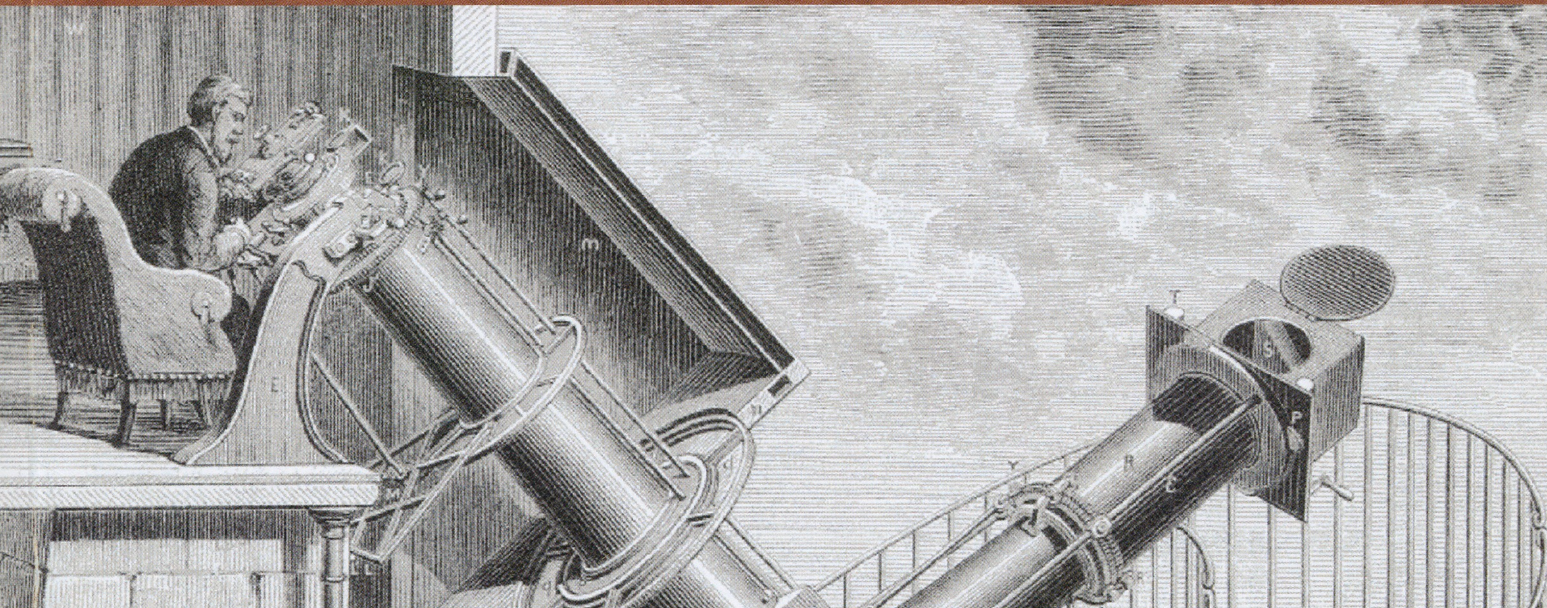
JOURNAL OF ASTRONOMICAL HISTORY AND HERITAGE



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COVER PHOTOGRAPH

A drawing of the 'Petit Équatorial Coudé' (Small Coudé Equatorial) at the Paris Observatory. This novel telescope was designed by Maurice Lœwy (1833−1907), an astronomer at the Observatory (and its Director from 1896), and was constructed in 1882. It featured a 27-cm diameter objective made by Paul and Prosper Henry and a mounting fabricated by Paul Gautier. Another astronomer at the Paris Observatory was Charles Nordmann (1881−1940), and in 1910 he and Pierre Salet used this telescope to carry out 3-colour photometry on 52 stars. Nordmann was one of the pioneers of multicolour stellar photometry, and his research is described by James Lequeux on pages 207-219 in this issue of *JAH*^{2}. The Petit Équatorial Coudé was eventually dismantled in 1971-1972. This cover image was kindly provided by the Bibliothèque de l'Observatoire de Paris.

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RONALD N. BRACEWELL: AN APPRECIATION

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Abstract: Ronald Newbold Bracewell (1921–2007) made fundamental contributions to the development of radio astronomy in the areas of interferometry, signal processing, and imaging, and also to tomography, various areas of data analysis, and the understanding of Fourier transforms. He was born in Sydney, Australia, and received a B.Sc. degree in mathematics and physics, and B.E. and M.E. degrees in electrical engineering from the University of Sydney, and his Ph.D. from the University of Cambridge, U.K., for research on the ionosphere. In 1949 he joined the Radiophysics Laboratory of CSIRO, where he became interested in radio astronomy. In 1955 he moved to Stanford University, California, where he became Lewis M. Terman Professor of Electrical Engineering. He retired from teaching in 1991, but continued to be active in radio astronomy and other applications of imaging techniques, etc. During his career he published ten books and more than 250 papers. Honors that he received include the Duddell Premium of the Institute of Electrical Engineers, London, the Hertz Medal of the IEEE, and the Order of Australia. For his work on imaging in tomography he was elected to Associate Membership of the Institute of Medicine of the U.S. National Academy of Sciences.

Keywords: Ronald N. Bracewell, radio astronomy, CSIRO Division of Radiophysics, Stanford University

1 EDUCATION AND EARLY YEARS

Bracewell attended the Sydney Boys High School 1933-1937. In addition to science and mathematics he was interested in languages and passed oral exams in French and German. In 1937 he was awarded the Alliance Française Prize and came third in the state in French. After high school, he was a student at the University of Sydney and in 1941 graduated with a degree in physics and mathematics, and in 1943 with a degree in Electrical Engineering with First Class Honours. He also received an M.E. degree in 1948 for his work at CSIRO. He spoke of the influence of Oxford-trained Victor A. Bailey (1895–1964) in his approach to physics and of Joseph L. Pawsey (1908–1962), a student of Cambridge Professor John A. Ratcliffe (1902–1987), in the duality of his physical versus mathematical approach to transmission lines and antennas.

In 1943-1945, during WWII, he was a member of the Radiophysics Laboratory of the CSIR (from 1949, CSIRO = Commonwealth Scientific and Industrial Research Organization), in Sydney, and worked with Pawsey and Edward G. ('Taffy') Bowen (1911–1991) on development of radar and radio communications. In 1946, after the War, Bracewell went to Sidney Sussex College at Cambridge (England) as Ratcliffe's graduate student. His research topic was the study of the ionosphere using propagation measurements at 16 kHz, for which he obtained his Ph.D. The ionospheric work resulted in the discovery that the D layer ionization consists of two components, for which he was awarded the Duddell Premium of the Institute of Electrical Engineers in 1952. The effect of solar activity on the ionosphere was one of the factors that led to Bracewell's lifelong interest in the Sun. His interest in the theory and applications of Fourier transforms, which was initiated by mathematics courses at Sydney University, was further stimulated by Ratcliffe who was a recognized authority on the subject.

2 INTRODUCTION TO RADIO ASTRONOMY

In 1949 Bracewell returned to Australia and again took up a position at CSIRO. Initially he continued his work on the ionosphere, but soon became involved in radio astronomy which was being actively pursued. He shared an office with radio astronomers W.N. ('Chris') Christiansen (1913–2007) and Harry Minnett (1917–2003), who were working on solar radio observations (see Orchiston, Slee and Burman, 2006). Christiansen had built grating arrays of parabolic antennas, aligned in N-S and E-W directions, along the edges of a reservoir at Potts Hill near Sydney (see Wendt et al., 2008). These produced fan-beam scans of the Sun over a range of angles each day. From these it was possible to derive radio brightness contours of the Sun in two dimensions (see Christiansen and Warburton, 1955a; 1955b). Bracewell was interested in this analysis, which involved Fourier transforms. He was also intrigued by the possibility of using two grating arrays to produce a matrix of pencil beams, using the cross configuration developed by Bernie Mills (1920–) for linear arrays (see Mills and Little, 1953). During this time Pawsey, the leader of the radio astronomy group, invited Bracewell to be co-author of the book *Radio Astronomy* (Pawsey and Bracewell, 1955), and Bracewell later surmised that this was partly a device to get him more involved in the subject. Pawsey also asked him to produce a pictorial dictionary of Fourier transforms, which later led to Bracewell's most important book, *The Fourier Transform and its Applications* (Bracewell, 1965).

During the academic year 1954-1955, Bracewell was invited by Otto Struve (1897–1963) to give a series of lectures on radio astronomy at the University of California, Berkeley. He also lectured at Stanford University, which led to his joining the Electrical Engineering Department at Stanford in December 1955. An interesting autobiographical account of the period from his first interest in radio astronomy through the early years at Stanford can be found in his paper, “Early work on imaging theory in radio astronomy”, published in Sullivan’s *The Early Years of Radio Astronomy* (1984), while his recollections of the Stanford years can be found in Bracewell (2005).

3 IMPORTANT EARLY PAPERS AND A BOOK

During the period 1949-1965, from his first interest in radio astronomy through his early years at Stanford, Bracewell produced a number of publications on interferometer theory, imaging with interferometers and arrays, and data analysis that established his expertise in this area. Examples of notable publications are discussed below.

3.1 “Aerial Smoothing in Radio Astronomy” (Bracewell and Roberts, 1954)

This paper was particularly important in the early years of radio astronomy, when the relation between the true profile of a source and the profile obtained by scanning with an antenna was not well understood. Bracewell and James A. (Jim) Roberts (1927–) explained the scanning as a convolution of the brightness function and the point-source response of the antenna. The convolution theorem of Fourier transforms shows that the Fourier components of the source profile are filtered by the Fourier spectrum of the antenna response. The concept of invisible distributions (i.e. Fourier components not detectable with a given aperture distribution) was introduced in this paper. This provided essential insights into the observing process. The later part of the paper is concerned with reducing the effect of aerial smoothing by analytically adjusting the antenna response so that all of the Fourier spatial components to which it responds are given equal weight. Bracewell referred to this process as *restoration* and the resulting profile as the *principal response*. The angular resolution is usually improved by the restoration process, but the sharp cutoff in angular frequency at the maximum to which the antenna system responds can result in extensive sidelobes which limit the dynamic range.

3.2 “Strip Integration in Radio Astronomy” (Bracewell, 1956)

This paper considered the construction of two-dimensional images from one-dimensional scans of a source with a range of position angles as was required, for example, to obtain a solar map from Christiansen’s early grating-array observations. The Fourier transform relationships involved are succinctly illustrated in a diagram (Figure 5 in his paper) which Bracewell later refers to in his chapter in Sullivan’s 1984 book as the ‘projection-slice theorem’. He used the term *reconstruction* to describe this method of production of two-dimensional images, a technique which was later adapted to tomography. Further development can be found in “Inversion of fan beam scans in radio astronomy” (Bracewell and Riddle, 1967).

3.3 “Radio Interferometry of Discrete Sources” (Bracewell, 1958)

This paper provides a precise development of the interferometer response and the Fourier transform relationship between the fringe visibility and the brightness distribution. The paper also unifies material discussed in earlier publications by various authors. Bracewell introduces the use of direction cosines for the angular coordinates on the sky, thereby avoiding the small-angle approximation used in most of the earlier discussions of interferometry. This paper also uses the sampling theorem of Fourier transforms to determine the most efficient choice of the spacings of antennas in interferometry.

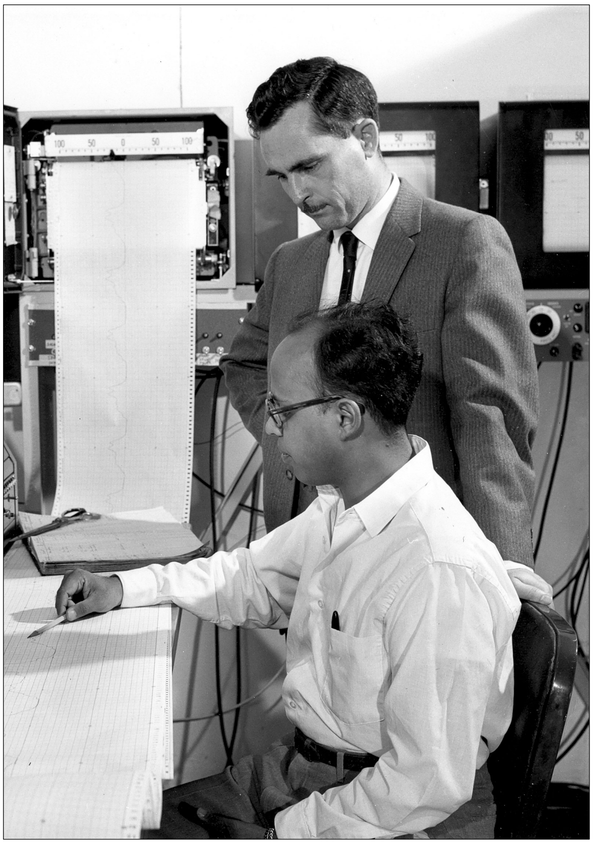

Figure 1: Ron Bracewell with his student Govind Swarup,[1] who was later awarded a fellowship of the Royal Society of London for his work in radio astronomy in India. This photograph was taken about 1960, and shows them examining records of solar scans taken in the early phase of the program with the solar cross (courtesy: Stanford University News Service).

3.4 “Tolerance Theory of Large Antennas” (Bracewell, 1961)

This paper precedes by several years the famous paper on the same subject by J. Ruze (1966). It is difficult to be sure about precedence of ideas on this subject, which was developing during the 1950s. Bracewell’s paper is one of the earliest detailed analyses.

3.5 *The Fourier Transform and its Applications* (Bracewell, 1965)

The end of this period saw the publication of Bracewell’s most important book, *The Fourier Transform and its Applications*. This book cemented the early ‘physical versus mathematical’ learnings from Pawsey, and the period with Ratcliffe, in a book that became the Fourier transform ‘bible’ for many in the radio astronomy scene. Through it, Bracewell established a level of recognition for his elucidation of the convolution theorem and its importance in the interpretation of observations. He developed a reputation for his demanding exactitude from those who worked in his space.

4 STANFORD AND THE HELIOPOLIS OBSERVATORY

At Stanford Bracewell established a Radio Astronomy Institute, and also an observatory which he named Heliopolis. This was located on the outskirts of the Stanford lands. The first instrument developed at Heliopolis was a solar cross, i.e. a crossed-grating array for solar observations, as he had considered earlier while at CSIRO. This array was made to Bracewell's design, and consisted of 32 parabolic antennas arranged in two linear arrays and operated at 9.1 cm wavelength. It is described by Bracewell and Swarup (1961). Phase adjustment of the cross led to the invention of the round-trip phase measurement technique by Bracewell's graduate student Govind Swarup (1929–; see Figure 1), which is described by Swarup and Yang (1961). An adaptation of this round-trip technique has subsequently been used in almost all large radio astronomy arrays. The solar cross was used to make daily maps of the Sun, with an angular resolution of 3.2 arcmin from June 1962 to August 1973. These were published monthly, and the observations also resulted in a number of papers on radio emission from the solar corona. Two additional antennas were added to extend the east-west arm of the cross to form a compound interferometer. This produced fan beams of width 52 arcsec, and east-west scans of several strong radio sources were obtained with this angular resolution (Swarup, Thompson, and Bracewell, 1963; Thompson and Krishnan, 1965).

The east-west arm[2] of the cross array was also used to study the radio source Centaurus A, a radio galaxy that was strong, optically identified, and of sufficient angular width that the beam of the arm could reveal interesting structural detail. The two components of the central part of the source were detected (Little, Cudaback, and Bracewell, 1964). In April 1962, during a trip to Australia, Bracewell had the opportunity to observe Centaurus A with the Parkes Radio Telescope at 10 cm. He was able to resolve the two components in the central part by driving the telescope in both azimuth and elevation simultaneously, so as to scan in the direction of the component separation. He was also able to rotate the feed and discover the linear polarization. However, there appeared to be some question of whether the observation was made during an officially-granted observing time, and Bracewell's letter to *Nature* (Bracewell, Cooper, and Cousins, 1962) was not published until 29 September 1962. Meanwhile, other observations made shortly after Bracewell's, also reporting polarization of Centaurus A, appeared in print a few weeks before Bracewell's letter. More detailed accounts of these circumstances can be found in Bracewell (2002) and Haynes et al. (1996).

At Heliopolis there were also two 30-ft diameter equatorially-mounted parabolic antennas, and during the 1960s these were used as a two-element interferometer at 9.8 cm (~3.1 GHz). They could be moved between several foundations to vary the length and direction of the baseline. The interferometer provided material for several of the Ph.D. theses listed in Section 8, but the collecting area was too small for observation of more than a few of the strongest galactic and extragalactic sources. Bracewell considered building an instrument with a much larger collecting area, using several long cylindrical reflectors. He envisaged an instrument that would grow with time, by the addition of more elements as funding allowed (Bracewell, Swarup, and Seeger, 1962). However, funds for a large instrument proved to be unavailable, and the development of Earth-rotation synthesis by Martin Ryle (1918–1984) showed the advantage of fully steerable antennas. Thus Bracewell concluded that the most economical way to obtain sensitivity would be by building an array of tracking antennas which could be designed and constructed under his direction. This resulted in five 18.3-m (60-ft) diameter antennas, which were made to Bracewell's design and constructed on-site at Heliopolis. The antennas were configured as an east-west, minimum-redundancy, linear array devised by Bracewell (1966), in which all spacings up to nine times the unit spacing are included. The operating frequency was 10.7 GHz, allowing synthesis of a beam of width 18.8". A well-illustrated description of the construction project is given in Bracewell et al. (1971) and full details of the array in Bracewell et al. (1973). Observations with the array provided data for a number of papers and theses by Bracewell's students, including further work on Centaurus A (Price and Stull, 1973). This array was in operation from 1972 until the closing of the Heliopolis observatory in 1979.

The discovery in 1964 of the cosmic background radiation (CMB) by Arno Penzias (1933–) and Robert Wilson (1936–) (see Penzias and Wilson, 1965) provided a radio astronomical feature that could be investigated without the use of large antennas. Bracewell realized that although the measurements made in the early years after the discovery indicated a uniform brightness temperature, the motion of the Earth with respect to the CMB would cause an observable variation, which he and his graduate student E.K. Conklin were able to calculate (Bracewell and Conklin, 1968). From observations at Heliopolis, only upper limits on the variation could be obtained. To reduce atmospheric absorption, the project was moved to a high-elevation site in the White Mountains of California, using two small horn antennas at a frequency of 8 GHz. Conklin (1969) was then able to publish a determination of the velocity of the Earth from measurements of variation of the observed CMB temperature at the mK level. This was the first detection of the effect, and a notable achievement considering that it was made with a simple system using two small horn antennas with an uncooled receiver.

In the late 1960s, Bracewell's work on reconstruction of images from one-dimensional scans became recognized as having an important application in medical imaging by X-ray tomography. As mentioned above, the theory of reconstruction of a two-dimensional image from one-dimensional scans had been explained by Bracewell (1956). The implementation was further advanced in the paper with graduate student A.C. Riddle (1941–2005) on "Inversion of fan-beam scans in radio astronomy" (Bracewell and Riddle, 1967). In this later paper the procedure is simplified by the avoidance of the need to compute Fourier transforms. Bracewell wrote two further papers specifically on tomography, one with graduate student J. Verley (Verley and Bracewell, 1979). He also devoted a chapter on tomography in his book *Two Dimensional Imaging* (Bracewell, 1995). For his contribution to tomography, Bracewell was awarded associate membership of the Institute of Medicine of the U.S. National Academy of Sciences in 1962.

5 WORK AT STANFORD AFTER HELIOPOLIS

Funding for the operation of Heliopolis was discontinued in 1979, as a result of the general policy of supporting a single national observatory for radio astronomy rather than a number of smaller ones operated by individual universities. Thus, radio astronomical observations at Stanford were discontinued, but Bracewell's interest in radio astronomy and related sciences continued unabated. In Bracewell (1978) he suggested the use of interferometry in space for detection of non-solar planets, and this idea and further details are discussed in several later papers. These describe a proposed application of infrared interferometry using space vehicles, in which a null in the fringe pattern is steered onto the position of a star to allow a search for much fainter images of planets. The idea has been widely discussed as a possibility for terrestrial telescopes or a future space mission (see, e.g., Hinz et al., 1998).

Starting in 1983, Bracewell published 13 papers (e.g. Bracewell 1984b) and a book (Bracewell 1986) on mathematical development of the transform introduced by Hartley, which is similar to the Fourier transform but does not involve complex factors. He developed Hartley versions of the numerous theorems and relationships that are well known in Fourier transform theory, and also a fast Hartley transform (FHT) algorithm, which could in many cases be used as an alternative to the fast Fourier transform (FFT). The avoidance of complex quantities for transformation of real data in the FHT allowed it to perform twice as fast as the versions of the FFT in use at the time, but later improvements to the FFT overcame its disadvantage in speed.

During the period 1985-1989 Bracewell published a number of papers on sunspot statistics and the solar cycle. In a much earlier paper (Bracewell, 1953) he had pointed out that since the magnetic polarization of sunspots changes sign in alternate 11-year sunspot cycles, the sign of the sunspot number should be reversed in alternate 11-year cycles, revealing a 22-year periodicity. This applies to studies in which the sunspot number is used as a measure of the active nature of the Sun. Without this sign reversal, the oscillations of the 22-year sunspot function are effecttively rectified, and artificial frequency components can be introduced. This important derectification step was included in Bracewell's later work in the 1980s. Examination of the sunspot numbers when plotted with the derectified 22 year cycle led him to the discovery of a three-halves power-law in the annual mean values, which he considered to be one of the more important results of his analysis (Bracewell, 1988a). He was interested in the basic mechanism of the sunspot cycle, and in Bracewell (1989) discussed a possible theory in which magneto-mechanical waves propagate outward from a source at the center of the Sun.

Another sunspot-number feature that Bracewell investigated involved a possible relationship with a series of geological laminae from the late Precambrian era, located in the Elatina area of South Australia, and hypothetically identified as varves (Bracewell, 1988b).[3] These had been studied by a geologist (Williams, 1985) who suggested that periodic variations in the thickness of the layers could be interpreted as indicating a time scale similar to that of the sunspot numbers. A putative mechanism linking the structure to solar radiation involved flow of melt-water and resulting variations in water levels on depositions in a lake. Thus, hypothetically, the thickness of the layers could provide an indication of the variation in the strength of solar radiation from year to year. However, a similar layered structure was later found in a different region of South Australia (Sonett et al., 1988) in which the geological situation suggested a luni-solar tidal mechanism rather than a solar radiation mechanism. The tidal mechanism was also found to be applicable to the Elatina laminae, and the solar cycle interpretation of the Elatina data has been largely abandoned.

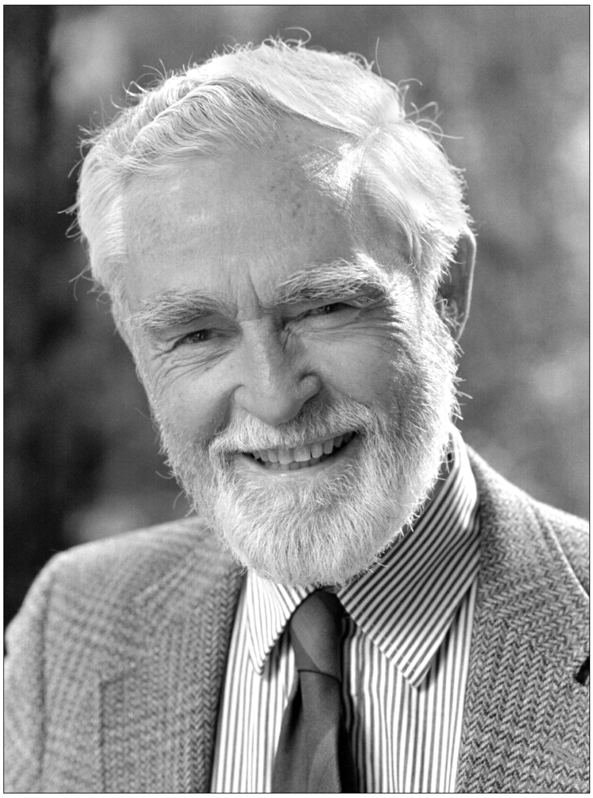

Figure 2: Ron Bracewell in 1997 (photograph by Linda A. Cicero/Stanford News Service, 1997).

6 BRACEWELL AS A TEACHER AND MENTOR

Bracewell always presented his lectures with an infectious enthusiasm. He was a challenging taskmaster for his graduate students. Bracewell had a good eye for, and an appreciation of, capable people and delighted in being able to stretch their capabilities. He was a great mentor and always demanded clear and detailed thinking when approaching any problem. He insisted upon precise definitions and disliked making changes in them. Thus, in his papers on interferometry he preferred to follow Michelson's original definition of fringe visibility, in which the zero-spacing value is normalized to unity, rather than expressing it in units of flux density as has become the common practice. He never fully approved of the use of image processing routines that introduced Fourier components of the brightness that had not been measured in the observations. His careful understanding of basic concepts and detailed thinking enabled him to make contributions in many fields, and influenced the lives of students and colleagues who worked with him.

When examining students, Bracewell liked to try to judge their ingenuity and power of observation as an indication of aptitude for experimental research. During annual interviews with prospective Ph.D. students in the Department of Electrical Engineering, he often tested their reaction to unusual things that they had not seen before. One year he asked each student to examine a piece of wood that he had made. This was approximately boat-shaped and had the property that when set spinning in either a clockwise or counter-clock-wise direction, it ended turning in the clockwise direction.[4] He wanted to see a careful inspection of the object, and tests of how it behaved under various conditions, rather than an attempt at a mathematical exposition. In another year he asked the students to examine a sample piece of the circular waveguide used for signal transmission in the VLA, without telling them what it was. A careful visual examination of this would show that the surface impedance of the inner wall was very low in the circumferential direction, but much higher in the longitudinal direction, which could provide a clue as to its use.

Bracewell retired from teaching in 1991, but continued to work in his areas of interest. His list of publications from these later years contains 22 papers and 12 book reviews. In 1994 he was awarded the Heinrich Hertz Medal of the IEEE for pioneering work in antenna aperture synthesis and image reconstruction as applied to radio astronomy and to computer-assisted tomography. In 1998 he was named Officer of the Order of Australia for his service to science in the fields of radio astronomy and image reconstruction. Figure 2 shows a photograph taken in 1997.

7 BREADTH OF EXPERTISE AND INTEREST

Bracewell's mathematical expertise is evident from much of his work, especially his books on the Fourier and Hartley transforms. He also had an excellent understanding of physics as is evident in publications such as "Rotation of artificial earth satellites" (Bracewell and Garriot, 1958) and "An observer moving in the 3° K radiation field" (Bracewell and Conklin, 1968). In Mihovilovic and Bracewell (1991) he and his student introduced the concept of chirplets as a representation for ionospheric whistler signals and similar data in a time-frequency domain. Practical engineering skills can be seen in Bracewell's designs of both the solar cross and the five-element array. In the latter, the detailed antenna design was his conception, and enabled the array to be implemented at relatively low cost. He enjoyed being involved at a hands-on level in engineering projects. An example of his understanding of fundamental theory in engineering is the paper on "Impulses concealed by singularities: transmission-line theory" (Bracewell, 1998).

The remarkably wide range of Bracewell's scientific interests can be clearly seen in the diversity of the subjects of his publications and lectures. Throughout his career he had a long-term interest in the possibility of the existence of extraterrestrial intelligence, and the practicality of extraterrestrial communication. This resulted in 19 papers and the book *The Galactic Club* (Bracewell, 1974). An example of his interest in the history of science and engineering can be seen in the paper "Planetary influences on electrical engineering" (Bracewell, 1992). He designed sundials, one of which was installed at the Terman Building on the Stanford campus. Bracewell had a life-long interest in trees, particularly those native to Australia, and in California he identified more than seventy species of the introduced eucalypts. He wrote two books on trees of the Stanford area and had some fine examples of banksias growing in the garden of his house at Stanford.

8 GRADUATE STUDENTS OF R.N. BRACEWELL

Below is a list of students who obtained advanced degrees by working in Bracewell's group. (In the case of D.D. Cudaback, the degree was awarded by University of California, Berkeley). Many of the radio astronomical observations used by Bracewell's students were made at Heliopolis, exceptions being those of Goldstein, who observed at the Harvard Radio Astronomy Station at Fort Davis; Lang, who used data from the 150-ft antenna of the Stanford Research Institute and the Arecibo antenna; and Hughes, who used the interferometer at Caltech's Owens Valley Radio Observatory. In the following list the titles of the theses are given, and where this is known the institutions or professions to which the persons moved after leaving Stanford.

Samuel J. Goldstein, (Ph.D. 1958, "On Wide-Band Two-Element Interferometers for Radio Astronomy"), University of Virginia.

Govind Swarup, (Ph.D. 1961, "Studies of Solar Microwave Emission Using a Highly Directional Antenna"), Tata Institute of Fundamental Research, Mumbai (India).

Alec G. Little (M.S. 1961), School of Electrical Engineering, University of Sydney, Australia.

Roger S. Colvin, (Ph.D. 1962, "A Study of Radio Astronomy Receivers"), Business (Electrical Engineering).

David D. Cudaback, (Ph.D. 1962, "Thermal Emission of the Moon at 9 cm Wavelength"), University of California, Berkeley.

Stanley H. Zisk, (Ph.D. 1965, "An Interferometric Study of Several Discrete Radio Sources").

Zvonko Fazarinc, (Ph.D. 1965, "An Interferometric Study of Orion and Omega Nebulae and of Sagittarius A"), Hewlett-Packard.

George W. Downs, (Ph.D. 1968, "An Interferometric Study of the Polarization of Two Radio Sources at a Wavelength of 9.8 cm"), JPL, MIT.

Anthony C. Riddle, (Ph.D. 1968, "High Resolution Studies of Solar Microwave Radiation"), University of Colorado.

Edward K. Conklin, (Ph.D. 1969, "Anisotropy and In homogeneity in the Cosmic Background Radiation), NRAO, Forth Inc.

Kenneth R. Lang, (Ph.D. 1969, "Lunar Occultations of Radio Sources"), Tufts University.

Michael P. Hughes, (Ph.D. 1970, "A Study of 21 cm Absorption by Neutral Hydrogen in the Galaxy"), North West Kent College of Technology (UK).

Werner Graf, (Ph.D. 1973, "Latitude and Solar-Cycle Dependence of the Height of 9.1 cm Solar Radio

Emission”), Stanford University, SRI International.

Larry R. D’Addario, (Ph.D. 1974, “The Stanford Synthesis Radio Telescope: Theory, Calibration, and Data Processing; and a Study of Galactic HII Regions”), NRAO, JPL.

Steven J. Werneke, (Ph.D. 1976, “Maximum Entropy Techniques for Image Reconstruction from Interferometer Measurements and Projections”).

C. John Grebenkemper, (Ph.D. 1977, “The Theory and Implementation of the Stanford Aperture Synthesis Radio Telescope; and Observations of the Solar Slowly Varying Component at a Wavelength of 2.8 Centimeters”).

Jacques G. Verley, (Ph.D. 1980, “High Resolution Imaging 2-D and 3-D Parallel-Beam X-Ray Computed Tomography”).

John D. Villasenor, (Ph.D. 1989, “Two-Dimensional Digital and Analog Hartley Transforms”).

David M.W. Evans, (Ph.D. 1989, “An Improved Approach to Harmonic Spectral Analysis, and the Canonical Transform”).

Domingo A. Mihovilovic, (Ph.D. 1992, “Feature Identification in Data Represented as Images”).

9 FURTHER INFORMATION

Some of Bracewell’s own descriptions of his work can be found in his chapter in Sullivan (1984), Bracewell (2005), and the text of a recorded interview by Ragbir Bhathal on 10 June 2000, for the Oral History Section of the National Library of Australia. Bracewell’s scientific papers are archived at the National Radio Astronomy Observatory, Charlottesville, VA. A complete list of his publications can be found at http://www.nrao.edu/archives/Bracewell/bracewell_top.shtml. This list includes 10 books, 218 articles in the open literature, 33 book reviews, and 34 internal reports.

10 NOTES

1. For details of Swarup’s career see Swarup (2006).
2. The maximum elevation of Centaurus A was too low for useful resolution with the north-south arm. For observations of Centaurus A a parametric amplifier developed by A.G. Little (1961) was used to improve the sensitivity. Alec Little (1925–1985) obtained an M.S. degree from Stanford for his amplifier work.
3. The Elatina layers were measured in detail from core samples. In terms of the solar cycle interpretation they covered a range of more than 1,300 years and thus might have provided a major chronological increase in solar-cycle data. Note that the term “varves” applies specifically to layers deposited in annual cycles.
4. The ‘rattleback’ phenomenon (see, e.g., Walker, 1979). The examination in which the device was used was in 1977.

11 ACKNOWLEDGEMENTS

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A. Richard (Dick) Thompson is a graduate of the University of Manchester, and in 1956 obtained his Ph.D. for work at the Jodrell Bank Experimental Station, where as a student of R. Hanbury Brown, he developed a long-baseline radio interferometer for measurement of angular widths of radio sources. From 1956-1957 he worked with E.M.I. Electronics, Middlesex, on missile guidance and telemetry. He then joined the staff of Harvard College Observatory as a Research Associate, working on the solar program at the Harvard Radio Astronomy Station, Fort Davis, Texas. In 1962 he moved to Stanford University as a member of R.N. Bracewell's radio astronomy group. During 1966-1972 he also held a visiting appointment at Caltech's Owens Valley Radio Observatory. In 1973 he joined the National Radio Astronomy Observatory (NRAO), and served in various engineering and management positions in the VLA and VLBA projects. From 1978 to 1998 he was also active in frequency coordination for radio astronomy and was a member of U.S. Study Group 7 of the International Telecommunication Union (earlier Study Group 2 of CCIR) and Chairman of the U.S. Working Group on Radio Astronomy. Between 1980 and 1991 he was a member of the Committee on Radio Frequencies of the National Academy of Sciences. He is first author of the book *Interferometry and Synthesis in Radio Astronomy* (Wiley, 1986, 2nd edition 2001), and is currently an emeritus scientist at NRAO.

Robert H. (Bob) Frater graduated in science and engineering from Sydney University. After working with the OTC and Ducon Industries he returned to Electrical Engineering at Sydney University where he worked on Mills Cross electronics development and improvements to the correlator system for R. Hanbury Brown's stellar interferometer. It was here that he first met Ron Bracewell, a valued mentor. Bob Frater was awarded a Ph.D. in 1967. He subsequently worked on the development of the Fleurs Synthesis Telescope and joined the Electrical Engineering academic staff at Sydney. He was awarded a D.Sc. in engineering in 1982.

He joined CSIRO as Chief of the Division of Radio-physics in 1981, and in this role he obtained funding for and directed the construction of the Australia Telescope. He was appointed to the CSIRO Executive in 1988, becoming Deputy Chief Executive in 1997. He joined medical device company ResMed as VP for Innovation in 1999.

He was a member of the Anglo-Australian Telescope Board from 1981 to 1993 (and Chair 1989-1993); Vice Chairman, then Chairman, of Commission J of URSI from 1984 to 1990; and Vice President and Secretary, Physical Sciences, of the Australian Academy of Science from 2004 to 2008.

He has been a Fellow of the Academy of Technological Sciences and Engineering since 1982 and the Australian Academy of Science since 1992, and was appointed an Officer of the Order of Australia in 1996.

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JAMES FERGUSON: A COMMEMORATION

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Abstract: James Ferguson (1710–1776) was a renowned author and lecturer on scientific subjects and maker of scientific instruments. His *Astronomy Explained upon Sir Isaac Newton's Principles of 1756* was an extremely popular non-mathematical exposition of Newton's ideas in English. He wrote numerous other books, some of which remained in print until the mid-nineteenth century. Ferguson rose from humble beginnings as a shepherd in north-east Scotland to become a wealthy lecturer, author and Fellow of the Royal Society, enjoying an international reputation. April 2010 marked the three hundredth anniversary of Ferguson's birth, and the present short communication briefly commemorates this event.

Keywords: James Ferguson, eighteenth century astronomy, astronomy popularisation, astronomy education, orreries, astronomical instruments.

1 INTRODUCTION

James Ferguson was born in April 1710 and the present note commemorates his tricentenary in 2010. Ferguson (1710−1776; Figure 1) is best remembered for his orreries and other scientific instruments and as an astronomer, author and lecturer on various scientific subjects, including astronomy. In 1756 he published *Astronomy Explained upon Sir Isaac Newton's Principles*, which presented a clear, non-mathematical account of Newton's ideas. It proved extremely popular and helped to bring the new astronomy to a wider audience.

Ferguson was born in north-east Scotland to poor parents who eked a meagre living from a smallholding. He had little formal education, but from a young age was fascinated by astronomy and showed an aptitude for mechanical devices. His early adult life was spent in Scotland, mostly working as a painter of portrait miniatures. In 1743 he moved to London and developed a career as an author and lecturer on astronomy and other scientific subjects. In the eighteenth century there was a great demand for public lectures on scientific subjects in both London and the provinces (e.g. see Inkster, 1982). Typically, such lectures would be a combination of entertainment and spectacle and serious instruction. Ferguson's work inclined to the latter rather than the former.

Ferguson's reputation rests on his work as an author and lecturer. He earned considerable renown, being elected a Fellow of the Royal Society, was awarded a pension by George III and his reputation spread overseas. In addition to *Astronomy Explained* he wrote several other books, some of which remained in print until the mid-nineteenth century. The sources for Ferguson, including those used in the preparation of this note, are discussed in Section 6 and not referenced elsewhere here. References for other individuals and subjects are given at the appropriate place in the text.

2 A LIFE IN TWO PARTS: SCOTLAND AND LONDON

James Ferguson was born on 25 April 1710 at Core-of-Mayen, Rothiemay, Banffshire, north-west of Aberdeen in Scotland. His parents were John Ferguson, a tenant farmer who rented a smallholding and his wife Elspeth Lobban. James was the second of at least six children. He learnt to read by listening to his father teach his elder brother a catechism. Ferguson had little formal schooling, just three months at the grammar school in nearby Keith. However, at the age of seven or eight an interest in mechanics was awakened by watching his father jack up the low roof of their cottage, and he was soon making models of mills and spinning wheels. Between 1724 and 1726 he worked as a shepherd for James Glashan, a local farmer, and in the evening he passed the time by making maps of the constellations using beads and string.

In 1728 Ferguson was offered a position by a local gentleman, Thomas Grant of Achoynaney, where he

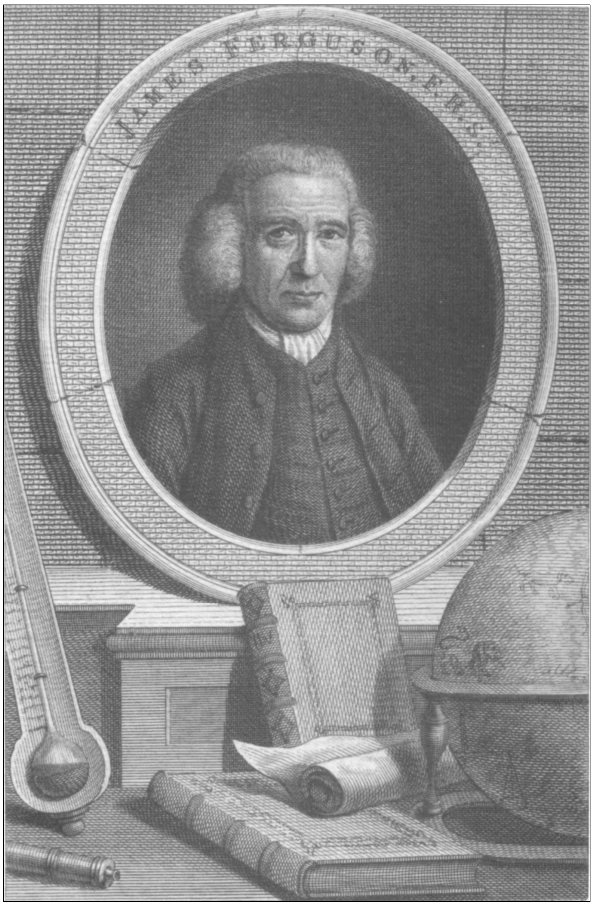


Figure 1: James Ferguson, FRS (1710–1776). This engraving by Thomas Cook formed the frontispiece to the posthumous second edition of *Select Mechanical Exercises*. The central portrait is based on a mezzotint by John Townsend.

was taught mathematics and other subjects by Alexander Cantley, Grant's butler and himself a self-taught polymath. In 1730 Cantley left for other employment and Ferguson returned home, where he followed var-

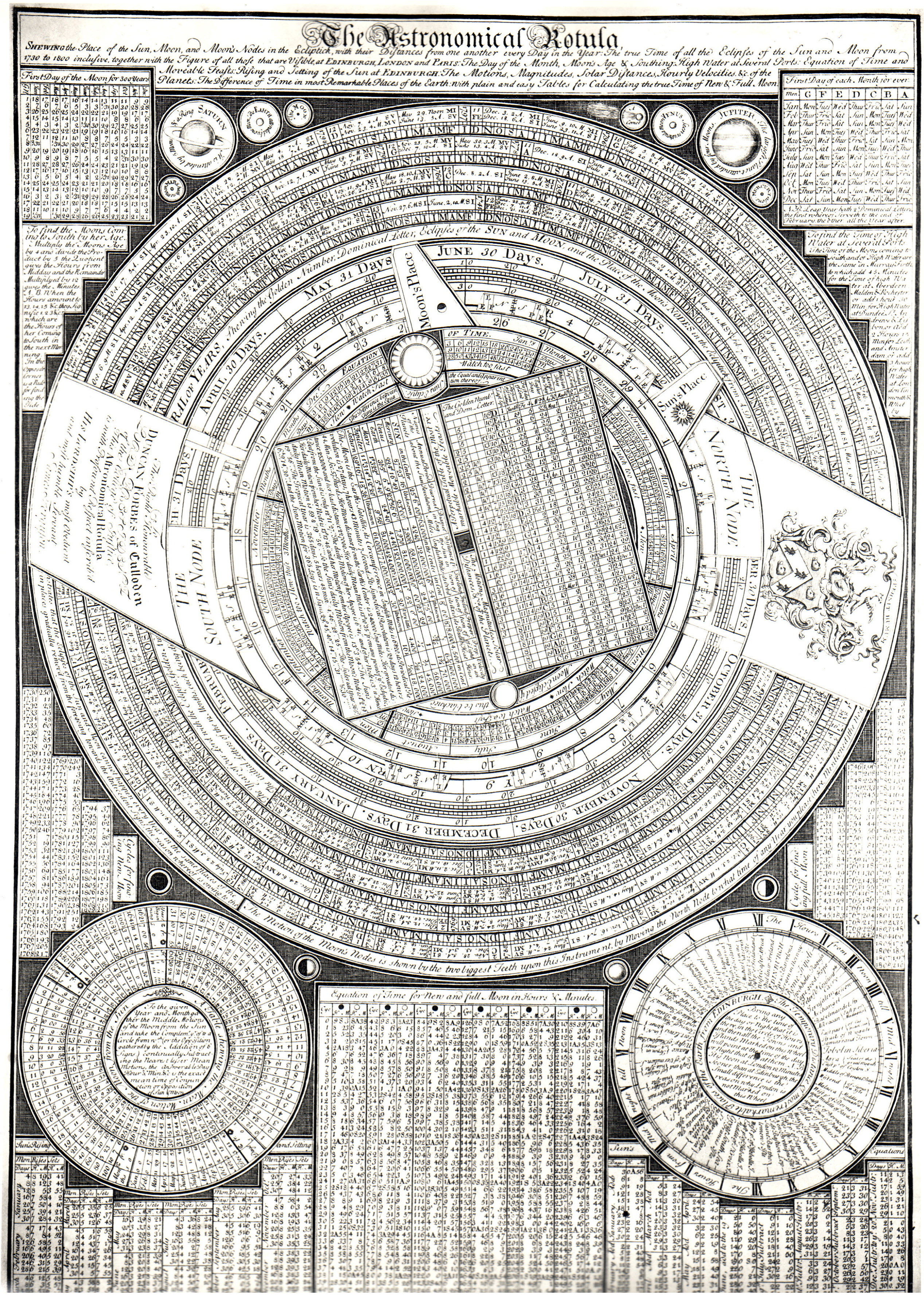


Figure 2: *The Astronomical Rotula* of 1742. For a close-up of part of *The Astronomical Rotunda* see Figure 2a, opposite (item T.1974.186, reproduced courtesy of The Trustees of the National Museums of Scotland, who retain copyright).

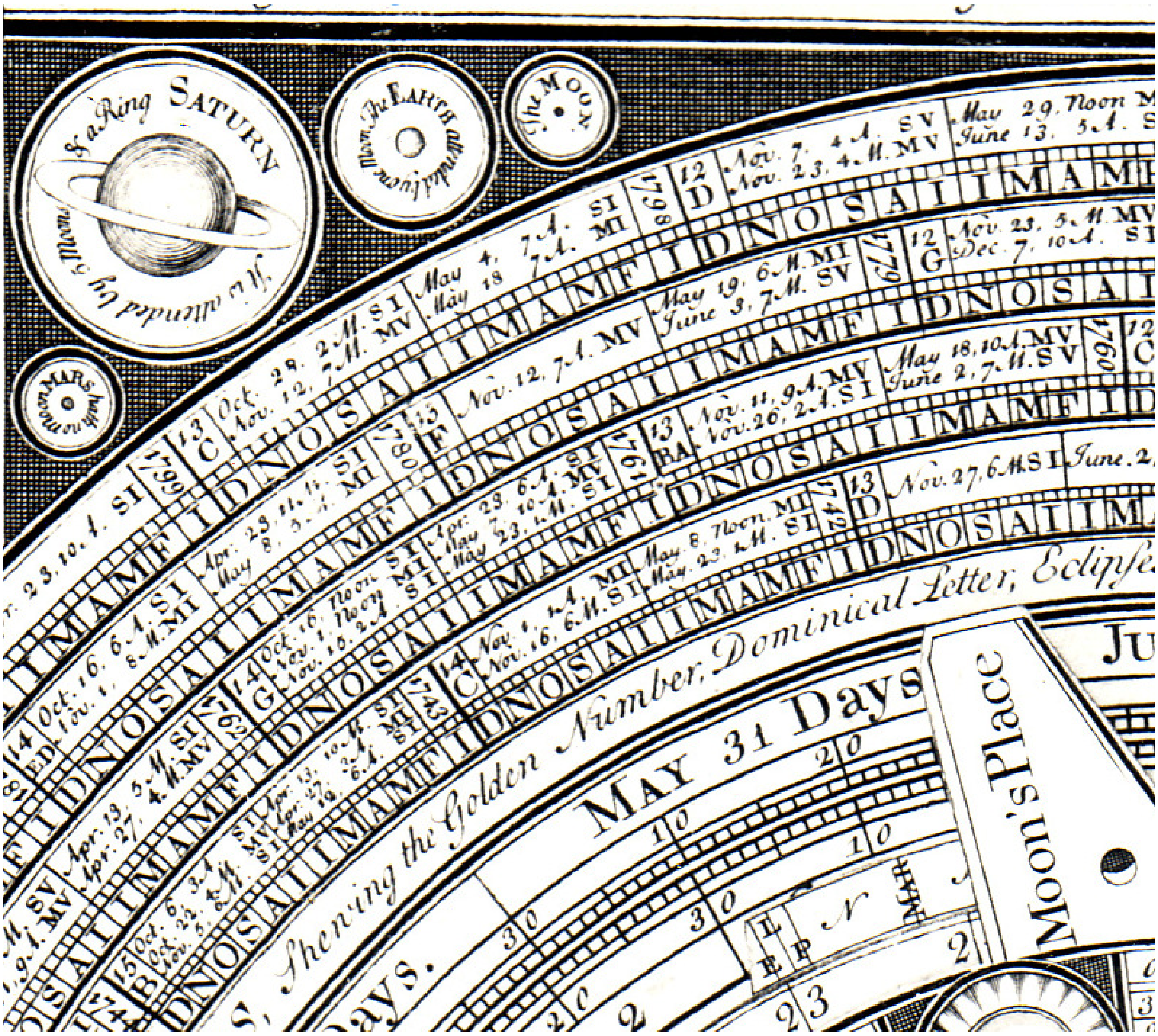


Figure 2a: Detail of *The Astronomical Rotula* of 1742 showing some of the inscribed circles (item T.1974.186, reproduced courtesy of the The Trustees of the National Museums of Scotland, who retain copyright).

ious occupations. He made a terrestrial globe, the first that he had ever seen, from the instructions in a copy of Patrick Gordon's *Geographical Grammar* which Cantley had given him. He also made his first clock, out of wood, and a watch with a whalebone spring.

Between 1732 and 1734 Ferguson resided with Sir James Dunbar of Durn, where he maintained clocks and repaired machinery. He decorated two spheres on the gateposts of Durn House, Sir James' residence at Portsoy, as a pair of terrestrial and celestial globes. Their principal axes were correctly aligned towards the celestial pole so that they acted as sundials. Sir James' sister, Lady Dipple, became Ferguson's patron and took him to Edinburgh to train as an artist, though he showed little aptitude for landscapes. He did, however, become a limner, or painter of pen and ink portrait miniatures. This occupation would provide the basis of his living for a quarter of a century. In 1734 to 1736, while staying in Edinburgh, Lady Dipple introduced Ferguson to Lady Jane Douglas of Merchiston Castle. Later at her invitation he would visit the Castle, staying in the room where John Napier had invented logarithms (for Napier see e.g. Gladstone-Millar, 2003). Around this time Ferguson taught himself medicine, intending to become a physician. He subsequently practised around Keith but was unsuccessful, not least because his bills were often unpaid.

Ferguson married Isabella Wilson (1719–1773) in 1739. Around the same time he moved to Inverness, resumed limning for a living and also took up his astronomical interests again. He invented an astronomical instrument with four rotating plates or 'volvelles' to show the positions of the Sun and Moon and to predict eclipses. He showed it to Colin Maclaurin (1698–1746; see, e.g. Hall, 2007), then Professor of Mathematics at Edinburgh, who became his friend and patron. Maclaurin had the device engraved and published in Edinburgh in 1742 as the *Astronomical Rotula* (Figure 2). After being shown Maclaurin's orrery, which had concealed an inaccessible wheelwork, Ferguson was able to work out for himself the necessary gearing. Maclaurin was sufficiently impressed to ask Ferguson to demonstrate and lecture on the orrery to his students. This demonstration marked the start of Ferguson's many lecturers.

In 1743 Ferguson moved to London. The reasons for his relocation are unclear. He may have perceived it would offer a better market for his miniatures, and, indeed, they would provide most of his income until the late 1750s.

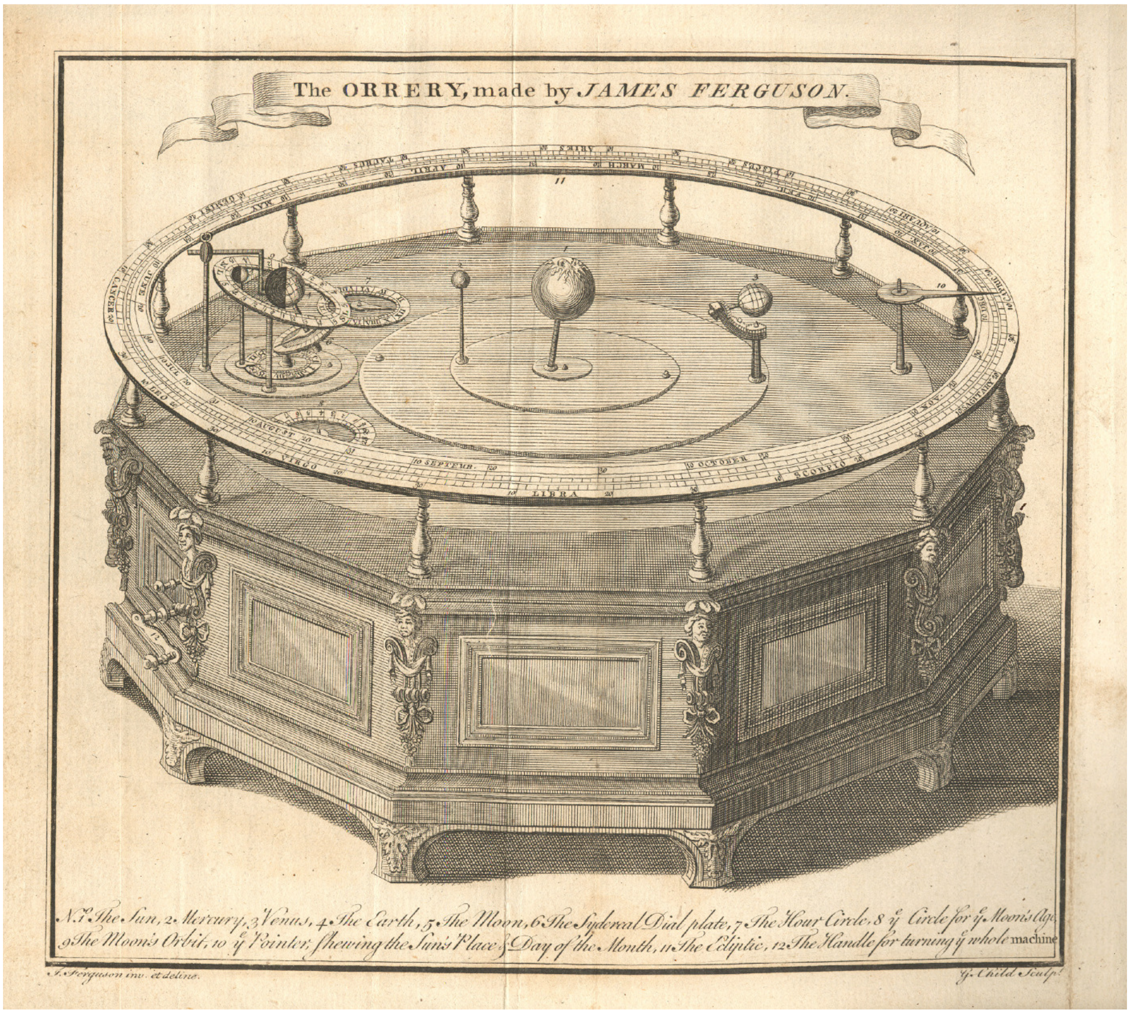


Figure 3: Ferguson's Venus orrery. This instrument was designed to show the orbit, axial inclination, seasons and related phenomena of Venus, as deduced from the observations of Francesco Bianchini (1662–1729) which suggested (entirely erroneously) a rotation period of about 24 hours and a rotation axis highly inclined to the ecliptic. The original engraving was for his book, *The Use of a New Orrery* (1746), and was reused as the frontispiece for the first edition of *Astronomy Explained* (1756). A paper describing the orrery and discussing the seasons that would result from Venus' supposed highly inclined axis of rotation was Ferguson's first communication in the *Philosophical Transactions*.

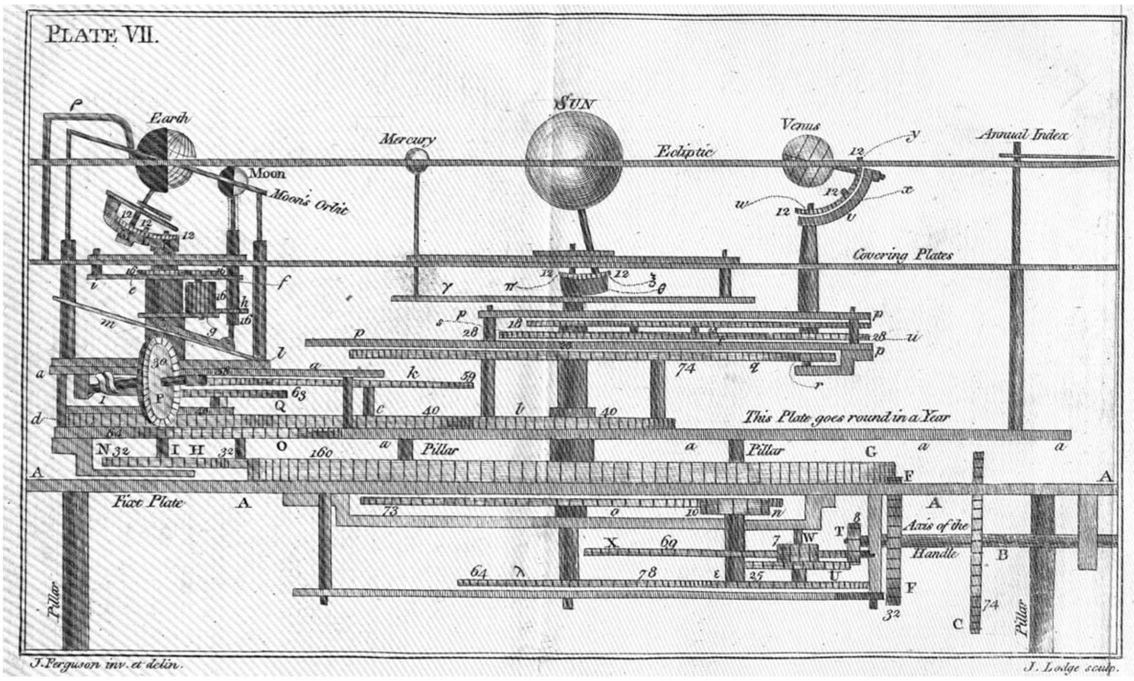


Figure 4: The wheel-work for the Venus orrery (Figure 3), from *Select Mechanical Exercises* (1773).

However, he took the opportunities offered by the metropolis to develop his other interests. Initially Ferguson's patron was the Rt. Hon. Stephen Poyntz, who tried to obtain training for him as a mathematics tutor, but Ferguson could not afford the apprenticeship. Poyntz then commissioned miniatures of his family from Ferguson in order to be able to recommend him. Ferguson remained based in London for the rest of his life, mostly living in either the areas around The Strand and Fleet Street or in Marylebone. From 1755 to 1757 he bought, ran and then sold, a business selling globes. Otherwise he continued as a limner, while developing his career as a lecturer, author and inventor on which his reputation now rests.

In late 1767 or 1768 Ferguson moved to his final address, 4, Bolt Court, Fleet Street (where Dr Johnson was briefly a neighbour). He legally separated from his wife, Isabella, in 1773. They had four children: Agnes (b. 1745), James (*b.* 1748), Murdoch (*b.* 1752) and John (*b.* 1753). James Ferguson died at home in Bolt Court on 16 November 1776 of 'gravel and other ailments.' He is buried in Old Marylebone churchyard, Marylebone High Street, Westminster, near Isabella and his oldest son, James. His estate amounted to the then very considerable sum of £6,000, which seems to have been accumulated largely through thrift and sound investment.

3 CAREER AS A LECTURER AND AUTHOR

James Ferguson's reputation rests on his work as a lecturer, author and inventor, starting with the *astronomical rotula* and orreries that he made shortly before moving to London in 1743. Though he is principally remembered as an astronomer he lectured on a range of other scientific subjects, most notably mechanics, horology and chronology. He also made forays into hydraulics, pneumatics, electricity and, briefly, optics (though he does not seem to have been comfortable with the last).

Shortly after moving to London Ferguson developed the *trajectorium lunare* to demonstrate that the Moon's path is always concave to the Sun. He displayed this device before the Royal Society in 1744. From 1744 he began giving lectures in his lodgings, illustrating them with the *trajectorium lunare* and other models. These lectures proved popular and successful. He lectured in London for the remainder of his life and later gave lecture tours in the provinces.

Ferguson's first published book was *The Use of a New Orrery* (1746; see Figure 3). He proved a prolific author, and numerous pamphlets, papers and several major books followed. Some of his more important books are listed in Table 1. Many of them went through numerous editions and remained in print until the mid-nineteenth century. Ferguson's first major work, and his first commercial success, was *Astronomy Explained upon Sir Isaac Newton's Principles* (1756), which described Newtonian astronomy without mathematics. It was not the first attempt to introduce Newtonian astronomy to a wider audience. For example, as early as 1719 John Harris (*ca* 1666–1719) had published *Astronomical Dialogues between a Gentleman and Lady,* in which a lady and gentleman discuss Newton's system of the world in non-mathematical terms (King and Millburn, 1978). Nonetheless, *Astronomy Explained* was extremely successful and went through several editions and numerous re-printings. It secured Ferguson's reputation, allowed him to give up limning and may have contributed to his decision to sell his globe-making business.

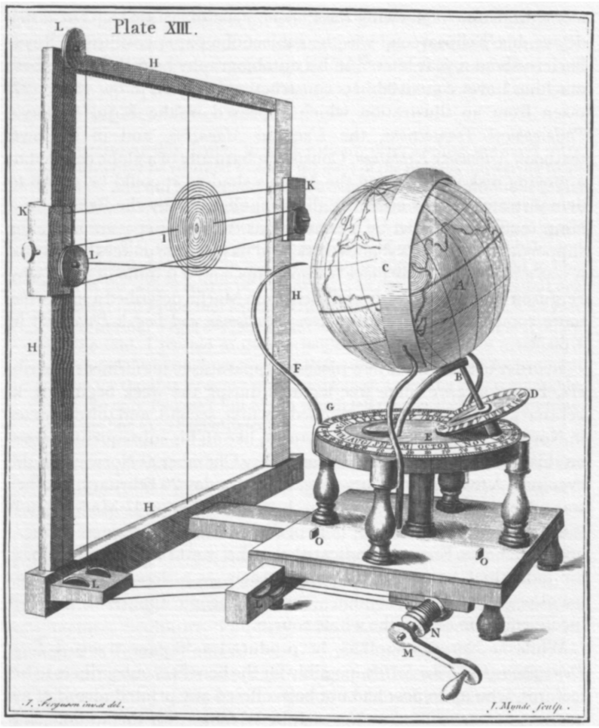


Figure 5: Ferguson's eclipsareon from *Astronomy Explained* (1756). This instrument demonstrated the time, duration and frequency of eclipses at any point on the globe.

Amongst Ferguson's books (Table 1) *Astronomy Explained* and *Lectures on Select Subjects* were serious scientific texts; the others were less substantial, and as their titles suggest his books often tied in with his lectures. The success of Ferguson's books may be attributed to their unpretentious style, clarity of exposition, avoidance of mathematics and, not least, their numerous striking and attractive illustrations; Ferguson was a skilled and imaginative draughtsman (see Figures 2-7). His last major book, *The Art of Drawing in Perspective* (Figure 7) appeared in 1775, less than a year before his death and nearly thirty years after *The Use of a New Orrery*. In the later 1760s he adapted

Table 1: Ferguson's major books. The date of first publication is listed.

1746	*The Use of a New Orrery, Made and Described by James Ferguson*
1756	*Astronomy Explained upon Sir Isaac Newton's Principles*
1760	*Lectures on Select Subjects in Mechanics, Hydrostatics, Pneumatics, and Optics; with the Use of the Globes*
1767	*Tables and Tracts, Relative to Several Arts and Sciences*
1768	*The Young Gentleman and Lady's Astronomy Familiarly Explained in Ten Dialogues*
1770	*An Introduction to Electricity, in Six Sections*
1773	*Select Mechanical Exercises: Shewing how to Construct Different Clocks, Orreries, and Sun-dials*
1775	*The Art of Drawing in Perspective Made Easy to Those who have no Previous Knowledge of the Mathematics*

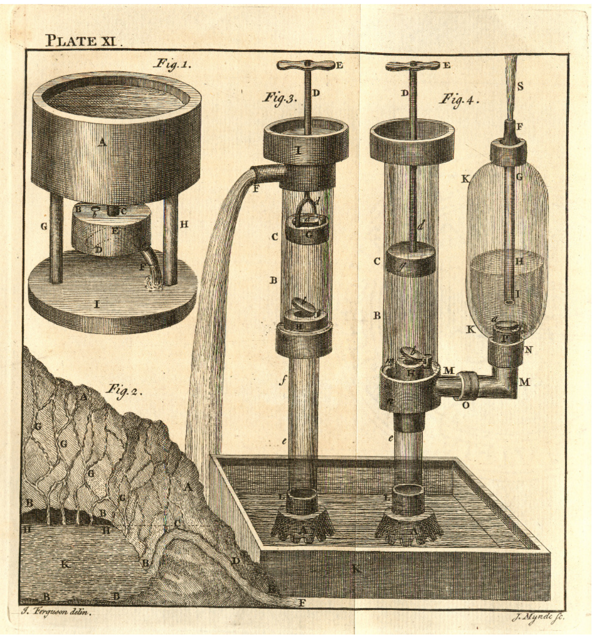


Figure 6: A plate from *Lectures on Select Subjects* (1760) illustrating the action of pumps. The pump chambers are shown as transparent to illustrate the principle of operation. Ferguson used a model of a similar device in his demonstrations.

material from several of his books as articles for the *Encyclopaedia Britannica* (which was first published in Edinburgh between 1768 and 1771). As well as his books Ferguson also published a number of minor works on various subjects, including tracts, prints and contributions to periodicals. The tract, *A Plain Method of Determining the Parallax of Venus* (of which two editions were published in 1761, prior to the transit in June of that year), might serve as an example.

In addition to lecturing in London Ferguson also gave lecture tours in provincial cities in England and Scotland. His tours divide naturally into two periods: 1749-1755 and 1765-1774, separated by the period when he ran a globe-making business and was preparing, publishing and revising *Astronomy Explained*. During the earlier period, 1749-1755, he was touring primarily as a limner looking for commissions, but would also give a five-lecture course on astronomy if there was demand. The later tours, 1765-1774, were principally to give lectures and he offered a twelve-lecture course on ‘Experimental Philosophy’.

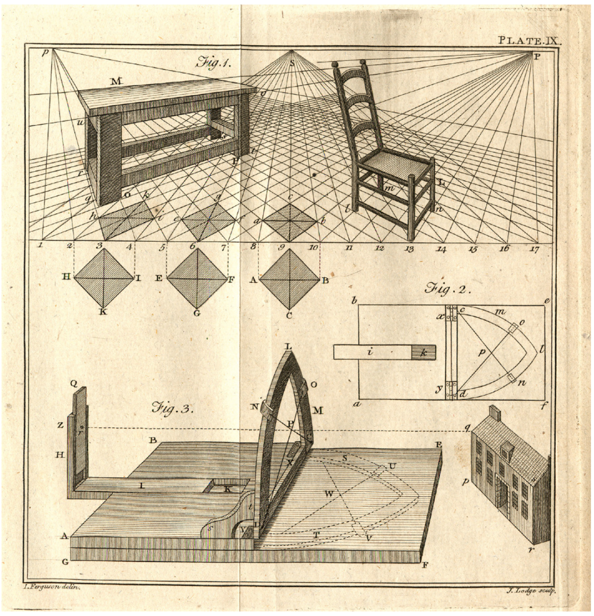


Figure 7: An engraving from *The Art of Drawing in Perspective* (1775). Items of furniture illustrate the use of perspective. An instrument to assist with the correct construction of perspective is also shown.

Ferguson continued to make orreries, versions of the *astronomical rotula* and other astronomical devices (Figure 5). His lectures were illustrated with demonstrations using ingenious models of his own construction (e.g. see Figure 6). He made many such devices to illustrate principles in mechanics, hydraulics, etc, and his books contain numerous attractive illustrations of them. Ferguson was never a commercial clockmaker, though he had built and maintained clocks in Scotland, and he retained a strong interest in wheelwork, particularly for reproducing astronomical phenomena. He devised several new types of timepiece, including a ‘three wheeled clock’ which was a modification of a design by his friend Benjamin Franklin.

Ferguson did not routinely make and reduce astronomical observations, though he did observe eclipses and sunspots. One notable achievement occurred during the solar eclipse of 1 April 1764, which he observed from Liverpool during a tour. Describing his observations in the *Philosophical Transactions* for 1765, Ferguson noted that “… little tremulous bright specks …” at the onset and cessation of totality, which he correctly surmised were “… owing to a dent or valley in that part of the limb of the Moon.” He had observed ‘Baily’s Beads’ some 70 years before Francis Baily gave his name to the phenomenon (though Luminet (2007) notes that the appellation arose informally from Baily’s evocative description rather than any claim to priority).

In addition to his scientific pursuits Ferguson was also interested in, and wrote on, topics in historical and biblical chronology and aspects of theology (though the distinction would have been less apparent in the eighteenth century). His *Tables and Tracts* (1767) covers a diverse range of unconnected topics, includeing, for example, how to gauge a vat or cask, eclipses, Jewish dry measures and instructions for drawing a meridian line.

James Ferguson received numerous honours. In 1761 he was granted a pension of £50 *per annum* by King George III. In 1763 he was elected a Fellow of the Royal Society and unusually was exempted the admission fee and annual contribution on account of his “… singular merit and circumstances.” In 1770 he was elected to membership of the American Philosophical Society.

4 FERGUSON’S LEGACY AND ENDURING INFLUENCE

James Ferguson was never a practical astronomer. He was, however, a significant figure in the development of orreries and similar devices, and amongst the lecturers who brought the new experimental philosophy and Newtonian astronomy to a popular audience in eighteenth century Britain.

Ferguson’s books and articles were widely read and had a lasting influence. Several went through numerous editions and reprintings, in some cases continuing, with revisions by later hands, into the mid-nineteenth century. Similarly, reprinting of his autobiography kept his story current. Indeed, the events of Ferguson's life inspired the novel the *Story of the Peasant Boy Philosopher* (1854) by Henry Mayhew, albeit relocated from Scotland to Wales.

5 THREE HUNDREDTH ANNIVERSARY

April 2010 marked the three hundredth anniversary of Ferguson's birth, and this event was commemorated on 15 April in a public lecture on Ferguson's life and work given by Professor Roland Paxton. This talk formed part of the programme for the 2010 Edinburgh International Science Festival and was organised by the Edinburgh Bibliographical Society. The National Library of Scotland, also in Edinburgh, organised a small public exhibition of Ferguson's notebooks, drawings and instruments which ran from 18 March to 28 April. In addition to the present short communication, the anniversary was also briefly mentioned in the Summer 2010 issue of the Society for the History of Astronomy's *Bulletin* (see Davenhall, 2010).

6 SOURCES AND SURVIVING ARTEFACTS

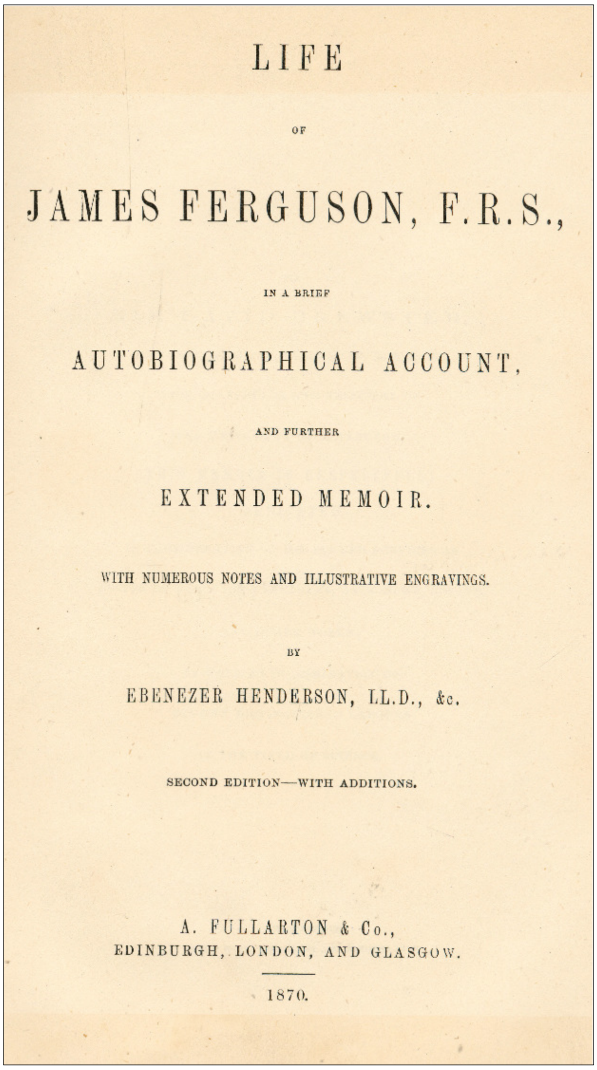
The definitive modern biography of Ferguson is *Wheelwright of the Heavens* by Millburn and King (1988) who give a detailed and thoroughly researched account of his life and work. They include as appendices an abridged bibliography and a list of manuscripts. Also Ferguson has entries in the *Biographical Encyclopedia of Astronomers* (Baum, 2007) and the *Oxford Dictionary of National Biography* (Rothman, 2007).

Millburn (1983) published a detailed annotated bibliography of Ferguson's works, including books, tracts, prints and periodical articles. This publication comprises a short-title list in a printed booklet and a detailed bibliography on two microfiches, which are enclosed in the back cover of the booklet. It was self-published and is now difficult to obtain. Copies are held in the libraries of the Royal Astronomical Society and the Royal Observatory Edinburgh, and in the National Library of Scotland.

The principal primary source for Ferguson's early life in Scotland is a short autobiography that he included in the *Select Mechanical Exercises* of 1773. Millburn and King reprint it in its entirety as their Chapter 2.

The first full biography of Ferguson was the *Life of James Ferguson, FRS* (1867) by Ebenezer Henderson (1809–1879; see Bayne, 2004; Neale, 2003), an astronomer, antiquarian and author originally from Dunfermline. The *Life* was a long-standing project for Henderson. As a young man he had chanced on a copy of the *Select Mechanical Exercises* while browsing an Edinburgh bookstall in 1827. He was intrigued by Ferguson's story and determined to find out more about him. Forty years later he delivered a detailed, authoritative account. Though he lacked some of the resources available to modern scholars he had access to some material that is now lost. Unfortunately in some cases he was deliberately misled by his correspondents. Henderson published a slightly revised second edition in 1870 (Figure 8) and a modern reprint has recently been published by Cambridge University Press.

The principal collections of Ferguson's manuscripts are held by the National Library of Scotland and the University of Edinburgh, which holds his Commonplace Book. Additional material is held by the Royal Society, the British Library, the Royal Society of Edinburgh and numerous other institutions. On-line versions of all of Ferguson's books, and many of his minor publications, are available as part of the *Eighteenth Century Collection On-line* provided by Gale Cengage Learning. A search of this resource for items published between 1740 and 1780 with 'James Ferguson' as the author yielded 56 results, though not all are by the present James Ferguson. Due to the popularity of Ferguson's books, and the large number of copies printed, the more common ones are still readily available from on-line second hand booksellers for a reasonable price.



LIFE

OF

JAMES FERGUSON, F.R.S.,

IN A BRIEF

AUTOBIOGRAPHICAL ACCOUNT,

AND FURTHER

EXTENDED MEMOIR.

WITH NUMEROUS NOTES AND ILLUSTRATIVE ENGRAVINGS.

BY

EBENEZER HENDERSON, LL.D., &c.

SECOND EDITION—WITH ADDITIONS.

A. FULLARTON & Co.,
EDINBURGH, LONDON, AND GLASGOW.

1870.

Figure 8: The title page of Ebenezer Henderson's *Life of James Ferguson, FRS*, second edition (1870).

On Ferguson's death, and following provision in his will, the apparatus used for demonstrations during his lectures passed to his friend Dr William Buchan (1729–1805; see e.g. Gavine 1982; Lawrence, 2006; Ruhräh, 1931), then resident in Edinburgh, who gave public lectures with them, though probably only briefly. Next they passed from Dr Buchan to Dr John

Coakley Lettsom (1744–1815), who used them for the private instruction of his family and friends rather than public lecturers. The collection was dispersed following Dr Lettsom's death and is now largely lost. A few are now held by the National Museums of Scotland in Edinburgh, which also holds an example of Ferguson's *Astronomical Rotula* (Figure 2). Some items, including a telescope reputedly made by Ferguson during his time at Durn House, some miscellaneous apparatus used during his lectures and seven of his portraits are held by Banff Museum. Rather more examples of Ferguson's globes have survived and several major collections hold examples, including the National Maritime Museum, Greenwich; the British Library, London; and the National Museums of Scotland.

7 CONCLUDING REMARKS

This short communication commemorates the three hundredth anniversary of Ferguson's birth. It is largely based on the modern secondary sources for Ferguson listed in the first paragraph of the preceding section, but particularly Millburn and King's 1988 book.

8 ACKNOWLEDGEMENTS

I am grateful to Professor Roland Paxton, Dr David Gavine and Mr William Johnston for useful discussions and for comments on a draft version of the manuscript. In addition, Professor Paxton kindly provided copies from his own collection of all the illustrations used in this article except Figures 1 and 2. Figure 1 is taken from Millburn and King (1988), while I am indebted to Dr Alison Morrison-Low (National Museums of Scotland) for Figure 2. I am also grateful to Dr Morrison-Low for providing details of items associated with Ferguson in the National Museums of Scotland and to Mrs Rosemary Sanderson and Mr James Cowie for similar information for the Banff Museum.

Finally, I would like to thank Ms Karen Moran for providing me with access to the Library of the Royal Observatory Edinburgh, while part of the computing infrastructure used in preparing the manuscript was provided by the University of Edinburgh. Access to the Eighteenth Century Collections On-line was under a subscription provided by the JISC (Joint Information Systems Committee).

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Journal of Astronomical History and Heritage, 13(3), 187-193 (2010).

ELISABETH VON MATT (1762–1814), AN ENLIGHTENED PRACTITIONER OF ASTRONOMY IN VIENNA[1]

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Abstract: Driven by her personal interest, Baroness Matt erected a private observatory in Vienna, bought and ordered precise instruments and carried out astrometric and geodetic observations at several places in Austria and in western Bohemia. Unfortunately her activities were hampered by the Napoleonic wars and were cut short by her early death.

Keywords: Elizabeth von Matt, astrometry, surveying

1 INTRODUCTION

For many members of the aristocracy of the late eighteenth century it was fashionable to own a telescope and to roam here and there through the night sky—certainly this was a greater pleasure than today, since the sky was dark in those days.

Elisabeth Marie Josepha von Matt, née von Humelauer, was more than just an occasional viewer of the heavens. In this paper we recall briefly what is already known about her (Angetter and Pärr 2009; Bode, 1814; Ma-Kircher and Brosche, 2001; Firneis, 1993; Lindenau, 1816: 116) and then we present some new material. A part of it—especially pictures—was kindly provided by a direct descendant, Mr Kurt Albert of Heidelberg.

In the title of this paper, why do we call Elisabeth von Matt 'enlightened'? It is because she devoted herself to the rational aspects of our science (including geodesy), to the type of research pursued by professional astronomers at that time, that is, the tedious labor connected with the determination of celestial and terrestrial positions. For these purposes, she erected a private observatory at her house in Vienna, purchased precise expensive instruments, and received guidance from local astronomers, but especially from Johann Tobias Bürg (1766–1834). At her house in Vienna she erected a private observatory. She carried out surveying operations near Vienna and in western Bohemia. Although she obviously overcame the obstacles of her sex, other adverse circumstances, especially the Napoleonic wars and her fading health, did not allow her to realize her full potential.

2 THE 'SPECULA DOMESTICA'

Elisabeth von Matt's house was in the centre of Vienna at Schulerstraße 18-20, on the corner of Kumpfgasse, not far from St. Stephen's Cathedral. The surviving plans of her house do not show the roof, so we are left in the dark with regard to the design of her observatory. The bird's eye view of Vienna by Huber drawn in 1778 reveals that almost all of the houses around St. Stephen's Cathedral had gabled roofs (see Figure 1).

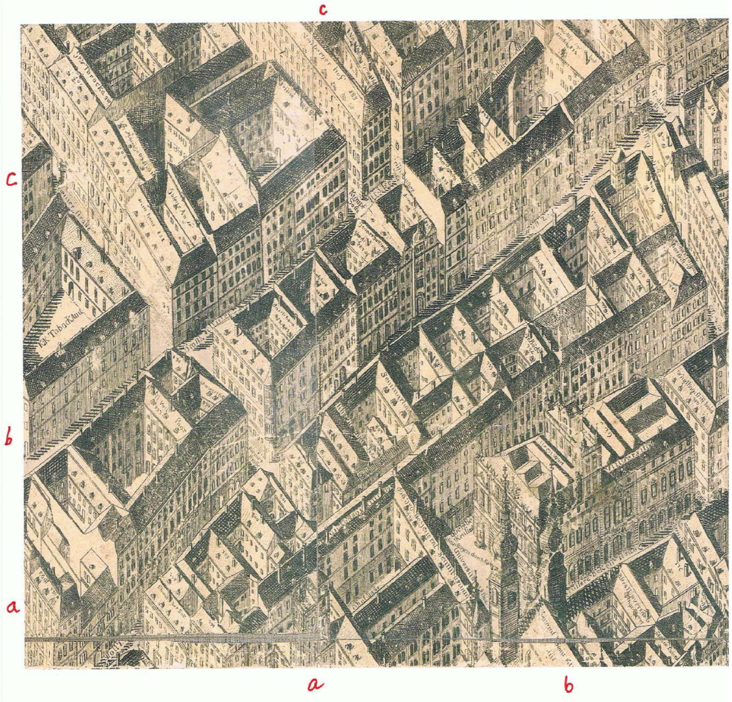


Figure 1: A few decades before Matt bought her house, Huber (1778) drew the area of the observatories discussed here, where (a-a) is the Jesuit Observatory, (b-b) the University Observatory, and (c-c) our choice of the location of Baroness von Matt's 'specula'. North is approximately to the right.

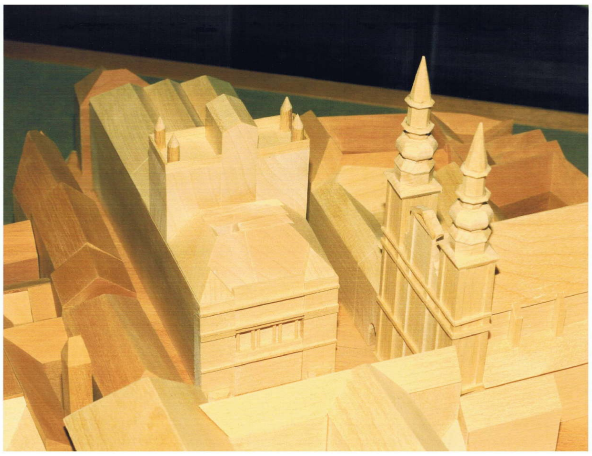


Figure 2: The (old) University Observatory of Vienna (wood model from University Archive, photographed by Franz Kerschbaum).

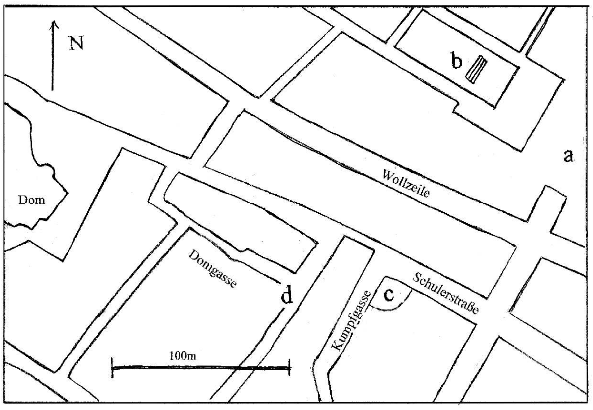


Figure 3: Sketch of the present situation. Meaning of the letters as in Figure 1; in addition Matt's house as derived from the relative coordinates is marked by the 'd'.

Although in theory Matt could have observed from another house—especially one of the few tower houses with flat roofs in the area—we can safely assume that she observed from her own house on the basis that her first published paper (Matt, 1805) refers to her "specula domestica" (= home observatory). Supporting this conclusion is the following statement by Karoline Pichler (1769–1843) that appears in her memoirs:

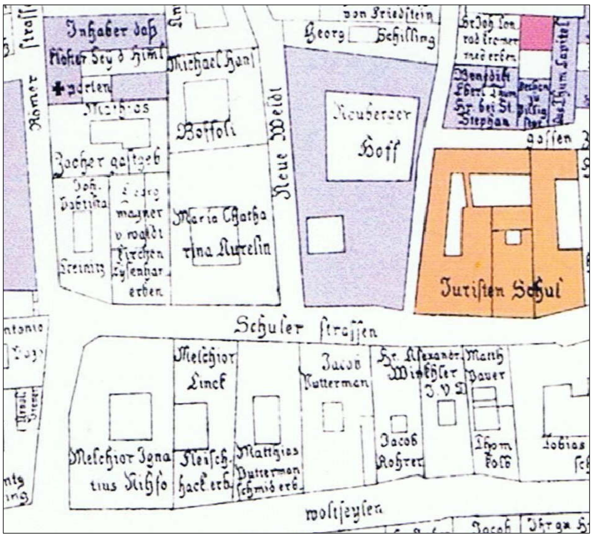


Figure 4: Houses and their owners in Matt's neighborhood in the year 1684 (after Suttinger, 1684).

"... and she [Matt] had erected an observatory in her house." (Pichler, 1914; our English translation).

The location of Matt's observatory in Vienna can be identified in two ways. First, we have the information from Harrer's house register (1950) that around 1800 the building at Schulerstraße No. 18/20 (the modern numbering) belonged to Elisabeth von Matt (and not to her husband). Second, we have the latitude and longitude of her 'specula', which are given in the title of her first paper (Matt, 1805); the same values are also cited by Triesnecker and Seeber (1805: 126). The longitude of her observatory is given as ⅓ of a second of time to the west of the University Observatory which itself was positioned with respect to the nearby Jesuit Observatory (Zach, 1801: 553). According to Zach's *Monatliche Correspondenz*, Joseph Liesganig's value of 48° 12' 36" was used for the latitude of the University Observatory, although in 1808 Augustin obtained a somewhat different figure (Augustin 1808; 1813; Zach, 1813: 138, 146). Hence the latitude of Matt's observatory was 4 arcseconds south of the University Observatory. We are perfectly aware of the location of the latter Observatory on the building which at present houses the Austrian Academy of Sciences (see Figure 2) and can therefore pinpoint the relative position of Matt's observatory on a map of the city.

Irrespective of whether the terrestrial transfer is made by inspection of a map or just by pacing the intermediate streets, the errors of $\Delta\lambda$ and $\Delta\varphi$ should be only rounding errors (this would not be true in case of astronomical measurements). For $\Delta\varphi$ this is then simply half a second of arc corresponding to ±15 m. For $\Delta\lambda$ we assume that the given ⅓ of a second of time means it is between ½ and ¼. A second of time in longitude corresponds at the latitude of Vienna to 308.6 m, the ⅓ second to 103 m and ¼ and ½ to 90 m and 120 m. If we use the two coordinate differences and their possible errors for fixing Matt's position on a map of Vienna we arrive at a place which agrees in the north-south direction with Schulerstraße 18/20 but not so in the east-west direction. As Steinmayr (2010) notes, it would lie at the crossing of Domgasse and Grünangergasse. At present we cannot account for this discrepancy but we would prefer to stick with Schulerstr. 20 since the whole difference relies on that "1/3" which could already be a typographical error. This position is shown as 'd' in Figure 3.

We also may refer to an older map of the area which shows the names of the proprietors of the various properties in 1684. According to Harrer (1950) the owner of Schulerstraße No. 18/20 was Maria Katharina Orelli. On the map shown in Figure 4 we find the name 'Maria Chatharina Aurelin' which we believe is merely the latinized form of Orelli (the root meaning 'gold' in both versions).

The consecutive house numbers introduced in the Josephinic era have been changed twice so that three versions must be recognized. The ones in the Huber (1778) plan belong to the first version, while the ones provided by Harrer (1950) to the last. The number 824 of Harrer corresponds to 840 in the first version. We cannot read a number for our choice of Matt's house in the Huber plan (the name is 'Grüne[s] Rößl'), however the next but one building (a 'Wirtshaus') to the south-east carries the number 838, thus supporting our identification. According to note 698 in Pichler (1914), Matt's house number was 874.

Further suggestions for the location of Matt's observatory neither fulfil the latitude nor the longitude condition, but may be motivated by the existence of a tower-like part of a building on the Huber plan. If we trust that Huber was precise in the representation of the roofs, even for private houses, then there was no 'tower' on Matt's house before she bought it. But Mr Albert has found a drawing from the inner court and representing the house in the late nineteenth century (Figure 5). It shows a nice turret with windows towards the south, hence well suited for astronomical observations! The name 'Stainhofersches Haus' is another house name collected by Harrer (1950) and goes back to a book printer of the sixteenth century who was perhaps the first owner. The drawing is also reproduced by Kisch (1883), who comments on the ancient nature of the house constituting the corner to the Kumpfgasse.

A 'specula domestica' could be anything from a formal observatory to just an ensemble of a telescope, a clock and an ephemeris. From what we know about Elisabeth von Matt's instruments (see Firneis, 1993 and Angetter and Pärr, 2009), they could be summarized as 'small but beautiful', but it should not be forgotten that her major instrument arrived too late to be useful (see Figure 10 in this paper). At least three items were used after her death: her Arnold chronometer (which is today owned by the Vienna University Observatory); a small (20-inch focal length, lens diameter 29 lines = ~65 mm) Fraunhofer refractor; and a nine-inch multiplication circle from Baumann. The last two items were used by Bürg in 1820 (see Bürg, 1821: 120).

3 ELIZABETH VON MATT: THE PERSON

Kurt Albert (pers. comm., 2010) has compiled a genealogical tree from information passed down through the pertinent families, and according to it Elisabeth von Matt's maiden name was Humelauer. Her paternal grandfather was a tailor, while her father, being a medical doctor, climbed the social ladder and reached the rank of a physician-in-ordinary ('Leibarzt') at the court in Vienna. He was ennobled in 1760 becoming 'Edler von Humelauer'.

From an inspection of the official death records a more precise date of birth for Elizabeth von Matt is obtained than was hitherto known: 20 August 1762. Likewise, we can eliminate the uncertainty over the date of birth of her husband, Ignaz von Matt: he was born on 6 July 1740 in Konstanz on Lake Constance. The age difference of more than 20 years makes the mistake of the 'Wurzbach' (Austrian biography) more understandable, namely referring to Ignaz as Elisabeth's father! Instead, they married on 2 October 1784.[2] He became a baron (Freiherr) in 1793 and according to the official death records and the *Wiener Zeitung* (1814) he died on 29 July 1814 (not June); he was 74 years of aged. While we presented in our previ-ous paper (Ma-Kircher and Brosche, 2001) evidence for two daughters, we see now that these two had an elder sister, Maria Regina, born in 1786 in Vienna, and, like Wilhelmine, married to a Count Finckenstein. These two Finckensteins were brothers.

Figure 5: The inner court showing Elisabeth von Matt's house. It is presumably the multi-storey tower on the left plus the building at the back with the balconies and gateway. From a drawing by Emil Hütter (1835–1886). Copyright: Wien Museum.

Harrer (1950) tells us that Elisabeth von Matt (and not her husband!) bought the house in the Schulerstraße on 9 February 1793 and bequeathed it to her daughters Karoline and Wilhelmine, but this is not completely correct. Since Wilhelmine died shortly before her mother, the daughters Maria and Karoline and a son of Wilhelmine inherited the house.[3] From them, parts of the house came into the possession of the Finckensteins, the Capellinis and the Pachers von Theinburg before it was razed in 1896. Our informant, Kurt Albert, is a descendant of the Pacher von Theinburg line.

Figure 6: Elisabeth von Matt, née Humelauer (1762–1814), in rococo style during her younger years (reproduced by kind permission of Franz Pacher-Theinburg).

Figure 7: Ignaz von Matt (ca. 1740–1814); one of a pair of miniatures with the painting in Figure 6 (reproduced by kind permission of Franz Pacher-Theinburg).

It is not surprising then that in such families portraits have survived up to the present. With kind permission of the owners we present here portraits of both Elisabeth von Matt and her husband (see Figures 6 to 8).

It seems appropriate to include here also a portrait of Johann Tobias Bürg (1766–1834),[4] who was the advisor and collaborator of Elisabeth von Matt in her astronomical work (see Figure 9).

Figure 8: Elisabeth von Matt as a middle-aged matron, wearing a kind of Biedermeier (reproduced by kind permission of Franz Pacher-Theinburg).

Zach (1800: 541) and Seetzen (1802: 487) describe some of Bürg's activities. When passing through Vienna in 1802, Seetzen seems to have mentioned all persons there who were at that time actively engaged in astronomy or geodesy, but Elisabeth von Matt is not amongst these. This gives us an earliest possible date for the start of her astronomical activities while her first publication, in 1805, provides an upper limit.

Handwriting is sometimes thought to give insight into a person, so here we present a page from the letter (Figure 10) that Matt sent to the instrument-maker Georg von Reichenbach (1772–1826) in 1809. She had ordered a transit instrument from him in about 1806, and was still awaiting its arrival in 1813 (see Matt, 1813). In order to understand her statements one has to recall that French troops occupied Vienna in May 1809 and that the state of war ended only with the peace of Schönbrunn in mid-October.

Reichenbach had the rank of a captain ('Hauptmann') and Elisabeth's title of 'Reichsfreyin' means baroness (of the Holy Roman Empire). An English translation of part of the letter follows:

> … and do not believe that the thunder of cannons and the clash of arms which sent threatening flashes into our eyes, in the least bit interrupted my passion for the noble science [of astronomy].

4 MATT'S ASTROGEODETICAL WORK

While her first paper (1805) refers to observations of the minor planets Pallas and Juno from her home observatory, all of her subsequent papers originate from other places and mainly deal with astrogeodetic work. One can probably associate this with the all-too-long seven year wait for the 6-foot transit instrument ordered from Reichenbach. She may have learned from Zach (with whom she was in contact, e.g. see Matt, 1808) that in the meantime one should not twiddle one's thumbs but could produce a considerable scientific harvest by using small transportable instruments to obtain geographic coordinates of many different places. Matt did this in collaboration with the professional Viennese astronomer, Johann Tobias Bürg, from about 1804 right up until her death (Bürg, 1814). Here we also see a certain parallelism with Zach and his duchess; however, the Duchess of Saxe-Gotha-Altenburg preferred to assist in private while Elisabeth von Matt did not hesitate to appear in public. One could surmise that Bürg performed the complicated reductions of her observations since on page 121 in his introduction to Matt's first 1810 paper Lindenau wrote that Bürg derived the results. On the other hand, Matt (1809) reported that she calculated lunar occultations, and later that she was waiting for Pasquich's book on computational astronomy (Matt 1811a). Her remarks on lunar tables and their coefficients (Matt, 1813) indicate familiarity also with such theoretical aspects. Bürg had only a subaltern position at the University Observatory, hence his cooperation with Baroness Matt may have given him the feeling that he was involved in an independent area of activity. After her death, Bürg (1814: 175) remarked on their ten-year friendship and his feeling of a great loss. He even went so far as to say that she was the only woman who remained his friend during the years when he was deaf.

Matt and Bürg observed at various places in Austria and Bohemia (Figure 11), mainly in connection with summer vacations or while visiting spas. In Austria, places in the 'Wiener Wald' were chosen, as well as Bruck an der Leitha, east of Vienna. The first include the famous Baden south of Vienna, Heiligenkreuz, more inside of the 'Wald', and smaller spots like the castles of Araburg und Bergau, and in Fridau, south of St. Pölten. At the Hocheck mountain (1037m), Bürg observed alone, while Matt participated from her possession 'Rehhof' to the north.

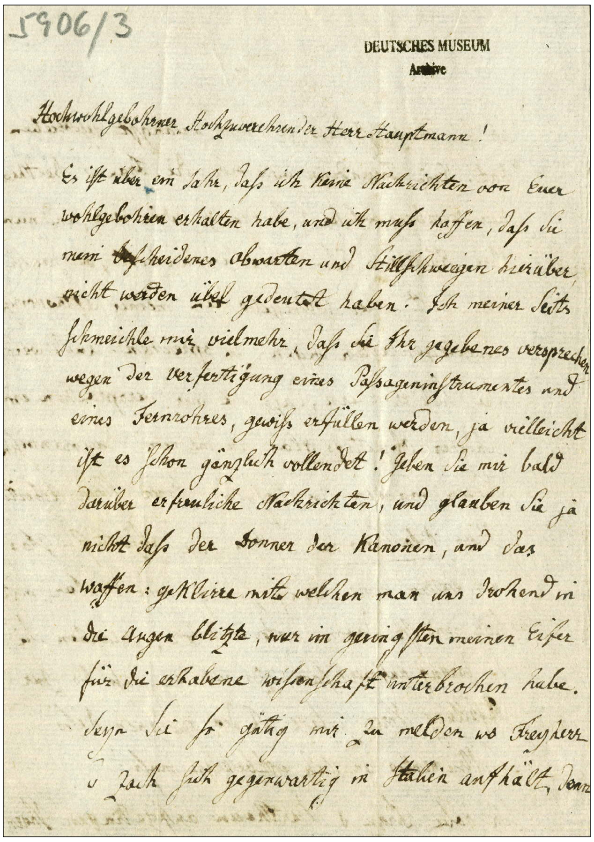
In Western Bohemia, we notice latitude and longitude determinations for Maria-Culm (a place of pilgrimage), Franzensbad, Elbogen and Engelhaus (represented by nearby Schödel's inn). West of the border, in Ansbach-Bayreuth (which since 1806 was a part of Bavaria), Bürg operated on the highest mountain of the Fichtelgebirge, the Schneeberg (1051m). In order to determine its altitude, he registered barometer readings there, and before at the nearby town of Weißenstadt. Father David, the leading astronomer of Bohemia, assisted in some of the measurements. He belonged to the order of 'Kreuzherren', and they had a central convent in Tepl and the one in Maria-Culm. David earlier had made the acquaintance of Franz Xaver von Zach (1754–1832) in Karlsbad, while Bürg worked with Zach several months on the Seeberg in each of the years 1801 through 1804. Hence Matt's references to Zach are natural.

In 1810 the editor of the *Monatliche Correspondenz* was officially still Zach, but *de facto* it was his disciple and follower at the Seeberg, Bernhard von Lindenau (1779–1854). He continued Zach's practice of placing long footnotes under his authors' text. Supplementing Matt's first 1810 paper (Matt, 1810a), his multi-page note starts on page 123 and runs until page 128, where he signs it as "v.L.". In the first part, he reduces Bürg's barometer observations, arriving at a new and more trustworthy altitude for the Schneeberg (1047 m as compared with the modern value of 1051 m, while the earlier value was 1196 m!). Then von Lindenau reports his own experiences on the neighbouring Ochsenkopf (on pages 126f.). At the request of the French Government he was concerned with a trigonometric connection between his Seeberg and the (Ober-)Pfalz, which had just been transferred by the French to their ally, Bavaria. And Lindenau's Saxe-Gotha-Altenburg, as a member of the Rheinbund, was also obliged to comply with any wishes of the French authorities. This part of Lindenau's biography is independently confirmed by his biographers Ebart (1896) and Volger (1896).

Ebart provides a fragment of a diary, which in August 1808 ends with Lindenau's departure for measurements in the Werra region. The main source of the Werra is not far from the Fichtelgebirge. Volger (1896) then tells us that Lindenau was working in Thuringia and Franconia for the *depot de la guerre* (obviously this institution also took care of the maps). In any case, the bad weather on the Ochsenkopf in October made Lindenau suffer, but not Elisabeth von Matt (who was only in Bohemia during the summer months). But her campaigns also included adventurous elements: when we read that she observed in Maria-Culm beside a charnel-house and a chapel situated on a former robber's den, it is comforting to note that this was during the daytime.

Figure 9: Johann Tobias Bürg (after *Monatliche Correspondenz* 1 (1800), begin of May issue, facing page 435).

If we compare the considerable intervals in latitude (~2.2°) and in longitude (~4°) of the two areas in which Matt and Bürg were active with the intervals of measurements of the degree before and around 1800 (Wolf, 1892), we are led to the suspicion that they may have had in mind a modest measurement of a degree. That concepts of a larger scale were under discussion is confirmed by Matt's reaction to a proposal by Lindenau: "Your proposal to connect the Seeberg with Prague by powder signals seems to me quite feasible." (Matt 1811a: 294). A list of mountains which could be used as intermediate points follows. The method of



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DEUTSCHES MUSEUM
Archive

Hochwohlgebohrner Hochzuverehrender Herr Hauptmann!

Es iſt über ein Jahr, daſs ich keine Nachrichten von Euer wohlgebohren erhalten habe, und ich muſs hoffen, daſs Sie mein ~~be~~ſcheidenes Abwarten und Stillſchweigen hierüber nicht werden übel gedeutet haben. Ich meiner Seits ſchmeichle mir vielmehr, daſs Sie Ihr gegebenes verſprechen wegen der verfertigung eines Paſsageninſtrumentes und eines Fernrohres, gewiſs erfüllen werden, ja vielleicht iſt es ſchon gänzlich vollendet! Geben Sie mir bald darüber erfreuliche Nachrichten, und glauben Sie ja nicht daſs der Donner der Kanonen, und das waffen: geklirre mit welchen man uns drohend in die Augen blitzte, nur im geringſten meinen Eifer für die erhabene wiſſenſchaft unterbrochen habe. Seyn Sie ſo gütig mir zu melden wo Freyherr v Zach ſich gegenwärtig in Italien aufhält, denn

Figure 10: Part of the letter from Matt to Reichenbach dated 30 September 1809 (with kind permission of the Deutsches Museum München; its accession number is HS 05906).

powder signals was subsequently reactivated by Zach in order to transfer local time and determine longitude (see Brosche, 2009: 169ff.)

Elisabeth von Matt furthered astronomy by allowing Bürg, and also F.W. Seeber from Karlsruhe, to use her Vienna observatory (see Triesnecker and Seeber, 1805). She also assisted with the exchange of books (Matt 1808; Triesnecker, 1807) and the ordering of instruments (Matt, 1808: 261), and her astrogeodetic data were later used by Wurm (1827).

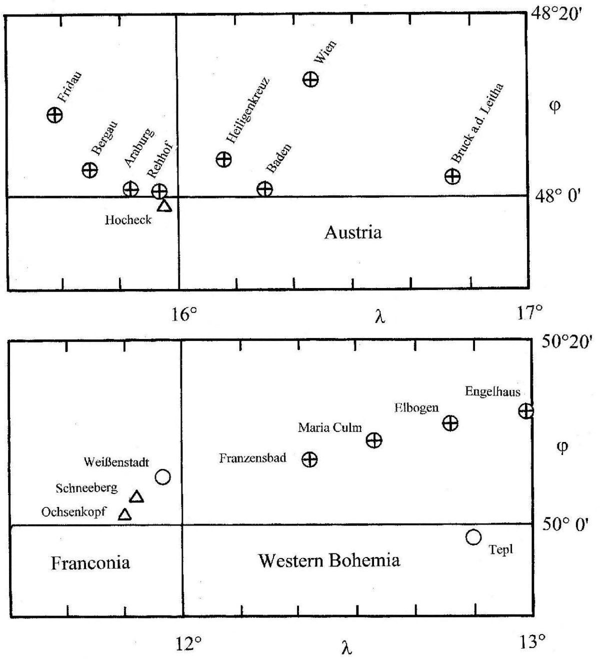

Figure 11: Diagrams showing the latitude and longitude of places in inner Austria and in western Bohemia surveyed by Elisabeth von Matt (circles with crosses). Other towns mentioned in the text are shown as open circles, and mountains whose altitudes were determined by Bürg and von Lindenau as triangles.

The wider interests of Elisabeth von Matt are best characterized by a full quotation from Karoline Pichler's (1914) memoirs, which are given here in translation:

> Already quite some time ago we had presented in our house plays by Goethe, Schiller, and others with much delight. Now, in March 1813, it was decided to read "The Bride of Messina" [a drama by Schiller] at the house of Baroness von Matt, a very learned, even erudite lady, who occupied herself with astronomy and had built an observatory in her house. Once every week the same circle of mutual friends gathered with this lady, among them very literate ladies and several excellent scholars were found, like Hammer, Schlegel, Adam Müller, a circle that had gathered in the past in the house of my departed lady friend Flies. Baron Hormayr and a Mr. Rupprecht, who himself was a brave poet, had taken over the roles of the two sons; a very pretty lady, to whom a very vivid interest in one of these gentlemen was ascribed, should read the role of Beatrice, and I myself the role of the mother.

The minor planet 9816 von Matt named in her memory was discovered in 1960 by C.J. van Houten and I. van Houten-Groeneveld on Palomar Schmidt plates. The name was suggested by Hermann Haupt of Graz.

5 NOTES

1. This paper is dedicated to Hermann Haupt (Graz) on the occasion of his 85th birthday.
2. Information kindly provided by Domarchivar Reinhard Gruber. The reference is: Domarchiv St. Stephan, Vienna. Trauungsbach der Dompfarrei St. Stephan zu Wien, Tomus 75, folio 238 recto.
3. *Verlassenschaftsakten* in *Allgemeines Verwaltungsarchiv* of the *Österreichisches Staatsarchiv*. This was partly destroyed by the great fire of 1927.
4. Since the day and the year of the death of Bürg vary in the literature (without an authority), it may be welcome here to quote the information from the diocesan archive in Klagenfurt (Mag. Ch. Salcher, letter dated 10 June 2010): Bürg died 25 November 1834 from pneumonia.

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TIME BALLS, TIME GUNS AND GLASGOW'S QUEST FOR A RELIABLE LOCAL TIME SERVICE

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Abstract: Edinburgh has had a time ball since 1853 and a time gun since 1861. In Glasgow, a time ball was erected in 1857, but the service was of questionable accuracy and had ended by March 1864. A new time service involving time guns controlled by Edinburgh Observatory was proposed in 1863, but a controversial experiment using four time guns was terminated in February 1864. Later that same year Glasgow received a reliable time service whereby public clocks were controlled from Glasgow Observatory.

Keywords: time balls, time guns, Glasgow Observatory, Edinburgh Observatory

1 INTRODUCTION

Glasgow and Edinburgh, the two principal cities of Scotland, have a long history of rivalry and differences of character that persist even today. Edinburgh, the seat of government and at the heart of political thought for centuries, is on the Firth of Forth to the east. Glasgow, one of the world's great industrial cities and at the heart of international trade by sea, is on the River Clyde to the west and remains much the larger; its modern history is rooted in ship-building and scientific achievement during the nineteenth and twentieth centuries. Both can justly claim high international stature for their universities and cultural lives.

While Edinburgh had a local time service based upon a time ball from 1853 and a time gun from 1861, Glasgow struggled to establish its own local time service. After starting with a time ball in 1857 it moved to an experiment involving time guns controlled from Edinburgh Observatory, and finally settled on a network of local public clocks controlled by signals from Glasgow Observatory. After discussing the critical roles that the Astronomers Royal, and particularly Sir George Airy, played in establishing reliable time services throughout the British Isles and the British Empire, we examine the short-lived yet painful path that Glasgow followed between 1857 and 1864 before it too finally acquired an accurate local time service.

1.1 Local Time Services and the Influence of the Astronomers Royal

The man at the centre of time signal provision was the Astronomer Royal, based at the Royal Greenwich Observatory. In an informative brief history, Malin (1987) records how the Observatory developed to the present day. It had been founded specifically for the accurate determination of longitude in 1675, with John Flamsteed (1646–1719) as the first Astronomer Royal. Flamsteed established that the rate of rotation of the Earth was constant (modern measurements have shown that there are tiny variations), so that it was possible to develop the 'method of lunar distances', using the position of the Moon against the background of stars as a clock. Earlier observations were of insufficient accuracy to allow determination of longitude for safe navigation, so he set out to improve the quality of measurements. King Charles II (1630–1685) "... certainly did not want his ship-owners and sailors to be deprived of any help that the heavens could supply, whereby navigation could be made safer." (ibid.: 248). Finally, in 1766, the fifth Astronomer Royal, Nevil Maskelyne (1732–1811), published the *Nautical Almanac* that would enable longitude to be determined in 1767 using the method of lunar distances. It was a triumph, but it was a method that tested the most skilled of navigators. Another solution was about to become practicable.

In a remarkable achievement which took most of his working life, John Harrison (1693–1776) in 1759 was able to produce his compact 'H4' timekeeper, which allowed Greenwich Time to be known accurately on a ship that had been at sea for many weeks (Sobel, 1995). Local time, determined from the Sun's position, then allowed accurate determination of longitude. However, it was not easy to manufacture accurate, reliable chronometers in the large numbers that would allow them to be carried by all ocean-going vessels, so the method of lunar distances remained in use for a long time. The general transition to chronometers actually took until about 1830, which marks the start of the time ball story (Rooney, 2009).

A few seconds of time represents a significant error in longitude. In 4 seconds of time the Earth rotates 1 minute of arc, which corresponds to a nautical mile at the equator and half a mile at Latitude 60°. A chronometer error of only ten seconds could be critical to a navigator trying to avoid hazards such as reefs. Accurate land-based time signals, visible or audible to nearby ships, were the key to chronometer calibration.

The concept of the time ball was developed by Captain Robert Wauchope, R.N. (1788–1862). His idea was that a large ball, visible to ships in harbour, would be dropped from a tower at an exact predetermined time each day (Bartky and Dick, 1981). This would be published in nautical almanacs, together with the latitude and longitude at the time ball location. Repeat measurements on successive days would allow the chronometer rate to be determined. Among other benefits, this removed the need for delicate chronometers to be moved ashore for calibration, a process that could easily lead to accidental damage.

An experimental time ball operated at Portsmouth for the first time in 1829. Wauchope proposed the construction of a public time ball at Greenwich, having seen hundreds of ships being made ready for sea in London docks, "… all of which could most distinctly see a chronometer signal from Greenwich Observatory." (ibid.) A letter from the Admiralty on 20 June

1833 stated that his plan had been referred to John Pond (1767–1836), the sixth Astronomer Royal, and construction started in August that year.

The 1833 Greenwich apparatus was supplied by Maudslay, Sons & Field. The same company built the apparatus for Edinburgh, Deal, and Sydney (N.S.W.) between 1852 and 1855 (Kinns and Abell, 2009). It has been shown recently that Maudslays replicated the Sydney apparatus for Lyttelton (New Zealand) in 1873-1874; it was shipped from London by Siemens Brothers and was long thought to have been built by that company (Kinns, 2009). All of these have survived, although the time ball at Deal is now operated using a modern apparatus. They were dropped automatically by electric telegraph, but are now operated manually. Many other companies built time ball apparatuses. For example, those at Liverpool and Quebec were built by Messrs. Forrester of Liverpool (Airy, 1871). Time balls for the Cape of Good Hope and the first (1864) time ball at Wellington (New Zealand) were supplied by Sandys & Co. of London (Maclear, 1863). None of these is still in existence.

The 1833 Greenwich apparatus was operated manually at first, but automatic electric operation was introduced during the 1850s. From the outset, the Edinburgh time ball apparatus had automatic triggering by telegraph from Edinburgh Observatory. It used a rack and pinion mechanism for hoisting the time ball with that at Greenwich having used a chain hoist. The 1853 design for Deal was similar to Edinburgh, but included a return signal to Greenwich. The 1855 time ball for Sydney Observatory used a further development of the mechanism, also with automatic electric operation, which was replicated at Lyttelton.

1.2 George Airy and the Development of the Time Signals

Sir George Airy (1801–1892; Figure 1) was Astronomer Royal at the height of time signal provision around the world, and his correspondence—now held in the University Library at Cambridge University—shows that he had a considerable influence on time signal development (see Airy, 1896) He often provided advice to those seeking to provide time signals, but he did not exercise control over the selection of designs or manufacturers, which was left to local initiative and budget constraints. The time ball at Deal was the only one outside Greenwich that was under his direct control. Airy often supplied the Deal drawings to third parties. There were many exchanges of letters about time signals from the 1850s onwards, showing the extent to which they were considered essential for navigation worldwide.

Devices other than time balls and time guns were sometimes selected. For example, a collapsible cone was introduced at Devonport in 1861 (Notice to Mariners, 1861); Admiralty lists of time signals show that this was replaced by a time ball at some time between 1880 and 1898. Airy himself suggested occasionally that a large semaphore arm with a disc at the end might provide a cheaper alternative to a time ball. In a letter of 28 January 1859 concerning a time ball for the Tyne, Airy comments "What shall be your signal? Drop of Ball? Drop of Semaphore Arm?" (Airy, 1859a).

Correspondence in 1860 concerning a possible time ball at Gravesend illustrates how the Astronomer Royal was asked for advice and how he responded. The approach was from Stephen Leach (1860a) at the Thames Conservancy. His letter to Airy includes the following remark:

> Mr Main, upon whom I called with reference to the subject, in your absence, informed me that Messrs. Maudslay & Field supplied the mechanical part of the apparatus & in order to save you trouble I have written to them for particulars.

Airy (1860) promptly replied:

> In regard to the Time Signal, if you decide on having a Ball, you cannot do better than consult Messrs. Maudslays but it has long since appeared to me probable that an efficient construction might be made on the Semaphore principle, at a much smaller expense. If yourself, or a good mechanical engineer in your company, could call on any morning at an early time, say 11 o'clock, I shall be happy to talk over the matter and to explain my views more fully.

Figure 1: Sir George Airy (after *Daily Graphic*, 1892).

Leach (1860b) wrote to Airy again a fortnight later:

> I have made a drawing of a Semaphore signal which I think would answer the purpose & which I shall be happy to submit to you. I find however a strong preference on the part of the Conservancy for a Ball, as being the commonly recognised mode of exhibiting the signal.

Semaphore signals were used in South Africa, but most were replaced by time balls. Gill (1913:) recorded that "… a time ball was dropped at the Docks in Cape Town; a Disc at the end of an arm was dropped at Simons Town, and similar Discs at the Light House, Port Elizabeth and at East London." Discs at Simons Bay (sic.) and Port Elizabeth were included in the first edition of the Admiralty list of time signals (List of time signals, 1880). The fifth edition showed that time balls were then in use at Port Elizabeth and East London; only the semaphore disc at Simons Bay remained (List of time signals …, 1898).

Conspicuous time balls were the favoured time signals, followed by time guns. If an audible signal was used, it was necessary to allow for the transmission of sound at about 340 m/sec in calculating exact time at the receiving location; the delay could be several seconds in a typical port location.

2 THE GLASGOW TIME BALL

2.1 Founding of the Time Service

The well-known Scottish astronomer, Sir Thomas Brisbane (1773–1860; Morrison-Low, 2004), spent some weeks studying the action of the Edinburgh time ball atop the Nelson monument on Carlton Hill before recommending that similar time balls should also be erected in Glasgow and Greenock (*The Practical Mechanic's Journal*).

Figure 2: The Glasgow Sailors' Home, in the left foreground (courtesy: Glasgow City Archives and Special Collections).

This suggestion was eventually acted upon, for the following note was published in the Edinburgh newspaper, *The Scotsman* on 6 June 1857: "A time-ball has been hoisted on the pole surmounting the Sailors' Home at the Broomielaw [a major road in Glasgow beside the Clyde—see Jones, 2010]." (Time Ball …, 1857), while a report in the 4 May 1859 issue of the *Glasgow Daily Herald* newspaper confirmed that the time ball was located on top of the Sailors' Home at 150 Broomielaw, on the north side of the Clyde near the City Centre. A manuscript in the Glasgow City Archives and Special Collections at the Mitchell Library reveals that the Glasgow Sailors' Home

> … was opened in 1857. The association which administered it was registered as a company in 1869 and subsequently acquired other properties in Govan and elsewhere, including Atlantic House. Atlantic House, at the corner of Argyle Street and York Street, was opened as a hostel during the Second World War, and was known latterly as Atlantic House Hotel. The original Sailors' Home was closed in 1960, and the company, by then the Glasgow Sailors' Hotel Ltd., was liquidated in 1979. (The Glasgow Sailor's Home, n.d.).

Figure 2 shows the Sailors' Home before its demolition in 1971. The photograph appears to date from the 1960s, long after the time ball had ceased to operate. The circular tower would have supported the time ball apparatus. The dome in the distance is part of the Clyde Port Authority building at the corner of Robertson Street and Broomielaw, which survives to this day.

Glasgow's time ball was intimately connected with the industrial development of the city, which depended crucially on the deepening of the River Clyde. Work began on this major undertaking in 1770 and by 1812 Glasgow no longer had to depend on its outports at Port Glasgow, Greenock and Dumbarton.

The Glasgow City Council had become trustees of the River Clyde in 1770, with responsibility for managing the River, dredging and harbour development. The River Improvement Trust was set up in 1809, but was superseded by the Clyde Navigation Trust, which was established by an Act of Parliament in 1858. The Clyde Trustees were representatives of the ship owners and harbour ratepayers, together with appointees by Glasgow Corporation; Glasgow Chamber of Commerce; the Merchants' House; the Trades House; the county councils of Lanark and Dunbarton; and the burghs of Dumbarton, Clydebank, Renfrew, Govan and Partick. Trust meetings were chaired by the Lord Provost of Glasgow (*The Glasgow Story*).

Although construction of the Glasgow Sailors' Home was completed early in 1857 it is not clear that a regular time ball service started at this time, but the following letter to the Clyde Trustees dated 14 December 1858 clearly indicates that by July 1858 the local firm of Duncan McGregor & Co., chronometer-makers, had entered into a contract with the Trustees to determine Greenwich Mean Time using astronomical observations and to operate the Glasgow time ball:[2]

> Dear Sir
>
> Your favour of yesterday to hand, and as requested beg to state that our duties with reference to the Time Ball are as follows –
>
> 1st To furnish the observations required in keeping the Time Ball regulator at Greenwich Mean time –
>
> 2nd To attend daily, and set the regulator at absolute Greenwich M. T. –
>
> 3rd To furnish & maintain the chemicals required in forming the Magnetic connexion between the regulator & Time Ball –
>
> 4th To attend daily for the purpose of putting the Battery in Action, Hoisting the Ball, seeing that it drops accurately, and generally to see that the whole Apparatus is kept in proper working order –
>
> The foregoing we undertake to perform from 1st July 1858 till 1st July 1859 for the sum of Sixty pounds stg. payable half yearly. (McGregor & Co., 1858).

Although this letter implies that the time ball service began on 1 July 1858, it is possible that earlier correspondence has been lost and that the contract actually started in 1857 soon after the installation of the time ball.

The firm of Duncan McGregor & Co. did not derive local Glasgow time from the Glasgow Observatory, or even from Edinburgh Observatory or the Royal Observatory at Greenwich. Rather, Duncan McGregor maintained a private observatory on the top of his house and presumably carried out transit observations there. McGregor's observatory was located about

200 yards from the Glasgow Sailor's Home and the time ball tower (Nichol, 1859b).

2.2 Disquiet Over the Operation of the Time Ball

From the start there was concern over the accuracy of the time ball service, primarily because (a) local Glasgow time did not originate from an 'official' (i.e. professional) observatory, and (b) the time ball mechanism was activated by hand and not by an electric current from an observatory.

One of those leading the charge to improve Glasgow's time service was John Pringle Nichol (Figure 3), Regius Professor of Practical Astronomy at the University of Glasgow from 1836 up until his death in September 1859. After his appointment to the Chair at the University, Nichol

> … became famous not only for his inspiring lectures to students but for those he delivered to huge audiences at public meetings in the city … His lectures are said to have inspired the young student William Thomson, later Lord Kelvin. (The University of Glasgow Story. Biography of John Pringle Nichol).

Nichol played a key role in 1841 when the Astronomical Institution of Glasgow raised funds for a new observatory at Horselethill in the West End of Glasgow.

On 26 April 1859 Nichol wrote to Airy expressing his concern about the Glasgow time ball, and his letter includes the following comment:

> I have been doing utmost to get them to put their Time-Ball here in a right state. It is kept by a watchmaker, who has a rickety [observatory] in the top of his house. (Nichol, 1859a).

With his letter, Nichol also included a newspaper article by a Mr Allan, one of the Clyde Trustees, which stated:

> … it should be known that Professor (sic) Hartnup of Liverpool does not recommend time-balls being dropped by electric current transmitted from Greenwich .... A time-ball was erected in Liverpool some time ago by the Electric Telegraph Company, and wrought from London, which had to be discontinued, as its signals were found not to be so correct as those dropped by hand in Mr. Hartnup's observatory. And, remarkably enough, the time-balls in Liverpool Observatory and at the Liverpool docks, are all at this moment dropped by hand, and not by electric currents ...

Airy (1859b) sent Nichol an immediate reply, where he corrected some of the erroneous statements made by Allan:

> In the extract from a letter in a Glasgow newspaper which you have sent me there are some inaccuracies which are important in reference to the question now before you.
>
> 1. The time-ball erected by the Electric Telegraph Company is in daily use at Liverpool, and is dropped with perfect accuracy (as regards the instant of time) by the current which originates at Greenwich. Occasionally, from defect of insulation, in damp weather, &c., it fails, but the failures are rare. 2. The time-ball at Greenwich is always dropped by the galvanic clock. It has not been dropped by hand for several years, except when the mechanism has been under repair or cleaning.
>
> I do not know precisely what is contemplated at Liverpool in reference to the proposed new time-balls, but remarking that there is at the Liverpool Observatory a first-class transit instrument, used by an accomplished and long experienced observer, and remarking that the longitude of the Liverpool Observatory from Greenwich has been determined with great care, I should think it prudent (in order to avoid the difficulties incidental to a long line of telegraph) to drop the balls by galvanic current from the Liverpool Observatory.
>
> I should recommend a similar course at Glasgow. – dropping the balls by current from the Glasgow Observatory. The distance of two or three miles offers no difficulty.

On 27 April 1859 John Hartnup (Director of the Liverpool Observatory) sent Nichol details of the set up at his Observatory:

> It is quite true that I have recommended the new time-ball, about to be erected on the top of the Victoria Tower, to be dropped by the large turret clock in that tower by a mechanical arrangement. In the event of this being done the turret clock will, of course, be controlled by our normal clock at the Observatory, and thereby made to keep time throughout the day with the same degree of accuracy that we could drop the ball ...

Figure 3: John Pringle Nichol, 1804–1859 (courtesy: Archive Services, University of Glasgow).

Hartnup (ibid.) also discussed the problem of trying to operate a local time service without the aid of a professional observatory. When the Liverpool Observatory was being planned

> … the Greenwich time obtained from various celebrated chronometer makers who had transit instruments of their own, had been found to differ from the correct Greenwich time sufficiently to cause a wreck; and it was recommended by scientific gentlemen, who were consulted by the Liverpool Corporation, and particularly by the Astronomer Royal, that an astronomical character should be given to the Liverpool Observatory ...

Finally, Hartnup (ibid.) made the following poignant comment that reflected directly on the operation of Glasgow's all-too-inadequate time service:

> The scientific public and intelligent shipmasters will never have confidence in either time-balls or clocks, which are not placed directly under the control of the officers of an astronomical observatory.

In a letter dated 30 April 1859 to David Dreghorn, a prominent local citizen, Nichol also discusses some of the issues raised in the afore-mentioned letters by Airy and Hartnup:

> I. I repeat emphatically, in reference to the use of "electric currents", that the thing requisite, and which alone is of much moment, is this:- The working current ought to pass to the machinery of the ball directly from the transit clock, and be set in action, automatically, by that clock. No intervention of "a man with a watch" is now permissible at any part of the process. The objection is to intervention of any kind; it is of no consequence at what part of the process such intervention may take place.
>
> II. Statements are made and vouched for that an "adequate observatory" exists, and is in operation, within two hundred yards of the turret of the Sailors' Home. I have only to express a hope that the Clyde trustees have an easy and comparatively inexpensive task before them. They have merely to lay a conducting wire through these two hundred yards; and to ensure that records of the working of the institution be regularly kept, and remain open to examination.

Nichol (ibid.) concluded that:

> It is plain enough that public controversy on such matters can lead to no good result. It is really a technical and strictly scientific subject, and the state of information of the public mind on questions of this description does not offer adequate security against the acceptance of reiterated and plausible statements, how inaccurate soever they may be.

Nichol (ibid.) then went on to suggest that the Clyde Trustees

> … request a visit and report from the Scottish Astronomer Royal, Professor Piazzi Smyth of Edinburgh ... [A] visit of half a day would enable him to report definitively concerning the "observatory", and every other arrangement connected with the time-ball.

For his part, Dreghorn (1859) identified the anticipated outcome of these discussions:

> I am sure if we set ourselves to the work, there can be little difficulty in placing Glasgow – as far as her great navigation interests are concerned – under the system to which Mr. Hartnup alludes, as already existing and about to be greatly extended and perfected in London and Liverpool.

The *Glasgow Daily Herald* editorial published on 30 October 1863, described later, displayed a subsequent souring of relations between Glasgow and Edinburgh on the matter of transmission of time.

Figure 4: The Broomielaw in about 1870 (courtesy: the Graham Lappin Collection).

2.3 Demise of the Time Ball Service

A letter from Duncan McGregor & Co. dated 3 December 1859 shows that his firm continued to supply the Clyde Trustees with a time ball service for the period 1 July 1859 to 1 July 1860, but this time for the twice-yearly amount of £40.

Further annual endorsements of the contract dated 1 July 1862 and 1 July 1863 were prepared (see McGregor & Co., 1859), suggesting that it was intended to operate the Glasgow time ball until at least the end of June 1864. The final contract between the Clyde Trustees and McGregor & Co. is likely to have been terminated early. In a letter to Airy dated 8 January 1878, Professor Robert Grant, who succeeded Professor Nichol as Director of Glasgow Observatory in 1859, stated that "… when this Observatory was finally, in 1863, connected electrically with the City of Glasgow the dropping of the time ball was discontinued." The 1863 date is probably an error of memory. Letters and editorials in the *Glasgow Daily Herald*, described later, show that the electrical connection to the City was implemented in March 1864.

Concerns about the accuracy of the Glasgow time ball service probably lay at the heart of its demise, but the fact that the time ball was not visible to larger vessels in the Clyde at a critical time in Glasgow's maritime development must also have played a role.

Although the time ball had ceased to operate by 1864, later photographs of the Broomielaw show that the ball and mast were not removed for a long time. Figure 4 is a photograph taken by George Washington Wilson in about 1870. It shows three paddle steamers and various small sailing vessels alongside the Broomielaw on the north bank of the Clyde near the centre of Glasgow. The tower of the Sailors' Home can be seen behind the mast of the middle steamer, with the ball in its lowered position (Jones, 2010). Figure 5 is a close-up of the time ball tower as photographed in 1876, and the mast and ball also appear in an 1897 collotype (private communication, Professor A Graham Lappin), so they certainly survived until the end of the nineteenth century.

3 THE TIME GUN PROPOSAL FROM EDINBURGH

In October 1863 the *Glasgow Daily Herald* published a 2,000 word editorial about time signals (*Glasgow Daily Herald*, 1863). Unknown to the leading astronomers and most authorities in Glasgow, Professor Charles Piazzi Smyth (1819–1900; Figure 6), the second Astronomer Royal for Scotland (see Brück and Brück, 1988), proposed to introduce a Glasgow time gun, controlled from Edinburgh Observatory. The following newspaper report, titled "Proposed time-gun in Glasgow" (1863), was published in the *Scotsman*, an Edinburgh newspaper, on 24 September 1863:

> We are informed that experiments are likely to be made this week with a view to the establishment of a Time-Gun in Glasgow. The gun will be fired from the Edinburgh Observatory, in the same way as that now fired in Newcastle. Instead of an electric clock being used to pull the friction tube as in the Castle, a small fuse filled with powder placed in the vent of the gun will be exploded by means of a spark evolved from Wheatstone's "magnetic exploder" – the electric current being transmitted precisely at one o'clock from the Observatory through one of the Electric Telegraph Company's wires to Glasgow.

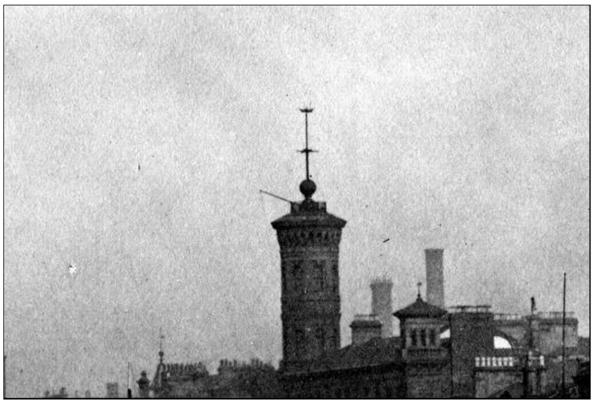

Figure 5: An enlarged image of the Glasgow time ball, taken in 1876 (courtesy: A Graham Lappin).

Meanwhile, Smyth had already demonstrated the feasibility of telegraphic control from Edinburgh in 1858:

> The subject of time-ball extension – that is, giving to other localities connected by telegraph the same electric signal as that which drops the Edinburgh ball – has likewise been discussed on former occasions by members of the Board, and an experiment of this sort was made during the meeting of the British Association at Glasgow, with the countenance of Professor Nichol; when a model apparatus was dropped daily in the mechanical section, meeting in Glasgow College, by the signal from the Edinburgh Observatory. (The Royal Observatory …, 1858)

Smyth's time gun proposal caused considerable offence in Glasgow, which can be illustrated by extracts from an editorial in the *Glasgow Daily Herald*:

> More than a month has now elapsed since the intelligence that a Time-Gun was to be introduced into Glasgow burst upon its inhabitants. An Edinburgh journal, in its impression of September 24, first gave currency to the report of the good things in store for Glasgow; for, up till then, the project had been matured with unac-

Figure 6: Charles Piazzi Smyth (after: http://pinetreeweb.com/pb-piazzi-smyth.htm).

> countable quietness. It was stated, further, that the gun was to be fired in connection with the Edinburgh Observatory. In our impression of September 26 there appeared fuller details, by which the public were informed that the scheme had originated with the Universal Private Telegraph Company, which had secured the co-operation of Professor Charles Piazzi Smyth, Director of the Edinburgh Observatory – that the arrangements were all but complete – that a site had been procured for the firing of the gun, and that maps, to enable the public to take advantage more effectually of the new time signal, had been *already prepared*, and might be seen in a bookseller's shop window. On the same day there appeared a letter from the Professor of Astronomy in our own University, by which it appeared that he had some time previously, submitted to the Town council a scheme for the transmission of time, of a totally different character, but which had been practised with admirable success in Liverpool for several years past. It was plainly apparent that neither the University of Glasgow nor Professor Grant had received any information respecting the Edinburgh project until it was announced in the public journals; and this was confirmed by a subsequent letter which the Professor addressed to the Lord Provost, in his capacity of Chairman of the Clyde Navigation. Referring to a special arrangement with her Majesty's Government, by which the University of Glasgow, as represented by its Observatory, is pledged to furnish the shipping of the Clyde with correct time, he assures his Lordship "that, under no circumstances whatever, will the University consent to forego this engagement, or permit the usurpation, by any other observatory, of the duties which it imposes." (*Glasgow Daily Herald*, 1863).

The intermediate paragraphs attack Smyth's presumption in behaving like the Astronomer Royal at Greenwich, and emphasized the comparable status of the observatories in Glasgow and Edinburgh. The following extract further demonstrates the disquiet in Glasgow about Smyth's approach:

> Professor Smyth speaks of Glasgow having *applied* for a signal gun; of its being the only Scottish city which had hitherto accomplished the object of its wish; of its citizens having locally provided a cannon; of their strong common sense in perceiving the superiority of the new system, and of their having vigorously adopted a new and more suitable locality for the firing of a gun. In reply to these statements, we have simply to say that in this city of half a million inhabitants, there were probably not more than half a dozen of persons who were recognisant of the project of the Private Telegraph Company and Professor Smyth, previous to the announcement of the Edinburgh *Scotsman*. (ibid.).

Notwithstanding the public disquiet, the plan by the Private Telegraph Company succeeded, and an experimental time gun service was initiated. Of all places, details of it were published in an 1865 Australian newspaper:

> The first Glasgow time-gun was supplemented by a second one in St. Vincent's Place on the 29th of October [1863], and these two by a third at the Broomielaw, on the 10th of November, while a fourth gun was added to the system at Greenock on the 21st November, all four being simultaneously fired through the agency of the electric current from the [Edinburgh] Observatory. (Time signals, 1865).

However, the service did not last for very long as the 3 February 1864 issue of the *Glasgow Daily Herald* contained the following report:

> I desire through your columns to inform those interested in the establishment of correct time signals for Glasgow, Greenock, and the surrounding parts, that the four time-guns hitherto fired daily at 1 P.M., Greenwich Mean Time, will cease firing on Saturday the 6th instant. The experiment I had the honour of introducing to this city has proved successful; and if it is desired to have guns – having laid the matter before the several authorities – the guns can be resumed as soon as the necessary arrangements have been made. (Holmes, 1864).

As it happened, the concluding section of the editorial that had been published in the 30 October 1863 issue of the *Glasgow Daily Herald* already set the scene for the developments that would occur in Glasgow over the following months:

> It is not within our province to pronounce an opinion on the respective merits of the different methods of transmitting time which are now before the public. The University, we believe, are quite prepared to co-operate in adopting, according to circumstances, whatever may be considered most suitable; and that, too, utterly irrespective of anything that may be done from any other quarter. (*Glasgow Daily Herald*, 1863).

4 THE TRANSITION TO CONTROLLED PUBLIC CLOCKS IN GLASGOW

When he wrote to Nichol on 27 April 1859, John Hartnup from the Liverpool Observatory foreshadowed the approach that Professor Nichol would take in establishing a reliable public time service in Glasgow:

> The practicality of controlling clocks by weak galvanic currents, is now attracting great attention in London, and … It is quite certain that we now have it in our power to control all the public clocks in a large town, thereby making them all strike simultaneously, and show the same time throughout the day as the normal clock at the observatory by which they are controlled.
>
> By a single wire you might control all the important clocks in Glasgow …

The Editorial published in the *Glasgow Daily Herald* on 30 October 1863 indicates that by this date Professor Grant at Glasgow had been working on a system whereby public clocks, and indeed any other public time signals, would be controlled from Glasgow Observatory.

> It is understood that the preliminary permissions for laying down a wire from the Observatory to the College Clock have been already obtained, and that actual operations will be commenced in the beginning of next week. We may expect, therefore, that in about three weeks hence the College Clock will be maintained in perpetual control by the Normal Clock of the observatory, and it will then be an easy matter to extend the system indefinitely.

Robert Grant (Figure 7) was the Regius Professor of Astronomy at the University of Glasgow and Director of the Observatory from 1859 to 1892. He succeeded John Nichol. After his *History of Physical Astronomy from the Earliest Ages to the Middle of the Nineteenth Century* was published in 1852 "… Grant became a well-respected figure in the world of astronomical research." (The University of Glasgow Story. Biography of Robert Grant).

The following editorial, titled "Controlling of the public clocks by an electric current from the Observatory of the Glasgow University" (1864), was published in the 5 January 1864 issue of the *Glasgow Daily Herald* and gave full support to Professor Grant's proposal for Glasgow and the Clyde:

> We understand that the University of Glasgow has submitted to the Town Councils of Glasgow, Paisley, Port Glasgow, and Greenock, a plan for the controlling of all the public clocks in the former towns, by means of a current of electricity directed from the standard mean time clock of the Observatory of the University, in accordance with the ingenious invention of Mr. Jones of Chester, which has been for several years in practical operation at Liverpool, where it has been attended with the most complete success. If this proposal be adopted, the result will be that the pendulum of all the clocks under control will vibrate in perfect unison with the pendulum of the Observatory clock, and the first blow of the hammer for the successive hours will indicate Greenwich mean time, and will, in the case of every clock, occur at the instant when the seconds' hand of the Observatory clock points to sixty. It may be interesting to the public to know that this beautiful result has been already realised in the most satisfactory manner in the case of the University turret clock, which was connected by an electric current with the Observatory clock about ten days ago. This will be apparent from the following letter, addressed to Professor Grant by Mr. Macfarlane, the senior assistant of Professor William Thomson who very obligingly undertook to compare daily the University clock with the indications of the Observatory clock. In order to appreciate the exact force of Mr. Macfarlane's observations it may be well to mention that at every second of the minute, except the thirtieth second, a current or pulse of the electric fluid is transmitted from the Observatory clock to the University clock. This effect is indicated at the University clock by a corresponding deflection of the needle of a galvanometer placed in the circuit, occurring at every second except the thirtieth, when, there being no current, the needle will stand for an instant in the vertical position. Now, if the two clocks beat simultaneously, this position of the needle, indicative of the absence of a current, ought to occur invariably at the instant when the seconds' hand of the University Clock (which, we may remark, is not seen from the outside of the College buildings) points to thirty. How far this result has been realised will be seen from Mr. Macfarlane's letter.

Here is Donald Macfarlane's letter:

> Sir, I have regularly observed the working of the College clock several times a day from Saturday the 26th of December last till to-day, with the exception of Friday and Saturday last, when my place was supplied by Mr. Tatlock, and we have invariably found the *no current* beat of the Observatory clock to coincide exactly with the 30th second of each minute of the College clock.

The editorial refers to an invention by R.L. Jones, Station Master of Chester, who was a pioneer in clock sychronisation:

> In his patent no. 702 of 1857, Jones adopted Bain's system of sympathetic pendulums. A mechanical master clock provided the electric pulses to keep the pendulums of his ordinary key-wound clocks in step. The bob of these key-wound clocks consisted of a coil sliding over two permanent magnets. The electric pulses received from the master clock kept these secondary clocks in harmony with his master clock. He used the tower clock of Chester as master clock providing the electric pulses to control his secondary clocks. (Bosschieter, 2000).

Another editorial about Glasgow time signals was published a little over one week later in the *Glasgow Daily Herald* (1864), and included the following paragraph:

> We have, then, submitted to us two projects for supplying the City and the Port of Glasgow with correct time – the one emanating from our ancient University, and having the source of operations included within the extreme boundaries of the City; the other offered from an establishment, under the joint management of Professor Piazzi Smyth, of the Edinburgh Observatory, and of Mr. Nathaniel Holmes, of the Private Telegraph Company. Discounting all extraneous considerations, it may not be an unprofitable task to cast a glance at the relative advantage of the two schemes.

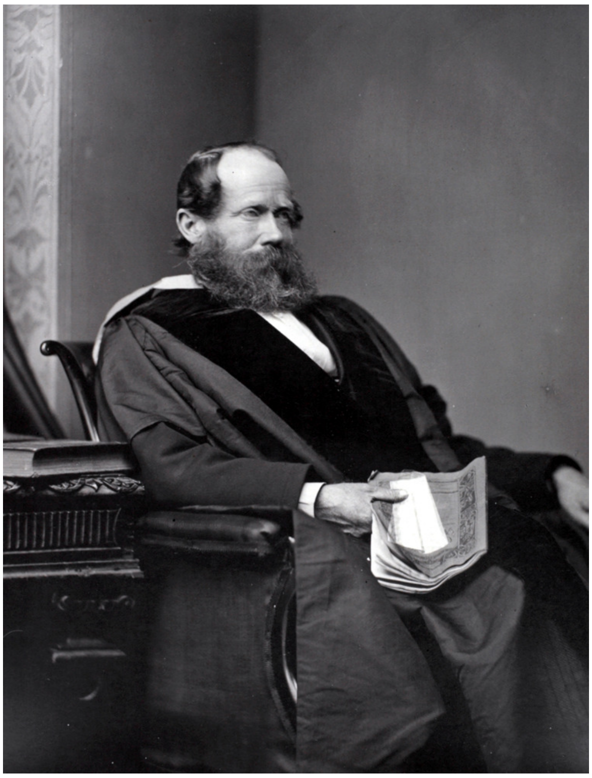
Figure 7: Robert Grant, 1814–1892 (courtesy: Archive Services, University of Glasgow).

Later in the same editorial there is a comment about the arrangements for the Tyne:

> ... about two months ago there was a good deal said respecting the rapid progress of the time-gun system at Newcastle, Sunderland and North Shields, under the joint management of Professor Smyth and Mr. Holmes. Recently, however, we are informed the tie which connected each of these three "affiliated cities" with their elder sister had been severed. Newcastle, while welcoming any useful suggestions from without, has reserved to itself the right of managing its own affairs in the way that may seem most conducive to its own interests, and neither of the gentlemen just mentioned have any connection with the gun which is fired daily in that town. We would desire to speak with the utmost respect of both Professor Smyth and Mr. Holmes – and, indeed, we thank them for the interest which their operations have excited in this quarter – but we cannot help thinking that if Newcastle, which has no Astronomical Observatory of its own, has been enabled to provide itself with correct time independently of either of these gentlemen, surely so can Glasgow, which is so much more favourably circumstanced in respect to astronomical advantages ... (ibid.).

Just four weeks later, on 3 February, one of two articles about Glasgow's time service that was published in the *Glasgow Daily Herald* reported that of the two options before it the Clyde Trust now favoured the use of telegraph signals from Glasgow Observatory to control public clocks in Glasgow:

> The Sub-Committee of the Harbour reported that, in accordance with a remit from the Committee of Management, they had considered a communication from Professor Grant regarding certain proposed arrangements for transmission by telegraph of correct time for the use of shipping of the Clyde and a communication from Mr. Holmes in relation to time-gun signals. The committee were of opinion that the Trustees should not entertain Mr. Holmes proposal as to time-gun signals; and, with regard to Professor Grant's communications as to the transmission of correct time by telegraph, they had remitted to the chairman and Messrs. Allan Gilmour and W. Allan to consider the proposal and report. (Clyde Trust, 1864).

On 5 March an editorial in the *Glasgow Daily Herald* titled "Transmission of time from Glasgow Observatory. Electric operations" showed that the decision had been made: the Directors of the Exchange had given Professor Grant their enthusiastic support. The opening and concluding sections of the editorial show its tenor:

> We understand that the directors of the Exchange, at a meeting held on Tuesday last, decided upon taking immediate steps for introducing into the Exchange the system of controlling clocks by electricity, which has been recently established in this city, in connection with the Observatory of the Glasgow University. The wire extending from the Observatory to the College, being already attached to the building of the Exchange, the clocks of the latter may be connected with the system at a trifling expense. It is proposed to place under control the great public clock and the clock in the interior, which is above the entrance into the building. A conspicuous clock, in place of the present small clock, showing the time to seconds, will also be fitted up in the great room, and will be similarly placed under control ...
>
> The University of Glasgow has freely placed the resources of the Observatory at the disposal of the city, with a view to the establishment of a complete system of correct time indications; and we have no doubt that not only the various corporate bodies, but also the inhabitants generally, will reciprocate this act of courtesy, by cordially supporting the University in its present exertions. *We want no official meddling from without. We feel perfectly competent to perform our own work*, and we are confident that, in the present instance, it will be accomplished with the dignity and importance of our ancient city. (My italics).

The italicized section, above, shows that there was still considerable resentment about Edinburgh Observatory's possible involvement in Glasgow's time service.

Progress was then rapid and Glasgow soon had a widely-accessible reliable time service available through public clocks in Glasgow and at ports along the Clyde that were regulated by electrical signals from Glasgow Observatory. The use of time balls and time guns as principal time signals for the Clyde finally had been abandoned.

Professor Grant then wrote a long letter that was published in three instalments in the *Glasgow Daily Herald* between 16 and 26 March 1864. Each part was entitled "How time is determined at the Glasgow Observatory" (Grant, 1864a; 1864b; 1864c), and collectively they constitute a fine exposition on the use of astronomical observations to determine time, and the accuracy that could be achieved.

Although Glasgow's controlled clocks were not listed in the Admiralty lists, their existence would have been known to mariners, and they were recognised by astronomers elsewhere as being accurate to within one second (e.g. see Ellery, 1868). Many of the public clocks had large dials, and some of them may have been visible from ships on the Clyde.

5 PROFESSOR GRANT'S LATER RECOLLECTION OF THE GLASGOW TIME BALL

In response to a query from Airy, in 1878 Grant supplied the following history of the Glasgow time ball and clarified the provision of time signals for Glasgow and the Clyde ports (his underlining):

> The story of time signals in connexion with Glasgow may be briefly told. When I came down here from London in November 1859 I found that a time ball was being dropped daily from a structure built expressly for the purpose on the north bank of the river, but the time rested on no astronomical authority and when this Observatory was finally, in 1863, connected electrically with the City of Glasgow the dropping of the time ball was discontinued. Indeed under the most favourable circumstances the situation from which the time ball was dropped was adverse to its practical usefulness.
>
> The time-signal system of this Observatory has consisted exclusively of a clock controlling by Jones's method. A considerable number of clocks both in the City and upon the river are connected in this manner with the Observatory. Furthermore I understand that Messrs. D. McGregor & Co Chronometer makers receive daily a signal from Greenwich ...

This account is of particular interest on three counts. First, there is no mention of the trials of the four-gun time signal, which were terminated in February 1864. Second, note that the former operator of the Glasgow time ball, the firm of D. McGregor & Co. ended up obtaining their time signals directly from Greenwich rather than from the local observatory. Third, Grant states that the time ball service was discontinued when the electrical connection between Glasgow Observatory and the City was implemented, but probably makes an error of memory in stating that the year was 1863. Editorials in the *Glasgow Daily Herald* indicate clearly that the link was completed in March 1864. It is therefore likely that the time ball service continued until that date.

6 DISCUSSION

6.1 The Abortive Plans for a Greenock Time Ball

Sir Thomas Brisbane was one of Scotland's foremost astronomers (see Morrison-Low, 2004), and in 1853-1854 he proposed that a time ball should be erected at Greenock (*The Practical Mechanic's Journal*). The idea was considered seriously, and there was a plan to erect a time ball as part of a memorial to James Watt (The proposed tower …, 1859):

> The monumental tower which it has been proposed to raise in memory of Watt will be reared in the cemetery occupying the heights to the west of Greenock, the birthplace of the great mechanician ... The upper turret is adapted for the reception of an electric time-ball, and for nautical and astronomical observations. Thus it sought to make the structure useful to all engaged in the navigation of the noble estuary of the Clyde.

The tower was built, but no record has been found that a time ball was ever erected at Greenock. Nevertheless, the idea was still current almost twenty years later:

> There has been talk about Greenock receiving a [time] signal from Greenwich. A time ball dropped there would be very desirable as it would enable the masters of ships leaving the Clyde to satisfy themselves respecting their chronometers ... (Grant, 1878).

6.2 Glasgow, and Airy's Lists of Time Balls and Time Signals

In May 1861 Airy compiled the following list of time balls, which shows that he was uncertain about the status of the Glasgow time ball:

> Greenwich;
> Deal;
> London (E and I Telegraph Co), City Observatory;
> Liverpool (E and I Telegraph Co), Victoria Tower;
> Portsmouth;
> Edinburgh;
> Glasgow (a ball was known to exist in 1859 but no particulars relating to it have been found);
> Cape of Good Hope (Simon's Town);
> Madras;
> Calcutta;
> Sydney;
> Quebec;
> Williamstown, Vic, Aus;
> Washington, US.

In fact, this list is not complete because time balls were also in operation at St. Helena and at the Royal Observatory in Cape Town, for example (see Bartky and Dick, 1981). But others, such as the one at Cornhill in London, were not useful to mariners and would have been excluded on that basis.

A high-level exchange of correspondence between Britain and Germany occurred during December 1877 and January 1878 when the German Government sought to obtain information about the British time signals. A letter was sent to the Astronomer Royal from the Foreign Office on 29 December 1877 (Foreign Office, 1877). Airy (1878a) replied initially with a holding letter to the Earl of Derby (who was then Foreign Secretary in the Disraeli Government) and he then wrote to various authorities, including Grant in Glasgow (Airy, 1878b; 1878c) and Smyth in Edinburgh, asking for detailed information about current time signals. The following letter to Grant shows that Airy (1878b) knew little about time signal provision in Glasgow at that time:

> I have been requested to procure some information respecting Time Signals. I know not whether there is such a thing in your important Port of Glasgow (I have not been there for some years) but I will suppose there is and will place before you all the questions which I wish to ask.

Airy then asked eleven questions concerning the type of signal, location, the authority for time and other operational features. He wrote another letter on the following day (Airy, 1878c), having forgotten to ask for the height of the signal above the ground and also above high water.

Replies to the twelve questions from the various correspondents were assembled into a large table in Airy's handwriting, which was then sent to the Earl of Derby with a covering letter (Airy, 1878d). Table 1 is a partial transcription of Airy's table, and shows the main part of the entries for Scotland. Additional columns in the complete table are headed: "Whether the signal reports the action to the Observatory; Action, in case of total failure; Action, in case of erroneous exhibition". Longitudes in this table are specified as time from Greenwich.

Table 1: An extract from Airy's summary of British time signals, dated 22 January 1878.

Exhibition of Public Time-Signals on or near to the Coasts of Britain:

(In all instances, the signal is exhibited every day at 1h.0m.0s Greenwich Mean Solar Time.)

Locality.	Approximate Latitude & Longitude.	Nature of the Signal.	Elevation above the Ground & above High Water.	Colour of Ball. Diameter. Rise for Signal.	Authority for Time.	Warning to the Public, of approaching Fall.	Specific Phase of Signal to be observed	Whether the signal is given by hand or by automatic action
Calton Hill, Edinburgh	55°.57'.23" $0^h.12^m.43^s$. W	Drop of Ball.	110 feet 457 feet	Dark grey 5 feet 10 feet	Transits at the Royal Observatory, Edinburgh.	As at Greenwich.	As at Greenwich.	As at Greenwich.
Castle Battery, Edinburgh	55°.57' $0^h.12^m.47^s$. W	Gun-fire.	200 feet 437 feet		Transits at Edinburgh.			Current from a clock controlled by R. Observatory, Edinburgh.
Docks, Leith	55°.59' $0^h.13^m$. W	Conspicuous Clocks.			Transits at Edinburgh.			Current from Edinburgh R. Observatory controlling the clocks.
Dundee	56°.28' $0^h.11^m.48^s$. W	Gun-fire.			Transits at Edinburgh.			Current from a clock controlled by R. Observatory, Edinburgh.
Inverness	57°.30' $0^h.16^m$. W	Small time-ball in private shop.			Transits at Greenwich.			Current in the Post Office Wires. As at West Hartlepool.
Glasgow	55°.52'.45" $0^h.17^m.11^s$. W	Several controlled clocks.			Transits at the Glasgow Observatory.			By galvanic current from the Glasgow Observatory controlling the Clocks.

Finally, we should note in passing that no time signals for the West of Scotland were mentioned in any of the five editions of the Admiralty list of time signals for mariners published between 1880 and 1898. The number of listed time balls increased from 52 to 94 world-wide during this period, while the number of listed time guns grew from 9 to 30. Overall, the number of distinct time signal locations listed by the Admiralty increased from 71 to 154, some having more than one type of signal. However, many other time balls and alternative signals existed for public use, away from coastal regions.

6.3 Glasgow's Public Time Service and Australian Time Signals

It is perhaps surprising that the system used for a local time service in Glasgow was recognised internationally. A plan to maintain true time in Melbourne, Australia, was outlined in a paper presented to the Royal Society of Victoria by Robert Ellery, the distinguished Government Astronomer of Victoria, Director of the Melbourne Observatory and President of the Society (see Gascoigne, 1992). Ellery (1868) noted that Glasgow clocks were "… correct to a second …" and that synchronism with the Observatory clock was confirmed using a simple system:

> In Glasgow, as an extra security to the public, it is made a *sine qua non* that those using the supply should have a small, simple, galvanometer beside their clock, which shows by right and left deflections of its needle the alternating currents, and also by an omitted deflection at the sixtieth second of each minute, if the controlled indicated the same second as the Observatory clock.

Ellery went on to point out that "The heavy two seconds pendulum of large turret clocks can be just as readily controlled by the same main, by a different disposition of the permanent magnets." He then reported on his own work to allow control of half seconds pendulums using the same currents.

There is also a surprising mention of the Glasgow time guns in the leading Tasmanian newspaper, *The Mercury*. During 1865 there was considerable debate at the Royal Society of Tasmania in Hobart about the introduction of a local accurate time service (see Royal Society, 1865). Francis Abbott, Tasmania's foremost astronomer (see Orchiston, 1992), had read a paper to the Society, which was published in the same column of *The Mercury* (Abbott, 1865). He mentioned many successful time ball and time gun installations worldwide, although he argued strongly in favour of time guns for Hobart. A more detailed account was published later in the same year, which made specific reference to the four time guns that had been used in Glasgow (Time signals, 1865). Abbott appeared to be unaware that he was describing a system that had by that time been discontinued.

7 SUMMARY

In 1857 a Glasgow time ball was erected on a tower above the Sailors' Home on the Broomielaw. It was maintained by the Clyde Trustees but operated by the firm of D. McGregor & Co., chronometer-makers of Glasgow and Greenock, which used its own observatory to determine Greenwich Time.

The accuracy and method of operation of the Glasgow time ball were criticised by leading astronomers, because time was derived from an unofficial observatory and because the ball itself was dropped by hand rather than automatically using an electric signal. Correspondence between Professor John Nichol of Glasgow Observatory, Astronomer Royal George Airy and John Hartnup, Director of the Liverpool Observatory, was published in the *Glasgow Daily Herald* in May 1859 in an effort to persuade the Clyde Trustees to adopt an improved arrangement, but this did not produce the desired result and the service was subsequently terminated late in 1863 or in the first three months of 1864. The fact that the Glasgow time ball could not be seen from larger vessels in the Clyde probably also contributed to its demise.

An alternative approach to provide a reliable local time service for Glasgow emerged in 1863 when Professor Charles Piazzi Smyth, Director of the Edinburgh Observatory and Astronomer Royal for Scotland, proposed that time guns operated by electric telegraph from Edinburgh Observatory should be installed in Glasgow. Although the idea that Edinburgh should control Glasgow's time service was strongly opposed by Glasgow Observatory and the University, an experiment using four time guns was carried out, but this was terminated in February 1864.

While Smyth was angling to control Glasgow's time service, Professor Robert Grant, Regius Professor of Astronomy at the University of Glasgow and Director of Glasgow Observatory was busy arranging a reliable local time service and this was achieved in March 1864 when public clocks in the city were brought under the control of the Observatory.

After consulting Grant, Airy included Glasgow's controlled public clocks in a list of British time signals that he prepared in January 1878, but no entries for the west of Scotland were included in the Admiralty lists of time signals for mariners that were published between 1880 and 1898.

8 NOTES

1. The history of time balls has been derived largely from the archives of the Royal Greenwich Observatory, held at the University Library in Cambridge while information relating to the Glasgow time ball is in *Glasgow Daily Herald*, microfilm copies of which are held in The Mitchell Library in Glasgow. Other relevant records are also held in the Glasgow City Archives at the Mitchell Library.
2. The *Annual Reports of the Sailors' Home* do not mention the time ball, which confirms that its construction and operation must have been independent of the Home (Annual Reports for the Sailors' Home). The first five meetings of the Glasgow Sailors' Home were held on 7 April 1858, 12 May 1859, 23 May 1860, 14 May 1862 and 30 May 1867. These span the period of the time ball operation.

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CHARLES NORDMANN AND MULTICOLOUR STELLAR PHOTOMETRY

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Abstract: Charles Nordmann (1881–1940), an astronomer at the Paris Observatory, was the first to determine the effective temperature of stars with his *photomètre hétérochrome*, simultaneously and independently of Rosenberg, Wilsing and Scheiner in Germany. He is also the remote precursor of the multicolour photometry of Johnson and Morgan. In spite of the quality of his temperature determinations, which were as good or better than those made by spectrophotometry, he rapidly fell into oblivion because of some failures in his scientific work. We examine his activity in the international context of the time, and explain why he has been forgotten, to be rediscovered only recently.

Keywords: multicolour stellar photometry, stellar spectrophotometry, interstellar medium, Paris Observatory, Charles Nordmann, François Arago, Maurice Lœwy, Benjamin Baillaud, Jules Baillaud, Petr Nicolaevich Lebedev, Hans Rosenberg, Julius Scheiner, Johannes Wilsing, Hermann Carl Vogel, Gavrijl Adrianovich Tikhoff

1 INTRODUCTION

Amongst early French astrophysicists, the most remarkable are undoubtedly François Arago (1786–1853), Jules Janssen (1824–1907), Henri Deslandres (1853–1948) and Charles Nordmann (1881–1940). Recent scientific biographies (in French) have been devoted to Arago and Janssen (respectively by Lequeux, 2008 and by Launay, 2009). The work of Deslandres remains to by studied in detail. Nordmann is the least known of the four, but not the least inventive. If Deslandres was one of the first to imagine that the Sun could emit radio waves, Nordmann actually attempted to detect them in 1901 by mounting an antenna over the Bossons glacier near Chamonix in the French Alps, but with no positive result (Débarbat et al., 2007). The present paper deals with another of Nordmann's more fruitful activities, namely the multicolour photometry of stars.

Charles Nordmann (Figure 1) was born in Saint-Imier, Switzerland, on 18 May 1881 (Esclangon, 1942: 5), fourth of the five children of Aron Nordmann (1842–1924) and Charlotte Didisheim (1847–1923). His family moved to Paris soon after. Little is known about his childhood and education. In 1899 he received a *licence ès sciences,* and he entered the Meudon Observatory the following year in an unpaid position (Nordmann, 1911). In June 1902 he obtained a position as an astronomer at the Nice Observatory, and he received a Ph.D. there the following year. He was perhaps unhappy in Nice, for in July 1903 he moved to the Paris Observatory whilst retaining his Nice appointment. In 1905, he was sent to northern Africa by the *Bureau des Longitudes* to lead a solar eclipse expedition and to compile a magnetic map of Algeria and Tunisia. Later in 1905, he obtained a permanent position of *astronome adjoint* at the Paris Observatory. He was promoted to *astronome titulaire* in 1920. Nordmann never travelled much after 1905, except to make a series of observations in Biskra (Algeria) in 1907 and to give lectures on astrophysics in Buenos Aires in 1928. He stayed at the Paris Observatory until his death in 1940, when he was aged only 59.

Nordmann's research activities were very varied: they included atmospherics physics, terrestrial magnetism, comets, variable stars and above all, stellar photometry and applications. His research was esteemed by his contemporaries: in 1907 and 1908 he won prizes from the *Académie des Sciences*. He was nominated as *Chevalier de la Légion d'Honneur* in 1912, not by the Paris Observatory Director of the time, Benjamin Baillaud (1848–1934), but by the Minister of Commerce, probably in relation to his work on atmospheric electricity and his lectures on 'Electrical meteorology' at the *École Supérieure des Postes et Télégraphes* (Baillaud, 1920: 8). However, at the same time, Baillaud succeeded in obtaining the *Légion d'Honneur* for three other astronomers at the Observatory (Baillaud 1913: 8). It appears that Baillaud and Nordmann did not get along well together. Nordmann's relations with Baillaud's predecessor, Maurice Lœwy (1833–1907), were much better.

During WWI, Nordmann developed the principle of acoustic localisation of artillery, based on the comparison of the times of arrival of gun noise on three microphones distant from each other. For this, he was

Figure 1. Charles Nordmann (after Berger and Rudaux, 1923: 242; Françoise Launay Collection).

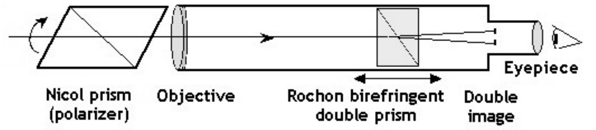

Figure 2: The principle of Arago's photometer. The light from the star is polarized by a Nicol prism placed in front of a small refractor. A Rochon birefringent prism (very similar to the Wollaston prism) inside produces a double image with orthogonal polarizations, whose separation can be changed by moving this prism back and forth. The intensities of these images can be changed in a controlled way by rotating the Nicol prism, until the fainter one disappears in the sky background (after Lequeux, 2008).

awarded the *Croix de Guerre* in 1915 and was promoted to *Officier de la Légion d'Honneur* in 1918.

2 STELLAR PHOTOMETERS

When Nordmann began to show interest in stellar photometry, it was by no means a new science (see Hearnshaw, 1996). After some attempts by William Herschel (1738–1822) and his son John (1792–1871), François Arago (1786–1853) initiated a program of photometry near the end of his life. The principle of Arago's photometer is illustrated in Figure 2. It used an ensemble polarizer-analyser with variable relative orientation in order to attenuate by a known quantity the light from the observed star until it disappeared in the sky background. For this, Arago took many pains to check the cosine square law of attenuation of the intensity of polarized light by an analyser. His photometric method was fast and sensitive but not very accurate because it depended on image quality and on the time and space variations of the sky background. However, the few results obtained before the program was terminated by the illness and death of Arago in 1853 are relatively unbiased.

A few years later, Karl August Steinheil (1801–1870) in Germany built a photometer in which images of pairs of stars were defocussed in a known way and compared visually until they reached the same brightness. His results were more accurate than Arago's, but were limited to bright stars. More convenient photometers were later constructed in Germany by Johann

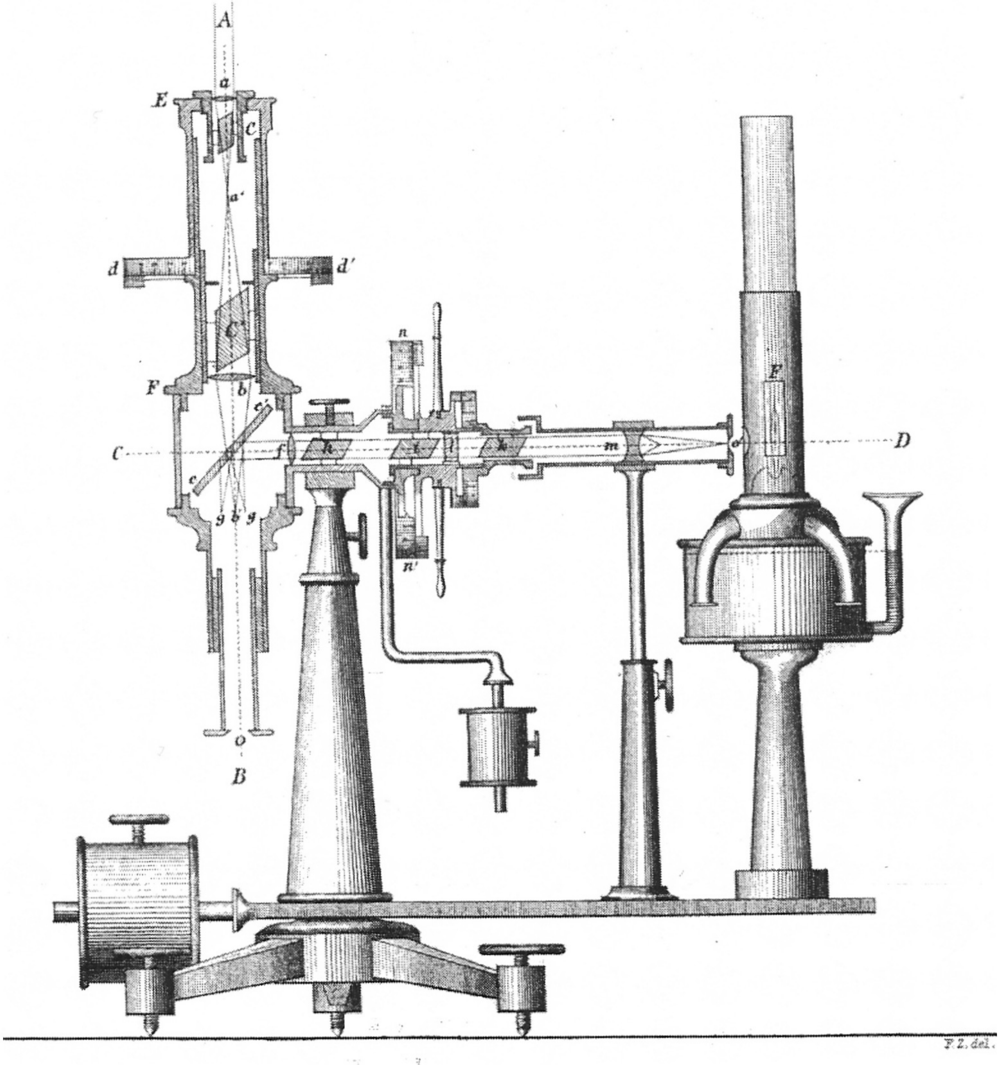

Figure 3: Zöllner's photometer (ca. 1860). The light from the star enters in *A* and is attenuated in a known way by the two successive Nicol prisms, *C* and *C'*, then crosses a semi-transparent 45° glass plate before being observed at *B*. It is compared visually to the light of a reference artificial star illuminated by a oil lamp, which is itself attenuated as needed by two other Nicol prisms, *k* and *k'*, and reflected by the 45° plate. The colour of the reference light can be matched to that of the star using chromatic polarization produced by an ensemble quartz plate/rotating Nicol prism placed between the Nicol prisms *k* and *k'* (courtesy: Bibliothèque de l'Observatoire de Paris).

Karl Friedrich Zöllner (1834–1882; Figure 3), and then in the United States by Edward C. Pickering (1846–1919). Pickering's photometer was used to measure magnitudes for all stars of the large Harvard catalogue, but Zöllner's one was better known in Europe. In both instruments, the starlight was compared visually to that of a reference star (Polaris for Pickering, and an artificial star lit by an oil lamp for Zöllner). The reference light was attenuated by means of two Nicol polarizing prisms rotated with respect to each other, according to the principle introduced by Arago.

In the 1880s, there was some interest in the colour of stars, and it was realized that it affects photometry. In order to solve the problem, Zöllner coloured the reference light using chromatic polarization, a property discovered by Arago in 1811, in order to match the colour of the observed star (see Figure 3). This particular set-up was not much used. In 1884, Seth C. Chandler (1846–1913) placed coloured filters inside his photometer and measured in this way colour differences between stars (Chandler, 1888). But no-one understood yet what to do with these observations.

It was already known at this time that the colour of light emitted by a body depends on its temperature: for example, George Stokes (1819–1903) wrote in 1876:

> When a solid body such as platinum wire, traversed by a voltaic current, is heated to incandescence, we know that as the temperature increases, not only the radiation of each particular refrangibility [i.e. wavelength] absolutely increases, but the proportion of the radiations of the different refrangibilities is changed, the proportion of the higher to the lower [blue to red wavelengths] increasing with the temperature.(Letter cited by Lockyer, 1875-1876: 353).

Nordmann was certainly one of the first astronomers to understand that one can obtain the surface temperature of a star by measuring its colour. When this occurred is not known, and it is not clear that this was the initial motivation for building the instrument we will describe. In any case, his attempts were well considered by Lœwy, who wrote in his Paris Observatory Annual Report for the year 1905:

> The Director of the Observatory was struck by the fact that astronomical photometry, which thanks to the works of Bouguer, then of Arago, was entirely created in France [sic! Lambert was ignored by Arago and by Lœwy as well], is not presently the object of any systematic work in French observatories. In order to remedy this deficiency, photometric studies have been undertaken at the Paris Observatory during the last year [1905]. The first results, based on principles imagined by M. Nordmann, were so satisfactory that it looked desirable to devote all the activity of this astronomer to these new researches. (Loewy, 1906; my translation).

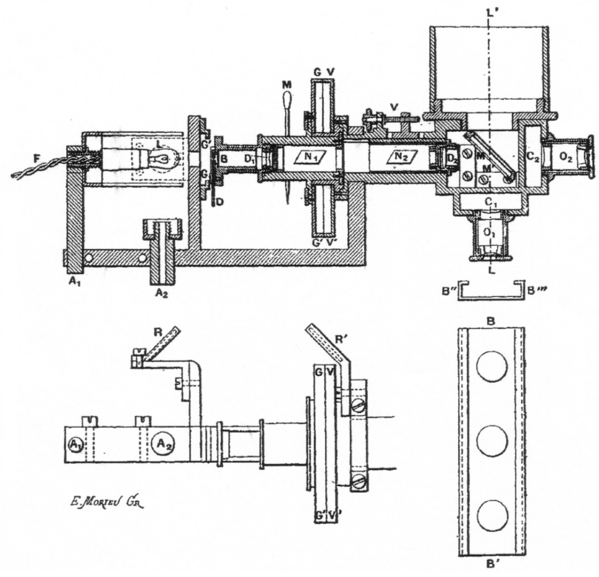

Figure 4: Principle of Nordmann's *photomètre hétérochrome* of (see Nordmann, 1909a:11). This is the 1909 version built by Paul Gautier (1842–1909). Top: a cut through the instrument, which is attached to a refractor. Light from the star travels in the direction L'–L and enters the eyepiece O_1. On the way it crosses the 45° glass plate M–M', then in C_1 one of the filters of the filter-holder B–B' depicted below together with its slide B''–B'''. The comparison artificial star is the hole B illuminated by the lamp L. The comparison light is attenuated by the Nicol prisms N_1 and N_2. The prism N_1 can be rotated by means of the handle M, which rotates at the same time the graduated drum G–G'. N_2 is fixed and attached to the fixed drum V–V'. D_1 and D_2 are two lenses giving a parallel beam through the Nicol prisms. The brighter stars are observed with the side eyepiece O_2, the filters being now placed in C_2: the light of the star is then decreased by vitreous reflection on the 45° plate, which the reference light crosses almost unattenuated. Bottom left: the lighting system for the graduated drum, which uses a part of the light of the lamp reflected by the two 45° flat mirrors R and R' (courtesy: Bibliothèque de l'Observatoire de Paris).

That year, Nordmann was testing a new device that he called a *photomètre hétérochrome* (multi-colour photometer) which uses coloured filters (Figures 4 and 5; Nordmann, 1909a: 9-12; Nordmann, 1909b). This is a Zöllner-type photometer in which the light from the star is compared to that of an artificial star: a small hole illuminated initially by an oil lamp, and later by an electric lamp with a metallic filament. The reference light is attenuated in a known way by two Nicol prisms with variable relative orientation. A coloured filter is inserted in the common path of the light from the star and of the reference light, and can be changed so that the comparison is made successively in three different colours. The filters are flat chambers between two glass plates containing a liquid coloured by aniline compounds. The blue filter transmits radiations below 490 nm, the green filter radiations from 490 and 590 nm and the red filter above 590 nm. The sensitivity of the eye limits the extreme blue or red wavelengths. There is no attempt to determine the energy spectrum emitted by the lamp, which has only to remain constant with time. The relative fluxes of the observed star through the three filters can be compared in this way, in different observations, to those of the Sun or to the radiation of ovens with known temp-

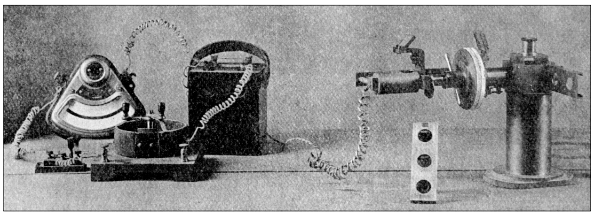

Figure 5: Photograph of the 1909 version of Nordmann's *photomètre hétérochrome* (Nordmann, 1909b:167). From left to right: the voltmeter, the rheostat and the lead battery which are feeding the comparison lamp with constant intensity, and the photometer with the filter holder in front (courtesy: Bibliothèque de l'Observatoire de Paris).

eratures, from which a small area limited by a diaphragm is then observed by the instrument.

The success of this photometer triggered the construction of several others for the observatories of Besançon, Lyon, Brussels and Bucharest, but nothing seems to remain of these instruments.

3 "IS THE CELESTIAL SPACE A DISPERSIVE MEDIUM?"

This was the first problem attacked by Nordmann with his photometer. It had already been considered by Arago, who observed variable stars like Algol (β Persei). In these eclipsing binaries, one component, which is smaller and colder than the other, passes periodically in front of and behind the other, yielding temporary light decreases, in general more important when the small component comes in front than when it is eclipsed. Arago noticed that their colour did not change during the eclipses: such a change was expected if red and blue light propagated with different velocities (for details see Lequeux, 2008: 290-292). He concluded that "… the rays with different colours propagate with the same velocity." (our translation). He also derived from his observations another conclusion which might seem more surprising, although it is logical (ibid., our translation):

> Everyone agrees that the celestial spaces are full of a very rarefied matter … The density of this matter cannot exceed a limit whose value can be derived from the observations of changing stars.

Table 1: Distances to five stars, as deduced by Nordmann (1908b).

Star	Nordmann Distance (parsec)	Modern Distance (parsec)
λ Tau	55	114 ± 13 (HIPPARCOS)
β Aur	29	25.2 ± 0.5 (HIPPARCOS)
β Per (Algol)	18.0 (reference, from geometrical parallax)	28.6 ± 0.7 (HIPPARCOS)
W UMa	7.7	49.6 ± 2.6 (HIPPARCOS)
RT Per	4.6	294 (photometric)

Arago thought that the interstellar medium (this term was not yet in use but we adopt it for convenience) was full of very low-density gas, which could be the ether which was then considered as necessary for the propagation of light. He knew, because he had measured it in the laboratory, that gases disperse light, i.e. that the velocity of light in gases depends on wavelength. Dispersion is proportional to the column density crossed by the light, i.e. the product of density with path length. The absence of dependency of the velocity of light on wavelength can thus, in principle, yield an upper limit to the density if the distance of the star is known; but this distance was not yet known, even for Algol.

Nordmann believed that he could obtain accurate determinations of the colour changes in variable stars using his photometer. Because the atmospheric conditions in Paris did not seem favourable, he obtained from the *Académie des Sciences* a grant to perform observations at Biskra in Algeria, where he stayed from mid-1907 to the beginning of 1908. He used an equatorial refractor with 6 French pouces (16-cm) aperture on loan from the Bureau des Longitudes. First he observed Algol and another Algol-type star, λ Tau, that he compared to non-variable stars (Nordmann, 1908a; 1909a). Nordmann saw a small relative delay in the variations he observed with his filters: the red light appeared to arrive 16 minutes earlier than the blue light for Algol, and between 40 minutes and one hour earlier for λ Tau. This was not much compared to their periods (which were respectively 69 and 95 hours) and the error in the measurement was large, but Nordmann triumphed: there was indeed a dispersion in the interstellar medium, and this dispersion was in the sense expected for most gases (the refractive index decreases with decreasing wavelength). He also observed β Lyr and δ Cep, for which the light curves differed much according to the colour, but he found no measureable delay.

It turns out that the Russian astronomer Gavrijl Adrianovich Tikhoff (1875–1960)—a future pioneer of astrobiology and known to Nordmann because he stayed several times in Meudon—made similar observations at the Pulkovo Observatory near St. Petersburg. For two Algol-type stars, RT Per and W UMa, he observed a delay in the light curve at shorter wavelengths, and one of his collaborators saw the same thing for another eclipsing binary, β Aur (Tikhoff, 1908a). Assuming the density of interstellar space to be uniform, Tikhoff and Nordmann considered that the time delays could derive from the relative distances of the stars. This would have been of extreme interest, given the difficulty in determining stellar parallaxes. Nordmann (1908b) then published the distances listed in Table 1, where they are compared to recent values.

As Table 1 indicates, there is no agreement at all! There is absolutely no relationship between the relative distances obtained from dispersion and the actual distances, but neither Nordmann nor Tikhoff could see that, because no independent determination of the distances of these stars existed, except for Algol. However, the very possibility of an appreciable dispersion in interstellar space raised a major criticism from an excellent Russian physicist, Petr Lebedev (1866–1912), who is known to have measured for the first time the radiation pressure of light. Based on Nordmann's result for Algol, he estimated that the dispersion was of the same order that a gas like air would produce if filling the interstellar medium uniformly with 1/100 of the atmospheric pressure (Lebedev, 1908a). Citing a 1904 paper of Max Planck (1858–1947), he remarked that such a dispersion should be accompanied by absorption, such that the Universe would be extremely opaque.[1] He then suggested another explanation: if the atmosphere of the smaller component of Algol were not spherically symmetrical, it could produce the observed colour change.

Lebedev's criticism was ignored by Nordmann, who probably did not possess the knowledge necessary to appreciate it, nor was he willing to surrender. He only discussed the alternative explanation proposed by Lebedev. But he began to have some doubts (Nordmann, 1908c; our translation):

> General causes that one did not suspect … tend to produce shifts between the minima of the monochromatic light curves.

However, he still hoped to be able to separate these effects from that of dispersion.

As for Tikhoff, he seemed more receptive to the criticisms of his compatriot. Anxious to reduce dispersion in order to decrease absorption, he estimated the distance of one of his stars, RT Per, as 740 light years (230 pc), which would give only a small delay between variations in different colours, and he concluded that dispersion was ten times smaller than the value adopted by Lebedev (Tikhoff, 1908b). Because it was closer than RT Per, Lebedev (1908b) had no difficulty claiming that Algol should exhibit a smaller delay, contrary to what was actually observed.

Tikhoff and Nordmann now gave up. They did not publish anything further on interstellar dispersion. The final word came from Harlow Shapley (1885–1972). After a thorough study of 22 variable stars belonging to the open cluster M5, he found no significant delay between their variations at different colours, and concluded:

> Radiations which differ in wave length by about twenty per cent, and in amplitude as well, can travel through space for 40,000 years without losing more than one or two minutes with respect to each other, if indeed there is any difference whatever. (Shapley, 1922: 2).

The delays announced by Nordmann and Tikhoff were illusory, as confirmed indeed by more recent observations. There is no detectable dispersion of light in the interstellar medium, as demonstrated today with very high precision by multicolour observations of very distant supernovae, and more recently of gamma ray bursts in extremely remote regions of the Universe. Conversely, such a dispersion is observed for radio waves, but is due in this case to free electrons in the ionized interstellar medium.

4 THE TEMPERATURE OF STARS

After this failure, Nordmann turned to another application of his multicolour photometer: the determination of the surface temperature of stars. At this time, it was generally considered that this temperature is related to age. Nordmann (1910; our translation) wrote in a popular style:

> We know that the gases of nebulae are very cold, and the great Helmholtz has shown that when a mass of nebular gas condenses, it heats up progressively by the sole effect of the fall of matter to its centre … When the gaseous mass has become sufficiently compact to impede the easy motion of the gas, calculation shows that the heat from condensation becomes smaller than that lost by radiation to outer space, so that the star cools … until total extinction.

Thus it was believed that measurements of the density and temperature of a star would allow its age to be obtained, and this was the motivation for Nordmann's observations. Lockyer already attempted to classify stars according to their temperatures, which he estimated from the appearance of their line spectra,[2] and also by "… utilizing the fact that an extension of spectra into the ultra-violet is produced by increased temperature, and further that a lower temperature in an atmosphere above a photosphere would increase the absorption in the blue end." (Lockyer, 1903: 228). But this remained qualitative.

Thanks to the theoretical work of Planck on the thermal emission of blackbodies, published in 1900, and to its experimental confirmation in 1901 by Heinrich Rubens (1865–1922) and Ferdinand Kurlbaum (1857–1927) in Berlin, it then became possible to determine the temperature of a star from its colour, provided it could be considered to be a blackbody. Given the shape of the energy distribution of blackbodies, it appeared that measurements in only two wavelengths bands would be enough to obtain a result, provided that these bands were sufficiently distant from each other. Nordmann decided to use his red and blue filters for this.

Nordmann had first to study selective atmospheric absorption of light, in order to correct for this in his future measurements as a function of the elevation of a star. He observed the same stars at different elevations and compared them to Polaris, with unexpected results. One reads in the report of the Paris Observatory for 1906):

> All measurements made during this year, of which there are more than 2500, establish with certainty an unexpected fact: until 80 degrees of zenith distance, the red and orange part of the spectrum of stars is much more absorbed than the blue and violet part. Experiments made in Switzerland, in a high station with a very pure atmosphere, rigorously confirmed these conclusions. The demonstration of these important facts is of such a nature as to change the present ideas on the optical properties of the Earth's atmosphere and on those of gases in general. (Baillaud, 1907: 9; our translation).

In 1909, Nordmann still believed in this result. Moreover he noted that, contrary to the stars observed at night, the Sun and Venus are reddened when they are observed during the day at low elevations, and hence he claimed that "… the magnitude and nature of atmospheric absorption of radiations of different wavelengths are closely linked to the presence or absence of the Sun above the horizon." (Nordmann, 1909b: 171). No details are given of these observations, so it is impossible to know how Nordmann came to this strange conclusion. Unfortunately, he does not say whether and how he corrected his photometric measurements for atmospheric absorption.

Nordmann (1909c) calibrated his photometer by measuring the ratio of intensities in the red and blue filters for radiations emitted by sources of known temperatures: ovens at 1408, 1648 and 1703 K, and the positive electrode of an electric arc at 3616 K.[3] Using Planck's Formula, he could now calculate this ratio for any source temperature. He observed the Sun, and obtained a temperature of 5990 K from the observed ratio, in agreement with the effective temperature derived from the total energy emitted at all wavelengths (the solar constant) using Stefan's Formula. The values obtained in this way lay between 5360 and 6200 K according to their author (present value: 5777 K). Nordmann estimated the error in the temperature of the Sun as 8%. He also obtained the temperature of 14 stars from observations with refractors whose apertures were smaller than 16 cm, hence probably made at Biskra, together with his observations of Algol and λ Tau. Note that what Nordmann actually determined is what we would today call the colour temperature, but what is of astrophysical interest is the effective temperature. To complicate matters, like most of his contemporaries, Nordmann (erroneously) claimed that he was measuring effective temperatures, and this might cause some confusion for modern readers.

However, Nordmann's first results were incorrect, because he used an effective wavelength for the two filters for calculating the temperature, the variation of

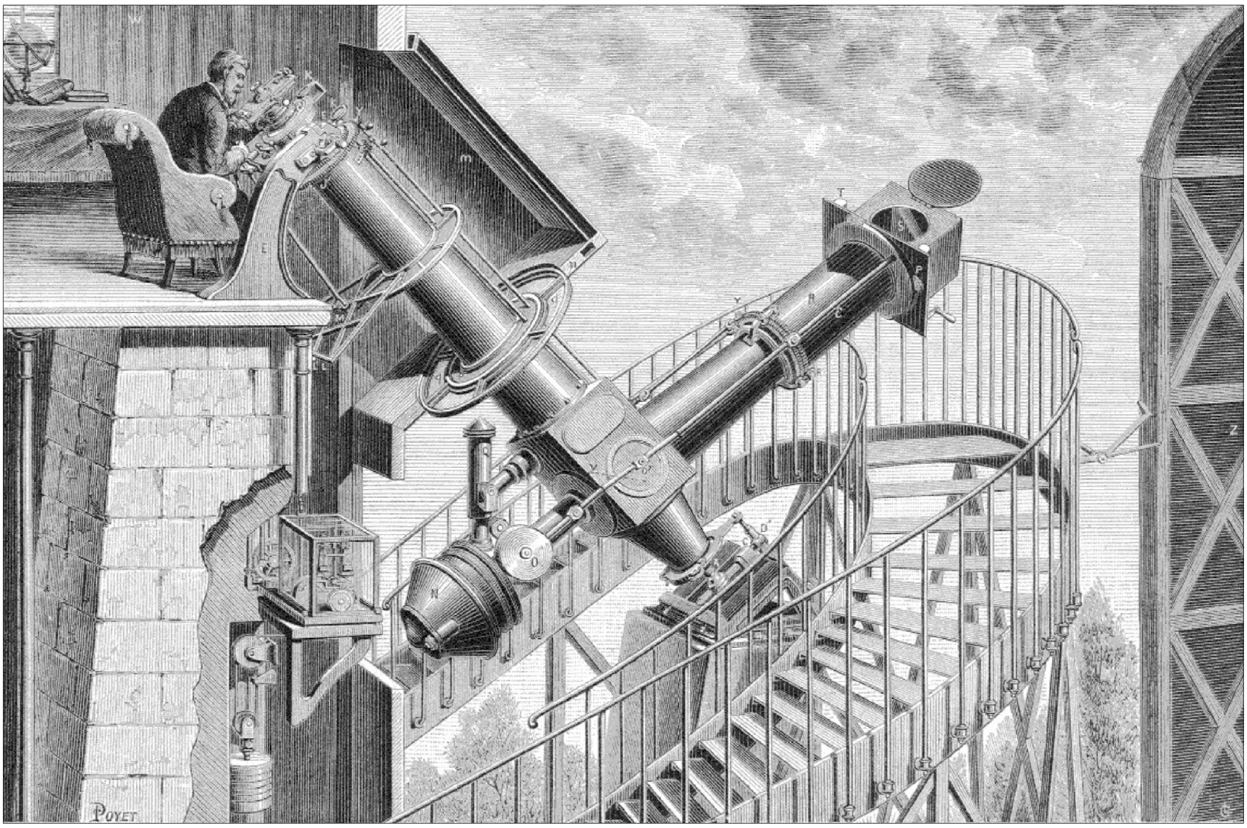

Figure 6: The small coudé equatorial of the Paris Observatory. In this refractor, designed by Lœwy and built in 1882, the observer sits in a fixed position and looks along the polar axis. The light falls on a 45° mirror inside the cube, which reflects the light onto the objective located at the end of the shorter tube. Another 45° flat mirror at the intersection of the two tubes receives the light and sends it to the eyepiece or to a focal instrument. The whole telescope rotates around the polar axis, and the cube can rotate around the axis of the shorter tube. This instrument was dismantled in 1971-1972 (courtesy: Bibliothèque de l'Observatoire de Paris).

which with stellar temperature he neglected. Nordmann (1909d) soon published the corrected results for the 14 stars and for the Sun, whose temperature was reduced to 5320 K. Later, Nordmann measured other stars in Paris with the *Petit équatorial coudé* (Figure 6). His initial plan was to observe 300 stars. In 1910 he observed 52 stars and Halley's Comet in three colours, with the help of another astronomer named Pierre Salet (1875–1936), who seemed to have had reservations regarding the method. Salet claimed that the colorimeter of Zöllner (his device to match the colour of the reference source with that of the star, see Figure 3) "… is as accurate as the spectrophotometer which can only be used for bright stars." (Baillaud, 1911: 21; our translation). This is a rather dubious statement, which points to possible personal problems between the two men.

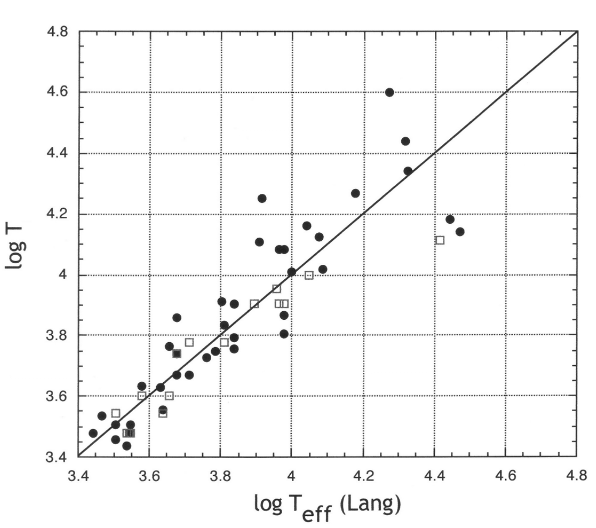

Figure 7: Comparison of stellar temperatures determined by Nordmann (circles) and by Coblentz (empty squares) with modern values of the effective temperatures.

In 1911 Nordmann was ill for several months, and after recovering he was ordered to take part in other activities of the Observatory for a large fraction of his time, as also was Salet. The latter left the service in 1912, and Nordmann, who was now alone, was asked to build a device to record rainfall, so he was able to make very few photometric observations. In 1914 the war broke out and Nordmann was called up and joined the army. He only returned to the Observatory in 1919, but the small equatorial coudé, which had been partially dismantled for its protection, had not yet been put back in service so no observations were possible. Finally, in 1920, a *Service de Photométrie Hétérochrome* was created for Nordmann and another astronomer, Charles Le Morvan (1865–1933). The observations then resumed, and in 1921 Nordmann and Le Morvan published new determinations of effective temperatures. Together with other results scattered in a number of papers in *Comptes Rendus des Séances de l'Académie des Sciences*, this gives a total of 41 stars with determinations of colour temperatures. Although the reports of the Paris Observatory mention many further measurements until 1931, none of these was published, except for a few Pleiades results that we will discuss later. All this work has since been lost, along with Nordmann's notes and observations.

In Figure 7, Nordmann's colour temperatures are compared with modern determinations of effective temperatures obtained from the SIMBAD spectral types using the calibration given in Lang (1991: 137-142). For carbon stars, we used the determination of Bergeat et al. (2001: 208-209). There are other calibrations, but they differ little from those we have used. The general agreement is good, showing that Nordmann's calibration is correct, but there is a dispersion due in part to measurement errors, but above all to the fact that stars are not blackbodies. The dispersion is large for B stars, because the colours are not sensitive to temperature at wavelengths much larger that the peak of the blackbody radiation (the Rayleigh-Jeans regime), and because the hydrogen lines and continua contribute strongly to the radiation in the ultraviolet for hot stars, causing large departures from blackbodies. In spite of this problem, Nordmann's measurements are a considerable achievement: for the first time, the temperatures of stars of various kinds were determined with reasonable accuracy. It was also clear that the temperature varied with the spectral type of the star, as suspected by Lockyer (1875-1776; 1903) for different reasons.

At the time of the measurements, it was not possible to go any further in the interpretation of the data. Not only was nothing known of the origin of stellar energy and of the evolution of stars, but the knowledge of their atmospheres was rudimentary. Since spectral lines were seen in absorption, it was believed, following Angelo Secchi (1818–1878), that the light of the *photosphere*, the surface of the star (a somewhat unclear notion since it was known since Arago that the source of light is a glowing gas), is absorbed in the lines (and, for some authors, also in the continuum) by a colder layer, the *reversing layer*, the whole being perhaps surrounded by a tenuous and transparent atmosphere, the *corona* (Figure 8). This description is simplistic and even misleading. Thanks to the slow progress in the theory, starting with Karl Schwarzchild (1873–1916) in 1905, we now know that the temperature and density increase progressively towards the inner regions of a star. Light is emitted at all depths and is scattered everywhere, both in the continuum and in the spectral lines. At a given wavelength, the emission comes mainly from the depth where optical thickness is of the order of unity as seen by the observer: since optical thickness is larger in the spectral lines than in the continuum, lines come from higher layers of the atmosphere than the continuum. Because these layers are colder, the lines appear in absorption. Rupert Wildt (1905–1976) discovered in 1939 that for ordinary stars the main cause for the opacity and thus the position of the continuum is due to the H^- ion. Atomic hydrogen also contributes for hotter stars. All this was unknown to Nordmann: his interpretations in terms of photosphere and reversing layer, the latter of which, for him, absorbed the continuum preferentially in the blue, are completely outdated.

5 COMPETITION

Nordmann was not the sole astronomer interested in measuring the colours and temperatures of stars. Multicolour stellar photometry appeared at the Potsdam Observatory in Germany around 1880 under the impulse of Hermann Carl Vogel (1841–1907), and developed fully two decades later. In 1899, an 80-cm diameter Repsold refractor was installed in Potsdam and in 1901 Vogel adapted a multicolour photometer at its focus, initially for a study of gaseous nebulae. This 'Spektralapparator' 'Spektralphotometer', built by Toepfer and Sohn (Figure 9), produced parallel spectra of the star and of the reference artificial star of a Zöllner photometer and these were separated by diaphragms into several identical wavelength bands in both spectra (Scheiner, 1903; Scheiner and Wilsing, 1902; Abbot, 1910, gives a short description of this instrument in English). The bands, centred at 448, 480, 513, 584 and 638 nm, were chosen so as to avoid the strongest lines. The flux from the star was compared visually in each band with that of the artificial star. The photometer was calibrated using blackbodies at different temperatures, as was Nordmann's instrument.

A few multicolour photometric measurements made with the Potsdam photometer were published in 1899. This was the beginning of a large program conducted by Johannes Wilsing (1856–1943) and Julius Scheiner (1858–1913): five-band photometry of 109 stars and 'effective temperatures' derived from their measurements were published by these authors (Wilsing and Scheiner, 1909; 1910), independently of Nordmann's work which was clearly ignored by his German col-

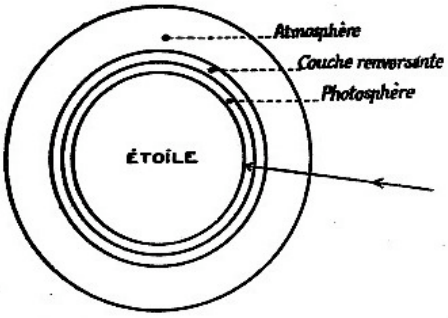

Figure 8. The structure of stellar atmospheres, as described in 1930 by Georges Bruhat (1887–1944) in a popular article (Bruhat, 1930: 302). Bruhat, a very good physicist, was interested in astrophysics, unlike most of his French colleagues (courtesy: Bibliothèque de l'Observatoire de Paris).

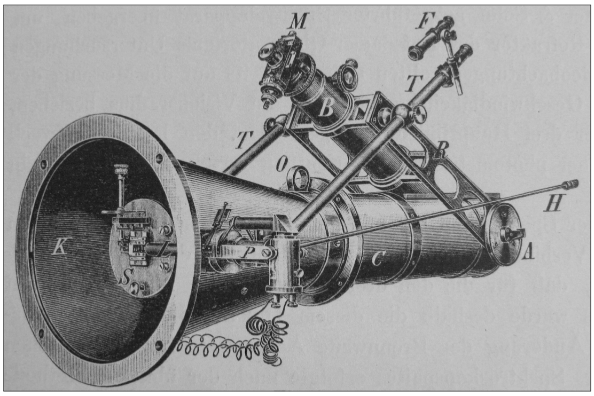

Figure 9: Vogel's *Spektralphotometer*. The cone is fixed to the 80-cm diameter Potsdam refractor. The image of the star is formed on an aperture of plate S, near the image of the artificial star of the Zöllner photometer P. The intensity of the latter image can be adjusted with the handle H. A complex system of prisms and mirrors form parallel spectra of the two stars. Diaphragms limit corresponding sections of these spectra for visual comparison of the intensities in the eyepiece, here represented with a micrometer for wavelength measurement (courtesy: Bibliothèque de l'Observatoire de Paris).

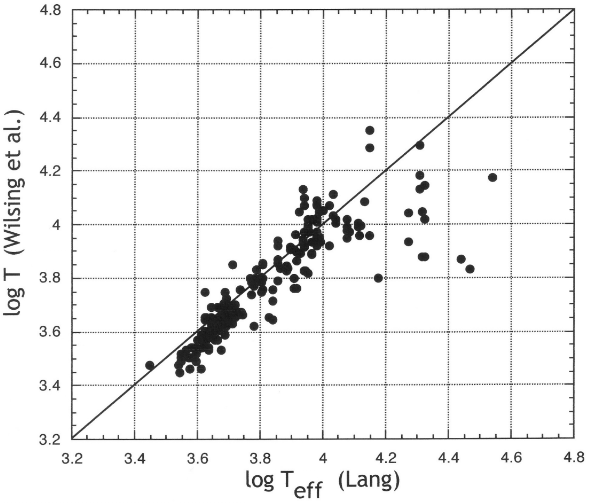

Figure 10: Comparison of effective temperatures determined by Scheiner, Wilsing and Münch with modern values.

leagues, and vice-versa. Charles G. Abbot (1872–1973) criticized some aspects of the reduction made by the Potsdam astronomers (Abbot, 1910). In their final work (Wilsing et al., 1919) made with the collaboration of W.H.J. Münch (1879–1969), which gave temperatures for 199 stars, they reduced anew all their data. Nordmann (1921a) acknowledged these results, while regretting that Wilsing did not cite his 1909 work but instead claimed priority for himself. He also remarked, rightly (ibid.), that his method was considerably more sensitive than Wilsing's method.

Figure 10 compares the Potsdam determinations with modern effective temperatures. The values calculated by Wilsing et al. are somewhat more scattered than Nordmann's, especially for hot stars, and systematically underestimate the effective temperature. Abbot (1910: 277) says rightly about their 1909 results:

> To the reviewer, the reductions of the stellar spectral results to "black" body temperatures seems a by-product, rather than a principal result of the investigation worthy to have its place in the title; for, in the first place, it seems misleading to compute temperatures from a spectral range of only 0.2μ, whose distribution is fixed by five observations with probable errors of 6 percent each. Moreover, Planck's "black" body formula does not represent the distribution, even of the solar radiation, in all parts of the spectrum

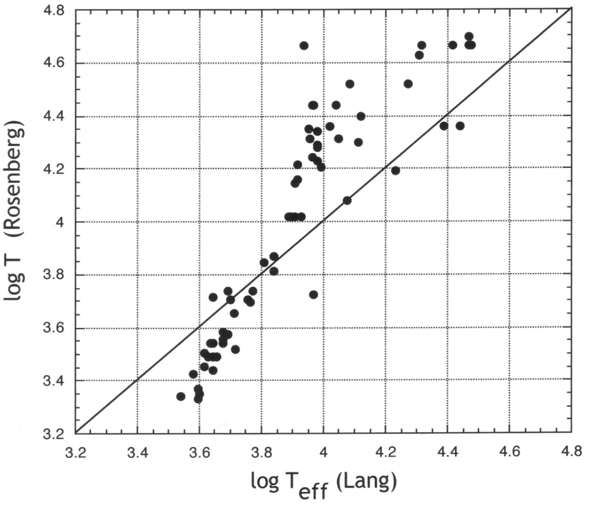

Figure 11: Comparison of effective temperatures determined by Rosenberg with modern values.

Even if the final measurements of Wilsing et al. had been made in more wavelength bands, these criticisms remain valid. Nordmann was right in using two wide filters with wavelengths as far as possible from each other. Moreover, it makes no sense to measure only the continuum between strong lines, as was done by Wilsing et al. Presumably they wanted to measure the temperature of the photosphere, believing that the lines were formed in a reversing layer which did not absorb the continuum.

Simultaneously with Nordmann and his Potsdam colleagues, Hans Rosenberg (1879–1940) in Göttingen made spectrophotometric measurements of 70 stars using photographic spectra between 400 and 500 nm (Rosenberg, 1913). He determined the magnitude difference between these two wavelengths and derived the 'effective temperatures' by comparing these differences with theoretical ones for blackbodies at different temperatures. The comparison with modern values of the effective temperatures (Figure 11) shows that these determinations were very poor. This can be explained by the small wavelength range of the measurements, which was not appropriate for determining effective temperatures, and by an unfortunate choice of the band where deviations from blackbodies are large. The author himself acknowledged the large differences between his determinations and those of the Potsdam astronomers. He obviously ignored Nordmann's measurements. Nordmann (1913) noticed Rosenberg's work and compared the two series of results. Since there was some agreement between the temperatures derived by Rosenberg and by himself for the 12 stars in common using different parts of the spectrum, Nordmann concluded that the stars were close to blackbodies!

The last determinations of effective temperatures discussed by Nordmann are those of William W. Coblentz (1873–1962), a pioneer of infrared astronomy who made the first attempt to measure stellar radiation at all wavelengths accessible from the ground. He worked first at Lick in 1914, then at the Lowell Observatory in Flagstaff. His determinations of 'effective temperatures' for 16 stars (Coblentz, 1922; 1923), plotted in Figure 7 together with Nordmann's results, are of the same quality but not better, which is not surprising because the main limitations in both cases are the departures of the stellar energy distributions from those of blackbodies. Coblentz correctly cited the results of Nordmann and Le Morvan; the latter also compared their results with Coblentz's and were satisfied with the agreement (see Nordmann and Le Morvan, 1922: 1692).

6 THE H-R DIAGRAM OF THE PLEIADES

In 1923, Nordmann and Le Morvan published in the *Comptes Rendus de l'Académie des Sciences* their last scientific paper of some importance (Nordmann and Le Morvan, 1923). They reported on measurements they had made with their photometer on 22 stars in the Pleiades. Their study had been stimulated by a photometric study of the Pleiades made at Yerkes by Harriet McWilliams Parsons (1892–1986; Parsons, 1918). Nordmann and Le Morvan (1923: 1054; our translation) wrote that "… the increase of the colour index of these stars [i.e. the difference between the photographic and visual magnitudes], which occurs at the seventh magnitude, is not visible from the second to the seventh magnitude." They were looking for another photometric quantity which would vary with magnitude in this magnitude range, and which could be used to obtain absolute magnitudes, then distances, of stars of the same types once the distance of the Pleiades was known. They claimed that a combination of the intensities in their three filters, that they called *B*, *V* and *R*, for blue, visible and red respectively, $y = \log(B/R)/\log(B/V)$, satisfied this criterion. This quantity is a measure of the curvature of the spectrum in the visible. However, when plotting it as a function of magnitude (Figure 12), one can see that the criterion is not convincing; it is thus not surprising that it has never been used in practice.

The colour-magnitude diagram of McWilliams Parsons (Figure 13) shows a systematic change of colour with a minimum near magnitude 5, contrary to Nordmann's claim. This change is even more marked if we build a colour-magnitude diagram from the earlier data of Rosenberg (1910; see Figure 14).[4] This diagram shows extremely well the turn-off from the main sequence at $m_{pg} \approx 6.5$. Probably Nordmann drew these plots himself and was distressed—as were most of his contemporaries—by the non-universality of the relation between colour and magnitude, the reason for which he could not understand. This is probably why he looked for a universal criterion.

7 EPILOGUE

After the Pleiades, Nordmann still observed several hundred stars with his photomètre hétérochrome, always attached to the small coudé refractor, as mentioned in the Annual Reports of the Paris Observatory. In 1931, he was given another collaborator, Miss (or Mrs?) Rose Bonnet (1894–?), to replace Le Morvan, who retired the following year and died in 1933. Miss Bonnet made some observations and reductions while working on a thesis on another subject. The liquid filters were replaced in 1933 by coloured glass filters from Schott in Jena. The observations continued at a slow pace until 1939, when the objective of the telescope was taken down owing to the threatening war. Although the report from 1928 says that "… the results might soon be published …" (Esclangon, 1929: 30), we could find no such publication, and the data themselves are now lost. Nordmann died on 28 August 1940 after a long and painful illness, and his death was relatively unnoticed. The Annual Report of the Paris Observatory for that year contains only a short obituary:

> A very original mind, he oriented most of his researches toward some questions of physical astronomy. His work on the temperature of stars, at a time when this question was completely new, was particularly remarkable some thirty years ago.
>
> Apart from his scientific merits, which were very great, he had exceptional pedagogical gifts, thanks to which he put within reach of the public the most complex topics of modern astronomy, in much appreciated popular papers. (Esclangon, 1942: 5; our translation).[5]

Even if Nordmann's work on the temperature of the stars was remarkable at the time of publication, this did not last for long. Visual observations were soon

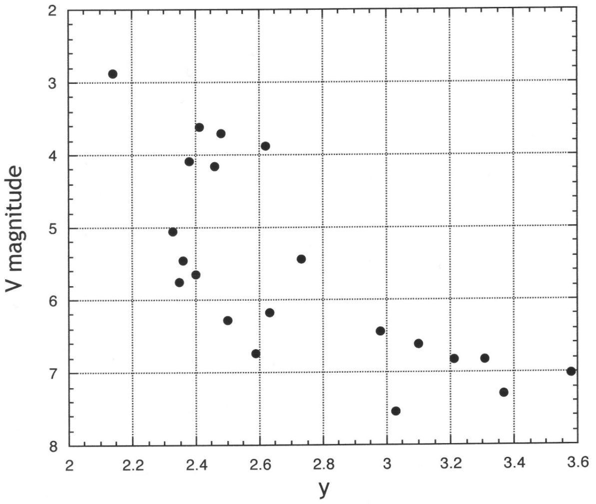

Figure 12: The photometric quantity *y* of Nordmann and Le Morvan (1923) plotted as a function of *V* magnitude for stars in the Pleiades. One non-member star, BD +23°556, has been eliminated.

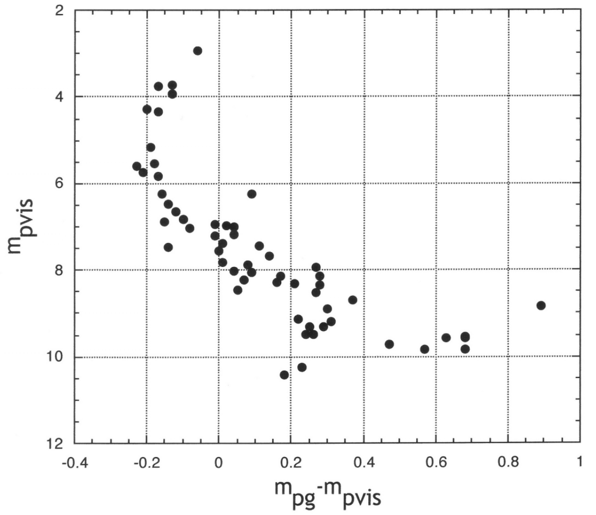

Figure 13: The H-R diagram of Harriet McWilliams Parsons for the Pleiades. The magnitudes are photovisual, from the author, and photographic from Münch. Non-member stars have not been plotted.

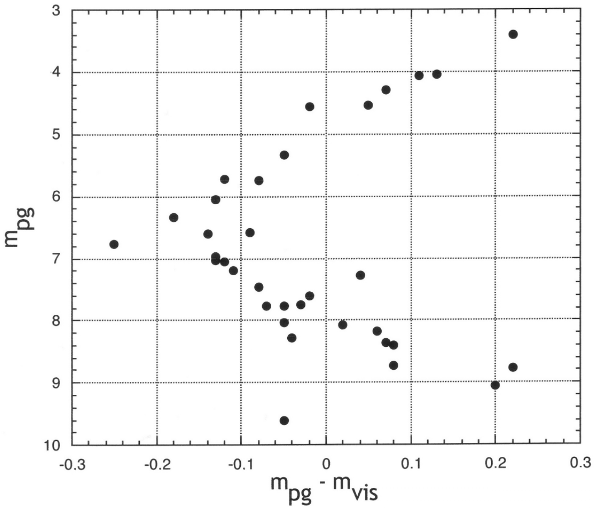

Figure 14: The H-R diagram of Rosenberg for the Pleiades. The photographic magnitudes are from Karl Schwarzschild and the visual ones from Müller and Kempf. A few non-member stars have not been plotted.

considered outdated. In Edinburgh, Ralph Allen Samson (1866–1939) explored the spectrum of stars with a photoelectric cell and gave 'effective temperatures' for 64 stars, citing only Wilsing (Sampson, 1923; 1925). Henry Hemley Plaskett (1893–1980) in Canada estimated 'effective temperatures' for seven stars using photographic spectrophotometry, comparing them with Coblentz, Wilsing and Sampson (Plaskett, 1923). Georgette Maulbetsch (1931; 1932) at Harvard, Hans Jensen (1933) in Kiel and William Greaves et al. (1934) in Greenwich were probably the last to determine stellar temperatures from spectra in the visible.

Still, Nordmann's determinations are the closest to modern determinations of effective temperatures, thanks to his judicious choice of two broad bands well separated in wavelength. Unfortunately no one seems to have realized that this choice was the most appropriate, and Nordmann's results were completely ignored from 1923 on. Even Anton Pannekoek (1873–1960), one of the best historians of astronomy ever, does not cite Nordmann in his remarkable review paper devoted to the methods used in determining stellar effective temperatures (Pannekoek, 1936). Nordmann was only 'rediscovered' in 1996 when John Hearnshaw published his book on the history of astronomical photometry.

Why has Nordmann been forgotten? Certainly it was as a consequence of some lack of rigour and of insufficient explanations of his procedures, and of his strange result on atmospheric absorption. His method was considered to be obsolete and inadequate. He had bad relations with more powerful colleagues, and this did not help his recognition. It is interesting to note in this respect that an astronomer at the Paris Observatory, Jules Baillaud (1876–1960), the son of Benjamin Baillaud, at the beginning of 1920 and in parallel with Nordmann, carried out stellar photographic spectrophotometry at the Pic du Midi Observatory with a UV spectrograph. This was clearly more modern than Nordmann's method. Baillaud (1923: 275; our translation) observed that the energy distribution in the UV and the blue can depart strongly from that of a blackbody, in particular for the hotter stars:

> The curve [spectral energy distribution] for α Canis Minoris is close to that for a blackbody at 7000 K … The curves for the other stars [all spectral types A and B] are completely different and it is impossible to use them for an evaluation of the colour temperatures.
>
> … The author thinks that the continuous spectrum of stars of type A and B is not due to a thermal radiation comparable to that of a blackbody, but, at least in part, to the radiation of ionized atoms similar to that which produces the continuous spectrum of hydrogen observed by several experimenters.

Baillaud (1923: 279, 342) went on to criticize Nordmann's calibration method and his results on atmospheric absorption. He could certainly have obtained some clarifications from Nordmann, but, like his father, he was obviously on bad terms with him, and did not take it upon himself to have an open discussion.

Baillaud's interesting remark on the similarity of the UV spectrum of hot stars with that of hydrogen, well developed later by Pannekoek (1936: 486-490), is probably at the origin of the extensive program of ultraviolet photographic spectrophotometry of hot stars led at the Paris Observatory by Daniel Barbier (1907–1965), Daniel Chalonge (1895–1977) and Étienne Vassy (d. 1969) in the 1930s (see Barbier et al., 1934; 1935a; 1935b; etc.).[6] Nordmann was left out of these developments, and worked in isolation and probably in frustration. He was a candidate for membership of the Académie des Sciences in 1929, 1930 and 1932, on each occasion without success. All this might explain why he did not publish anything of importance after 1923. It was a sad end to his career and to his life.

Nonetheless, we should not forget that Nordmann made the first determinations of the temperatures of stars, and that his work was a precursor for the multicolour photometry of stars developed by Johnson and Morgan (1953) after WW2. In spite of his errors and failures, which hampered too often his recognition by other astronomers, he deserves a significant place in the history of astronomy.

8 NOTES

1. Dispersion occurs when the frequency of light is not very remote from resonances in the material through which it propagates. For usual gases, these resonances are in the ultraviolet, and they correspond to the electronic absorption bands of the atoms or molecules. Absorption is not limited to the bands themselves, but extends to other frequencies because of the damping wings of transitions, which are very broad for these strong resonance transitions. So is dispersion, which is linked to absorption.
2. Lockyer thought that the atoms of chemical elements were not really simple particles, but broke up under high temperature into simpler constituents that he called 'proto-elements', essentially hydrogen and helium. Consequently the hotter stars had for him a simpler spectrum because the heavy elements were decomposed into lighter ones. For details, see Pannekoek (1989: 454-456).
3. Unfortunately Nordmann does not indicate how the calibration temperatures were measured. They must have been correct, for we see that his results were unbiased.
4. A figure in Rosenberg (1910: 76) is the first Hertzsprung-Russell Diagram ever displayed. For comparison, that of Ejnar Hertzsprung (1873–1967) dates from 1911 and that of Henry Norris Russell (1877–1957) from 1914. Rosenberg's early diagram gives for the Pleiades the relation between photographic magnitude and spectral index obtained as the ratio between the average strength of the Hδ and Hζ lines and that of the K line of ionized calcium. This index is related by Rosenberg to the spectral classification of Antonia C. Maury (1866–1952), and he writes: "

   > The plausible color differences among stars in the Pleiades – the fainter the star, the redder it is – following from the optical and photographic brightness measurements, are confirmed by the spectral properties. The color is a function of the radiative properties of the star only. A selective absorption in the space as an explanation of this effect is evidently inadmissible. (Rosenberg, 1910: 78; translation by Jan Hollan).
5. Indeed, right up until the end of his life Nordmann continued to publish large numbers of papers in popular journals, on astronomy and various other topics. He also produced several popular books of

good quality. The most interesting one, *Einstein et l'Univers* (Nordmann, 1921b), was a considerable success with 57000 copies sold from 1921 to 1927 and translations made into English, German, Russian and probably other languages. It is a defense of Special and General Relativity, which were still far from being universally accepted by scientists and the general public. The presentation of relativity is excellent. Nordmann acknowledges in a balanced way the contributions of Lorentz and Poincaré to this theory. However a sentence of this book, taken out of context, has been used by some people to claim that Poincaré was the inventor of relativity and that Einstein was a plagiarist. This is what Nordmann wrote (page 17; our translation): "Henri Poincaré … really has the merit of most of what is currently attributed to Einstein by the public. Following my demonstration [made afterwards in the book], the merit of Einstein will be in no way diminished: it is elsewhere." It is interesting to note that Nordmann did not abandon the idea of ether, writing (our translation):

> The indifference [of Einstein] with respect to ether, his disregard, disappears in the theory of General Relativity.[…] The trajectories of gravitating bodies and of light proceed directly, according to this theory, from the particular curvature and the non-euclidian character of the medium which, in vacuum, surrounds the massive bodies, i.e. ether. Ether, although its kinematical properties are not for Einstein what they are for classical scientists, becomes the substratum of all events in the Universe. It is the continuous medium in which spatio-temporal facts evolve. Thus in its general form and in spite of the new kinematic properties attributed to ether, the General Relativity of Einstein acknowledges the objective existence of ether.

In another popular book devoted to a presentation of time and the calendar (it contains an interesting history of the distribution of time by radio), *Notre Maître le Temps*, Nordmann (1924) also defends relativity against two famous philosophers, Henri Bergson (1859–1941) and Jacques Maritain (1882–1973). This book was translated into English by Edmund Edward Fournier d'Albe (1868–1933) under the title *The Tyranny of Time*. Fournier d'Albe was an English scientist and popular writer with the same interests as Nordmann. It might be that the latter's book, *New Light on Immortality* (Fournier d'Albe, 1908), inspired Nordmann (1927) to write his last book, *L'au-delà, Face au Problème de l'Immortalité*. It is on metaphysics, about which he appears to be somewhat sceptical.

6. Barbier et al. (1935a: 379) still considered that the hydrogen layer responsible for the Balmer lines and jump was located above the photosphere emitting the continuum. They derived 'effective temperatures' for A to O stars from the continuum gradient between 370 and 450 nm that they believed to be free of absorption by hydrogen. As can be expected, these temperatures are no better approximations of the true effective temperatures than those derived by the preceding authors.

9 ACKNOWLEDGEMENTS

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AN ABORIGINAL AUSTRALIAN RECORD OF THE GREAT ERUPTION OF ETA CARINAE

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Abstract: We present evidence that the Boorong Aboriginal people of northwestern Victoria observed the Great Eruption of Eta (η) Carinae in the nineteenth century and incorporated this event into their oral traditions. We identify this star, as well as others not specifically identified by name, using descriptive material presented in the 1858 paper by William Edward Stanbridge in conjunction with early southern star catalogues. This identification of a transient astronomical event supports the assertion that Aboriginal oral traditions are dynamic and evolving, and not static. This is the only definitive indigenous record of η Carinae's outburst identified in the literature to date.

Keywords: Historical astronomy, ethnoastronomy, Aboriginal Australians, η Carinae

1 INTRODUCTION

Aboriginal Australians had a significant understanding of the night sky (Norris and Hamacher, 2009) and frequently incorporated celestial objects and transient celestial phenomena into their oral traditions, including the Sun, Moon, stars, planets, the Milky Way and Magellanic Clouds, eclipses, comets, meteors and impact events. While Australia is home to hundreds of Aboriginal groups, each with a distinct language and culture, few of these groups have been studied in depth for their traditional knowledge of the night sky. We refer the interested reader to the following reviews on Australian Aboriginal astronomy: Cairns and Harney (2003), Clarke (1997; 2007/2008), Fredrick (2008), Haynes (1992; 2000), Haynes et al. (1996), Hamacher and Norris (2011), Johnson (1998) and Tindale (2005).

The first detailed publication on Aboriginal astronomy in the literature was by William Stanbridge, who described the astronomy and mythology of the Boorong clan of the Wergaia language from the dry Mallee country near Lake Tyrell in northwest Victoria (Stanbridge, 1858; 1861; see Figure 1). The Boorong word for Tyrell (tyrille) meant 'sky' and they prided themselves on knowing more astronomy than any other Aboriginal community (Stanbridge, 1857: 137; 1861: 301). Stanbridge read his seminal paper to the Philosophical Institute of Victoria on 30 September 1857. He wrote:

> I beg to lay before your honorable Institute the accompanying paper on the Astronomy and Mythology of the Aborigines, and in doing so I am sensitive of its imperfectness, but as it is now six years since I made any additions to it, and as my occupation does not lead me to that part of the country where I should be able to make further additions, I have presumed to present it to your society, hoping that it may be a means of assisting with others to gather further traces of the people that are so fast passing away.
>
> This statement of the Astronomy and Mythology of the Aborigines is, as nearly as language will allow, word for word as they have repeatedly during some years stated it to me. It is in the language of, and has been gleaned from, the Booroung Tribe, who claim and inhabit the Mallee country in the neighbourhood of Lake Tyrill, and who pride themselves upon knowing more of Astronomy than any other tribe. (Stanbridge, 1858: 137).

Stanbridge's work describes Boorong views of various celestial objects and phenomena, including the Sun, Moon, Jupiter, Venus, numerous individual stars, the Pleiades and Coma Berenices open star clusters, two compact constellations (Delphinus and Corona Australis), the Magellanic Clouds, the Coalsack Nebula, the Milky Way, meteors and the seasons. These celestial objects are represented by characters in oral traditions that are typically represented by animals or beings, and occasionally their spouses. In some cases, Stanbridge identified the star by name, while in other cases it is identified only by a general description, which typically includes its brightness, constellation, and proximity to particular stars. Stanbridge's work was later re-analysed by MacPherson (1881) and Morieson (1996).

In this paper, we identify one of Stanbridge's Boorong descriptions as referring to the outburst of the super-massive binary system Eta (η) Carinae. We begin by providing a brief biographical account of William Stanbridge in Section 2, while in Section 3 we independently identify all the celestial objects described in Stanbridge (1858). In Section 4 we summarise the evidence that indicates that the Boorong observed η Carinae during its Great Eruption in the nineteenth century and incorporated it into their oral traditions, while we discuss η Carinae in Section 5. In Section 6, we review previous attempts to identify the wife of *War* (the crow), while in Section 7 we use this as an exemplar to show that the Boorong incorporated η Carinae into their oral traditions during the nineteenth century period of outburst and not before. In Section 8 we explain how transient astronomical phenomena are often incorporated into oral traditions and show that sky knowledge is dynamic and changing, while in Section 9 we search for other indigenous records of η Carinae, before summarising our conclusions in Section 10.

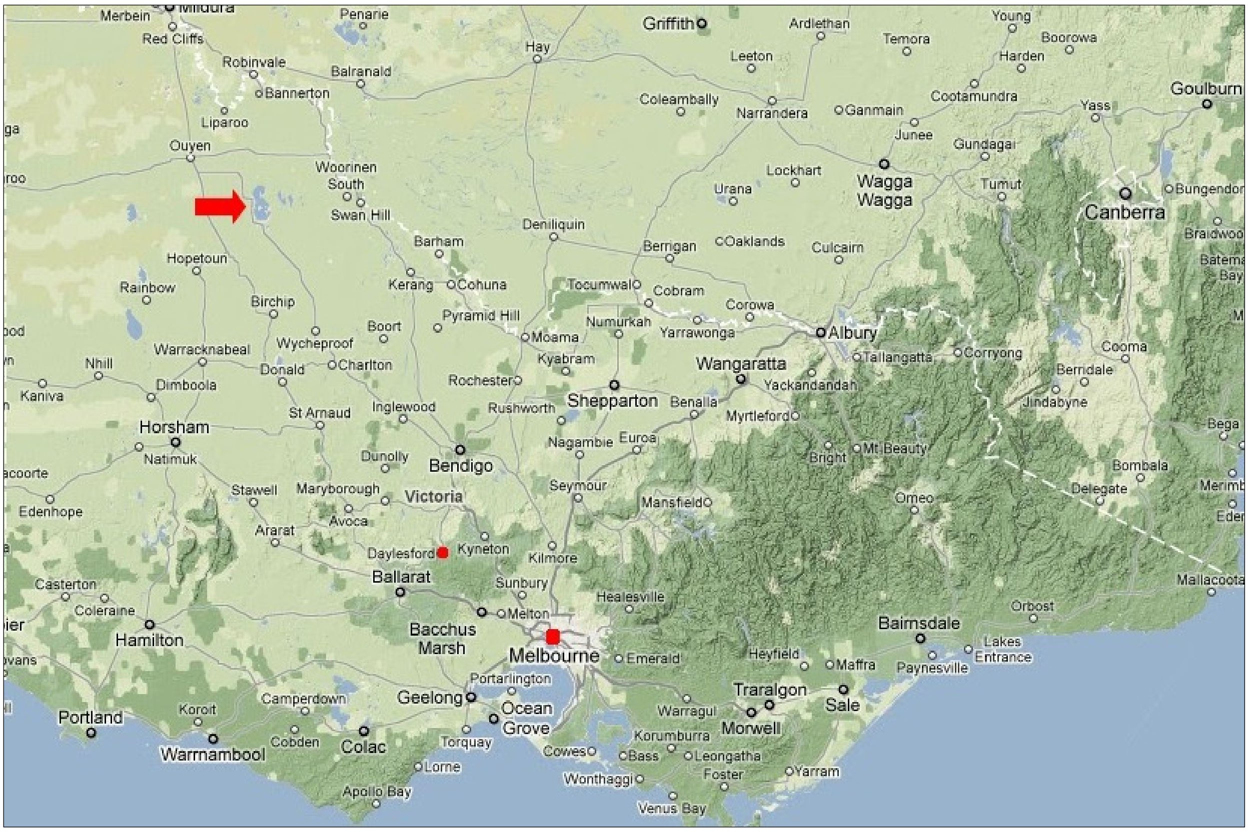


Figure 1: A map of Victoria (south-eastern Australia). Lake Tyrell, where Stanbridge acquired his knowledge of Boorong astronomy, is indicated by the red arrow, and Tyrell Downs is just to the east of Lake Tyrell. Melbourne, where he lectured to the Philosophical Institute of Victoria, and Daylesford, were he lived for a time, are marked by red dots (image taken from Google Maps).

2 WILLIAM STANBRIDGE: BIOGRAPHICAL DETAILS

William Edward Stanbridge (Esq, M.L.C., J.P., see Figure 2) was born on 1 December 1816 in the village of Astley in Warwickshire (England) to Edward and Anne Stanbridge (Parliament of Victoria, 2010). In November 1841, at the age of 24, Stanbridge arrived in Port Phillip Bay (Melbourne), and moved around the states of Victoria and South Australia over the next several years, finally settling near Daylesford in Victoria (Billis, 1974: 143; for Victorian localities mentioned in this paper see Figure 1). In 1851 or 1852, soon after his arrival in Daylesford, Stanbridge purchased the Holcombe run and later Wombat run, both north of Daylesford (*The Argus*, 1848; Billis, 1974: 221). He was issued a pastoral license for Tyrrell Station (*The Argus*, 1848), from September 1847 to January 1873 and was the first non-indigenous person to have one (Billis, 1974: 143).

On 8 July 1862 Stanbridge was appointed "… honorary correspondent for the Upper Loddon district, of the control board for watching over the interests of the aborigines." (*The Argus*, 1862). As a pastoralist and investor, he became wealthy from gold mining and later married Florence Colles on 21 August 1872 (*The Argus*, 1872), who died during the birth of their daughter, Florence Colles Stanbridge, on 1 August 1878 (*The Argus*, 1878). Later that year, as a memorial to his late wife, he founded the Florence Stanbridge Scholarship at Trinity College, Melbourne, where he was a member of the College Council (*The Argus*, 1881). Stanbridge was a member of the Philosophical Institute of Victoria during 1857-1859 (*The Argus*,

Figure 2: One of the few extant photos of William Edward Stanbridge, 1816–1894 (courtesy of Keva Lloyd). The date of the photograph is unknown, but is probably ca. 1880.

1857) and the Royal Society of Victoria from 1860 (Royal Society of Victoria, 2010); he was also a Fellow of the Anthropological Institute (London) and a member of the Church of England Assembly (Parliament of Victoria, 2010). He became the Member First Council and first Chairman of Daylesford, later the Councilor (1868-1874, 1880-1892) and finally the Mayor (1882-1883; Thomson and Serle, 1972). Stanbridge died in Daylesford on 5 April 1894, aged 77, and left funds in his will to found the Frances Colles Stanbridge Scholarship (named after his mother-in-law) at Trinity College in Melbourne (*The Argus*, 1895).

Stanbridge presented his paper on Boorong astronomy to the Philosophical Institute of Victoria in Melbourne on 30 September 1857 (which was subsequently published in their 1858 *Proceedings*). A second, longer paper was later published in 1861 and included all the essential astronomical information from the original 1858 manuscript, which was apparently destroyed in a fire (Stanbridge, 1861: 304). Stanbridge (1858: 304) claimed to have gained his information on Boorong astronomy from two members of a Boorong family who had the reputation of having the best astronomical knowledge in the community. He stated that his first fieldwork experience was conducted at a small campfire under the stars, located on a large plain near Lake Tyrell (Stanbridge, 1861: 301, 304). In his original 1857 address, Stanbridge said that he had not made any additions to the paper in the previous six years, implying that he did the bulk of his astronomical fieldwork between being issued a pastoral license at Tyrell Downs (ca. 1848) and 1851, with the latter date being better constrained.

Stanbridge's education and training in astronomy is unclear, but his written papers show that he had an acceptable knowledge of astronomy and navigation. It is also uncertain what astronomy references he had at his disposal while conducting his fieldwork, but the most widespread contemporary star catalogue was the *British Association Catalogue* (Baily, 1845). Other possibilities include the 'Paramatta' (sic.) or 'Brisbane' Catalogue (Richardson, 1835), the complete edition of La Caille's catalogue of 9,766 stars (Henderson and Baily, 1847), or the earlier La Caille (1763) catalogue of 1,942 southern stars. We will discuss these further in Section 4.

3 IDENTIFICATION OF BOORONG CELESTIAL OBJECTS

Stanbridge (1858; 1861) provides equivalent Western names for the majority of stars identified by the Boorong, which were repeated in Smyth (1876: 432-434). As part of our re-analysis of Stanbridge's work, we seek to independently identify these stars, as well as all the stars he did not specifically name. Since the Boorong clan apparently no longer exists as an entity and much of their traditional knowledge has been lost (Morieson, 1996), Stanbridge's papers are the only primary source on Boorong ethnoastronomy. We use Stanbridge (1858) to identify all stellar objects that are not identified by name, which we present in Table 1. We then provide complete lists of all the Boorong celestial objects and seasons identified by Stanbridge and ourselves in Tables 2 and 3, including visual magnitudes for all stars.

Table 1: Stars in Stanbridge (1858; 1861) not identified by name, which we identify using his descriptions.

Boorong Name	Stanbridge's Description	Name	Bayer Designation
Karik Karik	The two stars in the end of the tail of Scorpio	Lesath Shaula	υ Scorpii λ Scorpii
Bermbermgle	The two large stars in the forelegs of Centaurus	Rigil Kent Hadar	α Centauri β Centauri
Tchingal	The dark space between the forelegs of Centaurus and Crux	Coalsack	
Bunya	Star in the head of Crux	Gacrux	γ Crucis
Kulkunbulla	Stars in the Belt and Scabbard of Orion	Alnitak	ζ Orionis
		Alnilam	ε Orionis
		Mintaka	δ Orionis
			ι Orionis
			$\theta^{1,2}$ Orionis
		Orion Nebula	
Weetkurrk	Star in Boötes, west of Arcturus	Muphrid	η Boötis
Collowgullouric War	Large red star in Rober Carol, marked 966		η Carinae*
Collenbitchick	Double Star in the head of Capricornus	Prima Giedi Secunda Giedi	α^1 Capricorni α^2 Capricorni
Unurgunite	Star marked 5th mag 22 between two larger ones in the body of Canis Major		σ Canis Majoris
Wives of Unurgunite	The stars on either side of Unurgunite are his two wives	Adhara Wezen	ε Canis Majoris δ Canis Majoris
Wives of Totyarguil	Two stars on either side of Aquilla [Altair]	Tarazed Alshain	γ Aquilae β Aquilae

* Also known as η Roburis or η Argus

Some of our proposed object identifications need additional clarification. The Boorong object called *Totyarguil* is the bright star Altair rather than the whole constellation of Aquila, since Stanbridge (1858: 139) specifically noted that "... the stars on either side are his two wives." This comment certainly refers to β Aql and γ Aql, which flank Altair prominently in the sky; MacPherson (1881: 76) came to a similar conclusion. Similarly, *Neilloan* (a flying *Loan* or Mallee Fowl) is identified in Stanbridge with an object called Lyra. Stanbridge's description does not suggest that *Neilloan* refers to a group of stars. We note that prior to the late nineteenth century, Vega was commonly called 'Lyra' or 'Lucida Lyrae' in the literature (e.g. Herschel, 1847: 334), so we match *Neilloan* to the bright, zero-magnitude star Vega, as distinct from the whole constellation of Lyra, as proposed by Morieson (1996).[1] In agreement with our conclusion, MacPherson (1881) also identified *Neilloan* to be the star Vega.

We also note the explicit mention of the relatively inconspicuous star Sigma (σ) Canis Majoris (CMa) by Stanbridge. Perhaps it was pointed out to Stanbridge because it lies between the bright stars Wezen (δ CMa) and Adhara (ε CMa) on an approximate straight line (an apparent positional preference of the Boorong noted by MacPherson, discussed below). Alternatively, and less likely, it may have been noticed as being variable in brightness. In fact, this reddish star (V = +3.45, B-V = 1.72; spectral class M0-Ib), is a known irregular variable with a small amplitude of ~ 0.1 mag (Samus et al., 2010). There is a suggestion of larger amplitude variability in the past (J.E. Gore, quoted by Chambers, 1875), but this has not been confirmed by modern observations. Even so, there is a small possibility that the star may have been substantially brighter in the nineteenth century.[2]

As shown in Table 2, the Boorong created a reasonably good list of the brightest stars visible from northwestern Victoria. The only first magnitude stars omitted by Stanbridge were (with the V_{mag} in parentheses): Procyon (+0.40), Betelgeuse (+0.50, variable), Spica (+0.96), Fomalhaut (+1.14), Deneb (+1.26), and Regulus (+1.35). MacPherson (1881: 72-75) speculates that the reason for this is found in a Boorong preference to systematically group stars. He proposes that characters represented by stars of a particular family are either:

1) Grouped based upon their arrangement in the sky, specifically grouping three stars (or clusters) in a linear pattern;
2) Grouped into four linear arrangements that are roughly parallel to each other; or
3) Arranged roughly parallel to the horizon as they rise in the evening sky in their respective seasons at the latitude of the region (36° S).

Table 2: Table listing all stars specifically identified by Stanbridge, ordered by magnitude from brightest to faintest.

Western Name	Boorong Name	*V* mag	Constellation
Sirius	*Warepil*	–1.46	Canis Major
Canopus	*War*	–0.72	Carina
η Carinae	*Collowgullouric War*	–0.4*	Carina
Rigil Kent	*Berm-berm-gle*	–0.28	Centaurus
Arcturus	*Marpeankurrk*	–0.03	Boötes
Vega (Lyra)	*Neilloan*	+0.03	Lyra
Capella	*Purra*	+0.08	Auriga
Rigel	*Collowgullouric Warepil*	+0.15	Orion
Achernar	*Yerrerdetkurrk*	+0.45	Eridanus
Hadar	*Berm-berm-gle*	+0.61	Centaurus
Acrux	*Tchingal* [spear in neck]	+0.75	Crux
Altair	*Totyarguil*	+0.76	Aquila
Aldebaran	*Gellarlec*	+0.86	Taurus
Antares	*Djuit*	+0.98	Scorpius
Pollux	*Wanjel*	+1.16	Gemini
Mimosa	*Tchingal* [spear in rump]	+1.25	Crux
Adhara	*Wife of Unurgnnite*	+1.50	Canis Major
Castor	*Yurree*	+1.58	Gemini
Gacrux	*Bunya*	+1.62	Crux
Shaula	*Karik Karik*	+1.64	Scorpius
Alnilam	*Kulkunbulla*	+1.70	Orion
Alnitak	*Kulkunbulla*	+1.74	Orion
Wezen	*Wife of Unurgunite*	+1.82	Canis Major
Mintaka	*Kulkunbulla*	+2.23	Orion
Muphrid	*Weetkurrk*	+2.65	Boötes
Lesath	*Karik Karik*	+2.69	Scorpius
γ Aquilae	*Wife of Totyarguil*	+2.72	Aquila
ι Orionis	*Kulkunbulla*	+2.77	Orion
τ Scorpii	*Wife of Djuit*	+2.82	Scorpius
σ Scorpii	*Wife of Djuit*	+2.90	Scorpius
σ Canis Majoris	*Unurgunite*	+3.47	Canis Major
α^2 Capricorni	*Collenbitchick*	+3.56	Capricornus
β Aquilae	*Wife of Totyarguil*	+3.71	Aquila
$\theta^{1,2}$ Orionis	*Kulkunbulla*	+3.9**	Orion
α^1 Capricorni	*Collenbitchick*	+4.24	Capricornus

* Approximate magnitude in 1850.
** Combined magnitude of individual components.

Examples of this linear grouping include Orion's Belt, Aldebaran, and the Pleiades (Group 1), Vega, Altair, and α Capricorni (Group 2), Antares, Arcturus, Shau-la, and Lesath (Group 3). In these cases (except for Shaula and Lesath), the characters represented by these stars are of a particular family. MacPherson asserts that because Procyon, Betelgeuse, Spica, Fom-

Table 3: Table listing all celestial objects other than individual stars, plus seasons, specifically mentioned by Stanbridge.

Western Name	*Boorong Name*	*Western Name*	*Boorong Name*
Solar System		*General*	
Sun	*Gnowee*	Space	*Tyrille*
Moon	*Mityan*	Star	*Tourte*
Jupiter	*Ginabongbearp*	Milky Way	*Warring*
Venus	*Chargee Gnowee*	Magellanic Clouds	*Kourtchin*
Meteor	*Porkelongtoute*	Coal Sack	*Tchingal*
Constellations or Groups		*Seasons*	
Delphinus	*Otehocut*	Autumn	*Weeit*
Coma Berenices*	*Tourtchinboionggerra*	Summer	*Cotchi*
Pleiades	*Larnankurrk*	Winter	*Myer*
Corona Australis	*Won*	Spring	*Gnallew*

* Given as Cornua Berenices in Stanbridge (1858: 139) and Coma Berenices in Stanbridge (1861: 302).

alhaut, Deneb, and Regulus do not fall into this systematic mechanical grouping, despite their brightness, the Boorong did not include them. We refer the interested reader to MacPherson (1881) for a more detailed, in-depth explanation of this systematic grouping of stars. We must also remember that Stanbridge's source was apparently two members of a single Boorong family (Stanbridge, 1861: 301), and for unknown reasons particular bright stars may have been omitted by either Stanbridge or his Boorong informants.

Table 4: Comparative names of celestial bodies taken from Stanbridge (1861) for Boorong and Massola (1968) for the Wotjobaluk, Mara, and Kulin groups of Victoria. All objects are listed alphabetically.

Object	Boorong	Wotjobaluk	Mara/Moporr*	Kulin
Stars				
Achernar	*Yerrer-det-kurrk*	…	…	…
Aldebaran	*Gellarlec*	*Gallerlec*	…	…
β Aquilae	Wife of *Totyarguil*	Wife of *Totyarguil*	…	*Kunnawarra*
γ Aquilae	Wife of *Totyarguil*	Wife of *Totyarguil*	…	*Kunnawarra*
Altair	*Totyarguil*	*Totyerguil*	…	*Bunjil*
Antares	*Djuit*	*Djuit*	*Butt Kuee tuukuung*	*Balayang*
Arcturus	*Marpeankurrk*	*Marpean-kurrk*	…	…
Betelgeuse	…	…	*Moroitch*	…
$\alpha^{1,2}$ Capricorni	*Collen-bitchik*	*Collenbitchik*	…	…
α Centauri	…	*Purt-mayel*	…	*Djurt-djurt*
β Centauri	…	*Bram-bram*	…	*Thara*
σ Canis Majoris	*Unurgunite*	*Urnugunite*	…	…
Canopus	*War*	*War*	*Waa*	*Lo-an-tuka*
Capella	*Purra*	*Purra*	…	…
η Carinae	*Collowgulloric War*	*Collow-collouricwar*	…	…
Castor	*Yurree*	*Yurree*	…	…
δ Crucis	…	*Dok***	…	…
γ Crucis	*Bunya*	*Bunya*	…	…
Fomalhaut	…	[recorded, no name]	*Buunjill*	…
Muphrid	*Weetkurrk*	*Weet-kurrk*	…	…
Pollux	*Wanjel*	*Wanjel*	…	…
Rigel	*Collowgulloric Warepil*	*Yerrerdet-kurrk*	…	…
2 stars in Sag.	…	…	…	*Tadjeri*
	…	…	…	*Tarnung*
λ, υ Scorpii	*Karik Karik*	*Karik Karik*	*Kummim bieetch*	…
Sirius	*Warepil*	*Warepil*	*Gneeanggar*	*Lo-an*
Tarazed	…	Wives of *Totyarguil*	…	*Kunnawarra*
Vega	*Neilloan*	*Neil-loan*	…	…
Unknown Yellow Star in Orion	…	…	*Kuupartakil*	…
Clusters & Star Groups				
Beehive Cluster	…	*Coomartoorung*	…	…
Orion's Belt	*Kulkunbulla*	*Kulkunbulla*	*Kuppiheear*	…
Pleiades	*Larnankurrk*	*Larnan-kurrk*	*Kuurokeheear*	*Karatgurk*
Pointers	*Berm-berm-gle*	*Bram-bram-bult*	*Tuulirmp*	…
Constellations				
Coma Berenices	*Tourtchinboionggerra*	*Tourt-chimboion-gherra*	…	…
Corona Australis	*Won*	*Wom*	…	…
Crux	…	…	*Torong (or)*	…
	…	…	*Kunkun Tuuromballank*	…
Delphinus	*Otchocut*	*Otchout*	…	…
Hydra (head?)	…	…	*Barrukill*	…
Galaxy & Nebulae				
Coalsack	*Tchingal*	*Tchingal*	*Torong*	…
LMC	*Kourt-chin*	[recorded, male]	*Kuurn Kuuronn*	…
Milky Way	*Warring*	[smoke, name not given]	*Barnk*	…
SMC	*Kourt-chin*	[recorded, female]	*Gnaerang Kuuronn*	…
Solar System				
Comet	…	…	*Puurt Kuurnuuk*	…
Jupiter	*Ginabongbearp*	*Ginabonbearp*	*Burtit Tuung Tirng*	…
Mars	…	…	*Parrupum*	…
Meteor	*Porkelongtoute*	…	*Gnummae waar*	…
Moon	*Mityan*	*Mityan*	*Meeheaarong Kuurtaruung*	*Menyan*
Sun	*Gnowee*	*Gnowee*	*Tirng*	…
Venus	*Chargee-gnowee*	*Chargee-gnowee*	*Wang'uu/Paapee Neowee*	…

* All of these names are taken from Dawson (1881).

** Massola (1968: 8) refers to *Dok* (the frog) as the mother of *Bram-bram-bult* (the Pointers), represented by a star in Crux closest to the Pointers, referring to β Crucis. However, on page 108, he claims that *Duk [sic]* is the west star of Crux, referring to δ Crucis, and that α and β Crucis are represented by spears thrown by the *Bram-bram-bult* that pierced the emu (*Tchingal* – Coalsack). Both accounts are apparently taken from the Wotjobaluk clan.

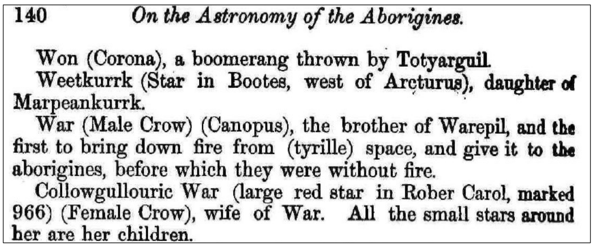
In 1968 Massola published *Bunjil's Cave*, a book highlighting the oral traditions of various Aboriginal groups of Victoria, including the Wotjobaluk, Mara, Kulin, Kurnai, Bidwel, Ya-itma-thang and Murray River communities (but he does not specify Boorong oral traditions). The Wotjobaluk and Boorong are both clans of the Wergaia language. Massola claims to have obtained his information from fieldwork over a period of ten years, and from "… the scant published material." (Massola, 1968: x). Massola (1968: 105) states that "… beliefs of the Victorian Aborigines regarding the world appear to have been much the same amongst all tribes." On page 109 he lists stars in Wotjobaluk and Mara traditions that were not mentioned by the Boorong, specifically Fomalhaut, which he describes as an eaglehawk ancestor that unspecified Murray River communities attribute to Mars. As we discuss in Section 6, some of Massola's descriptions of Wotjobaluk sky knowledge appear to have been adopted directly from Stanbridge's paper. Additionally, the Moporr (Mara) people included Betelgeuse in their sky knowledge, as opposed to the Boorong or Wotjobaluk (Dawson, 1881: 100-101). Betelgeuse is included in the oral traditions of other Aboriginal groups across Australia (see Norris and Hamacher, 2009; Maegraith, 1932), so it is unclear if MacPherson's hypothesis applies only to Wergaia oral traditions or if the Boorong simply did not tell Stanbridge about certain stars for some reason. In Table 4 we present a comparison of Boorong, Wotjobaluk, Mara/ Moporr, and Kulin star names.

Several studies (e.g. Fredrick, 2008; Johnson, 1998) have shown that many Aboriginal groups gave significance to the brightest individual stars, their nearby companion stars, naked-eye double stars, small distinctive asterisms or clusters, and the dark dust clouds silhouetted along the Southern Milky Way. Some Aboriginal groups noted compact, but distinctive, groups of relatively faint stars: for example, Mountford (1956: 479) and Haynes (1992; 2000: 58-59) have related how the Aboriginal people of Groote Eylandt gave the name of *Unwala* (the Crab) to the compact group of third and fourth magnitude stars that comprise the head of Hydra, midway between the first-magnitude stars Procyon and Regulus, the latter two stars apparently not considered significant. In contrast, Peter Beveridge, reported to the Select Committee of the Legislative Council of Victoria that Victorian Aborigines "... have a name and legend for every planet and constellation visible in the heavens." (Ridley, 1873b: 278), although this may have been a generalised statement that was not deeply researched by Beveridge.

These same general trends are also seen in the oral traditions of the Boorong, who identified all but five of the 21 first-magnitude stars, and a total of over 30 individual stars, plus Delphinus, Coma Berenices, the Magellanic Clouds, Venus, and Jupiter. There remains some confusion in the literature over the identity of the Boorong object called *Won*, which is identified simply as 'Corona' by Stanbridge (1858), representing the boomerang thrown by *Totyarguil* (Altair). We note that Corona Australis has nearly the same right ascension as Altair and is relatively near to it in the sky, so we identify *Won* as Corona Australis rather than Corona Borealis (cf. Massola, 1968; Johnson, 1998). Of the two constellations, Corona Australis has the more geometrically symmetric pattern, and is rather like a boomerang, representing the only apparent instance where a 'connect-the-dots' star pattern is applied by the Boorong (see Footnote 1). Corona Australis is quite distinctive under a dark sky, despite the relative faintness of its stars.

4 IDENTIFICATION OF η CARINAE

In Stanbridge (1858: 140), he describes a bright star called *Collowgullouric War*, as a female crow, the wife of *War* (Canopus). He labels it as "... a large red star in Rober Carol [*sic*] ...", and gives the identification number '966'; an extract is reproduced here as Figure 3. We deduce that *Collowgullouric War* is referring to η Carinae in outburst, during the period of Stanbridge's fieldwork, ca. 1848 to 1851, which coincides with the years during which η Carinae was at its brightest (Smith and Frew, 2010), and that this outburst was incorporated into Boorong oral traditions. We now expand on the reasoning that underpins our identification.



140 *On the Astronomy of the Aborigines.*

Won (Corona), a boomerang thrown by Totyarguil.

Weetkurrk (Star in Bootes, west of Arcturus), daughter of Marpeankurrk.

War (Male Crow) (Canopus), the brother of Warepil, and the first to bring down fire from (tyrille) space, and give it to the aborigines, before which they were without fire.

Collowgullouric War (large red star in Rober Carol, marked 966) (Female Crow), wife of War. All the small stars around her are her children.

Figure 3: An excerpt from Stanbridge (1858: 140) describing *War* (Canopus) and his wife, *Collowgullouric War*.

'Rober Carol' refers to the now-defunct constellation of Robur Carolinum (Latin for 'Charles' Oak') created by Edmond Halley in 1679,[3] after observing the southern sky from St Helena in 1677 (Halley 1679; cf. Baily, 1843; Brandt, 2010). This new constellation was appropriated from the classical star group of Argo Navis (also now defunct), and constituted stars now located in eastern Carina and Vela, and western Centaurus (see Figure 4). Halley (1679) recorded η Carinae as a fourth magnitude star (see Figure 5), and Frew (2004) showed that its magnitude at that time was $V = +3.3 \pm 0.3$ on a modern photometric scale.

Stanbridge cites the simple designation '966'. This certainly refers to a designation from La Caille's pioneering catalogue of 1,942 southern stars (La Caille, 1763). The reader is referred to Frew (2004: 9) for the cross-identifications of stars in this region of the sky, taken from old catalogues. We further note that the correct designation for η Carinae from La Caille's catalogue is '968 Argus', but the surrounding Carina Nebula (NGC 3372) received the designation '966 Argus', even though it is a non-stellar, extended object. This small discrepancy in the designation is probably the result of a transcription error by Stanbridge (see Figure 6), but we can deduce from this designation alone that Stanbridge was referring to a bright red star associated with the Carina nebula, i.e. η Carinae itself.

However, it seems unlikely that Stanbridge had a copy of La Caille's (1763) catalogue, which is a very rare work. Eta Carinae was not cross-referenced with La Caille (1763) in the British Association Catalogue,

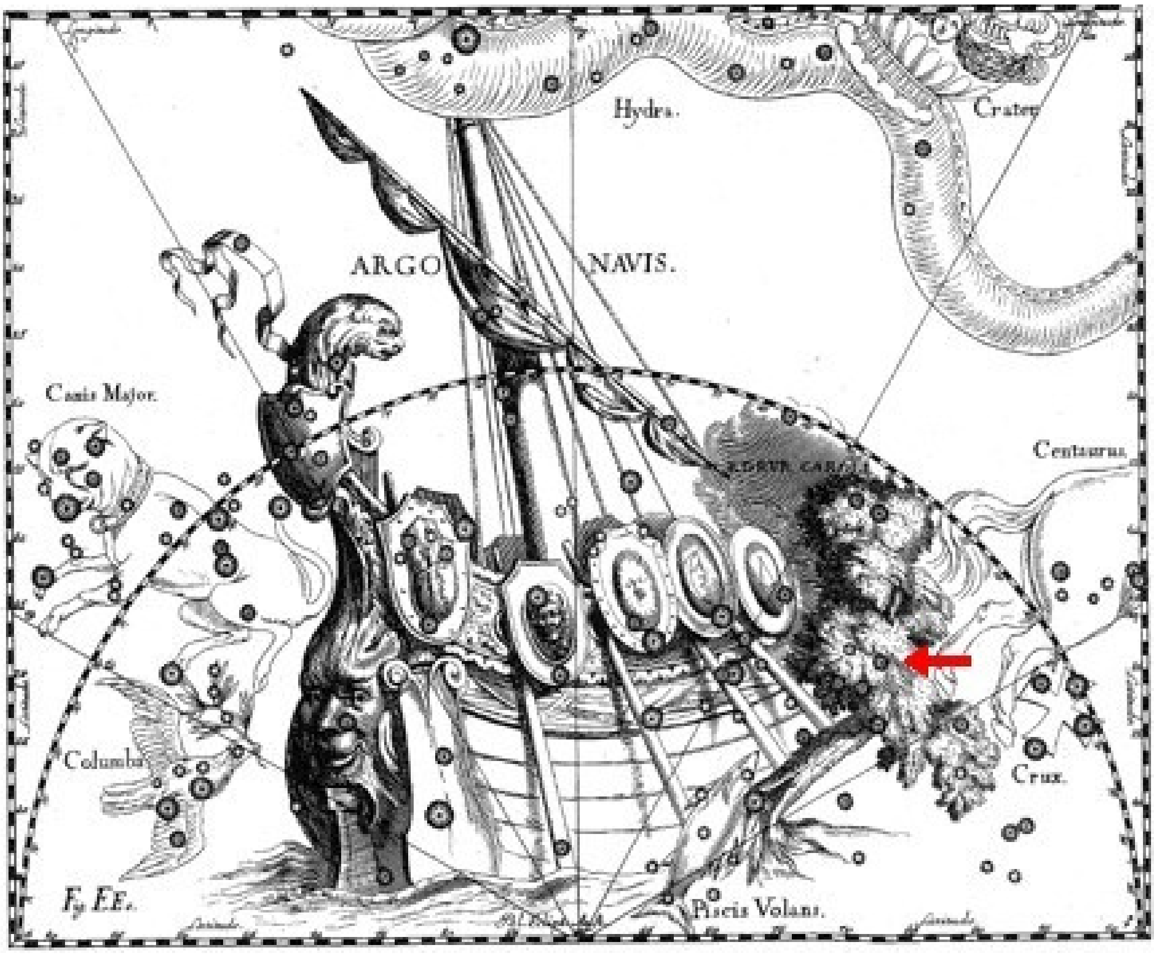
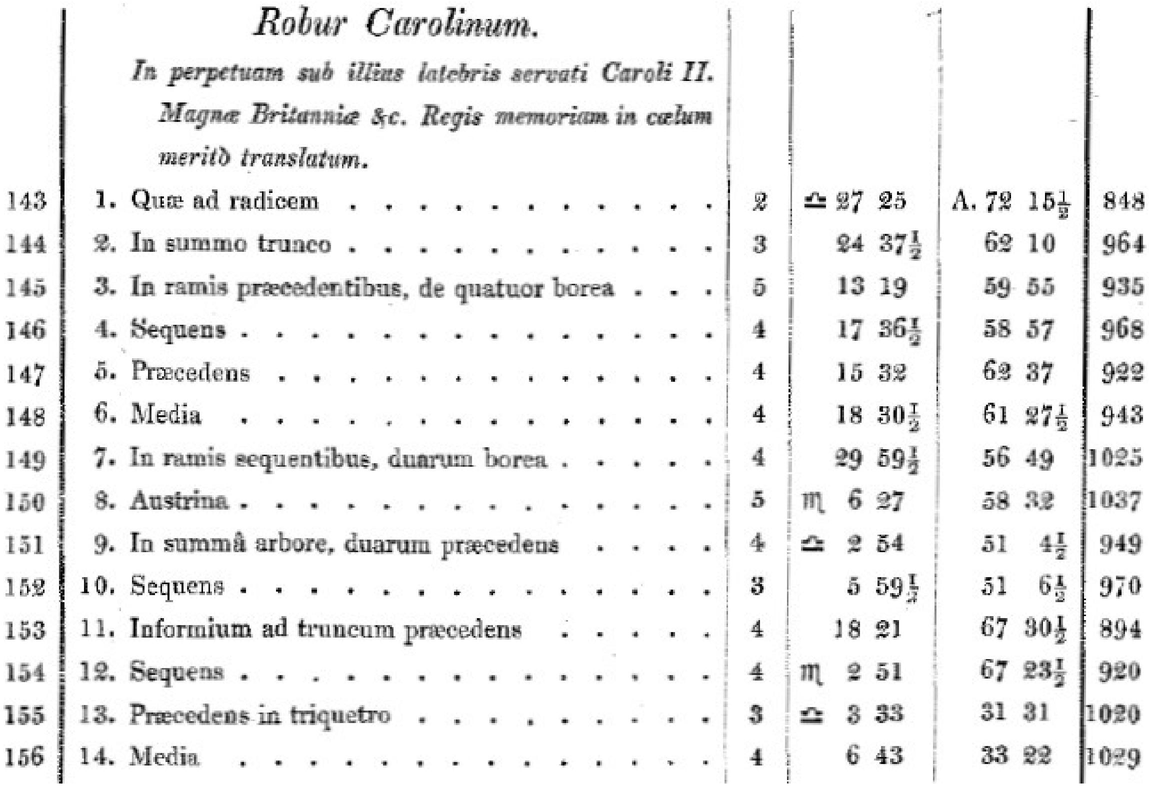


Figure 4: A star chart featuring Robur Carolinum from the star atlas of Jan Hevelius, who utilized data from Halley (1679). The image is adapted from the modern facsimile of this atlas by Sheglov (1968: 53). Eta Carinae has been marked with a red arrow.



Robur Carolinum.

In perpetuam sub illius latebris servati Caroli II. Magnæ Britanniæ &c. Regis memoriam in cœlum meritò translatum.

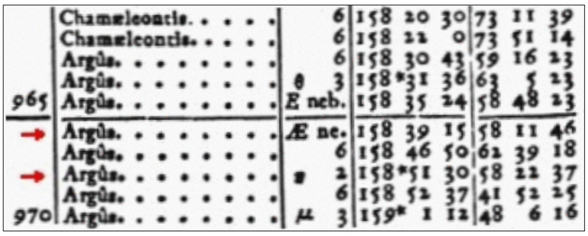
143	1. Quæ ad radicem	2	≏	27	25	A. 72	15½	848
144	2. In summo trunco	3		24	37½	62	10	964
145	3. In ramis præcedentibus, de quatuor borea	5		13	19	59	55	935
146	4. Sequens	4		17	36½	58	57	968
147	5. Præcedens	4		15	32	62	37	922
148	6. Media	4		18	30½	61	27½	943
149	7. In ramis sequentibus, duarum borea	4		29	59½	56	49	1025
150	8. Austrina	5	♏	6	27	58	32	1037
151	9. In summâ arbore, duarum præcedens	4	≏	2	54	51	4½	949
152	10. Sequens	3		5	59½	51	6½	970
153	11. Informium ad truncum præcedens	4		18	21	67	30½	894
154	12. Sequens	4	♏	2	51	67	23½	920
155	13. Præcedens in triquetro	3	≏	3	33	31	31	1020
156	14. Media	4		6	43	33	22	1029

Figure 5: An excerpt from Halley's (1679) Catalogue of Southern Stars, taken from Baily (1843: 173). Entry 146 (Sequens) refers to the coordinates of η Car, with the designation '968' taken from Lacaille (1763). Halley noted η Carinae as a fourth magnitude star, which was shown by Frew (2004) to be equal to $V = 3.3 \pm 0.3$ on the modern scale.

but was instead listed as ‘Lac 4457’ from the complete edition of La Caille’s catalogue of 9,766 stars. However, the ‘Paramatta’ (sic.) or ‘Brisbane’ Catalogue does cross reference η Argus as Lac 968, listing it as a second magnitude star and assigning it the name η Argus. Perhaps Stanbridge had access to Johann Bode’s *Uranographia* atlas (Bode, 1801), which shows the outline of Robur Carolinum, marked as Robor Caroli. In summary, it is unclear exactly what atlas and catalogue Stanbridge used to make his identifications. Nonetheless, this lack of knowledge does not affect our conclusions.

In the two decades prior to the publication of Stanbridge’s paper, η Carinae was one of the brightest stars in the sky and would have demanded attention from even a casual skywatcher (Frew 2004). Contemporary accounts commonly referred to its colour as orange or reddish during the Great Eruption (e.g. Smyth, 1845; Jacob, 1847; Gilliss, 1855, 1856; Moesta, 1856; Abbott, 1861; Powell, 1862; Tebbutt, 1866; cf. Smith and Frew, 2010), consistent with Stanbridge’s depiction of it as “… a large red star.” A cursory view of this region of sky with the unaided eye shows this to be one of the richest regions of stars in the southern Milky Way (called *Warring* in the Boorong language). Several third to fifth magnitude stars are located within a few degrees of η Carinae and are very likely the “small stars” (children) referred to in Stanbridge's account.

There is only one other star in Robur Carolinum that is reddish or orange in hue and is brighter than the fourth magnitude, and this is q Carinae (V = +3.32, spectral type K3Ib). Of the 34 stars positively identified in Stanbridge’s study (see Table 2), only three were below third magnitude ($V > +3.5$), of which two are components of a conspicuous naked eye double star (α^1 and α^2 Capricorni). It is unlikely that q Carinae is the star recorded by Stanbridge, but is more likely to be one of the “children”. Furthermore, this star is rather too faint for its colour to be *obvious* to unaided vision. While the naked eye limit for human foveal (direct) vision is $V \approx +4.1$ (Schaefer, 1993) or even a little fainter (Schaefer, 1996), stars much fainter than $V \approx +3.0$ fall in the domain of mesopic vision, where colour perception is quite poor (Malin and Frew, 1995: 86). This is further evidence that the “large red star”, recorded by Stanbridge (and by extension the Boorong) was η Carinae, and not q Carinae or some other fainter star.



	Chamæleontis.		6	158	20	30	73	11	39
	Chamæleontis.		6	158	22	0	73	51	14
	Argûs.		6	158	30	43	59	16	23
	Argûs.	θ	3	158*	31	36	63	5	23
965	Argûs.	Æ	neb.	158	35	24	58	48	23
→	Argûs.	Æ	ne.	158	39	15	58	11	46
	Argûs.		6	158	46	50	62	39	18
→	Argûs.	η	2	158*	51	30	58	22	37
	Argûs.		6	158	52	37	41	52	25
970	Argûs.	μ	3	159*	1	12	48	6	16

Figure 6: Excerpt from La Caille (1763) showing the entry for the Carina Nebula (966), described as “*ne.*” or nebulous, and η Carinae (968), listed as a second magnitude star with the designation η. We highlight these entries with a red arrow.

Given the brightness and colour of η Carinae during the years of Stanbridge’s fieldwork, its location in Robur Carolinum, and considering its designation in La Caille’s (1763) catalogue and those catalogues that cross-references La Caille, we determine that *Collowgullouric War* is a Boorong record of η Carinae during its period of outburst in the 1840s.

5 ABOUT η CARINAE

Eta Carinae is a luminous hypergiant at a distance of 2350 ± 50 pc from the Sun (Smith, 2006) in the constellation Carina (J2000, α: $10^h45^m04.0^s$, δ: –59°41′04″). It is a massive binary system with a combined mass exceeding 100 times that of the Sun. The current visual magnitude is $V \approx +4.6$ (Fernández-Lajús et al., 2009; Verveer and Frew, 2009). The dominant member of the binary system is an eruptive luminous blue variable star, with a luminosity approximately four million times that of the sun (Davidson and Humphreys, 1997).

Eta Carinae has varied markedly since its first recorded observation over four centuries ago (Figure 7). It was a first or second magnitude star at the begin-

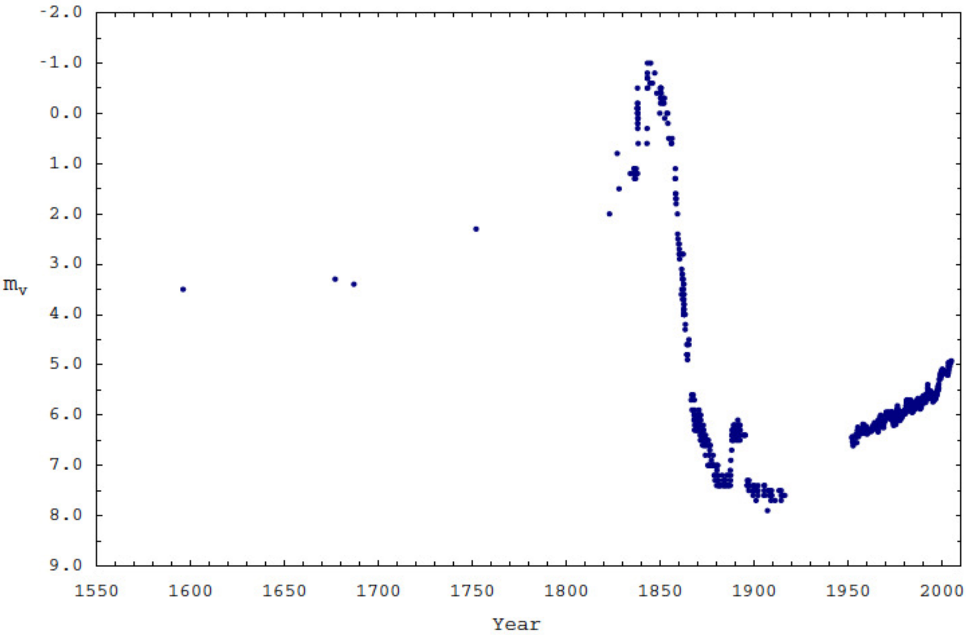


Figure 7: The visual light curve of η Carinae between 1596 and 2000 (after Frew, 2004).

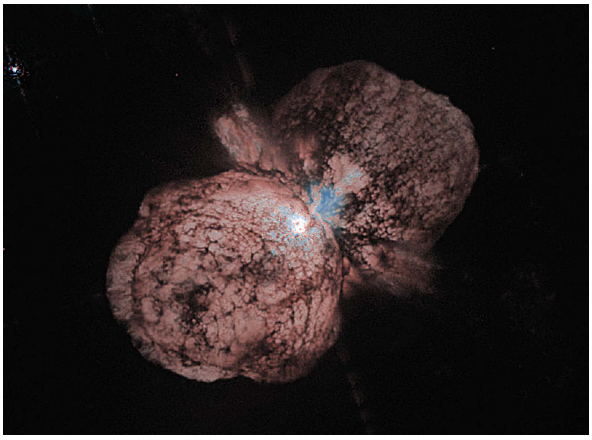


Figure 8: A NASA Hubble Space Telescope WFPC2 image of η Carinae (at centre) and its expanding bipolar Homunculus Nebula ejected during the Great Eruption in the 1840s; the image is 25 arcseconds wide (credit: J. Morse and K. Davidson, 10 June 1996).

ning of the nineteenth century, before John Herschel made the first detailed series of brightness measurements in the 1830s (Herschel, 1847). He noted that its brightness was relatively constant during this period (V = +1.2 on the modern Pogson scale), before he observed it to rapidly brighten at the close of 1837 to be as bright as Alpha Centauri, before quickly fading again—this brightening is generally considered to be the start of the period of enhanced brightness known as the 'Great Eruption' (Frew 2004; Smith and Frew, 2010).[4] Eta Carinae brightened markedly again during 1843; at its peak brightness in March of that year, and again in January 1845, it was the second brightest star in the sky after Sirius. The well-known Homunculus Nebula is the ejected debris from this explosive event (e.g. Thackeray, 1949; Gaviola, 1950; Smith and Gehrz, 1998; Walborn et al., 1978; see Figure 8). The origin of this eruption, sometimes called a 'supernova impostor' event, remains uncertain (e.g. Smith, 2008; Smith and Owocki, 2006). The star returned to its pre-outburst brightness in 1858, and continued to rapidly fade; by 1869, it was invisible to the naked eye.

6 PREVIOUS ATTEMPTS TO IDENTIFY COLLOWGULLOURIC WAR

MacPherson (1881: 73) explains that the female crow is the "… small red star No. 966 in King Charles' Oak [Robur Carol]." It is interesting that he would describe this star as "small", considering Stanbridge had specifically referred to it as "large". However, by the 1880s, η Carinae was much fainter with an apparent magnitude of V = +7.4 (see Figure 9), too faint to be discerned with the naked eye against the backdrop of the rich Carina nebula. In addition, Johnson (1998: 122), who cited MacPherson, described *Collowgullouric War* as "… a small red star, probably Epsilon (ε) Carinae …" (V = +1.86), to which Haynes (2000: 75) also agrees. It is possible that MacPherson attributed *Collowgullouric War* to a "small" red star because of the faintness of η Carinae during the time he published his paper (see Figure 9). Both Johnson and Haynes may have been unaware of η Carinae's variable past, and instead identified *Collowgullouric War* as η Carinae because of its current brightness and slightly orange tint.

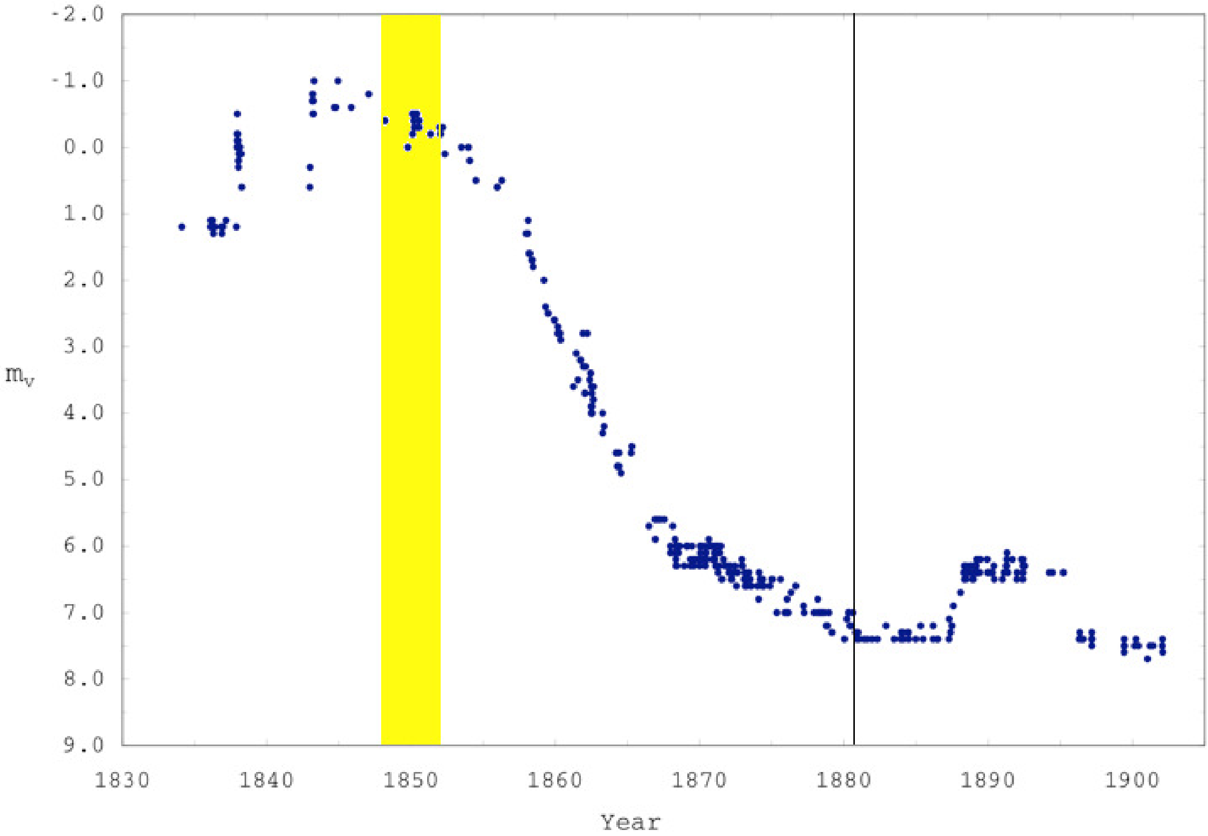


Figure 9: The visual light curve between 1830 and 1900, covering the period of the Great Eruption that extended from ca. 1837 to 1857 (after Frew, 2004). The time period in which Stanbridge was likely to have conducted his fieldwork (approximately 1847 to 1851) is denoted by the yellow vertical bar. The year in which MacPherson described η Carinae as a "small red star" (1881) is highlighted by the vertical line.

Stanbridge (1861: 303) said that neighboring Aboriginal groups, from Swan Hill (near Tyrell Downs) to Mount Franklin (near Daylesford), share similar names and associations of the stars with the Boorong. A perusal of Massola (1968) shows that the Wotjobaluk clan of the Wergaia language group, of which the Boorong is also a clan, has nearly identical views of the night sky as the Boorong. Although Stanbridge does not provide the details of stories associated with Boorong stars, Massola (1968: 3-27) does concerning Wotjobaluk stars. Massola (1968: 109) identifies the crow (*War*) in Wotjobaluk traditions as Canopus and mentions that the largest star in 'Rober Carol' is *Collow-collouricwar*, his wife, which we identify as η Carinae. In this case it is likely that Massola referred directly to Stanbridge's accounts, as most of the Wotjobaluk names as given by Massola are almost identical to the Boorong names recorded by Stanbridge. Furthermore, some descriptions are identical (e.g. *Muphrid* or *Weetkurrk* is described as a "… star in Boötes, west of Arcturus …" by both Stanbridge and Massola). Interestingly, Massola does note some celestial objects not mentioned by Stanbridge that have significance to the Wotjobaluk, such as Fomalhaut and the Beehive cluster (a conspicuous naked-eye star cluster, also called M44 or NGC 2632), although the reason for their exclusion in Boorong astronomy is unclear. It is worth mentioning that although Massola (1968: 109) mentions *Collow-collouricwar* as the wife of *War*, he does not include any mention of *Collowgullouric War* in the Wotjobaluk stories (Massola, 1968: 3-27).

In his unpublished M.A. thesis, Morieson (1996: 74) identified *Collowgullouric War* as η Carinae, but did not give his reasoning for this. However, he suggests that other nearby red stars, including R Carinae, S Carinae, and a fifth magnitude star near the open cluster NGC 2516, may also be *Collowgullouric War* (but excludes this possibility in later publications). We can rule these out as candidates, since they do not match Stanbridge's description as "large" (bright). Furthermore, R and S Carinae are both large-amplitude, Mira-type variable stars, spending most of their time below naked-eye visibility. And as mentioned earlier, stars of these magnitudes do not show apparent colour to the unaided eye. Finally, R Carinae, S Carinae, and NGC 2516 are not labeled '966' in any star catalogues, leaving no alternative star to identify as *Collowgullouric War*.

In summary, we consider the evidence for a Boorong identification of η Carinae during its Great Eruption to be unambiguous, as there are no alternative bright red stars nearby in the sky from which to choose, nor any others labeled '966'.

7 INCORPORATION OF η CARINAE INTO BOORONG SKY KNOWLEDGE

We further argue that η Carinae was probably not in the oral traditions of the Boorong prior to its outburst, and propose that this transient 'supernova impostor' event was significant enough to be included in their oral traditions during the 1830s or early 1840s. In Stanbridge's account, the Boorong associate *Warepil*, *Collowgullouric Warepil*, and *War* with some of the brightest stars in the sky (namely Sirius: $V = -1.46$, Rigel: $V = +0.15$, and Canopus: $V = -0.72$, respectively). This suggests that they chose η Carinae to represent Collowgullouric War given it was of similar magnitude during its Great Eruption ($0 > V > -1.0$).

Prior to its major outburst (i.e. before 1820), η Carinae was a second or third magnitude star in a region of the sky densely populated with stars of similar or brighter magnitudes, such as β Carinae ($V = +1.68$), ε Carinae ($V = +1.86$), δ Velorum ($V = +1.94$), ι Carinae ($V = +2.25$) and κ Velorum ($V = +2.50$). We emphasise that Stanbridge recorded none of these conspicuous stars.

An interesting trend regarding the magnitude of particular stars and their celestial spouses is apparent in Boorong traditions. Masculine stars with a single wife are both represented by objects of comparable brightness and are always in the same region of the night sky (see Table 5). If the husband has two wives, they are of different magnitudes, usually being fainter than the husband, except in the case of *Unurgunite* where the wives are brighter. Additionally, if a character has two spouses, the trio is found to be in a fairly straight line (see *Djuit*, *Totyarguil* and *Unurgunite* in Table 5). Such a linear preference in grouping stars was described by MacPherson (1881: 73-75), as discussed before.

The bright southern portion of the Milky Way in the vicinity of η Carinae is especially rich in moderately bright naked eye stars, but the only first magnitude stars in that region belong to Crux. Considering the magnitude of Canopus (*War*), we would expect to find his wife represented by a star of similar magnitude relatively nearby in the sky. We know that during its nineteenth century outburst, η Carinae was comparable in brightness with Canopus and is in the same general region of the sky. Therefore, it seems it was deliberately chosen to be *War's* wife, with its brightness as

Table 5: Comparative brightness between celestial objects representing husbands and those representing their wife or wives.

Husband	Object	V-mag	Spouse(s)	V-mag
Warepil	Sirius	–1.46	Rigel	+0.15
Ginabongbearp	Jupiter	–2.9*	Venus	–4.8*
War	Canopus	–0.72	η Carinae	–1.0*
Kourt-chin	LMC	+0.4:	SMC	+2.3
Djuit	Antares	+0.98	τ Scorpii	+2.82
			σ Scorpii	+2.90
Totyarguil	Altair	+0.76	β Aquilae	+3.71
			β Aquilae	+2.72
Unurgunite	σ Canis Majoris**	+3.47	ε Canis Majoris	+1.50
			δ Canis Majoris	+1.82

* At peak brightness

** This star is also called "22 Canis Majoris", and identified as such by Stanbridge.

a key factor. There is no obvious reason why η Carinae before its outburst would have been incorporated into celestial oral traditions so closely associated with the brightest stars in the night sky. Prior to the early 1800s, η Carinae was a second or third magnitude star (see Figure 9) in a region of the sky full of stars of similar magnitudes. It was only during the 20-year period between 1837 and 1857 that it became one of the brightest stars in the night sky before fading from view by the 1870s.

8 INCORPORATION OF CELESTIAL PHENOMENA INTO ORAL TRADITIONS

It is not uncommon for special events to serve as the foundation for new oral traditions or to be incorporated into pre-existing oral traditions (see Ross, 1986 for an in depth study of Australian oral traditions). Aboriginal oral traditions are not static, but rather dynamic and evolving. While Aboriginal oral traditions in most cases serve to illustrate and record a particular moral charter and to preserve the laws, cosmology, and social structure of the community, specific mnemonics can change over time. Several examples of transient celestial phenomena, including comets, meteors and meteorite falls, being incorporated into pre-existing oral traditions or serving as the foundation of others can be found throughout the literature (e.g. Hamacher and Norris, 2010a; 2010b; 2011), a few of which we discuss below.

The fall of a meteorite near Jupiter Well (Western Australia) was incorporated into a new oral tradition (Poirier, 2005: 237-238), as was an apparent meteorite fall witnessed by Aboriginal people and described to Barker (1964: 109-110). The Aboriginal informants' descriptions provided enough details to leave little doubt in Barker's mind that they had witnessed the fall. But since the meteorite was used as a source for sacred stories, the informants would not reveal its location to Barker or the other white Australians (for more examples, see Hamacher and Norris, 2010a; 2010b). In the 1800s, the Western Arrernte people of Ntaria (Hermannsburg, NT) incorporated Christian mythology into their pre-existing oral traditions during a period of conversion by Lutheran missionaries (see Austin-Broos, 1994). Some of these traditions were related to celestial phenomena, including a story of a falling star and rock art that depicted the Sun, the Moon and the stars (*ibid*).

In some cases, the appearance of a comet coincided with a natural disaster or catastrophic event. For example, the appearance of bright comets in Australian skies coincided with droughts (Parker, 1905: 99), disease epidemics (Spencer and Gillen, 1899: 549), war (Morrill, 1864: 61) or natural disasters (Mowaljarlai and Malnic, 1993: 194), prompting Aboriginal people to view the phenomenon with fear and apprehension (which is consistent with many indigenous cultures around the world, e.g. see Hamacher and Norris, 2011). These views were carried through successive generations through oral tradition. Even solar eclipses, which are rare occurrences from any given place on Earth, have been incorporated into oral traditions (Bates, 1944; Johnson, 1998; Norris and Hamacher, 2009; Warner, 1937). Therefore, the hypothesis that transient celestial events are incorporated into Aboriginal oral tradition is supported in the literature.

Without Stanbridge's description of *Collowgullouric War's* location and the catalogue designation he quoted, it would be difficult to argue that the Boorong were describing η Carinae. We have no records prior to Stanbridge's papers regarding Boorong astronomy, and indeed none since. The Boorong clan no longer exists as an independent entity, but their descendants still live in the region as members of the Kulin nations (Clark, 1990). It would be of interest to know how the oral traditions regarding these stars changed, if at all, as η Carinae faded to invisibility just a decade after Stanbridge's fieldwork.

9 ARE THERE OTHER INDIGENOUS RECORDS OF η CARINAE?

There are no unambiguous records of η Carinae from antiquity, and the earliest observations are derived from Dutch explorers at the close of the sixteenth century (Frew, 2004). The presence of faint nebulous ejecta exterior to the Homunculus Nebula suggests that η Carinae underwent a putative earlier outburst that occurred several centuries before the Great Eruption (Walborn et al., 1978; Walborn and Blanco, 1988; Smith and Morse, 2004), perhaps around A.D. 1000.

We have shown that the Boorong recorded η Carinae during its outburst in the nineteenth century, when it became the second brightest star in the night sky. Indeed, the long duration (≥ 20 yrs) of the Great Eruption,[4] far longer than any supernova event, and its sheer brightness compared to neighbouring stars, suggest it would have been widely observed by most, if not all, indigenous peoples of the Southern Hemisphere. Hence, we examined a number of accounts summarising the ethnoastronomy of Australian indigenous groups that post-date Stanbridge's work (including Beveridge, 1889; Dawson, 1881; Howitt, 1904; Maegraith, 1932; Massola, 1968; Manning, 1882; Mathews, 1904; Mountford, 1956; 1958; Palmer, 1884; 1886; Parker, 1905; Piddington, 1930; Ridley, 1873a; Stone, 1911; and Tindale, 1937), but we found no other definite accounts of an unidentified red star in Carina. Since the fieldwork for these studies dates from ca. 1870 to 1950, the simplest explanation is that as the star faded below naked-eye visibility in the 1860s, any oral traditions based on η Carinae that were authored during the Great Eruption were possibly lost, or no longer seen to be important.

In addition, we might ask whether there are any archaeological records of the putative earlier outburst of η Carinae. Teames (2002) cites three stone artifacts from the pre-Incan Tiahuanacan culture (ca. A.D. 1000) near the southern end of Lake Titicaca, Bolivia, that may depict the A.D. 1000 outburst. While her evidence is highly intriguing, it is too open to interpretation to be definitive. Interestingly, Orchiston (2000; 2002) and Green and Orchiston (2004) have identified a reference in Best (1922) to a possible transient source in the southern Milky Way, recorded by the Maori of New Zealand or their Polynesian ancestors. The object is called *Mahutonga*, which Best (1922: 46) records as "… a star of the south that remains invisible." This reference in turn derives from Stowell (1911: 202-203) who described *Maahu* (*Mahu*) as the star of the south, which "… has left its place in pursuit of a female. When it secures the female, it will come back again to its true home." Stowell (1911: 209) further states that "*Maahu-Tonga* is invisible." Based on this description, Green and Orchiston (2004) claim a transient event occurred in the region of *Mahu or Mahutonga*, Maori terms associated with the region of Crux and the Coalsack Nebula (Crux is the chamber of *Maahu-Tonga*; Stowell, 1911: 209), and identify it as a potential supernova. While they were unable to identify a particular supernova event, they highlighted the possibility of it being a transient observed in A.D. 185, which is generally, but not universally, understood to be a supernova (see Martocchia and Polcaro, 2009; Schaefer, 1995; Stephenson and Green, 2002; Zhao, Strom and Jiang, 2006). Its position, at α: 14^h43^m and δ: $-62°27.7'$ (J2000) is close to α Centauri, near the border of Centaurus and Circinus.

However, the identification of *Mahutonga* with SN 185 would indicate that the account originated in Polynesia, more than eight centuries before humans settled in New Zealand (~ A.D. 1000). Stowell's description might also be taken to describe a star that appears, disappears, and is expected to reappear again, suggesting a recurrent variable star as opposed to a supernova that suddenly appears before fading on a timescale of months (Stephenson and Green, 2002). Given that η Carinae's brightness fluctuated significantly over seveal decades during the nineteenth century, it is possible that *Mahutonga* may be a reference to this. Since η Carinae and SN 185 were at comparable angular separations from Crux, η Carinae remains a possible, albeit speculative, candidate for *Mahutonga*.

10 CONCLUSION

Given that transient celestial phenomena can be incorporated into either pre-existing Aboriginal oral traditions or form the basis of new traditions, we conclude that the Boorong people observed η Carinae in the nineteenth century, which we identify using Stanbridge's description of its position in Robur Carolinum, its colour and brightness, its designation (966 Lac, implying it is associated with the Carina Nebula), and the relationship between stellar brightness and positions of characters in Boorong oral traditions. In other words, the nineteenth century outburst of η Carinae was recognised by the Boorong and incorporated into their oral traditions. This supports the assertion that Aboriginal sky knowledge is dynamic and evolving, and not static. To date, the observations by the Boorong represent the only definitive indigenous record of the Great Eruption of η Carinae identified in the ethnographic literature.

11 NOTES

1. Many of the characters observed by the Boorong, identified as bright stars by Stanbridge (1858), have been considered by Morieson (1996; 2002; 2006) to represent patterns of stars, which sometimes include very dim stars. Since Aboriginal clans in southeast Australia generally avoided using a 'connect-the-dots' approach to grouping constellations (see Fredrick, 2008; Johnson, 1998; Massola, 1968), but instead preferred to attribute individual stars to specific characters in their oral traditions, these proposed constellation patterns seem unlikely to have been recorded by the Boorong.
2. In addition, Fredrick (2008:58) proposes that a Wiilman Dreaming story (southwest Western Australia), recorded by Bates (1904-1912), describes the variability of Betelgeuse:

   > Orion was a hunter of women, who was kept away from the sisters of the Pleiades by their older sister, thought to be the head of Taurus. Orion is described as wearing a feathered headdress, a string belt (the stars of Orion's Belt) and whitened tassel (Orion's Scabbard) and having a red-ochre body. The older sister throws out fire from her body and moves towards Orion, as she moves towards him she lifts her left foot and frightens him so much that the red magic of his arm and body becomes faint for a while. The magic comes back eventually and the sister asks for help from her family. All of the surrounding stars laugh at Orion and the red-back spider (Rigel) is ready to bite Orion … (Fredrick, 2008: 58).

   While the variability of Betelgeuse was first reported by Herschel (1840), the observed visual range of $V = +0.2$ to $+1.2$ (Goldberg, 1984) is large enough to be noticed by a regular sky-watcher. Indeed, Wilk (1999) has suggested that the variability of Betelgeuse was known in pre-Classical Greece.
3. This constellation (Charles' Oak) was named in honor of King Charles II who is claimed to have hidden in an oak tree for a full day, during his defeat by Oliver Cromwell in the Battle of Worcester in 1651 (see Ridpath, 1989: 147).
4. However, η Carinae appeared as bright as a first magnitude star as early as July 1827, when the naturalist William Burchell observed it to be "… as large as α Crucis." (Herschel 1847: 35; cf. Frew 2004: 24).

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THE CHANGING ROLE OF THE 'CATTS TELESCOPE': THE LIFE AND TIMES OF A NINETEENTH CENTURY 20-INCH GRUBB REFLECTOR

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Abstract: An historic 20-in (50.8-cm) Grubb reflector originally owned by the London amateur astronomer, Henry Ellis, was transferred to Australia in 1928. After passing through a number of amateur owners the Catts Telescope—as it became known locally—was acquired by Mount Stromlo Observatory in 1952, and was then used for astrophysical research and for site-testing. In the mid-1960s the telescope was transferred to the University of Western Australia and was installed at Perth Observatory, but with other demands on the use of the dome it was removed in 1999 and placed in storage, thus ending a century of service to astronomy in England and Australia.

Keywords: Catts Telescope, Henry Ellis, Walter Gale, Mount Stromlo Observatory, Mount Bingar field station, photoelectric photometry, spectrophotometry, Lawrence Aller, Bart Bok, Priscilla Bok, Olin Eggen, Don Faulkner, John Graham, Arthur Hogg, Gerald Kron, Pamela Kennedy, Antoni Przybylski, David Sher, Robert Shobbrook, Bengt Westerlund, John Whiteoak, Frank Bradshaw Wood.

1 INTRODUCTION

One of the roles of the Historic Instruments Working Group of the IAU is to assemble national master lists of surviving historically-significant telescopes and auxiliary instrumentation, and at the 2000 General Assembly in Manchester I presented a paper listing such instruments (and historically-significant astronomical archives) for Australia and for New Zealand (Orchiston, 2000; see, also, Orchiston, 2004a).

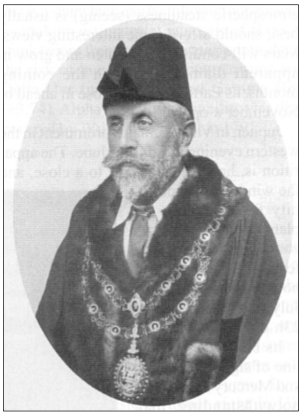
In my initial investigation of the Australian and New Zealand telescopes I encountered some difficulty in determining precisely where the cut-off point should lie for instruments that are deemed to be 'historically-significant'. All instruments pre-dating 1850 were automatically included in the master list—reflecting a criterion sensibly adopted by the late Derek Howse (1986, 1994) when he assembled the 'Greenwich List of Observatories'—as were those telescopes associated with notable astronomers, or that represented significant innovations in design. Thus, the Gregorian reflector supposedly associated with Solander and Cook's first voyage to the Pacific (Orchiston, 1999) and the various instruments used at Parramatta Observatory (Lomb, 2004) all belonged on the list, as did the 'Fletcher Telescope', with the world's first all-metal English equatorial mounting (Orchiston, 2001), and the Melbourne Observatory Dallmeyer photoheliograph, one of very few surviving and functional instruments of this type (Clark and Orchiston, 2004). Also on the list was the 8-in (20.3-cm)Grubb refractor that was used very effectively and over a long period of time by Australia's foremost nineteenth century astronomer, John Tebbutt, and then did further excellent service in the Cook Islands and in New Zealand whilst under Frank Bateson's care (Orchiston, 1982).

The problem lay in deciding on those telescopes that made a 'notable contribution to astronomy or astrophysics'. Some telescopes, such as the historic 9-inch (22.9-cm) Cooke photovisual refractor at Carter Observatory, made a long-term international contribution to both observational astronomy and (in its later years) astronomical education in England and New Zealand (Orchiston, 2002) and deserved to be on the list, but what of other telescopes, like the 20-in (50.8-cm) 'Catts Telescope'? After passing from amateur ownership to Mount Stromlo Observatory in 1952, this was used over the following twelve years to make a valuable contribution to astrophysics and to provide data for five different Ph.D. theses. Because of its short life-time as a 'cutting-edge' research instrument and its long period of inactivity (in both England and Australia) whilst in amateur hands, I originally passed over the Catts Telescope when assembling my 2000 IAU paper, but in hindsight I now regard this as a mistake. I believe that the Catts Telescope does belong on my Australian master list, but after reading this paper let you be the judge.

Figure 1: The 20-in 'Catts Telescope' (Orchiston Collection).

2 THE EARLY YEARS IN ENGLAND

The Catts Telescope began life as a 20-in (50.8-cm) f/4.5 Cassegrainian reflector, on a German equatorial mounting (Figure 1), complete with a 6-in (15.2-cm) guide scope. It is not known precisely when it was manufactured or for whom, but a 1947 Sydney newspaper article (While wives are asleep, 1947) suggests the last decade of the nineteenth century. This article discusses a stand-alone 6-in Grubb refractor, stated at the time to be "… at least 50 years old, [which] once



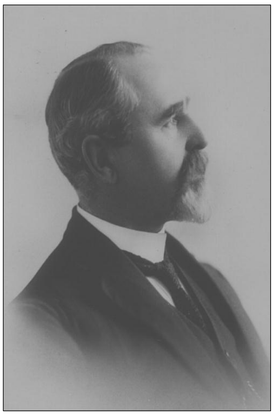


Figure 2 (left): Henry Ellis, 1858–1927, first known owner of the 'Catts Telescope' (after Marriott, 2005).
Figure 3 (right): Walter Gale, 1865–1945 (courtesy: British Astronomical Association Library).

belonged to the late Walter Gale of Waverley [Sydney], 'grand old man' of Australian astronomy." Elsewhere I have demonstrated that this instrument was originally the guide scope on the Catts Telescope (Orchiston, 1997b).

The first documented owner of the telescope was a well-known British amateur astronomer named Henry Ellis (Figure 2), who for many years was the Treasurer of the British Astronomical Association. He was born in 1858, and at the age of 16 joined the Indemnity Mutual Marine Assurance Company, and went to live just north of London at Potters Bar. He remained with the company until his retirement in 1909 and then moved to Lyme Regis on the south coast of England where he died in 1927.

An Obituary published in *Monthly Notices of the Royal Astronomical Society* merely states that "While at Potters Bar, he acquired a 20-inch reflecting telescope by Grubb, for which he built an observatory." (A.E.L., 1928). So an acquisition date in the 1890s is possible, and it is perhaps also relevant that Ellis was elected a Fellow of the Royal Astronomical Society in 1898.

Whatever the actual circumstances, Ellis seems to have made remarkably little use of this telescope. The first published mention of it dates to 1908, when slides of six photographs of Comet C/1908 R1 (Morehouse) taken with the instrument were exhibited at meetings of the British Astronomical Association (*Journal of the British Astronomical Association*, 1908). Then, in 1911, Ellis showed further comet photographs—this time of C/1911 O1 (Brooks)—at a meeting of the Association (see *Journal of the British Astronomical Association*, 1911). And although he published four short papers in the *Journal*, none of these related to the Grubb telescope.

3 TRANSFER TO THE ANTIPODES

The next owner of the telescope was Walter Gale of Sydney (Figure 3), one of Australia's most prominent early amateur astronomers. Gale was born in Sydney in 1865 (for Australian localities mentioned in the text refer to Figure 4), and after completing his schooling worked for five years in the insurance and commercial fields before joining the Savings Bank of New South Wales in 1888. He remained with the Bank until 1925, rising to the position of Manager and Chief Inspector at Head Office (Wood, 1981). He then worked as Manager of the Hoskins Investment Company, founded by George Hoskins (1883–1953), a wealthy industrialist and prominent amateur astronomer (see Orchiston and Bembrick, 1997). Gale died in 1945, and was remembered by his many friends for his "... personal qualities of helpfulness, enthusiasm, kindness, tolerance and understanding ..." (Obituary, 1945).

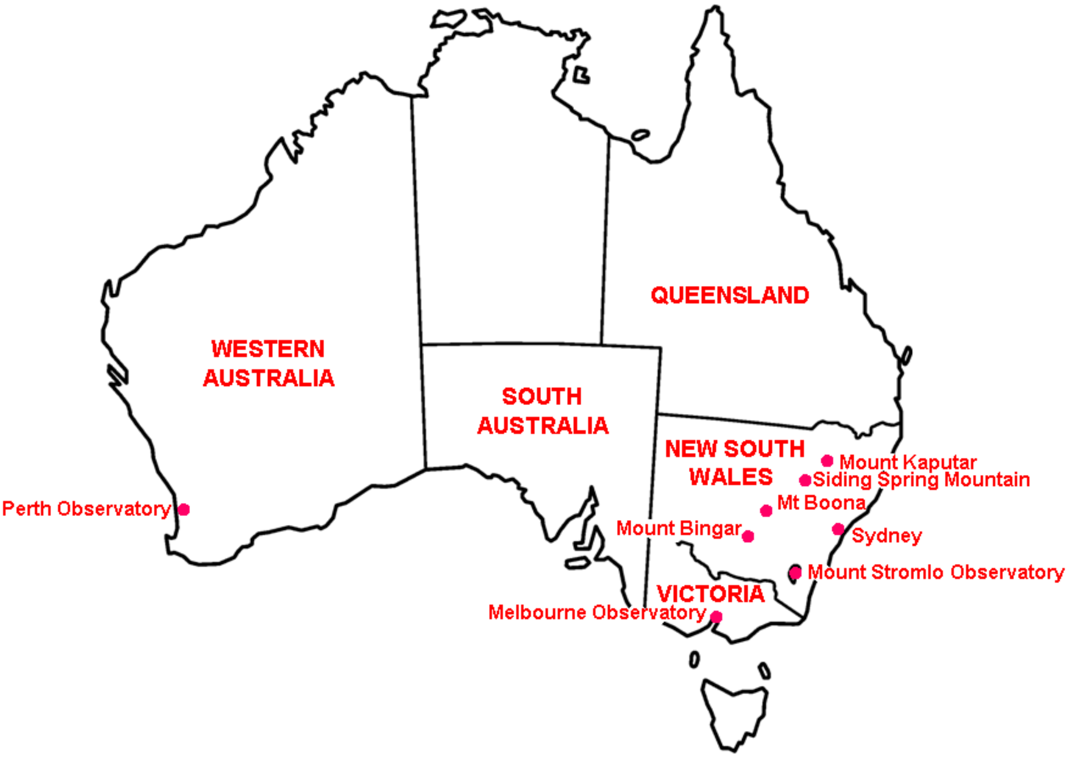


Figure 4: Australian localities mentioned in the text.

Gale inherited an early interest in astronomy from his father, but the Great Comet of 1882 (C/1882 R1) made a major impact (see Finds Venus Unexciting, 1943). He also acknowledged that newspaper articles written by John Tebbutt enticed him to seriously take up astronomy as a hobby (Gale, 1886). In 1884 he made a 17.8cm reflecting telescope (Gale, 1928), which was destined to be the first of many (Wood, 1981). The largest had an aperture of 12 inches (Obituary, 1945).

Unlike some amateur telescope-makers, Gale made effective use of his instruments, observing the planets, but particularly Mars, Jupiter and Saturn (Wood, 1981). He believed that the so-called 'canals' of Mars were genuine naturally-occurring surface features and that the planet "... may be inhabited by a race of sentient beings, perhaps not cast in the same mould as we are, but of a type suited to the conditions of the planet ..." (Gale, 1921). Like Tebbutt, Gale was addicted to comet-searching and independently discovered seven different comets, three of which (C/1894 G1, C/1912 R1 and 34P/Gale) now bear his name (Wood, 1946). He also discovered a number of double stars and a planetary nebula (Wood, 1981), experimented successfully with astronomical photography (Obituary, 1945), and participated in a number of solar eclipse expeditions (ibid.). In addition to publishing in the *Journal of the British Astronomical Association*, he made a point of promoting astronomy locally by writing for the Sydney newspapers and presenting popular public lectures (see Orchiston, 1997a).

Gale also promoted amateur astronomy by forming and developing one of Australia's earliest formal astronomical groups (Orchiston, 1998). In 1892 he teamed with R.T.A. Innes (1861–1933) to investigate the possible formation of an Australian Astronomical Society (Orchiston and Bhathal, 1984), deciding ultimately not to proceed, but in 1895 they succeeded in founding the New South Wales Branch of the British Astronomical Association in Sydney (Orchiston, 1988). Gale served as the inaugural Secretary and for many years was President of the Branch (Orchiston, 1990b; Orchiston and Perdrix, 1990). In 1935 he emulated Tebbutt by receiving the Jackson-Gwilt Medal and Gift from the Royal Astronomical Society, for his "... discoveries of comets and his work for astronomy in New South Wales." (Wood, 1981).

During the twentieth century, Gale was one of Australia's leading amateur 'telescope-brokers' and supposedly "... knew the history and characteristics of every astronomical instrument in Australia, and could tell many anecdotes relating to them." (Obituary, 1945). Over the years a large number of professionnally-made instruments passed through his hands, and these included the ex-Tebbutt 8-in Grubb refractor (see Orchiston, 1982), an 18-in (45.9-cm) Calver reflector (see Orchiston and Bembrick, 1995), and the Henry Ellis 20-in reflector. A letter by Gale in the library and archives of the British Astronomical Association in London documents his acquisition of the Ellis telescope, and states (*inter alia*):

> After an endeavour to reduce my equipment, I have increased it again by purchasing the outfit of the late Hy Ellis, to which you were good enough to refer me a few years ago ... I hope to get the telescope working somehow pretty soon after its arrival in a few months time ... The 20 in reflector will be principally employed in making long exposures upon the most interesting nebulae – if not by me then by some one who will come after ... I have not mentioned my intentions to any other as too much might then be expected of me. (Gale, 1928).

Despite good intentions and his excellent observational track record, Gale appears never to have used the Grubb reflector for any serious work. According to the late Con Tenukest (see Orchiston, 1990a), the figure of the primary mirror was not ideal, and this may have been the principal reason, especially since Gale was already making regular use of his 18-in equatorial reflector which reportedly had "… exceptional optics …" (C. Tenukest, pers. comm.).

At some date prior to his death in 1945, Gale sold the Grubb reflector to an unknown purchaser, and in 1945 or 1946 a Sydney astronomer named Horace Pinnock made a successful bid for it at the auction of this man's estate (ibid.). Pinnock had the telescope for a short time, selling it in 1947, but only after removing the 6-in guide scope—which he then proceeded to set up as a stand-alone telescope in his observatory, complete with English equatorial mounting (ibid.). It is this instrument which is discussed in the aforementioned 1947 newspaper article.

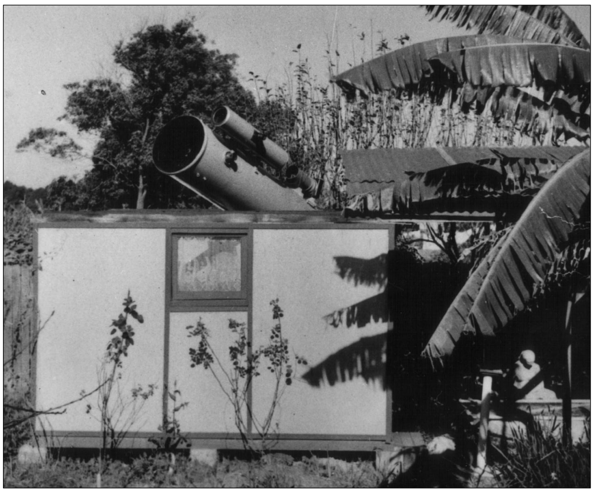


Figure 5: The 20-in reflector in Tenukest's Observatory in Sydney, ca. 1950 (Orchiston Collection).

The new owner of the 20-in Grubb reflector was Dr Con Tenukest of Sydney. Tenukest (1906–1989) was responsible for the Precision Optical Laboratory at the University of Technology in Sydney and was

> … one of Australia's most distinguished amateur astronomers during the 1940s and 1950s … [He] made important contributions in the fields of planetary observational astronomy, telescope-making (through his University of New South Wales classes) and astronomical education (mainly via the planetarium at the Museum of Applied Arts and Sciences in Sydney). He was a stalwart of the New South Wales Branch of the British Astronomical Association, and a number of large telescopes, both reflectors and refractors, passed through his hands. Some of the reflectors were historically significant instruments. (Orchiston, 1990a: 154).

The 20-in Grubb reflector could be counted as one of these "… historically significant …" telescopes, and it was installed in a roll-off roof observatory (Figure 5)

Figure 6: The Catts Telescope roll-off roof observatory at MSO (courtesy: Mount Stromlo and Siding Spring Observatories).

in the back yard of Tenukest's property. When he acquired this telescope, Tenukest was Director of the Planetary Section of the New South Wales Branch of the British Astronomical Association, and he used it for planetary observations (Orchiston, 1990a), but he was not happy with the condition of the primary mirror and had it refigured by the late Ron Schaefer who was employed by the CSIRO's Division of Physics (C. Tenukest, pers. comm.).

Tenukest believed that Sydney's sky conditions did not allow the Grubb reflector to be used to its full potential (ibid.) and so in 1951 he sold the instrument to another Sydney-based Branch member, J.H. Catts (*British Astronomical Association NSW Branch Bulletin*, 1952), but on the understanding that when he wished to part with it Catts would offer Tenukest first right of refusal (C. Tenukest, pers. comm.). Catts proceeded to install the telescope in an observatory at his home, but had little opportunity to carry out any useful astronomical work as he died in the following year.

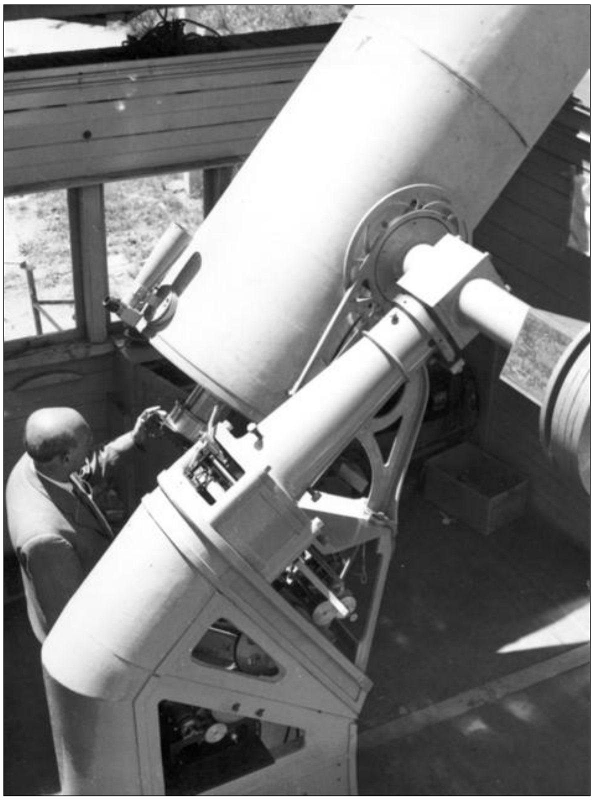


Figure 7: Arthur Hogg is shown with the Catts Telescope at Mount Stromlo (courtesy: Mount Stromlo and Siding Spring Observatories).

4 THE STROMLO ASSOCIATION

4.1 Photometry at Mount Stromlo

Much to Tenukest's chagrin, in 1952 Mrs Catts sold the 20-in reflector to Mount Stromlo Observatory (henceforth MSO) for a substantial profit (ibid.; cf. Haynes et al., 1996: 162-163, who incorrectly state that the telescope was gifted to MSO), but in fact it was only through this action that its true research potential could be realized (see Orchiston and Bembrick, 1995). At this time, this historic Grubb reflector came to be known colloquially as the 'Catts Telescope'.

MSO was located near the nation's capital, Canberra (see Figure 4), and by this time was Australia's foremost professional optical observatory. The decade following WWII was a critical one (see Davies, 1984; Frame and Faulkner, 2003; Gascoigne, 1984, 1988, 1992; and Hyland and Faulkner, 1989), and under the innovative leadership of Richard Woolley (1906–1986) the institution gradually shifted its research focus from solar to galactic and extra-galactic astronomy, acquired new telescopes and auxiliary instrumentation, recruited new staff, and became a *de facto* Department of Astronomy of the Australian National University (ANU) by offering courses in astronomy and attracting graduate students (as a prelude to later formally transferring from the Government's Department of the Interior to the University) (Woolley, 1968).

Vital in this renaissance were larger and more modern telescopes, to serve as company for the aging 30-in (76.2-cm) Reynolds Reflector, then Australia's largest telescope. Two telescopes were decided on, a new Grubb-Parsons 74-in (1.88-m) reflector and a 50-in (1.27-m) reflector, representing an extensively rebuilt and modified version of the notorious nineteenth century 'Great Melbourne Telescope' (see Gascoigne 1996). Since neither of these instruments was operational when the Catts Telescope came up for sale, it was seen as a particularly attractive short-term option —at least until the two new telescopes were ready in 1955.

On 17 March 1952 Woolley and his deputy, Arthur Hogg (1903–1966), went to Sydney, inspected the Catts Telescope and arranged for its immediate purchase. By the time it arrived at MSO on 15 April work had already started on its roll-off roof observatory, a converted old solar radiation hut. The completed observatory is shown in Figure 6. The telescope itself was installed on 12 May but the condition of the mirror caused some concern and in July it was repolished, refigured and realuminised (see Mount Stromlo Diary, 1951-1956). By late 1952 Stromlo finally had a new research telescope "… erected primarily to further a programme for photoelectric observations of eclipsing variables and other objects." (Hogg, 1953: 7), and shortly after this Hogg (1954: 54) wrote that the telescope (see Figure 7) was "… in continuous operation on photoelectric programmes." It was used in the f/18 Cassegrain mode (Buscombe, 1958), and its limiting magnitude for these 'programmes' would have been about 13 (Woolley, 1954b). Woolley (1953b) summarised the situation in his 1952 Report to the MSO Board of Visitors (my italics):

> A 20 inch equatorially mounted reflector by Grubb was purchased from the estate of the late Mr. J.H. Catts and removed from Sydney in April. The telescope was erected in an existing small building with sliding roof. The primary mirror was refigured and aluminised and a new secondary mirror (Cassegrain) in "Pyrex" was made and installed. An EMI photo-multiplier has been mounted on the telescope and with the loan of a Brown recording potentiometer from the Yale-Columbia Southern Station *a most useful photoelectric installation is now available*.

As it happened, the purchase was a fortuitous one for delays in the satisfactory completion of the 74-in and 50-in telescopes meant that the Reynolds and Catts reflectors would remain the mainstays of the Observatory's observational programs for somewhat longer than anticipated. While the Catts Telescope was dedicated to photometry, the larger Reynolds reflector was used both for photometry and for spectroscopy.

As might be inferred from the foregoing paragraphs, Arthur Hogg was the principal user of the Catts Telescope during its short time at Mt Stromlo (see Photoelectric observations … 1953-1954), although only two research papers based on his observations appeared in print. In one of these, Hogg (1955) reported Johnson *B* and *V* observations at a large number of points in the Large and Small Magellanic Clouds. In addition to deriving mean values for both Clouds (see Table 1), he produced isophote plots in *B* for both Clouds (Figure 8) and noted that

> The colour of the Small Cloud is found to be systematically bluer in the brighter central regions than nearer the edge. The Large Cloud shows no regular variation of colour over its surface. (Hogg, 1955: 473).

For the SMC, this effect is reflected in the *B–V* values listed in Table 1. Hogg (1955: 477-478) has more to say about this interesting effect:

> The distribution of colour in the Small Cloud is difficult to account for by absorption due to dust intermingled with the stars in any regular fashion. The distribution suggests that the hotter stars are concentrated towards the centre of the Cloud. The overall colour of the Small Cloud does not support the idea of a Type II population …

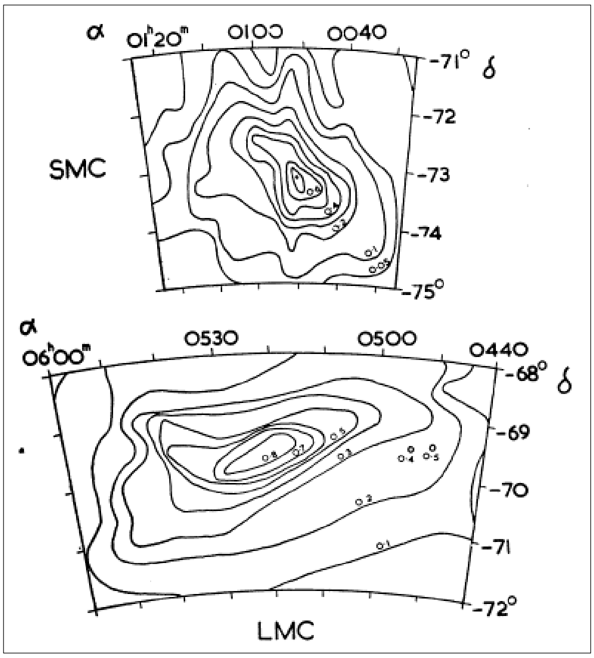


Figure 8: *B* system isophotes for the LMC and SMC. The contours refer to the magnitude differences between the central regions of the Clouds and the total light received from object + sky (after Hogg, 1955: 475).

This photometric study of the Magellanic Clouds was an important contribution to astrophysics, but Hogg was also interested in the properties of stars that lay within our Galaxy. One of these was ς Scorpii, which is a binary star with an 8.7 magnitude companion 20″ distant. The brighter component is both a spectroscopic binary (with a period ~34 days) and a β Canis Majoris type variable with a period of about 0.25 days. In 1954 and 1955 Hogg carried out *UBV* photometry of this system at MSO while Otto Struve (1897–1963) and his colleagues conducted radial velocity measures in the USA. In all, Hogg (1957: 96) was able to assemble seven "… substantially complete light curves (i.e. curves covering the whole of one cycle with readings of the variable at average intervals of 12 minutes) …", and some of these are reproduced here in Figure 9. Detailed examination of the photometric observations revealed the existence of a beat period of 8.028 days superimposed on the known short-period variation of 0.246846 days.

The arrival of the Catts Telescope at MSO was fortuitous in that the Observatory was rapidly expanding its doctoral program. The first Ph.D. scholar to use

Table 1: Surface photometry of the Large and Small Magellanic Clouds (after Hogg, 1955: 473).

Parameter	LMC	SMC
Area measured (square degrees)	27.5	10.8
B magnitude	+1.4	+2.6
B–V	+0.33	+0.1 to +0.6
Central brightness (mag.sec^{-2})	21.4	21.4

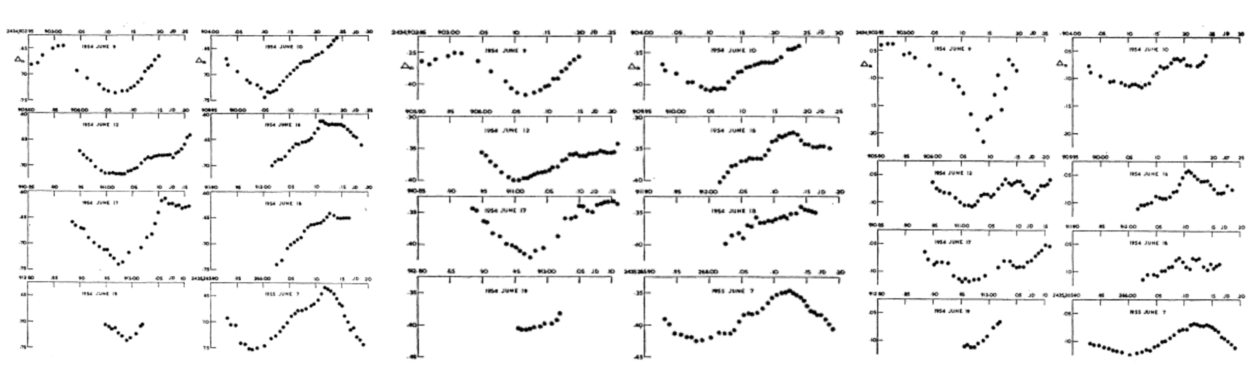


Figure 9: Short-period light variations in the β Canis Majoris-type variable, ς Scorpii. Two left columns: *U* magnitude; two centre columns: *B* magnitude; two right columns: *V* magnitude (after Hogg, 1957: 96-97).

Table 2: Three colour amplitude variations of SX Phoenicis in 1957 (after Wood, 1959b: 224).

Date JD 2436000+	Magnitude Variation		
	Yellow	Blue	Ultraviolet
158	0.43-0.47	0.58-0.64	
175	0.40-0.44	0.45-0.48	0.27-0.32
176	0.56-0.60	0.64-0.68	0.39-0.56
183	0.68-0.72	0.75-0.79	0.55-0.64
184	0.48-0.54		

the telescope for thesis-related observations was John Whiteoak (1937–), who began a photometric study of selected clusters in the southern Milky Way. This study would continue after the relocation of the Catts Telescope to Mount Bingar in 1959 (see Section 4.2).

The third local person to use the Catts Telescope during its sojourn at Mt Stromlo was the 'Uppsala Schmidt' astronomer, Bengt Westerlund (1921–2008),[2] who began a *UBV* survey of early type stars near the South Galactic Pole. This study would conclude once the refitted Catts Telescope was located at Mount Bingar.

Apart from Stromlo-based astronomers, at least two overseas visitors—Frank Bradshaw Wood and Olin Eggen—used the Catts Telescope.[3] Professor Wood (1915–1997) was from the Flower and Cook Observatory at the University of Pennsylvania, and from July 1957 to mid-1958 he spent his Sabbatical Leave at MSO while on a Fulbright Fellowship (Bok, 1958; Wood, 1958). Wood made photometric observations of the following Algol-type variables: ST Car, RS Lep, TZ CrA and V Tuc. They had known periods of 17-30 hours and deep primary eclipses with durations of 3-6 hours, and these stars were of special interest to him (Wood, 1959a: 56) because

> The short periods mean either extraordinarily large masses or small distances between the components. Similar systems which have undergone detailed analysis have shown normal masses for the brighter components; this, plus the short period, calls for a distance between components so small that the radii of the brighter components can only be about ½ those of normal A stars; this in turn locates the A components below their normal place in the HR-diagram. The secondary components in such cases have frequently been found to fill the limiting Jacobian surface and hence are in an interesting evolutionary stage. Lack of appreciable light change between eclipses, in such close systems can be most simply explained by a large mass-ratio. If this explanation survives detailed analysis, the fainter components of these systems must have abnormally low masses.

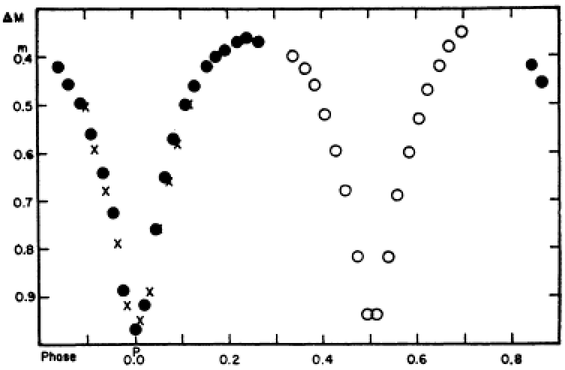


Figure 10: Light curve of BD–20°345 derived from observations made on 25 October 1955 with the 50-in telescope (filled circles), and with the Catts Telescope on 17 October (open circles) and 19 October (crosses) (after Eggen, 1956: 143).

Another star that Wood observed with the Catts Telescope and an EMI type 5060 photomultiplier was the short-period variable, SX Phoenicis. This was known to have a period ~80 minutes and a variation in magnitude ranging between 0.3 and 0.8. Wood carried out 2- or 3-colour observations on 3 nights in 1957 and recorded the magnitude ranges listed in Table 2.

He also found that

> By 1957 the beat phenomenon had shifted in phase so that the variations in phase and amplitude arrive about 0.1 beat-period earlier than in 1952. Thus the beat-period has shortened and this suggests that the period, P_0, has increased relatively more than the period P_1. (Wood, 1959b: 224).

In concluding his paper, Wood (1959b: 226) pointed to the need for further observations made simultaneously with two or more telescopes. Regrettably, the Catts Telescope was not to be a part of such a program, and no further papers by Wood involving observations with this telescope were found during an ADS search, notwithstanding Whiteoak's recollection (pers. comm., 2010) that

> … when I started at Mt Stromlo in March 1958 … the biggest user [of the Catts Telescope] was Frank Bradshaw Wood … who gobbled up as much time as possible. I had to scrounge a few days a month … Because of Frank's interest, the time was always fully booked!![4]

The other overseas visitor who used the Catts Telescope in the 1950s was Olin J. Eggen (1919–1998) from the Lick Observatory (at that time—somewhat later he would become a Director of Mount Stromlo and Siding Spring Observatories). Eggen used the 20-in and 50-in telescopes to study RR Lyrae variables (Woolley, 1955).

Presumably most of Eggen's time was spent on the 50-in, for an ADS search produced just one solitary paper listing Catts Telescope data. The stars in question were BD–20°345, HD273211 and HD206379, all of which had been identified as variables by Cuno Hoffmeister (1892–1968) in the 1930s and 1940s.

From photometric observations made in 1955 with the 20-in and 50-in telescopes, Eggen (1956) was able to show that BD–20°345 was a W Ursae Majoris-type variable with a period of ~7.5 hours and the light curve shown in Figure 10. On 8 December 1955 Eggen carried out photometry on the RR Lyrae variable HD273211 using the Catts Telescope, and found the magnitude varied between 9.50 and 10.85. Since the star was followed almost continuously and the comparison star was observed only occasionally, all Eggen could do was determine the basic form of the light curve, which is shown in Figure 11. HD206379 was observed with the Catts Telescope on 16 and 18 October 1955 and the period was shown to be ~3.5 hours. The magnitude varied between 7.65 and 8.22. Because of continuous monitoring, once again only the basic form of the light curve was determined (see Figure 12).

4.2 Photometry, Spectrophotometry and Sky-Monitoring at Mount Bingar

Once the Grubb-Parsons 74-in reflector and the refurbished 50-in Great Melbourne Telescope were operational at MSO the Catts Telescope was no longer in great demand, but a new project awaited its attention.

Richard Woolley left Canberra at the end of 1955 to become the thirteenth Astronomer Royal, and he was replaced by the inimitable Bart Bok (1906–1983) who soon realized that

> … the climate at Mt. Stromlo left a great deal to be desired, that with the growth of Canberra, conditions could not but deteriorate, and that a search should accordingly be made for a site where a field station could be established in the fairly near future. (Gascoigne, 1968: 65)

After considering possible localities in Western Australia, South Australia, Victoria and New South Wales, five sites were selected for detailed investigation (Bok, 1960a). In 1959, the number of sites to be monitored for evening cloudiness was increased to twenty, including Mount Bingar near Griffith, and Siding Spring Mountain near Coonabarabran, both in New South Wales (see Figure 4). Bok and his staff then decided to set up a provisional field station

> … so as to have a control for the testing programme, and to gain experience of operations remote from Mount Stromlo. The location chosen was Mount Bingar, which had topped the previous year’s statistics for highest quality nights, and which became a firm favourite with Bok. (Hyland and Faulkner, 1989: 220).

The Catts Telescope was assigned to this project, but only after the 20-in primary mirror was replaced by one of 26 inches aperture, “… a thick-ribbed, honeycomb disk of pyrex … made available to us by courtesy of Dr T. Dunham Jr. and the Fund for Astrophysical Research of the U.S.A.” (Bok, 1960b: 202).[5] A 10-in secondary was ground and polished in the MSO optical shop, and the original telescope mounting was modified to accommodate a new larger tube (Figure 13 lower insert). The upgraded Catts Telescope, with an

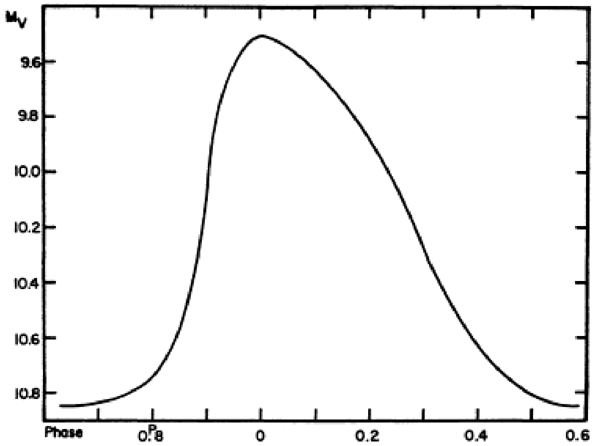


Figure 11: Basic form of the light curve of HD273211 (after Eggen, 1956:144).

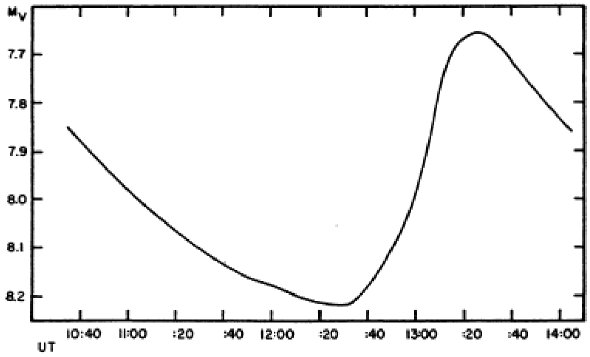


Figure 12: Basic form of the light curve of HD206379 (after Eggen, 1956:144).

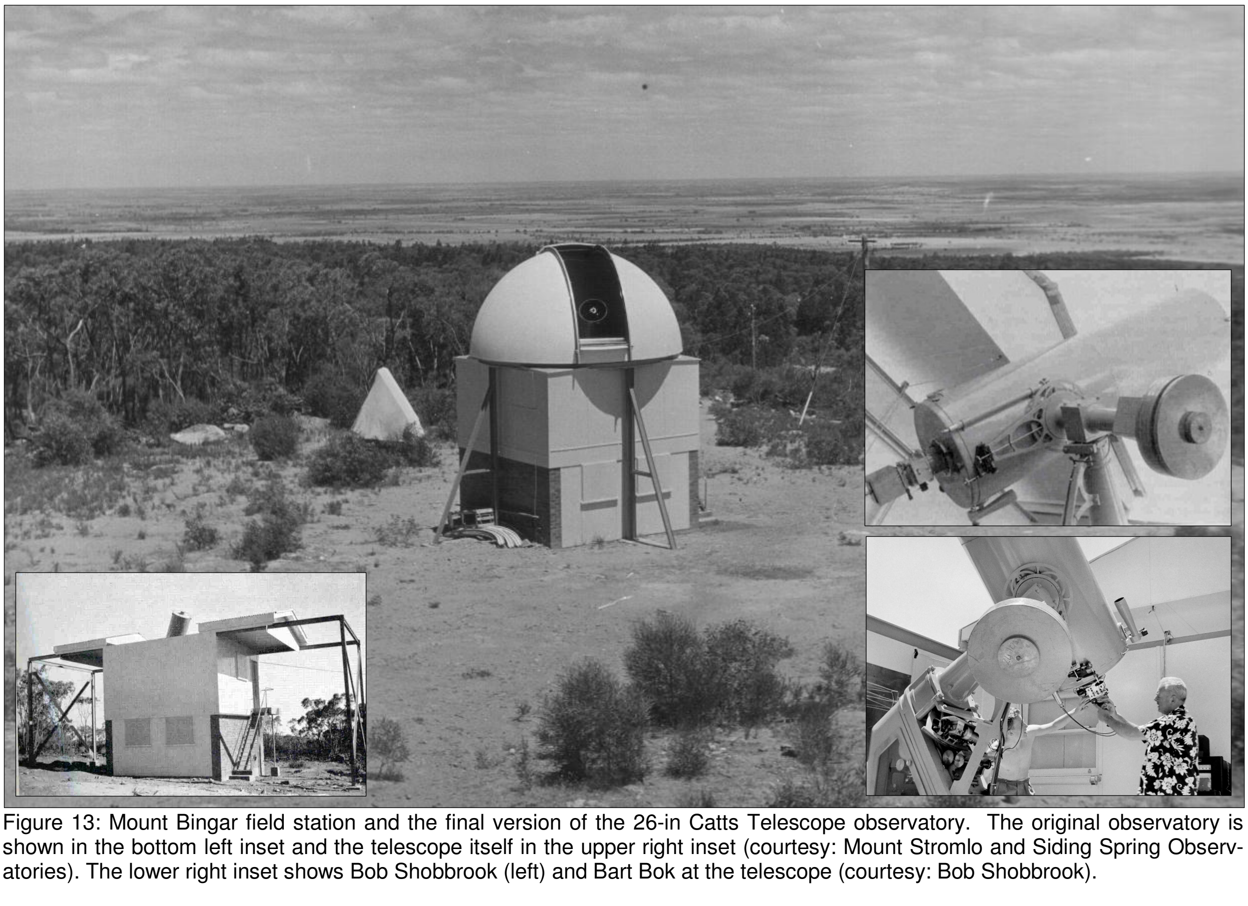


Figure 13: Mount Bingar field station and the final version of the 26-in Catts Telescope observatory. The original observatory is shown in the bottom left inset and the telescope itself in the upper right inset (courtesy: Mount Stromlo and Siding Spring Observatories). The lower right inset shows Bob Shobbrook (left) and Bart Bok at the telescope (courtesy: Bob Shobbrook).

Table 3: Mean integrated magnitudes and colours for two OB associations in the LMC (after Bok et al, 1962: 495).

OB association	V_0	$(B-V)_0$	$(U-B)_0$
NGC 1955	8.98 ± 0.03	−0.22 ± 0.02	−1.11 ± 0.02
NGC 1968-1974	8.79 ± 0.03	−0.27 ± 0.02	−1.13 ± 0.02

f/12 Cassegrainian configuration, was then installed in a roll-off roof observatory at Mount Bingar in 1959 (Figure 13 upper insert), and as the main image in Figure 13 illustrates, in February 1961 this facility was replaced by a 7.6m dome (see Mount Bingar, 1961). The first observations at Mount Bingar were carried out on Christmas Night, 1959, with sky monitoring proceeding throughout 1960. Although it proved favourable for photoelectric work (Bok, 1961), by the end of that year it was becoming obvious that the site was just far enough south to experience the northern extremities of the storm centres that formed to the south of the Australian continent.

Despite, this, Mount Bingar remained in contention as the possible MSO outstation, along with Siding Spring, Mt. Boona (near Condobolin) and Mt. Kaputar (north of Gunnedah) (for these localities see Figure 4). The last two sites were subsequently eliminated, and the final choice was made in 1962. Although Bok strongly favoured Mount Bingar, other staff opted for Siding Spring, which won the day—but only after the intervention of the University's Vice-Chancellor (see Gascoigne, 1968; Hyland and Faulkner, 1989). Initially, 16-in and 40-in Boller & Chivens reflectors were installed, and later they were joined by other ANU instruments, including the 2.3m New Technology Telescope. Siding Spring Mountain also became home to the 3.9m Anglo-Australian Telescope and the 1.22m U.K. Schmidt (see Gascoigne, Proust and Robins, 1990).

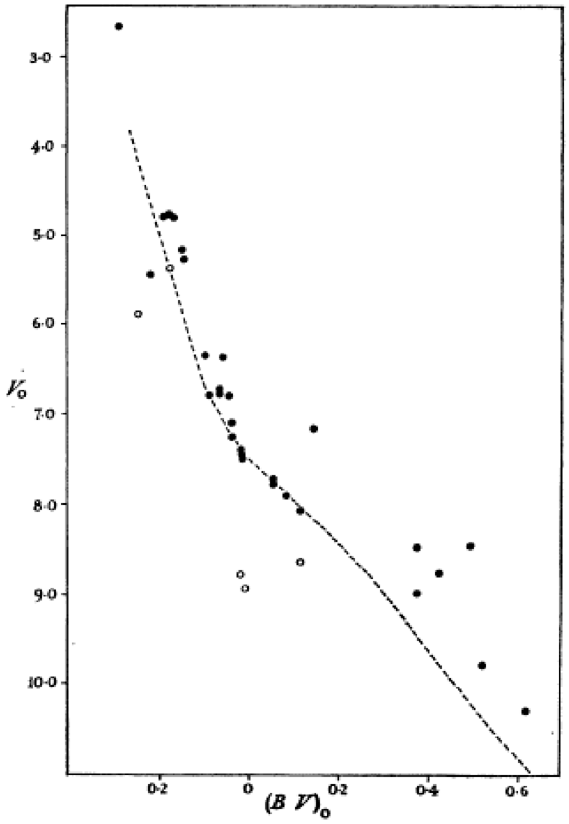


Figure 14: Colour-magnitude diagram for IC 2602 cluster members (after Whiteoak, 1961b: 251).

Apart from its sky-monitoring role, whilst stationed at Mount Bingar the refurbished Catts Telescope was used extensively by some MSO staff and graduate students for astrophysical research. Initially it was furnished with a *UBV* photometer that was constructed at MSO under the direction of Ben Gascoigne, and was modeled on the design of the Lick Wide Field Photometer.

John Whiteoak was one of the MSO doctoral students to use the refurbished Catts Telescope at Mount Bingar, and his thesis, "The Structure of the Southern Milky Way" (Whiteoak, 1961a) contains MSO and Mount Bingar observations.

One of the projects that Whiteoak (1961b) began at MSO but continued with the 26-in at Mount Bingar was a photoelectric, spectroscopic and photographic investigation of the galactic cluster IC 2602, near θ Carinae. Most of the photoelectric observations were made at Mount Bingar, initially with the EMI photometer, but this was subsequently replaced by one with a refrigerated RCA 1P21 photomultiplier tube. *UBV* photometric data were obtained for 67 different stars; spectra existed for about half of these, and most were either B- or A-type stars. Five stars stood out as more reddened than the others, and these were identified as background stars and not members of the cluster. After a correction for interstellar absorption was applied, a colour-magnitude diagram was prepared for the 34 stars with spectra, and this is shown in Figure 14 (where the non-cluster members are indicated by open circles). The dashed curve is the fitted 'zero-age' main sequence, displaced vertically by 5.95m, the distance modulus of the cluster. This equates to a distance of 155 parsecs (Whiteoak, 1961b: 251). The luminosity function of the cluster was also investigated, and stars of absolute magnitude +3 and +4 were shown to be under-represented (Whiteoak, 1961b: 253). Two different methods were then employed to derive the age of the cluster, yielding values of 1.2×10^7 years and 8×10^6 years; Whiteoak (1961b: 254) regarded the former figure as more accurate. On the basis of its age and its distance, Whiteoak (1961b: 255) concluded that "… IC 2602 may be a local condensation of the Scorpio-Centaurus Association."

Foremost among the MSO staff users of the Mount Bingar facility was Observatory Director, Bart Bok (see Figure 13) who, along with his wife Priscilla (1896–1975), was interested in photometric properties of young associations in the Large Magellanic Cloud. In Bok, Bok and Basinski (1962) they report *UBV* photometry of six OB stars in NGC 1955 and five stars in NGC 1968-1974, two distinctive concentrations of young stars and associated nebulosity. A preliminary survey showed

> … the fields to be remarkably free from overlying obscuration. Within the confines of the areas of high surface density of stars, the percentage of foreground stars should be relatively small … Because of the presence of irregular emission nebulosity, special care

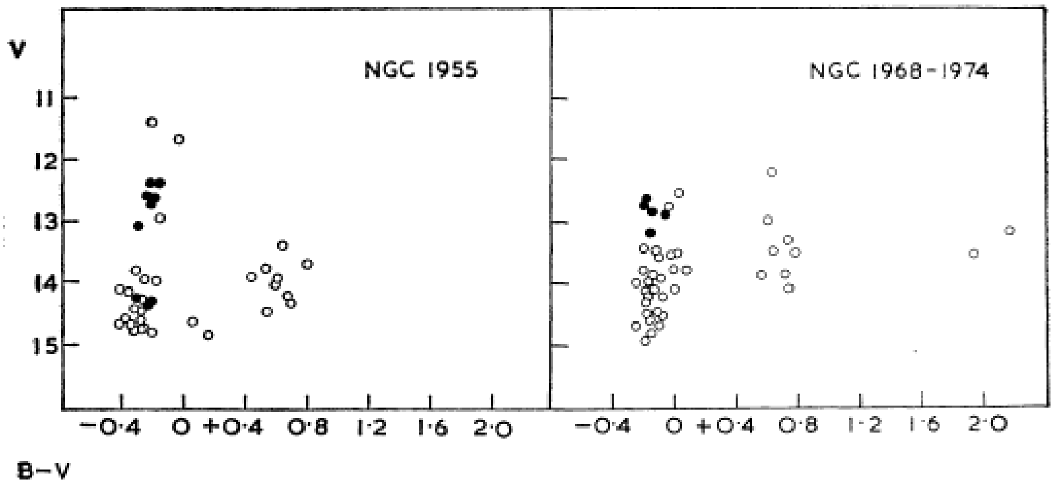


Figure 15: Colour-magnitude diagrams for NGC 1955 and NGC 1968-1974. Open circles represent photographic magnitudes and the filled circles the Mount Bingar photoelectric magnitudes (after Bok et al., 1962: 492).

> had to be taken in the execution of the photoelectric and photographic photometry. (Bok et al., 1962: 487).

The eleven stars subjected to photometric investigation at Mount Bingar ranged in *V* magnitude from 12.33 to 13.13, and the mean values for *B–V* and *U–B* were –0.22 and –0.17 respectively for stars in NGC 1955 and –0.97 and –0.91 respectively for stars in NGC 1968-1974. In an extension of the Mount Bingar study, 33 different stars in NGC 1955 and NGC 1968-1974 were subjected to photographic photometry at MSO using the 74-in reflector or the 20/26-in Uppsala Schmidt, and Bok et al. then combined the MSO and Mount Bingar data to produce the two colour-magnitude diagrams shown in Figure 15 (where the Mount Bingar stars are represented by filled circles). Bok et al. (1962: 492) noted that

> The two arrays exhibit the pattern which is by now familiar for Large Magellanic Cloud groupings, of very blue stars with colour indices mostly between –0.1 and –0.4 over the range $11 < V < 15$ and of a smaller number of stars with colour indices between +0.4 and +0.8. The absence of stars with colour indices between –0.1 and +0.4 is strikingly shown in these figures; the few stars which fall in the gap are most likely foreground stars or Magellanic Cloud field stars.

Following an August 1961 IAU Symposium at Santa Barbara (California), a decision was made to measure the integrated photometric magnitudes and colours of NGC 1955 and NGC 1968-1974, and observations were carried out over six nights in October 1961. After applying corrections for space reddening, Bok et al. derived the mean values listed above in Table 3.

Bok et al. (1962: 496; my italics) conclude their paper with the following pertinent remarks:

> It is quite evident that in the present study we are dealing with two very young stellar groups, whose probable ages since formation are almost certainly less than 10^7 years. These groups of young and luminous supergiants merit further study, in particular by extending the colour-magnitude arrays beyond the present limit of $V = 15$ to $V = 20$ or 21 and by eliminating foreground stars by means of future radial velocity and spectral studies. *In all of this work the great potential of (U–B) colours in addition to (B–V) colours should be realised.*

At the 1961 IAU Symposium in Santa Barbara, Dr B.E. Markarian (1913–1985) urged Bok and his MSO colleagues to measure the integrated magnitudes and colours of young associations in the LMC. Bart and Priscilla Bok responded by using the 26-in telescope at Mount Bingar to measure the 14 different associations listed in Table 4.

After applying a minor correction for absorption, Bok and Bok (1962: 443; their italics) concluded that "… through the use of these young associations, *readily identified by their UBV colour characteristics,* we are in a position to extend and make more precise the techniques of distance calibration suggested by Gum and de Vaucouleurs (2) and Sersic (3, 4) …" Furthermore,

> It should be a simple matter to locate and identify these young associations in galaxies at distances of the order of 6000 kiloparsecs. A large Schmidt telescope or modest reflector should permit the observer to establish their non-stellar appearance and, with $m = 18$, they should be within reach for photoelectric studies of their photometric properties in *UBV*. With the aid of large reflectors, and with refined photoelectric and photographic techniques, it should be possible to identify them with some certainty in galaxies as far distant as 25000 kiloparsecs. (ibid.).

Table 4: Mean integrated magnitudes and colours for OB associations in the LMC (after Bok and Bok, 1962: 438-439).

OB association	*V*	*(B–V)*	*(U–B)*
NGC 1770	9.06	−0.04	−0.96
NGC 1805	10.42	+0.06	−0.54
NGC 1814-1816-1820	8.80	+0.23	−0.60
NGC 1818	9.36	+0.16	−0.51
NGC 1929-1934-1935-1936-1937	8.46	−0.06	−0.99
NGC 1955	9.10	−0.18	−1.10
NGC 1968-1974	9.07	−0.17	−1.07
NGC 1962-1965-1966-1970	8.36	0.00	−0.84
NGC 1983	8.32	+0.11	−0.62
NGC 2004	9.07	+0.19	−0.64
NGC 2011	9.65	+0.05	−0.78
NGC 2014	8.61	+0.09	−1.00
NGC 2074	8.62	+0.06	−0.91
NGC 2100	9.08	+0.23	−0.50

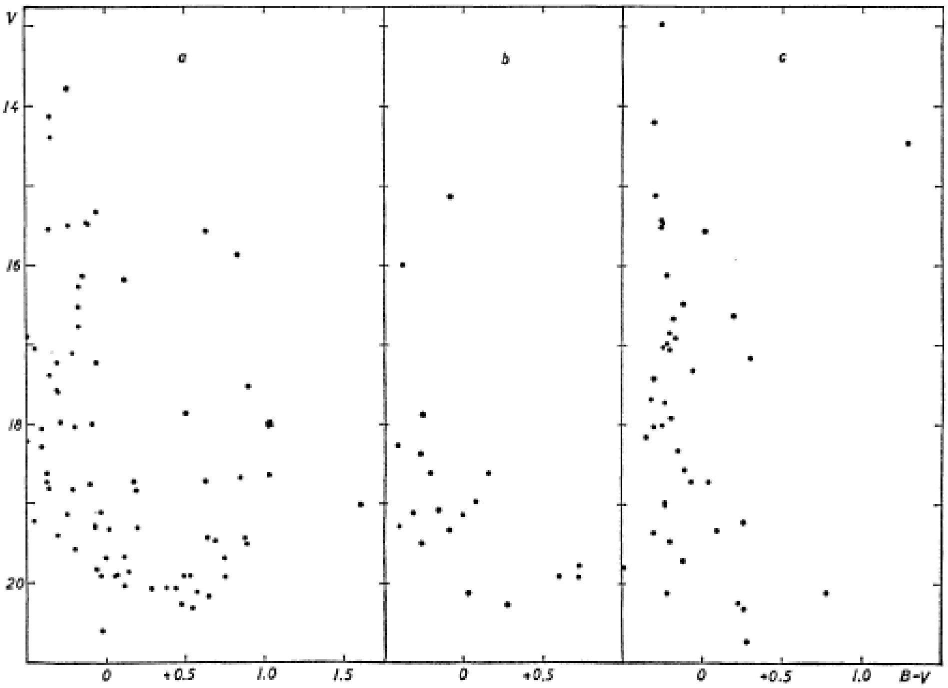


Figure 16: Colour-magnitude diagrams for NGC 602a, NGC 602b and NGC 602c respectively (after Westerlund, 1964: 439).

Complementing the Boks' study of young associations in the LMC was Westerlund's investigation of stars in the Wing of the SMC.

In Westerlund, Danziger and Graham (1963) they report on eight supergiants in the region of NGC 456-60-65 which were investigated to determine whether they were members of the SMC. *UBV* data obtained by Westerlund at Mount Bingar were combining with *Hβ* measures taken by Graham with the 50-in and 30-in telescopes at MSO. Spectroscopic observations were also made by Danziger at MSO. The authors concluded:

> It is evident from all our data that the eight stars are members of the Small Magellanic Cloud. They are all supergiant stars and have evolved away slightly from the zero-age main sequence … Our investigation also confirms previous results … that the Magellanic Cloud early-type supergiants are similar to those in our Galaxy.
>
> The present eight stars can hardly belong to a single association of normal size; if the distance of the Clouds is assumed to be about 55,000 parsecs, our stars No. 1 and No. 8 are about 2500 parsecs apart.
>
> However, it appears quite possible that the whole wing has an identical evolutionary history and, in spite of its size, may be treated as a unit. Judging from the present stars, its age is probably younger than 10^7 years. (Westerlund et al., 1963: 78-79).

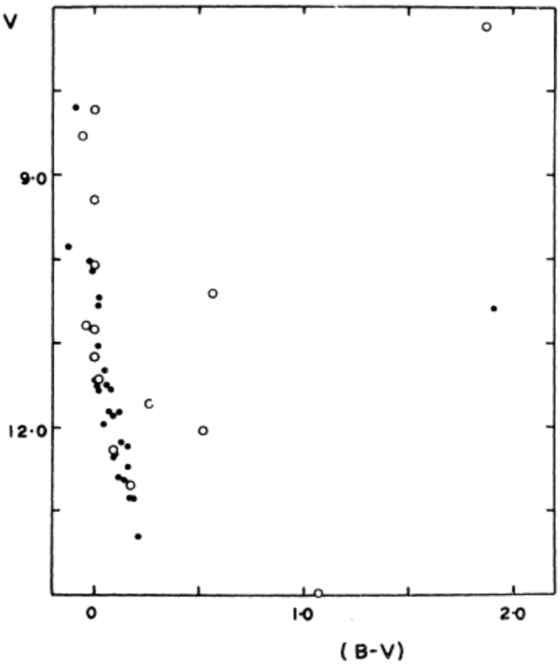


Figure 17: Colour-magnitude diagram for NGC 3766, uncorrected for absorption. The photometric observations are shown by open circles (after Sher, 1962: 64).

Westerlund (1964) followed up with a photometric study of three further concentrations of blue stars in the wing of the SMC, which he designated NGC 602a, NGC 602b and NGC 602c. *UBV* photometry was carried out at Mount Bingar on 26, 7 and 15 stars respectively in the three groups, and photographs were obtained at MSO with the 74-in reflector and the Uppsala Schmidt. Colour-magnitude diagrams were prepared for the three groups of stars and, as Figure 16 indicates, there is

> … a well-defined main sequence going vertically at about $B-V = -0.25$ mag. This blue mean colour indicates that hardly any interstellar absorption occurs in the region … the main sequence termination points in the diagrams all appear at about $V = 14$ mag. This value corresponds to an age of about 10^7 years … We conclude … [that] the blue field stars [in the wing of the SMC] and the concentrations NGC 602a, b and c form one association ... (Westerlund, 1964: 439-442).

Apart from the Magellanic Clouds, Bart and Priscilla Bok were also interested in young associations in our Galaxy. In Bok, Bok and Graham (1963) they discuss 17 OB stars that lie within one degree of *l* = 327° and *b* = 0°. When *UBV* data obtained by the Boks at Mount Bingar were combined with *Hβ* values obtained by

Graham with the 50-in reflector at MSO, Bok, Bok and Graham were able to identify two separate groupings of stars. Eleven stars of spectral type O or early B yielded a mean distance modulus of 12.0 ± 0.3, corresponding to a distance of 2,500 ± 300 parsecs. The authors noted that "… the dispersion of the individual distance moduli is small for this group. It is probable … that these stars form a physical system." (Bok, Bok and Graham, 1963: 517). The authors conclude that if the estimated distance was realistic, then this young association was situated in the Sagittarius spiral arm.

In a later study, Bok, Bok and Graham (1966) report on a *UBV* and *Hβ* photometric study of the I Scorpii association, which they describe as "… one of the most striking concentrations of blue supergiant stars to be found in the whole Milky Way ...." (Bok, Bok and Graham, 1966: 247). The Boks obtained most of the *UBV* measures with the 26-in telescope at Mount Bingar, while Graham made the *Hβ* observations with telescopes at MSO. Forty-three possible members of the association were investigated, and after corrections were made for interstellar absorption two different techniques were employed to derive the distance modulus of the group. Both values were similar, and the adopted mean value of 11.25 corresponded to a distance of 1,800 ± 200 parsecs. This result lay comfortably within the range 1,400-2,300 published by other researchers. Reflecting on their earlier LMC studies, Bok et al. (1966: 251) observed that

> It is instructive to note the general similarity between the I Scorpii group and the young associations in the Large Magellanic Cloud. At a distance of 55000 parsecs, the I Scorpii association would have an angular diameter of approximately 4′ by 2′. The brightest star in the association, ζ^1 Scorpii, would have an apparent magnitude of about 10.5, while there would be several stars in the group brighter than apparent magnitude 12.5. The HII ring would have an apparent diameter of about 8′. These general specifications can be applied to many of the young associations in the Large Magellanic Cloud.

John Graham, one of the authors of the two aforementioned studies, was a MSO doctoral student, and his thesis topic was "The Application of Hydrogen Line Photometry to Milky Way Research." Graham (1963) was particularly interested in early-type stars, and carried out *Hβ* photoelectric photometry with the 30-in and 50-in reflectors at MSO, but—as we have seen—in a number of published studies his photometric data were combined with those obtained by the Boks at Mount Bingar.

Graham (1965) also published a research note on the distances of the η Carinae and I Scorpii early type associations, on the basis of absolute magnitudes of seven Wolf-Rayet stars observed in *UBV* and *Hβ* at Mount Bingar and MSO. The absolute magnitudes of these stars ranged from –5.2 to –7.1 (with a mean of −6.4), and the derived distances of the η Carinae and I Scorpii associations were 2,800 parsecs and 1,800 parsecs respectively (ibid.; cf. Bok, Bok and Graham, 1966). Graham (1965: 197) makes an important point at the end of his short paper:

> It is interesting to note that Westerlund has found a mean visual magnitude of 12.63 for the Wolf-Rayet stars in the young associations of the Large Magellanic Cloud. Adopting an apparent distance modulus of 19.0 for the Large Cloud, the corresponding mean absolute magnitude for this particular class of Wolf-Rayet stars in −6.4, in good agreement with the present result.

This nicely complements the remarks made by Bok, Bok and Graham at the end of their 1966 paper.

Table 5: Data on five open clusters investigated by David Sher (1965).

Cluster	Stars observed at Mount Bingar	Distance (kpcs)	Age (yrs)
NGC 3496	3	1.1	10^9
NGC 3603	3	3.5	10^6
NGC 3766	9	1.9	10^7
Melotte 105	2	2.1	10^8
Trumpler 17	5	1.4	10^7

David Sher (1936–) was another doctoral student with an interest in galactic open clusters, and he wrote a thesis titled "Distances of Some Open Clusters near Eta Carinae" (Sher, 1963). In his first published paper (which he calls a "note"), Sher (1962) reports on the distance of NGC 3766, on the basis of *UBV* photometry carried out at Mount Bingar and with the MSO 50-in telescope and photographs taken with the Uppsala Schmidt. A colour-magnitude diagram was prepared and is shown here in Figure 17. The distance of the cluster was found to be 1,900 parsecs and the age ~10^7 years (Sher, 1962: 63).

Sher (1965) later used data obtained at Mount Bingar with the EMI photometer, along with readings from MSO, to investigate the ages of five open clusters located near η Carinae in the southern Milky Way. Table 5 lists the different clusters and the numbers of stars observed photometrically at Mount Bingar, while Figures 18 and 19 display colour-magnitude and two-colour diagrams for NGC 3603 and Melotte 105 respectively. In Figure 18 the solid line represents Blaaw's initial main sequence, adjusted for a colour excess of 1.42 and a distance modulus of 17.0, but

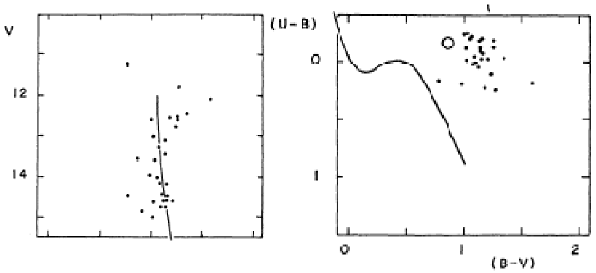


Figure 18: Colour-magnitude and two-colour diagrams for stars in the core of NGC 3603. The large open circle in the latter plot represents the integrated colours of the cluster (after Sher, 1965: 252).

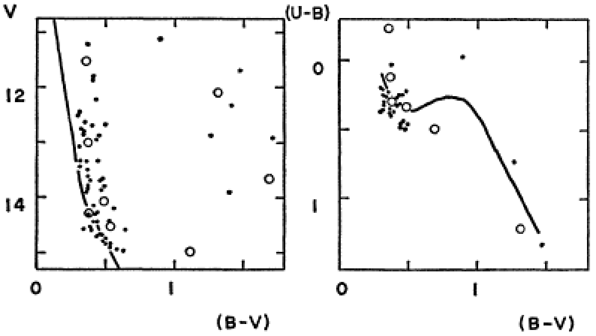


Figure 19: Colour-magnitude and two-colour diagrams for stars in Melotte 105 (after Sher, 1965: 256).

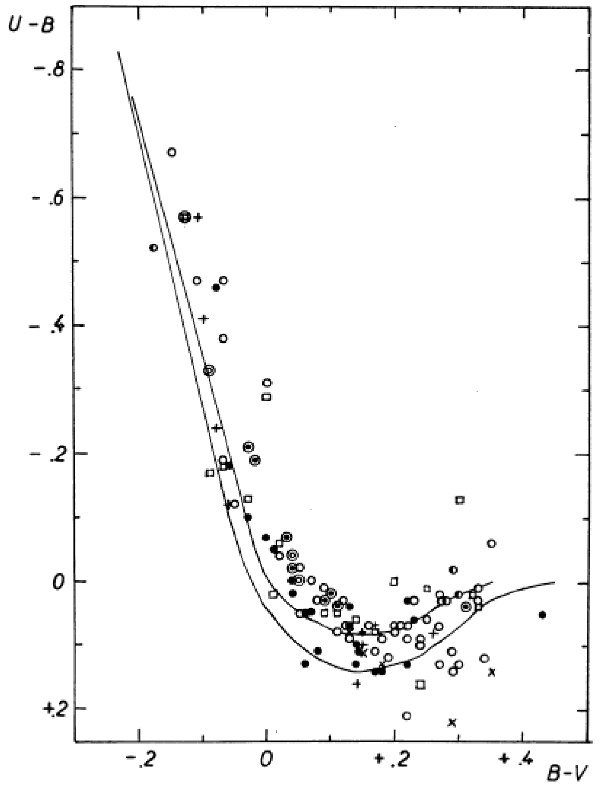


Figure 20: Two-colour diagram for stars near the South Galactic Pole (after Westerlund, 1963c: 93).

Sher points out that if the total absorption adopted throughout his paper is correct then the real distance modulus is 12.7. Meanwhile the solid line in Figure 19 is based on a colour excess of 0.38 magnitudes and a distance modulus of 12.7.

Derived ages and distances for the five clusters are included in Table 5.

Whilst all five asterisms listed in Table 5 were described initially as 'clusters', the scatter of points in the colour-magnitude and two-colour diagrams prepared for NGC 3496 and Trumpler 17 led Sher (1965: 260) to raise doubts about these two groupings:

> If Tr 17 is merely a chance collection of field stars, NGC 3496 must either be a cluster or a sample of field stars of an entirely different character as shown by the occurrence of so many red stars. If NGC 3496 is a cluster, and if it does indeed contain the red stars shown in Figure 14 [in his paper], it has a remarkably richly populated branch of K giants. It would nevertheless be advisable to await further proof of their reality as clusters before accepting any particular interpretation of the observations.

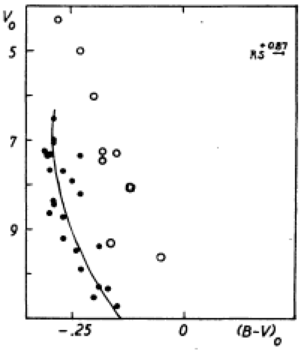


Figure 21: Colour-magnitude diagram for OB stars near RS Puppis. Dots represent members of the association and open circles field stars. RS Puppis is indicated by the star (adapted from Westerlund, 1963a: 76).

The Uppsala Schmidt observer, Bengt Westerlund, was another Stromlo astronomer who used the Mount Bingar facility to investigate OB associations and early-type stars in our Galaxy. After observing stars near the North Galactic Pole he turned his attention to the southern sky and carried out *UBV* photometry of 110 B- and A-type stars near the South Galactic Pole. The project was started when the Catts Telescope was still sited at Mount Stromlo, but continued at Mount Bingar. In addition, a few observations were made with the 30-in reflector at MSO. A two-colour diagram was prepared and is shown in Figure 20. The two lines delineate the distribution of the stars near the North Galactic Pole; the very different pattern for the South Galactic Pole stars is explained by blanketing effects and the presence of interstellar reddening in the southern region (Westerlund, 1963c: 93).

Westerlund (1963a) then carried out a study of RS Puppis and nearby OB stars, drawing on spectra obtained with the 20/26-in Uppsala Schmidt at MSO and *UBV* photometric data obtained at Mount Bingar. The initial photometry was carried out with an EMI photomultiplier tube, but this was later replaced by an RCA 1P21 tube. Thirty-one stars were observed, and when a colour-magnitude diagram was prepared (see Figure 21) all but 8 of these were seen to be members of an OB association. The distance modulus of this association was 11.2, corresponding to a distance of 1,700 parsecs.

Westerlund also used the Mount Bingar telescope to conduct *UBV* photometry on the Cepheid variable, RS Puppis, deriving the light curve shown in Figure 22 (where the cross and open circles represent observations made by other astronomers). Photometric properties of the star are listed in Table 6. A mean absolute magnitude of −6.1 was derived on the basis that the variable is also a member of the OB association, and this is in close accord with the value of −5.8 based on the period-luminosity relations of Cepheids in the LMC and SMC. RS Puppis and the OB stars form an association, and

> … are situated in a volume of space which is rich in dust as well as gas. The age of the association is about 4×10^6 years … [and] The Cepheid is probably the most evolved star in it. It appears quite likely that stars not yet on the main sequence or even in the stage of formation may be found in the region. (Westerlund, 1963a: 80).

Finally, in a paper presented at an international conference in Indonesia, Westerlund (1963b) reviewed his recent studies involving Mount Bingar photometry with the 26-in telescope and low dispersion spectroscopy with the 20/26-in Uppsala Schmidt at MSO.

After the Boks, Antoni Przybylski (1913–1986) and his MSO colleague Pamela Kennedy were the next most productive MSO astronomers to use the Mount Bingar 26-in telescope for astrophysical research. Their primary interest was in high velocity stars, and their overall aim was to secure data on 500-600 southern stars, thereby extending to the southern hemisphere a similar northern sky survey that had been carried out by N. Roman. In their second paper in this series, Przybylski and Kennedy combined spectra taken at

MSO on the 74-in reflector with *UBV* photometric measures made at Mount Bingar and reported observations of 52 southern stars with unusually large proper motions. Fifty-six percent of these showed ultra-violet excesses >0.10, indicating they were subdwarfs (Przybylski and Kennedy (1965a: 68). Twelve of the stars in the survey were early-type stars (i.e. with spectra up to F0), and most of these had low radial velocities. Two of these stood out: one was "… a peculiar A0 star with strong lines of strontium and chromium and … [the other was] a metallic line star with strengthened lines of the same elements. Other early type stars show no spectral peculiarities." (ibid.).

In the next paper in the series, Przybylski and Kennedy (1965b) present a long table listing spectral classifications and radial velocities for 127 high velocity southern stars and 39 low velocity stars. *UBV* measures—mostly taken with the Mount Bingar 26-in and the EMI photometer—are included for 149 of these stars, and the Australian photometric results are compared with data published by other researchers.

The last project Przybylski carried out with the Mount Bingar telescope was an investigation of HD 176387, which in the course of the southern high velocity survey was found to be a variable star. However, *UBV* observations made at Mount Bingar in 1961-1963 "…were insufficient for the determination of either the period or the light curve." (Przybylski, 1967: 185), and this information only became available when subsequent observations were carried out with the 30-in Reynolds reflector at MSO. HD 176387 proved to be the brightest-known c-type RR variable, with a period of 0.316899 days and an amplitude of $V = 0.6$, from 8.68 to 9.28 (ibid.).

A fourth graduate student who used the Mount Bingar telescope for doctoral research was the late Don Faulkner (1937–2004), whose thesis was titled "A Study of the 30 Doradus and Eta Carinae Nebulae" (Faulkner, 1963).

Unlike other MSO staff and students, Faulkner worked in collaboration with visiting Postdoctoral Fellow Lawrence Aller (1913–2003) to carry out photoelectric spectrophotometry with the 26-in telescope; some observations were also conducted with the 30-in and 50-in reflectors at MSO. The spectrophotometer had been constructed by William Liller (1927–), and was on loan from the University of Michigan. Aller et al. (1966: 1074) discuss the advantages of this type of instrument:

> A spectrum scanner has certain advantages for measuring monochromatic magnitudes. First, a precise wavelength internal λ_1 to $\lambda_1 + \Delta\lambda$ can be selected so that the effective wavelength is firmly fixed, regardless of spectral class. Second, the very nearly rectangular character of the "transmission function" involved makes it easy to interpret the measurements, particularly if scanner tracings are supplemented by slit spectrograms, so that the energy subtracted by absorption lines from the star's continuum can be properly measured. Third, since no integration over a long-wavelength interval is involved, atmospheric extinction coefficients can be accurately determined. Fourth, it is possible (Willstrop 1960) to calibrate the monochromatic magnitudes in units of flux, a task which is much more difficult for broad-band-pass measurements.
>
> A significant advantage of the spectrum scanner is that one can select the wavelength λ and interval Δλ, or one can scan the entire spectrum. A variety of slot and diaphragm sizes provides flexibility to the entire program. In studies of gaseous nebulae, for example, precise line ratios can be measured, and one can determine surface brightnesses in monochromatic radiations …

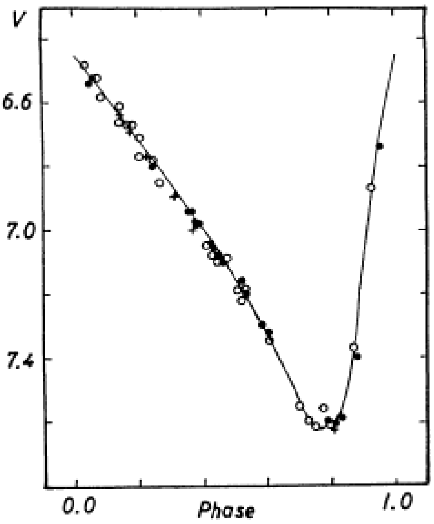


Figure 22: V light curve for RS Puppis (after Westerlund, 1963a: 78).

Table 6: Photometric parameters of RS Puppis (after Westerlund, 1963a: 79).

Parameter	*V*	*B–V*	*U–B*
Maximum	6.45	+1.10	+0.80
Minimum	7.62	+1.73	+1.79
Amplitude	1.17	0.63	0.99

Faulkner, of course, *was* interested in gaseous nebulae, and in 1965 he and Lawrence Aller published a paper about the prominent southern galactic nebula, η Carinae, and about 30 Doradus in the LMC. However, the Mount Bingar telescope was only used to establish line intensities for η Carinae. The resulting values, after correction for interstellar absorption using Whitford's (1958) reddening curve, are listed in Table 7. By using the values for [OIII] shown here, and an [OIII] figure for λ4363 derived from MSO observations, Faulkner and Aller (1965: 400) found a value of 620cm^{-3} for the electron density (N_e) of η Carinae and 10,200 ± 700 K for its electron temperature (T_e). They also concluded (ibid.: 402) that collectively the O^{+} and O^{+2} ions accounted for ~90% of all oxygen in this nebula, and they obtained an oxygen abundance, N(O)/N(H), of $1.8 \pm 0.6 \times 10^{-4}$.

Later in their paper, Faulkner and Aller (1965: 405) used corrected line intensities for Hγ, [OII] at λ3726 and λ3729, and [OIII] at λ4959 and λ5007 obtained

Table 7: Relative line intensities for η Carinae (adapted from Faulkner and Aller, 1965: 398).

Element	λ (Å)	Intensity (corrected)
[OII]	3726	86
[OII]	3729	89
H	3970	18.5
H	4102	27.5
H	4340	47.6
H	4861	100
[OIII]	4959	66
[OIII]	5007	200

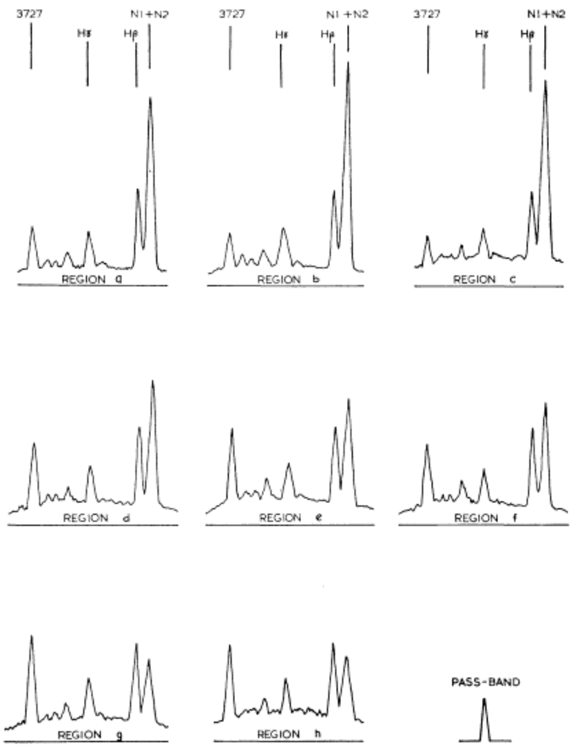


Figure 23: Low resolution spectral scans of eight different regions in Eta Carinae (after Faulkner and Aller, 1965: 396).

from the low resolution spectrograms shown in Figure 23 to calculate the electron temperature (T_e) at eights different locations within the η Carinae nebula. The derived values showed little variation, ranging from 9,600 to 10,400 K.

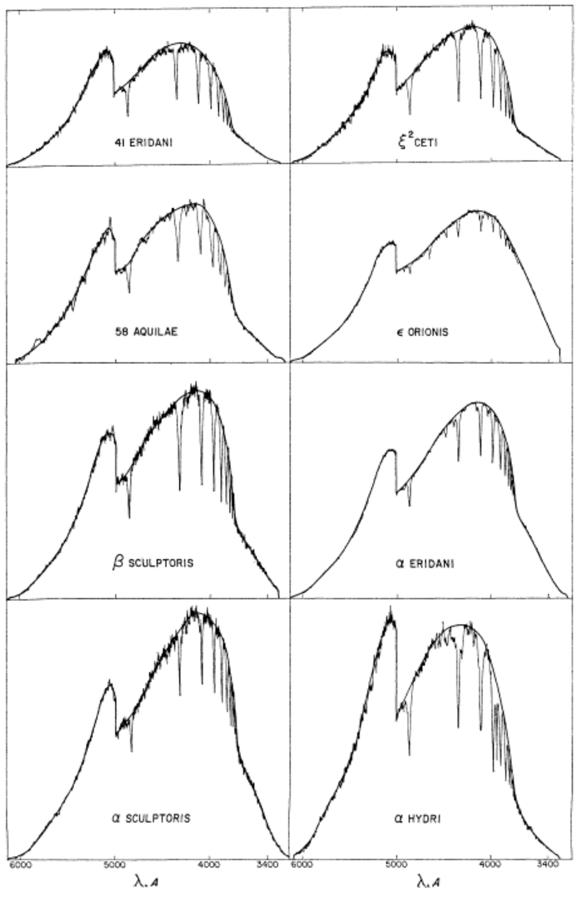


Figure 24: Spectral scanner tracings for selected southern stars made at Mount Bingar and/or MSO in 1960-1961 (after Aller at al., 1966: 1079).

In addition to their spectrophotometric investigation of η Carinae, Faulkner and Aller wanted

> … to establish a number of Southern Hemisphere stars as spectrophotometric standards, to measure the energy distributions in a number of stars of special interest (e.g., ζ Puppis, γ Velorum, and η Carinae), and to tie our spectrophotometric system as closely as possible to the system established in the Northern Hemisphere. (Aller, Faulkner and Norton, 1966: 1075).

Consequently, between 28 September 1960 and 16 March 1961 Aller teamed with Faulkner and R.H. Norton (1966) and they used the Mount Bingar telescope to examine the spectral-energy distributions of selected southern stars. They also carried out comparable observations with the 50-in reflector at MSO in August 1961 and from 20 December 1961 to 11 February 1962. In Table 2 in their paper Aller et al. (1966: 1077) list the spectral type, *V* magnitude, *B–V* and *U–B* colours and other values for the 28 stars observed at Mount Bingar and MSO, and in Figures 2-4 they reproduce the actual spectral tracings for 24 of these stars (e.g. see Figure 24), but nowhere do they identify which of the 28 target stars were actually observed at Mount Bingar.

Another MSO graduate student to use the 26-in reflector at Mount Bingar was Robert Shobbrook (1937–; see Figure 13) who in 1963 submitted a Ph.D. thesis titled "Photographic, Spectrographic and Photometric Studies of Southern Galaxies."

UBV photometric observations of 43 southern galaxies in Centaurus, Dorado, Grus and Telescopium were conducted at Mount Bingar with the 26-in telescope, one galaxy was observed at MSO with the 50-in reflector and nine galaxies were observed with both telescopes (Shobbrook, 1966a). During the 2.5-yr observing period, the following photomultipliers were used at Mount Bingar: an EMI type 5 659, 11 stage 950 V; an EMI 9 524S. 11 stage, 900 V; and a Lallemand blue sensitive, 19 stage, 1,300 V. For these observations, the 26-in telescope was used near its limiting magnitude of ~14 (Shobbrook, 1966a: 361).

Shobbrook (ibid.) also noted that

> … there was a significant dependence of the mean errors of observation on magnitude … Galaxies measured 2, 3, 4 or 5 times were used in the determination of the errors in the 10th, 11th, 12th and 13th magnitude intervals. The mean errors from one observation range from ±0.02 mag at the 10th magnitude to ±0.05 mag at the 13th magnitude in *V* and *B– V*, and from ±0.03 to … as high as ±0.10 mag [in *U–B*].

After correcting for interstellar absorption, Shobbrook produced scatter diagrams of $(U–B)_c$ vs $(B– V)_c$ for all of the observed elliptical and S0 galaxies (see Figure 25) and for spiral galaxies (Figure 26). The globular cluster NGC 6752 is also included in Figure 25. Because of the larger uncertainty in the Centaurus (*U–B*) colours and the large corrections for galactic absorption and redshift these galaxies (Cen E and Cen S0) are distinguished in Figure 25 from those galaxies for which more accurate data are available. The thin lines in Figures 25 and 26 connect points for different diaphragm measures of the same galaxy, with the direction of the arrow indicating increasing aperture, while the curved lines show the mean relations found previously by de Vaucouleurs (1961) and Hodge (1963) for comparable types of northern galaxies. These diagrams show that the galaxies observed from Mount Bingar and MSO do not differ appreciably from comparable galaxies in the northern sky, but Shobbrook (1966a: 363) offers a final word of warning: "However … observations should [also] be made of northern and southern galaxies using one telescope and photomultiplier, in order to check that all the galaxies are on the same system."

In yet another paper, Shobbrook (1966b) draws on photometric data in the above-mentioned paper and MSO spectral data presented in an earlier paper to examine the distances of the 53 southern galaxies, using the distance of the Virgo cluster for comparison. The southern galaxies were assumed to belong to four discrete clusters of galaxies located in Centaurus, Dorado, Grus and Telescopium, and their distances—after correction for galactic absorption—were calculated as 21.2 ± 3, 8.8 ± 0.2, 14.1 ± 1.1 and 15.9 ± 1.5 Mpc respectively. While these values were seen to be 'state-of-the-art' at the time, we now know that the distance to the Virgo cluster is ~16.5 Mpc (Mei et al., 2007) not the value of 9.7 Mpc adopted by Shobbrook.

Apart from MSO staff and graduate students, at least one visiting astronomer also used the Catts Telescope while it was at Mount Bingar. During an 8-month visit to MSO Gerald Kron (1913–) from the Lick Observatory used the 74-in, 50-in and 30-in telescopes at MSO in his research on southern Cepheids, but between October 1960 and April 1961 he also visited Mount Bingar and used the Catts Telescope and the RCA 7102 photometer to observe *l* Carinae, *β* Doradus, *κ* Pavonis and W Sagittarii (Breckinridge and Kron, 1963). This project was designed to extend his study of colour excesses in northern Cepheids to the Southern Hemisphere.

By the time Faulkner, Graham, Sher and Shobbrook completed their Ph.D.s, they and the astronomers at MSO not only had access to the 50-in reflector at MSO, but the 74-in reflector was also fully operational. This to some extent took the focus away from the 26-in reflector at Mount Bingar, and the decision to site the MSO outstation at Siding Spring Mountain in northern New South Wales rather than at Mount Bingar effectively sounded the death-knell for this particular telescope which, up to that point, had been regarded by MSO staff and graduate students as a useful complement to the MSO 50-in for *UBV* photometry.

4.3 The Fate of the Catts Telescope

Initially, the intention was that the Catts Telescope would remain at Mount Bingar and continue to play a role in astrophysical research—with a smaller primary mirror (Bok 1961)—but a decision was later taken to renovate the instrument so it would "… be ready for erection on Siding Spring Mountain *should demand warrant this*." (Bok, 1963: 233; my italics).

When the Mount Bingar field station was closed in 1963 the 26-in telescope was dismantled and the mirror was returned to the Fund for Astrophysical Research. Bok (1964: 253) then announced that "New optics for this telescope are being ordered … [so that it can] be moved to Siding Spring Observatory." However, this course of action was reversed the following year when it was decided that a 24-in Boller & Chivens reflector would be ordered for Siding Spring Mountain in place of the revitalized Catts Telescope, and that this new instrument would be dedicated to the study of polarization of starlight (Bok, 1965).

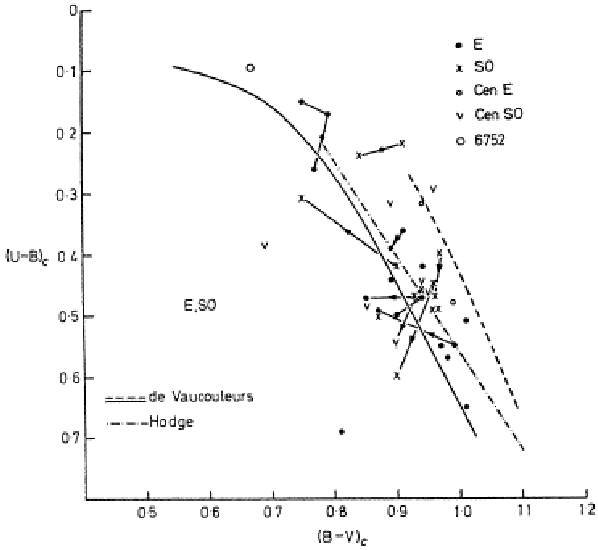


Figure 25: Scatter diagram of $(U\!-\!B)_c$ vs $(B\!-\!V)_c$ for elliptical and S0 galaxies (after Shobbrook, 1966a: 361).

With the imminent arrival of the new Boller & Chivens reflector there was no further need for the Catts Telescope, and MSO decided to donate it (minus the original 20-in mirror) to the University of Western Australia in Perth.

5 THE PERTH YEARS

After the acquisition of a new 16-in (40.6-cm) mirror, the new-look Catts Telescope was fabricated in the workshop of the Physics Department under the direction of Dr S.E. Williams (1919–1979) (Burman and Jeffery, 1992).

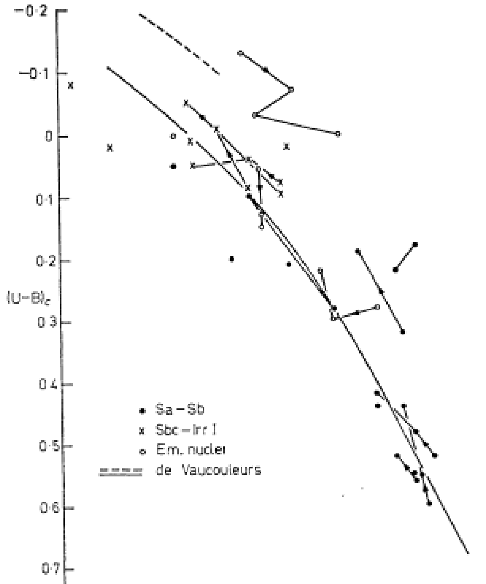


Figure 26: Scatter diagram of $(U\!-\!B)_c$ vs $(B\!-\!V)_c$ for spiral galaxies (after Shobbrook, 1966a: 362).

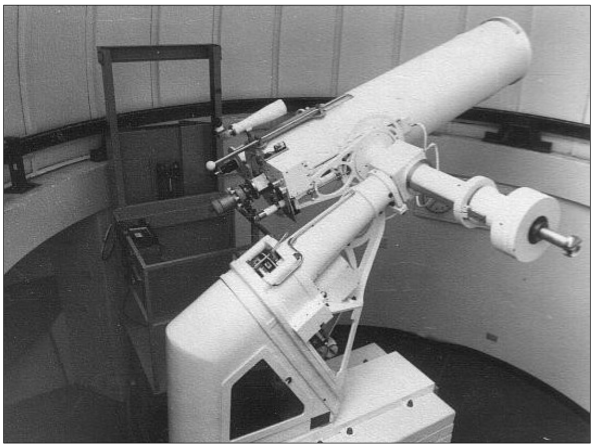


Figure 27: The refurbished 16-in Catts Telescope at Perth Observatory (Orchiston Collection).

The intention was to produce an instrument that could be used for photometric and spectroscopic research (Hunter, 1976), and in 1969 the completed telescope (Figure 27) was installed in a new dome at the Perth Observatory (*Review of Observatories*, 1978). Figure 28 shows this dome. Williams then used the telescope intermittently for photoelectric photometry of variable stars (Figure 29) from 1969 up until his retirement in 1975 (Burman *et al*., 1990), but it saw little use after this except on occasions by Perth Observatory staff and students from Murdoch University.

Two undergraduate students from the University of Western Australia used the telescope during the 1985-86 apparition of Comet 1P/Halley, and this led to a revival of research interest in the telescope from staff at that University and it was used in July-August 1987 to obtain photoelectric observations of flares on Proxima Centauri with the aid of a Gencom Starlight Photometer on loan from the Perth Observatory (Kroupa et al., 1989).

The plan then was to automate the telescope and use it for systematic supernova searches, but when observing time became available on the Perth Observatory's 24-in Boller & Chivens reflector in 1987 the program was transferred to that instrument. This successful program involved astronomers from the Observatory, the University of Western Australia, Curtin University and Murdoch University, operating under the acronym PARG (the Perth Astronomy Research Group), a collaboration that was formally established in 1988 (see Burman *et al*., 1990).

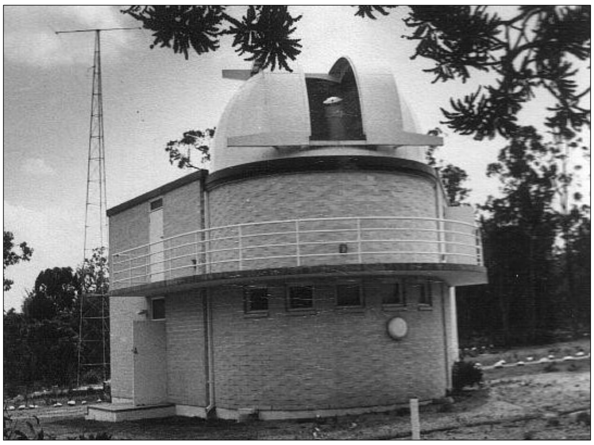


Figure 28: The Catts Telescope in its new dome at the Perth Observatory (Orchiston Collection).

The transfer of the supernova search program to the 24-in telescope ended the research role of the Catts Telescope, and in 1998, when Perth Observatory required the dome for a new telescope, the University decided to formally donate the 16-in reflector to the Observatory. The telescope was then removed from the dome and placed in storage. In 1999, James Biggs and Peter Birch reported that this telescope "… will be refurbished, as workshop time allows, and employed in the public star viewing sessions." They emphasized that upgrading the instrument to automatic operation was not a viable option as it would require a complete rebuild of the mounting.

6 DISCUSSION

6.1 The Research Potential of Small Reflectors

During the nineteenth century, prior to the emergence of astrophysics, telescopes with apertures comparable to and even considerably smaller than the Catts Telescope were eagerly acquired by professional observatories and amateur astronomers, and were used effectively for research (e.g. see Orchiston 1985; 1992; 2004b). However, the advent of astrophysics changed all this, and 'aperture-fever' and the quest for increasingly more sophisticated instrumentation permeated professional astronomy (e.g. see van Helden, 1984).

Nonetheless, even as recently as the 1950s and 60s modest instruments like the Catts Telescope were still capable of producing valuable results if placed in the hands of competent astronomers and directed towards viable research projects (such as those based on photoelectric photometry). This is clearly evidenced by the use of the Catts Telescope when it was located at MSO, and even though its transfer to Mount Bingar—complete with expanded optics—was primarily for site survey purposes, whilst there it also was able to fulfill an important research role. Without ongoing access to this telescope the research programs of a number of MSO staff and Ph.D. students would have been seriously compromised.

6.2 Glass' Master List of Grubb Telescopes

South African astronomer Ian Glass (1939–) has researched Grubb telescopes worldwide, and in 1997 published an invaluable book titled *Victorian Telescope Makers: The Lives and Letters of Thomas and Howard Grubb.* This book includes a master list of Grubb telescopes in decreasing order of aperture, and data are presented on three different 20-in reflectors:

1) Isaac Roberts' well-known twin 20-in reflector/7-in refractor, which was used for pioneering astronomical photography (e.g. see McNally and Hoskin, 1988; Roberts, 1893).
2) A speculum-metal reflector which was made in about 1851 and erected in Glasgow, Scotland.
3) The 16.5-in Grubb reflector made in about 1887 and transferred to Poona, India. In 1894 the original mirror was replaced by a 20-in figured by A.A. Common. In 1912 this instrument was transferred to the Kodaikanal Observatory.

Conspicuously missing from this list is the 20-in Catts Telescope, and it is to be hoped that data presented in this paper will justify its inclusion when a revised edition of Glass' book is published.

7 CONCLUDING REMARKS

The Catts Telescope was manufactured a little over a century ago, and witnessed three distinct phases of ownership. During the 'Amateur Era', which extended to 1952, its research potential was largely squandered, even though it had the potential to contribute in a meaningful way to science if placed in capable hands and directed to viable research projects.

The 'Stromlo Era' lasted from 1952 to 1963 and during this 12-yr interval the Catts Telescope was first used at MSO in its original 20-in Cassegrainian configuration and from December 1959 as a refurbished 26-in Cassegrainian reflector at the Mount Bingar field station. During the critical 'Stromlo Era' the Catts Telescope was used very effectively by ten MSO astronomers and visiting astronomers and by five different Ph.D. students for photometry or spectrophotometry of stars in our Galaxy and for photometry of clusters of southern extragalactic nebulae. These investigations resulted in the publication of twenty-six research papers based *in toto* or in part on observations made with the Catts Telescope, and these were published mainly in *The Astronomical Journal*, *The Astrophysical Journal*, *Monthly Notices of the Royal Astronomical Society*, *The Observatory* and *Publications of the Astronomical Society of the Pacific*. Apart from its valuable contribution to astrophysics, while at Mount Bingar the Catts Telescope also was the mainstay of the site-survey program that led ultimately to the establishment of a MSO outstation at Siding Spring Mountain.

The Mount Bingar field station was closed in 1963, thus ending a 12-yr period during which the Catts Telescope had been used extensively for photoelectric photometry. In the light of this record of achievement it is surprising that its research role is not mentioned in some historical papers about the Observatory (e.g. see Gascoigne, 1984; 1992; Hyland and Faulkner, 1989).

The final phase in the history of the Catts Telescope is the 'Perth Era', which extends from about 1965 to 1999. During this period, the refurbished 16-in Catts Telescope was based at Perth Observatory but was only used intermittently for astrophysical research. Finally, the telescope was removed from its dome in 1999 and placed in storage, thus ending a century of service to science, first in a primarily educational and recreational role, and later, during the 'Stromlo Era' as an instrument that made a meaningful contribution to Australian astronomy and to international astrophysics. In this context, the Catts Telescope certainly deserves to be included in the next edition of Glass' book on historic Grubb telescopes.

8 NOTES

1. An abbreviated version of this paper titled "The Role of the 'Catts Telescope' at Mount Stromlo and Mount Bingar: A Southern Hemisphere Analog to the Crossley Reflector" was presented at the Donald E. Osterbrock Memorial Symposium which was held at the University of California, Santa Cruz, on 2-3 August 2007. In utilizing this title, Dr William Sheehan (one of the Symposium organizers) and I wanted to pay homage to Don Osterbrock's long association with the Lick Observatory and his recognition that telescopes of modest aperture—like the 20-inch Catts Telescope and the 36-inch Crossley Reflector—were (and indeed still are) capable of being used for serious research. This paper is a companion paper to the contributions by Sheehan (2008), Misch (2008) and Pearson and Orchiston (2008) from that Symposium, which were published in the March 2008 issue of this journal.
2. Westerlund was in charge of Uppsala University's Southern Station at Mount Stromlo, which boasted a 20/26-in (50.8/66.0-cm) Schmidt.

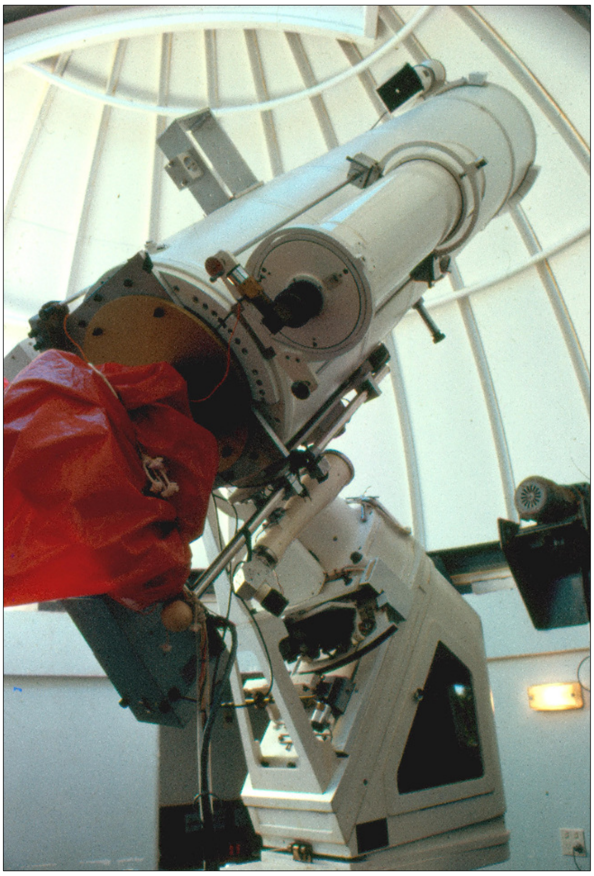


Figure 29: A later view of the Catts Telescope at Perth Observatory, complete with photoelectric photometer and a large new guide scope (courtesy: Graeme White).

3. Apart from Wood and Eggen, according to the Annual Report of the Observatory for 1952 (Woolley, 1953a), another overseas visitor to MSO was Professor J. Schilt (1894–1982) from Columbia University who arrived to spend about a year at MSO, "… making arrangements for the Yale-Columbia station and carrying out photoelectric observations of colours of southern stars." Later in 1952 he was joined by Cyril Jackson (1903–1988). In the next annual report, Woolley (1954a) writes about the acquisition of the Catts Telescope, and that this instrument was "… made available for a considerable part of the year to the Yale-Columbia observers, Professor Schilt and Mr. J. Jackson [sic.]." It is therefore surprising that an ADS search of publications by Schilt and Jackson for the period 1952-1969 (inclusive) failed to produce even a single paper incorporating Catts Telescope observations.
4. This coincides with John Graham's recollections: "When I was a summer student in 1957-58, Frank

Bradshaw Wood used it [the Catts Telescope] a lot and I remember spending a number of hours there while he was mumbling into his finding charts." (pers. comm., April 2002).

5. For some unknown reason Sher (1962: 63) erroneously gives the aperture of the Mount Bingar reflector as 36 inches.

9 ACKNOWLEDGEMENTS

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Finally, I wish to dedicate this paper to the two Dons: Faulkner and Osterbrock. Before he died, Don Faulkner took a personal interest in my Catts Telescope Project, chasing up photographs and information for me from the Stromlo archives (in the period before the disastrous January 2003 fire) and from a number of retired staff members; he also read the first draft of this paper and supplied many useful comments. For his part, the late Don Osterbrock was an unstinting supporter of the *Journal of Astronomical History and Heritage*, and his interest in and papers on historic telescopes were a constant source of inspiration to me. Don was very aware that 'modest' telescopes were capable of making valuable research contributions if placed in the right hands, and I know that he would have enjoyed learning about the Catts Telescope had he been in a position to attend the Santa Cruz Symposium.

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Wayne Orchiston is an Associate Professor in the Centre for Astronomy at James Cook University, Townsville, Australia. His main research interests relate to Cook voyages, Australian, English, French, New Zealand and U.S. astronomical history, with emphasis on the history of radio astronomy, comets, historically-significant telescopes, early astronomical groups and societies, nineteenth century solar physics, and transits of Venus. He is a member of the IAU Working Group on Historical Instruments and Vice-Chairman of the IAU Working Group on Historic Radio Astronomy, and has published numerous papers on notable Australian and New Zealand optical and radio telescopes.

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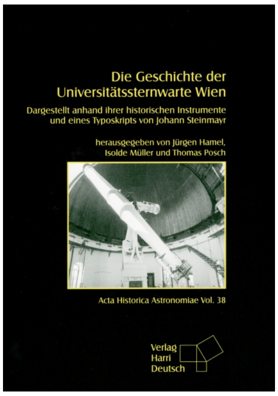
BOOK REVIEWS

***Die Geschichte der Universitätssternwarte Wien. Dargestellt anhand ihrer historischen Instrumente und eines Typoskripts von Johann Steinmayr,* herausgegeben von Jürgen Hamel, Isolde Müller und Thomas Posch. Acta Historica Astronomiae 38. (Frankfurt am Main, Verlag Harri Deutsch Gmb, 2010), pp. 324, appendices, index, ca. 150 illustrations, ISBN 978-3-9171-1865-6 (softcover), €29.80, 210 x 150 mm.**



For someone looking for the definitive history of Vienna University Observatory, this book will be a disappointment. For others, looking for building blocks for such a history, the book is a treasure chest.

Essentially, this book consists of two parts. The first one is an inventory of historical instruments, kept almost exclusively at the museum of Vienna Observatory. Telescopes of the last four centuries, meridian circles, theodolites, photometers, spectrometers, measuring engines, clocks etc. are shown in black and white photographs, and their manufacturers and provenance are described—150 items in total. A short list of modern instruments, as well as an index of manufacturers, completes this section. An online inventory (with colour photos) is in preparation.

The second part is the edited version of a set of manuscripts used for lectures by the Jesuit, Johann Steinmayr (1890–1944), in the 1930s. No astronomer by profession, he was a clockmaker by training, and had not only studied philosophy and theology but had also taken courses in the natural sciences. He became a priest in Vienna in that part of the city near the Observatory; later he worked in Linz and Innsbruck, where he was a member of scientific circles. After Austria was annexed to Nazi Germany in 1937, he became a member of a resistance group. Arrested in 1943, he was sentenced by the 'People's law court' in Berlin and was executed shortly afterwards.

After a biographical sketch of Father Steinmayr by Nora Pärr, the book contains seven carefully-edited lectures by Steinmayr. They deal with the first Jesuit Observatory, the old Vienna University Observatory, the Vienna University Observatory in the nineteenth century (in two parts), the meteorological research of the eighteenth century astronomer Anton Pilgram, a collection of anecdotes, and finally, a lecture on instruments, measurements and finances of the old Vienna Observatory.

The authors—astronomy historian Jürgen Hamel (Berlin) and the Vienna astronomers, Isolde Müller and Thomas Posch—have produced a very informative source book on astronomical history and heritage.

Professor Hilmar W. Duerbeck
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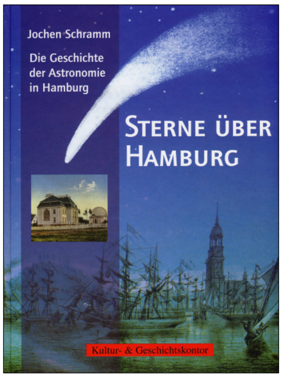
***Sterne über Hamburg - Die Geschichte der Astronomie in Hamburg,* by Jochen Schramm, with contributions by Gudrun Wolfschmidt, Dieter Engels and Matthias Hünsch. (Kultur- und Geschichtskontor, Hamburg 2010), pp. 333, ca. 334 illustrations, ISBN 978-3-9811271-8-8 (hardcover), €24.80, 270 x 205 mm.**



The first edition of Jochen Schramm's book, *Stars over Hamburg,* appeared in 1996, and since then the author has put large sections of it on the Internet. During my historical research, I was surprised how often I was led to these web pages in order to find some useful information that I had been looking for. Now the author has prepared a second revised edition, which updates the history from 1968 to about 1990 and contains additions on many earlier aspects. For example, a new access to the Zeiss Jena company archives permitted the author to include more technical facts and photographic documents of the Hamburg Observatory instrumentation.

The format has also been improved: it is now an attractive hardcover volume (see the above photograph), with some pages in colour, and prefaces by Hamburg's Senator of Culture and the President of the German Foundation of Monument Protection. There is also a plea by Professor Gudrun Wolfschmidt from the Institute for History of Science, Mathematics and Technology at the Hamburg University to include the Observatory as a UNESCO world heritage monument.

The book starts with astronomical and related events observed in Hamburg since the fifteenth century, with calendar-makers and globe-manufacturers, and continues with the astronomers of the eighteenth and nineteenth centuries, like Johann Elert Bode and Franz Encke. The activities of the instrument-maker and astronomer Johann Georg Repsold led to the founding of the first state observatory at the Millerntor (1825/1831). Parallel to these activities, the nearby Altona Observatory was run by Heinrich Christian Schumacher, the founder of the journal *Astronomische Nachrichten.* Christian Karl Ludwig Rümker, his son George Rümker, and later Richard Schorr, all became Directors of the Hamburg Observatory. While the small Altona Observatory closed in 1872 and was transferred to Kiel University, Hamburg Observatory was moved to the suburb of Bergedorf, on the outskirts of Hamburg, in 1912. With modern and large instruments, the Observatory then reached its prime, with Walter Baade as one of the observers, and Bernhard Schmidt as the optician. Very informative chapters follow on the Nazi times and the new start after the war, when Otto Heckmann was its Director (before he became the first Director General of ESO). A concluding chapter on present-day activities was contributed by Dieter Engels.

In addition to the purely astronomical activities, Schramm has also collected information on the history of the Seewarte (Naval Observatory), the Hamburg Planetarium, amateur activities (by Matthias Hünsch), and numerous instrument and clock makers. Also, a detailed chapter on the observatory's solar expeditions is included.

Written both for the interested layman and the historian of astronomy, Schramm's book can be wholeheartedly recommended as the definitive history of an important observatory

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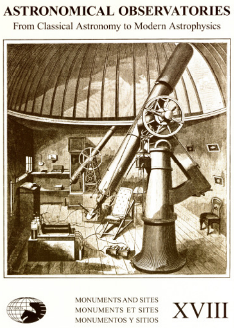
***Cultural Heritage of Astronomical Observatories. From Classical Astronomy to Modern Astrophysics,* edited by Gudrun Wolfschmidt (Berlin, Hendrik Bäßler Verlag, 2009), pp. 280, ISBN 978-3-930388-53-0 (softcover), €19.80.**



Cultural Heritage of Astronomical Observatories, from classical astronomy to modern astrophysics, contains the proceedings of the International Council on Monuments and Sites (ICOMOS) Symposium, held on 14-17 October 2008 in Hamburg. After various introductory speeches, the book includes papers on the UNESCO initiative "Astronomy and World Heritage" by A. Sidorenko-Dulom (UNESCO, Paris), "Astronomical Heritage—World Perspective and Action" (R. Kochhar, IAU) and "Cultural Heritage of Observatories and Instruments" by the organizer, G. Wolfschmidt (Hamburg University).

Dedicated, often well-illustrated presentations of many observatories follow: Pulkovo (V. Abalakin), Paris (S. Débarbat), Hamburg (P. Müller), Lisbon (P. Raposo), Istanbul (C. Benoist, G. Danisan and F. Limboz), Brazil (M. Granato), Marseille (J. Caplan), Vienna (A. Schnell), Budapest (L. Balazs et al.), Bucharest (M. Stavinschi and C. Mosoia), Greenwich (C. Grifton), Tartu (R. Mägi), La Plate (J.C. Forte and S.A. Cora), Cape of Good Hope (I.S. Glass), USNO Washington (B. Mason), Strasbourg (J. Davoigneau), Prague and Ondrejov (M. Šolz), Stockholm (I.E. Söderlund), Kodaikanal (R. Kochhar) and Christiana (V. Enebakk and B.R. Pettersen). I. Chinnici gave a talk on Italian observatories, B.S. Shylaya on Indian ones, and F. Le Guet Tully and H. Sadsaout on Mountain Observatories on the Mediterranean Coast. After these 25 contributions dealing with various sites and institutions, special talks focus on the Hamburg telescopes and buildings and the preservation of devices of industrial culture in general, as well as on historical astronomical plate archives.

This is a very well prepared conference proceedings volume (although some of the illustrations would have benefitted from higher resolution originals), and it can be recommended to anyone interested in the history and preservation of astronomical observatories. However, due to the attractive price, in combination with an obviously small printing run, the book is already out of print. Try to find it in a library, or hope that there will be an online edition in the near future.

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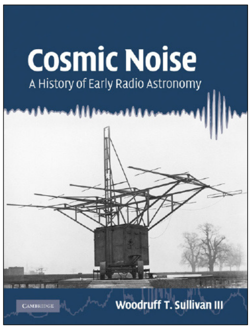
***Cosmic Noise. A History of Early Radio Astronomy,* by Woodruff T, Sullivan III (Cambridge, Cambridge University Press, 2009), pp. xxxii+542, ISBN978-0-521-76524-4 (hardcover), €85.00 and US$140:00, 251 x 194**



It is a great pleasure to review this long-awaited book. Woodruff T. Sullivan III—or 'Woody Sullivan' as he is affectionately known to his friends—is without doubt the world's foremost historian of radio astronomy, and over the past three decades has entertained us with two different books (in 1982 and 1984) and a succession of research papers, but all along 'the book' was hovering mysteriously in the background, never quite ready to make its grand entrance. Woody wrote most of it between 1984 and 1989, but then he was diverted by new subjects to teach—such as astrobiology—at the University of Washington and new books to write, and it was only in 2006 that he was able to take up the challenge and finish his history of world radio astronomy. Now it is out ... and the wait has been really worthwhile.

In more than 500 pages, *Cosmic Noise* relates the history of radio astronomy, from late nineteenth century abortive attempts to detect solar radio emission through to 1953. As Sir Francis Graham Smith explains in his Foreword,

> This is perhaps the latest date for which a comprehensive history can be contained in a single volume, but it is a good date to mark the emergence of radio astronomy as an integral part of modern astronomy. There was by this time a basic understanding of the origin of cosmic radio waves, and the techniques of radio telescopes, spectrometers, and interferometers. Funding for large projects was becoming available, and research groups were consolidating. (page xxvii).

Basically we can identify a number of discrete sections within the book. The first 28 pages provide introductory material and outline the unsuccessful endeavours in England, Germany and France to record solar emission during the 1890s and the first decade of the twentieth century.

Then come two chapters about the 'founding fathers' of radio astronomy, Karl Jansky and Grote Reber, which between them span 50 pages.

The next section deals with the various independent discoveries of solar radio emission during WWII, and pre-war reports during the previous solar maximum

> ... when we can recognize in retrospect that radio amateurs and professionals around the world were frequently encountering solar noise. No one convincingly interpreted this noise as direct solar radio waves, but at least one case came within a hairbreadth. (pages 85-86).

Then follow individual chapters on the leading pioneering teams of the immediate post-War era: Stanley Hey's Army group in England; Joe Pawsey's Division of Radiophysics team in Sydney, Australia; Martin Ryle's Cambridge group; and Bernard Lovell's Jodrell Bank group from the University of Manchester. Complementing these chapters is one that examines other less prominent pre-1952 radio astronomy groups in Canada, France, Germany, Japan, Norway, Sweden, the Soviet Union and the USA.

The orientation of the book now shifts from national overviews to astronomical subjects and methodology, with two successive chapters (collectively spanning more than 50 pages) that deal with radar observations of meteors and the Moon. Woody Sullivan has to remind us that during this early period these radar investigations were deemed an integral part of the overall portfolio of radio astronomy.

Continuing the thematic focus, the next four lengthy chapters discuss solar radio emission, 'radio stars' and the nature of discrete sources, 'Galactic noise', and investigation of the hydrogen line. These four chapters run from page 284 to page 417, and as in other areas of the book the text is well supported by direct quotes from archival records and oral history interviews, historical photographs and line drawings.

The penultimate chapter takes us in yet another direction as Woody Sullivan places early radio astronomy within a history and philosophy of science framework. Among other topics, the chapter titled "New Astronomers" (pp. 418-456) discusses "... the role of WWII in kickstarting radio astronomy ..."; introduction of the terms 'radio astronomy', 'radio astronomer' and 'radio telescope'; and the emergence of radio astronomy as a specialist area of astronomy.

Finally, "A New Astronomy" (pp. 457-471) focuses on intellectual issues. While astronomy *per se* made great strides through the emergence of radio astronomy, Sullivan merely views this as part of a wider *gestalt* involving X-ray, infrared, ultraviolet and gamma-ray astronomy. Thus, instead of seeing radio astronomy as a scientific revolution,

> ... I argue that radio astronomy (or more generally, the opening of the entire electromagnetic spectrum) was the mid-twentieth century's *New Astronomy*, with an impact every bit as important as New Astronomies of previous centuries such as those of Galileo or William Herschel or the first nineteenth century astrophysicists. Each of these New Astronomies was caused by researchers applying new technology to observing the sky, and each in its time profoundly transformed the perceived Cosmos. (Page 457).

Closing out this fascinating book are three appendices, a 21-page list of references and an Index.

Cosmic Noise is a *tour de force*, and provides an excellent overview of the key developments in radio astronomy up to 1953. Many areas of the book appealed to me, and although I only began my own involvement in Australian radio astronomy in 1961 when I joined the Division of Radiophysics in Sydney—long after the book's cut-off date—I personally knew most of the Australian 'players' and worked with many of them. I particularly found the use of oral history interviews and extensive use of archival records rewarding, while the 15-page annotated table of contents near the start of the book was an invaluable aid in searching out areas of special interest. With most books or papers that I read I find footnotes a distraction and tend to gloss over them, but for the most part I found those that Woody supplied to be both interesting and informative, and I religiously read them. I also enjoyed some of the 'Tangents' at the ends of chapters, designed to introduce definitions, basic concepts or expand on material in the body of the chapter. Something else I enjoyed reading about (and have written about myself) is what I like to call 'Appleton's obsession': his need to claim priority for important discoveries in which he played no part (despite his publications sometimes suggesting, or even stating, otherwise).

Finally, despite the lengthy treatment of the subject it is fortunate that *Cosmic Noise* is not *the* final word and that there is still room for further detailed research that can only serve to flesh out the excellent framework that Woody Sullivan has supplied. Thus, those in the IAU Working Group on Historic Radio Astronomy are free to investigate early developments in Canadian and Japanese radio astronomy for instance, along the lines of the Early French Radio Astronomy Project which is now nearing completion. And despite Woody Sullivan's scholarly and lengthy treatment of the subject, it is heartening to know that there are still viable Ph.D. projects for students who wish to research aspects of early radio astronomical history, but of course the post-1953 era is even more appealing, and is less charted territory.

Cosmic Noise is a thoroughly researched, well written and beautifully illustrated volume that will remain the standard work on this topic for years to come. Given its length and the scholarship involved, it is excellent value at €85.00 or US$140:00, and is a 'must' for the bookshelves of all those with a passion for radio astronomical history.

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