaza, which Gilliss called 'the Palacio' (Figure 11), and the main facade of the Moneda (the Mint—Figure 12), observed with a foreground space disproportionately wide; and of course, the view from Cerro Santa Lucía already showing the northern part of the observatory (Figure 3).

The scarcity of images in the book may be attributed to several reasons. One might be the high cost of including images of any kind in a publication at the time. This refers both to making lithographs and to the design of them and their arrangement in the book. Another hypothetical reason for the small number of images might be that Smith dedicated a great amount of his time to other duties, especially registering meteorological observations, which required constant attention to the pertinent instruments (Gilliss, 1855: 507). However, the remaining volumes of Gilliss' work also have illustrations which complement the first volume, especially those regarding zoology, botany, maps and archaeological topics.

It is also true that there are, apparently, different copies of the book, some with colored illustrations and different kinds of lithographs. An example of the differences may be observed in the plate that is the frontispiece, Cerro Santa Lucía seen from the southeast; there are two different versions of this, depending on the copy consulted.[7] The plates vary according to what is represented in the foreground of the image, providing the 'atmosphere' considered appropriate by the lithographer on duty. On the other hand, it seems clear that the information given in the middle ground and background was fundamental, and presumably was included in the original drawing.

We must also consider that some of the images in the book were taken from other sources or were made with the help of local specialists. This is the likely the case of the three city plans included: Santiago (see Figure 12), Valparaíso and Constitución. We must add to these plans, the maps mentioned above drawn up using those of Claudio Gay and Amado Pissis and the plan of the Province of Santiago, on which we also have previously commented (Figure 13). Lastly, the image of an Araucanian 'chief' stands out; no doubt included by young Edmond Reuel Smith. After the astronomical mission had come to an end, Smith stayed on in Chile to become better acquainted with the country, and the culture of one of its original peoples (see Smith, 1855).

In summary, the presence of images in this work is not only proof of an original point of view,

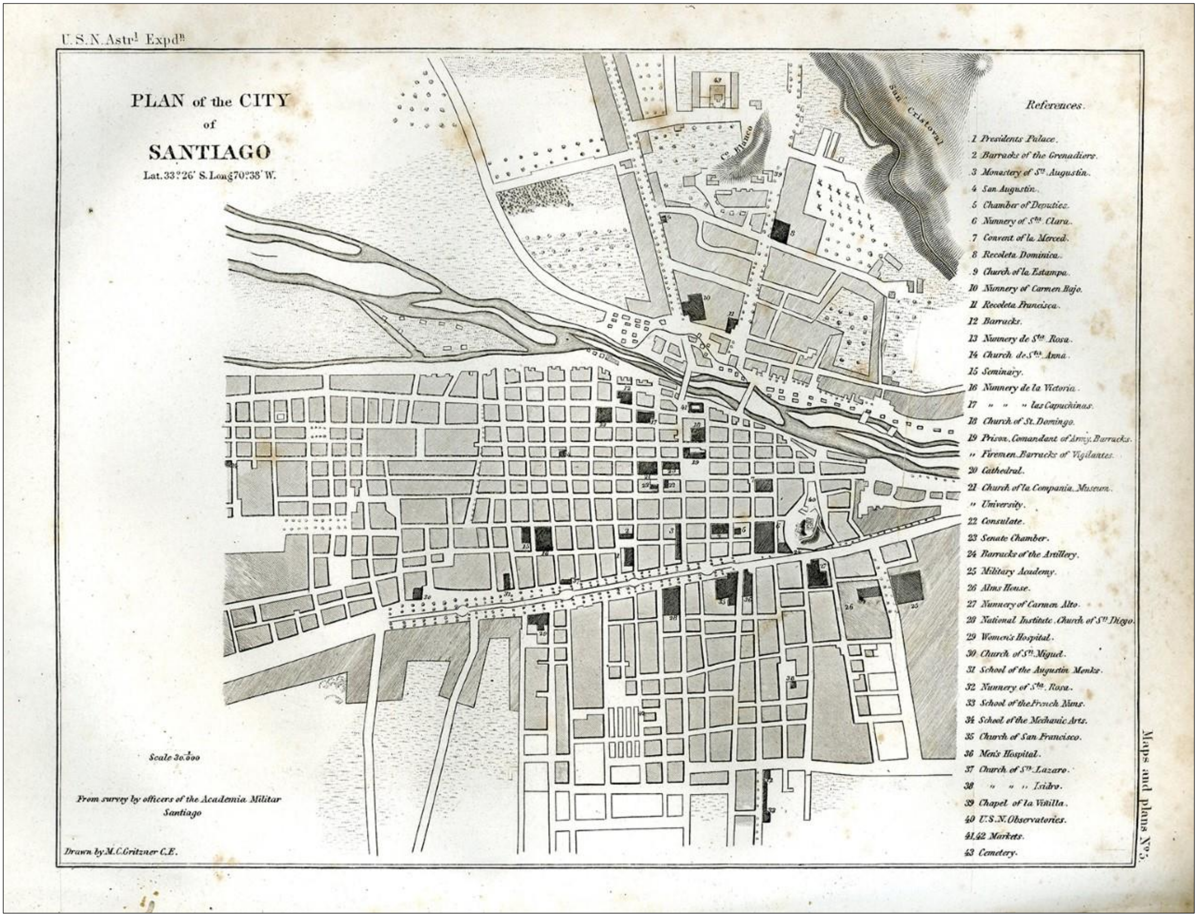


Figure 12: A plan of the City of Santiago, drawn in about 1850 by M.C. Gritzner C.E., following a survey by an officer of the Academia Militar Santiago (after Gilliss, 1855: Maps and plans No. 5).

but also of a highly selective view of reality, which after all was so broad and varied that a large quantity of images would have been required to do it justice. Much of this preoccupation with representation can be said to have culminated in the panoramic view of Santiago which, we believe, has no equal among representations of the capital carried out in the nineteenth century, for its breadth, descriptive thoroughness and its apparent authenticity.

3.3 Critical Acclaim and Cultural Transcendence

It must be said that the responses to and impact of Gilliss' published volumes has been varied, and even given rise to some polemics. This is apparent in the first critical reviews published in the United States and in Chile. But some signs of this may also be noted in recent opinions, both those considering the work's enormous value as testimony of an important mission in the development of astronomy, as also those that consider it a source of information of the process experienced by Chile in its becoming a State and a nation. Regarding the former, Gilliss' work was unsparing and ruthlessly criticized by one of his most prestigious interlocutors during his sojourn in Chile, the Polish scholar, Ignacio Domeyko. In his critical article published in 1857 in the *Revista de Ciencias y Letras* (1857) and then again, without alterations, in 1859, in the *Anales de la Universidad de Chile* (1859), Domeyko asks:

> How much of this first volume, the result of a three year scientific expedition, has contributed to broadening our positive geographic knowledge of Chile before the author arrived to these shores? (Domeyko, 1857: 633; 1859: 20).

Domeyko organized his analysis in order to expose the multiple errors in Gilliss' work. In the first part of his critical commentary, Domeyko took it upon himself to demonstrate the multiple of errors in Gilliss' description of Chile's physical geography; in the second part, he referred to the mistakes regarding the climate; and the third and last part was dedicated to the astronomer's comments on earthquakes. From the opening comments, Domeyko announced that only these three headings could be considered the 'serious, scientific part' of the first volume of *The U.S. Naval Astronomical Expedition.* He considered that that

> … part of the trip should be left aside, in which the author, as most travel writers on picturesque trips so abundant in modern literature, who speak of an infinity of personal events, depicts the personality of the traveler and not the country of his travels. (ibid.).

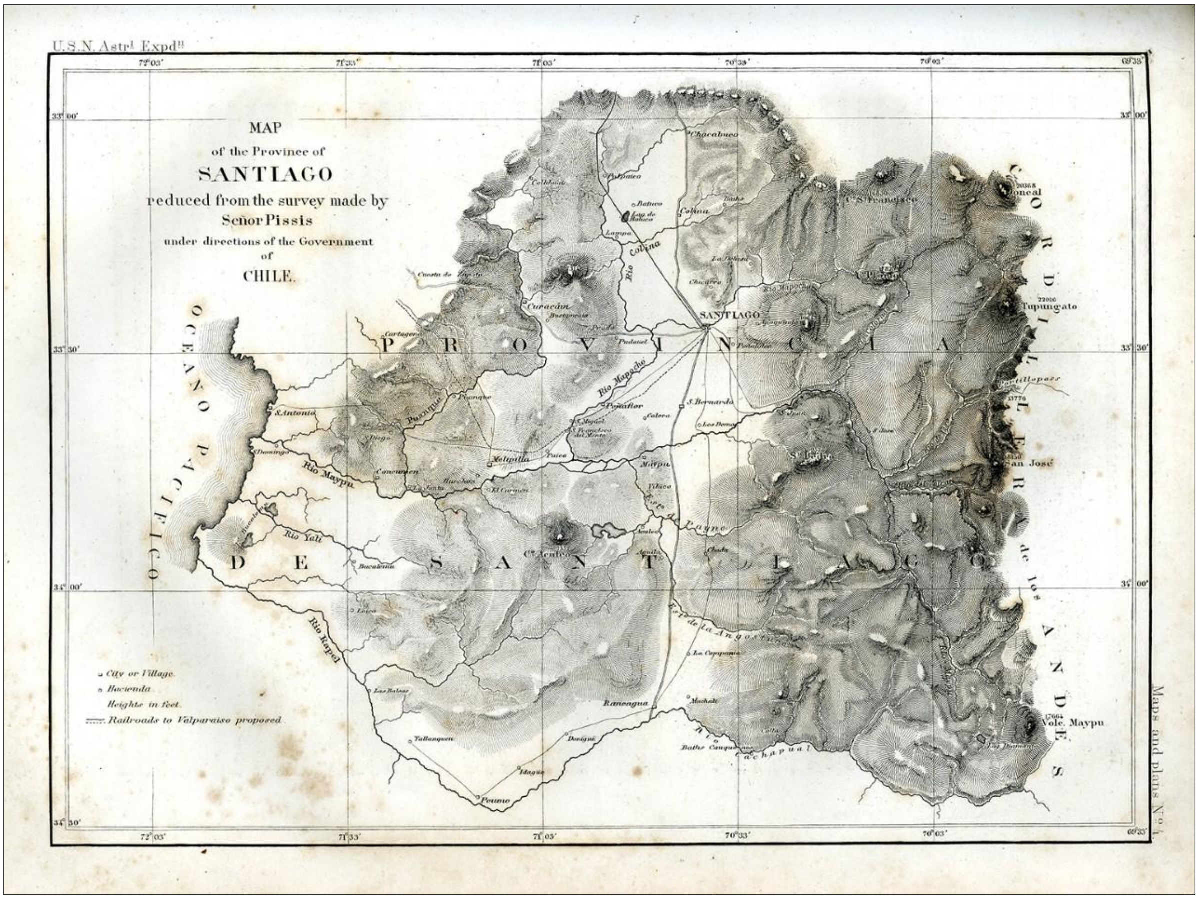


Figure 13: A map of the Province of Santiago, drawn in about 1850 by a member of the U.S. Naval Astronomical Expedition, and reduced from the survey made by Amado Pissis (after Gilliss, 1855: Maps and plans No. 4).

Nevertheless, by the end Domeyko's commentary takes on a more conciliatory tone:

> I hope, and I have reason to do so, that the three volumes of the American Expedition, which shall contain all the astronomical, meteorological and magnetic observations made by Mr. Gilliss and his companions in Chile, will compensate for the defects in his general geographical description of the country which I have noted. (Domeyko, 1859: 61).

As can be imagined—and Domeyko was well aware of this—the three years that Gilliss spent in Chile were mainly dedicated to his astronomical observations: measuring the motions of Mars and Venus, and cataloguing thousands of stars. Gilliss hardly had time to travel and observe the physical characteristics of the country with the scientific rigor of a naturalist—which, of course, he was not. In the best of cases, Gilliss saw fit to draw on the few writers who had begun this task, including Gay, and Domeyko himself. However, for Domeyko this was not enough, as he considered that Gilliss seasoned his writings with his own 'phantasy'. Beyond Domeyko's correct critical appraisals, his comments show his grievances provoked by Gilliss' contempt and irony regarding Chileans of the mid-nineteenth century.

Gilliss' comments were not only read in Chile. In his paper about the expedition, the agronomist Wayne D. Rasmussen (1954) agrees that the report was full of Gilliss' personal opinions, hinting that something more might have been expected of a representative of the United States. In effect, Gilliss' sometimes disagreeable comments about Chile and its people did not go unnoticed by his fellow countrymen. As Rasmussen (1954: 112) noted:

> A reviewer for a literary magazine, *Putnam's Monthly*, suggested that the narratives could have been much condensed and that the descriptions of social, civil and religious comments, might well have been omitted.

In Gilliss' favor, Rasmussen states that in agriculture, a field in which Gilliss wished to point out the contributions made by the expedition,

> Gilliss was in Chile for three years and he was a careful observer. If the reader discounts his prejudices, which are obvious, there is much material of value. (Rasmussen, 1954: 111).

Regarding Gilliss' alleged competence to interpret the social reality he observed, we have the more recent views of historians Simon Collier and William E. Sater. Certainly, in order to describe and analyze the behavior of Chilean society in the mid-nineteenth in the context of their *Historia de Chile 1808–1994*, Collier and Sater counted on "… the sharp-eyed Lieutenant Gilliss, an American visitor, whose account of mid-nineteenth century Chile is singularly comprehensive." (Collier and Slater, 1996: 91). These authors also made use of Gilliss' statistics (Collier and Slater, 1996: 92) and his descriptions of urban life in the capital, where, as we can see in Chapter 8, Gilliss went into great detail. In doing so, Collier and Sater (1996) advocate Gilliss as a source of historical information on nineteenth century Chile.

Toward the end of his writing, Gilliss also introduces nuances into his thoughts about Chile, highlighting its potentialities and stating that what had previously been written did not reflect its most recent improvements and transformations. Together with this, and in spite of his limitations as an author, Gilliss justifies his work as a writer who shows the world Chile as a living nation. This can be deduced from the "Prefatory", which is also a final assessment:

> Within the preceding quarter of century Chile has advanced far more rapidly than any other nation of Spanish America in intelligence, good order, agricultural and mineral wealth, and commercial importance. But all or nearly all, the volumes of information we possess of it were written before the era of progress, and what Chile was, not what it *is* … and in course of time, an account of its geography, ethnography, and statistics will probably follow. Until then, the present volume may supply some deficiencies. But I beg it may be remembered that no pretensions are made to elegance of literary composition, and if the most trustworthy information which other duties permitted me to obtain is detailed comprehensibly, it is all that it was expected to accomplish. (Gilliss, 1855: 4).

But this is not all; Gilliss was very aware of the thoughts and opinions expressed throughout his work, and in the end perhaps he was even counseled or warned about them. In Chapter XII of Section II, that is, in a sort of appendix, "A Brief Account of our Work", Gilliss wishes to be fair to the Chilean people, and in his own way, offers an apology for his earlier harsh words:

> A word more and I have done. Many things may have been told in the preceding pages apparently ungracious from one who acknowledges so many attentions, so many acts of courtesy, and such valuable assistance, but I claim justification and pardon … Constant occupations prevented much of the intercourse that would have imparted some of these softening influences and it may be that I continue scarcely more competent to truly estimate Chile and Chilenos than in 1849 … and next to my own, there is neither land nor people for whose prosperity and happiness I feel such earnest desire none whose advancement I would make such efforts to promote. Will these sentiments give me a right to indicate faults, not as a censor regardless of the pain he inflicts, but as the friend who details errors that they may be the better corrected by the admirer who desires to perfect the object of his esteem? On these grounds I ask the indulgence of friends in Chile, praying they will ever believe me grateful for their untiring kindness and hospitality. (Gilliss,

1855: 511).

Notwithstanding the initial criticism, with the passage of time Gilliss' work has become known and valued as a source of information, while his strongly worded appraisals of the Chilean people are not reason enough to doubt the quality of his detailed descriptions. Proof of this is that, nearly one hundred years since the publication of the first volume of Gilliss' work, Carlos Peña Otaegui, in his classic *Santiago de Siglo en Siglo,* used it as a main source for one of his chapters (Peña Otaegui, 1944: 213–233).

Gilliss' work is an important contribution to the field of the history of astronomy, not only as concerns Chile, but also the United States and Germany, the latter nation also being involved in the project carried out by the naval expedition. In this regard, in their *El Observatorio Astronómico Nacional de Chile: 1852–1965*, Keenan, Pinto and Álvarez (1985), give Gilliss' expedition a leading role in their first chapter.

In the United States, Gilliss' relevance is even greater. The astronomer and historian, Steven J. Dick, dedicates part of his book, *Sky and Ocean Joined*, *the U.S. Naval Observatory 1830–2000,* to Gilliss' expedition (Dick, 2003: 140–144), and one of his chapters describes the period when Gilliss directed the United States Naval Observatory (Dick, 2003: 140–160). Gilliss appears prominently in the frontispiece of this book, heading a row of four distinguished American astronomers (from left to right: James Melville Gilliss (1811–1865), Asaph Hall (1829–1907), Matthew Fontaine Maury (1806–1873) and Simon Newcomb (1835–1909)), in recognition of his role in the development of astronomy in North America. In fact, the library of the U.S. Naval Observatory itself bears Gilliss' name.

As for Germany, Gilliss' name is tied to that of Christian Ludwig Gerling, the astronomer who gave origin to the mission, and to Carlos Moesta, who took charge of the Chilean National Observatory once the Americans left. Meanwhile, Professor Andreas Schrimpf (2014) from Philipps University of Marburg has written about the scientific results of Gilliss' expedition.

In quite another field, a study of the élite and underprivileged in nineteenth century Santiago, the historian Luis Alberto Romero (2007: 57) calls Gilliss' work one of the "… principal testimonies about Santiago in the middle of the century."

4 CONCLUDING REMARKS

The contributions of the Gilliss expedition are not open to doubt. When the expedition came to an end, the Chilean Government purchased both the astronomical instruments and the buildings, and these marked the origin of the Observatorio Astronómico Nacional de Chile (Keenan et al., 1985). The facilities were placed under the care of a young German mathematician, Carlos Moesta (1825–1884), who on 17 August 1852 by Presidential Decree was officially appointed the founding Director of the new national observatory (see Keenan et al., 1985). Moesta worked alongside members of Gilliss' expedition during the last two weeks of their time in Chile, a reasonable amount of time, apparently, to become familiar with the instruments. This was the beginning of uninterrupted astronomical observations of the Southern skies from Chile, extending from Gilliss' day through to the present time.

As is well known, in the mid-nineteenth century the United States was also in the process of consolidation regarding its territories and institutions. In writing about the history of the United States Naval Observatory, Steven J. Dick makes use of a bird's eye view image of Washington in 1861, where the Capitol is seen as only half built, as a metaphor of this circumstance. At the same time, this choice of illustration also expresses well Gilliss' new role—the latter finally being able to bring the Observatory that he founded under his own management, having been appointed Superintendent of the Observatory that very year (Dick, 2003: 140).

Given the perspective of time we have to question the success of Gilliss' primary mission—the astronomical measurements. His observations certainly did not lead to an improved value for the Astronomical Unit (see Table 1 in Dick et al., 1998), but he did make useful observations of the Southern sky. However, Gilliss was instrumental "… in the beginnings of two national observatories thousands of miles apart." (Dick, 2003: 141), one in the United States and the other in Chile. In the case of our national Chilean observatory his account in *The U.S. Naval Astronomical Expedition …* is detailed, and his critical role in its founding is very clear (for details see Keenan et al., 1985). His 1849–1852 Expedition therefore represents a very early example of cooperative relations between two young American nations. Today, because of its clear skies and dry conditions in places like the Atacama Desert, Chile has become the astronomical capital of the world, with almost half of the world's major astronomical instruments. It all began with the work of James Melville Gilliss, and his successors at the Observatorio Nacional in Santiago.

Finally, as we noted previously, others have already discussed Gilliss' astronomical achievements while in Chile, so in this paper we have tended to focus on his extensive non-astronomical narrative contained in the first volume of *The U.S. Naval Astronomical Expedition to the Southern Hemisphere during the Years 1849-50-51-52*. Despite their somewhat controversial nature, these writings provide one of the most complete portraits available of the physical, cultural, social and political traits of mid-nineteenth century Chile, and as such are a unique historical document.

5 NOTES

1. The telescopes were a meridian circle by Pistor & Martins of Berlin and an American-built 6.5-in (16.5-cm) Young equatorial refractor with a Fitz objective (Gould, 1866: 163–164; Huffman, 1991: 201–211). At the time it was manufactured, the latter instrument was the largest refracting telescope that had been made in America. In Chile, the meridian circle was used to determine the positions of reference stars while the refractor was employed for micrometric measurements of the positions of Venus and Mars (for the parallax program) and Southern stars (for the star catalogue).
2. In their report on the scientific programs of the expedition Gilliss and Gould blamed this on the lack of simultaneous supporting observations from Northern Hemisphere observatories, but after reviewing the evidence Huffman (1991: 214–217) arrived at a somewhat different interpretation. In fact, there were many Northern Hemisphere observations (including from the U.S. Naval Observatory), but few of these coincided in time with Gilliss' own observations. Also, there was a problem observing Venus because of its relative proximity to the Sun; the opposition of Mars was unfavorable; and bad weather in both Hemispheres limited the number of observations. All-in-all, the Chile program failed because of "… insufficient planning and poor coordination of effort …" (Huffman, 1991: 216).
3. In fact Gay's *Historia Física y Política de Chile* was published in 30 volumes, between 1844 and 1871.
4. Gilliss (1855: 142) wrote that:

   > Though letters of introduction are not absolutely indispensable to obtain for one to gain access to the first circles of society, still, as in every other country, they greatly facilitate the intercourse of a stranger at the capital.

5. A note at the lower right hand corner of the plate fold-out reads as follows: "Drawn from camera sketches by E.R. Smith".
6. Gilliss' letters and details of his astronomical observations are now in the United States National Archive in Washington D.C. (Archive II, College Park).
7. We have consulted the following copies: one kept in the Biblioteca Nacional de Chile; one in the Library of the Astronomical Observatory of the United States in Washington D.C.; one in the Archivo Bello of the Universidad de Chile and, finally, one belonging to a private collector in Santiago, Chile.

6 ACKNOWLEDGEMENTS

I would like to thank to Dr Steven J. Dick (former NASA Chief Historian) and Professor Wayne Orchiston (National Astronomical Research Institute of Thailand) for their comments and help in the completion of this paper. This paper reports results of Proyecto Fondecyt Nº 1150308, "Santiago 1850: the capital before modernization. An urban view by James Melville Gilliss's United States Navy Astronomical Expedition", researcher-in-charge: Germán Hidalgo; collaborators: Rodrigo Booth, Amari Peliowski, Christian Saavedra, José Rosas, Wren Strabucchi, Catalina Valdés and Diego González.

7 REFERENCES

Collier, S., and Sater, W.F., 1996. *A History of Chile: 1808–1994*. Cambridge, Cambridge University Press.

Comstock, G.C., 1922. Biographical Memoir Benjamin Apthorp Gould 1824–1896. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 17, 158–180.

Dick, S.J., 2003. *Sky and Ocean Joined. The U.S. Naval Observatory 1830–2000*. New York, Cambridge University Press.

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.

Domeyko, I., 1857. Estudios Jeográficos sobre Chile, con ocasión de la publicación del primer tomo de la obra <U.S. Naval Astronomical Expedition to the Southern Hemisphere during the years 1849-'50-'51-'52> por J. M. Gilliss". *Revista Ciencias y Letras*, 632–674.

Domeyko, I., 1859. Expedición naval astronómica Norte-Americana al hemisferio austral durante los años 1849, 50, 51, i 52. Estudios Jeográficos sobre Chile. *Anales de la Universidad de Chile,* XVI, 18–61.

Gerling, C.L., 1847. Ueber die Benutzung der Venus-Stillstände zur Bestimmung der Sonnenparallaxe. *Astronomische Nachrichten*, 25, 363–368.

Gilliss, J.M., 1846. *Astronomical observations [1838–1842] made at the Naval Observatory, Washington, under orders of the Honorable Secretary of the Navy dated August 13, 1938*. Washington, Gales and Seaton Printers.

Gilliss, J.M., 1855. *U.S. Naval Astronomical Expedition to the Southern Hemisphere during the Years 1849-´50-´51-´52. Volume 1*. Washington, A.O.P. Nicholson Printer.

Gilliss, J.M., 1856. *U.S. Naval Astronomical Expedition to the Southern Hemisphere during the Years 1849-´50-´51-´52. Volume 3*. Washington, A.O.P. Nicholson Printer.

González, J.I., and Andrade, B., 2011. Geografía Física de la República de Chile por Pedro José Amado Pissis Marín 1812–1889. In Pissis, A. (ed.). *Geografía Física de la República de Chile*. Santiago, Centro de Investigaciones Diego Barras Arana. Pp. IX–XLV.

Gould, B.A., 1866. Memoir of James Melville Gilliss. 1811–1865. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 1, 135–179.

Guzmán y Lecaros, J.J., 1836. *El chileno instruido en* *la historia topográfica, civil y política de su país. Tomo 2*. Santiago, Imprenta Araucana.

Harper's Encyclopaedia of United States History, Volume IV. New York, Harper & Brothers (1905).

Hidalgo, G., 2010. *Vistas Panorámicas de Santiago 1790–1910.* Santiago, Ediciones Universidad Católica de Chile.

Huffman, W.W., 1991. The United States Naval Astronomical Expedition (1849–1852) for the solar parallax. *Journal for the History of Astronomy*, 22, 208–220.

Keenan, P., Pinto, S., and Alvarez, H., 1985. *El Observatorio Astronómico Nacional de Chile: 1852–1965*. Santiago de Chile, Universidad de Chile, Facultad de Ciencias Físicas y Matemáticas.

Leslie, J.P., 1866. Memoir of Edward Hitchcock. 1793–1864. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 1, 111–134.

Peña Otaegui, C., 1944. *Santiago de Siglo en Siglo. Comentario Histórico e Iconográfico de su Formación y Evolución en los Cuatro Siglos de su Existencia.* Santiago de Chile, Empresa Editora Zig-Zag.

Rasmussen, W., 1954. The United States Astronomical Expedition to Chile, 1849–1852. *The Hispanic American Historical Review*, 34, 103–108.

Romero, L.A., 2007. *¿Qué Hacer con los Pobres? Elites y Sectores Populares en Santiago de Chile 1840–1895*. Santiago, Ediciones Ariadna.

Schrimpf, A., 2014. An international campaign of the 19th century to determine the solar parallax. The U.S. Naval expedition to the southern hemisphere 1849–1852. *The European Physical Journal H*, 39, 225–244.

Seed, D., 2004. Nineteenth-century travel writing: an introduction. *The Yearbook of English Studies*, 34, 1–5.

Smith, E.R., 1855. *The Araucanians, or Notes of a Tour among the Indian Tribes of Southern Chile, by Edmund Reuel Smith, of the U.S.N. Astronomical Expedition in Chili*. New York, Harper & Brothers.

Germán Hidalgo Hermosilla is a Professor in the School of Architecture at the Pontificia Universidad Católica de Chile (Santiago, Chile) in the areas of theory and history of architecture. He specializes in cartography and historical iconography of Santiago, and has conducted multiple studies in the last fifteen years. His approach to knowledge emphasizes the architectural representation as the main argument, being the basic point of view used in organizing his lectures, investigations and papers. He received the title of architect from the Pontificia Universidad Católica de Chile in 1991, and obtained a Ph.D. on Theory and History of Architecture from the Universidad Politécnica de Cataluña, ETSAB, Barcelona (Spain) in 2000.

WANDERINGS OF THE ‘SIMPLY PERFECT’ BURNHAM TELESCOPE

James Lattis
475 N. Charter St., Department of Astronomy, University of Wisconsin-Madison,
Madison, Wisconsin 53706, USA.
Email: lattis@astro.wisc.edu

Abstract: S.W. Burnham’s 6-inch Clark refractor, in service from 1870, quickly became famous as a potent double star catcher. It was the instrument he used for the site survey of Lick Observatory in 1879. Sold to Washburn Observatory, it travelled to Caroline Island with Edward Holden to search for Vulcan during the total solar eclipse of May 1883. Back in Madison, it was used by George Comstock for his measurements of refraction and aberration. In the late 1950s it was used at the Knuijt Observatory in Appleton, Wisconsin. Travels and transformations of this famous telescope have spread its parts widely as astronomical relics, and it even remains in active service today.

Keywords: Burnham, Holden, Comstock, Stebbins, Romare, Washburn, Clark, telescope

1 INTRODUCTION

It is not often that astronomers mention their telescopes in the titles of publications since more often than not a telescope is to an astronomer as a saw is to a carpenter: the saw might be important, but it does not share credit for the work. Yet Sherburne W. Burnham (1838–1921; Figure 1; Barnard, 1921; Frost, 1921) gave one of his very early scientific publications the title “A third catalogue of 76 new double stars, discovered with a 6-inch Alvan Clark refractor.” (Burnham, 1873). If there is something naïve about the title, there is also justifiable pride in the discoveries that had managed to elude professionals with much larger telescopes.

No less than Robert Aitken (1864–1951; van den Boss, 1958), who dedicated the first edition of his binary stars book to Burnham, declared Burnham’s early papers to be “… the beginning of the modern period of double star astronomy.” (Aitken, 1935: 20). Joel Stebbins (1878–1966; Whitford, 1978) once remarked that quite aside from double stars, Burnham’s significance for astronomy was underestimated. Burnham, Stebbins (1944: 185) said,

> … initiated the practice of using a telescope during all of a good clear night. Previous to his time this procedure had been little followed anywhere in the world.

Edwin Frost (1866–1935; Struve, 1937; Frost, 1921) made a very similar comment. Barnard (1921) confirms this, reporting that in their years observing together at Lick Observatory, Burnham would work until midnight, pause for a snack and coffee, then observe until dawn. Burnham’s earliest all-night vigils were probably spent searching for double stars in his backyard observatory with his 6-in (15.2-cm) Alvan Clark refractor, which he would describe years later as “… simply perfect.” (Burnham, 1900: x). But Burnham’s double star searches were only the beginning of this telescope’s remarkable history of travels and transformations, as this paper will reveal.

2 CHICAGO

Burnham (1900, cf. 1906) tells us the essential details of how he acquired the legendary 6-in telescope in the introduction to his 1900 double star catalogue, where he also outlines the history of his double star research. It was not his first telescope, but his third. The first he had acquired in London in 1861: a 3-in (7.6-cm) refractor on an altazimuth mount, which was not very useful, he says, for astronomical observing. Some years later, shortly after the end of the U.S. Civil War, Burnham became more seriously interested in astronomy and purchased a 3.75-in (9.5-cm) Fitz refractor on an equatorial mount. The Fitz was “… good enough to be of some use …” (Burnham, 1900: vii), but left him wanting something better as his interest in astronomical observing deepened.

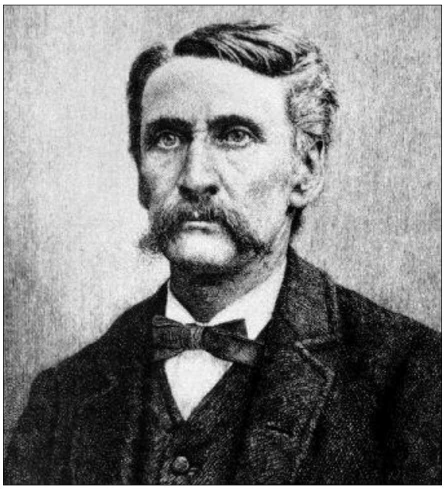


Figure 1. Sherburne W. Burnham, the original owner of the Burnham 6-inch Clark refractor (en.wikipedia.org).

In the late 1860s, Burnham lived quite near the Dearborn Observatory of the Old University of Chicago (long before their 18.5-in (47-cm) Clark refractor was relocated to Northwestern University in Evanston). His proximity to the observatory

—of which he would later serve as unpaid Acting Director—probably offered the connection that made possible his meeting in 1869 with Alvan Clark, the already famous telescope-maker, who had travelled to Iowa for the solar eclipse of 7 August and was returning to Massachusetts via Chicago. As a result of that meeting, Burnham tells us, he ordered from Clark a 6-in refractor on an equatorial mounting, leaving all design to Clark's judgement, but "… stipulating only that its definition should be as perfect as they could make it …" so as to achieve optimal performance, given the aperture, on double stars (Burnham, 1900: viii). According to several sources, including Burnham's colleague and close friend Edward Emerson Barnard (1857–1923; Sheehan, 1995), the cost, was $800 (Barnard, 1921).

Burnham took delivery on his bespoke telescope from Clark in 1870. Originally the mounting lacked a clock drive, but Burnham ingeniously contrived one (Barnard, 1921). He wrapped a rope around the polar axis and attached a weight to pull the rope, creating a torque on the axis. The weight rested on sand, which escaped from a hole in its container and allowed the weight to fall at a controllable rate. It was a crude mechanism but avoided expensive clockwork. Burnham's double star measurements with the 6-in Alvan Clarke telescope were always fairly crude, being estimates by eye of the separation and position angle (his later, more exact, work was done with telescopes equipped with micrometers, as at Washburn and Lick Observatories). The question of how much value Burnham added to his instrument comes up in the matter of its later sale to the University of Wisconsin. The mounting probably lacked setting circles as well since they are later mentioned as another improvement. But even without clock and circles, in its brand new state, it must have been a beautiful instrument. The tube is a cylinder formed of blackened wood staves wrapped in a dark wood veneer with a deep finish. The objective cell and tailpiece are brass, which would have nicely complemented the dark tube.

Burnham's first double star discovery came on 27 April 1870 (Eggen, 1953), which indicates that he had the telescope in operation quite soon after receiving it. But Burnham tells us his double star work effectively began in 1872. The years of 1870 and 1871 no doubt comprise the steeper part of the learning curve as Burnham worked with his fine new instrument and acquired familiarity with the double star catalogues available to him in the Dearborn Observatory library, which would have included those of Frederick Georg Wilhelm von Struve (1793–1864; Batten, 1988), Otto Wilhelm von Struve (1819–1905; Nyren, 1906), and John Frederick William Herschel (1792–1871; Buttmann, 1970). In fact, Burnham's need for the series of double star catalogues arose directly from his work with the 6-in refractor, as he tells us (Burnham, 1906). Burnham entered astronomical circles as a Fellow of the Royal Astronomical Society in 1874, and also was being noticed by the public at home. The *Chicago Tribune* criticized the neglect of the largely idle Dearborn telescope by pointing out how it was upstaged by the "… novice Burnham." (Fox, 1915: 4). It is said that the future astronomical empire-builder, George Ellery Hale (1868–1938; Adams, 1939), then in his early teens, visited Burnham's backyard observatory to admire the Clark refractor (Osterbrock, 1976). If that visit helped inspire Hale toward his career of building ever larger telescopes (Wright, 1994), then Burnham's 6-in telescope has had historical leverage far out of proportion to its size.

Burnham's 6-in Alvan Clark refractor was a rather small telescope for a research instrument, and with the passage of time its scientific significance would prove to be out of proportion to its size. By 1874 in the United States alone there were telescopes, refractors all, with apertures up to 26 inches (at the U.S. Naval Observatory) in use by professional astronomers. Burnham's productivity—he would eventually discover more than 400 new double stars with his 6-in telescope—far outpaced the better-equipped professionals and was a product of several factors, including his own work ethic, which kept him working those long nights even as he maintained his day job as a professional stenographer. He also was willing to search for double stars despite an attitude among professional astronomers that there was little potential for new discoveries. An (erroneous) intuition that a double star is a very rare occurrence might have suggested to astronomers that the existing catalogues should have nearly exhausted them, so any search for additional ones would prove futile. This may be a case where Burnham, as an outsider, came to astronomy free of the prejudices that constrained the thinking of the professionals. Or perhaps, as a hobbyist, Burnham felt free to follow pursuits that personally interested him, but might look unproductive to professionals.

But Burnham's success also came about because he and his telescope were literally made for each other. In requiring the most perfect possible definition in the Clark objective lens, Burnham was complementing the keen capacity of the eyes he was born with. Indeed, the acuity of his vision was legendary. "If a star disc deviated an almost infinitesimal quantity from the circular, his eye detected it at once …" declared William de Wiveleslie Abney (1843–1920; Hearnshaw, 2014), then President of the Royal Astronomical Society, upon awarding the Gold Medal to Burnham in 1894, and "… the catalogues of double stars which he has given us amount to no fewer than nineteen …" (Abney, 1894: 279, 277).

These catalogues contained 1,274 double stars that he had observed—although by then with the use of much larger telescopes. Note, also, that these nineteen publications were research papers and therefore quite different from Burnham’s later general catalogues, of 1900 and 1906.

In discovering double stars it was essential to have access to previous catalogues in order to know whether a given double star was already known. Burnham’s limited library led him to visit observatories whenever he could and to take notes from the sources that might be available there. It was on such a visit to the U.S. Naval Observatory in 1874 that he made the acquaintance of Edward Singleton Holden (1846–1914; Campbell, 1919), then an Assistant Astronomer to the USNO Director, Simon Newcomb (1835–1909; Campbell, 1924). Holden, an ambitious astronomer of a bibliographic bent, and Burnham seem to have hit it off well at their meeting, which began a long and complicated friendship with many collaborations, but ending in enmity (Osterbrock et al., 1988). Holden would also be the instigator of the Burnham telescope’s most extravagant travels.

3 MOUNT HAMILTON

Newcomb and Holden were early advisors to the Lick Trust, the members of which were planning the Lick Observatory, which would eventually host the world’s largest refractor (at that time), the 36-in Clark. When the question arose of testing the quality and steadiness of the astronomical ‘seeing’ on the peak of Mount Hamilton, where the Observatory would take form, Holden and Newcomb recommended Burnham for the task. The resolution of closely spaced stars is a test not only of the observer’s eye and the telescope’s quality, but also of the steadiness and clarity of the atmosphere, so an expert double star observer was a perfect choice to evaluate the conditions at the proposed site of the new Observatory. Burnham was interested in the job, but, like many an amateur astronomer, he had his day job to consider and family responsibilities too. He agreed to a fee of $500 plus expenses, in return for which he and his 6-in Clark refractor would spend two months at Mount Hamilton, report on the suitability of the site, and have the honor of initiating astronomical research at the site of the great Observatory to come (ibid.).

Burnham set up his 6-in telescope in a rough wood-and-canvas structure near the peak of Mount Hamilton, and observed double stars from 17 August until 16 October 1879. By then his telescope was equipped with setting circles and a clock drive. At the expense of the Lick Trust, the new Clark clock drive replaced the early, improvised device mentioned by Barnard. After his time on the mountain, during which he received an inspection visit by Simon Newcomb, Burnham pronounced the quality of the site to be excellent. Then having blazed the trail for one of the most important and productive observatories of the coming decades, he packed up his telescope and shipped it back to Chicago (ibid.; Eggen, 1953; Frost, 1921).

4 WASHBURN OBSERVATORY

By mid-March 1881, Edward Holden had given up his post at the U.S. Naval Observatory and relocated from Washington D.C. to Madison, Wisconsin, where he had accepted the position as Director of the new Washburn Observatory, which was still a work in progress. His immediate predecessor had been the famous astronomer James C. Watson (1838–1880; Figure 2; Comstock, 1895a), who had been lured to the University of Wisconsin away from his position as Director of the Detroit Observatory of the University of Michigan, in Ann Arbor. Watson accepted the post in October 1878 and had arrived in Madison in January 1879 just in time to oversee the installation of the 15.6-in (39.6-cm) Clark refractor that Governor Cadwallader C. Washburn (1818–1882) had ordered as the primary instrument of his new observatory, which he was building for the University of Wisconsin. Watson’s tenure was cut short by his sudden death in November of 1880, but in that brief time he both built and opened several doors through which Burnham’s Clark telescope would soon pass.

Figure 2: James Craig Watson, first Director of Washburn Observatory (courtesy: Department of Astronomy, University of Wisconsin-Madison).

Watson’s fame arose in part from his prolific work discovering asteroids—he held the world record at the time having discovered 22 of them.

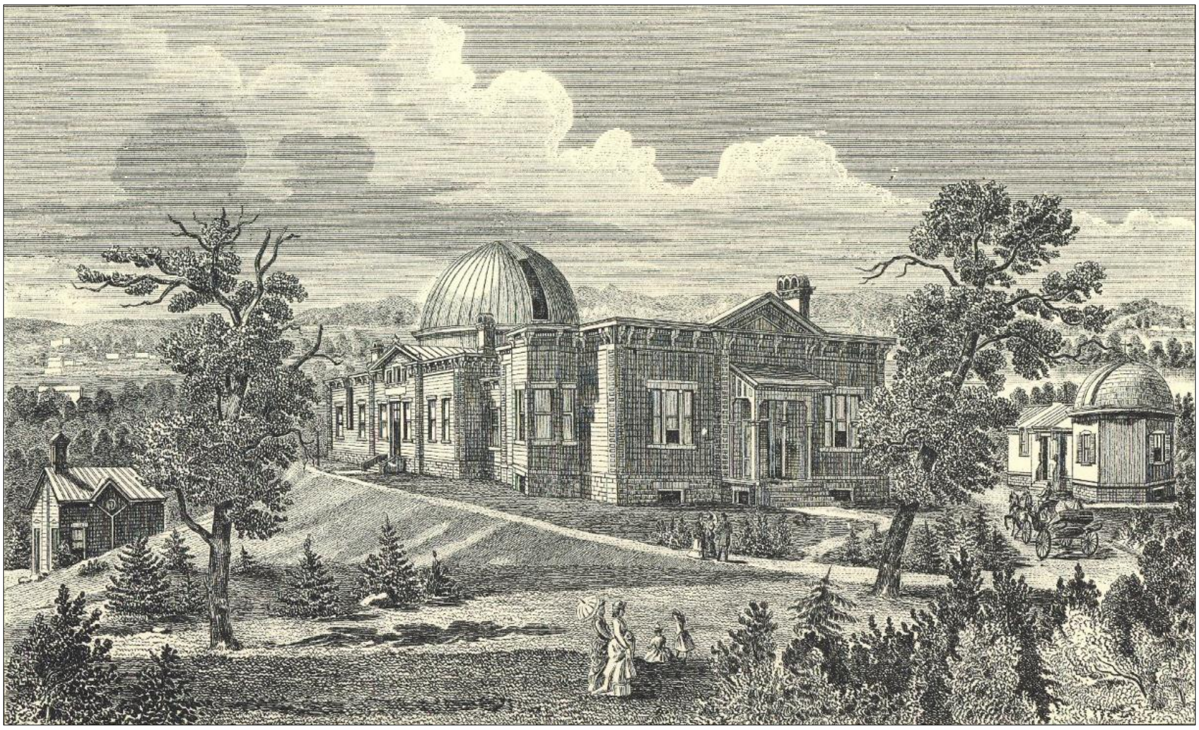


Figure 3: A view of Washburn Observatory, showing the Student Observatory to the right of the main building, and the Solar Observatory, to the left of the main building (courtesy: Department of Astronomy, University of Wisconsin-Madison).

He had also been in the news since the middle of 1878 for his apparent discovery of the intra-Mercurian planet Vulcan. But the ensuing controversy over Vulcan was intense (see Baum and Sheehan, 1997), and Watson took steps to vindicate his work in the shaping of the new Observatory. He began constructing, drawing on his personal wealth, a complex and unusual instrument that he hoped would allow him to confirm the existence of Vulcan without being constrained to observe only during total solar eclipses. In brief, a heliostat (a tiltable mirror rotating on a polar axis), would reflect light through a polar-aligned tunnel following the southern slope of Observatory Hill leading to a small building at the foot of the hill that would house a subterranean telescope. That telescope would be able to look, via the steerable mirror, into the daylight sky east and west of the Sun, and Watson's theory was that with this arrangement he would be able to see Vulcan, confirm its existence, and determine its orbit. Despite its real mission, to find Vulcan, it was always called the Watson Solar Observatory. This project, like nearly everything else in the Washburn Observatory of late 1880, was incomplete at his death (see Figure 3).

Watson also decided to build, again at his own personal expense, a small, separate observatory just east of the main observatory building. This was to be a Student Observatory, housing smaller versions of the larger research instruments in the main building. This structure was also incomplete when Holden, recruited by Governor Washburn to fill Watson's shoes, arrived in Madison.

Holden (Figure 4) was an unusual astronomer of great erudition and wide interests, although an enthusiasm for astronomical observing was not among his virtues. He was, however, a skilled (if somewhat authoritarian) organizer who perceived well the importance of staffing the new Observatory with experienced and dedicated observers who could begin delivering respectable results. Holden turned immediately to his friend Burnham, who was nearby in Chicago and was a dependable worker. Holden convinced Governor Washburn to pay Burnham's salary for six months in spring and summer at an effective annual rate of $2000, which was generous and comparable to Holden's own salary. So Burnham arranged to take leave of absence from his job as a recorder with Judge Drummond of the U.S. District Court in Chicago. He moved to Madison, was given lodging in the main Observatory building, and by 8 April 1881 took up duties as an Assistant Astronomer, working with Holden on the 15.6-in telescope and its Clark micrometer for double star measurements. Burnham also brought along his trusty 6-in Clark refractor, and when he departed in August this telescope remained in Madison, in the Student Observatory.

Just as he had done before coming to Madison, Holden maintained a lengthy correspondence with the Lick Trustees, advising them on various particulars of creating and running an observatory. He was clearly and genuinely interested in the success of the project as well as the prospect that he might become Director of the world's first mountain-top observatory, which would also be the home of the world's most powerful research telescope. He arranged for himself and Burnham to spend some weeks at Mount Hamilton during October and early November 1881, where they would install the Repsold meridian circle that Holden had advised the Lick Trustees to acquire (Holden and Burnham, 1882). While they were there, Burnham used a 12-in (30.5-cm) refractor that was already installed on Mt. Hamilton to observe the 7 November transit of Mercury (the 36-in telescope being still some years in the future). Meanwhile, Burnham's 6-in Clark refractor remained at Washburn Observatory.

Holden and Burnham both departed Mount Hamilton after the transit, returning to Madison and Chicago respectively, but Burnham did not collect his 6-in Clark from Madison and take it back to Chicago. Why did he leave it in Madison mounted in the Student Observatory? As would soon become apparent, Holden had plans for the Burnham telescope, so he surely encouraged leaving it and reported its status as "… on loan … for use in ordinary instruction …" from Burnham (Holden, 1882: 8). In fact, Holden hoped that Burnham would quit his job in Chicago and remain on the staff at Washburn Observatory. If Burnham was giving this move serious consideration, then he might have been inclined to leave his telescope where it stood until the matter was resolved.

But it could also be at this juncture that Burnham had decided to retire from astronomy (Eggen, 1953), even though he was only 43 years of age. Perhaps he had tired of the astronomer's life, after spending the previous six months as a full-time observer at Madison, plus the trip to Mount Hamilton for the November transit. Probably the insecurity of the position in Madison, funded basically by a personal grant from Governor Washburn, whose health was failing, worried him. Although Holden would have kept Burnham at Washburn Observatory if at all possible, in August 1881 he wrote Governor Washburn that Burnham declined to risk by further absence his position with Judge Drummond (Holden, 1881). Whether he hoped to return to Madison some day or planned to give up astronomy entirely, Burnham must have decided that he had no further need for a personal telescope. Whatever Burnham's thinking, his Alvan Clark telescope would never return to Chicago—at least not intact.

By January 1882 Holden had convinced Burnham to sell the 6-in Clark refractor to the University of Wisconsin and had convinced the Board of Regents to purchase the telescope from Burnham "… who offers it at a very moderate price …" of $1,200 (Holden, 1882: 8). Holden had advised the Board that this was a good deal since Burnham had paid $1,400 for it. Since, in fact, it seems that Burnham had actually paid Clark $800 for the telescope, the discrepancy is significant! It might be that the reported $800 figure was, in effect, a deposit Burnham paid to Clark rather than a full payment for the telescope, with the balance of $600, paid on delivery perhaps, and unreported by contemporaries. But this seems unlikely. Or perhaps the $1,400 figure was Holden's estimate of the value of the telescope after improvements made by Burnham, such as circles, clock drive and an improved mounting. Holden was also probably trying to obtain a good deal for his friend and recruit him to the Washburn staff, which could have influenced his generous assessment. In any case, the price was accepted by both parties, and the Burnham telescope became a permanent fixture at Washburn Observatory.

Figure 4: Edward S. Holden, second Director of Washburn Observatory (courtesy: Department of Astronomy, University of Wisconsin-Madison).

It is occasionally said that Burnham regretted parting with his 6-in telescope, and that is not hard to imagine. But after 1881 he never really needed a personal telescope again since he had his choice of positions, and eventually he spent time at several major Observatories, namely Washburn, Lick and Yerkes. And he retained his day job in Chicago for many of the years that he was observing at Yerkes Observatory, while following a demanding schedule of commuting to Williams Bay every weekend for observing. He could have made his life much easier by purchasing another backyard telescope, but he did not. He clearly loved working with the 'big glass'.

Yet it is also not difficult to hear a note of fond reminiscence, if not quite regret, in his 1900 *Gen-*

Figure 5: Washburn Observatory view from the southwest with the Solar Observatory in the foreground (courtesy: Department of Astronomy, University of Wisconsin-Madison).

eral Catalogue where he comments on the various telescopes that he had used for his double star work. When he mentions the 6-inch Clark, he says:

> It is hardly necessary to say, in view of the discoveries made with it and given in this catalogue, that its performance on the most difficult objects was simply perfect. Many of the stars discovered with it are by no means easy to measure with the largest telescopes now in use. Some of the most rapid and interesting binaries in this catalogue were discovered with this instrument. It now belongs to the Washburn Observatory of the University of Wisconsin. (Burnham, 1900: x).

5 TESTING WATSON'S THEORY

Holden felt bound to implement Watson's Solar Observatory plan (i.e. using a heliostat to reflect light down a tunnel to an underground telescope) in order to test its ability to detect intra-Mercurian planets, should they be there, and he was ready to do so by the summer of 1882. He needed a telescope small enough to place in the cellar of the Solar Observatory building at the base of the polar axis tunnel and with good enough optical performance to reveal a very small planetary disk against the daytime sky. The Burnham telescope was what he needed. Relatively large, bright planetary disks, such as that of Jupiter, can be seen against the daytime sky with the aid of a telescope. But the alleged Vulcan would not be nearly so bright, nor would its disk be very large. For the tests, Holden selected stars among the Pleiades cluster that have apparent brightnesses comparable to that reported by Watson for the elusive Vulcan. Holden aimed at night by setting the heliostat (which he borrowed for the purpose from Samuel Langley) on the meridian at the declination of the Pleiades, then, leaving the heliostat undisturbed, he tried to see the stars of the Pleiades in the daylight sky using the heliostat-telescope combination at the time when they were known to be transiting the meridian. But he could see nothing. Moreover, in the cellar where the telescope was mounted, there were problems with moisture and air currents in the tunnel that sloped up the hill to the heliostat (Figure 5).

In his report to the Board of Regents Holden (1882) explained his attempts, and these also appear in a brief publication, where he mentioned the 6-in Clark refractor, "… which has made a history for itself already." (Holden, 1883b: 112). The results were disappointing, of course, although not entirely unexpected because, as Holden noted, others had tried similar schemes, and also without success. Moreover, because of the

Figure 6: Holden's Caroline Island observing station (after Holden, 1884: Figure 5 following page 22).

moisture and other problems of a subterranean telescope, it was also not practical to use Watson's device to attempt direct spectroscopy or imaging of the Sun. Holden and the Burnham telescope gave Watson's ideas 'a fair shake', but vindication eluded them. Holden chose to publish the results in a German journal—the only place where they appear aside from in the Regents' Report—but not in the prestigious *Astronomische Nachrichten,* where he had published previously and would often again. Placing the unhappy result in a less-consulted journal was probably a gesture of deference to Watson's memory by giving the failure a low profile in the USA. The primary utility of the Solar Observatory building, before and after Holden's tests, was mainly to provide lodging for an Observatory Assistant.

6 THE CAROLINE ISLAND EXPEDITION

The first solar eclipse expedition by Washburn Observatory astronomers was an ambitious one, with the bills paid by the U.S. Government and the National Academy of Sciences. The destination of the U.S. expedition to observe the total solar eclipse of 6 May 1883 was Caroline Island, near Kiribati in the South Pacific,[1] more than 5,000 miles and many weeks of travel from Wisconsin. In fact, Holden did not initiate the enterprise but was asked to take the place of Charles Young (1834–1908; Frost, 1913), the Princeton astronomer, as leader. Such a project suited Holden's military background and organizational disposition well, and he meticulously planned and documented the expedition (Holden, 1884). Among the variety of scientific instruments along on the trip, which also had meteorological and geological goals, was the Burnham telescope, which, of course, was now part of the Washburn Observatory instrument stable. Undeterred by the failure of his tests of Watson's instrument, the basic concept of which he rightly suspected, Holden planned to test again for Vulcan or any other intra-Mercurian planets in the sky near the Sun rendered visible during the totality of the eclipse. This would require a nimble instrument to scan for dim, uncharted objects during the nearly five and a half minutes of totality. Holden does not tell us what kind of mounting he used, but the Clark equatorial mounting would have been useless at just 10° south of the Equator, as would a clock drive, so he probably made do with a simpler, more portable mounting (Figure 6).

The expedition members and their equipment embarked from New York City on 2 March 1883 and sailed westward via a series of ships and a portage across the Isthmus of Panama to their rendezvous with the U.S. Navy's sailing steamer, sloop-o-war *USS Hartford*, under the command of Captain C.C. Carpenter, at Callao, the port of Lima, Peru. The *USS Hartford* departed Callao for Caroline Island on 22 March and sighted the Island on 20 April. On the 20th and 21st, seamen from the ship rowed their whaleboat through the coral reefs, and settled the scientists on the archipelago with their "… bulky cases under rather exceptional difficulties." The *USS Hartford* sailed on to Tahiti on the 22nd, and by the 24th Holden (1883a) reported that his equipment and shelter were complete, and that the Burnham telescope was ready for its assault on the Southern sky. The

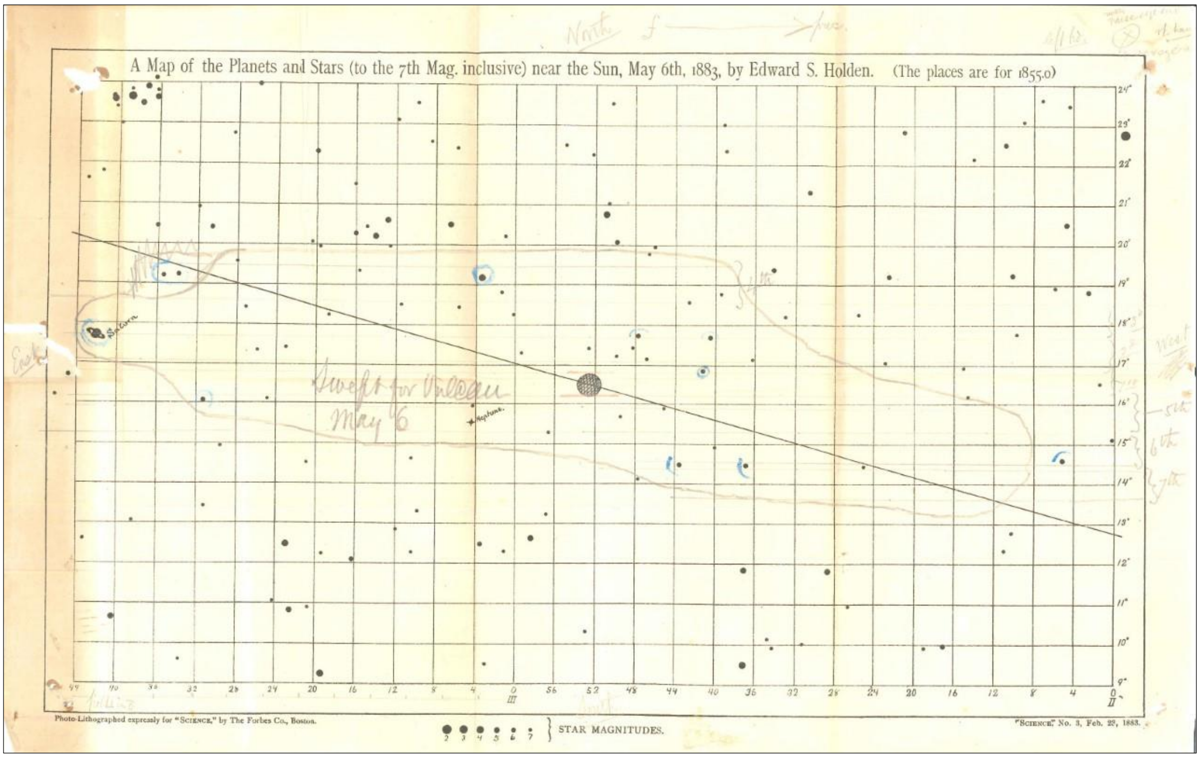


Figure 7: Star chart used by Edward Holden during his search for Vulcan on Caroline Island during the May 1883 total solar eclipse. His notations outline the area of the sky he scanned with the Burnham telescope (courtesy: University of Wisconsin Archives).

USS Hartford returned to Caroline Island on 8 May to take aboard the men and equipment for their return to the United States, via the Hawaiian Islands and San Francisco, where Holden and company arrived on 11 June.

While they were on Caroline Island, the eclipse party had clear weather during the eclipse, so Holden was able to make his final observations in a bid to vindicate Watson. But Holden (1883a) found nothing, and he reported that "… no star as bright as 5th mag. was visible in the space covered by my sweeps …" in the zones scanned east and west of the totally eclipsed Sun (Figure 7). A French solar eclipse expedition also was based on Caroline Island, and one of their astronomers, Johann Palisa (from the Imperial Observatory in Vienna), also scanned the sky for suspicious objects during totality and saw nothing. Holden (1884: 101) concluded that the non-existence of Vulcan or other intra-Mercurial planets was "… definitely settled …", and that there would be no point in conducting further searches for them at future solar eclipses. He was quite right about that.

The Burnham telescope had another role during the Caroline Island expedition, and that was the same task that had already made it famous: the discovery of new double stars. Observing with Johns Hopkins University physicist Charles S. Hastings (1848–1932; Uhler, 1938), Holden discovered 23 new double stars in those southern zones of the sky they had time to study: "… two or three hours of each clear night (with a few exceptions)." (Holden, 1884: 97). He also reported the discovery of five new red stars. All of this in so little time indicates, he said, the great value of an extended observing program in the Southern Hemisphere. He suggested the Chilean and Peruvian Andes, both of which would, of course, later become important observatory sites.

In comparing his double-star magnitude estimates with those of Hastings, which, he noted, show a systematic difference, Holden made the odd statement that Hastings' estimates should be preferred over his own because "I was not familiar with the appearance of stars in the 6-inch telescope." (Holden, 1884: 98). It is not surprising, perhaps, that he had not used the 6-in telescope much at Madison in the recent past since he had access to the much larger 15.6-in telescope, but it seems odd that he should suggest that Hastings would be better at estimating magnitudes through an instrument that he, presumably, had never used. There was another 6-in telescope taken on the expedition, but it was not brought by Hastings and seems to have been intended for spectroscopy. Moreover, Holden mentions the 6-in routinely and without qualification in his expedition observing note-book amid the double star records, so it seems all but certain that he used the Burnham telescope for those observations.

Holden took advantage of his repatriation at San Francisco to pay a visit to the developing Lick Observatory. There is no record to suggest that he took the Burnham telescope with him, so presumably it returned to Madison as freight some time that summer. Burnham also travelled with the Lick Observatory Crocker expedition to Cayenne, French Guiana, for the December 1889 solar eclipse, but there is no record that the Burnham telescope went along on loan to Lick Observatory.

The only other eclipse expedition involving the Burnham telescope was to North Carolina for the 1900 solar eclipse with Washburn Observatory's Albert Stowell Flint (1853–1923; Stebbins, 1923), but there is no record of how it was used there. That the Burnham telescope stayed at home for the eclipse expeditions during the Directorship of Joel Stebbins (from 1922 to 1948) is not surprising because the scientific goals of those trips involved wide-field photometry of the solar corona and used very simple collimating tubes instead of telescopes in front of the photoelectric photometers. So presumably the Burnham telescope resumed its location in the Student Observatory and its role as a telescope for student observers.

7 BACK IN MADISON

Near the end of 1885, Holden left Washburn Observatory for the University of California, where he served for a while as President until the completion of Lick Observatory in June 1888, where he then took over as Director. His departure produced an interregnum period at Washburn that was only resolved when George Cary Comstock (1855–1934; Figure 8; Stebbins, 1938), who had actually accompanied Watson from Ann Arbor and worked on and off at the Observatory with Holden, was named on-site Director in June 1887, but with oversight from the eminent Asaph Hall (1829–1907; Hill, 1908) of the U.S. Naval Observatory. That arrangement would end when Comstock became Director in his own right in 1889. Comstock set to work defining research programs for all of Washburn's major instruments: the 4.5-in Repsold meridian circle, the 15.6-in Clark equatorial and the Burnham telescope.

Comstock became interested in a novel method of studying two inescapable effects that observational astronomers must cope with: the refraction of light in our atmosphere and the aberration of starlight. At a practical level, quite aside from their physical significance, these two effects amount to corrections that astronomers must apply as accurately as possible if the reduced relative positions and motions of stars are to be correct. The refraction (or bending) of the light from a star has the general effect of making objects appear higher above the horizon than they really are. The magnitude of the effect varies from zero near the zenith to a considerable fraction of a degree near the horizon. Aberration of starlight produces an annual periodic displacement in the position of a star of more than 20 arc seconds depending on its location in the sky with respect to the direction of the Earth's orbital motion.

To launch a new inquiry into these effects, Comstock proposed to use an optical arrangement using a prism (for which he would soon substitute mirrors), called a Loewy apparatus after its inventor, the French astronomer Maurice Loewy (1833–1907). The Loewy apparatus, in effect, allows a telescope to simultaneously look in two directions, separated by 120°. It also transformed the task into a differential measurement between the two stars rather than an absolute measurement with respect to meridian and horizon. With funding from the Watson Fund of the National Academy of Science, Comstock (1895b) improved on the original Loewy design and constructed his own version of the device, which he mounted in front of the objective of the Burnham telescope. Burnham's double star work was, Comstock mentions, adequate testimony to the telescope's excellence. At the eyepiece end of the telescope he mounted an astronomical micrometer. He could then directly measure the angular separation of two very widely spaced stars.

Figure 8: George C. Comstock, third director of Washburn Observatory (courtesy: Department of Astronomy, University of Wisconsin-Madison).

Observing pairs of stars with such large angular separations required major modifications to the dome of the Student Observatory, where the Burnham telescope was mounted, because the slit opened only to a limited stretch of sky in an arc perpendicular to the horizon. Comstock's solution was to modify the dome by dividing its hemisphere into two semi-domes, one of which (the half containing the original slit and shutter assembly) he removed. Then he constructed an-

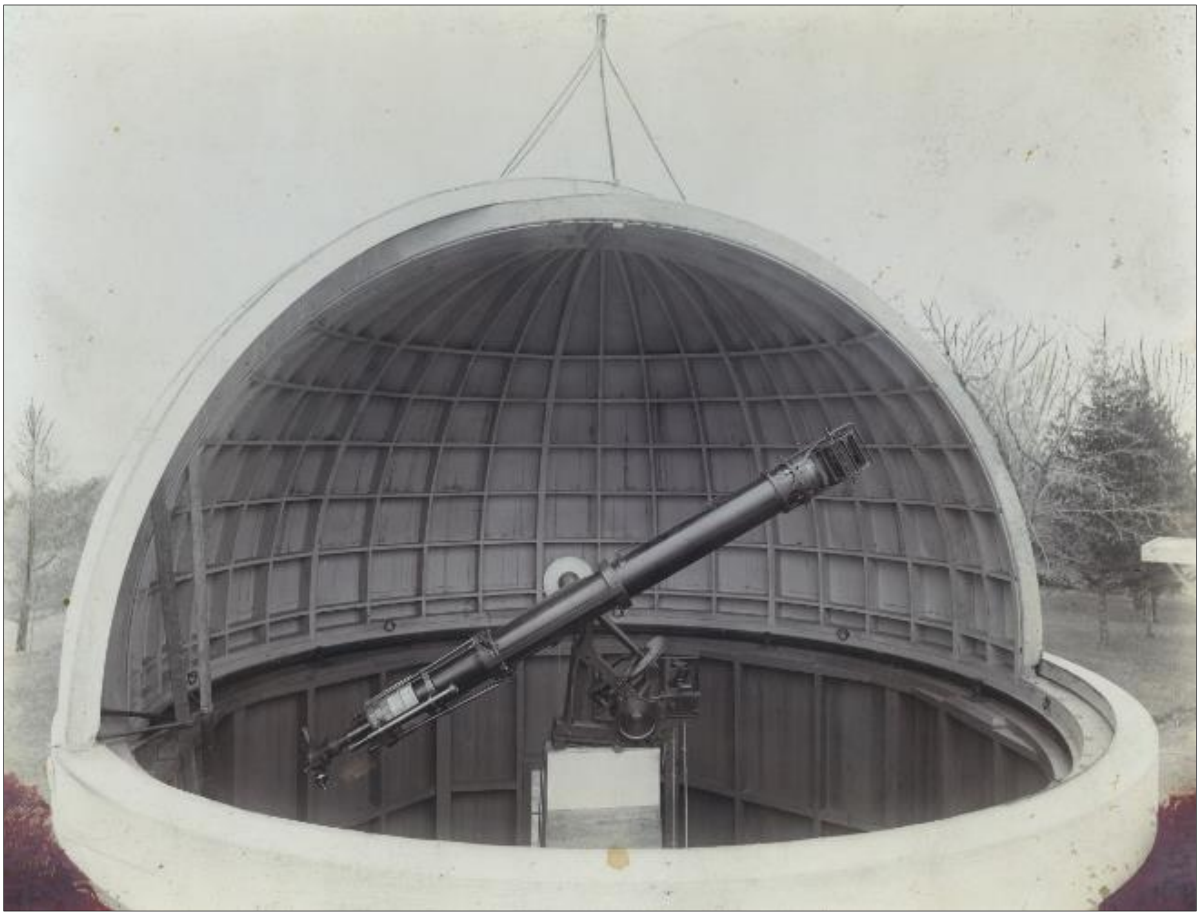


Figure 9: The Burnham telescope mounted in the Student Observatory equipped with the Loewy device in front of the objective. At this stage it still has the original wooden tube. The Clark mounting, made for Chicago's latitude, has been corrected by shims. Note the clock drive, probably the one paid for by the Lick Trustees, also in Fig. 10. Note also the semi-dome arrangement (courtesy: Department of Astronomy, University of Wisconsin-Madison).

another semi-dome of slightly larger radius and mounted it on a track concentric with and just outside of the original dome track. Thus the inner half dome would nest within the outer and, when rotated to maximum overlap, revealed fully half of the sky above the horizon and allowed pointings of the telescope that, with the Loewy device in place, spanned very large angles. The operation of the Loewy device required that it be able to rotate about the optical axis of the telescope, so Comstock had to arrange controls for this motion at the eye end of the telescope. This arrangement of telescope and dome is shown in Figure 9. This is the only existing photograph known that shows Burnham's telescope with the original wooden tube and Clark mounting.

By Autumn of 1889, Comstock reported that the modified observatory and telescope were ready and that he had begun observation trials to refine his as-yet 'imperfect' understanding of the theory of the Loewy optics. But in October he encountered a major setback owing to an attack of iritis, which was severe enough to require ophthalmological surgery and a temporary cessation of his observing activities. As it turned out, he could not begin the planned observations until after his eyesight recovered, and after he saw parts of volumes six and seven of the *Publications of Washburn Observatory* through the press, and after he spent part of the next summer touring European observatories.

Once he finally got the program underway, in September 1890, Comstock observed with the Burnham telescope steadily until July 1892 to accumulate his data, and he then spent about two years reducing and analyzing them. For refraction, his result amounted to formulae for corrections, including humidity of the air, to the standard refraction tables of Bessel and of Pulkowa Observatory, of which he judged the latter superior. He also published a new value for the constant of aberration, which he concluded to be 20.443 ± 0.010″, and "… one of the best determinations of the constant of aberration made up to that time." (Stebbins, 1938: 164). Comstock made note of the 'singular coincidence' that omitting correction for systematic personal error would result in the value 20.499″, "… which is very closely the mean of the more recent determinations of this quantity by other methods." (Comstock, 1895b: 203). Since the latter value is closer to the modern accepted value, and by quite

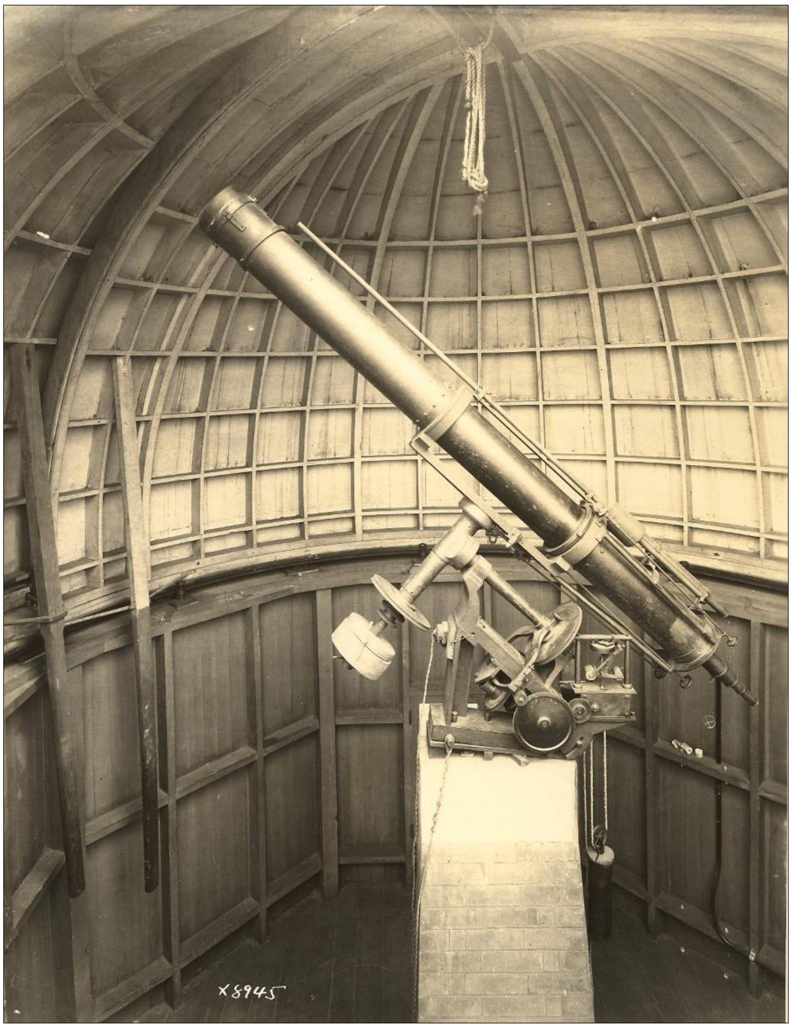


Figure 10: The Burnham telescope on the Clark mounting in the Student Observatory after conversion to the metal tube. Undated but not before 1908, when the conversion was done. The semi-dome arrangement was still in place (courtesy: Department of Astronomy, University of Wisconsin-Madison).

a bit more than his own error, it would seem that correcting for systematic personal error was counterproductive in this case.

With Comstock's refraction and aberration work, the research career of the Burnham telescope effectively came to an end in 1892. S.W. Burnham himself retired in 1902 from his job as Clerk of the U.S. District Court in Chicago, but he continued his observational work at Yerkes Observatory until 1914. Meanwhile the 6-in Clark telescope continued to be a valued instrument at Washburn Observatory judging by the subsequent history of its transformations. Presumably it continued in use as a telescope for astronomy students and astronomers-in-training. The semi-domes remained in place long after the conclusion of Comstock's Loewy device work and are still evident in photos taken as late as 1908, perhaps leaving open the possibility of further wide-angle observations. The semi-dome arrangement was eventually reverted to the conventional slit and shutter configuration, but the date is unknown.

The first major transformation of the Burnham telescope came in 1908 with the replacement of the telescope tube. The objective cell containing the 6 inch lens was removed from the original wooden tube and moved to a tube made of riveted sheet steel. Similarly, the brass tailpiece attaching the focuser and eyepiece were moved over to the new tube. The original components Clark had assembled thus began to part company. The motivations for this change are not recorded, but it seems probable that Comstock had concerns about the physical integrity of the old tube, the wood veneer perhaps separating from the structural staves after so much handling and variation in temperature and humidity during its traveling years. The new assembly took its place on the Clark mount in the Student Observatory (Figure 10), and the wooden tube went into storage at the Observatory.

George Comstock retired as Director of Washburn Observatory in 1921, the same year that S.W. Burnham died in Chicago. Comstock's suc-

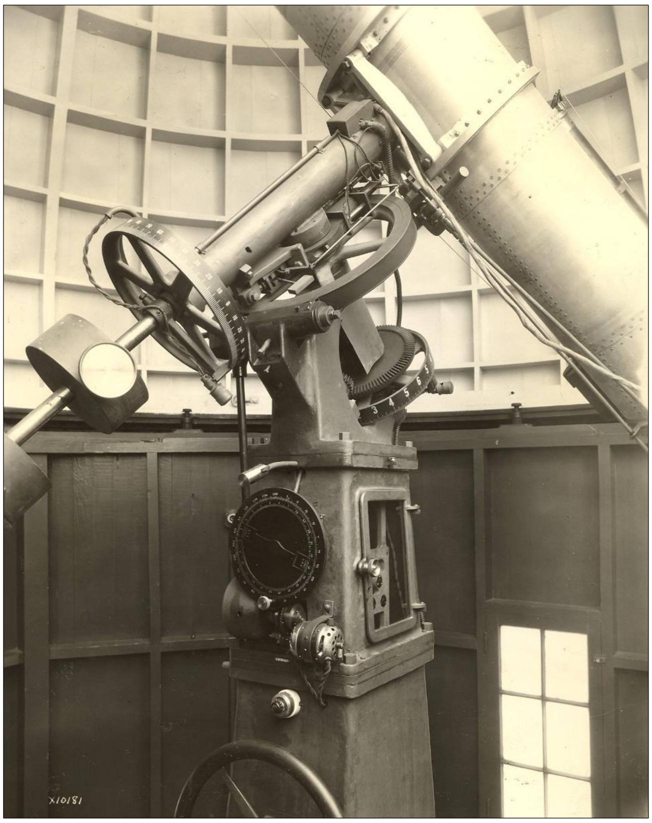


Figure 11: The 10-inch Fecker refractor on the new Romare mounting in the Student Observatory. The Burnham telescope had been on this mounting for testing before the Fecker took its place. A cast iron pier replaced the stonework pier that supported the Clark mounting. (courtesy: Department of Astronomy, University of Wisconsin-Madison).

cessor was Joel Stebbins, who had pioneered photoelectric photometry in Urbana at the University of Illinois Observatory. Stebbins began planing improvements to the Washburn telescopes even before he took up residence in the summer of 1922. In the coming years Stebbins removed the fine old Repsold meridian circle, which was quickly becoming obsolete in the dawning days of photographic astrometry and was in any case irrelevant to the Stebbins research program. The former meridian room, the observatory's west wing, became a class-room. Stebbins also replaced the original Clark equatorial mounting of the 15.6-in Clark refractor. That mounting had been problematic from the beginning, and much better designs were available to ease the finding and tracking of faint photometry targets. By a stroke of remarkable good luck, Stebbins had available at Madison the skilled and ingenious mechanical engineer Oscar E. Romare (1875–1932). Romare, a talented and energetic immigrant from Sweden, had come to the University of Wisconsin Engineering School in 1920 after many years at Yerkes Observatory, where he had designed and built telescopes and various astronomical devices. After Stebbins' arrival, Romare soon became very important around Washburn Observatory, and he built photoelectric instruments, participated in eclipse expeditions, and also designed telescope mountings.

As a prototype for the new mounting for the Washburn 15.6-in refractor, Stebbins had Romare design and build a smaller version for the Burnham telescope incorporating modern (by the standards of the 1920s) controls. The new equatorial mounting, fabricated by M.H. Kidder of the University Shops, was in place by early 1927 and judged a success. A weight-driven clock drive, designed by Romare, which could run the telescope for hours without attention, was engaged and disengaged by a button-operated electric clutch. The telescope could be driven in slow motion electrically on both axes. An integrated dial, driven by the clock, on the north face of the pier eased aiming by indicating both the sidereal time and the hour angle of the telescope. It was "… by far the most elaborately equipped instrument of its size in the world …" in the judgement (no doubt reflecting Stebbins' own) of the local student newspaper (Kulp, 1927: 267). Stebbins actually had a newer, heavier telescope in mind for the new mounting: a 10-in Fecker photographically corrected refractor (Figure 11). For the moment, however, the Burnham telescope's role was to test Romare's designs for the 15.6-in new

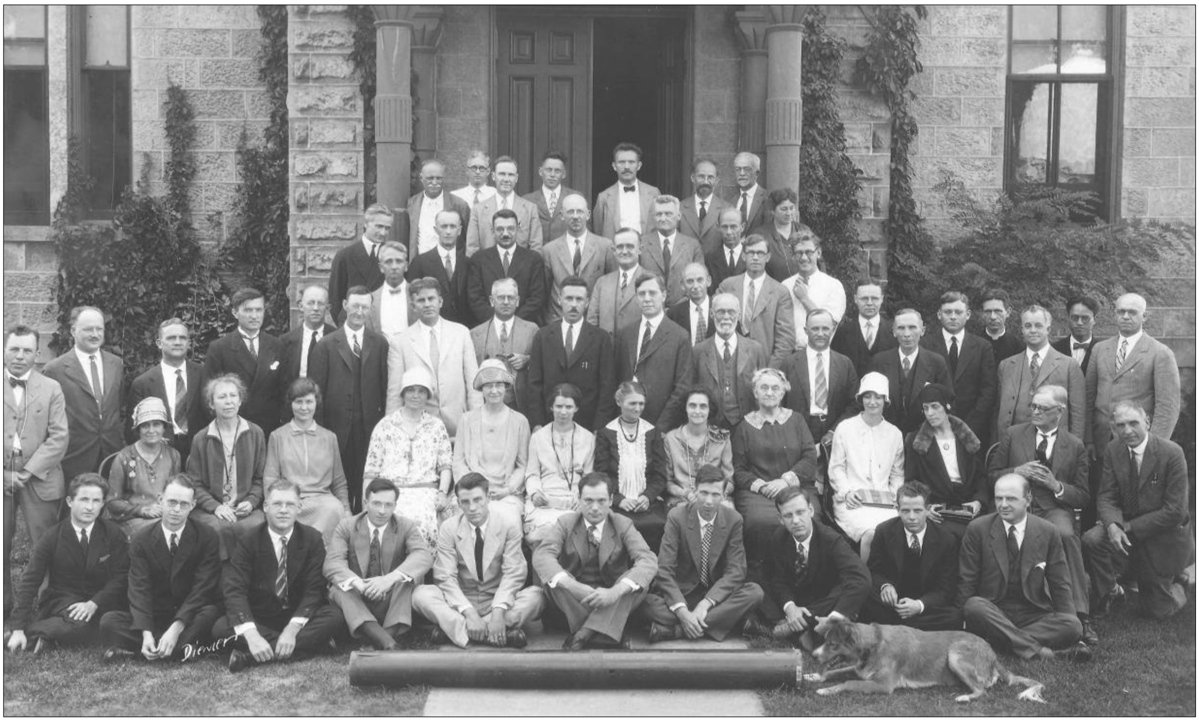


Figure 12: Group photo from the September 1927 AAS meeting in front of the Washburn Observatory east entrance. The wooden tube of the Burnham telescope lies in the foreground. Joel Stebbins, then director, is in the center of the second row from the top; on his immediate left is his predecessor, George Comstock; Philip Fox is in the light suit seventh from our left in the longest standing row (courtesy: Department of Astronomy, University of Wisconsin-Madison).

mounting, a project that was not completed until 1933 (delayed by Romare's sudden death in an automobile accident in April 1932). With the advent of this new mounting, the Burnham telescope's original Clark mounting parted company with the objective and tailpiece and joined the wooden telescope tube in storage.

8 THE AAS MEETING IN SEPTEMBER 1927

From 1917 to 1927, Stebbins (Director of Washburn Observatory since 1921) was the Secretary of the American Astronomical Society, and later he would serve that organization as President (1940–1943). George Comstock, teacher and predecessor to Stebbins, was President of AAS from 1925 to 1928 and he still maintained a home near Madison. So as the home to both the President and Secretary, it is no surprise to find that the AAS meeting of 6–8 September 1927 was held in Madison, Wisconsin, and hosted by Washburn Observatory.

Although the AAS was founded at and had met repeatedly at Yerkes Observatory, at Williams Bay in southern Wisconsin, this was the first meeting in Madison (about 70 miles away), so in addition to the usual scientific and organizational business, attendees were interested in touring the Madison area, sailing on the local lakes, walking the University campus, and, of course, getting a look at the Washburn Observatory. An unsigned account of the meeting describes the afternoon inspection visit of Washburn Observatory on Wednesday, 7 September, where "… perhaps the main item of interest was Burnham's famous six-inch refractor, now remounted but with the old mounting on exhibition as a historical relic." (Thirty-eighth meeting, 1927: 481). That account prints a typical AAS meeting group photograph, in this case in front of a fraternity house where many of the attendees were lodged. But there was another group photo taken at the meeting, which was taken in front of the east entrance of the Observatory, no doubt on the occasion of the tour (Figure 12). This shows 61 people (including most of the 48 AAS members attending), one dog, and what looks at first sight like a stove pipe poised in the foreground. But in fact this 'stove pipe' was the wooden tube of the Burnham telescope, which must have been of as much interest to the visitors as the original mounting (but the latter was probably too bulky to take outside for the photograph). The dog in the photograph is probably the Stebbins family dog, Tycho. What item of interest Stebbins stashed inside the tube to ensure Tycho's attention is not recorded.

9 THE ADLER PLANETARIUM

By April 1928, Washburn Observatory records indicate that the 10-in Fecker refractor had taken the place of the steel-tubed Burnham telescope, which had still been in the Student Observatory at the time of the AAS meeting the previous fall, on the new Romare mounting. The steel-tubed Burnham would then have joined the

Clark wooden tube and mounting in storage.

Meanwhile in Chicago, the planning for America's first planetarium, under the leadership of philanthropist Max Adler (1866–1952), was under way. From the very beginning of the planetarium project, Adler was personally responsible for what would become one of the planetarium's specialties, namely a fine collection and museum of antique and historical astronomical instruments (Taub, 1995). The astronomer taped to become the Adler Planetarium's first Director was Philip Fox (1878–1944; Stebbins, 1944), the Director of Northwestern University's Dearborn Observatory, the home of the 18.5-in Clark telescope with which Burnham had done some of his early work. Fox and Stebbins had known each other for many years and had been 'neighbors' along the Washburn-Yerkes-Dearborn Observatory axis since Stebbins arrived in Madison in 1922. As the Adler Planetarium neared its opening, which came in May 1930, Fox, who had been at the 1927 AAS meeting and seen the Burnham relics, wrote to Stebbins in June 1929 to ask if he would consider contributing the Burnham telescope for display at the new astronomical museum (Fox, 1929).

Figure 13: Original wooden tube of the Burnham telescope now part of the astronomical instrument collection at Adler Planetarium (photo by the author with permission of Adler Planetarium).

The appropriateness of returning the Clark tube and mounting of the Burnham telescope to Chicago had already occurred to Stebbins, and that produced a slightly embarrassing situation. In response to Fox's inquiry, Stebbins revealed that he had already made an offer to the Rosenwald Museum (as Chicago's Museum of Science and Industry was commonly known then), and the offer was accepted, although "... of course I intend to keep the objective to be used on stars for as long as it will serve." (Stebbins, 1929). They agreed in subsequent letters that if the Director of the Rosenwald, Waldemar Kaempffert (1877–1956), would release Stebbins from his offer, then the old tube and mounting could go to the new Adler Planetarium. Kaempffert then complied with Fox's request. Construction at the Planetarium was still under-way in early 1930, but by April 1930 Stebbins had shipped the original wooden tube and Clark mounting with clock drive to Fox, where they entered the instrument collection as items on loan. The Burnham items must have been some of the earlier artifacts in the collection, aside from the Mensing instruments acquired by Max Adler himself. It is not clear whether Fox and Stebbins were aware that the wooden tube might have been the last of the tapered wooden telescope tubes to be made by the Clarks (Warner and Ariail, 1968). The objective lens and tailpiece attached to the new steel tube remained in Madison, in storage at Washburn Observatory. So the Burnham telescope's parts diverged even farther (Figure 13).

10 STORAGE AND SOJOURN

It appears that the metal-tube Burnham remained in storage from 1928 until 1956—at least there are no log books or records for it during that time. Joel Stebbins had retired in 1948 and was succeeded by his younger colleague Albert Whitford (1905–2002; Osterbrock, 2004). Whitford was managing some major transitions for Washburn Observatory, including a new, rural observatory site with modern instruments, Pine Bluff Observatory. At the organizational level, the Observatory was making the transition from what was primarily a research institution into a fully fledged and rapidly growing University Astronomy Department. And finally, the astronomers, their offices, laboratories, and shops were preparing to move to a new wing of the Physics building, Sterling Hall.

The 15.6-in telescope remained on its Romare mounting in the old Washburn Observatory dome, where its primary purpose became use by astronomy classes and the general public, but the Student Observatory was about to be abandoned.

Before its final relocation, the Burnham telescope came out of storage to make one more trip away from Madison. In 1956, an energetic amateur astronomer from Appleton, Wisconsin, Jerome J. Knuijt (1959: 410), "... went to the Washburn Observatory to see Burnham's 6-inch refractor, but learned that this fine instrument had been put in storage." Knuijt had constructed his own rather impressive and unusual observatory in his hometown, which, coincidentally, featured a split-hemisphere dome similar to the arrangement Comstock had used on the Student Observatory for the refraction and aberration work with the Burnham telescope. Knuijt clearly impressed Whitford, who arranged for him to borrow the Burnham telescope for his personal use back in Appleton. Knuijt, using his own mountings, paired the Burnham with a 6-in reflector to make direct comparisons of the visual performance of the two types of telescopes (Figure 14).

Figure 14: Jerome Knuijt at his Appleton, Wisconsin, observatory with the Burnham telescope, which is piggy-back on a larger telescope (courtesy: University of Wisconsin Archives).

11 RETURN TO MADISON

In 1958 Albert Whitford left Washburn Observatory to become Director of Lick Observatory. His successor was Arthur Dodd Code (1923–2009), who came to Madison from California Institute of Technology, but had worked for a year at Washburn earlier in his career. The Burnham telescope returned to Madison from Appleton in late 1959. In summer that year the new Astronomy Department had moved from the old observatory building to the top floor of the new east wing of Sterling Hall. During the construction of the new wing of the building, provision was made by the architects for the installation of a planetarium and telescopes on the roof, including concrete columns extending vertically from the foundation up to rooftop level where they could support telescopes. Code (oral history interview with the author, 31 August 2001) was of the opinion that those telescope-supporting columns were the reason that the east wing of Sterling Hall did not collapse after the truck bomb attack of August 1970.

On the westernmost column, under a new dome, the Burnham refractor was reunited with the Romare mounting, where they remain today. Meanwhile, parts of the 10-in Fecker refractor went into storage. The Sterling Hall site suffers from serious light pollution and, being in the midst of campus, various rooftop heating and cooling systems degrade the seeing. But its location is nearly ideal for use by astronomy students, which is one of the reasons why Holden bought it from Burnham in the first place. The Romare clock drive and control system were replaced with more modern hardware in 2008, and the objective was cleaned and collimated a few years ago (Figure 15). These roles, travels, and transformations are testimony to the durability and versatility of a classic achromatic refractor, which remains in active use today nearly one and a half centuries later. Thanks to the expertise of the Clark shop long ago and the custodianship of several generations of astronomers, the optical performance of the Burnham telescope remains as 'simply perfect' as ever (Figure 16).

12 NOTES

1. Note that Caroline Island is a small isolated coral atoll in Polynesia, near Kiribati, and is not part of the much better-known Caroline Islands thousands of kilometres to the west.

13 ACKNOWLEDGEMENTS

Important resources in the preparation of this paper include University of Wisconsin-Madison Archives, Mary Lea Shane Archives of Lick Observatory, Adler Planetarium History of Astronomy Collection, and NASA Astrophysical Data System. The author thanks the referees for their insightful and helpful comments.

14 REFERENCES

Abney, W. de W., 1894. Address, delivered on presenting the Gold Medal to Professor S.W. Burnham. *Monthly Notices of the Royal Astronomical Society*, 54, 277–284.

Adams, W.S., 1939. Biographical Memoir of George Ellery Hale 1869–1938. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 21, 181–241.

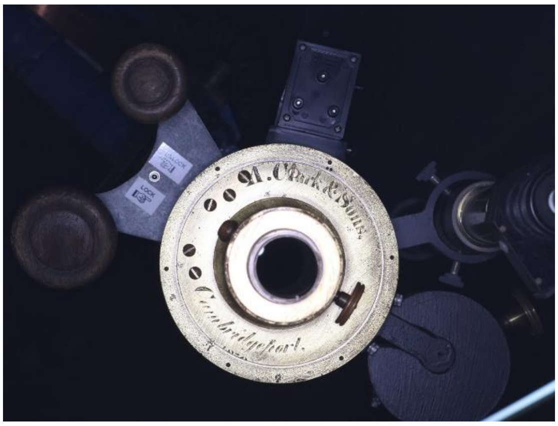


Figure 16. Original brass tailpiece with Clark's engraving (photo by the author with permission of the Department of Astronomy, University of Wisconsin-Madison).

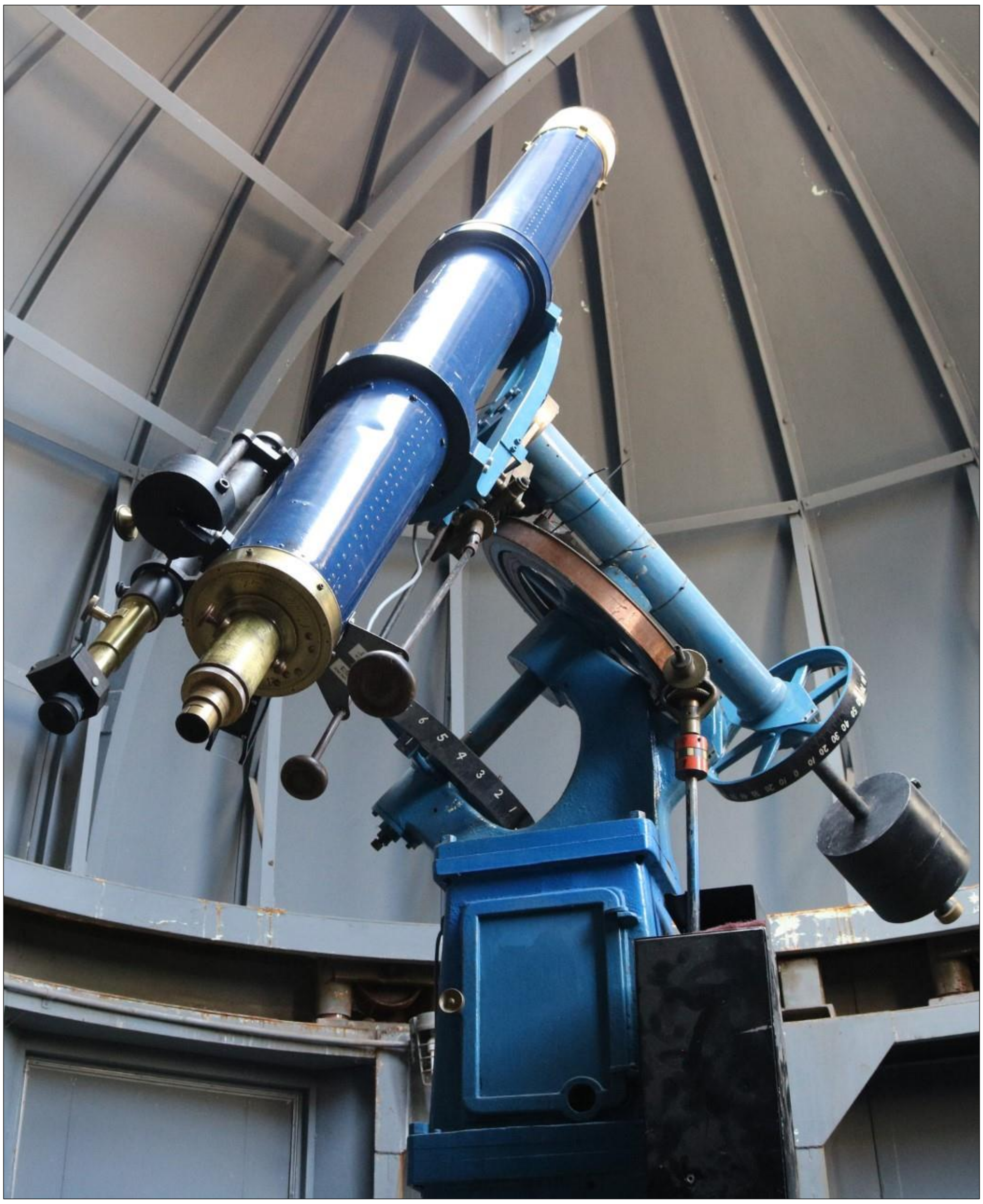


Figure 15: Contemporary view of the Burnham telescope in the dome on Sterling Hall (photo by the author with permission of the Department of Astronomy, University of Wisconsin-Madison).

Aitken, R.G., 1935. *Binary Stars*. New York, McGraw-Hill.

Barnard, E.E., 1921. Sherburne Wesley Burnham. *Popular Astronomy,* 29, 309–324.

Batten, A.H., 1988. *Resolute and Undertaking Characters: The Lives of Wilhelm and Otto Struve*. Dordrecht, Springer.

Baum, R., and Sheehan, W., 1997. *In Search of Planet Vulcan: The Ghost in Newton's Clockwork Universe*. New York, Plenum Press.

Burnham, S.W., 1873. A third catalogue of 76 new double stars, discovered with a 6-inch Alvan Clark refractor. *Monthly Notices of the Royal Astronomical Society*, 34, 59–72.

Burnham, S.W., 1900. *A General Catalogue of the Double Stars Discovered by S.W. Burnham from 1871 to 1899, Arranged in Order of Right Ascension*. Chicago, Yerkes Observatory (*Publications of the Yerkes Observatory*, 1, 1–271).

Burnham, S.W., 1906. *General Catalogue of Double Stars within 121° of the North Pole*. Chicago, University of Chicago Press.

Buttmann, G., 1970. *The Shadow of the Telescope: A Biography of John Herschel*. New York, Charles Scribner's Sons.

Campbell, W.W., 1919. Biographical Memoir Edward Singleton Holden 1846–1914. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 8, 347–372.

Campbell, W.W. 1924. Biographical Memoir Simon Newcomb 1835–1909. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 17, 1–70.

Comstock, G.C., 1895a. Biographical Memoir of James Craig Watson 1838–1880. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 3, 47–57.

Comstock, G.C., 1895b. *Investigation of the Aberration and Atmospheric Refraction*. Madison, Washburn Observatory (*Publications of the Washburn Observatory*, 9(1), 1–203).

Eggen, O.J., 1953. Sherburne Wesley Burnham and his double star catalogue. *Leaflet of the Astronomical Society of the Pacific*, 6, 354–361.

Fox, P., 1915. *Annals of the Dearborn Observatory of Northwestern University*. Evanston, Illinois: Northwestern University.

Fox, P., 1929. Letter to Joel Stebbins, dated 14 June. University of Wisconsin-Madison Archives (7/4/2 Box 14, General Correspondence, 1927–1930).

Frost, E.B., 1913. Biographical Memoir of Charles Augustus Young 1834–1908. *Biographical Memoirs of Academy of Sciences of the United States of America*, 7, 89–114.

Frost, E.B., 1921. Sherburne Wesley Burnham. *Journal of the Royal Astronomical Society of Canada*, 15, 269–275.

Hearnshaw, J., 2014. Abney, William de Wiveleslie. In Hockey, T. et al., (eds.). *Biographical Encyclopedia of Astronomers. Second Edition*. New York, Springer. Pp. 12–14.

Hill, G.W., 1908. Biographical Memoir of Asaph Hall 1829–1907. *Biographical Memoirs of Academy of Sciences of the United States of America*, 6, 241–275.

Holden, E.S., 1881. Letter to C. C. Washburn, dated 12 August. Mary Lea Shane Archives of the Lick Observatory (Washburn Observatory Papers, MS 274).

Holden, E.S., 1882. Washburn Observatory. *Annual Report of the Regents of the University of Wisconsin, 1881 & 1882*. Madison, Wisconsin: David Atwood, State Printer.

Holden, E.S., 1883a. Expedition notebook, University of Wisconsin-Madison Archives (Acc 2011/129 Box 7).

Holden, E.S., 1883b. Madison. *Vierteljahresschrift der Astronomischen Gesellschaft*, 18, 112–116.

Holden, E.S., 1884. Report of the eclipse expedition to Caroline Island May 1883. *Memoirs of the National Academy of Science*, 2, 1–146.

Holden, E.S. & Burnham, S.W., 1882. Observations of the transit of Mercury, 1881, November 7, at Mount Hamilton, California. *American Journal of Science*, 23, 48.

Knuijt, J.J., 1959. Gleanings for ATM's: a large amateur observatory of unusual design. *Sky and Telescope*, May, 406–410.

Kulp, J. H., 1927. Small telescope at Washburn Observatory completely rebuilt. *Wisconsin Engineer*, 31, 267, 284.

Nyren, M., 1906. Otto Wilhelm Struve. *Popular Astronomy*, 14, 352–368.

Osterbrock, D.E., 1976. California-Wisconsin axis in American astronomy I. *Sky and Telescope*, January, 9–14.

Ostercrock, D.E., 2004. Albert Edward Whitford. October 22, 1905–March 28, 2002. *Biographical Memoir of the National Academy of Sciences of the United States of America*, 85, 336–362.

Osterbrock, D.E., Gustafson, J.R., and Unruh, W.J.S, 1988. *Eye on the Sky: Lick Observatory's First Century*. Berkeley, University of California Press.

Sheehan, W., 1995.*The Immortal Fire Within: The Life and Work of Edward Emerson Barnard.* Cambridge, Cambridge University Press.

Stebbins, J., 1923. Albert Stowell Flint. *Popular Astronomy*, 31, 369–372.

Stebbins, J., 1929. Letter to Philip Fox, dated 16 June. University of Wisconsin-Madison Archives (7/4/2 Box 14, General Correspondence, 1927–1930).

Stebbins, J., 1938. Biographical Memoir of George Cary Comstock 1855–1934. *Biographical Memoir of the National Academy of Sciences of the United States of America*, 20, 161–182.

Stebbins, J., 1944. Philip Fox. *Science*, 100, 184–186.

Struve, O., 1937. Biographical Memoir of Edwin Brant Frost 1866–1935. *Biographical Memoirs of the Naional Academy of Sciences of the United States of* America, 19, 25–51.

Taub, L., 1995. 'Canned Astronomy' versus cultural credibility: the acquisition of the Mensing Collection by the Adler Planetarium. *Journal of the History of Collections,* 7, 243–250.

Thirty-eighth Meeting of the American Astronomical Society, 1927. *Popular Astronomy,* 35, 481–482.

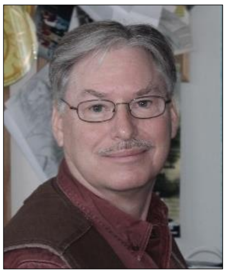
Uhler, H.S., 1938. Biographical Memoir of Charles Sheldon Hastings. 1848–1932. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 20, 273–291.

van den Bos, W.H., 1958. A Biographical Memoir of Robert Grant Aitken 1864–1951. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 32, 1–30.

Warner, D.J., and Ariail, R.B., 1995. Alvan Clark and *Sons: Artists in Optics*. *Second Edition.* Washington, Smithsonian Institution Press.

Whitford, A.E., 1978. Joel Stebbins 1878–1966. *Biographical Memoirs of the National Academy of Sciences of the United States of America*, 49, 293–316.

Wright, H.M, 1994. *Explorer of the Universe: A Biography of George Ellery Hale*. New York, American Institute of Physics.



James Lattis is an historian of science with research interests in Early Modern astronomy, astronomy in Italy, and the history of astronomy in Wisconsin. He currently focuses on the history of Washburn Observatory, the development of astronomical photoelectric photometry, the origins of interstellar medium studies, and the early days of space astronomy. As a Faculty Associate in the Department of Astronomy of the University of Wisconsin-Madison, Lattis teaches courses in introductory astronomy and the history of astronomy. He is also Director of UW Space Place, the astronomy and space science outreach facility of the Astronomy Department, in which role he teaches astronomy in various media for a wide range of audiences.

Journal of Astronomical History and Heritage, 20(2), 195–210 (2017).

THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 8: GROTE REBER AND THE 'SQUARE KILOMETRE ARRAY' NEAR BOTHWELL, TASMANIA, IN THE 1960s AND 1970s

Martin George, Wayne Orchiston
National Astronomical Research Institute of Thailand, 260 Moo 4, T. Donkaew, A. Maerim,
Chiang Mai 50180, Thailand, and University of Southern Queensland, Toowoomba 4350,
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 4350, Australia.
Email: rwielebinski@mpifr-bonn.mpg.de

Abstract: In the 1960s, Grote Reber (1911–2002) established and used an antenna array near Bothwell in Tasmania. Working independently, he produced a radio map of the southern sky at a frequency of 2.085 MHz (a wavelength of 144 metres). Encouraged by this success, he modified the array in the 1970s to work at ~1.155 MHz, but this second endeavour failed to produce any usable results.

Keywords: Radio astronomy, Tasmania, Reber, Bothwell, low frequency arrays

1 INTRODUCTION

Even prior to 1960, it was clear that radio astronomy at frequencies below 20 MHz was well worthwhile. Several researchers in this field, particularly in Australia, had produced results (see, e.g., Higgins and Shain, 1954; Shain, 1951; Shain and Higgins, 1954; cf. Orchiston et al., 2015a, 2015b). Beginning in 1946, the CSIR (later CSIRO) Division of Radiophysics maintained many field stations, mostly in the Sydney area (see, e.g., Orchiston and Slee, 2017; Robertson, 1992).

However, radio astronomy at low frequencies is hampered considerably by the absorption of radio waves by the Earth's ionosphere. A frequency of 10 MHz is often taken to be the lowest at which observations can normally be made, but under ideal conditions it is possible to detect celestial radiation down to about 1–2 MHz. Winter nights around the time of solar minimum offer the best conditions, because of the lower degree of ionisation of the ionosphere. However, the ease of observation at the lowest of these frequencies depends on the location on Earth from which the observations are made. In general, the lowest values of the critical frequency foF2 occur at locations that are sufficiently distant from both the geographic equator and the magnetic poles. Studies of ionospheric conditions in various parts of the world (see, e.g., Reber, 1982) showed that two important locations are north eastern North America (in the vicinity of the Great Lakes), and the island of Tasmania immediately to the south of the Australian mainland.

Several years after Karl Jansky's discovery of radio emissions from the Galaxy, Grote Reber (1911–2002) constructed the world's first purpose-built radio telescope in Wheaton, Illinois. He made a radio map of the sky at 160 MHz, and the resulting papers (Reber, 1940; 1944) became classic papers in radio astronomy (see Sullivan, 1982), largely setting the scene for future research at around this frequency.

Reber arrived in Tasmania in late 1954 and was involved in two major endeavours in low-frequency radio astronomy in the course of that decade. The first was at Cambridge, near Hobart, in collaboration with Graeme Ellis (Reber and Ellis 1956; George et al., 2015a). The second was a four-dipole array that he set up at Johnson Valley near Kempton, 50 kilometres by road to the north of Hobart, in an attempt to detect radiation at 0.52 MHz (Reber, 1958a; George et al., 2015b).

Thoughts of returning to Tasmania from the USA in order to carry out further low frequency research clearly were on Reber's mind following the Kempton work. Indeed, he even considered returning to the same valley in which he carried out his 1956–1957 observations. Thus, in May 1958 he wrote:

> I expect to find my way back to the land of the Southern Cross in the autumn of 1960 and string up my wires again at Johnson Valley. (Reber, 1958b).

In late 1959, Reber made a brief trip to Macquarie Island, part of Tasmania but well to the south of the main island, where he considered the possibility of setting up a low-frequency array,

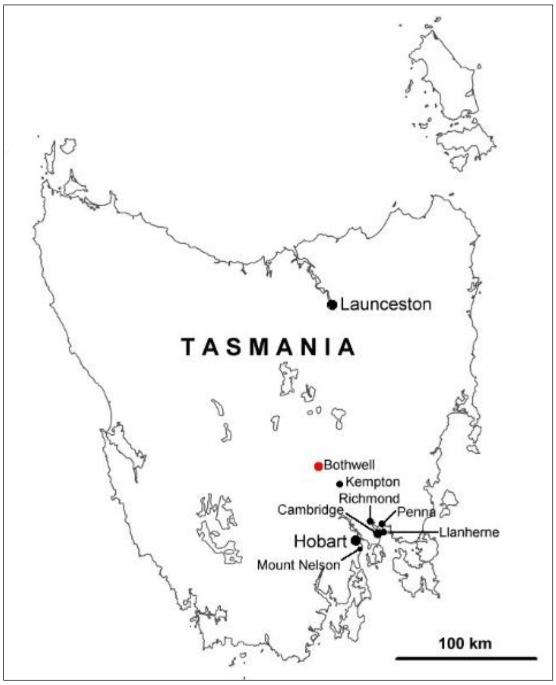


Figure 1: Key radio astronomy sites in Tasmania. This paper discusses Grote Reber's radio astronomy array near Bothwell, in southern central Tasmania, about 67 kilometres north-northwest of Hobart (map: Martin George)..

as well as making further observations from Kempton (Reber, 1960a).

However, his main location of interest was on the Tasmanian mainland, and from 1960 he embarked on a major project to map the low-frequency southern-hemisphere sky, not from Kempton, but from Dennistoun, a property seven kilometres from the town of Bothwell. The project was essentially in two parts: observations were made at a frequency of 2.085 MHz during the 1960s, and further observations were attempted at ~1.155 MHz in the mid-1970s. Although the earlier observations were successful in producing a radio map of the sky, the 1970s observations failed to produce useful results.

This paper describes Reber's research at Dennistoun, near Bothwell, undertaken in two distinct phases over a decade and a half between 1960 and 1976. Figure 1 shows the location of Bothwell and other key radio astronomy sites in Tasmania.

Figure 2: Grote Reber at Dennistoun in 1985 (photograph: Peter Robertson).

2 BIOGRAPHICAL NOTE: GROTE REBER

In 1937 Grote Reber (1911–2002; Figure 2) constructed the world's first purpose-built radio telescope at Wheaton, Illinois, in the USA. After following several other radio astronomy related pursuits, Reber developed a great interest in low frequency radio astronomy, and because of Tasmania's excellent location for such work, this led him to choose the island as a suitable site for southern-hemisphere observations, interspersed with several trips back to the USA.

Following his initial Tasmanian low frequency work in 1955 (at Cambridge), and then in 1956–1957 (Kempton), Reber continued his interest in low frequency observations.

During the 1960s, Reber (1968) set up a large array of dipoles near Bothwell, and over the period 1963–1967, mapped the sky at a frequency of 2.085 MHz. This was the biggest project of his lifetime, and made use of a large, flat piece of land on a property owned by Geoffrey Edgell.

Reber subsequently returned to Bothwell and modified the array in an unsuccessful attempt during the mid-1970s to map the sky at about 1.155 MHz.

Through this work, Reber became well known in the Bothwell community, and befriended many of the residents. He engaged several Tasmanian contractors to perform various aspects of the work, such as the erection of the poles and anchors, and kept detailed notes of his work.

After finishing his Tasmanian radio astronomy work, Reber constructed an energy-efficient house in Bothwell, which became his main home for the remainder of his life.

From the 1950s and for most of his life, Reber made many return trips from Tasmania to the USA, and in the mid-1980s he attempted low-frequency observations of the sky from a location near Ottawa, Canada.

Reber was not a mainstream astronomer; indeed, he disagreed with the concept of the Big Bang, preferring to interpret redshift as 'tired light' (see Kragh, 2017)—a view he promoted in his 1968 paper and especially later in life during many lectures and talks that he delivered in Tasmania and elsewhere. Nonetheless, he received many awards, including the Bruce Medal of the Astronomical Society of the Pacific, the Elliot Cresson Medal of the Franklin Institute, and an Honorary Doctor of Science Degree from Ohio State University.

He was keen on many other scientific and technological pursuits, including the study of cosmic rays, Tasmanian prehistory, plant growth and efficient transport.

Grote Reber never married and had no children. He passed away on 20 December 2002, two days before his 91st birthday. Further biographical and autobiographical details are provided in Kellermann (2005), and Reber (1983, 1984), respectively.

3 INSTRUMENTATION

3.1 Location and Planning of the Array

Following Reber's trip to Macquarie Island, he returned to Tasmania to visit the Kempton site of his 1956–1957 observations. For years he had been considering re-using this location, but this plan changed in January 1960:

> During the past couple of weeks I've been rather on vacation here. However, I dug up the cable at Johnson Valley [the Kempton site]. It was somewhat damaged and not safe to lay in the ground again, but may be used for other purposes such as delay lines ... (Reber, 1960b).

At this stage Graeme Ellis, with whom Reber had worked at Cambridge in 1955 (Reber and Ellis 1956; George et al., 2015a), was based at Camden, New South Wales, and Reber was expecting to be able to team up again with Ellis:

> We ... have located another good site at Bothwell which is 20 miles northwest of Kempton. Bill [Ellis] thinks he can get transferred back to Hobart and obtain at least part of the equipment money. I'd like to go along with this and secure a part in it with some Research Corp. money[1] along about 1961 or 2. (ibid).

The location mentioned was not actually at Bothwell itself, but on a property known as Dennistoun, 5.6 kilometres to the north-northeast of Bothwell, owned by Mr Geoffrey Edgell.

Collaboration with Ellis was, however, not to transpire, with Reber (1960c) entering into independent negotiations for the use of the land. This was not palatable to Ellis:

> I was surprised to find out on a recent visit to Tasmania that you had proceeded independently toward getting permission to use the site at Bothwell ... In any case I consider I have a prior right to use this site if no others become available. (Ellis, 1960a).

Reber continued to suggest collaboration, but Ellis (1960b) decided not to entertain the idea:

> I think it would be unwise and inconvenient to have two large radio telescopes on the same property operated by different organisations, and if you [Edgell] decide that Reber should have permission I shall look elsewhere.

From mid-1960, therefore, the Dennistoun property became solely Reber's location for radio astronomy. The arrangement between Reber and landowner Geoffrey Edgell was formally documented by a legal agreement on 4 May 1961 (Reber and Edgell, 1961) and was to continue for many years. The agreement had many specifications as to the use of the land and the amount of land that would be used by Reber. It allowed Reber to construct—in addition to the array itself—a hut, roads, bridges, and cattle grids. It also specified that Reber's work was not to "… interfere with impede interrupt or hinder the use of the property by the owner for grazing and as a home …", and that the annual fee payable to the landowner would be £50.[2] The agreement was to last for five years but interestingly, it included an option for Reber to continue the arrangement for a further eleven years—an option that Reber was to use.

The scene was therefore set for Reber to make use of the land, although animals would be grazing there.

Perhaps inspired by the newly-erected 19.7 MHz Shain Cross near Sydney (see Orchiston et al., 2015a), Reber was at first considering the erection of a similar cross-type antenna, with north-south and east-west arms 7,260 feet (2,213 metres) and 8,260 feet (2,518 metres) long, respectively (see Figure 3). However, in early 1961 he changed his plans, and decided to build a filled-aperture, approximately circular, dipole array. In March he performed calculations on a proposal that would see an array covering just under one square kilometre (Reber, 1961a). Later that year he wrote:

> The idea of wires strung out on long pole lines at rightangles in the form of a cross has been replaced by a more compact arrangement. Now the wires are to be in form of several parallel lines like rulings on paper. The lengths are adjusted so periphery is approximately a circle. (Reber, 1961b).

Detailed plans of the array, dated 22 November 1962, made it quite clear that the 'present structure' formed only the central part of what Reber planned to be a much larger (but still approximately circular) array with more than twice the diameter. However, there are no known records that show that this enlargement was ever attempted.

3.2 Construction and Layout of the 2.085 MHz Array

The array as eventually constructed was of the form of an ellipse (Figure 4) of eccentricity 0.54, based on the east-west and north-south extents of the poles being about 1212 and 1015 metres, respectively. Between the eastern and western halves was a north-south transmission axis (Figure 5). The array covered an area of 0.97 square kilometre, although the outermost east-west poles were used only to support the end di-

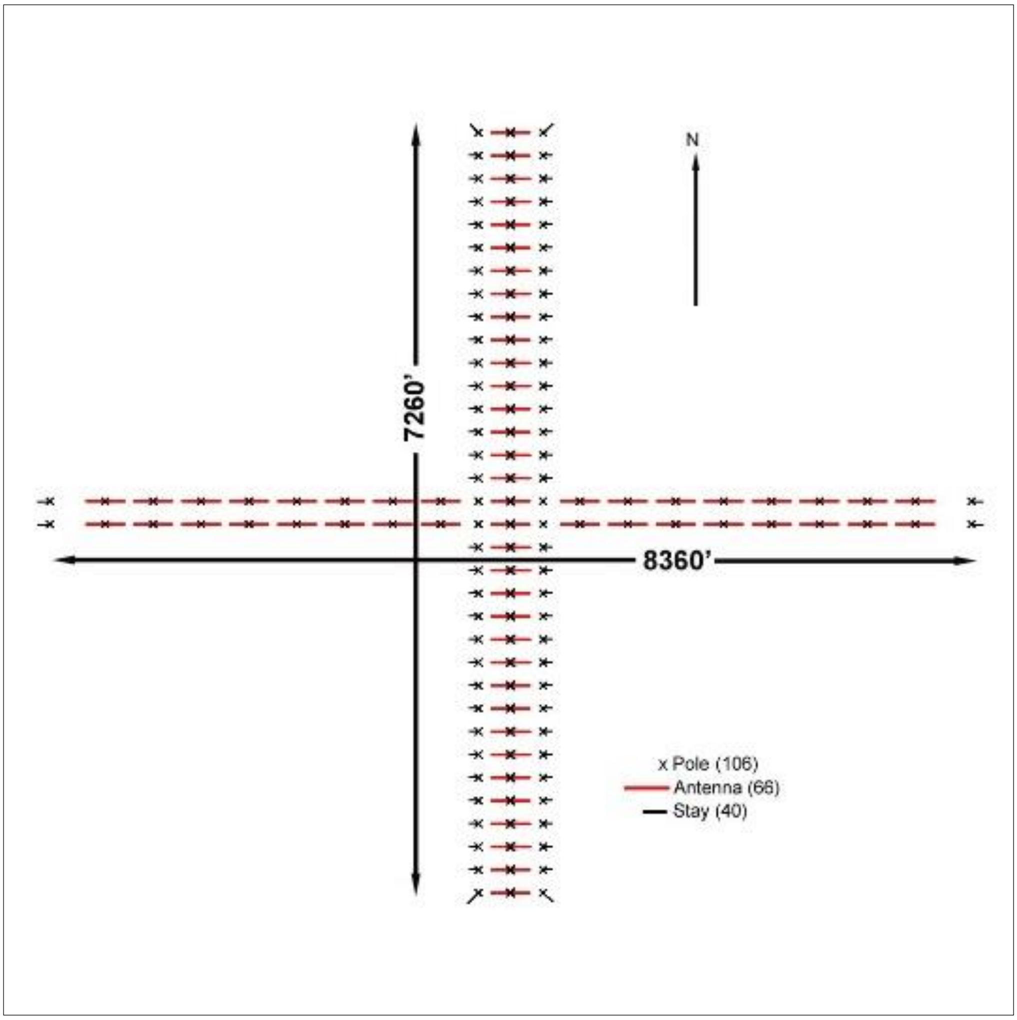


Figure 3: Reber's original cross-type concept for the Bothwell Antenna, adapted from his original diagram drawn on 18 April 1960. Courtesy Henry Edgell.

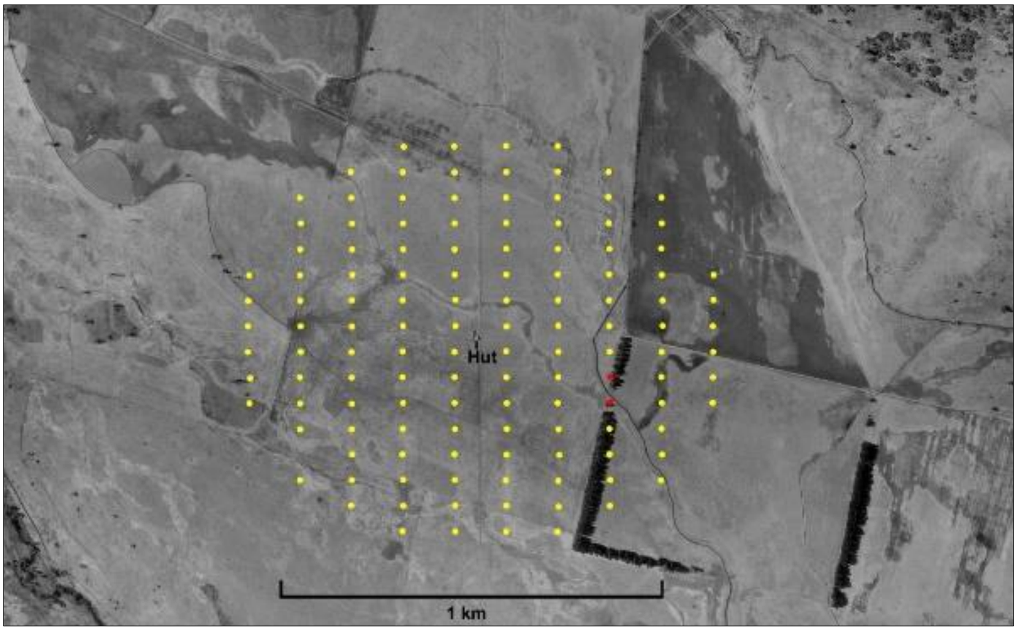


Figure 4: The locations of poles that can be identified on an aerial photograph taken on 15 February 1968. Yellow dots mark the positions of the 'pole' end of identified shadows; red dots are extrapolated from incomplete shadows. One pole, in the southwestern part, may have fallen (Base data from theLIST, www.thelist.tas.gov.au, © State of Tasmania).

poles in each row, making the filled-aperture area rather less than this. However, the construction, over this area, effectively made this the world's first 'Square Kilometre Array'. Figure 6 is an aerial view taken in 1965, showing a significant portion of the array.

The array was complete by August 1962. On 15 August, Reber (1962) issued a statement 'to whom it may concern', which included:

> Mr Leo Jeffries, as contractor has recently completed a radio astronomy installation at Dennistoun near Bothwell, Tasmania. The work consisted of securing and erecting 128 poles each 77 feet long plus numerous short posts and overhead trusses and stays. Several hundred crossarms, insulators, pulleys, counterweights, fortyseven miles of wire plus about one hundred each line transformers and antenna coupler boxes were all properly attached to the poles, posts and trusses and connected in an appropriate manner.

Figure 7 shows one frame of a 16 mm movie film depicting the erection of one of the tall poles; Leo Jeffries and his employees may be the people in this image.

The poles were separated by 440 feet (134 metres) in the east-west direction and 220 feet (67 metres) in the north-south direction. This allowed for two half-wavelengths of wire between each east-west pair of poles, separated by a spacer (see Figure 8). Except for the poles at the extreme eastern and western ends, each pole was the centre of an east-west full-wavelength dipole, with each dipole wire running over a pulley before dropping vertically and being kept straight by a counterweight (see Figure 8, upper part, and Figure 9).

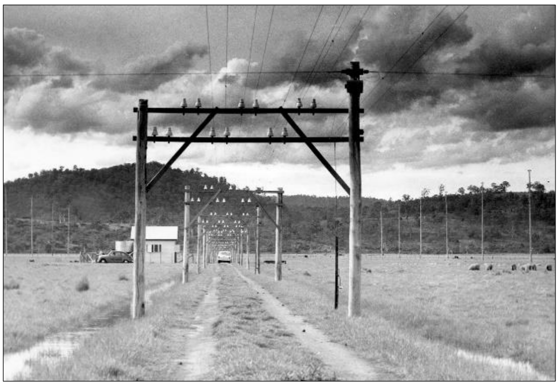


Figure 5: A view looking north along the central north-south transmission axis of the array, with the receiver hut on the left (courtesy Estate of Grote Reber).

Raymond Haynes (pers. comm., 2017) commented that the counterweights were too heavy and placed too much strain on the wires. As a result, some of them broke while he was there as a student in 1965.

The tall poles were buried 10 feet (3 metres) in the ground, so the height of each above ground level was 67 feet (20.4 metres). Midway

Figure 6: An aerial photograph taken during an afternoon in 1965. The original colour slide was processed in December 1965; the shadow lengths and azimuths make the likely date of the photograph early October (more likely, given the lush appearance of the scene) or early March. The photograph is likely to have been taken by Vern Reid (courtesy: Estate of Grote Reber).

Figure 7: A tall pole being inserted into the ground at Dennistoun in the early 1960s. This is a single frame from a 16 mm movie film by Geoffrey Edgell (courtesy Henry Edgell).

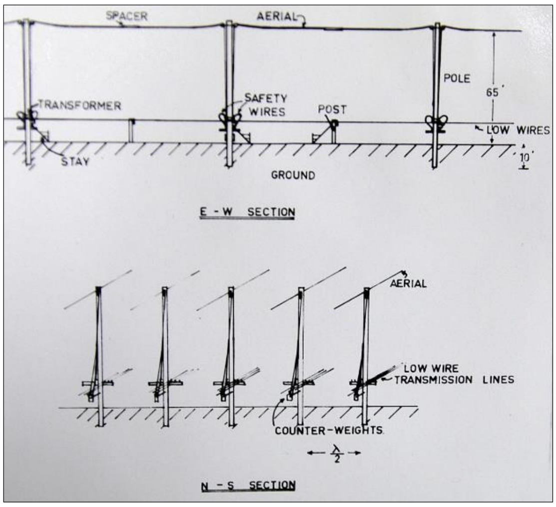


Figure 8: The east-west and north-south arrangement of the array. The east-west and north-south scales are not the same; the poles were separated by 440 feet (134 metres) (after Haynes 1966: 51).

Figure 9: A pair of pulleys that were mounted atop a tall pole. The east and west components of each dipole passed over the pulleys then dropped down to a few metres above the ground (photograph: Martin George; courtesy Estate of Grote Reber).

Figure 10: Reber climbing a pole just southeast of the receiver hut on 6 March 1979. Photographer unknown (courtesy: Estate of Grote Reber).

between the poles, a short insulating spacer was used to separate the dipoles (see Figure 8).

Reber would often climb the poles himself, using special grips that he had had made. He was still doing this as late as 1979 at the age of 68, well after both series of observations (Figure 10).

Reber was concerned about possible decay of the sections of the poles that were below ground; he added creosote to protect them. However, both Raymond Haynes and Graeme Ellis were of the opinion that the entire array was over-engineered, and that the creosote to protect the poles should not have been necessary (ibid.).

A hut was constructed very close to the centre of the array. This was to house the receiving equipment and was, essentially, Reber's 'workstation' (see Figures 5, 11 and 12). Using the 1968 aerial photograph (Figure 4) and comparing this with modern aerial images, the hut (WGS84 Datum) was positioned at longitude 147° 01′ 22.8″ East and latitude 42° 20′ 05.8″ South, plus or minus a few metres.

The array had a 'Christmas tree' feed and could be steered by inserting delay lines along the north-south transmission axis (Figure 5). The delay line lengths on the transmission lines were altered by moving terminators on those lines (Haynes, R., pers. comm., 2017). Reber (1966) commented that

> Steering is limited to plus and minus (north and south) 48° from zenith as this covers the entire south celestial hemisphere.[3] The beam direction may be shifted in two hours by two men and a tractor operating along the line of arches [the main north-south axis].

Electricity for the equipment was supplied by several batteries, to avoid interference from mains lines. Reber regularly measured the battery levels; indeed, many handwritten notes from the 1970s observations (see Section 6) mention checking the batteries.

Even after the array was completed, Reber was clearly concerned about the stability of the tall poles. Around October 1963 he advertised in *The Mercury*, Hobart's newspaper, for a contractor to provide and bury a number of poles in trenches in the ground to serve as anchors. The idea was that a hole would be bored through each pole before burying it, and a rod would be inserted that protruded from the ground and could be used to connect with the tall array pole via a cable. Reber (1964a) considered this to be correcting 'false economy'.

The successful tenderer was the young Darrell Browning of Fentonbury, who recalls:

> It [the advertisement] was in the Mercury. I was born in 1945 so I wasn't very old. If you

> didn't go out and get a job there was no Government money. I was working with my father. We had a farm; we used to do a lot of post and rail fencing. I just put in the tender. My father helped me with the work. He and another friend of ours helped. He [the friend] had a Ferguson Tractor – a 'Fergie' – a little grey one when they first came out … and a post hole digger on the back. (Darrell Browning, pers. comm., 2017).

4 THE 1960s OBSERVATIONS

4.1 Reber's Main Observations

The array had a quoted beamwidth of ~7.1° and was operated at a frequency of 2.085 MHz, slightly less than the ~134-metre length (67 metres each side, less half the spacer length) would suggest. The output was recorded on a pen recorder, with a chart speed of about 3 centimetres per hour (Reber, 1968b; Figures 13 and 14). The final choice of 2.085 MHz was based on finding a frequency most free of artificial interference (Haynes, 1966).

Reber was not present for all of the observations; indeed, the setup did not require constant attention. For much of the day-to-day work, at least during parts of 1962 and 1963, Reber engaged the services of Veio Fletcher, a young Dennistoun farm hand. Geoffrey Edgell agreed to Fletcher's partial secondment to Reber, noting in his diary that Fletcher was engaged in such activities as "harrowing middle race course", "sewing and rolling wheat", and "Reber" (Edgell, 1962; 1963).

Reber clearly regarded Fletcher as having given important assistance:

> Things are going well here with much good data being secured at Bothwell. The operation is now mostly in the hands of my capable man Veio Fletcher. (Reber, 1963).

The 2.085 MHz survey of the southern sky occupied the years 1963 to 1967. As expected, Reber noted the unfavourable summer periods, during which the higher degree of ionisation precluded obtaining good results. As with Reber's work at Kempton (Reber, 1958a), he was also often plagued by 'atmospherics' caused by poor weather. Indeed, one of the pen recorder illustrations (Figure 14) is annotated with the note "ELECTRICAL STORM OVER NORTHWEST TASMANIA".

The solar minimum of the 1960s took place in 1964. By the end of that year Reber (1964b) wrote:

> A large amount of good cosmic static data has been secured over the past two years. One more year of the present minimum still remains. When solar activity begins to rise, I will close this adventure and report my findings.

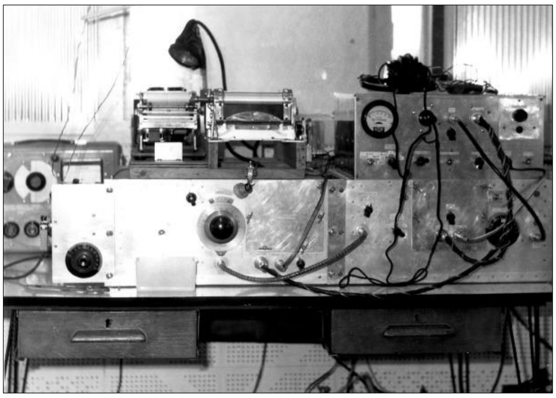


Figure 11: Reber's equipment in the hut. At far left is a Marconi Receiver Tester model TF888/3, which is on display in the Grote Reber Museum at Mount Pleasant, near Cambridge in Tasmania (courtesy: Estate of Grote Reber).

Figure 12: From left, Graeme Ellis, Bart Bok, Grote Reber and Peter McCulloch outside Reber's hut in the middle of the array, about 1965. Photographer unrecorded (courtesy: Peter McCulloch).

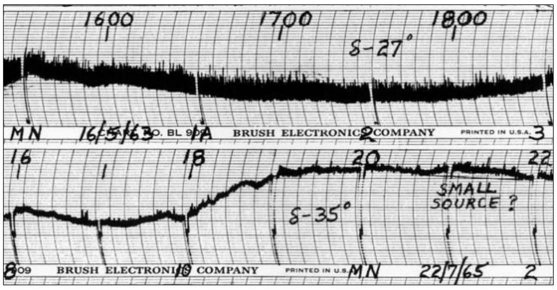


Figure 13: A typical pen recording of Reber's observations at 2.085 MHz on 16 May 1963 (top) and 22 July 1965 (bottom) (after Reber, 1968a).

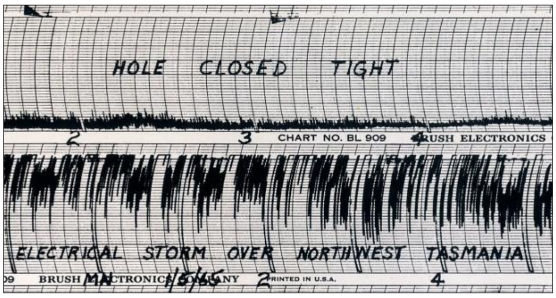


Figure 14: A pen recording of Reber's observations at 2.085 MHz on 1 May 1963 (top) and 1 May 1965. In the 1963 trace, the ionosphere precluded observations, and in the 1965 trace an electrical storm was spectacularly recorded. (after Reber, 1968a).

Reber's 2.085 MHz observations ran from 4 February 1963 to 10 May 1967 (Reber, 1968a). For many years later in life, he proudly displayed a panoramic picture of the array in his house, with annotations confirming that the observations ran from 1963 to 1967.

Even before the specified date of cessation of observations, Reber, on 8 May 1967, submitted his manuscript to The Franklin Institute for publication (Reber, 1967a), having returned to the USA in the few weeks preceding this. The paper was published in January 1968 (Reber, 1968b), and contained his 2.085 MHz map of the sky in both celestial and galactic coordinates, and a number of illustrative pen recorder traces.

The map (Figures 15 and 16) clearly shows the Milky Way in absorption, with noticeable regions of absorption by interstellar electrons in and near the Galactic Plane (the isophotes within a few degrees of the Galactic Plane all show minima). This was in agreement with other observations (see, e.g., Hoyle and Ellis, 1963; Ellis and Hamilton, 1966a; 1966b), although the displayed resolution shown in the region of the Galactic Plane appears rather high for the instrument he was using.

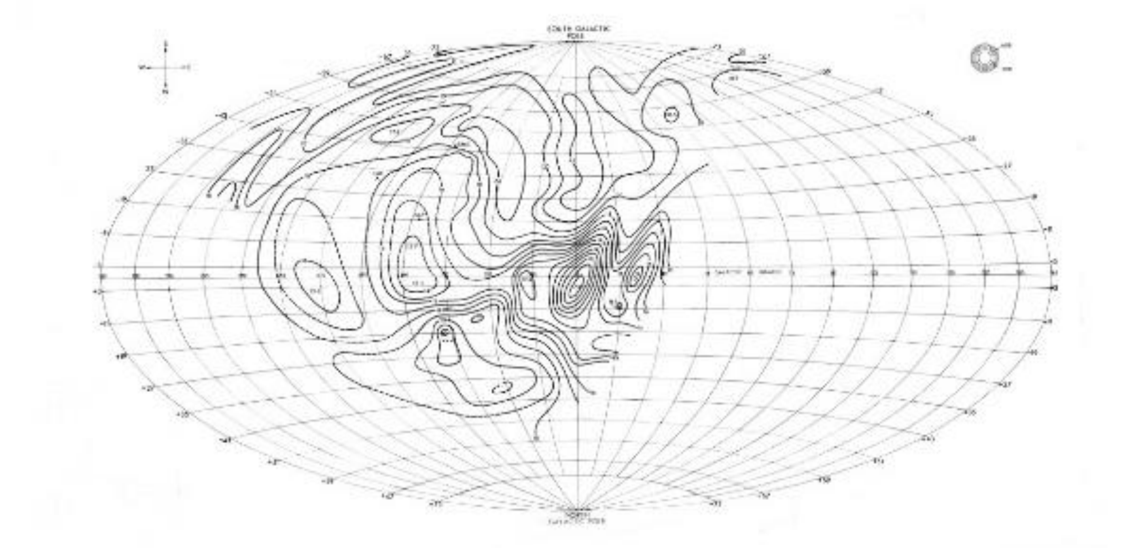


Figure 15: Grote Reber's 2.085 MHz map (Reber, 1968a). This is the version that was presented in galactic coordinates with the Galactic Equator running horizontally through the centre of the diagram, and the south and north Galactic Poles at the top and bottom, respectively.

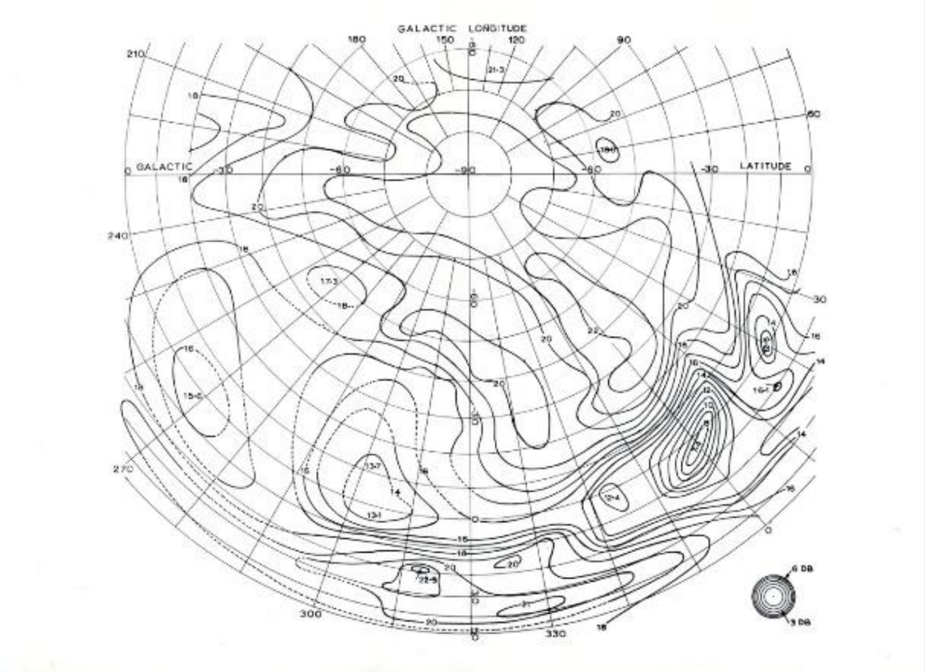


Figure 16: Reber's 2.085 MHz map in galactic polar coordinates. This version was not included in Reber's 1968 paper (courtesy Estate of Grote Reber).

There was no known attempt by Reber to publish his paper in a more mainstream astronomical publication such as *The Astrophysical Journal* or *The Astronomical Journal* (see the Discussion section near the end of this paper).

4.2 The Array as an Ionosonde

During 1965 the array was also used as an ionosonde.[4] This was a project supervised by Graeme Ellis and conducted by Raymond Haynes for a B.Sc. Honours thesis (Haynes, 1966). Ellis was keen to continue studying the Z-mode echoes from the ionosphere,[5] and

> … saw the opportunity to use Grote's array to do this. [The radio telescope at] Penna was too high a frequency … [We] needed a frequency that was in the right range; 2 MHz was a good option. (Haynes, R., pers. comm., 2017).

Haynes' ionosonde operated from about May until the beginning of November, 1965 (ibid.). It was set up to work at the same frequency (2.085 MHz) Reber was using for his astronomical observations. However, the ionosonde operated for only two minutes every hour (ibid.).

Many useful results were obtained, including frequent observations of Z echoes from the predicted region 8° north of the zenith. What, in retrospect, was an amusing incident occurred in October 1965:

> About the middle of October, a couple of burly guys turned up and they'd hunted down that some blighter was radiating Hobart with ionospheric radiation ... They suspected the Physics Department [of the University] had something to do with it so they came, and I had to admit that this happened when the beam was pointed to the south, and the beam came down straight over Hobart. (ibid.).

5 REBER'S RETURN TO TASMANIA

In 1964, while observations were proceeding at Dennistoun, it was clear that Reber intended to make his next series of observations from the USA or Canada. In a letter to G.L. Nelms of the Defence Research Board in Ottawa (Reber, 1964b), referring to the period following his Dennistoun observations, he wrote:

> Shortly thereafter, I expect to setup more elaborately in your part of the world in anticipation of the next solar minimum. The northern sky should be even more interesting than the southern at hectometer waves.

This plan is likely to still have been on Reber's mind when he wrote to Edgell in May 1967, showing little concern about the maintenance of the array:

> If a wire comes down, pull it up out of the way ... If a major disaster causes any of the poles to come down, please try to salvage the hardware. Remains of poles may be cut up for firewood. (Reber, 1967b).

In the same letter, Reber confirmed that he would continue to send cheques to Edgell, as clearly he had exercised his option to use the land beyond the expiry of the original agreement (see Section 3.1).

However, it did not take long for Reber to make a decision to return to Tasmania to make further observations. Certainly, this decision had been made by December 1968, but it may have been made earlier:

> I would like to establish myself somewhere just north of Bothwell within a few minutes drive of the scientific installation. This will cut down the amount of driving I used to do. (Reber, 1968b).

In the same letter, Reber describes the preparation of equipment for a new 'multibeam telescope'. He was also deciding on which items of equipment he would need to transport to Tasmania. He made further reference to this in 1969:

> Things are going well here [in the USA]. I've designed nearly all the electronic equipment for my new multibeam telescope. Prototypes of half the major assemblies have been built and tested. (Reber, 1969).

It is also clear, however, that Reber's problem was one of obtaining more funding from the Research Corporation. He had received this funding for his work since the 1950s, and he now needed further financial support for his new research program.

Following his application for further funds, letters were sent by the Research Corporation to prominent astronomers seeking their opinions. Several replied positively about Reber's ability to perform this work. No negative opinions on that topic appear in the records, but there was a difference expressed between Reber's ability to gather data and his ability to interpret it. Walter Orr Roberts, who was then the President of the University Corporation for Atmospheric Research in Colorado, wrote of Reber's proposal:

> ... it is highly meritorious of support. He is an unusual, imaginative, and utterly honest man, and the kind of person that I think deserves backing. He will do things the unconventional way, and sometimes his interpretations will be criticized, but his work always has a touch of experimental genius in it. (Roberts, 1971).

Reber also applied to the National Science Foundation for funding, but his application was rejected. However, as a result of the supportive letters, Reber was granted further financial support from the Research Corporation for his next venture in Tasmania.

6 THE 1.155 MHz ATTEMPT: 1971–1976

On 1 November 1971 Reber arrived back in Aus-

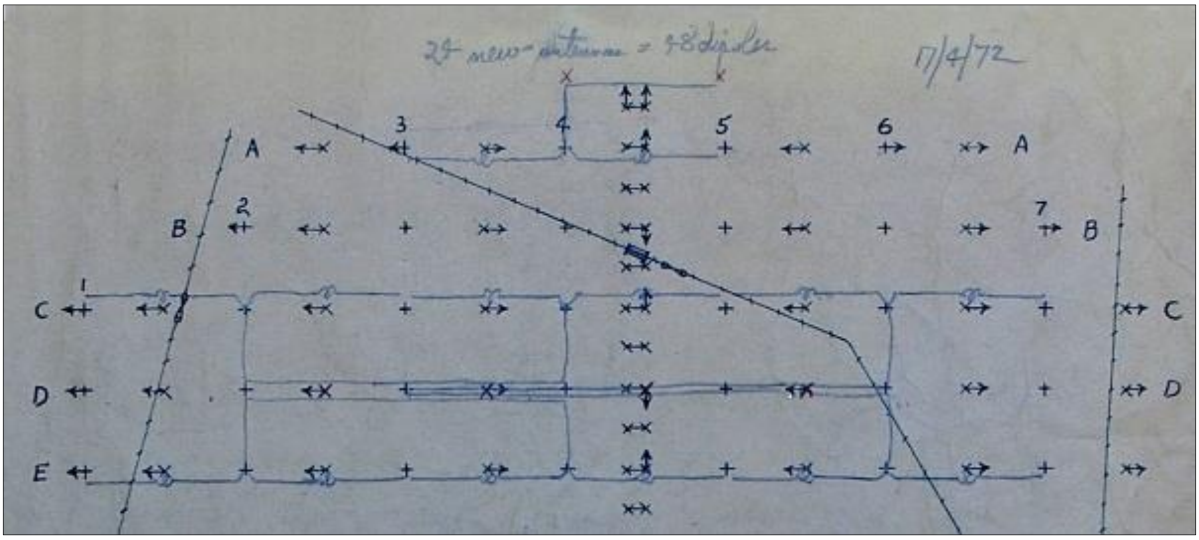


Figure 17: Part of Reber's plan, dated 17 April 1972, for re-wiring the array for use at 1.1 MHz (courtesy Estate of Grote Reber).

tralia. By then he was confident in his plans to re-establish the Dennistoun array for use at approximately 1 MHz. He wasted no time checking the status of his array. He discovered that about a quarter of the low wires (presumably meaning the transmission lines) had come down, but most of the high wires (the dipoles) were in place. Even so, he knew that all of the existing wires would need to come down anyway. He stated that his targets were to re-wire the array to get it into working order at one megacycle during that same summer, and extend it to larger dimensions the following year (Reber, 1971).

Neither of these targets was realised, but by April 1972 Reber had completed a pre-wiring plan based on the existing 128 poles, setting up 24 new antennas (Reber, 1972; see Figures 17 and 18 here). Reber counted one antenna as being two dipoles, so he considered his 24-antenna dipole system to have 48 dipoles.

However, by May 1973 Reber had re-wired the array to accommodate 48 antennas, which became the final configuration. In a handwritten list of activities that he had undertaken between November 1971 and May 1973 (Reber 1973), he noted a long list of achievements, including removal of 96 small poles and arches; testing of the 128 tall poles for internal decay; the purchase of pole-climbing hoops and the invention of new pole climbing claws; the rehabilitation of two miles of road and the construction of a quarter of a mile of new road; and the purchase of a tractor and four used Renault R4 vehicles. The array, as it appeared in 1975, is shown in Figure 19.

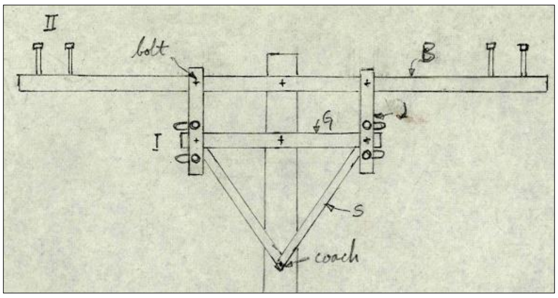


Figure 18: One of many crossarm designs, for transmission lines, that Reber produced in 1972. This example was drawn in December. These were either attached to the main poles or mounted on shorter, stand-alone poles (courtesy Estate of Grote Reber).

In early February 1974 Reber finally began actually living close to the site, as had been his desire for several years (Reber, 1968b). He rented a dwelling at 'Wetheron', a property with several cottages, just south of Bothwell and approximately 14.5 kilometres by road (about 15 minutes' drive) from the array.

Reber began attempting actual observations with the 'new' array during the winter of 1974, but through that year he was still erecting poles with crossarms, and adding crossarms to the existing tall poles (Figure 15); in mid-1974 only two dipoles were connected to the receiver system (Reber, 1974b). Reber recorded only three partial openings of the ionospheric hole at 1155 kHz, mentioning that solar activity and foF2 remained much too high (ibid.).

Reber was spending a lot of his time performing 'listening tests' in order to find a channel clear of broadcasting stations. At these new, lower frequencies, this task was much harder than at around 2 MHz, which had been his target in the 1960s. He found a multitude of stations, especially Radio Station 2WD in Wagga, New South Wales, which broadcast on 1150 kHz. This—the presence of 2WD and many other stations—was a problem that he encountered throughout. Because of this, the use of a minimum reader, to record the lowest intensity over a given (short) period of time, was most important. Reber also made use of two bandwidth

Figure 19: The Dennistoun array, looking south, photographed on 19 June 1975. Three images from a set of seven by Grote Reber, processed by us into a panorama (courtesy: Estate of Grote Reber).

filters: one 8.5 kHz and the other 2 kHz wide. With a wide, clear channel, the 8.5 kHz filter would have been preferable, but the frequencies were well populated and Reber calmly recorded his frustration, as in this example from 15 July 1974 (Reber, 1974a):

> 505a [5:05 a.m.] Another station came on at 1150 kc quite strong.
> 509a Another station came on at 1160 kc quite strong. Now entire region using band 2 [8.5 kHz] filter is covered by stations. Decided to let operate a while to see what will happen.
> 540a These stations will keep the receiver saturated. Decided to change back to band 1 (2.0 kc) filter. Splatter still present. Both stations at 1150 and 1160 kc will drive receiver to saturation when turned right on.
> 600a All stations on every channel very strong. Nothing more can be done.
> 620a Left. Moon peeks through clouds at intervals.

During early 1975 Reber continued to add the necessary components to the array, including the crossarms and tuner boxes. The attempt at making observations continued over the winter, although broadcasting stations continued to be a problem, and 1975 saw increasing physical problems with the array. On 25 January one of the poles—likely to have been a transmission pole—blew down (Reber, 1975a) and over several months many wires broke. He had problems with animals grazing on the property (although this was likely to have also been the case in the 1960s), and on 27 April he noted: "Cow number 343 is a pest." (Reber, 1975b).

Reber's increasing frustration is particularly apparent from his diary entry of 3 October 1975:

> During past few days they have plowed the entire area west of N/S road and some of area east of road. A few more wires have gotten tangled in machinery and come down. Whole place is big muddy mess. Don't feel like even trying to put wires back up. (Reber, 1975c).

After a trip back to the USA over the Tasmanian summer, Reber spent one more winter at Dennistoun attempting his observations. He tried recording when he could find a quiet channel. He had obviously performed some repairs since the problems of 1975, as he wrote on 12 June 1976 that

> Fixing the antenna has certainly reduced pick-up of BC [broadcasting] stations. Perhaps if entire array is finished the BC stations will be greatly suppressed further and allow a much wider bandwidth to be used. (Reber, 1976).

Reber was not necessarily referring to his original 1970s plans needing completion; it is more likely that he was referring to his thoughts of a much larger ~1 MHz array, which was never built.

Attempts in 1976 at recording celestial radiation in the ~1 MHz area produced no improvement over those of 1975 (see Figure 20), and this was the final Tasmanian effort made by Reber at making a low frequency survey of the sky. Reber (1977a; 1977b) attributed this singular lack of success to the relatively shallow 1976 solar minimum. Indeed, solar activity data (Meeus, 1983; Royal Observatory of Belgium, Brussels, 2017) do show that the 1976 minimum

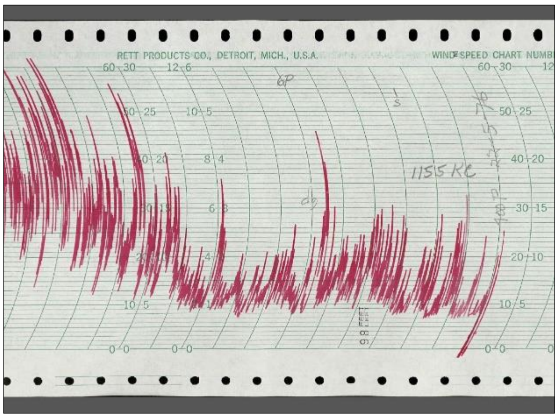


Figure 20: A pen recording at 1155 kHz, made on 22 May 1976. Time runs from right to left. The recording started at 16:00 hours, and the pictured section is five hours wide. Reber commented in his diary that the recording was useless because of a broadcasting station on this frequency (courtesy: Estate of Grote Reber).

Figure 21: The last remaining artefacts from the array at Dennistoun, 2003. Left to right: David Jauncey, Dale Blanchard, Henry Edgell, Anastasios Tzioumis, Esko Valtaoja, and David McConnell (photograph: Martin George).

was not quite as low as that of 1964, which in turn was less deep than the minimum of 1954.

7 THE END OF THE DENNISTOUN ARRAY

Even after the failed attempt of the 1970s, Reber was clearly still hoping for the possibility of more observations. Surprisingly, this was following the solar activity minimum. In a letter of 15 August 1977 to the landowner, Geoffrey Edgell, he wrote:

> As mentioned to you a few months ago, I intend to dismantle the installation in your paddock. However, it would be a shame to tear it down and then find good observing conditions had unexpectedly reappeared. I now intend to maintain it for a few more years just to see what is going to happen. It will never be expanded according to my grandiose ideas of several years ago. (Reber, 1977b).

As it happened, the array was gradually dismantled over a number of years; indeed, some tall poles and shorter transmission poles were still standing around 1991. An arrangement for their removal was proposed about 1980 with Henry Edgell, the landowner's son, using some of the last remaining funds received by Reber from the Research Corporation (Reber, 1980b); it was around 1980 when Reber was ending his long association with the Research Corporation (Reber, 1980a).[6] However, Henry Edgell (pers. comm., 2015; 2017) recalled that no formal arrangement was agreed, that there was a gradual removal over quite some time after 1980, and that eventually, some poles had started to rot. A photograph found amongst Reber's possessions, undated but likely to have been taken about 1991 or early 1992, shows some tall poles still standing.

Figure 22: An October 2004 photograph showing the Dennistoun hut arriving at its final home—the University of Tasmania's Mount Pleasant Radio Observatory (photograph: Martin George).

In the mid-1980s the shed that had housed the receiving equipment near the centre of the array was moved to Reber's house in the town of Bothwell, and used as a storage shed.

In 2003, one of us (George) and several others visited the site and examined the remains of several parts of the array: some poles that had been cut up, and a number of counterweights (Figure 21).

In 2004, the shed was moved (Figure 22) to the University of Tasmania's Mount Pleasant Radio Observatory near Cambridge, and eventually formed part of the Grote Reber Museum, which was opened in 2009.

8 DISCUSSION

It is interesting to consider Reber's undertaking at Dennistoun in light of the fact that the University of Tasmania was concurrently making independent observations at 4.7 MHz and 10 MHz at Penna (George et al., 2017).

The 2.085 MHz map certainly filled a gap at the time, and was indeed the first such map made at this low frequency. Later, the University constructed an array near Hobart airport that was used to make observations at a range of higher frequencies up to 16.5 MHz; this will be the subject of a future paper in this series.

Reber was well known for working independently, beginning with the construction of his first radio telescope in the USA, and another example was the work that he performed at Kempton in 1956–1957 (George et al., 2015b). One may therefore wonder whether his early suggestions of collaboration with Graeme Ellis at Bothwell were purely because he wanted to be seen to be doing the 'right thing', while all the while actually preferring to work independently. However, it is interesting that it was Ellis who refused to collaborate when Reber raised the idea, especially after their earlier successful joint effort at Cambridge.

Perhaps Reber's quest for independence can also be traced back to the difficulty that he experienced when trying to get research published and accepted in the 1940s (but at that time radio astronomy was in its infancy). We believe that Reber's realisation that his research was still controversial most likely led him to decide to publish his Dennistoun results in the *Journal of the Franklin Institute* rather than in a mainstream astronomical journal such as the *Astrophysical Journal*.

Reber's decision to attempt to conduct successful observations at ~1 MHz was a gamble, despite his gaining financial support—perhaps granted somewhat reluctantly—from the Research Corporation. He realised that the project would require an exceptionally low solar minimum in the mid-1970s, and this did not eventuate. Later he made it very clear that this was the reason for his failure; however, his many diary entries make it equally clear that broadcasting stations, even with a minimum reader, were a major problem. In addition, none of his diary notes contains information about making use of phasing on the array during the 1970s attempt, even though he had constructed a number of phase shifters in the USA around 1970, presumably for use in Tasmania. He had certainly long planned to have phasing performed electronically, rather than mechanically (Reber 1966).

It is interesting to contemplate whether Reber would have attempted the lower frequency observations anyway in the 1970s if the Research Corporation had turned down his funding request. He was not without private means, so in keeping with his known determination, he may still have proceeded (and the scientific result would have been the same).

Finally, during the solar minimum in the 1980s Reber attempted to make low frequency observations of the northern sky from near Ottawa, Canada. We mention this here because of his continued drive to make more and more low frequency observations. However, the Ottawa attempt also failed, but even this did not deter Reber: in 1987 he drew up plans for a large 1 MHz array, although he did not disclose its proposed location. It was never built.

9 CONCLUDING REMARKS

Grote Reber's project at Dennistoun was carried out in two parts and was a major undertaking. But only the first part was a success, and this resulted in the 2.085 MHz map of the southern radio sky. This was the first such map, and it has an important place in the history of radio astronomy.

Although we believe that Reber's Dennistoun research paper does not stand as high, historically, as his landmark paper of 1944 (Reber, 1944), the Dennistoun array was a major engineering challenge and a remarkable achievement, and it can justifiably be called the world's first 'Square Kilometre Array' since it covered nearly that area and was indeed a filled-aperture array at the wavelengths used.

10 NOTES

1. The Research Corporation or, more correctly, the Research Corporation for Scientific Advancement, was founded in 1912. It is a private foundation that supports innovative research at colleges and universities in the USA. As a US citizen, Reber had a long association with the Research Corporation, which helped fund his radio astronomical research for nearly 30 years.
2. Until 14 February 1966, Australia's unit of currency was the pound (£), divided into twenty shillings each of 12 pence. On that date Australia changed to a decimal system with the dollar being the unit, equivalent to ten shillings (half a pound). In 1967 Reber (1967b) paid $100 to the landowner, and this arrangement likely continued.
3. The distance from the zenith (the point overhead) to the Celestial Equator is equal to the observer's latitude, which in this case was 42° 20′ South. Forty-eight degrees would allow the beam of the array to have complete coverage of the southern celestial hemisphere.
4. An ionosonde is a device that transmits pulses toward the ionosphere and receives reflections from it, in order to examine the ionosphere. In particular, an ionosonde can be used to measure the current value of foF2, the frequency that indicates to radio astronomers the lowest frequency that may be observed from the ground.
5. There are normally two ionosonde reflections from the ionosphere, corresponding to the two main modes of wave propagation in a magneto-plasma, called the ordinary (O) and extraordinary (X) modes. However, a third mode, called the Z mode, can occur, resulting in a third reflection (see, e.g., Benson et al., 2006). The Z mode is a branch of the X-mode and was studied extensively by Graeme Ellis (see, e.g., Ellis 1955; 1956).
6. Reber received a total over US$ 200,000 from the Research Corporation between 1951 and 1981 (Kellermann, 2004). This was used for array construction, air fares, and various other expenses.

11 ACKNOWLEDGEMENTS

We wish to thank the following for their assistance: the late Dale Blanchard, Ellen Bouton, Karen Bradford, Darrell Browning, Henry Edgell, Dr Raymond Haynes, Dr Kym Hill, Dr David Jauncey, and Dr Kenneth Kellermann. We also wish to thank Dr Peter Robertson for supplying Figure 2, the Department of Primary Industries, Parks, Water and Environment (Tasmania) for providing the aerial image for Figure 4, Henry

Edgell for providing the digitised movie film for Figure 7, Dr Peter McCulloch for providing Figure 12, and the Estate of Grote Reber for providing images for Figures 5, 6, 10, 11 and 19.

12 REFERENCES

Benson, R.F., Webb, P.A., Green, J.L., Carpenter D.L., Sonwalkar, V.S., James, H.G., and Reinisch, B.W., 2006. Active wave experiments in space plasmas: the Z mode. *Lecture Notes in Physics*, 687, 3–35.

Edgell, G., 1962. Diary Notes by Geoffrey Edgell. Courtesy Henry Edgell.

Edgell, G., 1963. Diary Notes by Geoffrey Edgell. Courtesy Henry Edgell.

Ellis, G., 1955. *The Magneto-Ionic Triple Splitting of Ionospheric Echoes*. Ph.D. Thesis, Physics Department, University of Tasmania, Hobart, Australia.

Ellis, G., 1956. The Z propagation hole in the ionosphere. *Journal of Atmospheric and Terrestrial Physics*, 8, 43–54.

Ellis, G., 1960a. Letter to Grote Reber, dated 23 May. Courtesy Henry Edgell.

Ellis, G., 1960b. Letter to Geoffrey Edgell, dated 24 June. Courtesy Henry Edgell.

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.

George, M., Orchiston, W., Slee, B., and Wielebinski, R., 2015a. 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., 2015b. 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, 326–338.

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., Slee, B., and Wielebinski, R., 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. *Journal of Astronomical History and Heritage*, 20, 95–111.

Haynes, R., 1966. *High Resolution Ionospheric Sounding at 2 Mc/sec*. B.Sc. Honours Thesis, Physics Department, University of Tasmania, Hobart, Australia.

Higgins, C.S., and Shain, C.A., 1954. Observations of cosmic noise at 9.15 Mc/s. *Australian Journal of Physics*, 7, 460–470.

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.

Kellermann, K.I., 2004. Obituary, Grote Reber (1911–2002). *Publications of the Astronomical Society of the Pacific*, 116, 703–711.

Kellermann, K.I., 2005. Grote Reber (1911–2002): a radio astronomy pioneer. 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. 43–70.

Kragh, H., 2017. Is the Universe expanding? Fritz Zwicky and the early tired-light hypothesis. *Journal of Astronomical History and Heritage*, 20, 2–12.

Meeus, J., 1983. *Astronomical Tables of the Sun, Moon and Planets*. Richmond, Willman-Bell, Inc.

Orchiston, W., and Slee, B., 2017. The early development of Australian radio astronomy: the role of the CSIRO Division of Radiophysics field stations. In Nakamura, T., and Orchiston (eds.). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe. Cham, Springer.* Springer.

Orchiston, W., Slee, B., George, M., 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., 1940. Cosmic Static. *Astrophysical Journal*, 91, 621–624.

Reber, G., 1944. Cosmic Static. *Astrophysical Journal*, 100, 279–287.

Reber, G., 1958a. Between the atmospherics. *Journal of Geophysical Research*, 63, 109–123.

Reber, G., 1958b. Letter from Grote Reber to the Astronomical Society of Tasmania. Mentioned in *Bulletin of the Astronomical Society of Tasmania*, 179, June 1958.

Reber, G., 1960a. Letter to Charles Schauer of the Research Corporation (USA), dated 6 January. Papers of Grote Reber. Archives, National Radio Astronomy Observatory/Associated Universities, Inc./National Science Foundation.

Reber, G., 1960b. Letter to Charles Schauer of the Research Corporation (USA), dated 25 January. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1960c. Letter to Graeme Ellis, dated 31 May. Courtesy Henry Edgell.

Reber, G., 1961a. Handwritten diary note, dated 24 March. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1961b. Letter to Jennie Ewanoski of the Research Corporation, dated 8 September. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., and Edgell, G., 1961. Legal agreement for the use of land at Dennistoun, dated 4 May. Courtesy Henry Edgell.

Reber, G., 1962. Announcement of the completion of the radio astronomy installation, dated 15 August. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1963. Letter to Jennie Ewanoski of the Research Corporation, dated 30 August. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1964a. Letter to Jennie Ewanoski of the Research Corporation, dated 31 January. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1964b. Letter to G.L. Nelms of the Defence Research Board, Ottawa, Canada, dated

18 December. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1966. Letter to George Southworth, dated 28 October. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1967a. Letter to Dr Martin A. Pomeranz of the Franklin Institute, Philadelphia, dated 8 May. Courtesy Estate of Grote Reber.

Reber, G., 1967b. Letter to Geoffrey Edgell, dated 5 May. Courtesy Henry Edgell.

Reber, G., 1968a. Cosmic static at 144 meters wavelength. *Journal of the Franklin Institute*, 285, 1–12.

Reber, G., 1968b. Letter to Geoffrey Edgell, dated 18 December. Courtesy Henry Edgell.

Reber, G., 1969. Letter to Geoffrey Edgell, dated 28 April. Courtesy Henry Edgell.

Reber, G., 1971. Letter to Jennie Ewanoski of the Research Corporation, dated 20 December. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1972. Diagram of proposed layout of the 1.1 MHz array, dated 17 April. Courtesy Estate of Grote Reber.

Reber, G., 1973. Letter to Charles Schauer of the Research Corporation, dated 22 May. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1974a. Handwritten diary notes, dated 15 July. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1974b. Letter to Dr. R.M. Price of the National Radio Astronomy Observatory, Virginia, USA, dated 3 December. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1975a. Handwritten diary notes, dated 27 January. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1975b. Handwritten diary notes, dated 27 April. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1975c. Handwritten diary notes, dated 3 October. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1976. Handwritten diary notes, dated 12 June. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1977a. Letter to Charles Schauer of the Research Corporation, dated 10 June. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1977b. Letter to Geoffrey Edgell, dated 15 August. Courtesy Henry Edgell.

Reber, G., 1980a. Letter to Charles Schauer of the Research Corporation, dated 8 July. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1980b. Letter to Charles Schauer of the Research Corporation, dated 12 August. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Reber, G., 1982. My Adventures in Tasmania. *Tasmanian Tramp*, 24, 148–151.

Reber, G., 1983. Radio astronomy between Jansky and Reber. In Kellermann, K., and Sheets, B. (eds.). *Serendipitous Discoveries in Radio Astronomy*. Green Bank, National Radio Astronomy Observatory. Pp. 71–78.

Reber, G., 1984. Early radio astronomy at Wheaton, Illinois. In Sullivan III, W.T. (ed.). *The Early Years of Radio Astronomy*. Cambridge, Cambridge University Press. Pp. 43–66.

Reber, G., and Ellis, G.R.A., 1956. Cosmic radio-frequency radiation near one megacycle. *Journal of Geophysical Research*, 61, 1–10.

Roberts, W.O., 1971. Letter to Charles Schauer of the Research Corporation, dated 25 March. G. Reber Papers, NRAO Archives, NRAO/AUI/NSF.

Robertson, P., 1992. *Beyond Southern Skies. Radio Astronomy and the Parkes Radio Telescope*. Cambridge, Cambridge University Press.

Royal Observatory of Belgium, Brussels, 2017. SILSO data/image. http://www.sidc.be/silso/version archive. Retrieved 18 July 2017.

Shain, C.A., 1951. Galactic radiation at 18.3 Mc/s. *Australian Journal of Scientific Research*, A4, 258–267.

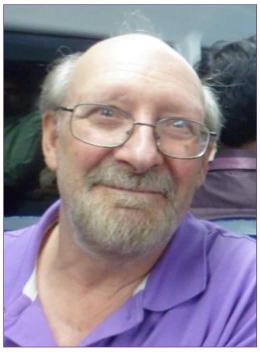
Shain, C.A., and Higgins, C.S., 1954. Observations of the general background and discrete sources of 18.3 Mc/s cosmic noise. *Australian Journal of Physics*, 7, 130–149.

Sullivan III, W.T., 1982. *Classics in Radio Astronomy*. Dordrecht, Reidel.

Sullivan III, W.T., 2009. *Cosmic Noise. A History of Early Radio Astronomy*. Cambridge, Cambridge University Press.

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 Chair-man 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(2), 211–222 (2017).

THE TIME LIGHT SIGNALS OF NEW ZEALAND: YET ANOTHER WAY OF COMMUNICATING TIME IN THE PRE-WIRELESS ERA

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

Abstract: The signalling of exact time using an array of lights appears to have been unique to New Zealand. It was a simple and effective solution for calibration of marine chronometers when transmission of time signals by wireless was in its infancy. Three lights, coloured green, red and white, were arranged in a vertical array. They were switched on in a defined sequence during the evening and then extinguished together to signal exact time.

Time lights were first operated at the Dominion Observatory in Wellington during February 1912 and on the Ferry Building in Auckland during October 1915. The Wellington lights were immediately adjacent to the observatory buildings, but those in Auckland were operated using telegraph signals from Wellington. The timings varied over the years, but the same physical arrangement was retained at each location. The time light service was withdrawn during 1937, when wireless signals had become almost universally available for civil and navigation purposes.

Keywords: Time lights, time balls, New Zealand

1 INTRODUCTION

Time balls and to a lesser extent time guns were common means of publically-communicating time to ships' captains and the general population in the pre-wireless era. At one time or another, the British Admiralty recognized New Zealand time balls in the national capital Wellington, Lyttelton (the port near the city of Christchurch) and Port Chalmers (near the city of Dunedin). Other time balls and time guns had existed in New Zealand, notably in Auckland, but did not have the same official status (see Kinns 2017). In the course of researching New Zealand time balls, I discovered that time light signals were used in Wellington, from February 1912, and in Auckland, from October 1915 (for New Zealand localities mentioned in this paper see Figure 1).

On present evidence, these time light signals appear to have been unique to New Zealand. They provided an important service for calibration of marine chronometers, replacing time balls at both locations. The Wellington time ball apparatus had been destroyed by fire in March 1909. The time ball service at Auckland, reestablished in April 1915 using a new apparatus, had to be withdrawn after a few months because of its unreliability.

New Zealand time signals were controlled by the Dominion Observatory in Wellington. They included the time ball at Lyttelton (up to 1934) and transmissions by telegraph and wireless, as well as the time lights. The time light signals at Wellington and Auckland had both been withdrawn by the end of 1937, when wireless signals were in almost universal use.

The history of time ball provision at Wellington, Auckland, Lyttelton and Port Chalmers has been described, including photographs of the various time balls (Kinns, 2017). Since that paper was published, it has been possible to establish some dates of operation more precisely, using announcements in the *New Zealand Times*. These are included in the following brief histories of time ball provision at Wellington and Auckland, prior to introduction of time light signals there.

Figure 1: New Zealand localities mentioned in the text. The red spots mark locations where there were time balls. The time light signals discussed in this paper were located in Auckland and Wellington.

Full details of time signals for chronometer calibration were published annually for 1903 onwards (*New Zealand Nautical Almanacs*). They were usually prepared in October of the previous year, so did not necessarily include late changes. For example, the Lyttelton time ball service was terminated at the end of 1934, but was still noted in the 1935 *Almanac* with the following entry:

> At Lyttelton time-signals are supplied by dropping the time ball on the time ball tower at 4h., G.M.T. The ball is dropped by direct signal from the observatory at Wellington. The signal is made on Tuesdays and Fridays only,
>
> Owing to the absence of a return signal to the Dominion Observatory, the accuracy of the Lyttelton signal cannot always be relied upon. The note "Reported unreliable 1927" is to be added to the existing note concerning the time ball on the chart.

This was a repeat of entries in previous years. There was no Lyttelton entry in the 1936 *Almanac*.

Transcriptions from successive *New Zealand Nautical Almanacs* demonstrate changes in the sequences of time lights that were used between 1912 and 1937. Photographs and newspaper articles show how the lights were deployed and operated.

2 TIME BALLS IN WELLINGTON AND AUCKLAND

2.1 Time Balls in 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. It was installed at the Customs House. Accurate determination of longitude at the time ball and observatory locations was a particular challenge; the drop time was adjusted when improved estimates of longitude became available. Announcements of the time ball drop were published in the *New Zealand Times*, usually every one or two weeks. The ball was dropped daily with a local newspaper announcement when star transit observations had allowed increased precision for chronometer-rating purposes (*List of Time Signals*, 1880; extracts included in Kinns, 2017: 71). Otherwise, the drop was regulated using observatory clocks, with time extrapolated from preceding transit observations. The usual accuracy was better than one second. The service had to be withdrawn from time to time, when repairs became necessary.

The last notice of a time ball drop at the Customs House location was in February 1882, prior to a long period of waterfront redevelopment (Shipping, 28 February 1882):

> The time ball may be used to-day for rating chronometers. A chronometer true on Greenwich time would show 12h 30m when the ball drops. Any difference is error, plus or minus, of the chronometer.

After prolonged discussion that included the possibility of a time ball on Mount Victoria, re-erection of a time ball at a different harbour location was announced in November 1888. 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 (Kinns, 2017: 76). The first notice in the *New Zealand Times* concerning drop of the time ball at its new location at the head of Waterloo Quay was in January 1889 (Late Shipping, 21 January 1889):

> CHRONOMETER-RATING NOTICE. The time-ball may be used to-day for rating chronometers. The ball will drop precisely at noon, New Zealand mean time, equivalent to 11hr 30min Greenwich mean time. Any difference on 11hr 30min shown by a chronometer at the moment of the signal will be the error, plus or minus, of the chronometer. Colonial Observatory, Wellington.

This notice followed star transit observations and did not mention that it was a new time ball service, so the ball may have been in use for some time before that. The newspaper announcement was usually repeated every one or two weeks. The early notices stated that noon, New Zealand time was equivalent to 11hr 30min, Greenwich Mean Time. This should have been 12hr 30min, Greenwich Mean Time (0.30 am at Greenwich on the same day as the NZ signal). At that time, GMT was based on noon at Greenwich for astronomical purposes.

The incorrect notice re-appeared on several occasions, but was corrected during April (Late Shipping, 13 April 1889):

> COLONIAL OBSERVATORY. Chronometer-rating Notice.
> The time-ball may be used to-day for rating chronometers. The ball will drop at noon precisely, at which hour a chronometer set to Greenwich Mean Time should show 12h. 30m. Any difference will be the error of the chronometer, fast or slow on Greenwich Mean Time. T. KING, Observer. Colonial Museum, Wellington.

The apparatus was destroyed by fire in March 1909. Tenders for a new system were obtained from various potential suppliers in England, but the time ball was never replaced (Kinns, 2017: 78). Instead, time lights were introduced in February 1912.

2.2 Time Balls in 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. Various proposals to establish a service for mariners were made from 1874 onwards, but foundered through lack of budgetary provision for the necessary apparatus and skilled staff, as well as problems in finding a suitable location in a rapidly growing city. A time ball was finally installed on the Harbour Board building in 1901 and started operation in September, with the following announcement (Time Ball, 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.

The signal was unreliable and the service was withdrawn in 1902. Complaints from ships' masters led to various attempts to re-establish a service (Kinns, 2017: 88). These included unsuccessful modifications to the external dropping arrangement. Finally, another time ball was erected on the new Ferry Building in 1912, but the service only started in April 1915, again proved to be unreliable and was soon discontinued. The time ball was replaced by time lights in October 1915.

3 TIME LIGHT SIGNAL ENTRIES IN *NEW ZEALAND NAUTICAL ALMANACS*

The first specific entry concerning time light signals is believed to have been in the 1913 *Almanac* (not seen by the author), although their introduction had been heralded in the previous edition (1912 *Almanac*: 209).

The entry for Wellington in the 1914 *Almanac*, published in October 1913, is transcribed below. It is similar to a newspaper announcement in February 1912 (Ships and Shipping, 22 February 1912), suggesting that the timings of individual lights had not been altered between February 1912 and October 1913.

3.1 Entry for Wellington in the 1914 Edition

> **Time-signal and General Service Arrangements**. - There is an astronomical observatory at Wellington on Battery Hill, in the Botanical Gardens, 418ft. above sea level, in latitude 41° 17′ 3.76″ S. and longitude 174° 46′ 4.0″ E. = 11h. 39m. 4.27s. From the tower of this observatory a time-signal by electric lights has been established.
>
> At 1 p.m. on chronometer rating-days a galvanometer signal for rating chronometers is sent from the observatory to the Public Telegraph Office, Customhouse Quay, Wellington, and to the Dominion Museum, Wellington. The needle moves at 1 p.m. exactly of New Zealand standard mean time, when a chronometer set to Greenwich mean time should show 13h. 30m. Anydifference will be the error of the chronometer at Greenwich mean time.
>
> At 9 p.m. on chronometer rating-days correct time is also signalled from the observatory by means of electric lights. A *green* light is switched on at about 8.45 p.m., a *red* one at about 8.55 p.m. and a *white* one at about 8.59 p.m., and all the lights are switched off at 9 p.m. exactly of New Zealand standard mean time. The preparatory switching-on of the lights must be considered as only approximately correct, and must not be used for rating chronometers. The correct time for rating is given by switching-off the lights simultaneously at 9 p.m. The lights are now shown from a flagstaff in a vertical line one over the other; the lower light *green*, middle light *red*, and upper light *white*.

3.2 Entry for Wellington in the 1915 Edition

The following text is taken from the 1915 *Almanac*. At the time of publication in October 1914, it was anticipated that a new time ball service would be operating in Auckland during 1915. The Wellington time light signals were now being repeated on four successive hours from 8 pm to 11 pm. Also, the switching on of the individual lights had been changed from 15, 5, 1 minutes to 50, 10, 5 minutes before the hour:

> **Time Service.** – 1. *Accurate Time Signals*. – On days when accurate time signals are given, the flag T of the international code will be hoisted on the Observatory flagstaff about midday.
>
> (a.) When the flag is flying, chronometers may be compared with a galvanometer in the public telegraph office, Featherstone Street. The galvanometer is controlled by the Observatory clock, and is deflected every hour of New Zealand mean time.
>
> (b.) Time signals are given by three vertical electric lights erected on the Observatory flagstaff. The bottom light is *green*, and is 30 ft. above the ground; the middle light is *red*, and is 36 ft. above the ground; the top light is *white*, and is 42 ft. above the ground.
>
> The green light is shown at 50 minutes, the red light at 10 minutes and the white light at 5 minutes to the hour; all three lights are extinguished simultaneously at the hour. The switching-on of the lights must be considered as only approximately correct; the correct time is given by switching off the three lights. This signal is given at 8, 9, 10 and 11 p.m. of New Zealand mean time.
>
> The corresponding Greenwich mean time and New Zealand civil mean time of these signals are as under:-

	G.M.T.				N.Z.C.M.T				
	H.	M.	S.		H.	M.	S.		
Green light switched on	19	40	0		7	10	0	p.m.	*
Red light switched on	20	20	0		7	50	0	"	*
White light switched on	20	25	0		7	55	0	"	*
All lights switched out	20	30	0		8	0	0	"	†
	* Approximate				† Time signal				

> And similarly at each succeeding hour until 23 h. 30m. G.M.T.
> N.Z.M.T. 11h. 0m. 0s.

3.3 Entries in the 1916 Edition

The time light service for Auckland was operational by the end of 1915 and was included in the 1916 edition. The separate entries for Auckland (1916 *Almanac*: 255) and Wellington (1916 *Almanac*: 291-292) are transcribed below. In 1916, the Wellington time light signals were advanced by one hour, so the time was now signalled at 7, 8, 9 and 10 pm. The time was signalled in Auckland at 9 pm only. The basic arrangement of lights was the same at both locations: three lights at 6ft. intervals; green lowest, red middle, white top. The lights were switched on at 50, 10 and 5 minutes before the hour, as at Wellington from 1915.

3.3.1 Entry for Auckland

> **Time Signals**. – 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.
> On those days when such signals are to be given, a red flag will be hoisted on the tower of the Ferry Buildings from 4 p.m. to 4.30 p.m.
> The following lights will be used on the flagstaff of the Ferry Buildings when such signals are given:-
>
> Green light switched on 8.10 p.m.
> Red light switched on 8.50 p.m.
> White light switched on at 8.55 p.m.
>
> All lights switched off 9 p.m. – 21h. 30m. 0s. G.M.T. These lights will be in a vertical line, 6 ft. apart, the green light being the lowest.

3.3.2 Entry for Wellington

> **Time Service.** – 1. *Accurate Time Signals*. – On days when accurate time signals are given, the flag T of the international code will be hoisted on the Observatory flagstaff about midday.
> (a.) When the flag is flying, chronometers may be compared with a galvanometer in the public telegraph office, Featherstone Street. The galvanometer is controlled by the Observatory clock, and is deflected every hour of New Zealand mean time.
> (b.) Time signals are given by three vertical electric lights erected on the Observatory flagstaff. The bottom light is green, and is 30 ft. above the ground; the middle light is red, and is 36 ft. above the ground; the top light is white, and is 42 ft. above the ground.
> The green light is shown at 50 minutes, the red light at 10 minutes and the white light at 5 minutes to the hour; all three lights are extinguished simultaneously at the hour. The switching-on of the lights must be considered as only approximately correct; the correct time is given by switching off the three lights. This signal is given at 7, 8, 9 and 10 p.m. of New Zealand mean time.
>
> The corresponding Greenwich mean time and New Zealand civil mean time of these signals are as under:-

	G.M.T.				N.Z.C.M.T				
	H.	M.	S.		H.	M.	S.		
Green light switched on	18	40	0		6	10	0	p.m.	*
Red light switched on	19	20	0		6	50	0	"	*
White light switched on	19	25	0		6	55	0	"	*
All lights switched out	19	30	0		7	0	0	"	†
	* Approximate				† Time signal				

> And similarly at each succeeding hour until 22 h. 30m. G.M.T.
> N.Z.M.T. 10h. 0m. 0s.
>
> *Approximate Time Signals*. – When owing to bad weather or other causes accurate time signals cannot be given, approximate ones will be given; but in these cases the flag will not be hoisted and the *green* light will not be shown. On application to the Observatory the error of these signals can usually be obtained.

3.4 Entries in the 1917 Edition

Entries in the 1917 edition were essentially the same as in 1916. The entry for Auckland included an additional statement:

> When the Time Signal is expected, but does not come through, the red light will remain burning till 9h. 5m. p.m., thereby notifying shipping that the signal has not been received.

3.5 Entries in the 1918 Edition

The entries in the 1918 *Almanac* were similar to those in 1916 and 1917, but timings at Auckland had been brought forward by 30 minutes. The signal sequence at Wellington was now given three times at 7.30, 8.30 and 9.30 pm, rather than four times at 7, 8, 9 and 10 pm. NZMT.

3.5.1 Entry for Auckland

> The following lights will be used on the flagstaff of the Ferry Buildings when such signals are given:-
>
> Green light switched on 7.40 p.m.
> Red light switched on 8.20 p.m.
> White light switched on at 8.25 p.m.
>
> All lights switched off 8.30 p.m. – 21h. 0m. 0s. G.M.T. These lights will be in a vertical line, 6 ft. apart, the *green* light being the lowest.
> When the Time Signal is expected, but does not come through, the red light will remain burning till 8h. 35m. p.m., thereby notifying shipping that the signal has not been received.

3.5.2 Entry for Wellington

> The green light is shown at 50 minutes, the red light at 10 minutes and the white light at 5 minutes to the hour; all three lights are extinguished simultaneously at the hour. The switching-on of the lights must be considered as only approximately correct; the correct time is given by switching off the three lights. This signal is given at 7.30, 8.30, 9.30 p.m. of New Zealand mean time.

> The corresponding Greenwich mean time and New Zealand civil mean time of these signals are as under:-
>
> | | G.M.T. | | | | N.Z.C.M.T | | | | |
> |---|---|---|---|---|---|---|---|---|---|
> | | H. | M. | S. | | H. | M. | S. | | |
> | *Green* light switched on | 19 | 10 | 0 | | 6 | 40 | 0 | p.m. | * |
> | *Red* light switched on | 19 | 50 | 0 | | 7 | 20 | 0 | " | * |
> | *White* light switched on | 19 | 55 | 0 | | 7 | 25 | 0 | " | * |
> | All lights switched out | 20 | 0 | 0 | | 7 | 30 | 0 | " | † |
> | | * Approximate | | | | † Time signal | | | | |
>
> The signal is repeated at 21 hours and 22 hours G.M.T. corresponding to 8.30 and 9.30 p.m. N.Z.M.T.

3.6 Entries in the 1928 Edition

By 1928 the signal was no longer repeated on successive hours (1928 *Almanac*: 131). Also, there was a clear distinction at Wellington between days when the signal was supervised personally and when it was automatic. The lights were now being switched on at 20, 10 and 5 minutes before the signal at 8.30 pm New Zealand mean time. GMT had been rebased to midnight for all purposes on 1 January 1925, so that NZMT was now 11h. 30m. ahead of GMT.

> CHRONOMETER RATING TIME-SIGNALS
> BY LIGHTS.
>
> System. – Three lights, vertically disposed six feet apart, green below, white above and red between. The green shows 20 mins, the red 10 mins, and the white 5 mins before the signal. Simultaneous extinction of all lights at 8.30 pm N.Z.T. (09 00 00 G.M.T.) is the time-signal. Supplied every Tuesday and Friday evening.
>
> Auckland. – From flagstaff atop Ferry Buildings. Should telegraphic transmission from Wellington fail, the red light will continue until 8.35 pm. (This time-signal is considered unreliable.)
>
> Wellington. – From Observatory flagstaff. Modified signals, without the green light and not under personal supervision, are supplied on Monday, Wednesday and Thursday evenings.

3.7 Entries in the 1933 to 1936 Editions

Entries in the 1933 to 1936 editions were identical, but showed changes in the timing sequence from earlier years. The lighting sequence was 50, 10 and 5 minutes before the signal at Auckland, but 20, 10 and 5 minutes at Wellington. The entry concerning time lights is shown below.

> TIME-SIGNALS BY LIGHTS.
>
> AUCKLAND.
>
> At Auckland time-signals are supplied from the flagstaff on the Ferry Buildings by extinguishing three electric lights at 9h., G.M.T. The lights are shown vertically, 6 ft. apart, white uppermost, red in the centre, and green below. The green light is shown 50 minutes, the red 10 minutes, and the white 5 minutes before the signal. Simultaneous extinction of the lights at 9h., G.M.T. is the time-signal. Should the signal fail, the red light will continue burning until 9h, 05m., G.M.T.
>
> The lights are extinguished by direct signal from the Observatory, Wellington, on Tuesdays and Fridays.
>
> WELLINGTON.
>
> At Wellington time-signals are supplied from the flagstaff at the Dominion Observatory, 416 ft. above mean sea level, by extinguishing three electric lights at 9h., G.M.T. The lights are shown vertically, 6 ft. apart, with white uppermost, 42 ft. above the ground, red in the centre and green below. The green light is shown 20 minutes, the red 10 minutes and the white 5 minutes before the signal. Simultaneous extinction of the lights at 9h., G.M.T. is the time-signal. The green light is used only on Tuesdays and Fridays. On the other nights of the week the signals are not personally supervised and the green light is not used.
>
> On New Zealand Government holidays the green light is not used.

3.8 Final Entries in the 1937 Edition

The final entries concerning time light signals were in 1937 (1937 *Almanac*: 130). A note was added to the 1936 entry to confirm that delay in the telegraph signal to Auckland was very small. The green light was no longer used at Wellington and the service was now fully automated; occasional signal failures were anticipated. The additional entries were:

> AUCKLAND.
>
> … The lights are extinguished by direct signal from the Observatory, Wellington, on Tuesdays and Fridays. Tests recently carried out by the Auckland Harbour Board indicate that the time taken by the telegraph signal operating the lights to reach Auckland from Wellington is less than one-tenth of a second.
>
> WELLINGTON.
>
> … The lights are *white* and *red*, shown vertically, 6 ft. apart, with *white* uppermost, 42 ft. above the ground. The *red* light is shown 10 minutes and the *white* 5 minutes before the signal. Simultaneous extinction of the lights at 9h., G.M.T. is the time-signal. The lights are operated automatically, but as they are not supervised, failures sometimes occur through unforeseen causes.

There were no entries concerning time lights in the 1938 *Almanac*, confirming that the service had been terminated during 1937.

4 WELLINGTON TIME LIGHTS

4.1 First Announcement

The first announcement including time light signals at Wellington appears to have been published in the *New Zealand Times* (Ships and Shipping, 22 February 1912). Earlier announcements in 1912 concerned galvanometer signals only (Ships and Shipping, 5 January 1912, for example). The February announcement is transcribed below.

> HECTOR OBSERVATORY, WELLINGTON. Latitude 41deg 17min 3.76sec south. Longitude 11hr 39min 4.27sec east of Greenwich. Height above 1909 mean sea level, 418 feet. CHRONOMETER RATING NOTICE. At 1 p.m. to-day a galvanometer signal for rating chronometers will be sent from the Observatory to the Public Telegraph Office, and to the Dominion Museum. The needle will move at 1 p.m. exactly of New Zealand standard mean time, when a chronometer set to Greenwich mean time should show 13hr 30min. Any difference will be the error of the chronometer on Greenwich mean time. At 9 p.m. correct time will also be signalled from the Observatory by means of electric lights. A green light will be switched on at about 8.45 p.m., a red one at about 8.55 p.m., and a white one at about 8.59 p.m., and all lights will be switched off at 9 p.m. exactly of New Zealand standard mean time. The preparatory switching on of the lights must be considered as only approx.-imately correct, and must not be used for rating chronometers. The correct time for rating will be given by switching off the lights simultaneously at 9 p.m. C.E. ADAMS, Government Astronomer.

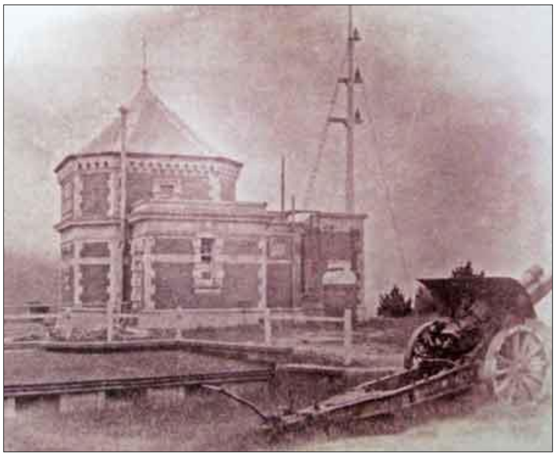


Figure 2: Dominion Observatory, about 1920 (courtesy: Friends of the Wellington Botanic Garden).

4.2 Wellington Time Light Article

A comprehensive article about time signals was published in the *Evening Post* (Correct Time, 9 July 1921). It included a brief description of how the time light signals in Auckland were operated from Wellington. The tenor of the article is illustrated by the following extracts:

> Beside the Observatory near the Kelburn tramway power-house there is a pole, on which in the evening lights shine out, and at times are suddenly extinguished. The curious and uninformed wonder what they are for; shrewder folk set their watches by them and become qualified to criticise the town clocks. The lights are time-signals, operated from carefully guarded clocks in the Observatory, and their chief duty is not to rectify watches in the city, but to help mariners ...
>
> The heart of the system is a small telescope on horizontal supports, which enable it to be aimed up or down, but not sideways. The axis is placed east and west, so that the telescope always points to the meridian. It enables its user to observe exactly when any star crosses the meridian, and carefully prepared tables are available showing the times when various stars are in that position ... The determination of the time by “observing the meridian passage” is only accurate if the mounting of the telescope, which stands on a concrete base, is faultless; but it hardly ever is. Once in a while the axis on which the telescope turns, may be truly east and west or truly level, but its position is always changing slightly through the elasticity of the earth’s crust and the effects of solar heat, tidal strains, and other causes. Consequently, though a very little time is needed to make an observation, a much longer time must be spent on each occasion in carefully checking the accuracy of the mounting so as to find the error of the instrument ...
>
> This article opened with a reference to the time signals and it may close with an explanation of them, and a reference to the latest addition to the time service, the wireless signal. There are three lights in the visual signal, the lowest green, the next red, and the top white. At 50 minutes before the hour to be signalled, the green light is turned on; at 10 minutes to the hour, the red one is lit; and at 5 minutes to the hour, the white one. These times are close enough for ordinary clock-setting purposes, but the three go out together as nearly as possible on the exact stroke of the hour and it is the extinction that constitutes the marine time signal. The signal is given each evening unless the clocks are believed to be too inaccurate for the work, and then the signal is given without the use of the green light. Three signals are made – one at 7.30 p.m., one at 8.30, and one at 9.30, corresponding exactly to 8 a.m., 9 a.m., and 10 a.m., Greenwich time. Just before the “9 a.m.” signal is sent on Tuesdays and Fridays, a telegraph line to Auckland is cleared of traffic, and an electrical impulse from the observatory puts out a set of signal lights on the Ferry Building.

4.3 Wellington Time Light Photographs

Figure 2 shows the arrangement of time lights at Wellington, on a mast next to the Dominion Observatory buildings. The photograph was published in about 1920 and was included in a comprehensive article about the history of structures in Wellington Botanic Garden (Tomlinson, 2015). Tomlinson also described earlier observatory buildings and apparatus, including photographs of the transit telescope that had been located near the first time ball in 1864.

Recently, the early history of Wellington astronomy has been explored in depth (Orchiston, 2016a, 2016b). The Dominion Observatory, known until 1925 as the Hector Observatory, was built in Wellington Botanic Garden during 1907. The photograph was certainly taken before 1926, when the building was extended. A cropped version of the same photograph was included in a factsheet about the observatory (Dominion Observatory, 2007).

The photograph in Figure 3 also preceded building redevelopment and was taken in about 1925. A low-definition image accompanied a lengthy article in the *Evening Post* about operation of the Dominion Observatory (In Starry Skies, 27 December 1930). The original photograph has not been found, but the extended buildings are obvious. The article included comment about the time light signals:

> At the Observatory, there is a mast with coloured lights arranged vertically, green (bottom), red, white (top). On Tuesday and Friday nights these are all lit up and are extinguished by means of the clock at 9 hours G.M.T. On other nights only the red and white lights are visible before extinction.

Figure 4 shows an unusually clear image of the lights themselves, with the newly completed Meteorological Office in the foreground (*Evening Post* original photographic prints and postcards). The photograph was taken during 1930. The physical arrangement of lights appears to be unchanged from earlier images.

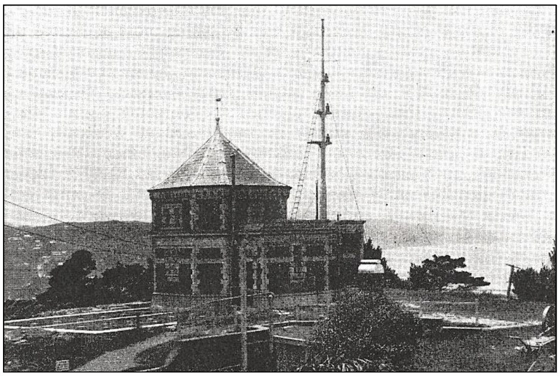


Figure 3: Dominion Observatory, circa 1925 (*courtesy* Geophysics Division, DSIR)

Figure 5 shows the layout of the Dominion Observatory buildings and time lights in 1935, from a different aspect. This is a detail from an aerial view of Kelburn and Wellington Botanic Garden. The Meteorological Office building is in the foreground.

Figure 4: Detail from a 1930 photograph showing the time lights and part of the Dominion Observatory (courtesy: Evening Post Collection, Alexander Turnbull Library, Wellington, EP-2845-1/2-G).

Figure 5: The upper Botanic Garden, circa 1935 (courtesy: Alexander Turnbull Library, Wellington, PAColl-5927-32).

5 AUCKLAND TIME LIGHTS

5.1 The Change from a Time Ball to Time Lights

The following notice was published in the *Auckland Star* on 17 August 1915 (Time Signals: a New Proposal):

> 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.

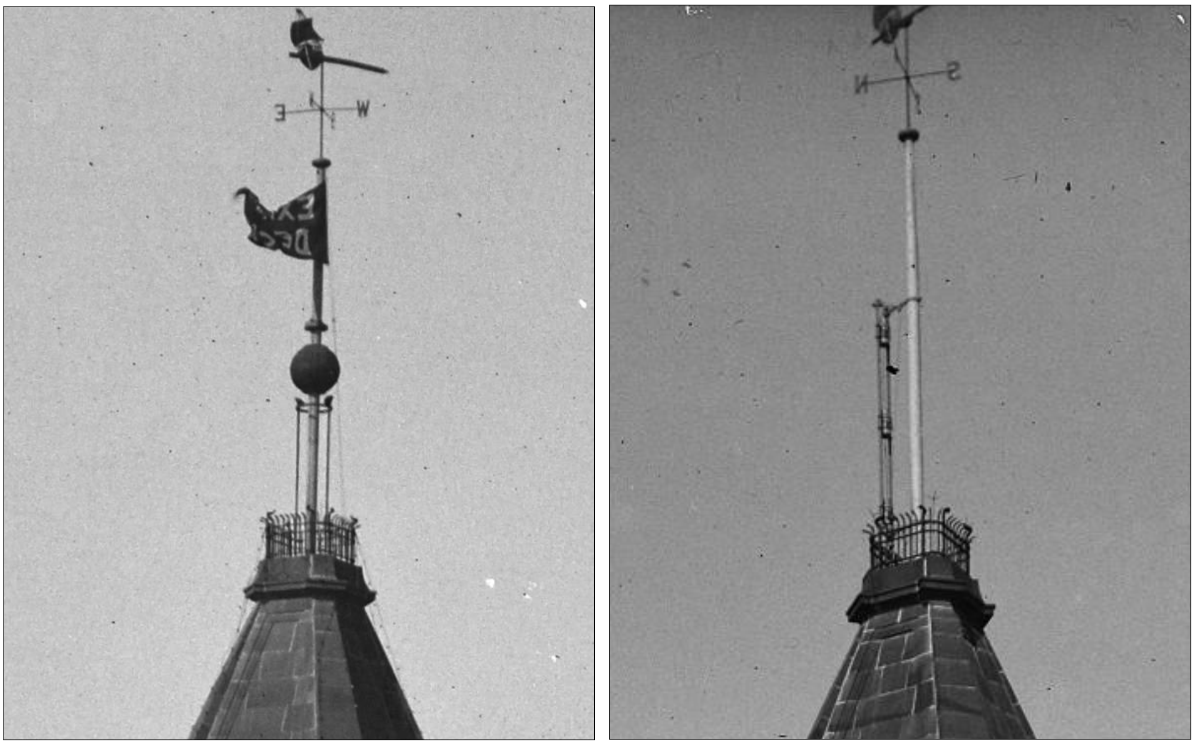


Figure 6: Time signals on the Ferry Building: (a) time ball, 8 April 1913; (b) time lights, 29 December 1915.

5.2 Auckland Time Light Photographs

Figure 6(a) shows the time ball on the Ferry Building, resting on supports while the building awaited installation of the clock (The Auckland Ferry Building on 8 April 1913, detail). Figure 6(b) shows the time lights at the end of 1915; they were attached to the mast that had previously been used to support the time ball (The Auckland Ferry Building on 29 December 1915, detail). The same arrangement of lights can be seen in photographs of the Ferry Building up to 1937.

Figure 7 shows a 1923 photograph by Henry Winkelmann of the Ferry Building, with time lights in place, and the turreted Harbour Board Building on the opposite side of the road to the right. The Ferry Building remains an important Auckland landmark, but the Harbour Board building, which supported the 1901 time ball, was later demolished to make way for new building development.

5.3 Announcements in 1937

An article was published in the *New Zealand Herald*, anticipating withdrawal of the Auckland time light service on 31 July 1937 (Visual Time Signals, 23 June 1937). It was actually decided to continue the service for another three months and it operated for the last time on 29 October, when the article was reprinted in a modified form (Visual Time Signals, 29 October 1937).

Both newspaper articles contained a number of significant errors concerning time ball provision at Auckland, suggesting that other details may not be reliable. They stated that lights in 1937 had been switched on at 45, 30 and 15 minutes before the signal at 8.30 pm. This contradicted the 1937 *Almanac* which stated that the lights in Auckland were switched on at 50, 10 and 5 minutes before the signal at 09.00 GMT (8.30 pm NZMT). The second *New Zealand Herald* article is transcribed below.

> Dating back to the early days of Auckland shipping - with one break of 15 years [*sic*] - visual Greenwich mean time signals on the waterfront, made for the purpose of enabling ships' navigators to compare their chronometers with Greenwich time, will operate for the last time this evening. The apparatus, located on the staff of the Ferry Building since 1915, has been displaced by the general use of wireless time signals.
>
> Since October 1, 1915, a system of electric lights on the staff on the Ferry Building tower, operated from the Dominion Observatory, Wellington, has given visual time signals to shipping at Auckland on Tuesday and Friday nights. After a red flag in the day has indicated that observations have been taken a green light appears on the staff at 8.15 p.m., New Zealand summer time, which corresponds to 8.15 a.m., Greenwich mean time. The green light is followed by the appearance at 15-minute intervals of a red and a white light, and the three lights show for a further 15 minutes [*sic*]. The instant at which they disappear indicates 9 a.m. at Greenwich, or 9 p.m., New Zealand summer time. From the early days of the port until 1900 [*sic*] a ball dropped on a staff on the

Figure 7: Looking south east from Princes Wharf 22 December 1923, showing the Ferry Building on the left (courtesy: Sir George Grey Special Collections, Auckland Libraries, W614).

> Auckland Harbour Board building served as a time signal. The signal was discontinued from 1900 until January, 1915 [*sic*], when the ball was used on the Ferry Building tower, being dropped daily at 1 p.m. The present electric light system was substituted in the following October. Although the ball and light signals with their visibility over a considerable distance, formed a very practical aid to mariners for adjustment of chronometers, the frequent radio time signals have naturally been found more convenient.

5.3.1 Errors in 1937 Announcements

The following summary of errors has been derived by comparing statements in the 1937 announcements with the known history of Auckland time balls (Kinns, 2017).

(1) A time ball was installed on the Harbour Board Building during 1901 and became operational during September 1901. There was no time ball on that building during the nineteenth century. Unofficial time balls had existed in Auckland from 1864, but they did not provide an official service for chronometer calibration.

(2) The ball on the Harbour Board building ceased to provide an official time signal in August 1902, because the service was unreliable. Various attempts were made to re-establish time ball operation, which included modifications to the dropping arrangement, but they were unsuccessful.

(3) There was no official time ball service in Auckland from August 1902 until April 1915, a gap of about 13 years. A new time ball, with a different drop arrangement, had been installed on the new Ferry Building in 1912, but various technical and management problems meant that announcement of the new service was delayed until April 1915. The new service again proved to be unreliable and it was abandoned in favour of a time light service.

6 CONCLUSIONS

The signalling of exact time using an array of lights appears to have been unique to New Zealand. It was a simple and effective solution for calibration of marine chronometers when transmission of time signals by wireless was in its infancy.

Time lights were operational at the Dominion Observatory in Wellington during February 1912 and on the Ferry Building in Auckland during October 1915. The Auckland lights were a direct replacement for an unreliable time ball, but the last time ball in Wellington had been destroyed by fire in March 1909, almost three years before the time lights became operational. During the intervening period, galvanometer signals were provided for calibration of marine chronometers. The Wellington lights were immediately adjacent to the main observatory buildings, but those in Auckland were operated using telegraph signals from Wellington. The time light service was withdrawn during 1937, when wireless signals had become almost universally available for civil and navigation purposes; other signal arrangements had been rendered obsolete.

An array of three lights, spaced by 1.8m (6ft.), was used at both locations. The physical arrangement of lights remained unchanged until the signals were withdrawn in 1937. The uppermost light was white, the middle light was red and the lowest was green. The green light was illuminated first, followed by the red light and finally the white light. They were then switched off simultaneously at the designated signal time. It was always emphasized that the times for switching on were approximate and that extinguishing of lights was the actual signal.

During the early years, the whole sequence at Wellington was repeated at hourly intervals during the evening, but this was simplified later to one sequence only. Specific signals were provided to indicate that the control clocks at Wellington had been calibrated using recent star transit observations, so that the time light signal provided the highest possible accuracy for chronometer rating. Developments and changes between 1912 and 1937 have been traced by reference to different editions of the *New Zealand Nautical Almanac* and newspaper announcements.

7 ACKNOWLEDGEMENTS

I am most grateful for generous support from library staff in Wellington and Auckland. Daryll Pike and Danielle Carter kindly provided extracts from nautical almanacs held by the Bill Laxon Library at the National Maritime Museum in Auckland. Ayla Koning-Thornton, Jenni Chrisstoffels and Diana McRae helped greatly in providing additional extracts and links to related articles and photographs at the Alexander Turnbull Library in Wellington. Phil Tomlinson, a senior guide at Wellington Botanic Garden and author of articles concerning observatory buildings there, provided important background information.

8 REFERENCES

Correct time: the signal service, clocks on Kelburn Hill. *Evening Post*, 9 July 1921, page 5.

Dominion Observatory. Factsheet published by the Department of Conservation, Te Papa Atawhai, 2007. http://www.doc.govt.nz/documents/conservation/historic/byregion/wellington/dominion-observatory-factsheet-2007.pdf

Evening Post original photographic prints and postcards, from file print collection, Box 2. Evening post (Newspaper. 1865-2002): Photographic negatives and prints of the Evening Post newspaper (PA-Group-00287). Alexander Turnbull Library, Wellington, New Zealand (PAColl-5927-32). https://natlib.govt.nz/records/22688174

In starry skies. *Evening Post*, 27 December 1930, page 22.

Kinns, R., 2017, The principal time balls of New Zealand. *Journal of Astronomical History and Heritage*, 20, 69–94. http://www.narit.or.th/en/files/2017JAHHvol20/

Late shipping. *New Zealand Times,* 21 January 1889, page 4.

Late shipping. *New Zealand Times,* 13 April 1889, page 4.

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).

New Zealand Nautical Almanac and Tide-Tables, and Information concerning the Principal Ports of New Zealand. Wellington, Government Printer. Published annually. Editions seen by the author are for 1903 (1st edition), 1905, 1906, 1907, 1908, 1910, 1912, 1914, 1915, 1916, 1917, 1918, 1928, 1933, 1934, 1935, 1936, 1937 and 1938.

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*, 47, 88–93, 2016. Available on-line: http://www.tandfonline.com/toc/tnzr20/47/1

Shipping. *New Zealand Times*, 28 February 1882, page 2.

Ships and shipping. *New Zealand Times,* 22 January 1912, Page 8.

The Auckland Ferry Building on 8 April 1913. Auckland Libraries, Sir George Grey Special Collections, 1-W1555.

The Auckland Ferry Building on 29 December 1915. Auckland Libraries, Sir George Grey Special Collections, 1-W01321.

Time ball. *Auckland Star*, 7 September 1901, page 8.

Time signals: a new proposal. *Auckland Star*, 17 August 1915, page 4.

Tomlinson, P.C., 2015. *Structures in the Garden: Wellington, New Zealand Observatories*. Wellington, Friends of the Wellington Botanic Garden.http://www.friendswbg.org.nz/newobservatories.html

Visual time signals: shipping facility system to be abandoned. *New Zealand Herald*, 23 June

1937, page 14.
Visual time signals: shipping facility system to be abandoned; last service tonight. *New Zealand Herald*, 29 October 1937, page 12.

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 M.A.Sc. degree in control engineering at the University of Waterloo, Ontario, before returning to Cambridge to complete a Ph.D. 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(2), 223–253 (2017).

A TALE OF TWO TELESCOPES: NORTH QUEENSLAND AND THE 1882 TRANSIT OF VENUS

Wayne Orchiston
National Astronomical Research Institute of Thailand, 260 Moo 4,
T. Donkaew, A. Maerim, Chiang Mai 50180, Thailand.
Email: wayne.orchiston@narit.or.th

and

Vicki Darlington
College of Science, Technology and Engineering, James Cook University,
Townsville, Queensland 4811, Australia.
Email: vicki.darlington@jcu.edu.au

Abstract: The 1882 transit of Venus offered the final opportunity for astronomers to use these rare events to pin down the distance from the Earth to the Sun. A British party based itself in southern Queensland, but total cloud cover prevented any observations being made on the critical day. In this paper we trace the preparations of the British party, and then show how they laid the foundations for the development of astronomy in Queensland by selling their two 6-in Cooke refractors before returning to Britain. Both instruments were purchased by a Townsville amateur astronomer, Edwin Norris, and although he installed one in an observatory, he made little use of it. However, he subsequently sold the other telescope to J. Ewen Davidson of Mackay, who also erected an observatory for it. Davidson then used his instrument for cometary astronomy, in the process discovering two new comets, one of which now bears his name. Unfortunately, recent attempts to track down the present whereabouts of the two telescopes have failed.

Keywords: 1882 transit of Venus, British transit team, Jimbour, Townsville, Edwin Norris, The Strand Observatory, Mackay, J. Ewen Davidson, Branscombe Observatory, Charles Sydney Norris

1 INTRODUCTION

The 7 December 1882 transits of Venus would offer astronomers their last chance to use these rare events to try and determine a value for the astronomical unit (Cottam and Orchiston, 2014; Cottam et al., 2012). To plan for this transit an international conference was held in Paris, from 5 to 13 October 1881. The British Delegate, Edward J. Stone from the Royal Greenwich Observatory, reported that Britain would establish transit stations in Bermuda, Jamaica, Barbados, the Cape Colony (3), Madagascar, New Zealand and the Falkland Islands. The conference also discussed the equipment to be used and the nature of observations to be made (The transit of Venus in 1882, 1882; W.H.M.C., 1882). Subsequently, the British decided to discard the Falkland Islands as an observing site (because of the multiple observations expected by American astronomers observing on home soil at similar longitudes), and Brisbane, Australia, was selected as a substitute (Argyll et al., 1882). This would not have been an easy choice for—weather permitting—the entire transit could be viewed from the Falklands whereas only the egress contacts would be visible from Brisbane (see Figure 1). New Zealand and South Africa also offered possible observing sites in the Southern Hemisphere and were part of the British Empire, but—as for Brisbane—only part of the transit would be visible (the ingress from South Africa and the egress from New Zealand).

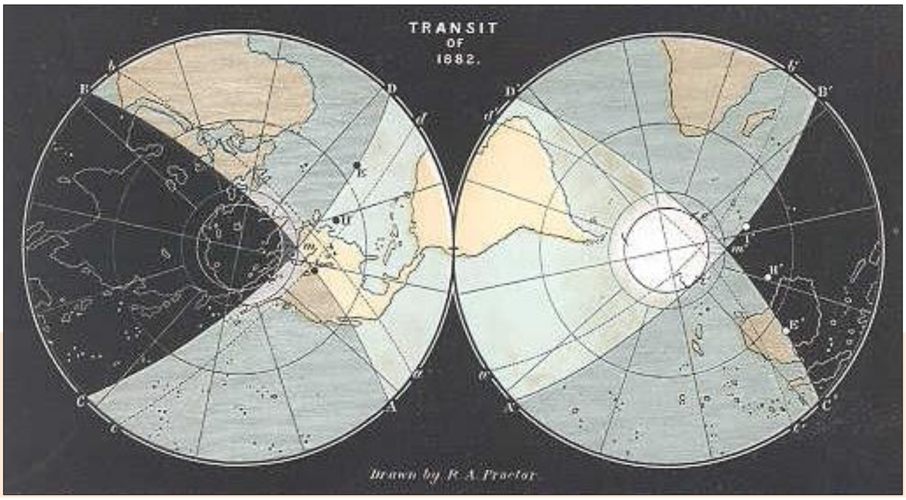


Figure 1: Visibility of the 1882 transit of Venus. The entire transit would be visible from those areas in pale blue and only a part of the transit in those dark blue areas (after Proctor, 1874: Plate VII).

As documented in Orchiston (2004b), the 1874 transit inspired a major Australian enterprise, with observations contributed by three of the colonial observatories, numerous amateur astronomers, and two U.S. transit parties based in Tasmania. Unfortunately, in 1882 only the egress of the transit would be visible from Australia, but even then only from the eastern half of the continent (see Figure 1), yet this did not deter the Adelaide, Melbourne and Sydney Observatories from planning elaborate transit campaigns (Baracchi, 1914), and again using photography as their primary investigative tool (despite concerns expressed following the 1874 transit—see Lankford, 1987). Some of the nation's leading amateur astronomers also planned to make observations, as did the aforementioned British transit party, which ended up in Jimbour, Queensland, rather than in Brisbane. Unfortunately, many hopes were dashed on the vital day when cloudy skies prevented observations being made, and this fate also befell the British visitors at Jimbour.

Successful Australian observations of the 1882 transit have already been reviewed by Orchiston (2004b), so in this paper we will focus on the British transit expedition, the only substantial campaign associated with the colony of Queensland, albeit an abortive one. We will then track two of the telescopes that belonged to that transit party, which were acquired by a Townsville amateur astronomer named Edwin Norris, with one telescope subsequently passing to J. Ewen Davidson, an accomplished cometary astronomy who lived near Mackay. So although from a Queensland and British perspective the 1882 transit itself may have been a disaster and a terrible waste of time and money, it had a fortunate sequel as it would unwittingly play a key role in the subsequent development of astronomy in North Queensland.

2 QUEENSLAND AND THE BRITISH 1882 TRANSIT EXPEDITION

2.1 From Britain to Jimbour

The British delegation sent to Queensland for the 7 December 1882 transit of Venus was sponsored by the Royal Geographical Society, and comprised Captain William George Morris (1847–1935; Plug, 2014), Lieutenant Leonard Darwin (1850–1943; Edwards, 2004), the fourth son of the celebrated Charles Darwin, and 'Gunner' Bailey, all from the Royal Engineers. Joining the official observers were two independent self-funded observers, amateur astronomer Cuthbert (later Sir Cuthbert) Edgar Peek (1855–1901; Grover, 1901; Hollis, 1912) and his assistant Charles Grover (1842–1921; Slater, 2005). All five members of the transit party are shown below in Figure 2.

Figure 2: The British transit party posing at Jimbour House. From left to right are Cuthbert Peek, Charles Grover, Captain Morris, Gunner Bailey and Leonard Darwin (courtesy: John Oxley Library, State Library of Queensland).

The transit party arrived in Brisbane on 26 October 1882 (*The Brisbane Courier*, 1882), six weeks before the transit, and Morris' initial task was to select a suitable site for their observations. Although Brisbane was their intended destination, in order to increase the chance of clear skies on the vital day and facilitate evening observations (for the determination of latitude) he chose to move from coastal hazy, smoggy Brisbane and go inland to Jimbour in the fertile, sunny Darling Downs west of Brisbane (see Figure 3). While Jimbour was not deemed completely ideal because of the low altitude of the Sun at the start of the transit, Peek (1882) felt it would be infinitely better than the hazy skies of Brisbane.

The actual transit station was sited at Jimbour Station, a recently-vacated large colonial mansion (Figure 4) that had suitable surrounding grounds for the various telescopes and other scientific equipment and offered an appropriate standard of accommodation for the observers. Morris was responsible for staffing the house, and he would employ a cook and two housemaids to provide for the transit party.

The transit party left Brisbane on 2 November and used a variety of transportation methods for the 2-day trip to Jimbour. The entire party travelled by train to Macalister (see Figure 3). From this point the senior members of the party travelled on a 4-horse wagon for the remaining 12-mile (19-km) journey (this took 2.5 hours) on what was described as " … the roughest possible track …" (Peek, 1882), and in the process they "… had been almost shaken to pieces." Grover and Bailey were given the responsibility of transporting the equipment up to Jimbour House from the railway station. It was late afternoon on the next day, 3 November, before they finally departed, as it had taken them all day to load five drays and hitch up sixty horses so they too could travel across the plains to Jimbour House. Grover (1882–1883) stated that the air was very clear, as they had a good view of the house throughout their entire journey. The drays travelled during the night, arriving at 1 am on 4 November.

2.2 Telescopes and Observatories

Three different equatorially-mounted refracting telescopes were taken to Australia for the transit observations. The Royal Geographical Society supplied the official party with two 6-in (15.4-cm) Cooke refractors and a small transit telescope (Grover and Peek, 1882; Haynes et al., 1993), while Peek brought along the 6.5-in (16.5-cm) Mertz refractor from his father's observatory at Rousdon (Slater, 2005).

Figure 3: The Darling Downs cover the area from just east of Toowoomba to Nanango and Kingaroy in the north, west to between Macalister and Miles, and south to Warwick and just north of Goondiwindi. The British transit party was located at Jimbour (marked by the red star) and travelled by rail from Brisbane to Macalister, via Toowoomba and Dalby. For scale, Macalister is 19 km from Jimbour (base map: en.wikimedia.org/wiki/Warrego_Highway#/media/File:Warrego_Highway_1712.svg; map modifications: Wayne Orchiston).

Figure 4: A 2011 photograph of historic Jimbour House (commons.wikimedia.org/wiki/File:Jimbour_House_-_Outside_-_Garden_View_5.jpg).

Figure 5: Jimbour House (left) and some of the temporary observatories of the British transit party. On the far right (with one of the telescopes protruding) are the observatories containing Peek's and Morris' refractors, while the transit telescope was housed in the building in the middle of the photograph. The location of the observatory that housed Darwin's refractor is not specified (after van Roode, 2011).

After settling in at commodious Jimbour House (Figure 4) the next task of the transit party was to erect the necessary observatories in the grounds behind the House (see Figure 5). At this point there was a notable division in labour. Peek and Grover set to work assembling the prefabricated wood and 'roll-off canvas roof' observatory for their Merz refractor (Figure 6) and Morris, Darwin and Bailey took responsibility for erecting the remaining buildings: two more wood and canvas observing huts for the two Cooke refractors (e.g. see Figure 7) and a hut for the transit instrument and an astronomical clock. In each observatory a stone pillar was installed, to support the telescope mounting.

2.3 Astronomical Observations Leading Up to the Transit

Once the transit telescope was operational a local time service was quickly established, and the challenge then was to determine the latitude and longitude of Jimbour House. For latitude, observations of selected stars were made every clear night (The transit …, 1882a; The transit …, 1882b), while the longitude (not just of Jimbour House, but also of Brisbane) was successfully determined via the telegraphic transfer of time signals. To accomplish this, Morris collaborated with Henry Chamberlain Russell (1836–1907; Bhathal, 1991), the Director of Sydney Observatory, and they found that Jimbour Station was almost due north of Sydney (it was a mere two miles east of due north).[1] Morris passed this finding on to Augustus Charles Gregory (1819–1905) in Brisbane, and the two of them then investigated the longitude of the Brisbane Observatory. Meanwhile, Lieutenant Darwin travelled north to Darwin, and oversaw the use of the telegraph to link longitudes determined in Australia with those of England and Singapore (The transit …, 1882b).

In the weeks preceding the transit, Grover (1882–1883) detailed the astronomical observations made with the Merz telescope, including Saturn and its satellites, Titan, Iapetus, Rhea, Dione and Tethys. He and Peek also observed the Eta Carinae region and found that it did not exactly resemble the drawing published earlier by Sir John Herschel (1847), which indicated that changes in the nebula may have occurred, as controversially suggested earlier by Hobart's Francis Abbott (see Orchiston, 1992). Grover also observed the Moon, and he described the transit of a Jovian satellite.

3 TRANSIT DAY AND BEYOND

In the weeks leading up to the 7 December transit the skies over the Darling Downs were beautifully clear, but on the morning of the transit the astronomers awoke and were shocked to find the whole sky clouded over. This situation did not change throughout the morning, and the heavy cloud cover prevented them from making any observations of the transit. We can only imagine how devastating a blow his must have been after all the careful preparations, following a long and tiring journey from the far side of the globe. The clear skies in the weeks leading up to the transit would not have prepared them for this sad outcome, and it was with heavy hearts that Morris and Peek telegraphed that no observations were possible from Jimbour (W.H.M.C., 1882).

Figure 6: Cuthbert Peek (right) making observations at Jimbour, assisted by Charles Grover (adapted from Slater, 2005: cover illustration).

Armed with accurate longitude and latitude values for Brisbane Observatory, Gregory also planned to observe the transit from Brisbane, but he, too, was destined to fail as there was total cloud cover over the Queensland capital and heavy rain all day.

After the transit the weather remained unsettled, and soon it was time to carefully pack up most of the instruments and transport them back to Brisbane before Christmas. Peek and Grover then travelled back to Britain and returned the 6.5-in Merz refractor to its rightful home at the Rousden Observatory in Devon (Slater, 2005), but even before they could leave Jimbour Morris and Darwin had to dispose of the two Royal Geographical Society Cooke refractors.

Figure 7: Lieutenant Darwin (left) making observations at Jimbour with one of the two 6-in Cooke refractors, with Gunner Bailey in the background (courtesy: John Oxley Library, State Library of Queensland).

This course of action had been planned long before the transit, as Peek indicated in a letter penned to his father on 22 October 1882 while the transit party was still in Sydney. In this letter, Peek (1882: 9) indicated that both Cooke refractors were to be sold after the transit, and that the reserve price would be £220, well below the cost price of £315. Interestingly, Peek (ibid.) also commented that he felt sure there would be no one in Queensland interested in purchasing the two telescopes.

On 4 November, nearly five weeks before the transit, Morris had placed the following advertisement in the *South Australian Register*, with an identical one in the *Sydney Morning Herald*:

> INSTRUMENTS FOR SALE—Captain Morris, B.E., Transit of Venus Expedition, has received instructions from the Home Government to sell two 6-inch equatorially-mounted REFRACTING TELESCOPES, with all the usual appliances, manufactured by Cooke & Sons, of York, for the Expedition. Cost price, £300. Applications for purchase will be received up to December 1, but not after that date. The instruments will be delivered at the Transit of Venus Observatory, near Brisbane, to *the purchaser or his agent* on December 10, 1882. (Transit of Venus, 1882; cf. Capt. Morris R.E., 1882; our italics).

Note that the italicised section of the advertisement indicates that this was intended as a single 'job lot'—that is, the purchaser had to buy *both* telescopes and associated equipment.

Given his earlier comments to his father, Peek would have been very surprised when the successful purchaser turned out to be an amateur astronomer named Edwin Norris from the North Queensland city of Townsville (for Australian localities mentioned in the text see Figure 8). So who was Edwin Norris?

4 EDWIN NORRIS AND THE STRAND OBSERVATORY

4.1 Edwin Norris: A Biographical Sketch

Edwin Norris was born in England in Stedham, Sussex, in 1829 to Charles Norris, the proprietor of a large paper mill (Personal report …, 2011). Their different christian names suggest that Edwin may not have been the eldest son, which could have helped him make the decision to run away to sea while still a teenager (Death …, 1892). In 1848 the vessel he was aboard was ship-wrecked off the southern African coast but he survived, and two years later he arrived in Australia and subsequently made his way to Ballarat to "… make his fortune …" on the goldfields (ibid). Interestingly enough, he was there at about the same time as the amateur astronomer and Ballarat storekeeper James Oddie (1824–1911; Haynes et al., 1996).

By 1855 Norris had moved north to Murrurundi, New South Wales, becoming Chief Constable as well as Inspector of Slaughter Houses and Inspector of Distilleries (Government Gazette, 1855). In 1856 he married Charlotte May

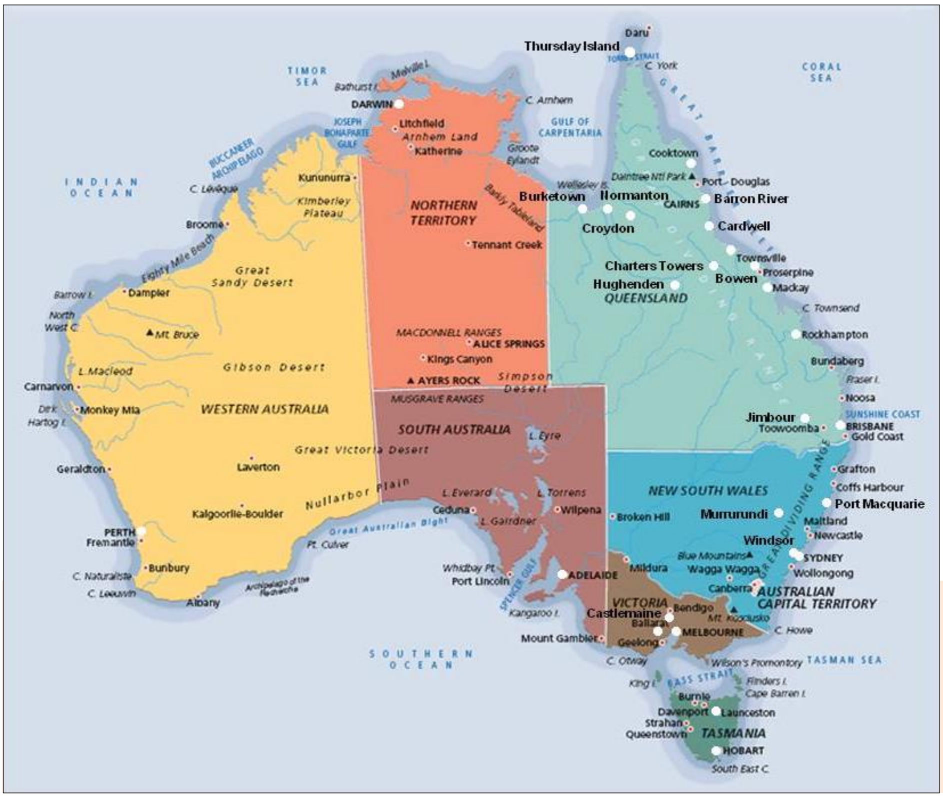


Figure 8: A modern Australian map with localities mentioned in the text shown as white dots (base map: http://www.connectionsworldwide.co.uk/australia-map.asp; map modifications: Wayne Orchiston).

Robertson, and they had their first child a year later.

In late 1857 the young family moved to Brisbane (Births, 1857), and soon after Edwin began to develop an interest in astronomy. His obituary, which dates to 1892, states: "For twenty-five years previously he had taken a deep interest in the study of Astronomy, and for many years was engaged as an amateur in taking astronomical observations in Brisbane, Bowen and Townsville." (Death …, 1892). While living on Wickham Terrace he had a view of the Old Windmill, the site of the time-ball service that commenced in 1861 (Argus Correspondent, 1861). His residence also was within walking distance of the residence of Henry O'Reilly (1824–1877; Figure 9) in Felix Street (Figure 10). Captain O'Reilly, who moved to Brisbane in late 1863 as Manager of the Australian Stream Navigation Company, soon became Brisbane's leading amateur astronomer, and he maintained a well-equipped private observatory (see Haynes et al., 1993). Joy (1984) has suggested that perhaps O'Reilly provided some of the inspiration for Edwin's developing interest in astronomy.

Edwin was appointed as a clerk in the Crown Solicitor's office, and a Commissioner of the Courts (Supreme Court, 1861). Later he managed the office, and then was admitted to the bar in 1864 (Death …, 1892). It was through this position, at the Crown Solicitor's office, that he gained his great depth of understanding of the law.

In 1866 Edwin made a major decision: to take his family north to the 'frontier town' of Bowen (Figure 11) and open his own practice as a solicitor (The Gazette, 1866). By this time, Edwin and his wife had five children, and as we shall see, one of these, Charles Sydney Norris (who was born in January 1859), would inherit his father's passion for astronomy and meteorology. While living in Bowen, Edwin Norris made several attempts to enter local politics, but his lack of success later was attributed to "… deafness which came upon him 37 years ago [in 1855] … [but for which] he would undoubtedly have taken a leading position in political affairs." (Death …, 1892). He also was very much a stickler for the obeisance of rules, and this may have hampered any endeavours within the political realm.

In 1870 Edwin again decided to relocate his family, this time further north to the prosperous city of Townsville, and on 24 September the *Cleveland Bay Express* announced his arrival as both a solicitor and a notary public (Notice, 1870). This coincided with his formal appointment as Commissioner of Affidavits on the same day (Commissioner …, 1870). His business premises were located in Wickham Street (Notice, 1872), an address that surely brought back memories of his time in Brisbane.

Figure 9: Captain O'Reilly (brisbaneheritage.org.au/meet-captain-oreilly/).

In 1872 medical circumstances forced Edwin and his growing family to move temporarily to Sydney, and while there he probably visited the observatory of Dr Horatio Wright (1827–1901) in Wynyard Square (Norris, 1883). Then on 1 August 1873 the family returned to Queensland, settling in Rockhampton (Clearances, 1873), where he again practised as a solicitor and notary public (*Rockhampton Bulletin*, 1873). But their stay was short-lived, for by the end of the year they were back in Townsville, and Edwin was

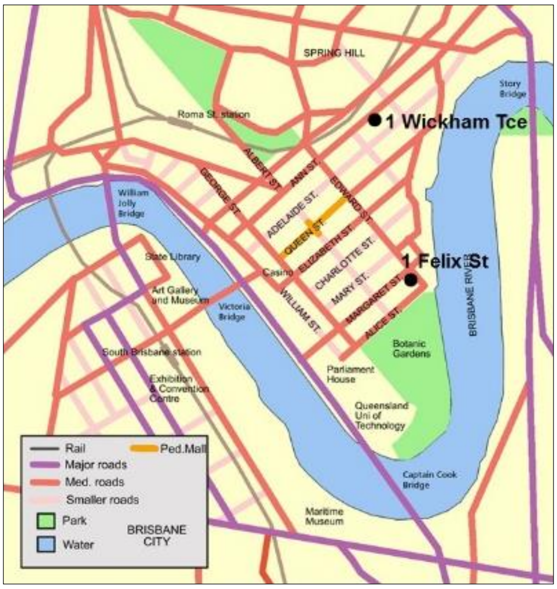


Figure 10: Note the locations of Wickham Terrace and Felix Street as marked, approximately 1km apart (base map: https://commons.wikimedia.org/wiki/File:Brisbane-map-of-the-city-cbd.PNG; map modifications Wayne Orchiston).

Figure 11: A photograph of Bowen in 1867. After busy Brisbane, the Norrises would have found Bowen very quiet (courtesy: John Oxley Library, State Library of Queensland).

working out of his old Wickham Street offices (Notice, 1874). In about 1877 the family purchased land and a house on The Strand (A sure fortune …, 1877), a prestigious location overlooking the sea, and this is where Edwin would erect his observatory after purchasing the transit of Venus telescopes in 1882. Although he was supporting a large family, Edwin Norris' astute business sense not only allowed him to acquire this expensive astronomical equipment in 1882 but also to purchase land in downtown Townsville and erect new business premises there (Death …, 1892).

Despite his hearing impairment, Edwin Norris held a number of positions of importance within the Townsville community, including Town Solicitor. In 1884 he was appointed trustee of the yet-to-be-established Townsville Grammar School (Official notifications, 1884), and a few years later he was nominated for a similar trusteeship position with the Townsville School of Arts (Queensland news, 1887). Thus, by Victorian standards, he was a very successful wealthy businessman, and this allowed him to spend much of 1888 in England (Darlington, 2011).

Edwin Norris died quite suddenly and unexpectedly from heart failure on 13 April 1892, after a short illness (Funeral notice, 1892). Flags were flown at half-mast across Townsville (Funeral …, 1892), and he was buried in the West-end Pioneer Cemetery (see Figure 12). The somewhat austere inscription on his headstone is perhaps reflective of the deceased, and reads:

> Sacred to the memory of EDWIN NORRIS (Town Solicitor) Born at Stedham, Sussex England 17th October 1829. Died at Townsville 13th April 1892. Respected by all who knew him.

4.2 Purchase of the Transit of Venus Equipment

By 1882 Edwin Norris was in a financial position to indulge his passion for astronomy in a major way, and was the successful purchaser of the transit of Venus instruments. What is a little surprising is that his bid was successful, and this has been attributed to an oversight by the Queensland Government of the day that enabled him to make the purchase (Funeral …, 1892). But perhaps it was simply a matter of timing, not oversight, as just one year earlier the Queensland Government had established the Brisbane Observatory, having spent the considerable sum of £225 purchasing a transit telescope, two clocks, a chronograph and two chronometers from the estate of Captain O'Reilly (see Page, 1959). There was also a small refractor involved, so the total purchase price would have been even more. So although the instrumentation at the Brisbane Observatory was definitely inferior to the attractive 'package' offered by Captain Morris, and the Government was aware of the sale, they probably did not feel justified in placing a bid given their recent substantial outlay in the name of astronomy.

Looking further afield, with the notable exception of the Hobart Observatory, the other Australian colonial observatories already possessed instruments of superior aperture to the 6-in Cooke refractors (see Haynes et al., 1996; Orchiston, 1988a: Table 1). However, professionally-manufactured equatorially-mounted 6-in refractors were certainty an attractive proposition for a serious Australian amateur astronomer (e.g. see Orchiston, 1989; 1997b), so it is a little surprising that one of Norris' wealthy astronomical confrères from New South Wales or Victoria did not succeed in making the purchase.

In writing earlier about Norris' acquisition, one of us (Orchiston, 1997b) referred only to one telescope, but the advertisements placed in Australian newspapers by Captain Morris prior to the transit indicate that the 1882 equipment was to be sold in its entirety to a single purchaser (Capt Morris R.E, 1882), so Norris definitely purchased *two* 6-in Cooke refractors, along with their associated attachments (A new observatory, 1884).

This confusion about the number of telescopes that Norris purchased is also reflected in newspaper accounts of the day. For example, when his new observatory was opened in 1884 the *Brisbane Courier* provided details of his purchased equipment but—perhaps as might be expected—there is mention of just one telescope, which was mounted in the observatory. This was described as a "…very fine achromatic equatorial …" manufactured by Cooke & Sons of York (ibid.). The objective was 6-in (15.2-cm) in diameter, with a focal length of 8.5 ft (and therefore the focal ratio was f/17, slightly greater than the more typical f/15 for refractors of around this aperture). The tube was made of a heavy brass, painted grey.

The telescope was mounted on a substantial cast-iron circular pillar, also painted steel grey. This pillar was 6 feet 6 inches (1.98 m) in circumference at the base and was described as being approximately 7 feet 6 inches to the middle of the declination axis when adjusted to the horizontal. The telescope, on this pillar measured approximately 9 feet (2.74 m) to the declination axis when laid horizontal (and this vertical measurement determined the height of the observatory walls). The pillar was divided 3 feet (091 m) from the base with a "… means of adjustment in azimuth to any extent." (ibid.). The pillar was purpose built, and was buried deep into the ground to combat any possible vibration.

Further information about the telescope indicated that there were clamping controls for right ascension and declination which could be operated from the "… eye end [of the telescope] with roll and handle." (ibid.). In addition, both the polar and declination axes were manufactured out of steel, with friction-rollers and counterpoises to reduce pressure on the bearings (ibid.).

The telescope was described as being "… driven by a clock." (ibid.). The drive was attached to the south side of the pillar, just below the end of the polar axis. A governor containing billiard-sized brass balls regulated the equatorial motion. A 20-in (50.5-cm) diameter circle was used to switch between sidereal and lunar rates of motion; this was also manufactured out of brass. Slow motion controls in right ascension and declination were present and were accessible from near the eyepiece of the telescope.

Figure 12: The impressive headstone marking Edwin Norris' grave at the Westend Pioneer Cemetery in Townsville (photograph: Vicki Darlington).

The telescope had been designed to operate outside the confines of a purpose-built observatory so it had further attachments (ibid.). A large position circle, was placed near the eyepiece of the telescope and could be read with the aid of a microscope to view the silver graduated scale along with a silver vernier. The microscope had rack and pinion motions and clamps. Further to this, there was a 10-in (25.4-cm) hour circle, with divisions and verniers of silver, read using a microscope. A 17-in (43.2-cm) diameter, solid brass declination circle had both an edge scale that provided coarse measurement of face divisions and a vernier for finer detailed measurement. It was read using a separate microscope clamped at the eye end of the telescope.

Additional attachments were included in the purchase. A "… prismatic illuminating apparatus …" could be attached to the main tube to enable observation of dark and bright fields when undertaking micrometric observations, and was described as "… an elegant specimen of the optician's art." (ibid.). It consisted of a suspended lamp, to ensure it always hung at right angles to the telescope, along with a prism to reflect light into the tube with the attached diaphragms and coloured glasses that regulated both the quantity and colours of light allowed to enter. The telescope also had both a counter-poise and gravity poise. The eye-end of the telescope had a rack and pinion focussing mechanism, and a dew cap was attached that took the overall length of the telescope to 9 feet. The article described the attached finder as being "… a good sized telescope in itself …", having a 2-inch aperture (ibid.). A rack was attached within reach of the observer when using the telescope, and this was used primarily for the collection of filters that came with the telescope, some of which enabled solar viewing. The filters, of graduated dark glass were fitted into metal frames and could be placed in the attached rack without moving from the eyepiece. "A battery of eyepieces of various powers …" (ibid.) also came with the telescope, and

Figure 13: Edwin Norris erected his Strand Observatory on the corner of The Strand and King Street, at what is now Number 9 The Strand (shown here in yellow). Norris' residence was next door, on the site of the large white multi-storey apartment building shown in this recent aerial photograph (www.realcommercial.com.au/property-land+development-qld-townsville+city-501662497#).

> In addition to the various magnification options other attachments included but packaged separately in a highly polished mahogany case was supplied:
>
> - A transit eyepiece
> - A comet seeker eyepiece,
> - A double parallel wire micrometer graduated on silver
>   - Enabling distance measurements to be made
> - A first surface reflecting prism
>   - To enable the telescope to be used for terrestrial observations as it inverts the image.
> - A star diagonal
>   - The attachment used to make overhead viewing more comfortable for the observer

This same long and detailed newspaper article described this telescope as "… more than twice as large as the telescope at the Government Observatory at Brisbane." (ibid.). This statement was somewhat of an exaggeration as the Brisbane Observatory telescope, originally owned by O'Reilly, had an aperture of either 3.75 in (9.2 cm) (Grover, 1882–83: 39) or 4.5 in (11.5 cm) (Joy, 1874). Norris' Cooke refractor was also described as the largest telescope in Queensland (ibid.), which was indeed true at that time, but proud fellow-Townsville resident, Pio Vico Armati (1997) later erred in describing it as the largest telescope in the Southern Hemisphere. Even within Australia there were larger refractors at Adelaide, Melbourne and Sydney Observatories (Haynes et al., 1996), while one of Sydney's amateur astronomers, leather merchant J.W. Ward, already owned a 6-in refractor (see Orchiston, 1997b: 90–92).

4.3 The Strand Observatory

After purchasing the transit of Venus telescopes Norris finally was in an ideal position to indulge his interest in astronomy. Admittedly, by world standards, 6-in refractors were distinctly modest in 1882, but even so they were capable of good work if properly mounted and placed in the right hands. Thus, Australia's leading astronomer at this time, the Windsor amateur, John Tebbutt, was furnished with only a 4.5-in (11.4-cm) Cooke—which even lacked a drive—yet he was able to carry out a wide range of observations that resulted in a never-ending stream of publications in leading international astronomical journals (see Orchiston, 2004a). And Tebbutt was not alone—there were other Australian amateur astronomers who pursued less ambitious observing programs, but still managed to produce publishable material (see Orchiston, 1989). So Norris also had a chance to contribute to science, and surely he was aware of this.

Norris therefore decided to build an observatory to house one of his Cooke telescopes. This would be located on the Strand, where he owned two adjacent properties, on the corner of King Street and across the road from the Criterion Hotel (see Figure 13). On one of these properties was a large family residence (Notice of Sale, 1897), and the Strand Observatory was erected near it, with a view out across Cleveland Bay.

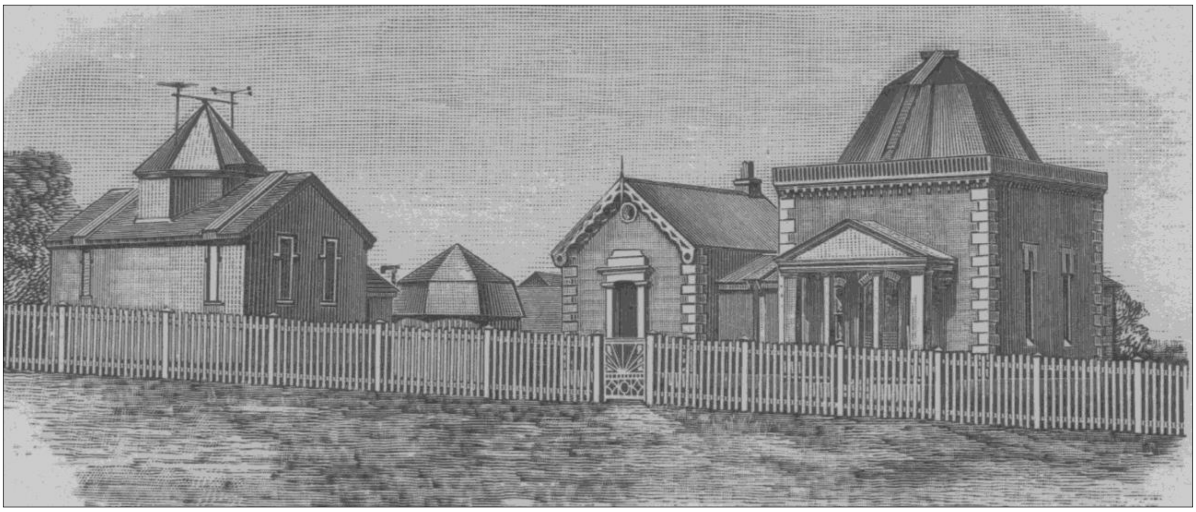


Figure 14: A woodcut showing the three conical domes at Windsor Observatory in 1880 (Orchiston Collection).

Figure 15: Brisbane Observatory had a small hemispherical dome (after Haynes et al., 1993).

Long before construction of the observatory began, Norris approached various astronomers and observatories to gather information on an appropriate design. Consequently, on 17 September 1883 he wrote to John Tebbutt asking for information on dome and shutter design and construction (Norris, 1883). By this time Tebbutt had designed three different observatory buildings (see Figure 14), all with conical domes (Orchiston, 2001a; 2017: Chapter 8) so was in an ideal position to provide advice. In his letter of enquiry, Norris also mentioned Dr Wright's observatory in Sydney which was located "… on the top of his house …" and had a dome. Norris also indicated that he planned to build a model of the new observatory for the builder's guidance, as there were no such structures within the Townsville region at that time (but we will query this statement later).

In 1884 Norris followed up on this correspondence by travelling to "… the Southern Colonies …" and examining the designs of the various buildings at the Government observatories in Brisbane (Figure 15), Sydney (Figure 16), Melbourne (Figure 17) and Adelaide (Figure 18). He also visited Tebbutt's Windsor Observatory and the observatory maintained by Dr Horatio Wright (Figure 19) in Wynyard Square, Sydney (Death …, 1892). Between them, these institutions offered Norris details of drum-shaped, hemispherical and conical domes, as well as roll-off roof observatories (e.g. see Haynes et al., 1996), and as we shall see, he chose this last-mentioned design for his Strand Observatory. He then proceeded to prepare both a plan and a model of his intended observatory (ibid.).

Norris employed a local builder to construct

Figure 16: Sydney Observatory only had standard hemispherical domes (courtesy: Harley Wood).

Figure 17: At Melbourne Observatory there was the roll-off roof observatory built for the 48-in (1.22-m) Great Melbourne Telescope (courtesy: Harley Wood).

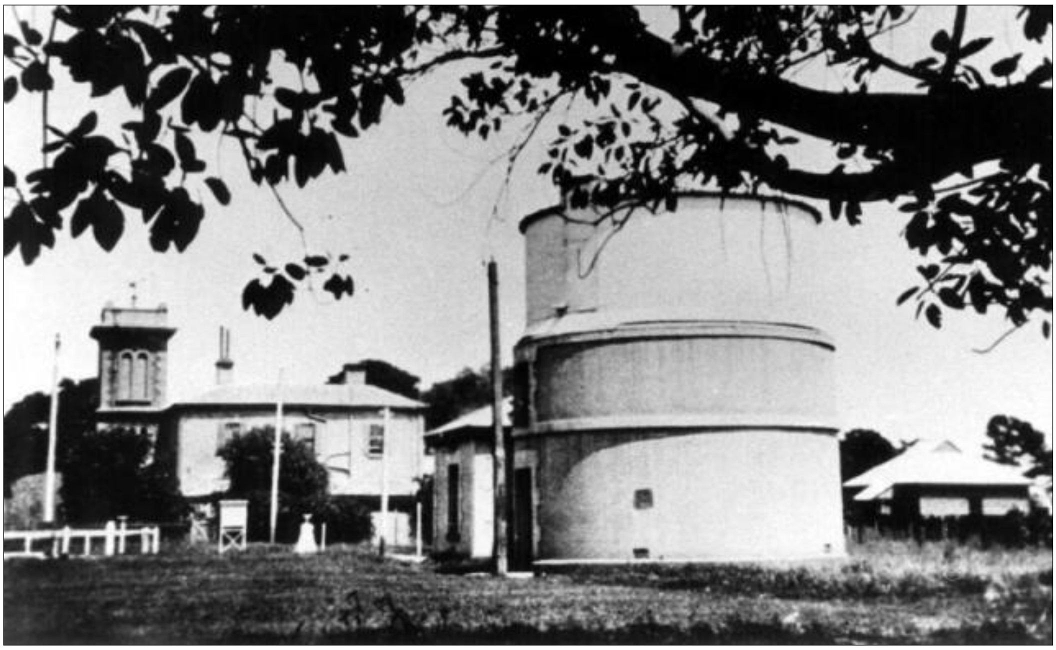


Figure 18: Adelaide Observatory featured a drum-style observatory (courtesy: setterfield.org).

his Strand Observatory. The design was intended to be easy to construct and cool, an important consideration for late nineteenth century tropical Townsville. It also had to contain a minimum of moving parts, to ensure longevity, and it had to provide protection against the weather—and not just tropical rain, as Townsville lay in Australia's notorious 'cyclone belt' (A new observatory, 1884).

This article in the *Brisbane Courier* (ibid.) goes into a great deal of detail about the observatory. The base dimensions were 13 ft × 13 ft (~ 4 m × 4 m), with the walls 8 ft 6in (~ 2.6 m) high when measured from the floor. The telescope measured 9 ft (2.74 m) from the horizontal making it possible to view over the top of the walls when it was in a horizontal position. The wall plates were hardwood and the design had them extending 7 ft (~ 2.1 m) beyond the building both north and south. The wall plates were supported from below and braced. On top of these wall plates rails were placed to hold the eight 4-in (10.2-cm) diameter wheels that had been specially manufactured in the Townsville Foundry. These wheels were fitted into frames to support the movable roof structure, and were mortised into place (ibid).

The roof frames were built of Oregon Pine and the ceiling boards were 3.5-in × 1-in (8.9-cm × 2.5-cm) tongue-and-grooved boards of American Pine. The frame was topped with galvanized iron. The movable roof formed a circle with a split down the middle dividing the eastern and western walls. The roof was described as being "… separated easily by the observer …" (ibid.). A canvas sheet or screen was used to cover the unused opening. This design was employed to "… always attain a good meridian altitude." The entire roof structure could be rolled back to provide complete open-air viewing and help combat the tropical temperatures. Sliding windows were present on the northern wall of the observatory, which enabled the observer, using a terrestrial eyepiece, to have good views of Cleveland Bay. This same newspaper article mentioned that a transit annex, with associated instruments, was still to be added to the observatory (ibid.). Unfortunately, we were unable to locate any photographs of the Strand Observatory.

Contrary to Norris' claim, it would appear that the Strand Observatory was not the first astronomical observatory erected in Townsville. Early cadastral records dating to 1873 (Armati, 1997) show an observatory on the property owned by John Melton Black and Robert Towns on what is now Melton Hill (see Figure 20). Originally, Black (1830–1919) was in partnership with the wealthy Sydney businessman Robert Towns (~1794–1873), who only visited Townsville once—even though the city is named after him (Doherty, 1934). In contrast, Black was one of the first Europeans to settle in Townsville, and a residence was constructed for him around 1865. This was the first house erected in Townsville, and is shown in Figure 21. We suggest that part of the small white-painted building behind the house probably was his observatory. But it is unlikely that this observatory was still in existence when Norris erected his Strand Observatory, for although Black

> … came to a coastal creek in North Queensland and planted a city. He planned the erection of the first wharf, surveyed the first allotments and superintended the erection of the flrst buildings. In the course of three years be figured as a stockman, merchant, surveyor, newspaper editor and pioneer of the meat industry. For the first two terms he was Mayor of the Municipality ... (ibid.)

At the end of 1867 he left Townsville and returned to London, where he lived until he died. So even if Black's observatory still existed, as a building, in 1884 it certainly was not operational at that time.


Figure 19: Dr Horatio Wright (adapted from Russell, 1892b: Frontispiece).

4.4 Astronomy at the Strand Observatory?

Edwin Norris' enthusiasm for the study of astronomy is mentioned in his obituary. He was described as

> … an inveterate student … [and having] For twenty-five years previously … taken a deep interest in the study of Astronomy, and for many years was engaged as an amateur in taking astronomical observations in Brisbane,[1] Bowen and Townsville. (Death …, 1892).

This interest in astronomy could have originated during his youthful days as a seaman—if he learnt the rudiments of marine navigation—and as we have seen may have been encouraged through contact with Captain O'Reilly during his Brisbane years. By 1884 his passion for astronomy was well known outside Townsville, with confirmatory evidence appearing in Melbourne's

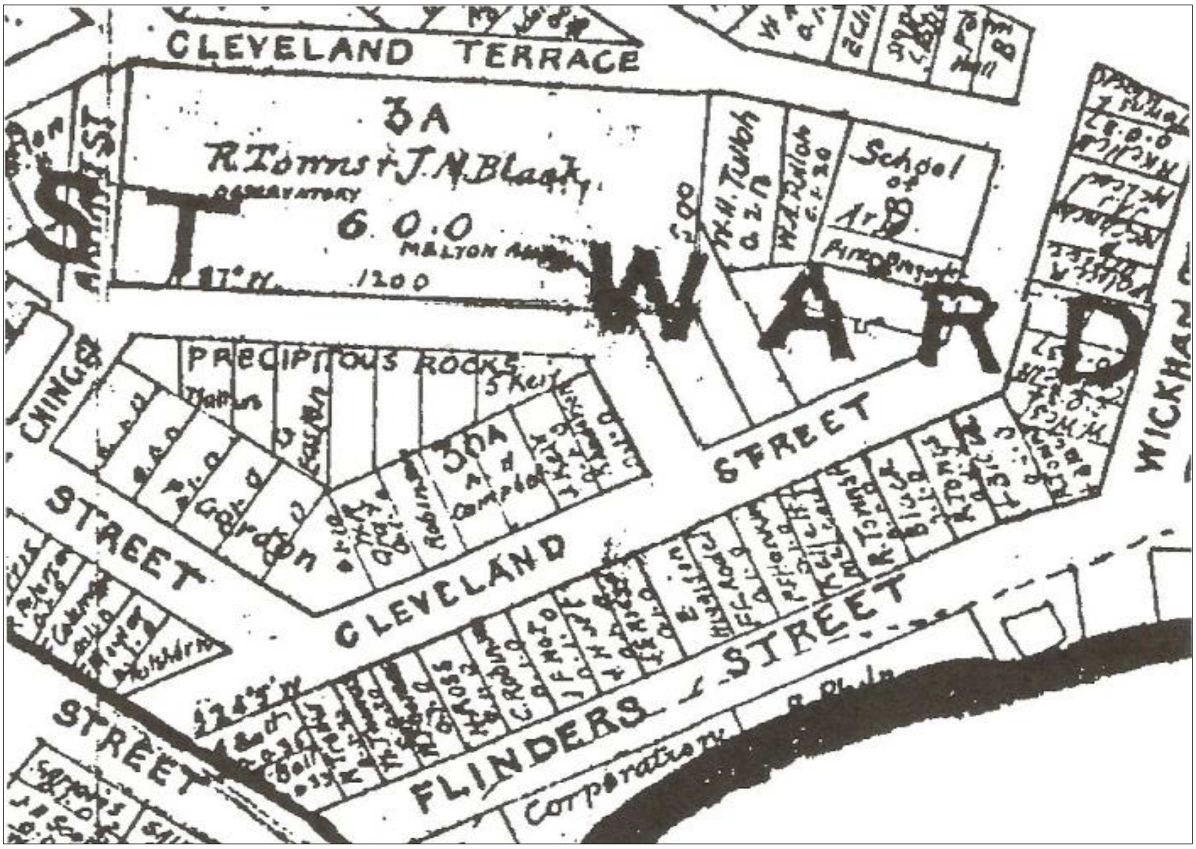


Figure 20: By far the largest property shown on this map is Allotment 3A, which was owned by Robert Towns and John Melton Black and is shown as containing an observatory (after Armati, 1997).

Figure 21: A view of Melton Hill in Townsville, looking north. We suggest that the small structure with a verandah to the rear of Black's house included his observatory. The mountain in the far distance on the extreme right is Cape Pallarenda, the beach on the right is The Strand with the suburb of North Ward; and the small hill at the end of the beach is Kissing Point (courtesy: National Museum of Australia: Richard Daintree Collection).

The Argus newspaper and *The Brisbane Courier* (The Vagabond …, 1884; Vagabond, 1884).

Armed with an observatory and 6-in equatorially-mounted refractor with all the necessary accessories, Norris was now in an ideal position to carry out serious astronomical observations. Inspired by other leading Australian amateur astronomers furnished with similar instruments he could have pursued any one or combination of the observing programs listed in Table 1, and ideal Australian role models included Francis Abbott (Figure 22), Alfred Barrett Biggs (Figure 23), Dr William Bone, William Macdonnell (Figure 24), Ebeneler Reginald Morris, David Ross (Figure 25) and of course Australia's leading astronomer at that time, John Tebbutt (Figure 26). Information on these amateur astronomers and their instruments is listed in Table 2.

Table 1: Principal research programs undertaken by leading Australian amateur astronomers (1880–1889).

- Transitory Events
    - Eclipses of the Moon
    - Eclipses of the Sun
    - Lunar occultations of planets
    - Lunar occultations of stars
    - Jovian satellite phenonema
    - Transits of Mercury
    - Transits of Venus
- Short-term Monitoring Projects
    - Comets (positions and appearance)
    - Planets (positions)
- Long-term Monitoring Projects
    - Double stars (separation and position angle)
    - Planets (appearance)
    - Variable stars (magnitude variations)
- Search Programs
    - New double stars
    - New variable stars

Figure 22: Francis Abbott seated in front of a doorway, ca. 1860 (courtesy: Allport Library and Museum of Fine Arts, Tasmania Archives and Heritage Office, Hobart, 607375).

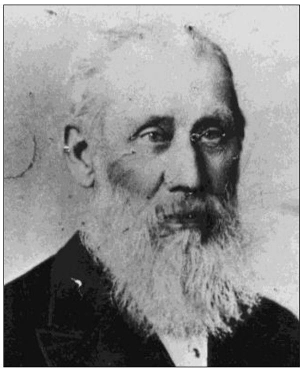


Figure 23: Alfred Barrett Biggs (Orchiston Collection).

Figure 24: William Macdonnell (courtesy: Port Macquarie Museum, William Macdonnell's Photo Album, A 57).

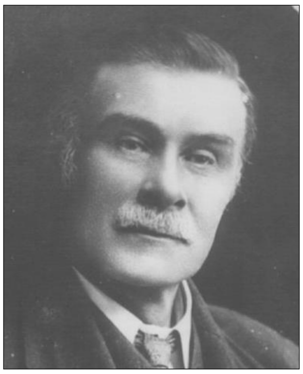


Figure 25: David Ross (Orchiston Collection).

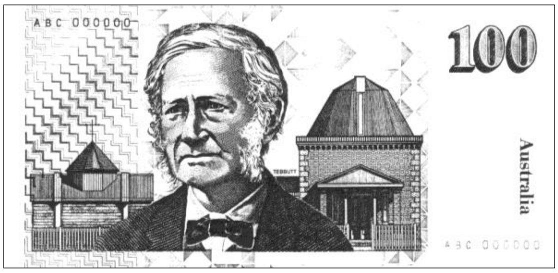


Figure 26: John Tebbutt and the $100 note (Orchiston Collection).

Table 2: Leading Australian observational amateur astronomers, 1880–1889.

Name	Location	Main Telescope*	Reference
Francis Abbott (1799–1883)	Hobart (Tasmania)	4.5-in OG	Orchiston (1992)
Alfred Barrett Biggs (1825–1900)	Launceston (Tasmania)	8.5-in spec	Orchiston (1985)
Dr William Bone (1836–1885)	Castlemaine (Victoria)	8-in OG	Orchiston (1987b)
William Macdonnell (1842–1910)	Port Macquarie (NSW)	6-in OG	Orchiston (2001b)
Ebeneler Reginald Morris	Sydney (New South Wales)	8.5-in spec	Orchiston (1987a)
David Ross (1850–1930)	Melbourne (Victoria)	3-in OG	Orchiston and Brewer (1990)
John Tebbutt (1834–1916)	Windsor (New South Wales)	8-in OG	Orchiston (2004a; 2017)

* Key: OG = refractor; spec = reflector

Norris needed a functioning transit annex in order to time solar eclipses, lunar occultations, Jovian satellite phenomena, and transits of Mercury and Venus, but even so he could have observed and reported on lunar eclipses, searched for new double stars and variable stars, tracked Jupiter's changing belts and transitory black and white spots (not to mention the Great Red Spot) and made variable star magnitude estimates. He also could have used his telescope and micrometer to record the positions of comets and selected planets. So there was much useful astronomical work that he could have accomplished but there is no evidence he did anything. Rather he would appear to have been a recreational astronomer who made no attempt to contribute to research astronomy, despite possessing suitable facilities that would have allowed him to do so if he had wished to.

Most of the role models mentioned above also were committed to bringing astronomy to the public (see Orchiston, 1997a), and did so through one or a combination of the following:

- Offering public nights at their observatories
- Supplying astronomical, and sometimes meteorological, information to individuals
- Supplying astronomical, and sometimes meteorological, information to local newspapers
- Delivering public lectures
- Presenting courses of lectures
- Writing books, booklets or chapters of books about astronomy

Perusal of the local Townsville newspaper and other Queensland newspapers indicates that—as with research—Edwin Norris made little if any commitment to astronomical education. While his hearing impairment may have made lecturing difficult and dissuaded him from running public sessions at the Strand Observatory, this would not have prevented him from supplying written information to individuals and newspapers or writing more substantial pieces on astronomy. That he did not do so could indicate a lack of interest, or that he was a busy public figure and simply did not have the time.

The US astronomer Dr Tom Williams (2000) has analysed amateur astronomers, and he distinguishes between those who actively contributed to science and those who engaged in astronomy for recreational purposes only. It is clear that Edwin Norris belonged to this latter category.

Canadian sociologist and amateur astronomer Professor Robert A. Stebbins has published on amateur astronomy and amateur astronomers (e.g. see Stebbins, 1980; 1981; 1982a; 1982b; 1987), and would go further. Using 'dedication' as a criterion, Stebbins distinguishes 'devotees' from 'dabblers'. Devotees were individuals who were happy to make a substantial commitment to astronomy in terms of both time and money, but although Norris certainly made a outlay very substantial in order establish his Strand Observatory he would appear to have been a 'dabbler'.

Using another dimension, 'knowledge and involvement', Stebbins differentiates between 'active' and 'armchair' amateur astronomers. Active amateur astronomers were engaged in observational or mathematical astronomy, or in instrument-making, and each individual lay somewhere within an 'apprentice – journeyman – master' continuum. Apprentices were beginning their astronomical avocations, while masters were the acknowledged experts who were capable of making a meaningful contribution to science and could communicate effectively with professional astronomers. Given the existence of the Strand Observatory, we can presume that Norris had the potential to be an active amateur astronomer but, using Stebbins' criteria, we would have to class him as an armchair astronomer.

5 EWEN DAVIDSON AND THE BRANSCOMBE OBSERVATORY

In 1888, nearly six years after the 1882 transit of Venus and four years prior to his death, Edwin Norris sold a 6-in refractor to J. Ewen Davidson of Branscombe (Death …, 1892), near Mackay, ~330 km to the south of Townsville (see Figure 8). This must have been Norris' second Cooke telescope, not the one in his Strand Observatory, because Norris died intestate and at the sale of all of his possessions in 1897 it was stated that at the time he died Norris still owned a

> Large Astronomical Telescope (on stand, with all necessary mechanism), and Four smaller and Pocket Aneroids. (Notice of Sale, 1897).[2]

telescopes, Binoculars, Sextant, Microscope

So who was this proud new owner of the second of the two British transit expedition Cooke refractors?

5.1 J. Ewen Davidson: A Biographical Sketch

John Ewen Davidson (1841–1923; Figure 27; Mills, 1981) was born in London, his father being a successful merchant and associated with the Davidsons of Tulloch Castle in Scotland. He was educated at Harrow, and graduated with an Oxford University B.A. in 1863 after specialising in science.

After examining sugar plantations in the West Indies and British Guiana he came to Australia in 1865 and the following year began working a sugar plantation near Cardwell, in North Queensland north of Townsville. The following year he moved to coastal Mackay (south of Townsville) where he teamed with Thomas Henry Fitzgerald (1824–1888) and established a sugar and cotton plantation on the fertile flood plain of the Pioneer River to the west of the city. Having proved that sugar-growing was a commercially-viable proposition, in 1868 they built the first sugar mill in the district (Roth, 1908).

Davidson went on to become a 'sugar baron' and a prominent pioneer of the Australian sugar industry, but he also played a leading role in 'local politics'. Consequently,

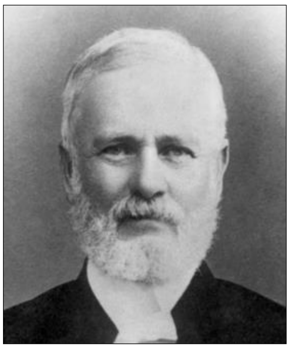


Figure 27: J.E. Davidson (http://www.archivessearch.qld.gov.au/Image/DigitalImageDetails.aspx?ImageId=3055).

> As chairman of the Pioneer Shire Divisional Board for many years and of the Mackay Planters Association in 1878-83, he helped improve shipping facilities in the port and river, and eventually became a member of the Mackay Harbour Board. He also was on the committee of the Agricultural Pastoral and Mining Association. (Mills, 1981).

He also was an active sportsman: he "… played in Mackay's first cricket match … and was also the founding president of the Mackay Cricket Association." (Sugar pioneer …, 2009).

Over the years Davidson personally owned or managed a number of different sugar plantations in the Mackay district, and one of these was Branscombe, where he lived and operated a sugar mill (see Figures 28 and 29) at the time he purchased the Cooke telescope from Norris.

Figure 28: A modern map showing the location of the centre of the Branscombe Estate sugar plantation (marked by the red bull's-eye) in relation to the centre of Mackay. For scale, Branscombe Estate is ~12 km from Mackay Airport (base map:www.weather-forecast.com/locations/Mackay; map modifications: Wayne Orchiston).

Figure 29: A 1974 Greenmount Parish map showing the location of the Branscombe plantation (in pink), with the site of the sugar mill on the banks of the Pioneer River marked by the large red cross (after Branscombe Sugar Mill, 1871–1884).

Following the depression of the early 1890s, Davidson found himself in an untenable situation:

> The approach of Federation, the impending collapse of the coloured labour system [which Davidson had championed] and the introduction of government-sponsored central mills led to the breaking up of the sugar estates. The system of which Davidson had been so much a part was dying. (Mills, 1981).

There also were climatic extremes that made any form of farming risky (e.g. see Kennedy, 2002: 111). Davidson's response was to retire. He moved back to England in 1900, settled in Oxford, and died there in 1923 at the age of 85 (A sugar pioneer, 1923).

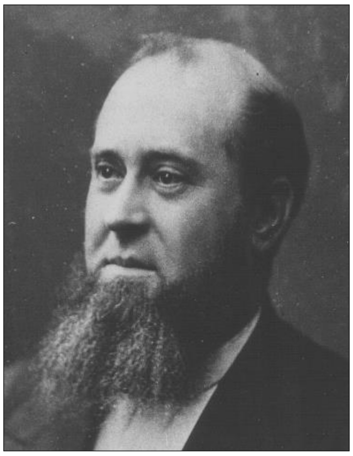


Figure 30: Henry Chamberlain Russell, 1836–1907 (courtesy: Harley Wood).

5.2 Branscombe Observatory and Cometary Astronomy

Davidson's new telescope was described as "… a splendid telescope, brought out to Australia by scientists some years ago to observe the transit of Venus." (A peep …, 1889). Soon after acquiring it, he erected an observatory near the homestead on his Branscombe property. We have been unable to trace any photographs of the homestead, or archival sources that pinpoint the location of the observatory within the estate.

Although no description of Branscombe Observatory has been published, a *Sydney Morning Herald* newspaper article mentioned that rather than featuring a dome, it had a roof that "... folding back ..." (A peep ..., 1889). Nor did Sydney Observatory Director, Henry Russell (Figure 30), provide any details when he wrote to the Secretary of the Royal Astronomical Society on 17 September 1889:

> It may be of interest to state that Mr Davidson has purchased the Cook [*sic*] 6in Equatorial which the 1882 transit of Venus party sold in Queensland[3] and he has established a small observatory with transit instrument chronometer, micrometer for Equatorial &c upon his Sugar Plantation near Mackay in Queensland, and he finds time amidst the pressing duties of a Planter's life for some study of the heavens. (Russell, 1889b).

Instead, we must rely on a photograph of the Observatory that exists in the Lick Observatory

Figure 31: A view of Davidson's Branscombe Observatory (courtesy: Lick Observatory Records UA 36, Accession No: ua0036-pho-2051).

archives, and this is reproduced in Figure 31. This shows a transit annex and adjacent square-shaped roll-off roof observatory, but with a single high-pitched roof. Note that this roof differs markedly in design from the one that was constructed by Norris, and was well adapted to deflecting the heavy rainfall that the Mackay region received each year during the wet season.

Note that this photograph reveals that the Observatory was sited some distance from the Branscombe Sugar Mill. Meanwhile, if the hill directly behind the Sugar Mill in this photograph is Falls Hill (shown near the top right hand corner in Figure 29) and Branscombe Observatory was aligned east-west, with the gable roof sliding off to the west, then the orientations indicated in Figure 31 show that the Observatory was located somewhere in the north-western area of the Branscombe Estate, and most likely in the allotment number 1 shown in Figure 29 that lies north of Eungella Road (that runs more-or-less east-west through the Estate), and probably quite close to the north-south road that marks the boundary of the Estate. A second, though less likely, possibility is that the Observatory was situated somewhere in neighbouring allotment number 2.

Finally, since we can expect that the Observatory was located reasonably near Davidson's homestead, even though there is no record of its location, a search should now be made to see if there is a surviving cluster of old trees somewhere in allotments 1 or 2, (bearing in mind that the site of the Branscombe Sugar Mill on the river bank is marked by old mango trees—see "Branscombe Sugar Mill 1871-1884").

Davidson's interest in observational astronomy certainly predated his acquisition of the Cooke telescope. Thus, in January 1886 he wrote to *The Queenslander* newspaper about the cause previous November's prominent Leonid meteor shower,[4] and went on to explain the links between meteor showers and specific comets. He also mentioned that at that time he was watching for the reappearance of Biella's Comet (Dav-(idson, 1886), which indicates that he already possessed an astronomical telescope prior to purchasing the 6-in Cooke refractor. However, this instrument—which was never described—either was portable and simply taken outdoors when observations were intended, or else was mounted outdoors but under a cover of some kind. On the basis of Russell's (1889b) letter reproduced above, we know that it was not housed in an observatory.

Once Davidson's new Cooke telescope was operational he continued his romance with comets, and

> He told the editors of the Mackay Mercury and the Mackay Standard that at 9pm on the night of Monday, July 22 [1889], he observed a comet in the constellation Centaurus in a region where there were no conspicuous fixed stars. He said that it was visible to the naked eye as a hazy star. He gave the exact location of the comet and said that it was travelling at the rate of four degrees per day in a north-westerly direction towards Virginis, which it would reach in about 10 days …
>
> Mr Davidson did not know whether any of the southern observatories had seen the comet … He advised that if the night was clear the comet could be seen nightly in the western sky

> between seven o'clock and 11 o'clock. (Sugar pioneer …, 2009).

Overseas astronomers heard about the new comet when they opened the 1 August issue of the British scientific journal *Nature*, which announced "… the discovery of a bright new comet by Mr. Davidson, of Queensland, on July 21." (Our Astronomical Column, 1889). Apparently, "The comet was found accidently when Examining the heavens in the neighbourhood of Eta Argus [now Eta Carinae]." (Russell, 1889b), and at the time it had a "Bright nucleus about 5th magnitude, 5 minutes diameter, no tail, but extenson of nebulosity …" (Ellery, 1889). Meanwhile, the August 1889 issue of *The Observatory* incorrectly reported that "Mr Davidson, *of the Melbourne Observatory*, discovered a bright comet on 21 July." (Comet e …, 1889: 334; our italics). When he saw this, Davidson was quick to correct the error:

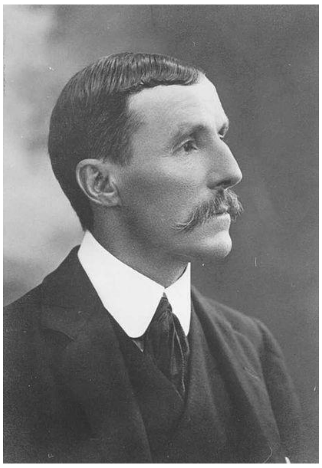


Figure 32: A Royal Society of Victoria Presidential photograph of Pietro Baracchi (en.wikipedia.org).

> Will you kindly allow me to correct … [the error]? The Comet e, 1889, was discovered by me *here*, Lat. 21° 9′ S., on July 19, 1889, was wired by me to the Sydney Observatory the following day, was not seen on account of clouds till the 22nd, when it was wired to Melbourne, and from thence to Europe.
>
> The matter is unimportant, except that Queensland being a young colony,[5] and this being the first comet discovered from her territory, she ought at least to get the credit, and, as a colonial paper puts it, "enter into the comity of nations"! …
>
> P.S. Beyond being slightly acquainted with Mr. Ellery, I have no connections with the Melbourne Observatory. (Davidson, 1890).

After being advised of the discovery, Sydney Observatory Director, Henry Russell, told Davidson of a comet reward and asked him to describe his *modus operandi*:

> I duly received your telegram re comet on Sunday for which I am very much obliged. On the Sunday evening it was cloudy and wet … but on Monday evening I found it without difficulty … I got a good set of observations and published the position in our local newspapers stating that you had sent me a telegram about the comet. I have since that: had a cablegram sent to Europe announcing the discovery, and if it prove that you are the discoverer, you will have the honour: and if you like to claim it: a reward offered by an American citizen for the discovery of comets.[6] *I should like to know how you discovered it i.e. whether you were searching the heavens or whether you found it by accident. and if you are an astronomical worker. I should be glad to know something of your work and observatory*. (Russell, 1889a; our italics).

Subsequently, Davidson was credited with the discovery of this comet, which is now known as C/1889 O1 (Davidson).

This new comet quickly attracted the attention of Australian cometary astronomers, both professional and amateur. At Melbourne Observatory, Pietro Baracchi (1851–1926; Figure 32) made 10 micrometric measures of the comet's position between 23 July and 18 August (inclusive) and published these in *Monthly Notices of the Royal Astronomial Society* (Baracchi, 1889; cf. Ellery, 1889).

Using an 8.5-in (21.6-cm) With-Browning reflector, Launceston's Alfred Barrett Biggs (Figure 23) reported:

> The comet was first observed here on 26th July, faintly visible without telescope. Tail about 1deg. in length … Nucleus, sharp and starlike, about 7 mag, surrounded with considerable nebulosity ... The star comparison measures were all taken with a *Bar* Micrometer … owing to persistent cloudy and unsettled weather, very few opportunities for star measures were afforded. (Biggs, 1889).

After hearing about the comet on 23 July, Biggs' mentor, John Tebbutt (Figure 26), observed the comet and published a brief account of it in the respected German journal *Astronomische Nachrichten*:

> It was observed here [i.e. Windsor Observatory, near Sydney] on the evenings of the 23rd and 24th, but the observations on the latter date were made with difficulty in consequence of the hazy state of the sky. The comet was a conspicuous object to the naked eye, being fully as striking as a star of the 4th magnitude. In the telescope the nucleus was small and not brilliant, and was surrounded with an extensive coma. (Tebbutt, 1889).

Tebbutt (1890) later published a further paper, where he reported 12 different micrometric positions of the comet made between 27 July and 15 August (inclusive) using his 8-in Grubb refractor.

Although C/1889 O1 (Davidson) was discov-

Table 3: Australian cometary discoveries, 1880–1889 (adapted from Orchiston, 1999b: 213).

Year	Designation	Discoverer	Reference(s)
1880	C/1880 C1 (Great Southern Comet)	Dr William Bone	Orchiston (1987b; 1997c)
1881	C/1881 K1 (Great Comet: Tebbutt)	John Tebbutt	Orchiston (1999a; 2010)
1883	-----	H. Clevers/ L.C. Thirlwall	Orchiston (1983)
1884	C/1884 A1 (Ross)	David Ross	Orchiston and Brewer (1990)
1889	C/1889 O1 (Davidson)	J. Ewen Davidson	This paper; Baracchi (1914)

ered in the southern sky, in Centaurus, it quickly moved north, and from 25 July was visible to Northern Hemisphere observers. It then became yet another example of a comet that experienced nuclear splitting:

> A. Ricco (Palermo, Italy) was the main observer of the double nucleus. Observing between August 3 and 11, using a 25-cm refractor, he reported that the separation between the components became more distinct every day until August 8, with the fainter and larger component following the brighter one. Between the 8th and 11th, the separation increased to about 16 arcsec, but the secondary nucleus became larger and fainter and was not seen by Ricco after the latter date … While observing with a 38-cm telescope in late August, F. Rens also discovered a secondary nucleus on August 28, and reobserved it on September 2. (Kronk, 1984: 81).

Sekanina (1979) included C/1889 O1 (Davidson) in his analysis of comets with possible multiple nuclei, and found it to be a likely candidate.

Back in 1889 James E. Keeler was interested in spectroscopy, and on 31 July and 1 August he obtained spectra of Davidson's comet using the 12-in (30.5-cm) and 36-in (91.4-cm) refractors at Lick Observatory (Keeler, 1889). According to Marsden and Williams (1996: 22) the final recorded telescopic observations of this comet were made on 14 November 1889.

We should note that while this was Queensland's first comet discovery, it was by no means Australia's first (e.g. see Haynes et al., 1996). However, the 1880s were halcyon days for Australian cometary astronomy (see Table 3) because "… Australians accounted for more than 10% of all new comets discovered worldwide during the period 1881–1889 inclusive." (Orchiston, 1999a: 43), and this figure does not allow for Bone's priority in independently discovering and reporting the Great Comet of 1880, which was advanced elsewhere (Orchiston, 1997c).

Davidson was fortunate in independently discovering a second comet, on 9 November 1892, but on this occasion he was not the first to detect it (see Table 4) and consequently his name was not assigned to it. On 21 November Davidson wrote to Henry Russell about what became known as the 'Andromeda Comet', and Russell quoted from his letter in forwarding Davidson's discovery details to the Royal Astronomical Society:

> On the 9th of November I discovered the Comet now visible in Andromeda, it was Cloudy and I could not vertify the position for a week owing to cloud and rain, it is just visible to the naked eye, and is now … 8′ in diameter and moving nearly due South about 6′ per day, there is no Nucleus and faint stars are visible through even the centre of it. (Russell, 1892a; Davidson's underlining).

As Australia's foremost cometary astronomer, Tebbutt (1893a; 1893b; 1893c) used his 8-in Grubb refractor (acquired in 1886) and occasionally his 4.5-in Cooke refractor to make a long series of micrometric observations of this new comet. These extended from 28 November 1882 through to (and including) 19 June 1893. Tebbutt (1893a: 125–126) noted that

> In November and December the comet had a fairly bright condensation … [which subsequently] grew fainter but at the same time smaller … A faint tail was occasionally perceptible in the telescope during November, December and January … [By] April 20 the comet was seen as a faint condensed point.

By 1892, Tebbutt and other leading Australian amateur astronomers "… were so enterprising that increasingly the professional [Australian] observatories left cometary astronomy to their exclusive attention." (Orchiston, 1999b: 212). Consequently, on 22 November 1892 Melbourne Observatory Director, Robert Ellery (1827–1908), advised Tebbutt that "The Andromeda Comet is just within our reach but we are not observing it as we know you are looking after it." (Ellery, 1892). Note that Ellery specifically refers to this as the 'Andromeda Comet' rather than 'Davidson's Comet'.

Subsequently this new discovery was shown to be a periodic comet, and is now known as 17P/Holmes. It has a relatively short period

Table 4: Independent discoverers of Comet 17P/Holmes, in chronological order.

Discoverer	Location	Date (1889)
Edwin Holmes	London, England	6 November
Dr Thomas David Anderson	Edinburgh, Scotland	8 November
Mike Brown	Wilkes, USA	9 November
J. Ewen Davidson	Branscombe, Australia	9 November

(6.88 yrs), which was first investigated by Kreutz (1892) and Searle (1892a; 1892b). After being observed during the 1899 and 1906 apparitions this comet was lost, and was only recovered in 1964 by Elizabeth Roemer (1964), thanks largely to predictions provided by Brian Marsden (1963). However, Comet 17P/Holmes' prime claim to fame is the major outgassing event that occurred in 2007:

> Although normally a very faint object, Holmes became notable during its 2007 return when it temporarily brightened by a factor of about half a million, in what was the largest known outburst by a comet, and became visible to the naked eye. It also briefly became the largest object in the solar system, as its coma … expanded to a diameter greater than that of the Sun … (Comet Holmes, 2010).

Figure 33: Charles Norris at the age of 45 (after Mr C.S. Norris, 1897).

Comet 17P/Holmes turned out to be Davidson's last cometary discovery but obviously he anticipated further success for we find that in early 1897 he was being coached in the calculation of orbital elements by the noted Sydney mathematical astronomer and comet specialist, Charles James Merfield (1866–1931; Merfield, 1897; Orchiston, 2015). But no new comets came Davidson's way and, as we have seen, eventually he became disillusioned with Australia and in 1900 decided to return to England. This effectively ended Queensland's initial romance with cometary astronomy.

5.3 Countering the Isolation: The Role of Astronomical Societies

As an active observational astronomer, one of the ways that Davidson tried to counter the geographical and intellectual isolation of living in country Queensland was to join international astronomical societies. Thus, when the Astronomical Society of the Pacific was formed in 1889 (Bracher, 1989) he was one of the first Australians to join. The following year the British Astronomical Association (BAA) was established in London (e.g. see Kelly, 1948; McKim, 1990), and Davidson was the first Queenslander to join, in early 1891 (see Candidates ..., 1891). In 1895 a New South Wales Branch of the BAA was founded in Sydney, and during its formative years this vibrant group included some of the nation's leading observational and mathematical astronomers and telescope makers, and it played a key role in the development of astronomy in Australia (see Orchiston, 1988b). Despite his distant domicile, Davidson joined the Branch and sometimes sent reports that were read at the Branch's monthly meetings (e.g. see Davidson, 1897a; 1897b).

Much closer to home, a Brisbane Astronomical Society was founded in 1897, three years before Davidson returned to Britain, but unlike the NSW BAA Branch, this Queensland group was not research and observationally orientated (see Orchiston, 1998), and there is no evidence that Davidson was ever an active member (or even that he joined the Society). We must remember that in the days before rapid air travel, accessing Brisbane from Mackay involved a long voyage by steamer, which made attendance at society meetings a formidable challenge.

As we saw towards the end of Section 4.4 the Canadian sociologist-astronomer Robert Stebbins proposed a range of criteria that can be used to categorise amateur astronomers. Edwin Norris did not rank highly, but Davidson is another story. Despite leading a busy life, he clearly was a 'devotee' (not a 'dabbler') and definitely was an 'active' (as opposed to 'armchair') amateur astronomer. By the time he made his second comet discovery, in 1892, Davidson could probably be classified as a 'master' rather than a 'journeyman'.

6 DISCUSSION

6.1 Charles Sydney Norris: Evidence of a Norris Astronomical Dynasty?

Charles Sydney Norris (Figure 33) was born in 1859 in Brisbane, the second child of Edwin and Charlotte Norris, and was the only one of their nine offspring with an interest in astronomy and meteorology. Charles moved with his family to Bowen in 1866 and then to Townsville in 1870. Initially he was schooled in Townsville before being sent to Sydney Grammar School where he completed his education.

In 1878 Charles Norris returned to Townsville to take up a position as an articled clerk, and on 8 March 1887 he was admitted to the bar (Supreme Court of Queensland Library, 2007a). As a result, six months later he accepted a partnership in his father's law firm. When his father died in 1892 Charles was appointed acting Town Solicitor. He was part of a growing legal community within the Townsville region, and was appointed Deputy Sheriff on 12 February, 1909 (Official notification, 1909), performing this role in addition to holding the position of Court Registrar, Town Council Solicitor and running his own law firm. By this time his older brother, Edwin Henry Norris, had joined the firm, after relocating from Cooktown (Supreme Court of Queensland Library, 2007b).

Like his father, Charles Norris was a prominent member of Townsville society. He inherited his father's interest in yachting, and was a leading member of the Cleveland Bay Sailing Club, serving for a time as Commodore. He also was a gifted swimmer and athlete (Mr C.S Norris, 1897).

At the end of 1915 Charles was promoted by the Queensland Government and had to move to Brisbane (Public curator, 1915). He retired in 1924, and died on 24 December 1935. Because he never married his estate was divided amongst his relatives, but there was no mention of any scientific instruments or an astronomical library (Solicitor leaves £10,688, 1936).

While he was still living in Townsville, an 1897 article in the *North Queensland Herald* mentioned that Charles Norris was an "… enthusiastic astronomer and meteorologist, especially the latter for the past eighteen years." (Mr C.S. Norris, 1897), and this statement is supported by a number of meteorological reports that were published in this newspaper over the years (see Darlington, 2011: Appendix 8.1). Meanwhile, Charles' interest in astronomy was apparent in February 1882—more than 9 months before the transit of Venus—when he sent John Tebbutt information about a trip he made to Adelaide and Port Louis, Mauritius, in mid-1881 (Norris, 1882). As we have seen, Charles had a passion for sailing, and this 1881 journey coincided with his entry of a half-size model of a centre board yacht in the Melbourne International Exhibition (for which he took second place for 'all-comers'). After travelling to Melbourne for the exhibition Charles may then have continued on to Adelaide to embark on the voyage to Port Louis.

At that time Mauritius was a centre for sugar refining, and both Charles and his father had pur-chased land in the Barron River region near Cairns that they planned to plant in sugar cane (From the past …, 1930; Land, 1897). Charles informed Tebbutt that during this trip he had an opportunity to view the "… 5-inch Cook [*sic*] telescopes …" at Adelaide Observatory and in Mauritius. In fact, there was no 5-in (12.7-cm) refractor at Adelaide Observatory at this time, and undoubtedly what Charles saw was the 4.5-in (11.4-cm) Cooke that had recently been acquired from the late B.H. Babbage (see Edwards, 1993) and a little over nine months later would be used to view the 1882 transit of Venus (Edwards, 2004). During his visit it is also likely that Norris saw the Observatory's principal instrument, an 8-in (20.3-cm) Cooke refractor, which was operational by this time.

Mauritius was a British colony in the Indian Ocean ~2,000 km off the African coast, due east of Madagascar. The Royal Alfred Observatory which Charles visited had been established in 1870 and was located at Pamplemousses nearly 10 km to the northeast of the capital, Port Louis. The main building was "… a handsome stone structure standing in eleven acres of Crown land, tastefully laid out with palms and other tropical trees." (Macmillan, 1914: 192), and although the Observatory functioned primarily as a meteorological, geomagnetic and seismological institution, there also were two 3-in transit telescopes and a 6-in equatorial telescope (ibid.) —which obviously is the instrument that Norris saw and mistook for a 5-in refractor.

Notwithstanding this purported interest in astronomy, just like his father there is no evidence that Charles Norris ever made any serious observations with the 6-in telescope in the Strand Observatory. There are no papers by him (or his father) listed in the leading astronomical journals of the day, *Astronomische Nachrichten*, *Monthly Notices of the Royal Astronomical Society* or *The Observatory*, and apart from Charles' occasional meteorological reports most newspaper references to him—and his father—relate to their legal activities or yachting interests and prowess.

Nor is there any indication that the transit annex that Edwin Norris planned to erect as part of the Strand Observatory was ever set up by him or by his son, which would indicate that the Norrises never provided a time service for Townsville. Thus the Strand Observatory never functioned as a *de facto* city observatory in this sense (cf. Orchiston 1989). Instead, Brisbane Observatory supplied Townsville with a time service, via a telegraphic link (By telegraph …, 1891).

The accumulated evidence clearly shows that there never was a Norris astronomical or meteorological dynasty in Townsville. In this regard, the Norrises are somewhat of an enigma. They were independently wealthy, one of the prerequisites for a successful amateur astronomer in nineteenth century Australia, and this allowed Edwin to purchase two significant telescopes (plus accessories) and construct an observatory for one of these instruments. Yet both Edwin and Charles Norris squandered the research potential of this wonderful facility, and in the eyes of the public what little observational astronomy that they did accomplish was probably viewed as a private indulgence.

6.2 The Ultimate Fate of the Two Cooke Refractors

Edwin Norris' estate was auctioned in Townsville on 9 February 1897, and there is no record of the purchaser of the Cooke refractor in his Strand Observatory, or for that matter of the other smaller telescopes that were for sale. It is unlikely that the large telescope was purchased by a member of the family. Even though Charles Norris remained in Townsville and continued to run his Flinders Street legal practice, he was a bachelor and moved every few years. There is no evidence that he purchased the telescope, let alone rehoused it after the sale of The Strand property. Apart from Charles, none of Edwin's other children ever showed an interest in astronomy, and following his death most of them, along with their mother, moved to Brisbane.

It may simply be a coincidence, then, that in May 1897—several months after the auction of the Norris estate in Townsville—Dr E. Sandford Jackson (1860–1938; Love, 1975), the Medical Superintendent of the Brisbane Hospital, announced he had received a "… large telescope …" as a gift from an anonymous donor (An anonymous gift, 1897). This was to be given to the Lady Lamington Nurses Home. While the term "large telescope" is ambiguous, and to the average layman could mean a 4-in (10.2-cm) refractor or an 8-in (20.3-cm) reflector, nonetheless, could this possibly be the ex-Norris 6-inch Cooke refractor?

We are in no better a situation regarding Davidson's Cooke telescope, which presumably returned to England with him in 1900. Although we know that he lived in Oxford, we do not know whether he remounted the telescope or whether it remained in storage, and unfortunately we know nothing of its fate following his death in 1923.

6.3 Townville's Third Observatory

As we have seen, Edwin Norris established Townsville's second astronomical observatory, on The Strand, in 1884. The town's third observatory was erected in 1892 (the same year in which he died), but it was not a 'conventional' astronomical observatory in that it was designed for the type of astronomy associated with the trigonometrical survey of Queensland.

It should be remembered that Queensland originally was part of the colony of New South Wales, and only became a separate colony in 1859. However, it was not until 1883 that "… the Government commenced a trigonometrical survey [of the colony], under direction of the Surveyor-General, Mr. McDowell …" (Ellery, 1900: 45). The aim of the survey, conducted by the Lands Department, was to determine the position of Queensland's boundaries, and the locations of lighthouses along the coast and various settlements established in the colony. The Survey also would provide reference points for a range of utilitarian purposes, such as land subdivision, and road and railway construction. It is interesting that the 1882 transit of Venus played an important part in this:

> The astronomical datum [for the trigonometrical survey of Queensland] is the position of the station at Jimbour as determined by Capt. Morris, R.E., and Lieut. Darwin, when preparing to observe the transit of Venus in 1882, the longitude being deduced by the telegraphic exchange of time signals with Sydney. (Spowers, 1912: 41).

Because of the topography of expansive inland Queensland, the procedure of establishing a baseline and then a succession of first, second and third order trig stations—as practised in neighbouring New South Wales (see Baracchi, 1914; Orchiston, 1987a)—would not work, so the focus was on establishing a succession of first order stations.

In May 1891 the Chief Surveyor of Queensland, Robert Hoggan (1852–1929),[7] began the trigonometrical survey of North Queensland (see Queensland latitudes …, 1891), with the following settlements identified for first order trig stations: Burketown, Cairns, Charters Towers, Croydon, Hughenden, Normanton and Townsville (The Public Lands …, 1892; see Figure 8 for locations). The equipment supplied for this survey was

> … a 12-inch altazimuth [theodolite], by Troughton and Simms, a chronograph, a mean solar and a sidereal chronometer, furnished with electrical attachment for automatically sending the time signals. (ibid.).

Time was supplied telegraphically by a small observatory in Brisbane with a 30-in transit telescope (Ellery, 1900).

The prefabricated portable observatory set up at each North Queensland first order trig station consisted of a circular tent observatory and an adjacent tent for associated equipment. Figure 34 shows the general appearance of the 'Charters Towers Observatory' in May 1891, which would have been similar, if not identical, to the observatory established in Townsville in 1892.

The location of the Townsville Observatory is well known: it was erected on the top of Stanton Hill, some distance from Black's observatory on Melton Hill and Norris' Strand Observatory (see Figure 35), and currently is

> … on the northern boundary of a home units complex which occupies the summit of Stanton

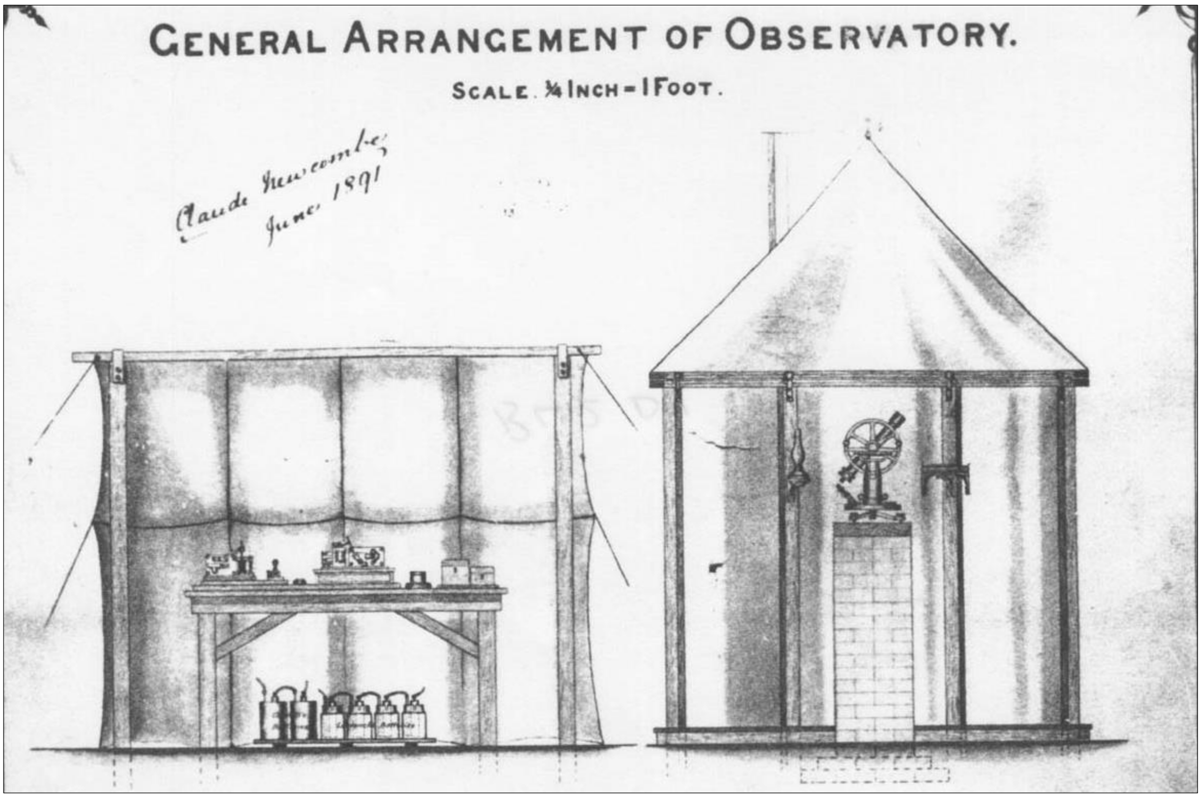


Figure 34: A cut-away side elevation of the Charters Towers Trigonometrical Observatory (courtesy: Museum of Lands, Mapping and Surveying, Queensland, acc. No. M 134).

> Hill.
>
> It is constructed of concrete and is cone shaped. The pillar stands 1.5 metres high by 0.3 metres in diameter with three holes on the top, which supported the theodolite.
>
> A paved area and gardens surround the trig station. (Townsville Astronomical Trigonometrical Station, 2013).

The thing that sets the Townsville trig station apart from other trig stations is that

> Most of the Queensland trig stations were timber posts, only remnants of which survive, erected to support a theodolite … [but] At Townsville and Thursday Island, concrete pillars rather than timber posts were erected, and these have survived largely because of their more substantial construction.
>
> While surveyors no longer need to use the Townsville trig station it is still in serviceable condition. (ibid.).

Because of this, the Townsville Observatory site is historically important in the context of land surveying in nineteenth century Queensland.

7 CONCLUDING REMARKS

For Queensland the 7 December 1882 transit of Venus was a great disappointment, with those areas occupied by observers either clouded out or rained out. However, the transit did leave a welcome legacy: two 6-in equatorially-mounted Cooke refractors and associated accessories would remain in the colony and had the potential to contribute in a valuable way to astronomical research and/or education.

Both telescopes were purchased by the wealthy Townsville solicitor, Edward Norris, and although he erected an observatory for one of the telescopes, its research and educational potential were squandered. Norris had an obvious interest in astronomy and was willing to outlay a considerable sum of money for the purchase of the telescope and construction of the Strand Observatory, but he had no serious observational aspirations with this research-class telescope. Rather, he was a 'dabbler', and astronomy was a personal indulgence. Unfortunately, the fate of this telescope after the auction of Norris' estate in 1897 remains unclear.

One of Edwin Norris' sons, Charles, also was interested in astronomy, and even more so in meteorology, but like his father he made no contribution to either discipline. Thus, father and son were wealthy pioneers from Australia's colonial era, and their affluence provided them with opportunities to participate in serious avocational scientific pursuits outside of their regular business endeavours, but they chose not to do so.

As partial compensation for this rather unsatisfactory state of affairs, Norris' second 6-in Cooke refractor fortunately fell into safe hands when it was sold to the Mackay sugar 'baron' J.

Figure 35: A modern map of downtown Townsville, Castle Hill, The Strand and Cleveland Bay, showing the positions of Townsville's first three astronomical observatories (the red circles with crosses). From left to right they are: the Townsville (Trigonometrical) Observatory (on Stanton Hill), John Melton Black's observatory (on Melton Hill) and Edwin Norris' Strand Observatory (base map: https://divezone.net/travel/townsville; map modifications: Wayne Orchiston).

Ewen Davidson in 1889. Once housed in his Branscombe Observatory near Mackay, Davidson used the telescope very effectively to discover and then track two different comets, one of which now bears his name. Yet once again we have no knowledge of the current whereabouts of this telescope, though we presume that it returned to England when Davidson retired and moved to Oxford in 1900.[8]

Finally, we should note that although Jimbour did not afford the visiting British astronomers views of the transit of Venus on 7 December 1882, the site later served as the datum point for the colony's trigonometrical survey. So in the end the transit was able to play a valuable—even if unintended—role in the development of colonial Queensland science.

8 NOTES

1. Professor Nick Lomb (pers. comm., 2017) notes that this an impressive value as agrees almost exactly with modern calculations.
2. Note that the sums only just add up. The obituary, written in 1892, states that Norris began observational astronomy 26 years earlier, which means in 1866, the very year that he left Brisbane and moved to Bowen. We can presume, though, that his astronomical 'apprenticeship' began earlier, before he became an observer.
2. This auction was the result of court action brought on by a disagreement between Charles Norris and his sister, Charlotte Alice Knapp (1867–1950), over the division of their father's considerable estate. His Honour Justice Chubb appointed J.N. Parkes as auctioneer to dispose of *all* of Edwin's property, including personal and business premises (Notice of Sale, 1897).
3. This would imply that Russell was unaware that two 6-in Cooke telescopes were sold, which is reinforced by the following details included later in his letter:

> It is satisfactory also to know that the Cooke Equatorial has fallen into his [Davidson's] possession [as] the Mr Norris who bought it from Capt Morris has I believe never used it. (Russell, 1889b).

Russell's Victorian counterpart, Robert Ellery (1900), also made this same mistake in thinking that Norris only purchased one telescope, which subsequently passed to Davidson.

4. This was a typical annual Leonid meteor shower, not one of the captivating Leonid ‘meteor storms’ that occur every 33 years. At the time, the next storm was due in 1899—see Dick (1998) for further details.
5. Prior to 1859, Queensland was part of the colony of New South Wales and not a separate colony in its own right.
6. We presume this was the new Donohoe Comet Medal awarded by the Astronomical Society of the Pacific (ASP) and endowed by the wealthy San Francisco businessman Joseph A. Donohoe (d. 1895). Since the decision to establish this medal only was made at the 27 July 1889 meeting of the ASP (Meeting …, 1889: 335) and Russell already knew about this prize by 25 July (when he wrote to Davidson), we must presume that at an earlier date one of his American colleagues forewarned Russell of the plan to establish this new award.
7. Hoggan was an ex-naval captain, who was trained in the technicalities of trigonometrical survey astronomy at the Royal Greenwich Observatory (Haynes et al., 1993).
8. Surprisingly, the existence of this telescope was unknown to those British colleagues listed in the Acknowledgements who are familiar with the history of Oxford astronomy, and we are grateful to them for trying to track down information about it.

9 ACKNOWLEDGEMENTS

We would like to thank the following people for their assistance: Dr Alan Chapman (Oxford University), John Edgar (Townsville City Council), Glen Hall (Mackay Historical Society and Museum), the late Peter Hingley (former Royal Astronomical Society Librarian, London), Dr Roger Hutchins (Oxford), Barbara Mathieson (Townsville City Libraries), Kaye Nardella (Museum of Lands, Mapping and Surveying, Queensland), staff of the Mitchell Library (Sydney), staff at the Port Macquarie Historical Society and Museum, NSW), Dr David Simcock (Museum of History of Science, Oxford), Dr Graeme White (formerly James Cook University, Townsville) and the late Dr Harley Wood (Sydney Observatory Director).

We especially wish to thank David Sellers (England) for informing us that there was a photograph of Branscombe Observatory in the Lick Observatory Archives. We also are grateful to Professor Nick Lomb (University of Southern Queensland), Associate Professor Russell McGregor (James Cook University) and Dr Peter Robertson (University of Melbourne) for reading and commenting on the MS.

Finally, we wish to thank the Allport Library and Museum of Fine Arts (Tasmanian Archives and Heritage Office, Hobart); John Oxley Library (Brisbane); Museum of Lands, Mapping and Surveying (Brisbane); National Museum of Australia (Canberra); Port Macquarie Historical Society and Museum (Port Macquarie, Australia), and the University of California (Santa Cruz) for kindly supplying Figures 2, 7, 11, 21, 22, 24, 31 and 34.

9 REFERENCES

A new observatory. *The Brisbane Courier*, 16 October, 1884. Retrieved from http://nla.gov.au/nla.news-article3435158

A peep into Queensland houses. *The Sydney Morning Herald*, 12 September 1889. Page 5. Retrieved from http://nla.gov.au/nla.news-article13740215

A sugar pioneer. *Cairns Post,* 14 December 1923. Page 9. Retrieved from http://nla.gov.au/nla.news-article40209855

A sure fortune to the purchaser. *The Queenslander*, 8 September 1877. Page 32. Retrieved from http://nla.gov.au/nla.news-article19761492

An anonymous gift. (1897, Tuesday 25 May). *The Brisbane Courier,* 25 May 1897. Page 4. Retrieved from http://nla.gov.au/nla.news-article3651492

Argus correspondent. *The Argus*, 28 October 1861. Page 6. Retrieved from http://nla.gov.au/nla.news-article5705430

Argyll, B.R.S., Doberck, W., Dreyer, J.L.E., Wragge, C.L., Denning, W. F., et al., 1882. The transit of Venus. *Nature*, 27, 154–159.

Armati, P.M., 1997. *Pio Vico Armati, 23 August 1846 to 5 December 1923: A Family History Concerning Pio, His Family and Descendants*. St. Ives (Sydney), P. Armati.

Baracchi, P., 1889. Observations of Comet e 1889, (Davidson), made at the Melbourne Observatory with the South Equatoreal and dark-field micrometer. *Monthly Notices of the Royal Astronomical Society*, 50, 46.

Baracchi, P., 1914. Astronomy and geodesy in Australia. In Knibbs, G.H. (ed.). *Federal Handbook Prepared in Connection with the Eighty-fourth Meeting of the British Association for the Advancement of Science Held in Australia, August, 1914*. Melbourne, Government Printer. Pp. 326–390.

Bhathal, R., 1991. Henry Chamberlain Russell – astronomer, meteorologist and scientific entrepreneur. *Journal and Proceedings of the Royal Society of New South Wales*, 124, 1–21.

Biggs, A.B., 1889. Observations of comet of July and August, taken at Launceston, Tasmania, Lat. 41° 26′ 01″; Long. 9° 31′ East. *Papers and Proceedings of the Royal Society of Tasmania*, 105.

Births. *The Moreton Bay Courier*, 7 April 1857. Retrieved from http://nla.gov.au/nla.news-article3718046

Bracher, K., 1989. *The Stars for All: A Centennial History of the Astronomical Society of the Pacific*. San Francisco, Astronomical Society of the Pacific.

Branscombe Sugar Mill 1871–1884. Mackay, Mackay Historical Society and Museum. Retrieved from http://www.mackayhistory.org/research/sugar_mills/branscombe.html

By telegraph and otherwise. *The Queenslander*, 1 August 1891. Retrieved from http://nla.gov.au/nla.news-article20294899

Candidates for Election as Members of the Association. *Journal of the British Astronomical Associa-*

tion, 1, 361 (1891).

Capt Morris R.E., 1882. Transit of Venus instruments for sale. *The Sydney Morning Herald*, 30 October. Retrieved from http://trove.nla.gov.au/ndp/del/article/13516962

Clearances. *The Sydney Morning Herald*, 2 August 1873. Retrieved from http://nla.gov.au/nla.news-article13317549

Comet e, 1889. *The Observatory*, 12, 334 (1889).

Comet Holmes, 2010. Retrieved from http://www.wikipedia.org/wiki/Comet_Holmes

Commissioner of affidavits. *The Brisbane Courier*, 26 September 1870. Retrieved from http://nla.gov.au/nla.news-article1330053

Cottam, S., Orchiston, W., and Stephenson, F.R., 2012. The 1882 transit of Venus and the popularisation of astronomy in the USA as reflected in *The New York Times*. *Journal of Astronomical History and Heritage*, 15, 183–199.

Cottam, S., and Orchiston, W., 2014. *Eclipses, Transits and Comets of the Nineteenth Century: How America's Perception of the Skies Changed*. New York, Springer.

Darlington, V., 2011. *The Norrises: Australian Amateurs or Private Hobbyists?* Unpublished Master of Astronomy Pilot Research Project Paper, Centre for Astronomy, James Cook University, Townsville.

Davidson, J.E., 1886. The November meteors. *The Queenslander,* 16 January. Page 1. Retrieved from http://trove.nla.gov.au/ndp/del/printArticlePdf/198027

Davidson, J.E., 1890. Comet e, 1889. *The Observatory,* 13, 247.

Davidson, J.E., 1897a. Letter to John Tebbutt, dated 15 November. In *Letters to John Tebbutt*, Mitchell Library, Sydney.

Davidson, J.E., 1897b. Letter to John Tebbutt, dated 13 December. In *Letters to John Tebbutt*, Mitchell Library, Sydney.

Death of Mr Edwin Norris. *North Queensland Herald*, 20 April 1892. Page 2.

Dick, S.J., 1998. Observation and interpretation of the Leonid meteors over the past millennium. *Journal of Astronomical History and Heritage*, 1, 1–20.

Doherty, W.J., 1934. John Melton Black. The founder of Townsville. *Townsville Daily Bulletin*, 10 July. Retrieved from http://trove.nla.gov.au/ndp/del/article/61964570?searchTerm=&searchLimits–l-publictag=John+Melton+ Black%2C+1830+-+1919

Edwards, A.W.F., 2004. Darwin, Leonard (1850–1943). *Oxford Dictionary of National Biography*. Oxford, Oxford University Press.

Edwards, P.G., 1993. Charles Todd and the Adelaide Observatory. *Proceedings of the Astronomical Society of Australia,* 10, 349–355.

Edwards, P.G., 2004. Charles Todd's observations of the transit of Venus. *Journal of Astronomical History and Heritage*, 7, 1–7.

Ellery, R.L.J., 1889. Observations of Comet 1889 IV (Davidson). *Astronomische Nachrichten*, 123, 91–92.

Ellery, R.L.J., 1892. Letter to John Tebbutt, dated 22 November. In *Letters to John Tebbutt*, Mitchell Library, Sydney.

Ellery, R.L.J., 1900. A brief history of the beginnings and growth of astronomy in Australasia. In Hall, T.S. (ed.). *Report of the Eighth Meeting of the Australasian Association for the Advancement of Science, Held at Melbourne, Victoria, 1900*. Melbourne, AAAS. Pp. 34–50.

From the past. Reflections of 1895. *Cairns Post*, 18 April 1930. Retrieved from http://nla.gov.au/nla.news-article41058883

Funeral notice. *Townsville Evening Star*, 13 April 1892.

Funeral of Mr Norris. *Townsville Evening Star*, 14 April 1892.

Government Gazette. *The Maitland Mercury & Hunter River General Advertiser*, 22 September 1855. Retrieved from http://nla.gov.au/nla.news-article706427

Grover, C., 1882–1883. The "Southern Cross" an astronomer's notes of a voyage to Australia 1882–3. In Grover and Peek, 1882.

Grover, C., 1901. Obituary. Cuthbert Peek. *The Observatory*, 24, 306–307.

Grover, C., and Peek, Sir Cuthbert, 1882. Transit of Venus 1882. MS (Canberra, Australia Joint Copying Service).

Haynes, R.D., Haynes, R.F., and Kitson, W.S., 1993. The history of astronomy in Queensland. *Vistas in Astronomy*, 36, 231–252.

Haynes, R.F., Haynes, R.D., Malin, D., and McGee, R., 1996. *Explorers of the Southern Sky: A History of Australian Astronomy*. Cambridge, Cambridge University Press.

Herschel, Sir John, 1847. *Results of Observations Made During the Years 1834, 5, 6, 7, 8, at the Cape of Good Hope* ... London, Smith, Elder and Co.

Hollis, R.P., 1912. Peek, Cuthbert Edgar. In *Dictionary of National Biography. Supplement*. Retrieved from https:/en.wikisource.org/wiki/ Peek_Cuthbert_Edgar_(DNB12)

Joy, 1874. Our local observatory. *The Queenslander*, 12 December.

Keeler, J.E., 1889. The spectrum of Davidson's Comet. *Publications of the Astronomical Society of the Pacific*, 1, 36.

Kelly, H.L., 1948. *The History of the British Astronomical Association*. *The First Fifty Years*. London, British Astronomical Association, Historical Section Memoirs, 36(2).

Kennedy, K.H., 2002. *Mackay Revisited*. Mackay, Mackay City Council and the State Library of Queensland.

Kreutz, H., 1892. Elliptische elemente und ephemeride des Cometen 1892 … (Holmes Nov. 6). *Astronomische Nachrichten*, 131, 167–168.

Kronk, G.W., 1984. *Comets. A Descriptive Catalog*. Hillside, Enslow Publishers.

Land – private sale. *Morning Post*, 9 September 1897. Retrieved from http://nla.gov.au.

Lankford, J., 1987. Photography and the 19th-century transits of Venus. *Technology and Culture*, 28, 648–657.

Love, W.R.F., 1975. St Helen's Hospital has played a living role. *Journal of the Royal Historical Society of Queensland*, 9(6), 78–88.

McKim, R.J., 1990. E.W. Maunder and the formation of the British Astronomical Association. *Journal of the British Astronomical Association*,100, 166–168.

Macmillan, A. (ed.), 1914. *Mauritius Illustrated: Historical and Descriptive, Commercial and Industrial Facts Figures & Resources*. London, W.H. & L. Collingridge.

Marsden, B.G., 1963. On the orbits of some long-lost comets. *Astronomical Journal*, 68, 795–801.

Marsden, B.G., and Williams, G.V., 1996. *Catalogue of Cometary Orbits*. Cambridge (Mass.), Central Bureau for Astronomical Telegrams & Minor Planet Center.

Meeting of the Astronomical Society of the Pacific. 1889, July 27th. *The Observatory*, 12, 335–339 (1889).

Merfield, C.J., 1897. Letter to John Tebbutt, dated 7 February. In *Letters to John Tebbutt*, Mitchell Library (Sydney).

Mills, J.A., 1981. Davidson, John Ewen (1841–1923). In *Australian Dictionary of Biography, Volume 8*. Melbourne, Melbourne University Press. P. 228.

Mr C.S. Norris. *North Queensland Herald,* 20 October 1897. Page 2.

Norris, C.S., 1882. Letter to John Tebbutt, dated 7 May. In *Letters to John Tebbutt*, Mitchell Library, Sydney.

Norris, E., 1883. Letter to John Tebbutt, dated 17 September. In *Letters to John Tebbutt*, Mitchell Library, Sydney.

Notice. *Cleveland Bay Express & Cape River Mining News*, 24 September 1870.

Notice. *The Sydney Morning Herald*, 27 September 1872. Retrieved from http://nla.gov.au/nla.news-article13264057

Notice. *The Brisbane Courier*, 15 January 1874. Retrieved from http://nla.gov.au/nla.news-article 1378012.

Notice of Sale. *The Brisbane Courier,* 30 January 1897. Page 10. Retrieved from http://nla.gov.au/ nla.news-article3644613

Official notification. *The Brisbane Courier*. 12 February 1909. Retrieved from http://nla.gov.au/ nla. news-article19563146

Official notifications. *The Queenslander*, 27 December 1884. Retrieved from http://nla.gov.au/ nla.news-article23977193

Official notifications. *Cairns Post*, 5 November 1909. Retrieved from http://nla.gov.au/nla.news-article 39391342

Orchiston, W., 1983. Illuminating incidents in Antipodean astronomy: the mysterious Tasmanian comet of December 1883. *Proceedings of the Astronomical Society of Australia*, 5, 282–284.

Orchiston, W., 1985. The contribution of Alfred Barrett Biggs to Australian and Tasmanian Astronomy. *Records of the Queen Victoria Museum*, 89, 1–28.

Orchiston, W., 1987a. Contribution of the Lands Department to the development of astronomy in New South Wales during the nineteenth century. *Australian Journal of Astronomy*, 2, 65–74.

Orchiston, W., 1987b. Dr William Bone, and the role of the amateur observatory in Australian astronomy. *Southern Stars*, 32, 111–128.

Orchiston, W., 1988a. The emergence of professional astronomy in nineteenth century Australia. *Search*, 19, 76–81; 20, 23.

Orchiston, W., 1988b. Illuminating incidents in Antipodean astronomy: formation of the New South Wales Branch of the British Astronomical Association. *Journal of the British Astronomical Association*, 98, 75–84.

Orchiston, W., 1989. The role of the amateur in early Australian astronomy. *Search*, 20, 16–23.

Orchiston, W., 1992. The contribution of Francis Abbott to Tasmanian and Australian astronomy. *Vistas in Astronomy*, 35, 315–344.

Orchiston, W., 1997a. The role of the amateur in popularising astronomy: an Australian case study. *Australian Journal of Astronomy*, 7, 33–66.

Orchiston, W., 1997b. The role of the large refracting telescope in Australian amateur astronomy: an historical perspective. *Australian Journal of Astronomy*, 7, 89–114.

Orchiston, W., 1997c. The “tyranny of distance” and Antipodean cometary astronomy. *Australian Journal of Astronomy*, 7, 115–126.

Orchiston, W., 1998. Amateur-professional collaboration in Australian science: the earliest astronomical groups and societies. *Historical Records of Australian Science*, 12, 163–182.

Orchiston, W., 1999a. C/1881 K1: a forgotten “Great Comet” of the nineteenth century. *Irish Astronomical Journal*, 26, 33–44.

Orchiston, W., 1999b. Comets and communication: amateur-professional tension in Australian astronomy. *Publications of the Astronomical Society of Australia*, 16, 212–221.

Orchiston, W., 2001a. ‘Sentinel of the Southern Heavens’: The Windsor Observatory of John Tebbutt. *Journal of the Antique Telescope Society*, 21, 11–23.

Orchiston, W., 2001b. William John Macdonnell and the development of astronomy in New South Wales. *Journal of the British Astronomical Association*, 111, 13–25.

Orchiston, W., 2004a. John Tebbutt and observational astronomy at Windsor Observatory. *Journal of the British Astronomical* Association, 114: 141–154.

Orchiston, W., 2004b. The nineteenth century transits of Venus: an Australian and New Zealand overview. *Journal of Astronomical Data*, 10, 219–308.

Orchiston, W., 2010. The Great Comet of 1881, John Tebbutt and poor old ‘Jacko’. *Journal of the British Astronomical Association*, 120, 116–117.

Orchiston, W., 2015. The amateur-turned-professional syndrome: two Australian case studies. In Orchiston, W., Green, D.A., and Strom, R. (eds.). *New Insights from Recent Studies in Historical Astronomy: Following in the Footsteps of F. Richard Stephenson*. New York, Springer. Pp. 259–350.

Orchiston, W., 2017. *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy*. Cham, Springer.

Orchiston, W., and Brewer, A., 1990. David Ross and the development of amateur astronomy in Victoria. *Journal of the British Astronomical Association*, 100, 173–181.

Our Astronomical Column. *Nature*, 40, 328–329 (1889).

Page, A.A., 1959. Astronomy in Queensland 1849–1959. *Proceedings of the Astronomical Society of Queensland*, December, 19–24.

Peek, C., 1882. Letter to his father, dated 22 October. In Cuthbert E Peek’s Letters from Australia and New Zealand 1882–1883. In Grover and Peek, 1882, 3/F6.

Personal report – cemetery listings. *Westend Pioneer Cemetary*. Townsville City Council (2011).

Plug, C., 2014. Morris, Colonel William George (geodesy). In S2A3 Biographical Database of Southern African Science. Retrieved from http://www.s2a3.org.za/Biograph_final.php?serial=1965

Proctor, R., 1874. *The Transits of Venus. A Popular Account of Past and Coming Transits*. London, Longmans, Green & Co.

Public curator. *The Queenslander*, 18 December 1915. Retrieved from http://nla.gov.au/nla.news-article22304013

Queensland latitudes and longitudes. *The Brisbane Courier*, 8 May 1891. Page 5. Retrieved from http://nla.gov.au/nla.news-article3525789

Queensland news. *The Brisbane Courier*, 2 April 1887. Retrieved from http://nla.gov.au/nla.news-article3466192

Rockhampton Bulletin, 27 September 1873. Retrieved from http://nla.gov.au/nla.news-article51806381

Roemer, E., 1964. Comet notes. *Publications of the Astronomical Society of the Pacific*, 76, 358–361.

Roth, H.L., 1908. *Discovery and Settlement of Port Mackay, Queensland*. Halifax.

Russell, H.C., 1889a. Letter to J.E. Davidson, dated 25 July. Retrieved from http://www.sydney observatory.com. au/tag/comet-discovery/

Russell, H.C., 1889b. Letter to W.H. Wesley, dated 17 September. In RAS Archives.

Russell, H.C., 1892a. Letter to W.H. Wesley, dated 26 November. In RAS Archives.

Russell, H.C., 1892b. *Observations of the Transit of Venus, 9 December, 1874; Made at Stations in New South Wales*. Sydney, Government Printer.

Searle, G.M., 1892a. Elliptical elements of Comet 1892f (Holmes). *Astronomical Journal*, 12, 127–128.

Searle, G.M., 1892b. Comet *f* 1892 (Holmes). *Astronomical Journal*, 12, 144.

Slater, B., 2005. *The Astronomer of Rousdon. Charles Grover 1842–1921.* Norwich, Stream Mill Publishing.

Solicitor leaves £10,688. *The Courier-Mail*. 11 April 1936. Retrieved from http://nla.gov.au/nla.news-article36801590

Spowers, A.A., 1912. Queensland triangulation. Appendix D in *Conference of the Director of Commonwealth Lands and Surveys, the Surveyor-General and the Government Astronomer of New Zealand, and the Surveyors-General of the States of the Commonwealth of Australia; Melbourne, 20th to 25th May, 1912*. Melbourne, Government Printer. P. 41.

Stebbins, R.A., 1980. Avocational science: the amateur routine in archaeology and astronomy. *International Journal of Comparative Sociology*, 21, 34–48.

Stebbins, R.A., 1981. Science amators? Rewards and cost in amateur astronomy and archaeology. *Journal of Leisure Research*, 13, 289–304.

Stebbins, R.A., 1982a. Amateur and professional astronomers: a study of their interrelationships. *Urban Life*, 10, 433–454.

Stebbins, R.A., 1982b. Looking downwards: sociological images of the vocation and avocation of astronomy. *Southern Stars*, 29, 177–188.

Stebbins, R.A., 1987. Amateurs and their place in professional science. In Hayes, D.S., Genet, R.M., and Genet, D.R. (eds.). *New Generation Small Telescopes*. Mesa, Fairborn Press. Pp. 217–225.

Sugar pioneer sighted a new comet in 1889. *The Daily Mercury*, 14 October 2009.

Supreme Court. *The Courier*, 8 July 1861. Retrieved from http://nla.gov.au/nla.news-article4599822

Supreme Court of Queensland Library. North Queensland legal practitioners – Norris, Charles Sydney (2007a). Retrieved from http://www.sclqld. org.au/schp/northqld/details.php?id=79

Supreme Court of Queensland Library. North Queensland legal practitioners - Norris, Edwin (2007b). Retrieved from http://www.sclqld.org.au/schp/northqld/details.php?id=327

Tebbutt, J., 1889. Observations of Comet 1889 … (Davidson). *Astronomische Nachrichten*, 122, 349–350.

Tebbutt, J., 1890. Observations of comets at Windsor N. S. Wales. *Astronomische Nachrichten*, 123, 409–410.

Tebbutt, J., 1893a. Observations of Comet 1892 VI at Windsor, N.S. Wales. *Astronomische Nachrichten*, 133, 125–132.

Tebbutt, J., 1893b. Further observations of Comet 1892 VI at Windsor, N.S. Wales. *Astronomische NacNachrichten*, 133, 195–198.

Tebbutt, J., 1893c. Last Windsor-observations of Comet 1892 VI. *Astronomische Nachrichten*, 133, 347–348.

The Brisbane Courier, 28 October 1882. Page 4. Retrieved from http://nla.gov.au/nla.news-article 3405442.

The Gazette. *The Brisbane Courier*, 23 April 1866. Retrieved from http://nla.gov.au/nla.news-article 1266229

The Public Lands: Annual Report of the Department for 1891. *The Brisbane Courier*, 15 June 1892. Page 6. Retrieved from Http://nla.gov.au/nla.news-artlcle3543442

The transit of Venus. *The Brisbane Courier*, 29 November 1882(a). Page 5. Retrieved from http://trove. nla.gov.au/ndp/del/printArticlePdf/3410994

The transit of Venus. *The Queenslander*, 2 December 1882(b). Page 781. Retrieved from http://trove.nla. gov.au/ndp/del/printArticlePdf/19788139/3

The transit of Venus in 1882. *Nature, 25*, 2 (1882).

The vagabond. In Northern Queensland, *The Argus*, 16 February, 1884. Page 4.

Townsville Astronomical Trigonometrical Station, 2013. Queensland Government, Department of Environment and Hertitage Protection. Retrieved from https://heritage-register.ehp.qld.gov.au/place Detail.html?siteId=15701

Transit of Venus. *South Australian Register*, 4 November 1882. Retrieved from http://nla.gov.au/ nla. news-article43332849

Vagabond, T., 1884. At Townsville. *The Brisbane Courier*, 3 March. Page 3. Retrieved from http://nla.gov.au/nla.news-article3427621

van Roode, S., 2011. The transit of Venus. Jimbour 1882. Observatories at Jimbour House.

W.H.M.C., 1882. The transit of Venus. *Monthly Notices of the Royal Astronomical Society*, 42, 181–182.

Williams, T.R., 2000. Getting Organized: A History of Amateur Astronomy in the United States. Unpublished Ph.D. thesis, Rice University, Houston (http://hdl.handle.net/1911/19569).

Professor Wayne Orchiston has a Ph.D. from the University of Sydney and is a Senior Researcher at the National Astronomical Re-search 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 exten-sively on the history of Aus-tralian

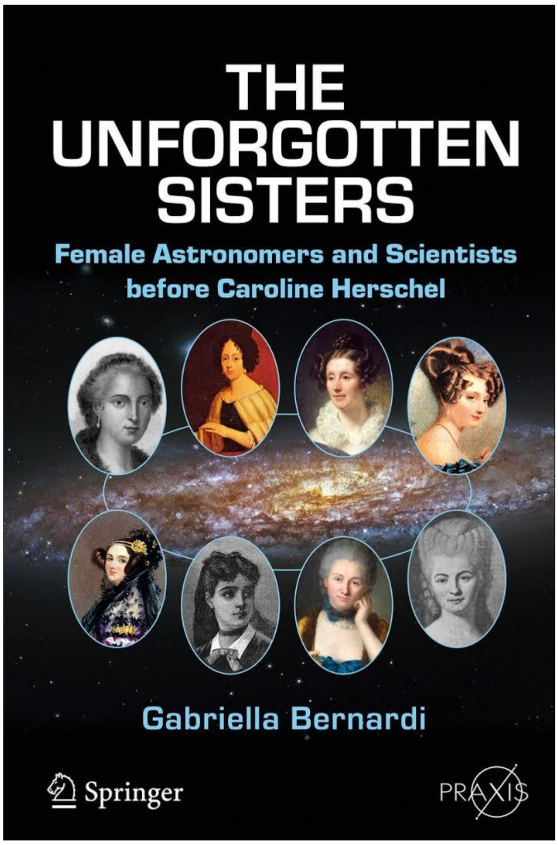
context, his recent books included *Eclipses, Transits, and Comets of the Nineteenth Century: How America's Perceptions of the Skies Changed* (2015, Springer, co-authored by Stella Cottam), *Exploring the History of New Zealand Astronomy: Trials, Tribu-lations, Telescopes and Transits* (2016, Springer), which examines in detail the 1874 and 1882 transits of Venus, and *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy* (2017, Springer). 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 in his honour.

Vicki Darlington is a former Townsville secondary school science teacher with a strong interest in astronomy and geology. After completing a Master of Astronomy degree in the Centre for Astronomy at James Cook University (Townsville, Australia) and writing a mini-thesis about the astronomical interests and activities of the Norris family of Townsville (which are discussed in the present *JAHH* paper) she enrolled for a Ph.D. in Geoscieces at James Cook University, and currently is studying the Bald Hill Meteorite Impact Crater in northern Australia for her thesis project.

BOOK REVIEWS

***The Unforgotten Sisters: Female Astronomers and Scientists before Caroline Herschel*, by Gabriella Bernadi. (Springer International Publishing, 2016). Pp. 179. ISBN 978-3-319-26127-0 (eBook), ISBN 978-3-319-26125-6 (softcover), 155 × 234 mm, € 83.**

The Unforgotten Sisters traces the history of women engaged in mathematics and science, especially astronomy, from the twenty-third century BC to the nineteenth century AD. Gabriella Bernardi has degrees in physics and popular science and is a freelance journalist who specializes in astronomy. She does a masterful job in this book describing the hurdles women have historically faced as they pursued their interests in areas that were, for the most part, reserved for men. Numerous illustrations bring to life the women and the instruments they utilized in their work.



Although *The Unforgotten Sisters* contains actual letters of correspondence, the title Bernardi chose for this book comes from a fictional letter by Caroline Herschel that is written in poetic form by Siv Cedering. In it she describes some of her observations, calculations, and her work on the lenses and mirrors of the telescope that she and her brother, William Herschel, use to sweep the heavens. She then notes that:

> Sometimes when I am alone in the dark, and the universe reveals yet another secret, I say the names of my long lost sisters, forgotten in the books that record our science.

The book is divided into five major parts with a chapter devoted to each of the twenty-five women in chronological order. Timelines are given for each of the major parts, alerting the reader to well-known historical events and scientific discoveries that occurred during the same time period. Though not a distinctive topic, Bernardi discusses in unusual detail the historical context in which each of these women worked, their main area of expertise and any papers published, as well as records and citations of their observations and calculations. She livens up what could have become a dry presentation of historical facts with curious facts about these women, their families, and their individual circumstances.

Bernardi offers clear-cut examples of women in astronomy whose work has been unrecognized or almost forgotten over time. For instance, Maddalena and Teresa Manfredi, with the possible collaboration of another sister, Agnese, aided their brother Eustachio in the astronomical observations and mathematical calculations required for the 1715 publication of the *Ephemerides of Celestial Motion*. However, they never signed or took credit for any of their work. It is only in the preserved original manuscript—not the printed edition—that their brother states this work, including the required calculations, was completed with the help of his sisters.

Most of the women Bernardi includes in her book came from privileged backgrounds, with access to an education in science and mathematics historically denied to women. One such example, Sonduk, the first female monarch of Korea (from AD 634–637), developed a strong interest in astronomy at a young age. After she succeeded her father, her continued interest and means led to the construction of the oldest surviving astronomical Observatory in the Far East.

Quite a few of these early female astronomers studied privately with their fathers, brothers or husbands. However, if they went on to work ‘professionally’ with these men, their research was often incorporated with and credited to their male mentors. For instance, Maria Margarethe Winkelmann-Kirch was the first woman to officially discover a comet. As was the custom of the time, though, all her independently made discoveries were incorporated under the authorship of her husband, so her discovery of a comet in 1702 originally was credited to him.

Disappointingly, the early chapters of this book provide few specific details such as those given above. However, this is not due to a lack of effort on the author's part, it is simply due to the fact that many of the ancient Babylonian, Egyptian and Greek manuscripts were destroyed or lost over time. Bernardi fills in, though, with interesting historical notes regarding ancient customs and astronomical knowledge. This book would be useful as a reference, but is confusing in places due to an incorrect usage of personal pronouns. A more careful edit would have made it easier to read.

The Unforgotten Sisters will be appreciated by anyone interested in the history of astronomy or women in science and mathematics. It will be of particular benefit to girls wishing to pursue a degree or career in astronomy as it highlights achievements made by women through sheer determination. All readers will come away with a high regard and an appreciation for each of these women and the individual challenges they faced while pursuing a greater understanding of all things astronomical.

Dr Jana Ruth Ford
Department of Physics and Astronomy
Middle Tennessee State University
Email: jford@mtsu.edu

***The Glass Universe: How the Ladies of the Harvard Observatory Took the Measure of the Stars*, by Dava Sobel. (New York, Viking, 2016). Pp. xii + 324. ISBN 978067001952 (hardback), 160 × 235 mm, US$30.**

The popular science author Dava Sobel has produced some excellent books, and one that is questionable. My favourite one is *Letters to Father* from 2001, consisting of letters written to Galileo by his daughter. Her 1995 book *Longitude* unfairly maligned Great Britain's Astronomer Royal, Nevil Maskelyne, as a villainous character. She is back on solid ground with this book about the women who by virtue of their intelligence, dedication and largesse played a pivotal role in the development of astronomy at Harvard Observatory in the late nineteenth and early twentieth centuries.

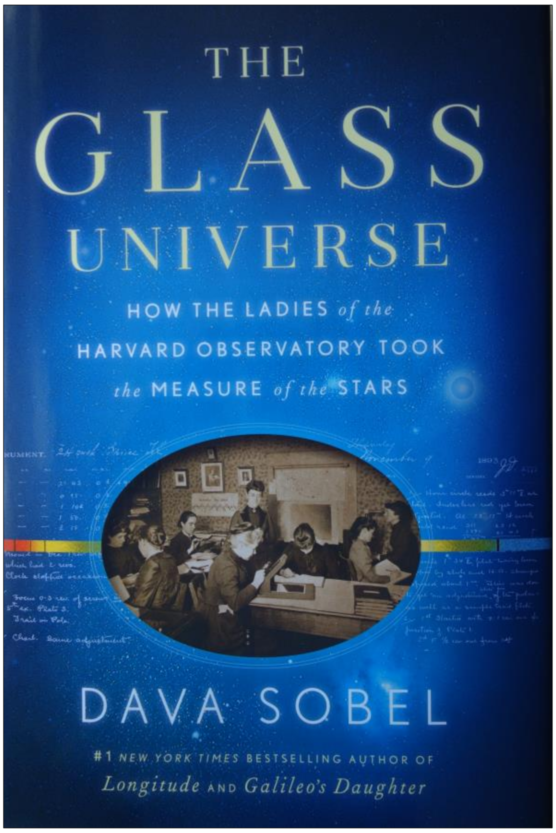
Elements of the book were especially interesting to me as I knew several of the people Sobel writes about. These include Bart Bok, and Helen Sawyer Hogg, who officially opened my own observatory dedicated to asteroid photometry. The timeline at the conclusion of the book includes Dr Hogg's marriage in 1930 and her award of the Annie Jump Cannon Prize in 1950. However, the timeline is inconsistent as it notes the passing of some, but not all, women who feature in this book. Among these missing entries are Drs Hogg and Priscilla Fairfield, in 1993 and 1975 respectively. In 1921, Fairfield was one of the first women to receive a Ph.D. in astronomy. She began working at Harvard in 1923,

> … comparing the spectra and proper motions of giant and dwarf stars belonging to Draper class M, in order to more clearly define the line distinctions between them. (page 217).

Sobel tells us that Fairfield was able to pay her student assistants 30 cents an hour to help, thanks to a $500 grant from the National Academy of Sciences.

In 1928 Fairfield attended "… the largest and most global gathering of astronomers ever united." (page 223). This was in Leiden, where 243 delegates, including 14 from post-world war Germany, met to discuss all aspects of astronomy. Sobel informs us "The moment Miss Fairfield stepped off the train at the Leiden station, she attracted the attention …" of a certain Dutch astronomy student. Miss Fairfield

> … tried to fend off the amorous advances of her new suitor, who, at twenty-two, was a good ten years her junior. Bart Bok persisted, however, and at length overcame her misgivings. (page 224).



Miss Fairfield thus became Mrs Bok. This extract is given to show one of this book's great strengths—the interweaving of both professional and personal information, which provides texture to the great story Sobel offers us.

While she concentrates on the ladies of Harvard Observatory, Sobel necessarily must also delve into the careers of the men who ultimately ran the place. Among these is Harlow Shapley, whose views of the cosmos were repeatedly shown to be at odds with reality. Sobel quotes from his letters to give us a real-time sense of what he was thinking on the great issues of the day. In July 1918, while World War I was still raging, Shapley wrote to Edward Pickering

> I believe the most important photometric work that can be done on Cepheid variables at the present time is a study of the Harvard plates of the Magellanic clouds. (page 170).

This is a perfect example of the warning, 'be careful what you ask for'. Shapley believed our Galaxy was the entire Universe, but a study of Cepheid variable stars, particularly in the so-called 'Andromeda Nebula', proved that our Galaxy is one of many. It was Edwin Hubble in 1924 who found a Cepheid in the Nebula, showing it is at least a million light years away. Instead of just mentioning such a discovery in dispassionate scientific terms, Sobel puts us in the moment with this dramatic sentence:

> After Shapley read Hubble's news and looked at the light curve, he held out the pages to Miss Payne, saying, 'Here is the letter that has destroyed my universe.' (page 204).

I have just mentioned the Harvard plates, which, along with the ladies, are the co-stars of this book. Thanks to the large and continuing grants of money from Anna Palmer Draper, Harvard was able to establish a suite of telescopes in various countries to advance astronomical research. The centrepiece of this work was photographic, and resulted in hundreds of thousands of plates that contained the treasures of the Universe. It was this treasure trove that was mined by dozens of young women whose lives and careers are sensitively traced by Sobel. She looks at those who achieved immortal fame, such as Annie Jump Cannon, Antonia Maury and Henrietta Leavitt, along with many others who are nearly forgotten. Some of these dedicated women literally worked themselves to death in the cause of science, and this book serves as a fine testament to their efforts.

The index has some issues. For example, the asteroid Eros is listed with several page entries, but its appearance on pages 155 and 160 are missing. The 8-inch Bache telescope at Harvard College Observatory is likewise given several page references, but its mention on page 72 is missing from the index. Fairfield's entry is given twice, once under Fairfield, Priscilla and again under Bok, Priscilla. These are just three examples.

Despite my minor quibbles, Sobel has produced a readable and engaging account of how modern astrophysics developed, and the crucial role of women in that grand endeavour.

Dr Clifford J. Cunningham
National Astronomical Research Institute
of Thailand, Chiang Mai, Thailand.
Email: Cliff.Cunningham@usq.edu.au

***Discovery of the First Asteroid, Ceres*, by Clifford Cunningham (Springer International Publishing, 2016). Pp. xiii + 333. ISBN 978-3-319-21776-5 (hardback), 157 × 240 mm, €129.99.**

***Early Investigations of Ceres and the Discovery of Pallas*, by Clifford Cunningham (Springer International Publishing, 2017). Pp. xix + 412. ISBN 978-3-319-28813-0 (hardback), 157 × 240 mm, €149.99.**

This five volume series covers historical studies in asteroid research and, judging by the first two volumes reviewed here, this project will be an all-encompassing compilation and definitive study of this topic. Building upon and substantially revising the author's earlier work in many areas, Cunningham combines a historian's love of detail with a sense of the wider impacts of events to retell one of the great stories in the development of our understanding of our Solar System through the application of mathematical tools that has focused the power of human intellect to understand the nature of the Universe.

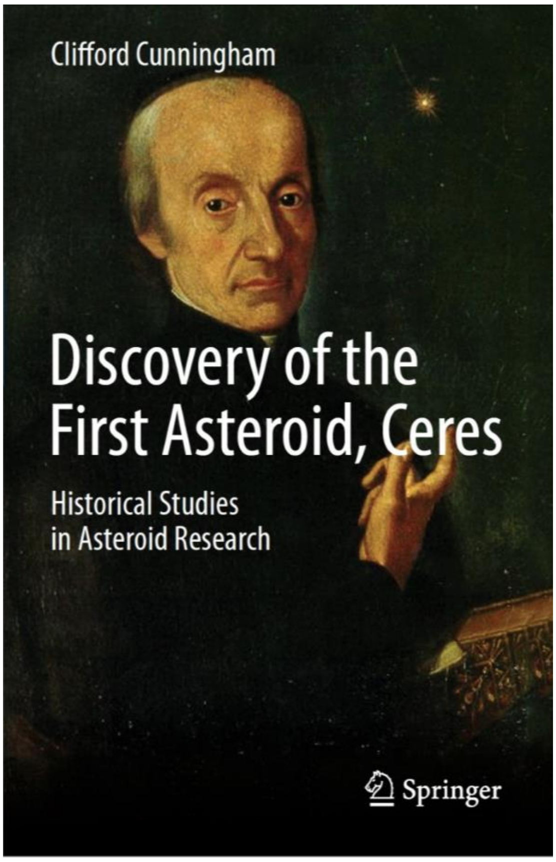
These two books follow a common structure: the introductory chapters cover the main topics and draw upon correspondence between the major figures to advance the narrative. Subsequent chapters reproduce books, correspondence and letters to provide an original source perspective on the events of the time. This is one of the books' major strengths, namely the publication in English of original sources regarding historical developments. Cunningham illustrates the broader impact of events through examples of verse and art. The illustrations enrich the story and include images of people covered in the narrative, together with cover pages of major publications.

Another strength of these volumes is the connection that the author makes between the tight world of professional astronomy and the broader aspects of human society. The impact of new discoveries on literature and art is presented by numerous excerpts from noted writers and by many illustrations from publications of the times communicating discoveries to the broader public.

Volume One, Discovery of the First Asteroid, Ceres

After tracing the idea that there just might be another planet between Mars and Jupiter back to its origin with Kepler, Cunningham describes its development as a mathematical relationship relating the size of planetary orbits in the introductory chapter. Herschel's discovery in 1781 cemented the validity of this theory when Uranus fitted nicely into the framework. Plausibly there was an undiscovered planet there so European astronomers set out to find it. Chapter 2 relates the intriguing story of how Ceres was actually discovered, including errors made along the way. The following chapter covers one of the great stories in astronomy: the recovery of Ceres due to the mathematical genius of Gauss when observational searches proved fruitless. This chapter is enriched with an essay by Brian Marsden recounting this recovery. Chapters 4 and 6 describe the ensuing controversy over naming of this new world and how the public first learned about Ceres.

Chapter 5 describes the initial efforts to determine the physical properties of Ceres and the realization that it did not fit any of the models for what a planet or a comet should be.



Books by Piazzi, Bode and Schroeter, and correspondence and letters between the leading figures in this story are included in Chapters 7–14. Four appendices flesh out details of the instrument that Piazzi used to discover Ceres, a chronology of the events of 1801, development of the orbital elements of Ceres and a recounting of the various star charts that played a crucial role in the discovery.

The story of their success is interwoven with the personalities and politics, along with contextual international events. What sets this volume apart from previous works is the comprehensive detail that Cunningham has assembled. Numerous interesting details bring human elements to the story such as the account of Cacciatore on the events surrounding the discovery of Ceres and the subsequent efforts of Piazzi to minimize the importance of his role. Cacciatore's alternative perspective points out the all-too-human characteristics of who history records as great discoverers. Piazzi's eagerness to receive full credit is further illustrated by the apparent efforts that he took to make it difficult for others to find Ceres in the sky. The collecting of original communications, publications and notes, all presented in English, provides a valuable resource for any student of asteroid science and the scientific historian.

There are only minor issues with this volume. The section in Chapter 2, page 38, titled "When Was Ceres Seen for the First Time", leaves the reader puzzled as to what the answer is. This rather vague recounting adds little to the question. Also, the caption to Figure 2.3 on page 29 states that "Figure 2.3 show the seven stars from Piazzi's …" However this figure actually depicts the front and back of a medal.

Finally, an update. The table on page 89 now needs to be modified to reflect the DAWN determination of the size of Ceres (a mean diameter of 588 miles), rather than using Millis' 1987 value.

Volume 2. Early Investigations of Ceres and the Discovery of Pallas

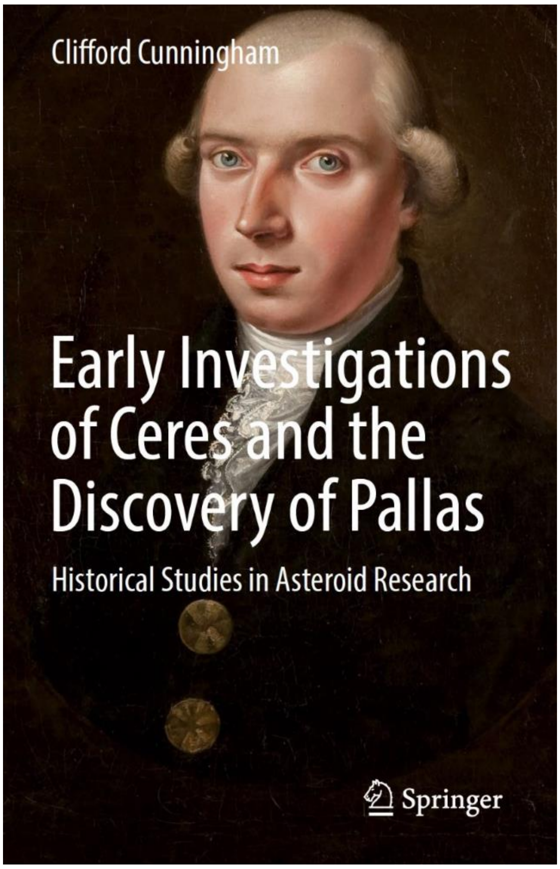
The first five chapters of this volume cover a wide range of topics, from the general state of mathematics in European countries to the origin of the word 'asteroid' to describe Ceres and the other bodies found in this region of the Solar System. Chapter One explores the role of mathematics in understanding the world and then explores why there were fundamental difference between the methods of celestial mechanics as practiced in France and Germany. This difference was crucial as the French failed to successfully predict the location of Ceres, while Gauss, with the German influence (Ramism), succeeded. Cunningham inserts his own perspective:

> I contend that one of these new aspects arose in the study of celestial mechanics around 1800. My analysis does not suggest that Ramism was deliberately or consciously employed in this effort that found its greatest expression in the recovery of Ceres. (page 12).

One need only look ahead 45 years to the discovery of Neptune to see how the fortunes of French celestial mechanicians had improved.

Chapter 2 compares the state of science and mathematics in France with that of Germany, with a bit of England and English satire thrown in, while Chapter 3 explores professional rivalries among the leading German, French and English astronomers of that time. The following chapter recounts the origin of the term 'asteroid' to describe these newly discovered objects that clearly did not belong to the same class of objects as the planets. The section on "What is a Planet? A View from the Eighteenth Century" raises a question that invokes deeply held opinions even today and will likely undergo further revisions as our knowledge of exoplanets expands.

In Chapter 5 we arrive at The Discovery of Pallas by Olbers, on 28 March 1802. Rather than describing the discovery events in detail in his own words, Cunningham tells the story as told in the words of Olbers himself from a letter. Few words are spent on the actual discovery before the narrative moves on to a discussion of the nature of Pallas. This is followed by a discussion of the 'exploded planet' hypothesis of Olbers, presented on 15 May 1802. The remainder of this chapter deals with Bode's attempt to preserve his law and an extensive section on how the public learned of the discovery of Pallas. More details of the circumstances of the discovery of Pallas would be welcome here. While Olbers was searching for another planet, in the broad sense, he was following Ceres on 28 March—so was it sheer luck that Pallas was close by, thus enabling its discovery? Did Olbers have a broader strategy in his search for a new world? Why was Olbers looking for another planet in the first place, since Ceres had filled the gap between Mars and Jupiter? Appendix B gives the positions of Ceres and Pallas in 1801–1802, but the ephemeris for Pallas (Figure A2) covers only dates in April and May, not 28 March. Giving the location of both bodies on the discovery date would enable the reader to judge the degree to which chance was crucial in the discovery of Pallas.



Chapters 6–10 reproduce original logbooks, letters, books and scientific papers by various participants in this story and contain interesting insights into the origin of various ideas. For example, Ende suggested to Olbers that Pallas might have resulted from a cosmic catastrophe (the 'exploded planet hypothesis'), but is never given credit for this, as Cunningham notes. Another example is in the letter from Gauss to Olbers where Gauss introduces the idea that these bodies might collide:

> Both paths would come frightfully close together at a place not far from the area where the two stars are. Our descendants could perhaps some day be spectators of the most terrible phenomenon: the collision of the two celestial bodies!

Today studies of asteroid collisional evolution are a fundamental component of understanding the origin and evolution of this population.

These two books are definitive works on the discoveries of Ceres and Pallas and provide deep insights into the broader context and impact of these events. They are intended primarily for the historian of planetary science and those interested in the impact of new discoveries in science on human culture. While the vast amount of material assembled in these volumes may be intimidating for the casual reader, they do provide a rich resource for both serious researchers and students of asteroidal history. Cunningham has done a great service to this field by producing these works.

Dr Donald R. Davis,
Planetary Science Institute, Tucson,
AZ 85719, USA.
drd@psi.edu

***Roman Portable Sundials: The Empire in Your Hand*, by Richard J.A. Talbert. (Oxford, Oxford University Press, 2017). Pp. xxi + 236. ISBN 9780190273484 (hardback), 170 × 240 mm, US $55.**

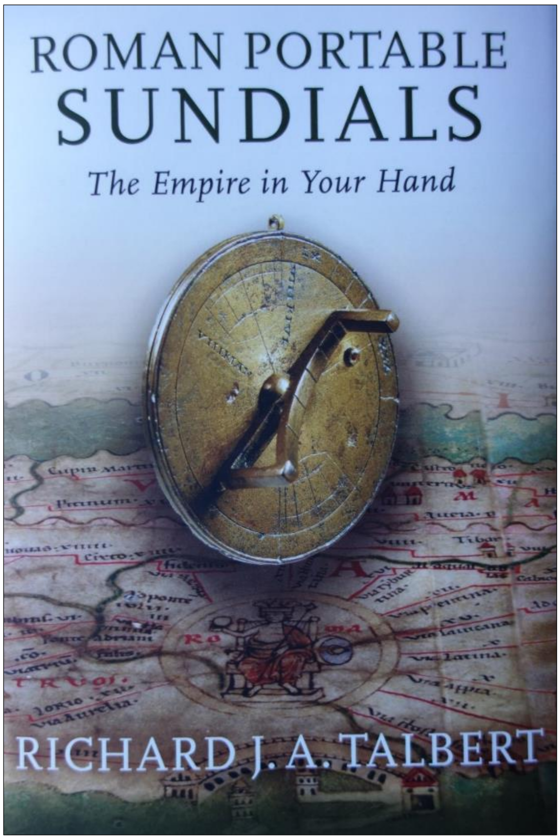
Richard Talbert, the William Rand Kenan Professor of History at the University of North Carolina, is the world's leading authority on ancient geography. He has now brought this expertise to bear on portable sundials that embody spatial data.

During the annual conference of the Classical Association of Canada in May 2017, at which we both presented research papers, I was able to interview Professor Talbert about his book, and this is what he told me:

> I am not interested in these instruments *as such* … For the ancient sundials, all the conversation has always been about how these instruments are designed and produced and how accurately they can tell the time.

This book is a noted and welcome departure from those purely technical studies, and gives us a novel insight into the role of time in everyday Roman life.

Talbert looks not just at portable sundials, but at a subset of them that contain geographical information. "On the reverse there is a listing of either province, island or city names each with its own latitude figure …" Talbert explained. He then elaborated:



> What interests me as a historian, is that when you look at these lists, almost all of them are pretty clearly individual creations. They can fit as many as 36 names on these sundials. These belonged to people who are cosmopolitan: they have a vision of the whole Greek and Roman world. They then pick some that they want to have on the back of the sundial as a kind of speed dial list.

This way of regarding these portable sundials opens up a whole new field of investigation into ancient Roman people and society. Talbert told me he terms it 'mental mapping', a way of getting "… a glimpse of what these peoples' world view was."

In the first, rather brief, chapter, Talbert notes only one mention of portable sundials in ancient literature. It comes from Vitruvius (late first century BCE) who tantalising says sundials were made "… for taking on a journey and hanging up." (page 10). As the author makes clear, our certain knowledge about portable sundials derives entirely from the extant examples. Who made them, where they were made, who owned them, and many other basic questions, cannot yet be answered.

Chapter 2, which comprises 90 pages, is a case-by-case review of each portable sundial that is engraved with geographic information. In all there are 16, although Talbert suggests that others may be languishing in private hands or museum collections. Of the 16, several have been lost, and we are left only with a diagram. Most consist of circular disks, but one in the Archaeological Museum at Philippi in Greece comprises three nested rings. "It's design is remarkable …" the author writes. "It matches that of the 'astronomical ring dials' known from the Renaissance onward and not previously thought to have had any forerunners." (page 76). It likely dates from between 250 and 350 CE.

The center ring of this unique example comprises two half-rings, which contain four locations: Alexandria, Rhodes, Rome, and Vienne (located in the southeast portion of France). The inner ring (marked with 12 divisions for the hours) includes a slit "… pierced in the center by a small hole. Rays of the sun passing through this hole mark the time." (page 81).

The remaining three chapters look at the existing evidence for clues about the use of these small sundials. Some derive their geographical information from Ptolemy's *Geography* (ca. 150CE). In this volume, Ptolemy gives the position of 6,000 settlements and features across the known world. Talbert notes "His inspiration came from celestial mapping …" (page 119) in his *Almagest*, which is known in astronomy as the most influential book of all time as it shaped our understanding of the cosmos to the time of Copernicus and beyond.

Talbert's book concludes with an intriguing appendix about a marble fragment found in Budapest in 1990. Talbert is the first to suggest that this is a sundial-makers' manual that was "… discarded sometime during the second or third centuries CE." (page 218). This highlights the likelihood that future archaeological discoveries will reduce the level of conjecture about portable sundials that Talbert was obliged to take.

This is a fascinating and eminently scholarly book that is the first to focus attention on this important aspect of Roman timekeeping, and Oxford University Press is to be commended for publishing the many photographs with the clarity required to see the fine details commented upon by the author.

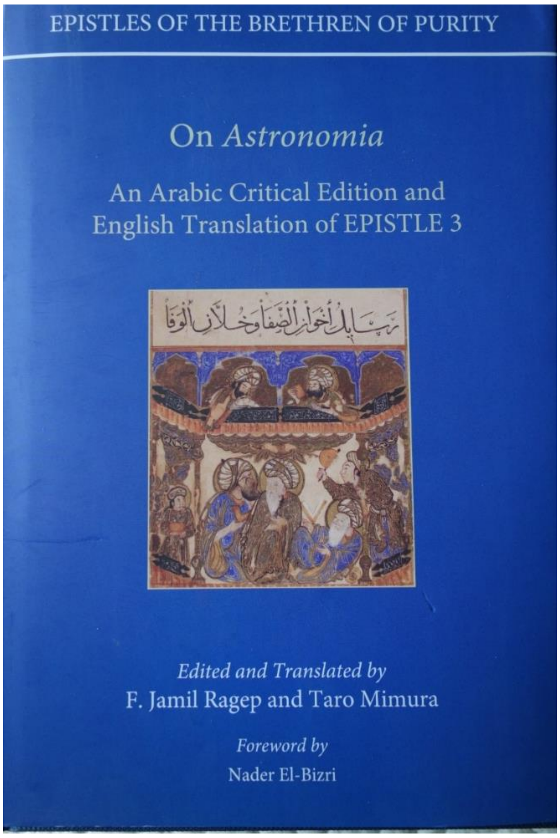
Dr Clifford J. Cunningham
National Astronomical Research Institute
of Thailand, Chiang Mai, Thailand.
Email: Cliff.Cunningham@usq.edu.au

***On* On Astronomia*: An Arabic Critical Edition and English Translation of EPISTLE 3*, edited and translated by F. Jamil Ragep and Taro Mimura, foreword by Nader El-Bizri, Epistles of the Brethren of Purity (Oxford, Oxford University Press in association with The Institute of Ismaili Studies, 2015), pp. 352. ISBN 9780198747376, 156 × 234 mm, £50.**

The Brethren of Purity were a secretive society in tenth-century Iraq. They gained prominence in the history of Islamic science and philosophy through fifty-two Epistles that were widely read and copied. Written by anonymous members of the fraternity, the Epistles covered various branches of the natural sciences, philosophy, and theology. The brethren were perhaps not among the greatest scientific authorities of their age. However, they were still influential in bringing together, and popularizing, diverse areas of knowledge. Due to their prominence, modern scholars started editing the Epistles and translating them into European languages as early as the nineteenth century. However, these editions and translations were incomplete and often uncritical. The Institute of Ismaili Studies in London built on these efforts to produce a more definitive edition of the Arabic text as well as an English translation. After an introductory book published in 2008, Epistle 3, *On* Astronomia, is the eighth volume in the Institute's series.

The word *Astronomia* in the epistle's Arabic title (*al-asṭrunūmiyā*) is the transliteration of a Greek word that encompasses both astrology and astronomy in the modern sense. The Epistle covers both areas of knowledge, but with a focus on astrology. It is primarily didactic and scientifically neither 'creative' nor 'insightful', as the editors write in their introduction (page 4). The astronomical and astrological contents can be found in earlier works by Ptolemy, Abū Maʿshar, and Farghānī. The most interesting aspect of the work is perhaps its adaptation and combination of Arabic and Greek, Islamic, Christian, and pagan thought. The Epistle quotes the Qur'an as well as the gospels of Matthew, Mark and Luke. Muhammad is part of the Epistle, as are various Biblical figures, including Abraham, Jesus, John the Baptist, Moses, Noah, and Zachariah. Among Greek philosophers and scientists, Aristotle, Diogenes, Ptolemy, Pythagoras, and the Pythagoreans appear. The Brethren of Purity engaged in such syncretism in order to demonstrate the harmony of the Universe and to offer the reader moral and spiritual guidance. The Epistle's subtitle describes it as a text "… for improving the soul and rectifying character." (page 21). Understanding God's perfect design of the cosmos would help people adopt proper conduct and reach happiness and salvation, the fraternity argued.

The Epistle contains around thirty-two main chapters plus thirteen additional ones at the end of two of the manuscripts. The astronomical content includes the yearly motion of the Sun, the seasons, and solar and lunar eclipses. The Brethren of Purity also described the motions of Saturn, Jupiter, Mars, Venus and Mercury through the orbs, which are, "… spherical, transparent, and hollowed-out bodies." (page 26). Astrological chapters characterize and divide the zodiacal signs. Furthermore, the Epistle relates these signs to the Sun, Moon and planets through accounts of houses and detriments, decans and their lords. Other chapters are devoted to divine providence and salvation as well as numerology.


EPISTLES OF THE BRETHREN OF PURITY

On *Astronomia*

An Arabic Critical Edition and
English Translation of EPISTLE 3

رسائل اخوان الصفا وخلان الوفا

Edited and Translated by
F. Jamil Ragep and Taro Mimura

Foreword by
Nader El-Bizri

The editors have produced the most comprehensive and useful edition and translation of the brethren's Epistle 3 to date. F. Jamil Ragep and Taro Mimura used seven manuscripts from Istanbul and Tehran that had been completed between the twelfth and the fifteenth centuries. Footnotes and appendices with additional chapters preserve the variations between the different manuscripts. Another appendix consists of a concordance of manuscripts and a previous edition published in Beirut. The English translation is accurate and mostly literal, giving a good feel of the Arabic. However, as a result, perhaps only specialists in ancient and medieval history will find the text easy to read and particularly enjoyable. Even the editors' introduction is itself very technical. Nevertheless, Ragep and Mimura have tried to help modern readers as much as possible. Arabic and English indices list subjects, terms and quotations from scripture. Moreover, a glossary includes Arabic concepts and their English equivalents. Finally, a four-page bibliography includes valuable suggestions for further reading.

Although the epistles of the Brethren of Purity were popular in pre-modern times, the appeal of a critical edition and largely literal translation, like Ragep and Mimura's, might be limited to scholars. Nevertheless, among academics, *On* Astronomia is of interest not just to historians of Arabic and Islamic science. Because of the Brethren's inclusion of Hellenistic philosophy and Biblical material, the epistle is a valuable document for the wider study of late antique and medieval intellectual history and for understanding the relationship between science, religion and philosophy. In his foreword, Nader El-Bizri, the General Editor of the series, placed the Epistles of the Brethren of Purity "… amongst the distinguished Arabic classics and the high literature of Islamic civilization." (page xx). However, *On* Astronomia can be seen as part of Hellenistic and wider Abrahamic traditions as well as an Islamic one.

Dr Jörg Matthias Determann
Virginia Commonwealth University School of the Arts in Qatar
E-Mail: jmdetermann@vcu.edu
orcid.org/0000-0002-9463-9408