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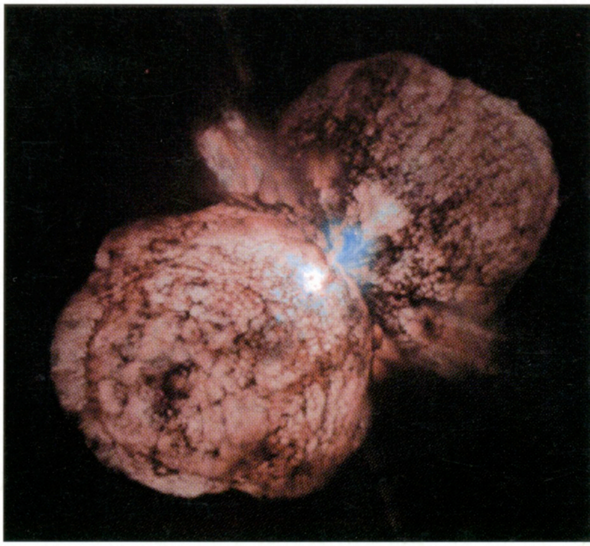

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The discovery of strong extragalactic polarization using the Parkes Radio Telescope

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Abstract
By the end of 1961, interferometry to arc-minute precision in the East-West direction had resolved the compact source at the centre of Centaurus A into two unequal components spaced about 5′ in right ascension and with measured widths. Were they on the dark bar of the associated extragalactic nebula, NGC 5128, and perhaps indications of a toroidal source, or were they in the perpendicular direction and on their way out to feed the extended radio source Centaurus A? The 6′.7 pencil beam of the Parkes Radio Telescope, employed in an unusual scanning mode, was capable of just separating the peaks and resolving the ambiguity in declination. In 1962 April, I carried out the first observations of linear polarization in Centaurus A using the Parkes antenna, and these were soon followed by other observations made by Brian Cooper and Marcus Price and then by Frank Gardner and John Whiteoak. Because the research papers reporting these pioneering observations were not published in chronological order and the dates of the observations and submission of the manuscripts are not mentioned in them there has been considerable confusion surrounding the discovery history of Centaurus A polarization at Parkes, and this has been compounded by a misleading contemporary newspaper report, uninformed folklore, and conflicting recollections printed 30 years after the event. This paper clarifies the situation by presenting a first-hand account of the original observations and associated publications.

Keywords: *Centaurus A, extragalactic nebulae, Parkes Radio Telescope, polarization*

1 INTRODUCTION

There was a time when astrophysicists did not feel the need for magnetic fields to account for celestial phenomena. Even solar physicists, despite the discovery of kilogauss fields in sunspots, did not call upon magnetic fields to interpret chromospheric and coronal structure. When Alfvén published his masterful *Cosmical Electrodynamics* in 1950 a new dimension was introduced into astrophysics, but there was still little inclination on the part of astronomers to embrace radiophysics, let alone radio engineering. By 1962, the year to which this paper refers, today's awareness of the pervasiveness of magnetic fields in the universe was not yet shared by textbooks. Traces of polarization had been detected in the light of stars, but this was explained optically by reflection and scattering of initially unpolarized radiation by interstellar dust.

By 1953 Ginzburg, Pikel'ner, and Shklovsky had separately studied the theory of how energetic electrons might be influenced by magnetic fields on a galactic scale, and arrived at the idea of synchrotron emission of radiation. The following year Dombrovsky and Vashakidze observed that the light of the Crab Nebula was polarized, just as Shklovsky had predicted, and the prediction was confirmed soon afterwards in the USA, France, and Holland. In 1955 Hanbury Brown, Palmer, and Thompson tried to detect radio-frequency polarization, and Westerhout was also unsuccessful in 1956. But in this same year, Mayer, McCullough, and Sloanaker used a meticulous observational technique that allowed the parallactic angle to vary as the Crab Nebula was tracked by the 15-m antenna at the Naval Research Laboratory (henceforth NRL) in Washington, and they found substantial plane polarization at a wavelength of 3.15 cm. By the following year they had installed a motorized rotatable feed horn in the antenna, and were able to convincingly establish the polarization at ~10%.

Taken together, the optical and radio observations supported the proposed synchrotron mechanism of magnetic field interaction and established, within a few years from the time of Alfvén's vision, that magnetic fields were present on a vast scale in the Galaxy; they would henceforth play an essential role in astrophysics.

The even vaster realm of extragalactic space was then addressed at the NRL with the excellent instrumental arrangements and careful calibration procedures developed for the pencil-beam observations of the Crab Nebula. During 1961 Cygnus A, which had previously been investigated without success, was re-observed with improved equipment and methodology and was found to have 8% polarization at 3.15 cm. Mayer *et al.* (1962a) submitted their report to the *Astrophysical Journal* on 1962 January 22, and it was published in March.

Meanwhile, in Australia, Twiss, Carter, and Little discovered something that was to influence the first use of the Parkes 64-m Radio Telescope for polarization measurement. Tracking with different sets of four-dish interferometers that formed part of the 21-cm Chris Cross at Fleurs with a view to improving on the signal-to-noise ratio obtainable from a simple scan, they noticed that by the time the spacing reached 464λ the compact source situated between the two extended lobes of Centaurus A had structure of its own. Extrapolating visibility amplitudes and phases out to 1000λ they found that two regions each 2′.5 wide spaced 5′ East-West would fit the interferometer data (Twiss *et al.*, 1960), and this was later proven to be about right. The declinations were not determined, but the right ascensions straddled the nominal RA position adopted.

I was present during the Fleurs observations, and by the time the paper by Twiss *et al.* was published one of the authors, Sydney radio astronomer Alec Little, was at Stanford completing an M.S. degree. By using his wide-band parametric amplifier at 9 cm (Little, 1961) to improve the sensitivity, we were able to make direct fan-beam scans of Centaurus A with the East-West arm of the Stanford cross (Bracewell and Swarup, 1961) and verify the interpretation reached by the Fleurs observers. With a baseline of 1255λ at 9.1 cm and an East-West beamwidth of 2′.3, a good profile was obtained, and a final manuscript on this work was presented at the 1961 May 15-20 Symposium on Radio Astronomy held at Green Bank and eventually published in *Proceedings of the National Academy of Science* (Little *et al.*, 1964). The preceding component of Centaurus A was found to be unresolved (width <1′) while the following component had a substantial width of 2′.6. The spacing in RA was 5′.1. Since it was not feasible to rotate all 16 feedhorns, these results referred only to East-West polarization.

Concurrently in 1960-1961 an ambitious programme of interferometry was under way at the Owens Valley Radio Observatory to observe 180 different sources. No doubt stimulated by the reports that Cygnus A, and now Centaurus A, were double, Moffet and Maltby (1961) reported that nine of their sources, including Centaurus A, fitted a model with two equal centres of emission. And by 1961 August 19 Maltby (1961) could report enough detail in declination for Centaurus A to challenge the earlier suggestion by Mills (1953) that the central source could be elongated along the dark bar that crossed NGC 5128. Maltby (op. cit.) showed two equal racetrack-shaped sources in position angle 46 ± 2°, each with an axis ratio of about 2:1, the long axes parallel to each other in position angle 17°. The awkwardness of tracking for four hours with a north-south interferometer aimed at the southern horizon must account both for the racetrack-type elongation and the two-fold rotational symmetry of the half-intensity contours (implying that a constant fringe phase was accepted). None of the shape parameters was later confirmed, but the spacing and orientation, roughly perpendicular to the dark bar, would prove to be correct.

A radiating toroid enclosing the dust lane and seen edge-on could give the appearance of two sources but would have to present a width less than 10″ to be compatible with the Stanford scan. This deduction was presented at the 1961 Greenbank Symposium by Little *et al.* (1964) and the 1961 June 18-21 meeting of the American Astronomical Society (Little and Bracewell, 1961) as a basis for preferring two more or less globular volumes on their way outward along a line perpendicular to the dark band to join the components of the extended source.

2. THE PARKES OBSERVATIONS OF 1962 APRIL

When I visited the Radiophysics Laboratory in Sydney early in 1962 I had a rough picture, based on the various Australian and US observations, of the layout of the central components of Centaurus A. I was also keenly aware of the handicaps of working with a southern source at 43° S from a northern latitude of 37°. A direct map with a pencil beam and controllable polarization would clarify the situation so I asked my old mentor and Chief of the Division of Radiophysics, Taffy Bowen, for observing time on the 64-m Parkes Radio Telescope.

This was granted,[1] and on 1962 April 14 I went up to Parkes to observe, but on the understanding (as was the practice at National Observatories in America) that technically I would be collaborating with one of the Radiophysics research staff, in this case Brian Cooper.[2] My three days of observations of Centaurus A at Parkes were on April 15, 16, and 17. The 10-cm receiver readied by Tom Cousins was in the receiver room at the time. The circumstances were not entirely favourable because the beamwidth of 6′.7 was not as good as the 2′.3 I had been working with at Stanford when two peaks were recorded with an East-West spacing of only 5′.1 (Figure 1). Before my arrival at Parkes, this 6′.7 beam had already been scanned over the central source but no structure had been seen. This is what you would expect when scanning at different declinations with a 6′.7 beam over point sources spaced 5′.1 in RA – you only get one peak on any one scan, even though there are two sources – but if you looked closely you would see the peak shifted a little bit in RA between scans. However, by scanning diagonally one could separate two sources disposed on a NE-SW line because they would be 7′ apart. No such separation would be noted for a NW-SE disposition. Diagonal scanning with both drive motors running was therefore employed with a view to being able to see double peaks on the record, and to be able to get right on to each peak by eye without relying on dead reckoning. Calibration errors of about one minute in dish pointing were expected at the time but the character of the errors was not known to me.

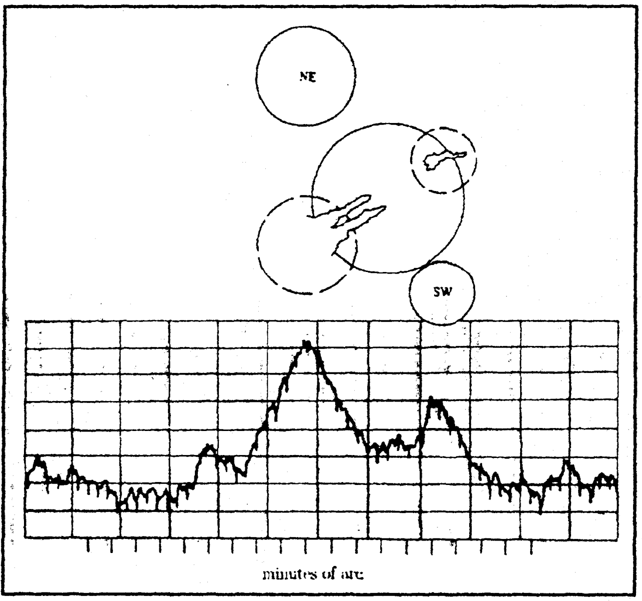

Figure 1. Stanford observations had shown that the NE and SW components of Centaurus A were unequal in size; the chart record, above, showing a single scan with a 2′.3 fan beam was made on 1961 March 14 (Little *et al.*, 1964). Observations at Parkes made with a 6′7 beam at 10 cm, undertaken to distinguish between the alternatives (full and dashed circles respectively), were successful. They established the NE-SW configuration, the one preferred in 1961 May (ibid., and Little and Bracewell, 1961). The alternative configuration is shown by two dashed circles lying on the dark belt in the same right ascension. At the same time, the unprecedented high degree of polarization of 15% was found in the NE component.

From the console I could drive the dish first downward from NE to SW, then stop the declination drive, wait a moment while the antenna continued westward, reverse the HA drive to take out the backlash, before restarting the declination going upward with both drives running and with a controlled shift in RA. The resulting scan pattern looked something like a set of hysteresis curves for iron and the peaks recorded were clearly seen to be quite unequal both in amplitude and diameter. This sort of manual mapping was repeated for four feed position angles spaced about 45°; maps for 115° and 25° were prepared for publication after 115° had been selected as giving maximum variation on the following source.

It was found that the NE component exhibited 15% plane polarization at a position angle of 115°, at that time an unprecedented degree of extragalactic polarization, while no polarization was noticed on the SW component (Figure 2). This was the first detection of linear polarization using the Parkes telescope, and although not world shattering perhaps, in view of the long history of astronomical polarization, it was memorable. The somewhat tricky observation established that the compact components were on the route leading to the outer extended lobes.

Immediately after I left Parkes, an American, Marcus Price, spent Easter weekend at the Radio Telescope, and his chatty account in *Serendipitous Discoveries in Radio Astronomy* (Price, 1983) exposes some of the trials and tribulations experienced by astronomy graduate students in those days and illustrates the workings of the Radiophysics 'hierarchy'. After installing the 21-cm receiver, Marcus found about 7% polarization in the emission from the two components which of course were not resolved in the 14′ beam, but he noted that "Poor old Ron got his feed angle wrong, because indeed at 21 centimeters the position angle of the linear polarization in Centaurus is exactly 90° different than it is at 11 centimeters." (Price, 1983:303). This discrepancy led to a comprehensive multi-wavelength programme (Cooper and Price, 1962) that would establish the existence of Faraday rotation and hence of magnetic fields within the Galaxy, as had been proposed by Alfvén in 1937.

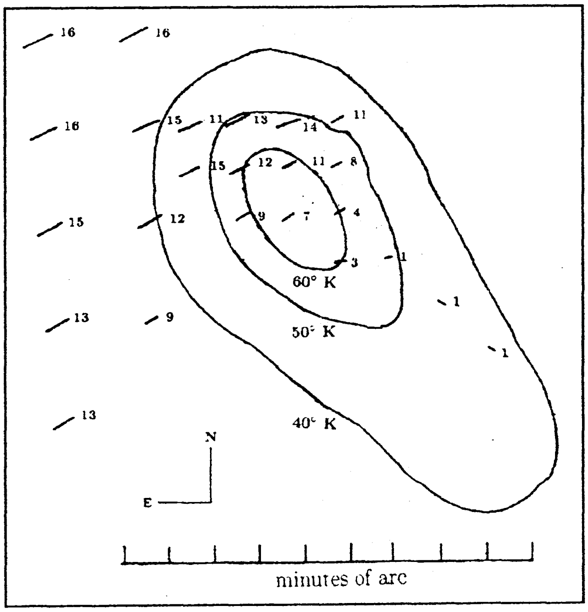

Figure 2. This data presentation from a preliminary draft gives an impression of the pencil-beam response to two components and shows some polarization directions and magnitudes.

Soon after Price's Easter adventure, Radiophysics staff members Frank Gardner and John Whiteoak exploited the 20-cm cooled parametric amplifier developed by Gardner and Milne, and quickly surveyed 15 sources for polarization, including several of the double sources previously reported by Moffet and Maltby (1961).

3 THE CONVOLUTED PUBLICATION SAGA

The telescope operators on my Parkes shift were George Henderson and L Fellows, who were mentioned in the manuscript draft that I wrote upon returning to Sydney, as was Tom Cousins. I listed the authors as myself and Brian Cooper, in accordance with my understanding with Taffy Bowen. Following the custom at Radiophysics, I handed the draft, including mention of permission to use the dish, to Bowen, and it came back with a page of his handwriting that superseded my introductory paragraph. I copied this out in a legible hand, added some extras, and gave it to the office for typing.[3] I will refer to this as Paper I, as it was the first written reporting observations of Centaurus A polarization using the Parkes Radio Telescope.

After returning to Stanford I received a letter from Brian Cooper saying that Mayer had observed some polarization in Centaurus A with the NRL's 15-m antenna, which I found impressive given that the centre of Centaurus A rises only 9° above the Washington horizon. I wrote to Connie Mayer on 1962 August 20, mentioned that my Parkes observations were about to appear in print, and included the precise optical position for NGC 5128 (13h 22m 31.6s ± 0.3, –42° 45′ ± 0.05, 1950) that I had circulated on 1962 May 21 and later published (see Little and Bracewell, 1966).[4]

Then I attended a meeting in Newhaven, Connecticut between 1962 August 26 and 29 at which Mayer reported polarization results for the Crab Nebula, Cygnus A, and Centaurus A. Six months had been devoted to the Crab and Cygnus A observations in 1961, as reported on 1962 January 22 (see Mayer *et al.*, 1962a), while the Centaurus polarization results were brand new. The Newhaven paper was published in 1962 November (Mayer *et al.*, 1962b). The NRL's developed observing technique was then applied to a series of other sources at wavelengths of 3.15, 3.47, and 9.45 cm, and the results were reported in the major paper of 1964 January (Mayer *et al.*, 1964) where Centaurus A was shown to exhibit 13.5% polarization at 3.15 cm and 7.2% at 9.45 cm. In none of these studies was the beamwidth narrow enough to resolve sources with double structure; hence the results refer to the composite source as a whole and not to the components.

Since the great Paris Symposium of 1958 it was usual for many of the world's radio astronomers to maintain close personal contact both through travel and correspondence, and not infrequently news from A reached B via a traveller from C who passed through both A and B. Presumably, this was how word of Mayer's Centaurus A polarization observations reached Sydney a week or two before the Newhaven conference.

While these US developments were in train I was eagerly anticipating the publication of my Parkes paper. Instead it was Gardner and Whiteoak's paper that first appeared in print, even though it was the third Centaurus A polarization study carried out at Parkes in 1962 and the third paper written (Paper III). This important paper (Gardner and Whiteoak, 1962), which exemplified the power of the new 64-m Radio Telescope, was received by *Physical Review Letters* on 1962 July 11, and was published in the September 1 issue.

Strangely, Cooper and Price's paper, reporting the second Centaurus A polarization study carried out at Parkes in 1962 (Paper II), was the second paper published, appearing in the September 15 issue of *Nature* (Cooper and Price, 1962). Two weeks later my own long-awaited paper finally appeared in the 1962 September 29 issue of *Nature,* with its figure of 15% polarization (Bracewell *et al*, 1962). Immediately I noticed that Tom Cousins had been promoted to co-authorship, and although this was irregular – in the sense of never happening to a paper I wrote before or since – it did not strike me as out of keeping with the hierarchical structure that I was familiar with after a dozen years or so at Radiophysics. Besides, Tom had made the crystal mixer that was used! What did surprise me though was a 'Note added in Proof' stating that C.H. Mayer had "... detected a similar degree of polarisation." at 3.15 cm. Clearly, submission or publication of our paper had been delayed for reasons that at the time were not apparent, notwithstanding the fact that the Australian Scientific Liaison Office in London used to read the proofs of papers submitted to *Nature* in order to minimize the delay. In a letter to me, co-author Brian Cooper (1962), said that he could not understand why the NRL result should have caused any delay, but Haynes *et al.* (1966: 251-252) later laid the blame squarely with John Bolton: "... Bolton, furious at this unscheduled use of the telescope, intervened to delay submission of the paper... [and] Bolton, ever the *éminence grise*, arranged that this paper should appear in *Nature* two weeks before the report of Bracewell's earlier observation."

If this is a realistic account of Bolton's role (and it is the only such mention that I have seen or heard), then it is ironic that Bolton should rate these observations so highly, for when asked what he considered was the greatest discovery made with the Parkes Radio Telescope, he immediately identified the occultation of 3C273, but was quick to add: "I would place, certainly on an equal footing, the discovery of polarisation in the extragalactic radio sources as one of the really fundamental discoveries." (see Bhathal, 1996: 113). The Parkes telescope saw 'first light' in 1961 October, was opened on 1961 October 31, and detected strong polarization on 1962 April 15. The occultation of 3C273, the first accredited quasar, was observed by Cyril Hazard, a visitor from the Physics Department at Sydney University, on 1962 August 5.

4 UNINFORMED FOLKLORE AND CONFLICTING RECOLLECTIONS

Obviously, the chronological reversal of the publication order of Papers I, II and III was a surprise to me but I thought the dates of observation and submission would speak for themselves. However, in 1996 I noticed that none of the papers included the dates of the observations; nor did the two papers published in *Nature* state the dates upon which they were received. As the discovery paper was the last of the three to appear in print, although written up and submitted promptly, there has been some confusion on the part of subsequent authors as to the true sequence of events. Yet the priority of the initial observations is clearly confirmed by the dates, and acknowledgments to Brian Cooper, Tom Cousins, Les Fellows, G. Henderson and Jim Roberts, recorded in the Parkes Visitor's Book. This was the first entry by a visiting observer in the Book, and it reads:

> 1962 April 14-18. I came as a guest investigator to study the central source of Centaurus A, which had been resolved into two components by Alec Little of the Radiophysics Laboratory. He used the 2′.6 fan beam of my aerial at Stanford, Calif. Centaurus A furnishes a wonderful opportunity for understanding the evolution of a radio galaxy. I measured polarization parameters over the field, finding a degree of polarization much higher than has been observed hitherto in galactic or extragalactic sources. It is a great privilege to use this magnificent

> instrument and to have had the assistance of Geo. Henderson and L. Fellows, who drove the telescope, and Tom Cousins, who operated the 10 cm receiver. To Brian Cooper and Jim Roberts my thanks for advice and guidance.
>
> R.N. Bracewell, Radio Astronomy Institute,
> Stanford University,
> Stanford, California

Undoubtedly, a contributory factor in this later confusion was an article that appeared in the *Sydney Morning Herald* on 1962 September 15, which reported that

> Two C.S.I.R.O. scientists, using the new radio-telescope at Parkes, have discovered what they believe is a possible clue to the origin of the universe. They have discovered the existence of magnetic fields in outer space... The two scientists who made the discovery are Mr Brian Cooper, of Sydney, and Mr Marcus Price, an American, both of C.S.I.R.O.'s Radio-physics Division ... The scientists discovered that radio waves were 'linearly polarised' – the electrical vibrations lay in a definite plane. When the scientists changed the frequencies on which they were receiving signals, they found the plane had rotated.

This article did not mention Paper I, which was about to appear in print, or even Paper III, which had already been published. On 1962 September 18 Alec Little sent me a clipping of the article knowing I would find it of interest, and in his accompanying letter noted: "Apparently your discovery is being turned to good advantage, but it is a pity that you didn't get a mention!"

With the passage of time and dimming of memories, even some of the authors of the 1962 papers have shared in the confusion. For example, John Whiteoak (1994:76), a co-author of Paper III, states in *Parkes. Thirty Years of Radio Astronomy*: "I am a little hazy as to what actually happened at Parkes, but the word filtered back to Sydney that, at some stage during the visit, Ron had rotated the feed system and found that the radio emission of the southern radio galaxy Centaurus-A was polarised ..." Likewise, Marcus Price, a co-author of Paper II, says in *Serendipitous Discoveries in Radio Astronomy*: "... the Australians, with help from an ex-patriot [*sic*], namely Ron Bracewell, were measuring and reporting the polarization of Centaurus A." (Price, 1983:302). Robertson's (1992:223) account in *Beyond Southern Skies. Radio Astronomy and the Parkes Telescope* says: "The Parkes observations by Ron Bracewell, Brian Cooper and Tom Cousins detected 13% polarisation at 10 cm from one of the two compact central sources of Centaurus A."

A more realistic account of the actual sequence of events has been published by Haynes *et al.* (1996:251):

> In April 1962, Brian Cooper and his technical officer, Tom Cousins, had just installed a 10-cm receiver and retired for a well-earned rest, when Ron Bracewell of Stanford University, Palo Alto, and a former staff member of the Radiophysics Laboratory, who happened to be visiting Parkes and who knew of the as-yet unpublished paper from Mayer's group, noticed that the new polarisation equipment was in place. Pointing the telescope to Centaurus A, he rotated the feed antenna and immediately found that the radiation from the source was indeed polarised. Describing his observations in the visitors' book, he quickly prepared a note to *Nature* with himself, Cooper and Cousins as authors ...

Yet this version reveals no awareness of the purpose of my visit to Parkes, or of the official scheduling by Bowen. However, it is right about who made the observations and prepared the manuscript of Paper I (even if the list of original authors is wrong).

5 CONCLUDING REMARKS

The first observations that resolved the two central components of Centaurus A while providing polarization readings were made with the Parkes Radio Telescopes at 10 cm between 1962 April 15 and 17. The 15-m NRL antenna never managed to resolve the central component of Centaurus A, nor did the Parkes observations reported in Papers II and III – and the polarizations reported were necessarily composite because the beamwidths exceeded the 7′ component separation.

Because the three different suites of observations that were made at Parkes in 1962 were not published in the logical chronological order and a contemporary newspaper report and later reminiscences have added further confusion, there has been considerable uncertainty surrounding the 1962 observations of Centaurus A, but this account documents the actual sequence of events.

The polarization studies of 1962 initiated a whole new research focus at Parkes, and in due course suitable receivers at short wavelengths enabled the 64-m Radio Telescope to return to fine-structure polarimetry, while the VLA and AT were designed from the start with polarimetry in mind. Further developments of the extra dimension added by polarimetry to both extragalactic and galactic studies continued in subsequent years, and are still under way, with more discoveries to come. Intergalactic Faraday rotation must exhibit a dependence on the cosine angle between the source direction and the direction of the Sun's velocity relative to the cosmic background radiation, an effect waiting to be convincingly discerned.

Looking back, it is hard to recall that astrophysics once did without magnetism, accelerated beams of high-energy particles, and, for that matter, radio waves.

6 ACKNOWLEDGEMENTS

I should like to thank Woody Sullivan (University of Washington, USA) for kindly providing a copy of the relevant page of the Parkes Visitors' Book, and Wayne Orchiston for comments that benefited the manuscript.

7 NOTES

1. I should mention that shortly before my observing run, Taffy Bowen kindly flew me up to the Parkes Radio Telescope to look around, and on the way home I was allowed to fly the plane over the Blue Mountains and to take a look at the Fleurs field station from a rather unusual angle.
2. As with many other novices who joined Radiophysics, I was turned over to Brian when I arrived in 1942, and he gave me things to do – such as making a speech-controlled pulse-width modulator for the E1210B magnetron (one of which had arrived from England), to see if we could communicate speech at 10 cm (see RP182, 1943 March). We set up a link between the National Standards Laboratory tower and Kensington Racecourse (where the University of New South Wales now stands) and although I thought this was a pretty exciting achievement Brian told me in 1996 April that in his opinion the speech quality was a little garbled. Another assignment was to characterize a specimen of the great 701A modulator tetrode, a magnificent bottle that is now a collector's item (see TI49/2, 1943 March). Yet another project related to a lighthouse triode that had arrived from the USA. This had been designed to operate in one coaxial line inside another, and by building it instead into a pair of cylindrical cavity resonators sharing a common plane wall it was induced to produce 70 mW at 21 cm (see RP261, 1945 September).
3. I still have these manuscript drafts and a carbon copy of the resulting typescript in my files.
4. It was needed for absolute purposes because of the minute-of-arc accuracy achieved, and has probably not been improved upon. The two radio components are at significantly different distances from the optical position (see Little and Bracewell, 1966).

8 REFERENCES

Bhathal, R., 1996. *Australian Astronomer.* Australian Academy of Science, Canberra.

Bracewell, R.N., Cooper, B.F.C. and Cousins, T.E., 1962. Polarisation in the central component of Centaurus A. *Nature*, **195**:1289-1290. [Paper I]

Bracewell, R.N., and Swarup, G., 1961. The Stanford microwave spectroheliograph antenna, a microsteradian pencil beam antenna. *Transactions IRE on Antennas and Propagation*, **AP-9**:59-67.

Cooper, B.F.C., 1962. Letter to R. Bracewell, dated September 19. Original in Bracewell Collection.

Cooper, B.F.C. and Price, R.M., 1962. Faraday rotation effects associated with the radio source Centaurus A. *Nature*, **195**:1084-1085. [Paper II]

Gardner, F.F. and Whiteoak, J.B. 1962. Polarisation of 20-cm wavelength radiation for radio sources. *Physical Review Letters*, **9**: 197-199. [Paper III]

Haynes, R., Haynes, R., Malin, D. and McGee, R., 1996 *Explorers of the Southern Sky. A History of Australian Astronomy.* Cambridge University Press, Cambridge.

Little, A.G., 1961. A wide band single diode parametric amplifier using filter techniques. *Proceedings of the Institution of Radio Engineers*, **49**:821-822.

Little, A.G., 1962. Letter to R. Bracewell, dated September 18. Original in Bracewell Collection.

Little A.G. and Bracewell, R.N., 1961. The central component of Centaurus A. *Astronomical Journal*, **66**:290-291.

Little, A.G. and Bracewell, R.N., 1966. The central component of Centaurus A. *Australian Journal of Physics*, **19**:421-426.

Little, A.G., Cudaback D.D. and Bracewell, R.N., 1964. Structure of the central component of Centaurus A. *Proceedings of the National Academy of Science*, **52**:690-691.

Maltby, P., 1961. Central component of the radio source Centaurus A. *Nature*, **191**:793-794.

Mayer, C.H., McCullough, T.P. and Sloanaker, R.M., 1962a. Evidence for polarized 3.15 cm radiation from the radio galaxy Cygnus A. *Astrophysical Journal*, **135**:656-658.

Mayer, C.H., McCullough T.P. and Sloanaker, R.M., 1962b. Polarization of the radio emission of Taurus A, Cygnus A, and Centaurus A. *Astronomical Journal*, **67**:581.

Mayer, C.H., McCullough T.P. and Sloanaker, R.M., 1964. Linear polarization of the centimeter radiation of discrete sources. *Astrophysical Journal*, **139**:248-268.

Mills, B.Y., 1953. The radio brightness distributions over four discrete sources of cosmic noise. *Australian Journal of Physics*, **6**:452-470.

Moffet, A.T. and P. Maltby, 1961. Distribution of brightness in extragalactic radio sources. *Nature*, **191**:453-454.

Price, M., 1983. The first years at Parkes. In K. Kellermann and B. Sheets (eds.) *Serendipitous Discoveries in Radio Astronomy*. National Radio Astronomy Observatory, Green Bank. Pp. 300-306.

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

Twiss, R.Q., Carter, A.W.L. and Little, A.G., 1960. Brightness distribution over some strong radio sources at 1427 Mc/s. *The Observatory*, **80**:153-159.

Whiteoak, J., 1994. Early polarisation research at Parkes. In D.E. Goddard and D.K. Milne (eds.). *Parkes. Thirty Years of Radio Astronomy*. CSIRO Publishing, Melbourne. Pp. 75-80.

Ronald Bracewell is Terman Professor of Electrical Engineering Emeritus at Stanford University. From 1942 to 1946 he worked on microwave radar devices at the CSIRO's Division of Radiophysics in Sydney and then on E G Bowen's recommendation he went to the Cavendish Laboratory, Cambridge, to do very long wave ionospheric research under J A Ratcliffe. Returning to Radiophysics in 1950 he collaborated with J L Pawsey on the writing of the book *Radio Astronomy* (Oxford 1955). He spent 1954-1955 teaching a course on radio astronomy in the Astronomy Department at Berkeley, then chaired by O Struve, returned briefly to Sydney during a period of turbulence, and went on leave to Stanford University to build a series of high-resolution, microwave radio telescopes. In retirement he continues to write books and papers.

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Analysis of dates and lunar phase records in *Wucheng*

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Abstract

There is a series of dates with month, sexagenary day and lunar phase in the ancient archive *Wucheng*, which are important clues to date King Wu's conquest. This paper mathematically analyzes the relationship between the explanation of the lunar phase terms and the date of the historic event. Combining with other related astronomical records, we offered some possible suggestions as to the date of King Wu's conquest.

Keywords: *chronology, ancient astronomical records, history of astronomy, Chinese history*

1 INTRODUCTION

In the eleventh century BC, King Wu conquered King Zhou and set up the West Zhou Dynasty. This was an important event in Chinese history and many records relating to it have survived. However, the date of King Wu's conquest is still a puzzle, even though many historians have studied it over the last two thousand years. According to a recent review (Beijing Normal University, 1997), forty-four different conclusions, dating between 1127-1018 BC, have been published.

Many ancient records mention King Wu's conquest, and one of the key ones is *Wucheng*. It is a section of the famous classic *Shujing*, which collected the government statements in early times. A more complete fragment of *Wucheng* has survived in *Hanshu-Lulizhi*, and is a diary-style story on this war:

> The first month, day Renchen (29), it was Pang-Sipo. The next day was Guisi (30); the morning, King Wu departed from Zhou [state] to crusade against King Zhou [of Shang State]. Counting from the day Ji-Sipo of the second month, the fifth day was Jiazi (1) when King Zhou was killed. Counting from the day Jipang-Shengpo of the fourth month, the sixth day was Gengxu (47) when King Wu prayed at the grand temple of Zhou (state). The next day, Xinhai (48), the King prayed to the sky. The fifth day Yimao (52) sacrifice prisoners of the war at the temple.

Here the dates were counted with a sexagenary cycle, and we have placed the order numbers in parentheses. Usually the first month is the one that contains the winter solstice. A lunar phase system was used to determine the lunar day in West Zhou, and this is seen in bronze inscriptions and in historical records. Lunar phase terms used are Chu-ji, Ji-sheng-ba, Ji-wang and Ji-sipo, but the exact meaning of these is difficult to determine and many different hypotheses have been offered (e.g. see Zheng, 1981). From the text we see that each term must be a certain lunar day, on which a particular lunar phase could be seen. Other dates in the month were then counted from these days.

From *Wucheng* we can deduce three dates with sexagenary days and lunar phases. They are:

A: day Renchen (29) of 1st month Pang-sipo
B: day Gengshen (57) of 2nd month Ji-sipo
C: day Yisi (42) of 4th month Ji-pang-shengpo.

In the sexagenary series, Ji-sipo of the 2nd month is 57, so Ji-sipo of the 1st month would be $57 - 29.5 = 27.5$ (a month is 29.5 days). Pang-sipo (29) was 1.5 day latter than Ji-sipo in the 1st month. Ji-sipo of the 4th month would be $57 + (2 \times 29.5) - 60 = 56$. Ji-pang-shengpo (42) was 14 days before Ji-sipo. Here we have found that Ji-sipo and Ji-shengpo were the opposite lunar phase (14 or 15 days different), and that Pang was 1 or 2 day latter than Ji. In Chinese language, *sheng* (live) and *si* (death) are opposites; *Ji* means 'already'; *Pang* means 'beside' or 'next'. Here we show that the linguistic and mathematical meanings are in accord.

If we can determine the year of *Wucheng*, we can establish the meaning of these lunar phase terms. Normally an historian would select a particular year for King Wu's conquest and then prove that this date adequately explains the lunar terms, but in this investigation we shall discuss all dates that fit certain hypotheses relating to these lunar terms.

2 METHODOLOGY

Lunar calendar day (lcd) is a convenient way to express lunar phases, in which the New Moon day (when the Sun and the Moon are in conjunction) is number 1. There are three different types of hypotheses relating the lunar phase terms:

Hypothesis 1.	Jisipo is the New Moon day (lcd 1) and Jishengpo is the Full Moon day (lcd 16).
Hypothesis 2.	Jishengpo is the First Quarter day (lcd 8) and Jisipo is the Last Quarter day (lcd 23).
Hypothesis 3.	Jishengpo is the day when the New Moon is first seen (lcd.3) and Jisipo is the first day when the loss of the Full Moon begins to be noticed (lcd 18).

The following method has been used to analyze the lunar data in *Wucheng*:

1) The sexagenary number of the 1st day of the 1st month is derived from day Renchen (29) Pang Sipo according to an hypothesis of lunar terms. The sexagenary number of the 1st day of the 2nd month is derived by adding 29 or 30 days, then the lunar calendar day number (lcd) of day Gengshen (57) of the 2nd month. The sexagenary number of the 1st day of the 4th month is derived by adding 59 days, then the lcd of day Yisi (42). These are then listed in Tables 1a, 2a, and 3a (for the three different hypotheses). We then check to see whether the three days fit the lunar hypothesis. Finally we derive the sexagenary number of the 1st day of the 1st month.
2) With modern astronomical knowledge we can compute a New Moon list (e.g. see Zhang, 1990), which includes every New Moon day, its Julian date (year, month and day) and the sexagenary number. Winter solstices are also listed. We can now find in which years the 1st day of the 1st month has the given sexagenary number, and then the New Moon days of the 2nd, 3rd, and 4th months, their Julian dates and their sexagenary numbers. These are listed in Tables 1b, 2b, and 3b.
3) We then insert the three dates in *Wucheng* in Tables 1b, 2b, and 3b, and see if they fit the lunar hypothesis, and if they have 'Jupiter in the constellation Chunhuo' and 'The Sun in the constellation Ximu'.

Our analysis assumes that the date of King Wu's conquest was 1085-1020 BC, and that the 1st day of the 1st month was between November 1 to January 31 (based on the knowledge that the winter solstice (December 30) was in the first month at that time). *Guoyu* records that "Jupiter was in constellation Chunhuo; the Sun was in constellation Ximu." and we note them in passing in Tables 1b, 2b, and 3b under sub-columns J (Jupiter) and S (Sun) – but for details see Liu and Zhou (2001).

3 THE DIFFERENT HYPOTHESES

3.1 Hypothesis 1

In this hypothesis, Jisipo is the New Moon day (lcd 1), Jishengpo is the Full Moon day (lcd 16), and Pang-sipo therefore is lcd 2 or 3. We list lcd 0, 1, 2, 3, 4, and 5 in the second line of Table 1a for a wider discussion. If Renchen (29) Pangsipo is lcd 2, the sexagenary number of its previous day must be (28). In the same way, we get the numbers in the first line. One month (29.5 days) latter we get the third line; then another month latter we get the fifth line, the numbers of the 1st days of next two months. For the same example they are 28 + 29.5 = 57.5 and (57.5 + 29.5) – 60 = 27. If the 1st day of the 2nd month is (58) and Gengshen is (57), then Ji-sipo must be lcd 0. In the same way, we get the lcd numbers in the 4th line. If the 1st day of the 3rd month is (27) and Yisi is (42), then Jipang-shengpo must be lcd 16. In the same way, we get the lcd numbers in the 6th line.

We have noted that there is no Yisi (42) day in the 4th month, so we have to suppose that '4th month' is a mistake and that the original record should have been '3rd month'. This is an important weakness of Hypothesis 1.

Table 1a. The relationship between dates in *Wucheng*, Hypothesis1

1st day of 1st month: 60 No.	(30) (29) (28) (27) (26) (25)
Renchen (29) Pangsipo: lcd	0 1 2 3 4 5
1st day of 2nd month: 60 No.	(60) (59) (58) (57) (56) (55)
Gengshen (57) Jisipo: lcd	-2 -1 0 1 2 3
1st day of 3rd month: 60 No.	(29) (28) (27) (26) (25) (24)
Yisi (42) Jipangshengpo: lcd	14 15 16 17 18 19

From Table 1a we found that if Renshen is (29), then Pangsipo is one of lcd 0-5, Jisipo will be in lcd -1-3, and Jipangshengpo in lcd 14-19. They are all consistent with Hypothesis 1. On the other hand, the sexagenary number of the 1st day of the 1st month must be in (30-25), so we looked for such dates in a New Moon list and inserted them and the first days of the 2nd and 3rd months in Table 1b. Accordingly, the lcd numbers of the three dates are also entered in columns A (Renchen Pangsipo), B (Gengshen Jisipo) and C (Yisi Jipangshengpo). In Table Ib, if Jisipo is lcd 2, 1, or 0 we consider it is good and insert • in the sub-column L (lunar phase). If Jisipo is 3 or –1, it is acceptable and we insert ○. In the same way, Jishengpo lcd 15, 16, or 17 is good (•) while lcd 14 or 18 are acceptable (○). In passing, the Sun and Jupiter rankings are also listed under S and J.

Table 1b. The dates fitting *Wucheng*, Hypothesis 1

No.	1st day of 1st month	A	1st day o 2nd month	B	1st day o 3rd month	C	L	S	J
1	1081.12.15 BC (27)	3	1.14(57)	1	2.12(26)	17	•	○	○
2	1076.11.20 BC (28)	2	12.20(58)	0	1.18(27)	16	•	•	
3	1075.1.18 BC (27)	3	2.17(57)	1	3.18(26)	17	•		
4	1071.12.25 BC (29)	1	1.23(58)	0	2.22(28)	15	•		•
5	1066.11.30 BC (30)	0	12.30(60)	-2	1.28(29)	14		•	
6	1065.1.28 BC (29)	1	2.27(59)	-1	3.27(28)	15	○		
7	1060.12.23 BC (25)	5	1.21(54)	4	2.20(24)	19			○
8	1055.11.28 BC (26)	4	12.28(56)	2	1.27(26)	17	•	•	
9	1054.1.27 BC (26)	4	2.25(55)	3	3.27(25)	18	○		
10	1050.11.4 BC (28)	2	12.3(57)	1	1.2(27)	16	•	○	
11	1049.1.2 BC (27)	3	1.31(56)	2	3.1(25)	18	○		
12	1045.12.7 BC (28)	2	1.6(58)	0	2.4(27)	16	•	•	
13	1040.11.13 BC (30)	0	12.12(59)	-1	1.11(29)	14	○	•	
14	1039.1.11 BC (29)	1	2.9(58)	0	3.10(27)	16	•		
15	1035.12.16 BC (29)	1	1.15(59)	-1	2.14(29)	14	○	○	•
16	1029.11.11 BC (26)	4	12.10(55)	3	1.9(25)	18	○	•	
17	1028.1.9 BC (25)	5	2.8(55)	3	3.9(24)	19			
18	1024.12.15 BC (26)	4	1.13(55)	3	2.12(25)	18	○	○	

Under Hypothesis 1, no one group of dates supports all three conditions. Groups 1, 4, and 15 are better than others. Group 4 seems to be the best one. We pay more attention to Jupiter than to the Sun (see Liu and Zhou, 2001).

3.2 Hypothesis 2

In this hypothesis, Jishengpo is the First Quarter day (lcd 8), Jisipo is the Last Quarter day (lcd 23), and Pangsipo must be in lcd 24. Also, we discuss a wider range, lcd 22-27. In the same way as Hypothesis 1, we derive Table 2a. On this occasion there is a Yisi (42) day in the 4th month. However, according to the text, the day Yimao (52) was counted from Yisi (42). If Yisi was during the First Quarter (lcd 7 or 8) and Yimao is lcd 17 or 18, why did not the ancient people count Yimao from Jiwang since Jiwang is a lunar term with a well-known meaning (i.e. Full Moon)? This is a weakness of Hypothesis 2. Employing the same method as previously, we prepared Table 2b, using • for 'good' if Jisipo is in lcd 22, 23, or 24 and Jishengpo is in lcd 7, 8, or 9, and ○ for 'acceptable' if Jisipo is in lcd 21 or 25 and Jishengpo is in lcd 6 or 10.

Under Hypothesis 2, no one group of dates supports all three conditions. Groups 4, 12 and 16 are better than others, and Group 4 seems to be the best one.

Table 2a. The relationship between dates in *Wucheng*, Hypothesis 2

1st day of 1st month: 60 No.	(8)	(7)	(6)	(5)	(4)	(3)
Renchen (29) Pangsipo: lcd	22	23	24	25	26	27
1st day of 2nd month: 60 No.	(38)	(37)	(36)	(35)	(34)	(33)
Gengshen (57) Jisipo: lcd	20	21	22	23	24	25
1st day of 4th month: 60 No.	(37)	(36)	(35)	(34)	(33)	(32)
Yisi (42) Jipangshengpo: lcd	6	7	8	9	10	11

Table 2b. The dates fitting *Wucheng*, Hypothesis 2

No.	1st day of 1st month	A	1st day o 2nd month	B	1st day o 4th month	C	L	S	J
1	1082.11.27 BC (3)	27	12.27(33)	25	2.24(32)	11		●	●
2	1081.1.26 BC (3)	27	2.24(32)	26	4.23(31)	12			●
3	1077.12.30 BC (3)	27	1.29(33)	25	3.29(32)	11			
4	1072.12.6 BC (5)	25	1.5(35))	23	3.5(34)	9	●	●	○
5	1067.11.11 BC (6)	24	12.11(36)	22	2.8(35)	8	●	●	
6	1066.1.9 BC (5)	25	2.8(35)	23	4.8(34)	9	●		
7	1062.12.15 BC (6)	24	1.14(36)	22	3.14(36)	7	●	○	
8	1057.11.20 BC (8)	22	12.20(38)	20	2.17(37)	6		●	
9	1056.1.18 BC (7)	23	2.17(37)	21	4.16(35)	8	○		
10	1052.12.24 BC (8)	22	1.23(38)	20	3.23(37)	6			
11	1051.12.14 BC (3)	27	1.12(32)	26	3.12(31)	12		○	
12	1046.11.19 BC (4)	26	12.19(34)	24	2.16(33)	10	○	●	
13	1045.1.18 BC (4)	26	2.16(33)	25	4.15(32)	11			
14	1041.12.23 BC (5)	25	1.21(34)	24	3.21(33)	10	○		
15	1036.11.28 BC (6)	24	12.27(35)	23	2.25(35)	8	●	●	
16	1035.1.26 BC (5)	25	2.25(35)	23	4.25(34)	9	●		○
17	1031.11.4 BC (8)	22	12.3(37)	21	1.31(36)	7	○	○	
18	1030.1.2 BC (7)	23	1.31(26)	22	3.31(35)	8	●		
19	1026.12.7 BC (7)	23	1.6(37)	21	3.5(36)	7	○	●	
20	1020.11.1 BC (3)	27	12.1(33)	25	1.30(33)	10	○	○	
21	1020.12.31 BC (3)	27	1.30(33)	25	3.29(31)	12			

3.3 Hypothesis 3

In this hypothesis, Jishengpo is the day when the New Moon begins to be seen (lcd 3), Jisipo is the first day when the loss of the Full Moon begins to be noted (lcd 18), and Pangsipo must be in lcd 19. Also, we discuss a wider range, lcd 17-22. In the same way as for Hypothesis 1 we derive Table 3a. Unlike Hypotheses 1 and 2, this hypothesis has no obvious weaknesses. Using the same methodology, we have prepared Table 3b, and inserted ● for 'good' if Jisipo is in lcd 17, 18, or 19 and Jipangshengpo is in lcd 3, 4, or 5, and ○ for 'acceptable' if Jisipo is in lcd 16 or 20 and Jishengpo is in lcd 2 or 6. Under Hypothesis 3, group 10 supports all three conditions, while groups 1 and 11 are also acceptable. In this context it is important to point out that Hypothesis 3 is supported by independent investigations using data drawn from astronomy (Jing, 1999), palaeography (Wu, 2000), and bronze inscriptions (Chen, 2000).

4 THE RELATIONSHIP BETWEEN LUNAR TERMS AND THE YEAR OF KING WU'S CONQUEST

We have shown above that if we have an explanation for the lunar terms, we can derive one or several groups of dates for King Wu's conquest. On the other hand, if we suggest a specific year for King Wu's conquest, this would provide an explanation of the lunar terms. Since Jishengpo and Jisipo are opposite lunar phases, we only need to discuss one of them, and we choose Jisipo because it is more popular in bronze inscriptions. For example, our Hypotheses 1, 2 and 3 can all be indicated by Jisipo 1, 23, 18 (lcd).

Table 3a. The relationship between dates in *Wucheng*, Hypothesis 3

1st day of 1st month: 60 No.	(13) (12) (11) (10) (9) (8)
Renchen (29) Pangsipo: lcd	17 18 19 20 21 22
1st day of 2nd month: 60 No.	(42) (41) (40) (39) (38)
Gengshen (57) Jisipo: lcd	16 17 18 19 20
1st day of 3rd month: 60 No.	(41) (40) (39) (38) (37)
Yisi (42) Jipangshengpo: lcd	2 3 4 5 6

Table 3b. The dates fitting *Wucheng*, Hypothesis 3

No.	1st day of the 1s month	A	1st day o 2nd month	B	1st day o 4th month	C	L	S	J
1	1083.12. 8 BC (9)	21	1.7(39)	19	3.6(37)	6	○	●	●
2	1078.11.13 BC (10)	20	12.12(39)	19	2.9(38)	5	●	●	
3	1077. 1.11 BC (9)	21	2.9(38)	20	4.9(38)	5	○		
4	1073.12.17 BC (11)	19	1.15(40)	18	3.15(39)	4	●	○	
5	1068.11.22 BC (12)	18	12.21(41)	17	2.18(40)	3	●	●	
6	1067. 1.20 BC (11)	19	2.18(40)	18	4.18(39)	4	●		
7	1063.12.26 BC (12)	18	1.25(42)	16	3.25(41)	2	○		
8	1057. 1.30 BC (13)	17	2.28(42)	16	4.27(41)	2	○	○	
9	1052.12.24 BC (8)	22	1.23(38)	20	3.23(37)	6	○		
10	1047.11.30 BC (10)	20	12.30(40)	18	2.27(39)	4	●	●	●
11	1046. 1.28 BC (9)	21	2.27(39)	19	4.26(37)	6	○		●
12	1042.11. 5 BC (11)	19	12.4(40)	18	2.1(39)	4	●	○	
13	1041. 1. 3 BC (10)	20	2.1(39)	19	4.1(39)	4	●		
14	1037.12. 9 BC (12)	18	1.7(41)	17	3.8(41)	2	○	●	
15	1032.11.14 BC (13)	17	12.14(43)	15	2.10(41)	2	○	●	
16	1031. 1.12 BC (12)	18	2.10(41)	17	4.10(40)	3	●	○	
17	1027.12.18 BC (13)	17	1.17(43)	15	3.17(42)	1		○	
18	1021.11.12 BC (9)	21	12.12(39)	19	2.9(38)	5	●	●	
19	1020. 1.11 BC (9)	21	2.9(38)	20	4.9(37)	6	○		

Now our discussion is confined to one date: the day Gengshen (57) in the 2nd month Jisipo. Conventionally, the 1st month contains the winter solstice. We do not know exactly which New Moon belongs to the 2nd month, therefore we searched for Gengshen (57) in the winter solstice month and the following three months and found its lcd numbers (obviously Gengshen appears twice in this range). Inserting them in Table 4, we get different lunar phases for Jisipo in different years. In Table 4, 'a' stands for the month that contains winter solstice, 'b' is the next month, and so on.

It is easy to find the corresponding years for different lunar term definitions. For example, for Hypothesis 1, Jisipo lcd 0, 1 and 2, we can easily find 1085, 1080, 1075, 1070, 1054, 1049, 1044, and 1039 BC. They are exactly the same as we get from Table 1b. On the other hand, if we determine that 1027 BC was the year of King Wu's conquest, we find that Jisipo was lcd 9. That means that Jisipo was the First Quarter day and Jishengpo the Last Quarter day. Of course, the lunar term hypotheses also have to fit other conditions implied in *Wucheng*, and we have showed the weaknesses of Hypotheses 1 and 2 in Section 3.

Table 4 lists only four months. Had we decided to accept a wider suggestion about the definition of the 1st month, then the table would have been enlarged to the right until all twelve months were listed and it linked to the following year. We have found a cycle of approximately five years, because two months (59 days) differ from the 60-day cycle by just one day, and after five years there is one month difference.

5 CONCLUDING REMARKS

In this paper, we have mathematically analyzed the relationship between lunar calendar days and the sexagenary days of the dates in *Wucheng*. Using three popular hypotheses for different lunar phase terms, plus ancient records relating to the Sun and Jupiter, we obtained three series

Table 4. The lcd numbers corresponding to day Gengshen in the 2nd month Jisipo

BC	a	b	C	d	BC	a	b	c	d	BC	a	b	c	d	BC	a	b	c	d
1087	21		21		1070		0		0	1053	8		8		1036		17		17
1086		27		28	1069		6		6	1052	14		14		1035		23		23
1085	2		3		1068		11		12	1051		20		21	1034	29		29	
1084		9		10	1067	17		18		1050		26		27	1033		5		5
1083		14		15	1066	22		23		1049	1		2		1032	10		11	
1082		19		21	1065		29		30	1048		7		9	1031	15		17	
1081	25		26		1064	4		5		1047		13		14	1030	21		22	
1080		1		2	1063	9		10		1046	18		19		1029		27		29
1079		7		8	1062		16		17	1045	24		25		1028	3		3	
1078	13		14		1061		22		22	1044		0		1	1027		9		10
1077	19		20		1060		28		28	1043	6		7		1026		15		16
1076		25		26	1059		4		5	1042	12		13		1025		21		22
1075	0		1		1058		9		10	1041	18		19		1024	27		28	
1074	5		7		1057	15		16		1040		24		25	1023		3		4
1073		12		13	1056	20		21		1039		29	0		1022		8		9
1072		18		19	1055	26		27		1038	4		5		1021	13		15	
1071		23		24	1054	2		3		1037		11		12	1020	19		20	
BC	a	b	c	d	BC	a	b	c	d	BC	a	b	c	d	BC	a	b	c	d

of results for the date of King Wu's conquest. Our work was only a small part of a much larger project, and the Xia-Shang-Zhou Chronology Project recently accepted 1046 January 20 BC as the date of King Wu's conquest on the basis of our research and other astronomical, historical and archaeological information (The Expert Group ..., 2000). Although this is a pleasing solution to what has been a complex long-term problem, further works remains to be done.

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7 REFERENCES

Note: in the following references (C) indicates that the book, research paper or report is written in Chinese.

Beijing Normal University (ed.), 1997. *Chronology of King Wu's Conquest.* Beijing, Beijing Normal University Press (C).

Chen Jiu-jin, 2000. Reconstruction of the calendar of the West Zhou Dynasty by bronze inscriptions. Unpublished report of the Xia-Shang-Zhou Chronology Project (C).

Jing Bing, 1999. A study of four time-recording terms of Chuji, Jiwang, Jishengpo and Jisipo in the Western Zhou Dynasty. *Studies in the History of Natural Sciences*, **18**:55-68 (C).

Liu Ciyuan, and Zhou Xiao-lu, 2001. Analysis of astronomical records on King Wu's Conquest. *Science in China A*, **44**:1216-1224.

The Expert Group ..., 2000. *The Concise Report of Xia-Shang-Zhou Chronology Project, 1996-2000.* Beijing, World Book Company (C).

Wu Zhen-wu, 2000. Comprehensive investigation on lunar phase terms. Unpublished report of the Xia-Shang-Zhou Chronology Project (C).

Zhang Pei-yu, 1990. *Calendar and Astronomical Phenomena for 3500 Years.* Zhengzhou, Henan Education Press (C).

Zheng Tian-jie, 1981. Calendar and chronology of early Zhou Dynasty. *Shixue Huikan*, **11** (C).

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Christopher Hansteen and the first observatory at the University of Oslo, 1815-28

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Abstract
A small observatory for astronomical and geodetic purposes was established in 1815, shortly after the University of Oslo came into being. The initial equipment came from the surveying community in Norway, but was rapidly supplemented by both new and second-hand instruments acquired from abroad. Several observing methods were employed to determine the geographical position of the observatory, and the results are re-analysed and compared in this paper. Providing correct local time to society was considered an important task, and this triggered the development of methods of time-determination suitable for an institution with limited resources. The first University of Oslo Observatory also became a site where geodetic techniques suitable for establishing an improved national geodetic net based on triangulation and astrogeodetic observations were developed. These activities led to the establishment of a new observatory at the University in 1833.

Keywords: *Christopher Hansteen, scientific instruments, latitude and longitude, time determination, geodetic surveying*

1 INTRODUCTION

The University of Oslo was created through a royal decree by Frederik VI, King of Denmark and Norway, on 1811 September 2. Decades of perseverance, repeated proposals and a successful fund-raising campaign with significant contributions from private Norwegian citizens (some of whom had received their academic training in Copenhagen) finally permitted undeveloped Norway to plan for a higher education programme. A detailed plan for the new Norwegian University was accepted by the King on 1812 March 24 and teaching began in 1813 June. This was very fortunate timing as Denmark had to turn over Norway to Sweden following the 1814 January 14 peace treaty in Kiel. A separate statement in the treaty obliged the King of Sweden to allow the future development of the University.

Although the plan listed the facilities required for the new University (including a library, museums and collections, laboratories and special lecture theatres, a botanical garden, and an astronomical observatory), only in 1833, nearly two decades later, would funds be allocated for the establishment of a permanent, fully-equipped observatory. In the interim period, Christopher Hansteen, a lecturer of applied mathematics at the new University, established a small observatory, making use of second-hand instruments then available in Norway. This first observatory introduced and established astronomy as an academic discipline at the University and became a development site for time-determination and geodetic operations.

In this paper, we review the work that was done at this first University of Oslo Observatory and re-analyse the observational results and compare them to modern values. We also discuss the current whereabouts of the original instruments, and trace their individual histories through information contained in documents and unpublished correspondence in a number of different European archives.

2 THE OBSERVATORY AND ITS INSTRUMENTS

Christopher Hansteen (1784-1873)[1] had been appointed lecturer of applied mathematics in 1813, and was offered a one-year stipend to study abroad before taking up the post. He returned to Oslo (then Christiania) in 1814 July by sailing an open boat from Denmark to Norway during wartime conditions. Upon arrival, he was required to lecture on introductory astronomy and physics. Employing a Troughton sextant and an Arnold chronometer (No. 132) borrowed from Jens Esmark, Professor of Mineralogy at the University, Hansteen used solar observations to determine the time (and to acquaint himself with astronomical observing techniques), finding to his surprise that the official local time in Oslo was incorrect by 45 minutes. He then suggested that regular observations should be carried out in order to maintain a local time service, and he also stressed the importance of determining the geographical co-ordinates of the new capital of Norway. The University responded positively to these recommendations, and provided funds for a small observatory.

Thus the University of Oslo Observatory was founded in the summer of 1815, and it was located on exposed bedrock on the southern shore of the harbour close to the Akershus fortress (Figure 1). It comprised a 5 m diameter octagonal building with an observation pillar, and housed a small transit telescope, a sextant, and a pendulum clock (Hansteen, 1822a).

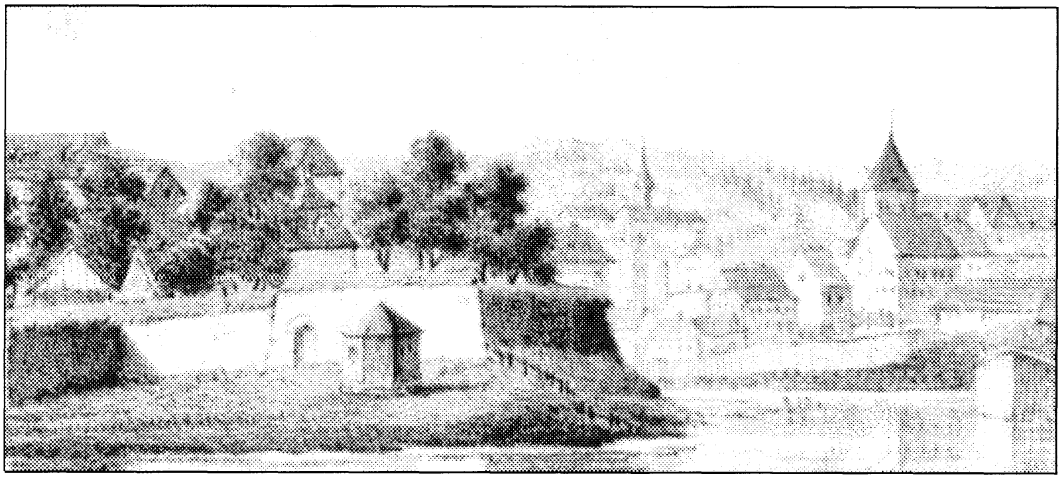

Figure 1. The first University of Oslo Observatory, as depicted in a lithograph by P E Wergmann.

The initial astronomical observations were made with Esmark's sextant and with a 35 mm diameter transit instrument that was made by Johan Ahl[2] of Copenhagen (Blankenburgh, 1973:4, Schalen *et al.*, 968:25). Due to its inferior performance, Hansteen replaced the latter instrument in 1815 August with an f/12 Sisson's transit instrument of identical aperture (Figure 2), finding this optically and mechanically excellent for its size (Hansteen, 1816). Esmark had acquired this instrument at an auction in London earlier in the year, and he sold it to the University upon returning to Oslo (see Esmark, 1815). After visits to observatories in neighbouring countries, Hansteen (1817a) concluded that by comparison his own small transit

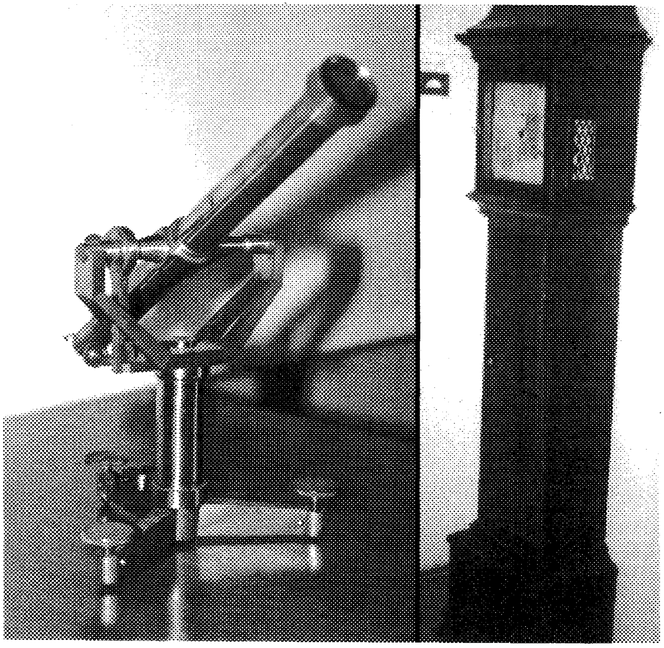

Figure 2. The transit instrument by Jonathan Sisson (left) and a pendulum clock by Abraham Pihl were initial core instruments at the Observatory.

instrument had larger magnification, showed sharper images with less chromatic aberration, and mechanically performed much better than the others he had examined.

Meanwhile, a pendulum clock made by the Reverend Abraham Pihl (1756-1821), a Norwegian multi-talented innovator and scientist, was used to record time. Esmark had acquired it from the Pihl estate and lent it to the Observatory during its first three years of operation. This clock was replaced in 1818 by a pendulum clock by Jahnson of Copenhagen, which was loaned by the Geographical Survey of Norway.[3]

3 THE POSITION OF THE OBSERVATORY

3.1 Latitude

Geographical latitude was determined by repeatedly observing circum-meridian altitudes of the Sun (i.e. near the meridian) with a sextant furnished with an artificial horizon. Typically, a dozen measurements were made within a 15-minute interval. Time was determined by observing the meridian transit of the Sun or a bright star with the transit instrument, or with the sextant by applying the method of corresponding (i.e. equal) altitudes on either side of the meridian. The results of the two timing methods would usually not differ by more than 4-5 seconds.

The initial observations with the sextant did not achieve the expected accuracy. Hansteen (1822a) therefore selected a test area and compared relative angle determinations made with the sextant and with a geographical circle made by Johan Ahl.[4] His detailed investigations led to the conclusion that the scale of the divided circle on the sextant was in error, and it was then sent to Troughton in England to be re-divided. When the instrument returned in the summer of 1818, Hansteen started his latitude observations from scratch. Later that year someone broke into the Observatory, and some instruments were stolen and others were damage. The University then sent Hansteen to England to arrange the repair of the damaged instruments, and they also provided him with funds to purchase a good sextant from Edward Troughton (see Figure 3).

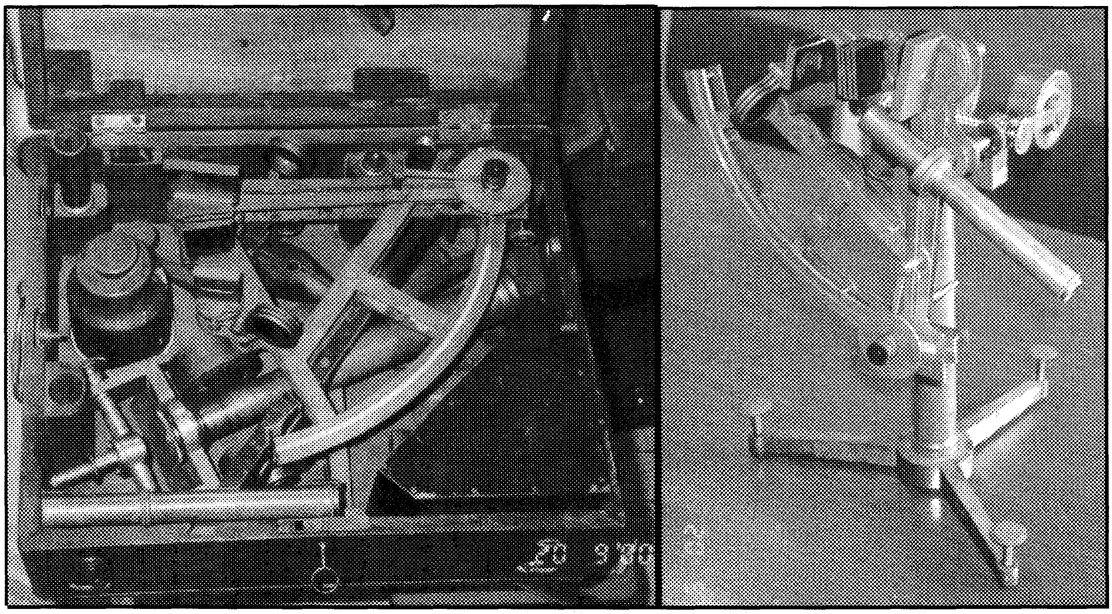

Figure 3. The sextant by Edward Troughton (No. 1385), acquired in 1819.

From three years of solar observations[5] made by Hansteen (1822a, 1823a) with the new sextant, we derive a value of $\varphi = 59° 54' 07''.2 \pm 3''.9$ for the latitude of the Observatory. During the autumn of 1821 Hansteen repeatedly observed α UMi, obtaining $\varphi = 59° 54' 03''.7 \pm 2''.4$. Sidereal time was determined before and after the α UMi observations by observing the altitude of α Lyr.

In 1817, Hansteen (1817b) had requested the advice and assistance of his colleague at Copenhagen University, Professor Heinrich Christian Schumacher, in acquiring an astronomical theodolite. Schumacher (1817) visited instrument makers in Munich that summer and reported to Hansteen that Reichenbach had agreed to finish the instrument by the summer of 1818. The delivery was delayed several times, and at the end of 1821 Schumacher (1821) was so embarrassed that he decided to sell Hansteen the best universal instrument at his own observatory in Altona (Figure 4). It had been made by Reichenbach some years earlier, and was used by Schumacher in 1815 to determine the latitude of Copenhagen (Repsold, 1918). The two vertical circles had diameters of 27 cm and the horizontal circle was 36 cm, while the refracting telescope had an objective lens with a diameter of 46 mm, a broken optical axis, and a focal length of 50 cm. Hansteen had used this instrument during a visit to Schumacher's observatory in 1820 so he knew he was being offered a high–quality instrument, and his reply to Schumacher immediately reveals this:

> Your very nobleminded offer ... caused me great joy; in my current situation I really need your instrument far more than I need a theodolite ... If you can really bear to separate yourself from this beautiful instrument, then send it as soon as the first ships arrive from Christiania ... but I can easily conceive that you find yourself in the same position as a father of a delicate and well behaved daughter who's hand in marriage is proposed by a totally unknown man; the father fears that the delicate flower will wither by the coarse touch of rough hands, and his heart bleeds as he gives his consent. I totally respect this feeling and know I would have had it, perhaps to a degree that would require me to say no!... In my short paper you will find that I have treated my sextant delicately and I believe also sensibly, although I had never had my hands on a sextant before returning to Christiania. Of course there is a large distance from a sextant to a universal instrument by Reichenbach, but one should consider only the philosophy expressed. And I promise that if I were to succeed in obtaining the utmost performance the instrument has to offer, this will happen with no harm or rough treatment to the instrument. (Hansteen 1822b):

They agreed on a price of 1550 fl., and the instrument arrived in Oslo on the schooner *Fortuna* in 1822 May (Schumacher 1822). A series of daytime observations of α UMi made at the Observatory with this instrument in the course of the year produced a latitude of $\varphi = 59° 54' 08''.4 \pm 1''.6$.

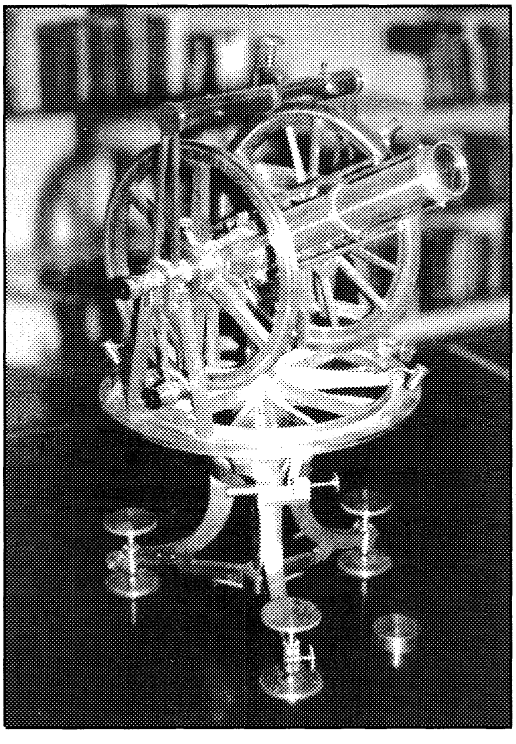

Figure 4. The universal instrument by Georg F Reichenbach.

3.2 Longitude

Longitude was determined by two different methods. The first involved timing of astronomical events from simultaneous observations at two sites. A measured difference in local sidereal time corresponded to the longitude difference between the observatories. Further connections to other observatories would eventually give the longitude relative to a reference meridian. Two centuries ago several such reference sites were used (e.g. Ferro, Greenwich, and Paris). The astronomical events observed were eclipses of the Sun, Moon, and the satellites of Jupiter, and lunar occultations of stars.

At the University of Oslo, The Physical Cabinet contributed a small Gregorian reflector (Figure 5) for these observations. It is a rare signed piece and one of very few remaining from the hands of Jesper Bidstrup, a Danish instrument-maker who spent several years in England in the 1790s. The brass tube is 102 cm long and 13 cm in diameter, and the mirror has a diameter of 12 cm. The University had acquired this telescope from the estate of Thomas Bugge, Professor of Astronomy in Copenhagen, when he died in 1815.

Figure 5. The Gregorian reflector by Jesper Bidstrup, *c.* 1790.

In 1826 Hansteen (1826) requested Schumacher's assistance to order a small Fraunhofer refractor with micrometer. Fraunhofer died that summer, but Schumacher knew that Dr Wolff of Hamburg had a 65-mm Fraunhofer telescope of 100 cm focal length for sale, which he agreed to sell for 212 fl. (190 fl. for the telescope and 22 fl. for the ring micrometer). A year later, after Hansteen (1827b) had received funding for his Siberian expedition, he collected the instrument while visiting Schumacher and brought it (Figure 6) back to Oslo, where he used it to observe lunar occultations (Hansteen 1827c, 1827d, 1827f, 1828b). The following year he took it on a two-year geomagnetic expedition to Siberia.

From Hansteen's observations of lunar occultations of stars between 1816 and 1827 we derive a longitude of $\lambda = 42^m\ 59^s.3 \pm 2^s.6$ east Greenwich, while the partial solar eclipses of 1818 and 1820 give $\lambda = 42^m\ 59\ ^s.9 \pm 3\ ^s.7$ east Greenwich. It is much more difficult to time partial solar eclipses than lunar occultations, where the star disappears abruptly behind the Moon's limb.

The other method of longitude determination involved transport of local time with a portable chronometer. In practice this required one or more chronometers that would run properly and precisely over several days. Local time was determined successively over several days by astronomical observations at the University of Oslo Observatory, in order to determine the clock drift. During the journey to a neighbouring observatory the chronometers were kept running, and upon arrival they were compared to local time derived from astronomical observations at the second site. This yielded the longitude difference directly, but the only control of clock behaviour would be a continued measuring of its drift. Obviously, a number of error sources could affect the result. Travelling on land was slow due to variable road conditions and the chronometers were frequently exposed to external forces. Travelling at sea took between 3 and 5 days from Oslo to Copenhagen. The temperature and humidity during the journey might differ from the observatory conditions and would affect the result by an unknown amount, as would the ship's movement.

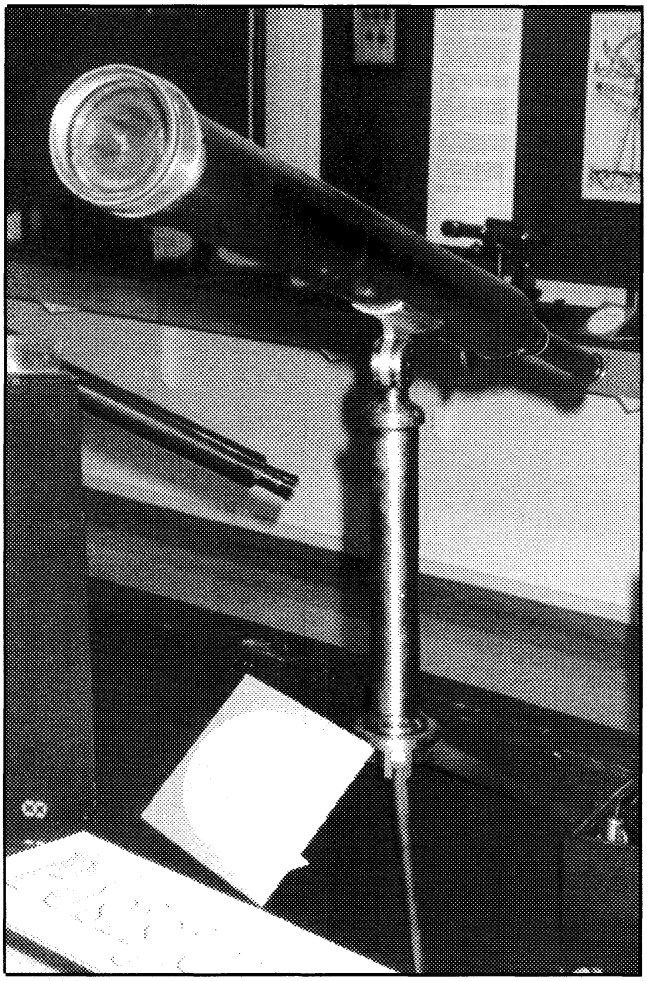

Figure 6. The small achromatic refractor by Joseph Fraunhofer, acquired in 1827.

In 1816 August, Hansteen travelled to Stockholm taking the Arnold chronometer with him. He determined the longitude difference between Stockholm and Oslo to be $\Delta\lambda = 29^m\ 16^s.1$ (Hansteen 1822:177). Using modern calibration numbers to eliminate all errors except those connected to the original observation, the derived longitude of the Observatory in Oslo is $\lambda = 42^m\ 57^s.9$ east Greenwich.

In 1817 August and 1822 July Hansteen (1822:156, 1823b:78) took the chronometer to Copenhagen by sailing ship and found longitude differences of $\Delta\lambda = 7^m\ 18^s.6$ and $\Delta\lambda = 7^m\ 17^s.9$, respectively. A repeated effort by steamship in 1827 (Hansteen 1828b: 472) with three different chronometers (Figure 7) and measurements made in both directions of the journey gave a mean of $\Delta\lambda = 7^m\ 21^s.8$. If we combine these results by giving equal weight to each chronometer per journey, the derived longitude of the Oslo Observatory is $\lambda = 42^m\ 57^s.9 \pm 1^s.6$ east Greenwich.

Hansteen's results compare well with modern values. Using his surveying results and old maps of Oslo I have been able to locate the site of his Observatory. My own GPS observation at this location on 2001 December 3 yielded a geodetic latitude of $\varphi = 59°\ 54'\ 11''$ N and a longitude of $\lambda = 10°\ 44'\ 28''$ E. A corresponding observation at the old Observatory meridian in Stockholm on 2001 October 17 implies a longitude difference of $\Delta\lambda = 7°\ 18'\ 49'' = 29^m\ 15^s.3$, which can be compared to Hansteen's value of $\Delta\lambda = 29^m\ 16^s.1$. After appropriately correcting for the deflection of the vertical, I derived a geographical position of $\varphi = 59°\ 54'\ 8''.5$ N and $\lambda = 10°\ 44'\ 46'' = 42^m\ 59^s.0$ east of Greenwich from the GPS observation at the University of Oslo Observatory site. Referring to Table 1, the modern position is closest to the latitude determined with Reichenbach's universal instrument and the longitude determined from lunar occultations. The other techniques contributed results that deviate from the modern value by factors of 1-2 of their respective standard deviations.

Table 1. Geographic coordinate determinations

Latitude

Sextant	Sextant (α UMi)	Reichenbach	GPS
59° 54′ 07″.2	59° 54′ 03″.7	59° 54′ 08″.4	59° 54′ 08″.5

Longitude

Occultations	Eclipses	Stockholm	Copenhagen	GPS
$42^m\ 59^s.3$	$42^m\ 56^s.9$	$42^m\ 57^s.9$	$42^m\ 57^s.9$	$42^m\ 59^s.0$

4 DETERMINATION OF TIME

The pendulum clocks and chronometers available in early nineteenth century Norway were partly of local origin and partly imported from nearby European countries. The quality varied dramatically, and local time throughout the country was often grossly in error. Accurate local time was determined astronomically only at the University of Oslo Observatory and in Bergen. When Hansteen (1855:9) compared time as determined from sextant observations of the Sun in 1815 with public clocks in the capital (e.g. those in church towers), the deviation was as large as 45 minutes. He responded by regularly providing time corrections determined from astronomical observations so that all clocks in Oslo would be consistent and show correct time. He also offered chronometer corrections to ships' captains to ensure accurate starting and ending points for their navigation. This activity was a forerunner to a more general time service, which was initiated at the University's second observatory in 1833 when a time ball was introduced.

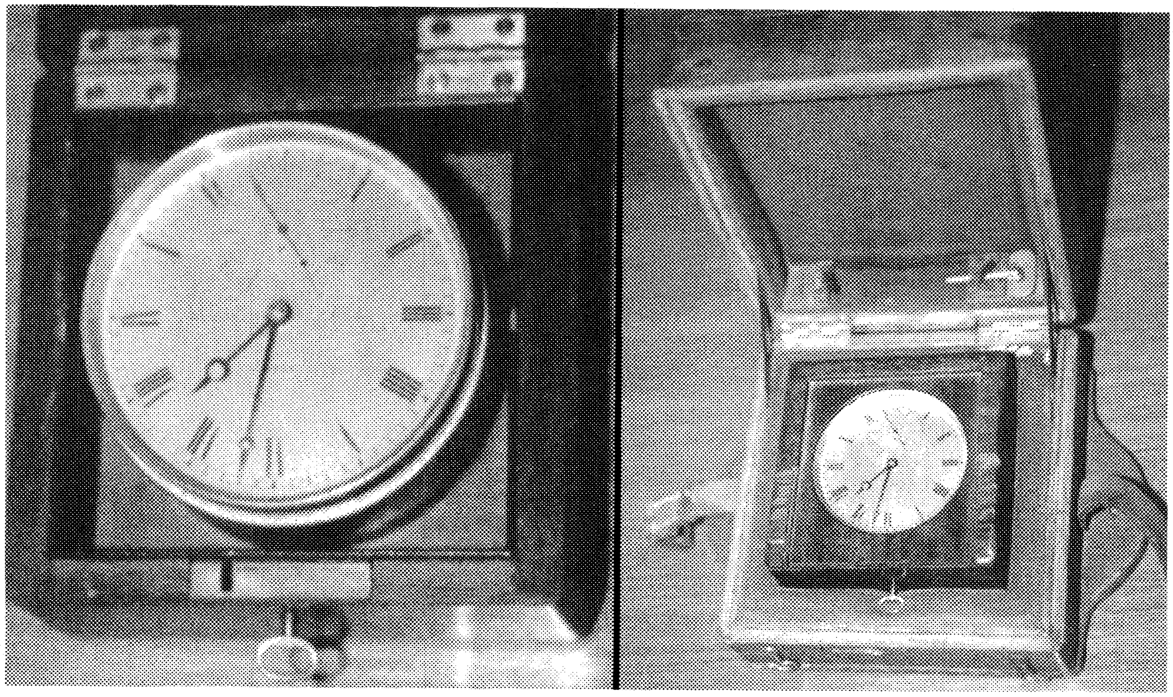

Figure 7. The Kessels No. 1259 chronometer that was used on the expedition between Oslo and Copenhagen in 1827.

Hansteen initially used the transit instrument for time determination, and these observations are discussed in his 1816 letter to Schumacher and in an unfinished text book on spherical astronomy that he was working on in about 1824. Accurate alignment of the transit instrument with the local meridian was essential, and over the years Hansteen was able to improve this by observing successive upper and lower culminations of circumpolar stars. In 1816 January his observations of β and γ UMi indicated that the transit instrument pointed 57″ and 63″ east of the meridian, respectively. Further adjustments led to an extended observing series of upper and lower culminations of α UMi in 1816 December, whereby the alignment was improved to 3″ west. Daytime transit observations of bright stars with known right ascension would provide the time directly. The alignment of the transit telescope was monitored by utilizing a meridian marker.

Due to the limitations of a meridian transit, Hansteen soon began investigating methods to determine time from non-meridian observations. He extensively employed the method of corresponding (i.e. equal) zenith distances of the Sun to determine the time with a sextant. In principle, this involves recording the time when an astronomical object of known declination reaches a given value of zenith distance and comparing it to the computed hour angle for the observing site. When more than one observation is made, the combined derivation of the average hour angle becomes non-trivial because the zenith distance does not change linearly with time. Hansteen (1827d, 1827e) developed a method of time determination which involved using a sextant to observe a series of zenith distances, separated by a fixed change (e.g. 10′) between each recording of the time. The relationship between the hour angle and zenith distance was expressed as a Taylor series, and the appropriate formulae were derived. This method was used to complement and validate time determinations derived from transit instrument observations at the Observatory, and it also proved to be efficient and practical during field expeditions.

When Hansteen received the Reichenbach universal instrument in 1822 he realized that a new approach to time determination could be implemented. Due to lack of space at the University Observatory he removed the transit instrument and installed the universal instrument. He would no longer benefit from the distant meridian marker, which was only visible in daylight. Hansteen (1824a, 1824d) thus began employing the pole star α UMi as a reference since it always appears near the meridian. The telescope would be pointed at α UMi and locked at its azimuth while a new zenith distance would allow timing the transit of another bright star through the same vertical plane. The difference in celestial coordinates and the measured time interval yielded the hour angle at the transit of the latter star. This observation would only take a few minutes and effectively eliminated error sources related to the mechanical properties of the instrument when repeated for several programme stars. The method was equally useful during the day and at night. Hansteen (1828c) derived the basic equations from spherical trigonometry and developed mathematical approximation formulae that simplified the practical computations relative to the exact case. He also discussed the effects of instrument imperfections on the accuracy of the final results and devised the observing strategy necessary to correct for them. Hansteen's paper (ibid.) prompted Bohnenberger (1828) to consider alternative derivations and compare the accuracy obtained by each approach.

5 GEODETIC OPERATIONS

On 1816 May 15 the King of Sweden and Norway ordered that a joint plan for the national surveying of the two countries should be drawn up. At about this time Hansteen detected contradictory results in the triangulation work of the Geographical Survey of Norway (which was then under military command), and on 1817 May 20 he was appointed Co-director of the Survey with the specific responsibility of analysing and evaluating the precision of all previous and future geodetic observations conducted in Norway. He soon began to influence the joint surveying plan, insisting that astronomical positioning and geodetic triangulation were employed in all future work. This also included determinations of the azimuth angle of selected triangle sides for the purpose of accurate orientation of a geodetic net. At this time Hansteen (1816) was investigating the cause of his own contradictory results for the position of the University of Oslo Observatory, and he was unable to suggest an accurate position. Instead he had to accept that the prime meridian for Norway would continue to be referred to the flagpole of Kongsvinger fortress[6] rather than to the University's Observatory. Finally, his experience during the chronometer expedition that summer to determine the longitude difference between Oslo and Stockholm encouraged him to propose that astronomical observations should be introduced as a control of the planned connection of the geodetic networks of the two countries.

The King approved the joint surveying plan on 1817 December 2 and the following summer Hansteen initiated a triangulation project to connect the geodetic nets of Norway and Sweden. With no theodolites available, the measurements had to be made with a geographical circle divided to 1 arc minute and made by Johan Ahl in 1779. The triangulation work was carried out by Svend Stenersen Collin, an army officer first assigned to the Survey in 1810, and took the best part of two summers. In 1818 it extended from Kongsvinger to the University of Oslo Observatory, and in 1819 from Oslo to the Norwegian-Swedish border near Halden. No separate length measurements of triangle sides were made. Rather, the scale of the geodetic net was based on average values for two triangle sides as determined from previous baseline measurements on frozen lakes during the winters of 1780-1782. The azimuth angle of the starting side from Kongsvinger flagpole was not very accurate either, so the derived length of the final triangle side near the border deviated significantly (175 m) from its accurate value determined locally, yielding a relative error of 1:65. Hansteen realized that new instruments were needed, and this triangulation effort was the final one in Norway with a geographic circle.

In 1817 Hansteen had ordered a 20 cm diameter astronomical theodolite with a 35 mm objective lens from Reichenbach, but delivery was delayed until 1823 (Figure 8). This instrument, which is currently on display in the museum section of the Norwegian Mapping Authority, was paid for by the University, and Hansteen (1824e) was eager to demonstrate its performance in an attempt to release government funds for similar acquisitions by the Geographical Survey of Norway. In a demonstration surveying project he determined the position of the University Observatory relative to permanent buildings in Oslo and surrounding hills (Hansteen 1824c). He established a scale by measuring a baseline of 760 m on the frozen Oslofjord directly south of the Observatory,[7] and from its end points he measured directions to church towers and hilltop cairns (Hansteen 1824b).

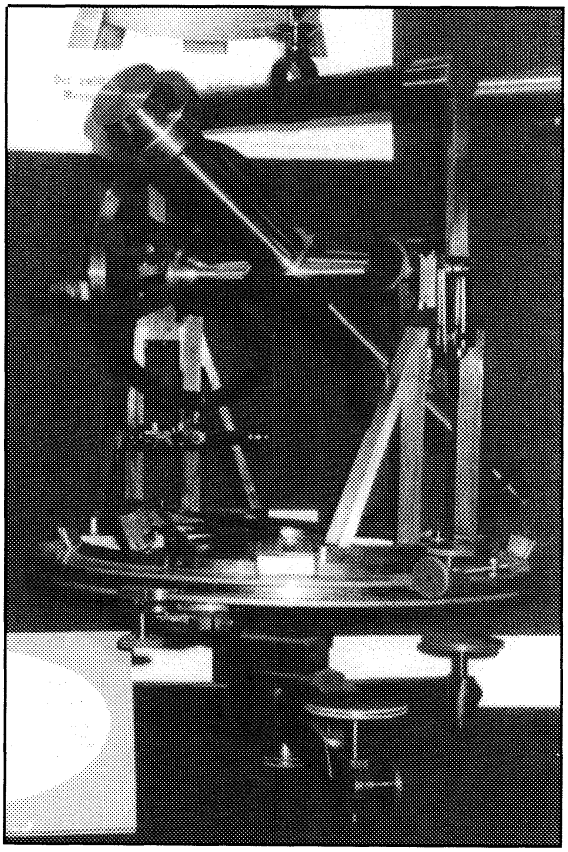

Figure 8. The astronomical theodolite by Reichenbach, 1823.

The results impressed the Government and that summer Hansteen (1824e) received permission to order two new theodolites from Ertel. They were divided to 10 arc seconds and an experienced observer could estimate to one arc second with an eyepiece and vernier. Hansteen wrote a detailed observing manual for the surveyors of the Geographical Survey of

Norway, and he arranged for Theodor Broch, an Army officer with the Survey, to measure a longitudinal arc of triangles between Femunden and Bygdin in 1826 and 1827 in order to investigate the precision obtained in a first order geodetic net. Suitable mountaintops above the forest line were selected as observing stations to ensure uninterrupted line of sight. Cairns separated by several tens of kilometres were put up to serve as observing signals. The distance between two particular mountaintops had been determined by a series of expanding triangles, starting from a baseline measured on the frozen Lake Femunden in 1782. This rather imprecise value was used to establish the scale of the test net. The orientation of the net was determined by an existing somewhat inaccurate 1782 astronomical observation of the azimuth angle of the direction between two selected mountaintops. This effort represents the first triangular arc determined by theodolite in Norway. A mercury barometer was tested as a height determination device during this pilot project, and was standard procedure for several decades to follow.

6 CONCLUDING REMARKS

The first University of Oslo Observatory existed from 1815 to 1828, and served as a training facility for Hansteen and his assistants in astronomy and geodesy. Through it, Hansteen learnt the value of possessing first-class scientific instruments, and the endless labour and frequent loss of results which could occur if forced to work with low-quality equipment; as a result, he always strove to obtain the best instruments available at the time. The Observatory also became a development site for techniques of time determination and geodetic surveying, thus directly affecting time-keeping in the capital and surveying and mapping of the young nation. Eventually the geographical position of the Observatory was better determined than that of the nation's official prime meridian.

In 1828 Hansteen departed on a geomagnetic expedition to Russian Siberia, and when he returned in 1830 the University provided funding for a new, larger, and even better-equipped Observatory. Construction started that summer and Hansteen moved in three years later. Eventually the location of this new facility would become known with even greater precision than its earlier counterpart, and only then was the position of the nation's prime meridian transferred to the University's Observatory.

7 NOTES

1. Christopher Hansteen had studied at the University of Copenhagen and won a gold medal for a treatise on geomagnetism. He expanded this work and published it in a book titled *Untersuchungen über den Magnetismus der Erde (Investigations of Terrestrial Magnetism)* in 1819. This immediately gained him an international reputation. Three years later he was able to announce in *Astronomische Nachrichten* that the King of Sweden and Norway had agreed to fund an expedition to Siberia to investigate the reality and whereabouts of a second magnetic pole on the Northern Hemisphere (Hansteen, 1822a). This two-year expedition occurred in 1828-1830. Terrestrial magnetism remained Hansteen's primary interest and research topic throughout his career. Hansteen was promoted to Professor in 1816, and by this time was already the editor of the official Almanac of Norway (1815-1862). In 1817 he took up the (part-time) position as Co-Director of the Geographical Survey of Norway, a post which he held till 1872. He was appointed to the National Commission for Weights and Measures in 1818, and served on this body for 55 years. In 1823 he began publishing the *Magazin for Naturvidenskaberne* (*Journal of Natural Sciences*) with two other professors, thus creating a forum for science news and original papers. The following year he was a co-founder of a scientific society in Christiania, which served as a precursor to the Academy of Sciences. Hansteen taught mathematics, mechanics, geodesy, and astronomy to the cadets of the Norwegian Military Academy between 1826 and 1849, and he authored several textbooks in these fields. He also founded the University's second Observatory, in 1833, and remained its Director until 1861.
2. This transit instrument, which was manufactured in 1783, has a focal length of 95 cm and is equipped with a levelling tube and a small vertical half-circle. It is on display in the museum section of the Norwegian Mapping Authority.
3. The involvement of the Geographical Survey of Norway, then a military unit, was secured by the personal interest of its Director, Major Benoni Aubert. On 1813 December 17 he

had submitted a proposal to Copenhagen for funds to establish a small observatory at Akershus fortress in Oslo, the office location of his institution. The proposal stated that the Geographical Survey of Norway already possessed suitable instruments, but that they were stored and unused due to lack of proper housing. Aubert argued that an observatory was needed for the astronomical determination of the position of the capital and for the continual training of young officers in preparation of their geodetic field surveying in the summer months each year. The proposal was never considered because Norway was separated from Denmark in the peace negotiations in Kiel one month later. Christopher Hansteen revitalized the proposal in early 1815 as a University of Oslo project, and was supported with instruments and the site by Aubert. Two years later, Hansteen was appointed a Co-Director of the Geographical Survey of Norway, in charge of astronomical and geodetic surveying. He trained and supervised young officers who carried out the observations in the field.

4. This circle, which was made in 1779, has a diameter of 46 cm, and its two telescopes have objective lenses with diameters of 18 mm and focal lengths of 56 cm. It is on display in the museum section of the Norwegian Mapping Authority.
5. Most of the observations were made in the garden outside Hansteen's residence, about 1½ km north of the University Observatory. At first the observations were carried out at the Observatory, but Hansteen found it time-consuming to walk back and forth on observing nights, especially since what promised to be a clear night was often interrupted by a rapid change of weather and the effort was wasted. Moreover, the Observatory was accessed via a locked gate in the Akershus fortress wall (see Figure 1) and Hansteen had to request the key from the guard house at the main gate of the fortress, but in winter often he found his own gate impossible to open because it was blocked by solid ice (Hansteen 1855:10). After a few years of frustration he began observing in his own garden. Local surveying (Hansteen 1823a, 1824c, Hansteen and Fearnley 1849:7) revealed this site to be 49″.6 north of the Observatory and 4″.7 west of it. The observations at the two sites may thus be combined for a corresponding estimate of the latitude of the Observatory.
6. This flagpole was chosen for the location of the prime meridian of Norway in 1773 when the Danish-Norwegian army began surveying and mapping the areas along the Norwegian-Swedish border.
7. In fact, the field work was carried by an army officer, Captain Nils Arntzen Ramm (permanently assigned to the Geographical Survey of Norway from 1818 to 1832), assisted by three young lieutenants from the Norwegian Corps of Engineers, using four equally long rods of pine with flat iron ends. Hansteen (1824b) calibrated the rods (total length = 20.0073 m) using a metre standard by Fortin in Paris. Thirty-eight rotations of the four rods imply a baseline length of 760.277 m. Two full measurement operations produced a difference of 2 mm.

8 REFERENCES

The following abbreviations are used:

SB = Staatsbibliothek zu Berlin
UOA = University of Oslo Archives.

Blankenburgh, J.C., 1973. Historikk. Astronomiske arbeider. Unpublished internal memo (in Norwegian) in the library of the Norwegian Mapping Authority.

Bohnenberger, J.G., 1828. Ueber den Gebrauch des Polarsterns als Meridianzeichen. *Astronomische Nachrichten*, **6**:317-328.

Esmark, J., 1815. Letter to the Academic Collegium, dated 9 August. Original in UOA.

Hansteen, C., 1816. Letter to Heinrich Christian Schumacher, dated 27 December. Original in SB.

Hansteen, C., 1817a. Letter to Heinrich Christian Schumacher, dated 30 January. Original in SB.

Hansteen, C., 1817b. Letter to Heinrich Christian Schumacher, dated 1 May. Original in SB.

Hansteen, C., 1822a. Geographische Bestimmungen in Norwegen. *Astronomische Nachrichten*, **1**:137-144; 145-156; 177-184.

Hansteen, C., 1822b. Letter to Heinrich Christian Schumacher, dated 17 January. Original in SB.

Hansteen, C., 1823a. Geographiske Bestemmelser i Norge. *Magazin for Naturvidenskaberne*, **2**:266-288.

Hansteen, C., 1823b. Christiania's Länge. *Astronomische Nachrichten*, **2**:77-78.

Hansteen, C., 1824a. Sternbedeckungen in Christiani. *Astrononomische Nachrichten*, **3**:225-228.

Hansteen, C., 1824b. Oplösning af en Opgave i den praktiske Geometrie. *Magazin for Naturvidenskaberne*, **3**:249-260.

Hansteen, C., 1824c. Geographiske Bestemmelser af nogle Punkter i Christianias Omegn. *Magazin for Naturvidenskaberne*, **4**:107-136.

Hansteen, C., 1824d. Letter to Heinrich Christian Schumacher, dated 24 April. Original in SB.

Hansteen, C., 1824e. Letter to Heinrich Christian Schumacher, dated 17 July. Original in SB.

Hansteen, C., 1826. Letter to Heinrich Christian Schumacher, dated 13 February. Original in SB.

Hansteen, C., 1827a. Debt certificate to Heinrich Christian Schumacher, dated 26 August. Original in SB.

Hansteen, C., 1827b. Letter to Heinrich Christian Schumacher, dated 5 February. Original in SB.

Hansteen, C., 1827c. Letter to Heinrich Christian Schumacher, dated 2 November. Original in SB.

Hansteen, C., 1827d. Letter to Heinrich Christian Schumacher, dated 8 November. Original in SB.

Hansteen, C., 1827e. Ueber Zeitbestimmungen. *Astronomische Nachrichten*, **6**:125-130.

Hansteen, C., 1827f. Sternbedeckungen in Christiania beobachtet. *Astronomische Nachrichten*, **6**:147-148.

Hansteen. C., 1828a. Sternbedeckungen in Christiania am 23. December 1827. *Astronomische Nachrichten*, **6**:471-472.

Hansteen, C., 1828b. Beitrag zur Bestimmung des Längenunterschiedes zwischen Christiania, Gothenburg und Kopenhagen vermittelst drei Chronometer. *Astronomische Nachrichten*, **6**:469-472.

Hansteen, C., 1828c. Über Zeitbestimmungen. *Astronomische Nachrichten*, **6**:189-196.

Hansteen, C., and Fearnley, C. F., 1849. *Beschreibung und Lage der Universitäts-Sternwarte in Christiania*. Universitetsprogram, Oslo.

Hansteen, C., 1855. Om det Norske Universitets og dets Observatoriums Oprindelse. *Nordisk Universitets-Tidskrift*, **3**:1-15.

Repsold, J.A., 1918. H. C. Schumacher. *Astronomische Nachrichten*, **208**:17-34.

Schalén, C., Hansson, N. and Leide, A., 1968. *Astronomiska Observatoriet vid Lunds Universitet*. Gleerups, Sweden.

Schumacher, H.C., 1817. Letter to Christopher Hansteen, dated 20 December 1817. Original in UOA.

Schumacher, H.C., 1821. Letter to Christopher Hansteen, dated 28 December 1821. Original in UOA.

Schumacher, H.C., 1822. Letter to Christopher Hansteen, dated 25 April 1822. Original in UOA.

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The fall of a meteorite at Aegos Potami in 467/6 BC

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Abstract

Cosmic catastrophes have been associated from time to time with the fall of celestial objects to Earth. From the writings of ancient Greek authors we know that during the second year of the 78th Olympiad, that is the year corresponding to 467/6 BC, a very large meteorite fell at Aegos Potami, in the Gallipoli Peninsula (in Eastern Thrace). This event was predicted by Anaxagoras, and the meteorite was worshipped by the Cherronesites until at least the first Century AD. The fall of the Aegos Potami Meteorite was not associated with any cosmic catastrophe, but it was believed to have foretold the terminal defeat of the Athenians by the Spartans in 405 BC near Aegos Potami, which brought to an end the Peloponnesian War in favour of Sparta.

In addition, according to the Latin author Pliny the Elder, during the first century AD the inhabitants of Avydus in Asia Minor worshipped another meteorite that was displayed in the city's sports centre. The fall of this meteorite is also said to have been predicted by Anaxagoras.

Keywords: *Aegos Potami, Avydus, meteorite, Anaxagoras*

1 INTRODUCTION

Aegos Potami, a name meaning in Greek 'Rivers' *(=Potami)* 'of the Goat' *(=Aega)* – although the Greek prefix 'aeg' means a place generally near water – was a stream with an ancient small town built next to its estuary on the eastern shore of the Gallipoli Peninsula in Eastern Thrace, opposite Lampsacus and Avydus. Today the Turkish village of Kara-kova occupies this site.

On the shore of Aegos Potami in the autumn of 405 BC the Athenian and the Spartan fleets faced each other, and the Spartan Admiral, Lysander, succeeded in conquering the Athenian fleet. The catastrophe was complete for the Athenians: 170 ships were seized by the Spartans and 3000 men were captured and then killed (Xenophon, 1918). This disastrous encounter virtually signified the end of the great Peloponnesian War. The Spartans, under King Agis and Lysander, then besieged Athens, which was finally forced to capitulate under humiliating terms.

Plutarch (1916:260) mentions that ancient writers were of the opinion that this catastrophe had been foretold by the fall of a very large meteorite at Aegos Potami in 467/6 BC. Furthermore, according to Pliny the Elder (AD 23-79), Plutarch (AD 45-120), Philostratus (2nd century AD), Diogenes Laertius (3rd century AD), and other authors, the philosopher Anaxagoras even predicted the fall of this meteorite. For example, Philostratos (1912:9) writes: "... we might also accuse Anaxagoras because of the many things which he foretold.

[including] ... that day would be turned into night, and stones would be discharged from heaven round Aegos Potami, and of how his predictions were fulfilled."

Anaxagoras certainly was a remarkable man, and he was very knowledgeable about astronomy. He held the view that meteorites were celestial bodies that from time to time happened to fall to Earth, and he also held equally progressive views about meteors and the composition of stars (Diels, 1996). Born near Smyrna about 500 BC, he

> ... took the more materialist Ionian ideas of philosophy with him to Athens forty years later. To Anaxagoras matter was a crowd of different entities each with different qualities or accidents as the sences suggest. However far division is carried, the parts contain things like the whole, though differences may arise from different proportions in the ingredients. Motion was originally started by Mind, a subtle fluid causing rotation which spreads and so makes and orders the world. The heavenly bodies are matter of the same nature as the Earth; the Sun is not the God Helios, but an ignited stone; the Moon has hills and valleys. Besides these speculations Anaxagoras made some real advance in exact knowledge. He dissected animals, gained some insight into the anatomy of the brain, and discovered that fishes breathe through their gills. (Dampier, 1946:22-23)

Because of these views and others, Anaxagoras was so unpopular in Athens that he almost lost his life, and he was even accused of atheism (see Diogenes Laertius, 1925; Heath, 1981; Plato, 1914; Sextus Empiricus, 1933).

2 THE FALL OF THE METEORITE ACCORDING TO THE ANCIENT SOURCES

Let us see now how the ancient writers and doxographers (writers who record the theories of older philosophers) describe the fall of the Aegos Potami Meteorite. In his *Lives of Lysander and Sulla,* Plutarch (AD 45-120) states:

> There were some who declared that the Dioscuri (Castor and Pollux) appeared as twin stars on either side of Lysander's ship just as he was sailing out of the rudder-sweeps. And some say that the falling of the stone was also a portent of this disaster; for, according to the common belief, a huge stone had fallen from heaven at Aegos Potami, and it is shown to this day by the Cherronesites, who hold it in reverence. It is said that Anaxagoras had predicted that if the heavenly bodies would be loosened by some slip or shake, one of them might be torn away, and might plunge and fall down to earth, and he said that none of the stars remained in its original position; because, as they are compact as stones and heavy, they shine due to friction with the revolving aether, and they are forced along in fixed orbits by the whirling impulse which gave them their circular motion, and this was what prevented them from falling to our earth in the first place, when the cold and heavy bodies were separated from the whole universal matter...
>
> But there is a more plausible opinion than this, and its advocates hold that shooting stars are not a flow or emanation of aetherical fire, which the lower air quenches at the very moment of its kindling, nor are they an ignition and blazing up of a quantity of lower air which has made its escape into the upper regions; but they are plunging and falling heavenly bodies, carried out of their course by some relaxation in the tension of their circular motion and falling, not upon the inhabited region of the earth, but for the most part outside of it and into the great sea; and this is the reason why they are not noticed....
>
> However, the theory of Anaxagoras is supported by Daïmachus in his treatise Peri Eusebias (On Religion); he says that prior to the fall of the stone, for seventy-five days continually, there was seen in the heavens a huge fiery body similar to a flaming cloud, not resting in one place but moving along with intricate and irregular motions, so that fiery fragments broken from it by its plunging and erratic course were carried in all directions and flashed fire, just as shooting stars do. But when it had fallen in that part of the Earth and the inhabitants, after recovering from their fear and amazement, were assembled around it, no action of fire was seen, nor even so much as trace thereof, but a stone lying there, of large size, it is true, but one which bore almost no proportion at all to the fiery mass seen in the heavens. Well, then, that Daïmachus must have indulgent readers, is clear; but if his story is true, he utterly refutes those who affirm that a rock, which winds and tempests had torn from some mountain top, was caught up and borne along like a spinning top, and that at the point where the whirling impetus given to it first relaxed and ceased, there it plunged and fell. Unless, indeed, what was seen in the heavens for many days was really fire, the quenching and

> extinction of which produced a change in the air resulting in unusually violent winds and agitation, and these brought about the plunge of the stone. However, the minute discussion of this subject belongs to another kind of writing. (Plutarch, 1916:260-265).

According to Pliny (1938, II:149) the meteorite fall occurred in the year 467/6 BC, while Aristotle (384-22 BC) records that the event took place during daylight hours and that a comet was visible in the evening sky at the time: "... when the stone fell from the air at Aegos Potami it had been lifted by the wind and fell during the daytime; and its fall coincided with the appearance of a comet in the west." (Aristotle, 1952:55). In another account, Aristotle provides more details:

> On the occasion when the (meteoric) stone fell from the air at Aegos Potami, it was caught up by a wind and was hurled down in the course of a day; and at that time too a comet appeared from the beginning of the evening. Again, at the time of the great comet (373/2 BC) the winter was dry and arctic, and the tidal wave was caused by the clashing of contrary winds; for in the bay the north wind prevailed, while outside it a strong south wind blew. Further, during the archonship of Nicomachus at Athens (341/0 BC) a comet was seen for a few days in the neighbourhood of the equinoctial circle; it was at the time of this comet, which did not rise with the beginning of the evening, that the great gale at Corinth occurred. (Heath, 1981:246).

These accounts by Aristotle appear to be the earliest mention of the Aegos Potami Meteorite by any writer whose works has survived, while the second century BC doxographer, Aetius, also reports this event:

> Diogenes says that the stars are like pumice stones, and he considers them as pores through which the world breathes; and that they are red-hot. In addition to the visible stars, invisible stones also wander through the heavens, having no name. They frequently fall on Earth and their fire gets extinguished, like the stony star which fell in flames at Aegos Potami. (Aetius, 1879:342).

Diogenes was a contemporary of Anaxagoras.

Pliny the Elder (AD 23-79) reports the same event in his *Naturalis Historia*, and he also mentions a meteorite that fell at Avydus, again apparently after a prediction by Anaxagoras. An English translation of the relevant passage reads:

> The Greeks say that Anaxagoras of Clazomenes succeeded during the second year of the 78th Olympiad [467/6 BC] with his knowledge in astronomical literature to predict that some days later a stone from the Sun would fall, and this happened during the daytime at the area of Aegos Potami of Thrace – and this stone can be viewed even today, having the size of a chariot and brown color – when a comet was shining during the nights. If one believes in this prediction, he must at the same time accept that the supernatural abilities of Anaxagoras consisted of an even greater miracle, that our understanding of nature is zero and everything is in confusion if it is credible that either the Sun itself is a stone or it ever used to have a stone inside it. Yet it is not doubted that stones do fall frequently. For this reason, in the sports center of Avydus they still worship today a stone, medium-sized to be fair, for which it is said that Anaxagoras had again predicted its falling at the middle of the Earth. (Pliny, 1938:284).

Pliny also describes the Aegos Potami Meteorite as "... the size of a wagon and black in colour." (cited in Brown, 1973:153).

The other meteorite that Pliny refers to above was located at Avydus. This ancient Greek city was located north-east of the present-day Turkish town of Çanakkale, on the Asian shore of Hellespontus and at the narrowest part of the channel. Perhaps it is a coincidence, but in 411 BC, prior to the battle at Aegos Potami, one of the most violent naval battles of the Peloponnesian War took place near Avydus, with victory in this instance going to the Athenians.

3 DISCUSSION

Apart from Pliny the Elder's reference to its size and colour, there are no descriptions of the appearance or physical properties of the Aegos Potami Meteorite, but its brown or black colour suggests oxidation and that it was more likely an iron meteorite rather than a stony or stony-iron. This view is also supported by its size, for large iron meteorites are more commonly found intact, whereas stony meteoroids often disintegrate prior to impact. Thus, the largest known iron meteorite is the 60 ton Hoba West mass from Namibia, whereas the largest extant stony meteorite currently on record weighs 1.9 tons and was recovered near Jilin in China (Norton, 2002:45). If the Aegos Potami Meteorite really was of chariot- or wagon-like proportions, then it would have weighed an impressive several tons, but it would hardly have rivelled the Hoba West Meteorite.

What became of the Aegos Potami Meteorite is not clear. In the era of the Roman author Pliny the Elder (AD 23-79), it was still visible at its impact site, and was revered by the local population. In 2002 June three of us (E.T., P.N. and V.M.) were in the Turkish city of Çanakkale attending a binary stars workshop, and were able to visit the village of Kara-kova, where Aegos Potami once stood. The present inhabitants of Kara-kova are farmers who knew nothing about the fall of a meteorite there more than two and a half millennia earlier, and we could not find any remains of the ancient settlement. However, in geological terms, estuarine coastal localities like this are subject to rapid change as a result of erosion and/or sedimentation, so it is possible that with the passage of time the Aegos Potami Meteorite was been covered with sediments or may even have weathered away. However, it would be a worthwhile exercise to conduct a systematic geophysical survey of the area just in case it has survived intact.

The current whereabouts of the Avydus Meteorite is also unknown. During the 2002 June Workshop we also had the opportunity to visit this ancient city, which contains many archaeological remains, and we learned that when Sultan Selim III constructed the walls of the Nara Castle in 1807 he used material from the ancient city. The sports centre was apparently destroyed at this time, and the present inhabitants of the city had no knowledge of the meteorite mentioned by Pliny the Elder.

Although the fall of the Aegos Potami Meteorite is one of the most comprehensive that has been documented in the early literature, reference to it is surprisingly rare in books on meteorites or astronomy (but for some exceptions see Bagnall, 1991:1; Brown, 1973:153; Flammarion, 1955:395; Moore, 1971:1). Nor is the Aegos Potami Meteorite fall the earliest on record. According to Bevan and De Laeter (2002:12), "The earliest known record of a meteorite fall comes from around 4000 years ago in Phrygia (now part of Turkey). According to the Roman historian Titius Livius, the celebrated meteorite at Phrygia was later transported in royal procession to Rome where it was worshipped for another 500 years." In 1873 Daniel Kirkwood consulted various sources in order to compile a list of falls, and the following also pre-date the Aegos Potami event:

(1) About 1478 BC an aerolite or thunder stone, as it was called, fell in the Island of Crete.
(2) A number of stones which were anciently preserved in Orchomenos, a town in Boetia, were seen to have fallen from Heaven about 1200 BC
(3) In 1168 BC a mass of iron was seen to descend upon Mount Ida in Crete. (Cited in Nininger, 1952:5).

Meanwhile, Meunier lists 28 different falls that were documented between 1478 BC and 6 BC (ibid.).

In contrast, the earliest fall associated with a known meteorite that is currently in existence occurred on 861 when a meteorite landed at the Suga Jinja Shinto shrine at Nogata, Japan. This treasured fist-sized relic has been preserved there ever since, and the "... date of fall – May 19, 861 AD – is recorded in old literature as well as on the lid of the wooden box in which it has been stored." (McSween, 1987:1-2). But perhaps the best-known early fall took place near Ensisheim (now part of France) on 1492 November 16 (Zanda and Rotaru, 2001:16-19). There is a sizable body of literature about this event (e.g. see Marvin, 1992), and the main mass of this large stony meteorite is still preserved in the town's Palais de Régence.

4 CONCLUSION

Ancient Greek authors and doxographers have documented the fall of a relatively large meteorite at Aegos Potami in the Gallipoli Peninsula in the year 467/6 BC. This fall, which was possibly predicted by the philosopher Anaxagoras, did not cause a cosmic catastrophe or any kind of extended damage, but it was associated with a tragic defeat of the Athenians by the

Spartans during the battle of Aegos Potami in 405 BC, thus bringing to an end the Peloponnesian War. The historical records contain tantalizing little about the nature and appearance of the Aegos Potami Meteorite, which we surmise to be an iron meteorite, and its current whereabouts is unknown.

In addition to recording the Aegos Potami Meteorite, Pliny the Elder also reports the existence of a revered meteorite at the nearby city of Avydus during the first century AD. The current location of this meteorite is also unknown.

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6 REFERENCES

Aetius, 1879. *Aetii De Placitorum Compositione (De Vestutis Placitis).* Diels, H., *Doxographi Graeci. Editio Quarta.* Walter De Gruyter et Socios, Berolini (reprinted 1965).

Aristotle, 1952. *Meteorologica.* Heinemann, London (The Loeb Classical Library; English translation by H.D.P. Lee).

Bagnall, P.M., 1991. *The Meteorite & Tektite Collector's Handbook.* Richmond, Willmann-Bell.

Bevan, A., and de Laeter, J., 2002. *Meteorites. A Journey Through Space and Time.* Sydney, University of New South Wales Press.

Brown, J.L., 1973. *Comets, Meteorites and Men.* Hale, London.

Dampier, W.C., 1929. *A History of Science and its Relations with Philosophy and Religion.* Cambridge University Press, Cambridge (reprinted 1946).

Diels, Hermann, 1996. *Die Fragmente der Vorsokratiker. Herausgegeben v. Walter Kranz (Volumes I and II).* Weidmann, Zurich.

Diogenes Laertius, 1925. *Lives of Eminent Philosophers.* Heinemann, London (The Loeb Classical Library; English translation by R.D. Hicks, revised and reprinted 1959).

Flammarion, C., 1955. *Astronomie Populaire.* Édition Entrièrement Refaite. Flammarion Librairie, Paris.

Heath, Th.L., 1981. *Aristarchus of Samos the Ancient Copernicus. Part II: Aristarchus of Samos: On the Sizes and Distances of the Sun and Moon.* Dover, New York.

McSween, H.Y., 1987. *Meteorites and Their Parent Planets.* Cambridge University Press, Cambridge.

Marvin, U.B., 1922. The meteorite of Ensisheim: 1492-1992. *Meteoritics*, **27**:28-72.

Moore, C.B., 1971. *Meteorites.* Houghton, Mifflin, New York.

Nininger, H.H., 1952. *Out of the Sky. An Introduction to Meteoritics.* Dover, New York.

Norton, O.R., 2002. *The Cambridge Encyclopedia of Meteorites.* Cambridge University Press, Cambridge.

Philostratus, 1912. *The Life of Apollonius of Tuana, The Epistles of Apollonius and the Treatise of Eusebius.* Heinemann, London (The Loeb Classical Library; English translation by F.C. Conybeare, 1969).

Plato, 1914. *Euthyphro, Apology, Crito, Phaedo, Phaedrus.* Heinemann, London (The Loeb Classical Library; English translation by H.N. Fowler, 1953).

Pliny, 1938. *Naturalis Historia.* Heinemann, London (The Loeb Classical Library; English translation by H. Rackham, 1958).

Plutarch, 1916. *Lives of Lysander and Sulla. Volume IV.* Heinemann, London (The Loeb Classical Library; English translation by Bernadotte Perrin, 1950).

Sextus Empiricus, 1933. *Outlines of Pyrrhonism. Volume I.* Heinemann, London (The Loeb Classical Library; English translation by R.G. Burry, 1967).

Xenophon, 1918. *Hellenica. Books I-V.* Heinemann, London (The Loeb Classical Library; English translation by C.L. Brownson, 1947).

Zanda, B., and Rotaru, M., 2001. *Meteorites. Their Impact on Science and History.* Cambridge University Press, Cambridge.

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The 1900-1 opposition of 433 Eros, the solar parallax, and the contribution of Padova Observatory

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Abstract

In 1898 a new asteroid, 433 Eros, was discovered. As the opposition of 1900 October 30, would bring this asteroid very close to Earth, the *Comité International Permanent pour l'Exécution Photographique de La Carte du Ciel* instituted a special temporary Commission with the task of co-ordinating micrometric, heliometric, and photographic observations from different places on Earth, in order to determine the solar parallax. Fifty-one astronomical observatories, including the Italian Observatories of Arcetri, Padova, and Teramo, took part in this project with visual and photographic observations. Antonio Maria Antoniazzi, astronomer at the Padova Observatory, observed the new asteroid from 1900 October to 1901 February. The 122 observations made in Padova from October to December, formed part of the data set used by Arthur Hinks of the Cambridge Observatory, who had the task of reducing all of the observations. In addition to discussing the final outcome of the 1900-1 programme, this paper briefly examines the solar parallax investigations associated with the Eros opposition of 1930-1.

Keywords: *Eros oppositions, solar parallax, Padova observations*

1 INTRODUCTION

On 1898 August 13, Gustav Witt of the Urania Observatory[1] in Berlin (Witt, 1898, 1899b), and independently on the same date, Auguste H P Charlois of the Nice Observatory (Perrotin, 1898), discovered a new asteroid, named 1898 DQ, on their photographic plates. From the moment of this discovery, the *Astronomische Nachrichten* (1898-9) started to publish ephemerides, orbital elements (Berberich, 1898; Millosevich, 1899), magnitude estimates, and other kinds of observations from European observatories. Meanwhile, *The Astronomical Journal* (1898-9) published data mainly from North American observatories.

Witt assigned the new celestial body the masculine name of Eros, in contrast with the tradition of giving feminine names to asteroids. In fact, because of its peculiarly high diurnal motion in RA (100^s), he believed that the new body could not belong to the asteroid group (Witt, 1899a), but Julius Bauschinger, Professor of Theoretical Astronomy in Berlin, claimed that 1898 DQ was an asteroid, arguing that its aphelion was 0.17 AU from the inner asteroid ring and that other asteroids had been found with their perihelion distances internal to the orbit of Mars. He also pointed out that because of the small mass and high eccentricity of its orbit, Mars could not be the absolute inferior limit of the asteroid ring, and it was probable that other asteroids would be found between Eros and Hungaria (Bauschinger, 1899). Eros was the first member of the group of Earth-approaching asteroids to be discovered, and the number 433 was assigned to it.

The Eros opposition of 1900 October 30 would bring the asteroid very close to Earth (minimum distance, December 26), and would provide astronomers with an excellent opportunity to determine the solar parallax. This encouraged the *Comité International Permanent pour l'Exécution Photographique de La Carte du Ciel* (Permanent International Committee for Photographic Execution of Sky-map) to establish a special temporary Commission with the task of co-ordinating observations.

In his opening speech at the meeting of 1900 July 19 – the fifth session of the International Committee – the President, Maurice Loewy, highlighted this extraordinary event with the following words:

> But you will have to examine one of the greatest problems of astronomy, the solution to which, sought for a century and more in many different ways, now seems ripe for serious progress. In fact, the discovery of the planet *Eros* will give the possibility of determining the parallax of the Sun at certain epochs, with a precision until now unattainable. The strong organisation of the observatories associated in the sky-map undertaking, has led many members of the Committee to believe that this work may be done efficaciously by many of those establishments, the geographic location of which is best suited for such a mission. (Réunion ..., 1900:3; translated from French).

The special Commission, presided over by Loewy, consisted of nine members: W H M Christie (RGO), D Gill (Royal Observatory, Cape of Good Hope), E Weiss (Vienna Observatory), C Trépied (Algiers Observatory), H G van de Sande Bakhuyzen (Leiden Observatory), W L Elkin (Harvard Observatory) G Hartwig (Bamberg Observatory), C-L-F André (Lyons Observatory) and P Henry (Paris Observatory). The Commission was charged with the task of preparing resolutions to be submitted to the International Committee and then organizing the associated observations. Work started during the 1900 meeting, and in a short time observational criteria were adopted and six circulars were issued, containing all the necessary instructions on how to correctly perform the observations and data reductions.

2 THE WORK OF THE COMMISSION

The special Commission decided that parallax determinations of Eros would be carried out by means of micrometric, heliometric, and photographic observations, by co-operation between European and North American observatories, and between observatories in the Northern and Southern Hemispheres. Observations were to be performed with the widest convenient hour angle, to obtain the maximum value of parallactic displacement. However, the asteroid had to be observed at zenith angles of ≤70° in order to reduce refraction effects. Observational continuity was to guarantee determination of the asteroid's motion with the greatest precision and directly, day by day: this fact was essential in determining accurately the parallax of Eros. The Commission also established the need to take a series of photographic plates covering the whole region of the sky where Eros was situated in order to determine the positions of suitable comparison stars with extreme precision, and this task was particularly entrusted to those observatories which were already involved in the Carte du Ciel project (*Circulaires* 1-2, 1900:103-112).

Observatories which participated in the project from the beginning were: Algiers, Athens, Bamberg, Bordeaux, Cambridge (England), Cape of Good Hope, Catania, Cordoba, Edinburgh, Greenwich, Harvard, Heidelberg, Leiden, Leipzig, Lyons, Marseilles, Minneapolis, Mount-Hamilton, Nice, Paris, Potsdam, Collegio Romano, San Fernando, Strasbourg, Tacubaya, Toulouse, Upsalla, Vienna, Vienna, Washington, and Williams Bay (*Circulaire* 1, 1900:108). These were soon joined by observatories in Berlin, Besançon, Brussels, Charlottesville, Christiania (= Oslo), Denver, Dublin, Evanston, Florence, Helsingfors, Koenigsberg, Lisbon, Madison, Northfield, Oxford, Padova, Palermo, Poulkovo, Thachent, and Teramo (*Circulaire* 5, 1900: 126). According to *Circulaire* 1 (1900:108),

> The initial challenge for each Observatory contributing to this common work ... [is to] decide what part it will carry out. We kindly request Observatories to inform the President of the Executive Commission, as soon as possible, about their precise intentions, so that the necessary arrangements can be made to complete the general plan ... (translated from French).

In *Circulaire* 3, dated 1900 August 17, the Commission provided all the observatories with a table of the daily period of visibility of Eros; a second table of the equatorial coordinates of its orbital points, spaced at approximately one degree intervals; and ephemerides of Eros up to 1901 January 7, calculated by E Millosevich (1900) of the Collegio Romano. Later ephemerides, up to March 8, were published in *Circulaire* 5, dated 1900 October 10. *Circulaire* 4 listed 307 comparison stars whose positions would have to be determined with extreme precision, and a further 352 stars were added in *Circulaire* 5. Lastly, in *Circulaire* 6, which was actually issued on 1900 December 4 while the Eros observations were in progress, the Commission provided the apparent positions of the 77 fundamental stars and the 4 polar stars in Newcomb's Catalogue (Newcomb, 1898), that could be used in the reduction of the meridian observations of Eros.

Between 1901 and 1907, when *Circulaire* 12 was printed, the Commission published observations and results from the various observatories. *Circulaire* 10 (1903) contained visual observations from Arcetri, Besançon, Charlottsville, Cordoba, Edinburg, Heidelberg, and photographic observations from Bordeaux and Paris, while in the Supplements Loewy provided tables to facilitate the transformation from rectangular to equatorial coordinates on the photographic plates. *Circulaire* 11 (1904) listed visual observations from Marseille, Padova, and Paris; photographic observations from Alger, Northfield, Catania, San Fernando, Paris, Toulouse, and Bamberg (heliometric observations); and the star catalogue prepared by Tucker of Mount Hamilton. *Circulaire* 12 (1907) provided visual observations from Teramo, Paris, Poulkovo, Christiania, and Nice, and photographic observations from Helsingfors, Greenwich, Cambridge, Oxford, Poulkovo, Upsalla, and Minneapolis. The newest and best ephemerides, computed with the vast quantities of data collected; the most recent positions of comparison stars; and all the equations useful for data reduction, concerning measurement errors, effects of atmospheric refraction, etc., were also published.

3 THE PHOTOGRAPHIC OBSERVATIONS

The Eros campaign was strictly linked to the Astrographic Catalogue (*Carte du Ciel*) because of the positions of the reference and comparison stars, both for visual and photographic observations of the asteroid. The precision of the stellar positions would impact on Eros's coordinates and, in consequence, the value of the solar parallax.

Newcomb (1900) favoured photography as the best method of observing the asteroid during this important campaign. He was convinced of this because of the precise positions of celestial bodies that were attainable on photographic plates, and because suitable photographic telescopes were in use at various observatories that were favourably located in relation to the Eros observations. However, there was a problem concerning the faint photographic magnitude of Eros and its rapid motion, so Hinks (1900) suggested that observers should track the asteroid and let the stars trail in guiding telescope. The next step was the reduction of the photographic plates, where many exposures of Eros were present, and the accuracy of the measures partly depended upon the plate-measuring machines (Hinks, 1901a, 1901b, 1901c, 1901d, 1904c, 1904d).

In 1903, a dispute arose between Hinks, Loewy, and Dyson about the collection and publication of data from the various participating observatories and methods used in the reduction of the photographic plates, and a number of papers using the generic title 'Eros and the solar parallax' appeared in *The Observatory*. Hinks (1903) began by complaining about the increasing size of Circulars. He also criticized the fact that each observatory had derived 'individual means' from its own observations, thereby preventing the derivation of a conclusive and definitive mean, and he suggested that the accumulated material might have been handed over to an individual who was expert in working up observational data. In particular, he deplored the procedure adopted by the Committee for the determination of the position of Eros on the photographic plates and in consequence its parallax (i.e. the method of transforming the measured rectangular coordinates into differences in RA and Dec), whilst keeping in mind the missing of faint comparison stars and the very imprecise positions of the reference stars published by the Paris and Bordeaux Observatories.

Loewy (1903) refuted all of Hinks's criticisms: he explained that many comparison stars were missing because data from many observatories had not arrived when the last circular was published; that Paris and Bordeaux observations from the period November 7 to 15 were insufficient because of bad weather; that equatorial coordinates of the reference stars were used successfully for more general scientific purposes, not just for calculating the solar parallax; that individual astronomers were thoroughly competent to effectively reduce their own observations; and finally that data were published as early as possible so that Hinks could use them in his own investigation of the solar parallax.

Hinks (1904a) responded by referring to the differences between the "French and English schools" when it came to photographic methods, and the fact that the photographs had to be used to derive relative places and not absolute ones.

Dyson (1904) from the RGO then entered the dispute. He totally supported Loewy's methodology and derivation of RA and Dec. from the photographic plates, and believed that each observatory should be responsible for the reduction its own measurements.

Once again Hinks (1904b) wrote a short reply in order to emphasize the different opinion between Dyson and himself.

Hinks (1903:343) was also involved in a controversy regarding the measures made with the great equatorials of Washington, Lick, and Yerkes, concluded that "... nearly one half the results ... are useless ..." Tucker (1903), from the Lick Observatory, was quick to respond. He explained the observational methods and their associated errors, provided a list of the mean differences in RA and Dec. derived from observations of 351 different reference stars observed at the Lick Observatory and the U.S. Naval Observatory, and concluded by stating: "It is my purpose to give some attention to the discussion of the list places published in the Circulars of the International Conference." (Tucker, 1903:461).

The Eros campaign continued in spite of this dispute, and it is therefore a little ironic that the processing of all of the photographic and visual observations published in the Circulars and provided by the various participating observatories ended up being undertaken by the University Observatory in Cambridge (UK), under the patronage of the Royal Astronomical Society, and entrusted to none other than Arthur Hinks (see Hinks, 1906, 1907, 1909a, 1909b, 1910). After reducing all of the photographic, heliometric, and micrometric observations made by the participating observatories around the world, Hinks presented his final results to the Paris Academy in 1909. This very large data set produced parallax values of $\pi = 8''.807 \pm 0''.0028$ based on the photographic observations and $\pi = 8''.806 \pm 0''.004$ based on all of the micrometric measures (Solar parallax, 1911). For this work, Hinks was awarded a prize by the *Fondation Leconte*, and the Gold Medal of the Royal Astronomical Society. In his presentation address, the President of the RAS began with these words: "The Gold Medal of the Society has been awarded by the Council to Mr. Arthur Robert Hinks for his Determination of the Solar Parallax from Observations of Eros. It is my privilege to lay before you the grounds of this award." (Address ..., 1912).

4 THE PADOVA OBSERVATORY OBSERVATIONS

4.1 The Micrometric Observations

Antonio Maria Antoniazzi[2] (Figure 1), Assistant at the Padova Observatory, was entrusted to make micrometric observations with the 187-mm f/16 Merz Refractor, the largest telescope at the Observatory (Figures 2 and 3).[3]

For micrometric observations, the Commission (*Circulaire* 2: 110) recommended measuring RA and Dec. with the micrometer, as asteroid and comparison star were contemporaneously visible in the telescope field, so that their differences in RA and Dec. could be measured directly. Instead Antoniazzi decided to employ the transits method, which he thought was more suitable for the small Padova refractor. This method consisted of recording by means of a chronograph and along the same hour circle, the difference in times of transit of the asteroid and the comparison star across the wires of the micrometer, and of measuring the difference in Dec. keeping the telescope fixed. Although this method had a larger number of instrumental errors than that proposed by the Commission (e.g. instability of the telescope, stationary conditions, micrometer orientation, etc.) and was affected by the 'equation of magnitude' (the time difference between the observations) when the comparison star and the asteroid were not of the same magnitude, it did have the great advantage of using the same comparison stars both in the evening and in the morning – something which was impossible with the Commission's method, because of the rapid motion of Eros in RA.

On this occasion, Antoniazzi used the original filar micrometer (Figure 4) of the telescope, which had been adopted by its previous owner, Baron Dembowski, for the measurement of double stars. However, the micrometer was partially modified: the five hour wires were substituted and two parallel wires replaced the single movable one (so that the Dec. measurements were executed by setting the planet between these two wires, instead of bisecting it with only one wire). In addition, Antoniazzi accurately re-measured the pitch of the micrometer screw, obtaining results consistent with the earlier measurements of both Dembowski and also Antonio Abetti (when he was an astronomer at the Observatory).

Antoniazzi's observations commenced on 1900 October 23 and continued until 1901 February 13. A complete observation lasted on average half an hour and consisted of ten 'pointings' with the telescope fixed. For each 'pointing', Antoniazzi recorded the transit times across the five hour wires of both Eros and the chosen comparison star and he also made one or two Dec. measurements. The whole procedure was then repeated both east and west, for each available comparison star, and thus Antoniazzi determined the differences in RA and Dec. between Eros and the comparison star (see Figure 5). In order to minimize the 'equation of magnitude', he took care to select comparison stars of $m_v = 8.5–9$, comparable to the magnitude of Eros at the time. Over a period of four months, Antoniazzi performed 180 micrometric observations, employing 113 different comparison stars, all chosen from the *Astronomische Gesellschaft Catalogue.* He then published his derived geocentric co-ordinates of Eros in *Circulaire* 11 (1904:25-35), and compared them with Millosevich's (1902) ephemerides.

Figure 1. Portrait of Antonio Maria Antoniazzi (1872-1926).

4.2 Data Reduction and Parallax Determination

As is well known, the starting-point for trigonometric determination of the solar parallax is the definition of the equatorial horizontal parallax, π, which is the angle, in seconds of arc, subtended by the equatorial radius of Earth, r, at the Sun's mean distance, d. Thus, the mean Earth-Sun distance, d, also known as the astronomical unit, is given by the formula

$$d = r / \sin \pi$$

However, numerous complex calculations must be performed in order to reduce the observations and derive the solar parallax. As a solution, the method of the transit of Venus gives the difference between the parallaxes of the Sun and Venus, but the opposition of Eros has the advantage that the angle of parallax is larger and thus more easily measurable, and in addition the asteroid appears as a stellar object in the telescope field, so that the position errors are smaller. In both cases, the calculations are laborious, but the latter case avoids the errors of the former due to poor precision in determining the contact times, and the difficulty of using observers located at different observing stations, the geographical coordinates of which have to be very accurately determined.

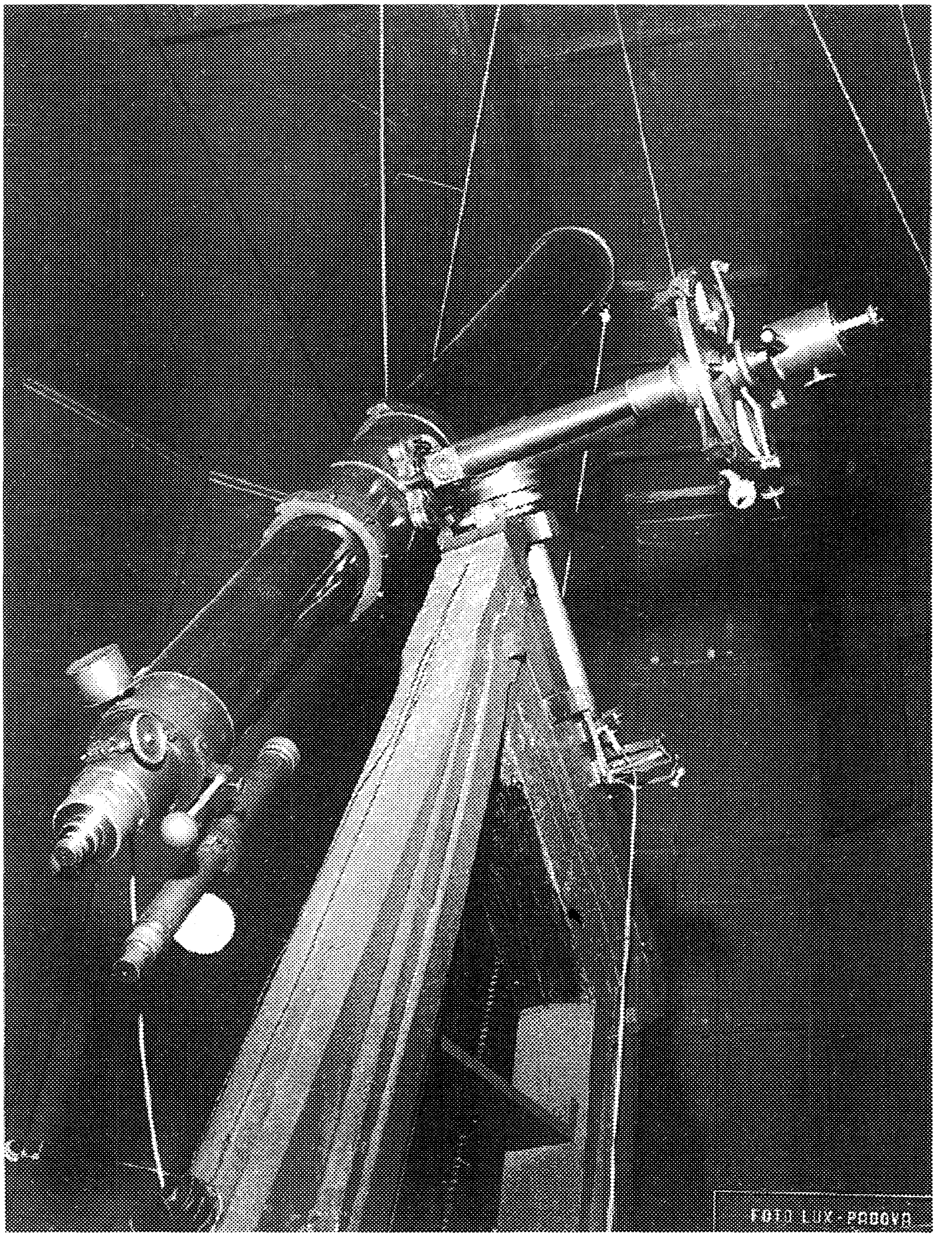


Figure 2 The 187-mm Merz refractor of Padova used for the Eros observations (Photograph: Astronomical Observatory of Padova, Historical Archives).

In Antoniazzi's procedure, the correction to be derived concerns the standard solar parallax adopted for the calculations, and this depends on the diurnal parallax of the asteroid, the unknown correction of its ephemeris, and the mean deviation of the hour wires from the direction of the declination circle, in short, three unknowns for each equation. For instance, the comparison of the observed RA and that calculated of the ephemeris, gives the difference $(O-C)_\alpha$. If α is the true RA, it will be $O_\alpha = \alpha + \Delta O_\alpha$ and $C_\alpha = \alpha + \Delta C_\alpha$, so that $(O-C)_\alpha = \Delta O_\alpha - \Delta C_\alpha$. Of the systematic errors of the observed values, only two are considered: one from calculation of the diurnal parallax by adopting the standard value of solar parallax, which must in turn be corrected, and the other regarding the above-mentioned orientation of the hour wires. The general form of the equation is:

$$(O-C)_\alpha^s = -\frac{\rho}{15\Delta}\cdot\frac{\cos\varphi\cdot\sin\tau}{\cos\delta}d\pi'' - \frac{(\delta_\circ-\delta_*)''}{15}\cdot\frac{\tan\omega}{\cos\delta} + \frac{x''}{15\cos\delta}$$

where $x'' = -15\Delta C_\alpha \cos\delta$, and is the correction for the ephemeris in seconds of arc.

Figure 3. The high medieval tower transformed into the Padova Astronomical Observatory from 1767 to 1777. On the left is circular brick dome constructed in 1882 to house the Merz refractor (Photograph taken in 1929: Astronomical Observatory of Padova, Historical Archives).

Thus, because the difference between observed and calculated RA is equal to the difference between their respective errors, an equation of three unknowns, as mentioned above, is found. Antoniazzi (1911:318) concluded: "It will be possible to determine the three

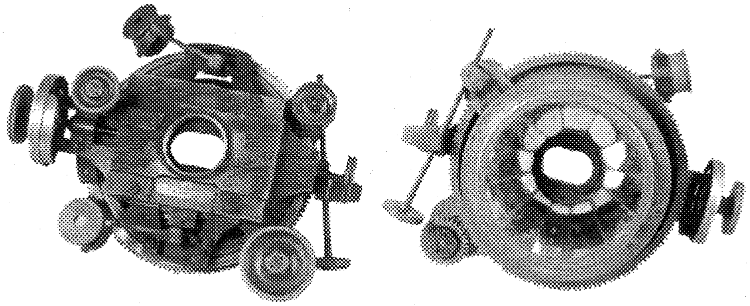
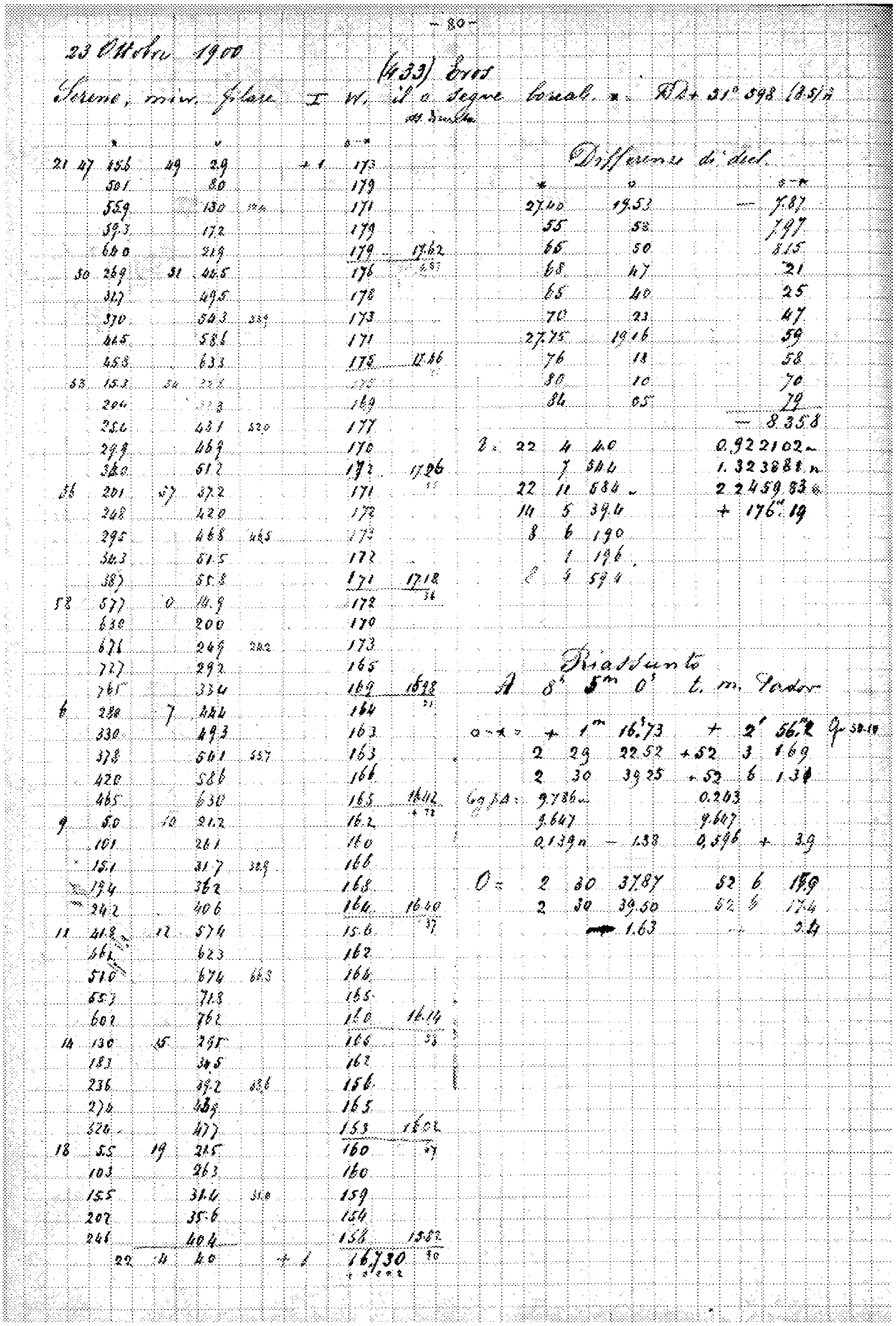


Figure 4. The filar micrometer used for the Eros observations. Shown on the right is the reflecting mirror system used to obliquely illuminate the thin spider wires with red light (Museo *La Specola*, Astronomical Observatory of Padova).

unknowns by combining equations relative to time intervals in which the three unknowns may be considered constant, or to combine equations relative to time intervals in which one or more unknowns have different values, provided that the number of unknowns will correspondingly increase." The solution of this system of equations gives $d\pi$, the correction to be added to the adopted value of solar parallax.



— 80 —

23 Ottobre 1900

(433) Eros

Differenze di decl.

Riassunto

Figure 5. The Observations Register showing the first page of micrometric measures of Eros made by Antoniazzi (Register of observations: Astronomical Observatory of Padova, Historical Archives).

We report here other details described by Antoniazzi, in order to show how accurate his calculations were:

> Because of the long duration of each observation, I thought that in reductions related to this time interval, I should have to take into account the second variation of the parallax; therefore, differences $\alpha_0 - \alpha_*$, $\delta_0 - \delta_*$ [asteroid minus star] derived from each comparison were corrected for the difference between the corresponding parallax and that corresponding to the mean of the times. These differences were also reduced to the mean time of observations by means of the asteroid's motion derived from the ephemerides. Then, the two means were calculated, and their probable errors extracted by the deviation of the single values from them; so, through the errors, I thought to be able to give a summary indication *a posteriori* of the general conditions in which observations had been made, as they might have affect the precision of the results. (Antoniazzi, 1911:314).

The latter values were then corrected for differential refraction and for the error relative to the position of the instrumental pole. Antoniazzi (1904) made a preliminary calculation of the solar parallax before sending his data to Paris, deriving a value of $\pi = 8''.84 \pm 0''.03$. But he suspected that the error in micrometer orientation would have a sensible influence on this determination, which could be best evaluated by using more precise positions of comparison stars.

Of the 131 observations made in Padova between 1900 October and December, 122 formed part of the data utilized by Hinks. According to the method of transits, the mean value was $\pi = 8''.839 \pm 0''.015$, corresponding to 8″.91 for the Padova observations (Hinks, 1910). Antoniazzi realized that the wrong parallax value, calculated from his observations, was perhaps due to the relatively-inaccurate positions of the comparison stars he had adopted. For this reason, he asked Hinks for data from his *Standard Photographic Catalogue*, and he then repeated his computations, including also his observations of 1901 January and February. This analysis produced a solar parallax of $\pi = 8''.795 \pm 0''.023$ (Antoniazzi, 1911), which is remarkably close to the modern value of $\pi = 8''.794148 \pm 0''.000007$ adopted by the IAU, especially given the unfavourable conditions under which he made the observations: a small telescope located just a few metres above ground level, close to a river, with a damp atmosphere lit by newly-introduced electric street-lamps. Antoniazzi's result is also within the error limits of $\pi = 8''.806 \pm 0''.004$, which is the figure that Hinks derived from all micrometric measures.

5 DISCUSSION AND CONCLUDING REMARKS

Eros continued to be in the limelight for solar parallax measurements, and during the opposition of 1930-1 was at a closer distance to Earth than it had been at any time since 1900. In 1925 and in subsequent years, the discoverer of Eros, Gustav Witt (1925, 1930) calculated ephemerides for the up-coming opposition, and in 1931 he published advice for visual micrometric observers (see Witt and Kopff, 1931).

The International Astronomical Union played an important role in these activities. During the 1925 General Assembly Commission 34 (Solar Parallax) was created (Fowler, 1926), and in 1927 a special grant of £50 was given to the President of the Commission, the Astronomer Royal, Frank Dyson. In his report at the General Assembly of 1928, Dyson recommended that improved photographic observations be made (Stratton, 1929), but with his election to the Presidency of the IAU Harold Spencer Jones took over as President of Commission 34.

In 1930, Jones published guidelines for the photographic observations in *Astronomische Nachrichten*, *The Astronomical Journal*, and *Monthly Notices of the Royal Astronomical Society* (Jones, 1930a, 1930b, 1930c, 1930d), and at the same time he wrote to the Presidents of the various National Committees affiliated with the IAU asking for their co-operation in this important project. He stressed that it was essential that observatories widely distributed in both latitude and longitude took part to the campaign, making micrometric and photographic observations.

Emilio Bianchi, Director of the Observatory of Milan and President of the Italian Committee, made inquiries among Italian observatories, and six of them (Trieste, Padova, Milan, Florence, Catania, and Teramo) agreed to participate; Antoniazzi's micrometric observations of 1900-1 were taken as a guide (Bianchi, 1930). Giovanni Silva, Director of the Observatory of Padova, trained the young astronomer Ettore Martin (1934) on how to observe

Eros with the 187-mm Merz Refractor, the very same instrument that had been used by Antoniazzi during the opposition of 1900. Most other Italian observatory also conducted micrometric observations (see Gennaro, 1937; Righini, 1937), but Catania decided to rely on photography (Taffara, 1936, 1937).

Because of Eros's brightness, Jones favoured photography, with multiple exposures on the same plate rather than individual long trailed images. This method, although not previously used, "... proved to be an unqualified success and is undoubtedly the best method for the photographic observation of a fast moving object giving a stellar image." (Jones, 1955:16).

When it came to reducing the observations, Jones found the photographic observations were more accurate and more numerous than the micrometric measures, and so he decided to use only photographic data in deriving a value for the solar parallax. Data came from 2847 photographic plates taken with 30 different telescopes at the following observatories (18 in the Northen Hemisphere and 6 in the Southern Hemisphere): Pulkovo, Bergedorf, Radcliffe (Oxford), Greenwich, Leipzig, Uccle, Prague, Dearborn, Van Vleck, Allegheny, Washington, Leander McCormick, Catania, Lick, Algiers, San Fernando, Tokyo, Zô-Sé, Union, Yale (Johannesburg), Cape of Good Hope, La Plata, and Melbourne. The data reductions were concluded during the Second World War, and Jones (1941) arrived at a solar parallax of $\pi = 8''.790 \pm 0''.001$ (although subsequent investigations by Atkinson (1982) were to show that he had underestimated the probable error). At the 1943 Annual General Meeting of the Royal Astronomical Society he was awarded the Gold Medal for this result (Chapman, 1943), but a complete and detailed discussion of the data from all the participating observatories was only published in 1955 (Jones, 1955).

The value of the solar parallax determined from Eros observations of 1930-1 was not definitive (e.g. see Hughes, 2001), and a new value for the astronomical unit (A.U. = 149,597,870 km) derived from primary astronomical constants (Duncombe *et al.*, 1977) was adopted by the IAU in 1976, from which a calculated solar parallax of $\pi = 8''.794148$ is given. Astronomical constants are continuously the subject of attention and revision, and the most recent determination of π was based on radiometric observations of the inner planets and was in agreement with the IAU value of 1976 (see Pitjeva, 2001).

As regards the Eros campaigns, two final points deserve to be mentioned. Firstly, between the oppositions of 1900 and 1930 astronomical photography became an indispensable tool in positional astronomy, as plate reduction techniques were continually refined. Secondly, a phenomenon not mentioned above is the variability in brightness of Eros. This feature was observed in 1901 (Parkhust, 1901; *Report* ..., 1902) and also during the 1930-1 opposition, and many astronomers carried out magnitude estimates and derived light-curves. The hypothesis that Eros could be a complex system consisting of two or more bodies was suggested in order to explain the variability. If this was so, then Eros was hardly a suitable body for the derivation of an improved value of the solar parallax. As Jones (1940:422) later pointed out: "If these conclusions are confirmed, the extensive programme of observations made at the opposition of 1931 and the heavy labour of their reduction, as well as the considerable, though less extensive, programme of 1901, have been made in vain." However, Jones (ibid.) believed that the light curve of Eros was due to the irregular shape of the asteroid, and that this body therefore was a suitable target for solar parallax determinations. History has proved him right, for images obtained by the spacecraft NEAR-Shoemaker recently showed Eros to be an irregularly-shaped asteroid with approximated dimensions of 34 × 13 × 13 km (e.g. see Veverka, *et al.*, 2001).

6 NOTES

1. The Urania Observatory was a public observatory of the Urania Society, founded in Berlin on 1888 March 8, on the initiative of Wilhelm Foerster, Director of the Royal Observatory of Berlin. The founding principle of the Urania Society was "Verbreitung der freude an der naturerkenntniss" (To spread pleasure in knowledge of nature), and for this aim a journal, *Himmel und Erde* (*Sky and Earth*), was also founded. The telescope used by Witt in discovering Eros was a 12 Parisian inches (*c.* 35-cm) refractor.
2. Antonio Maria Antoniazzi (*b.* Collalto di Refrontolo [Treviso], 1872 April 1; *d.* Padova, 1926 November 30) received a degree in mathematics from the University of Padova in 1893, and became Assistant to Giuseppe Lorenzoni, Director of the Astronomical

Observatory, in 1894. He taught theoretical geodesy from 1908. In 1913, Lorenzoni retired, and Antoniazzi was appointed Professor of Astronomy at the University of Padova and Director of the Observatory. During his appointment, he petitioned in vain for funds to improve the old astronomical instrumentation. However, the political situation in that time was critical and, when the First World War broke out, the high tower of the Observatory was commandeered by the army for the purpose of sighting enemy aircraft, since the city of Padova was only a short distance from the theatre of war, and Supreme Headquarters were located in it. Antoniazzi's scientific activity was devoted to classical astronomy – in particular, to calculations of planetary and cometary orbits, which he published in *Astronomische Nachrichten* – and to geodesy. He also published papers in *Atti dell'Istituto Veneto di Scienze Lettere ed Arti.*

3. This instrument had been purchased in 1881 by Lorenzoni (1881) from the heirs of Baron Ercole Dembowski, an astronomer from Milan who was famous for his double star work. In order to house the refractor, Lorenzoni had a dome built for it at Padova Observatory in 1882.
4. The 'equation of magnitude' mentioned by Antoniazzi, depends on the error in recording the exact instant at which two objects of different magnitude, such as an asteroid and a comparison star, are crossing the micrometer wire.

7 REFERENCES

Address Delivered by the President, F. W. Dyson, M.A., LL: D., F.R.S., on presenting the Gold Medal of the Society to Mr. A. R. Hinks. *Monthly Notices of the Royal Astronomical Society*, **72**:352-365 (1912).

Antoniazzi, Antonio Maria, 1904. Documents relatifs a l'organisation des travaux d'observation de la planète Èros, 1900. *Réunion du Comité International Permanent de la Carte Photographique du Ciel tenue a l'Observatoire de Paris en 1900*, Institute de France Académie des Sciences, Circulaire **11**:25-35.

Antoniazzi, Antonio Maria, 1911. Il valore medio della parallasse solare risultante dalle osservazioni di passaggi del pianeta "Eros" fatte all'Equatoriale Dembowski dell'Osservatorio di Padova da 23 ottobre 1900 a 13 febbraio 1901. *Atti del Reale Istituto Veneto di Scienze, Lettere ed Arti*, **70**:309-336.

Astronomische Nachrichten, **147**: 207, 223, 253, 269, 279, 281, 285, 335, 363, 367, 383, 397 (1898); **148**: 27, 29, 45, 59, 69, 95, 119, 127, 143, 157, 159, 189, 205, 213, 215, 217, 269, 271, 299, 381, 389 (1899); **149**: 49, 151, 191, 277, 291, 345 (1899); **150**: 215, 361 (1899).

Atkinson, R. d'E., 1982. The Eros parallax, 1930-31. *Journal for the History of Astronomy*, **13**:77-83.

Bauschinger, Julius, 1899. Über die bezeichnung des planeten 1898 DQ. *Astronomische Nachrichten*, **148**:223-224.

Berberich, Adolf, 1898. Erste bahnbestimmung des planeten 1898 DQ. *Astronomische Nachrichten*, **147**:221-224.

Bianchi, Emilio, 1930. Letter to Giovanni Silva dated February 5. Original in Padova Observatory Archives.

Chapman, S., 1943. Address, Annual General Meeting. *Monthly Notices of the Royal Astronomical Society*, **103**:45.

Circulaires **1-6**: Documents relatifs a l'Organisation des travaux d'observation de la Planète Èros, 1900. *Réunion du Comité International Permanent de la Carte Photographique du Ciel Tenue a l'Observatoire de Paris en 1900*, Institute de France Académie des Sciences, Paris, Gauthier-Villars. Pp. 103-154.

Circulaires **7** (1901), **8** (1901), **9** (1902), **10** (1903), **11** (1904), **12** (1907). *Conférence Astrophotographique Internationale de Juillet 1900*, Institute de France – Académie des Sciences, Paris, Gauthier-Villars.

Duncombe, R.L., Fricke,W., Seidelmann, P.K., Wilkins, G.A., 1977. Joint report of the Working Groups of IAU Commission 4 on Precession, Planetary Ephemerides, Units and Time-Scales. In E.A. Muller and A. Jappel (eds.). *Proceedings of the Sixteenth General Assembly Grenoble 1976*. Dordrecht, Reidel (IAU Transactions, Volume XVIB), pp. 56-67.

Dyson, W. Frank, 1904. Eros and the solar parallax. *The Observatory*, **27**:130-131.

Fowler, A. (ed.), 1926. *Transactions of the International Astronomical Union. Vol. II. Second General Assembly held at Cambridge July 14 to July 22, 1925*. London, Imperial College.

Gennaro, Antonino, 1937. Relazione sulle osservazioni del pianeta Eros eseguite nell'Osservatorio di Trieste durante l'opposizione del 1930-31. *Memorie della Società Astronomica Italiana (già degli Spettroscopisti) (19345-36)*, **9**:87-98.

Hinks, Arthur Robert, 1900. On planning photographic observations of Eros. *Monthly Notices of the Royal Astronomical Society*, **60**:543-546.

Hinks, Arthur Robert, 1901a. The Cambridge machine for measuring celestial photographs. *Monthly Notices of the Royal Astronomical Society*, **61**:445-458.

Hinks, Arthur Robert, 1901b. Experimental reduction of some photograph of Eros made at the Cambridge Observatory for the determination of the solar parallax. *Monthly Notices of the Royal Astronomical Society*, **62**:22-41.

Hinks, Arthur Robert, 1901c. On the accuracy of measures on photographs: Remarks on recent papers by M. Loewy and Mr. H.C. Plummer. *Monthly Notices of the Royal Astronomical Society*, **62**:132-137.

Hinks, Arthur Robert, 1901d. Experimental reduction of photographs of Eros for the determination of the solar parallax. Second paper: Combination of results from Mount Hamilton, Minneapolis and Cambridge. *Monthly Notices of the Royal Astronomical Society*, **62**:551-561.

Hinks, Arthur Robert, 1903. Eros and the solar parallax. *The Observatory*, **26**:341-344.

Hinks, Arthur Robert, 1904a. Eros and the solar parallax. *The Observatory*, **27**:97-101.

Hinks, Arthur Robert, 1904b. Eros and the solar parallax. *The Observatory*, **27**:207.

Hinks, Arthur Robert, 1904c. On the new Greenwich micrometer for measurements of photographs of Eros. *Monthly Notices of the Royal Astronomical Society*, **64**:626-640.

Hinks, Arthur Robert, 1904d. Reduction of 295 photographs of Eros made at nine observatories during the period 1900 November 7-15, with a determination of the solar parallax. *Monthly Notices of the Royal Astronomical Society*, **64**:701-727.

Hinks, Arthur Robert, 1906. Solar parallax papers. N° 5. Examination of the photographic places of stars published in the Paris Eros circulars. *Monthly Notices of the Royal Astronomical Society*, **67**:70-85.

Hinks, Arthur Robert, 1907. Solar parallax papers. N° 6. Construction of a standard catalogue of photographic star places. *Monthly Notices of the Royal Astronomical Society*, **68**:82.

Hinks, Arthur Robert, 1909a. Solar parallax papers. N° 7. The general solution from the photographic right ascensions of Eros, at the opposition of 1900. *Monthly Notices of the Royal Astronomical Society*, **69**:544-567.

Hinks, Arthur Robert, 1909b. Solar parallax papers. N° 8. The mass of the Moon, derived from the photographic observations of Eros made in 1900-01. *Monthly Notices of the Royal Astronomical Society*, **70**:63-75.

Hinks, Arthur Robert, 1910. Solar parallax papers. N° 9. The general solution from the micrometric right ascensions of Eros, at the opposition of 1900. *Monthly Notices of the Royal Astronomical Society*, **70**:588-603.

Hughes, D.W., 2001. Six stages in the history of the astronomical unit. *Journal of Astronomical History and Heritage*, **4**:15-28.

Jones, H. Spencer, 1930a. Observations of Eros at the opposition 1930-31. *The Astronomical Journal*, **40**:117-119.

Jones, H. Spencer, 1930b. Observations of Eros at the opposition 1930-31. *Astronomische Nachrichten*, **239**:43-46.

Jones, H. Spencer, 1930c. Observations of Eros at the opposition 1930-31. *Monthly Notices of the Royal Astronomical Society*, **90**:724-726.

Jones, H. Spencer, 1930d. Observations of the opposition of Eros. *Astronomische Nachrichten*, **239**:431-432.

Jones, H. Spencer, 1931. The observations of Eros, 1930-31. Notes on methods of reduction and publication of results. *Monthly Notices of the Royal Astronomical Society*, **92**:12-18.

Jones, H. Spencer, 1940. On the suitability of Eros for the accurate determination of the solar parallax. *Monthly Notices of the Royal Astronomical Society*, **100**:422-434.

Jones, H. Spencer, 1941. The solar parallax and the mass of the Moon from observations of Eros at the opposition of 1931. *Monthly Notices of the Royal Astronomical Society*, **101**:356-366.

Jones, H. Spencer, 1955. The solar parallax and the mass of the Moon from observations of Eros at the opposition of 1931. *Memoirs of the Royal Astronomical Society*, **66**:12-66.

Lorenzoni, Giuseppe, 1881. L'Equatoriale Dembowski al Reg. Osservatorio di Padova. *Atti del Reale Istituto Veneto di Scienze, Lettere ed Arti*, **7**:1-2.

Loewy, Maurice, 1903. Eros and the solar parallax. *The Observatory*, **26**:455-458.

Martin, Ettore, 1934. Contributo alla campagna internazionale per la parallasse solare (opposizione di Eros 1930-31). *Atti del Reale Istituto Veneto di Scienze, Lettere ed Arti*, **93**:600-612.

Millosevich, Elia, 1899. Sull'orbita di (433) Eros in base alle osservazioni degli anni 1898-99. *Astronomische Nachrichten*, **151**:129-140.

Millosevich, Elia, 1900. Ephémérides d'Eros. *Conférence Astrophotographique Internationale de Juillet 1900*, Circulaire **3**:113-115.

Millosevich, Elia, 1902. Ephémérides de la planète Eros. *Conférence Astrophotographique Internationale de Juillet 1900*, Circulaire **9**:180-197.

Newcomb, Simon, 1898. *Catalogue of Fundamental Stars for the Epochs 1875 and 1900 Reduced to an Absolute System.* Washington.

Newcomb, Simon, 1900. Feasibility of determining the solar parallax by observations of Eros, at the coming opposition, 1900-01. *The Astronomical Journal*, **20**:189-191.

Parkhust, M. Henry, 1901. Photometric observations of Eros. *The Astronomical Journal*, **21**:148-149.

Perrotin, Henry-Joseph-Anastase, 1898. Photographische aufnahmen kleiner planeten. *Astronomische Nachrichten*, **147**:175-176.

Pitjeva, E.V., 2001. Progress in the determination of some astronomical constants from radiometric observations of planets and spacecraft. *Astronomy and Astrophysics*, **371**:760-765.

Report of the Council to the Eighty-second Annual General Meeting. *Monthly Notices of the Royal Astronomical Society*, **62**:293-294 (1902).

Réunion du Comité International Permanent pour l'exécution de la Carte Photographique du Ciel tenue a l'Observatoire de Paris en 1900. Institute de France – Académie des Sciences, Paris, Gauthier-Villars (1900).

Righini, Guglielmo, 1937. Posizioni di Eros determinate in Arcetri nell'opposizione del 1930-31. *Memorie della Società Astronomica Italiana (già degli Spettroscopisti) (1935-36)*, **9**:65-81.

Solar parallax. Report of the Council to the Ninety-first Annual General Meeting of the Royal Astronomical Society. *Monthly Notices of the Royal Astronomical Society*, **71**:324-326 (1911).

Stratton, F.J.M. (ed.), 1929. *Transactions of the International Astronomical Union. Vol. III. Third General Assembly held at Leiden July 5 to July 13, 1928.* Cambridge, Cambridge University Press.

Taffara, Salvatore, 1936. Metodo di riduzione delle lastre di Eros. *Memorie della Società Astronomica Italiana (già degli Spettroscopisti) (1934-35)*, **8**:75-81.

Taffara, Salvatore, 1937. Posizioni di Eros dedotte da lastre fotografiche ottenute intorno all'opposizione del 1930-31. *Memorie della Società Astronomica Italiana (già degli Spettroscopisti) (1935-36)*, **9**:5-28.

The Astronomical Journal, **19**:11, 112, 120, 147-148, 155, 160-162, 164 (1898); **19**:169-170, 196 (1899); **20**:8, 31-32, 49-56, 61-64, 103-104, 134 (1899).

Tucker, R.H., 1903. Systematic differences in the places of the Eros stars. *The Observatory*, **26**:460-461.

Tucker, Richard Hawley, 1926. The next close opposition of Eros. *Publications of the Astronomical Society of the Pacific*, **38**:228-230.

Veverka, J.F., Thomas, P.C., Robinson, M.S., Murchie, S.L., 2001. NEAR's Landing on Eros: Clues to Geological Processes on Small Asteroids. *American Geophysical Union, Fall Meeting* 2001.

Witt, Gustav, 1898. Entdeckung eines neuen planeten 1898 DQ. *Astronomische Nachrichten*, **147**:141-142.

Witt, Gustav, 1899a. Auszug aus einem schreiben von Herrn G. Witt in Berlin betr. den planeten (433) Eros. *Astronomische Nachrichten*, **148**:175-176.

Witt, Gustav, 1899b. Ein neuer planet zwischen Erde und Mars! *Himmel und Erde, Illustrierte naturwissenschaftliche Monatsschrift*, **11**:37-40.

Witt, Gustav, 1925. Vorläufige Ephemeride des planeten 433 Eros für die opposition 1930-31. *Astronomische Nachrichten*, **224**:387-404.

Witt, Gustav, 1930. Ephemeride des planeten 433 Eros für November 1930. *Astronomische Nachrichten*, **239**:427-430.

Witt, Gustav & Kopff, Auguste, 1930. Bemerkungen zur beobachtung des planeten Eros bei der opposition 1930-31. *Astronomische Nachrichten*, **237**:285-288.

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The mechanics and origin of cometaria

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Abstract
The cometarium, literally a mechanical device for describing the orbit of a comet, had its genesis as a machine for illustrating the observable consequences of Kepler's second law of planetary motion. The device that became know as the cometarium was originally constructed by J T Desaguliers in 1732 to demonstrate, in a sensible fashion, the perihelion to aphelion change in velocity of the planet Mercury. It was only with the imminent, first predicted, return of Halley's comet in 1758 that the name cometarium was coined, and subsequent devices so named. Most early cometaria used a pair of elliptical formers joined via a figure-of-eight cord to translate uniform drive motion into the non-uniform motion of an object moving along an elliptical track. It is shown in a series of calculations, however, that two elliptical former cometaria do not actually provide a correct demonstration of Keplerian velocity variations and nor do they actually demonstrate Kepler's second law of planetary motion.

Keywords: *comets, cometary orbits, orreries*

"Now we know the sharply veering ways of comets" (Edmund Halley, "*Ode to Newton*", 1686)

1 INTRODUCTION

On 1732 March 8 John Theophilus Desaguliers demonstrated to the assembled Fellows of the Royal Society an instrument "... to show the different velocities of a planet or comet in its motion round the Sun." (Desaguliers, 1732). The device displayed by Desaguliers was like no other machine then in existence, and it had been especially designed for the purpose of illustrating Kepler's second law, which requires that the planet-Sun vector sweeps out equal areas in equal time. Desaguliers did not apply a name to his new device, but it, and subsequent devices like it, have at various times been called 'equal-area machines', 'mercuria' and 'cometaria'.

From an engineering perspective, the problem with Kepler's second law is that it cannot, in fact, be explained or easily illustrated by mechanical means. As Isaac Newton showed in his *Principia*, first published in 1687, Kepler's laws are a manifestation of the principles of universal gravitational attraction and the conservation laws of energy and angular momentum. The point is that none of these deep physical concepts can be exactly described with the aid of mechanical gears, springs and/or linkages. Desaguliers' machine, therefore, was designed to illustrate (or mimic) the potentially observable consequences of the second law, which most noticeably for the observer would be a marked decrease in the angular velocity of the model planet (or comet) as it moved from perihelion to aphelion. Desaguliers' machine was in this latter context neither a fully predictive nor an explanatory device. This situation can be offered in contrast to the other planetary machines that had been constructed at that time. The 'telluria' and 'lunaria' first constructed circa 1715, were used, for example, not only to demonstrate the scale of the Solar System (that is relative orbital size and planetary motion), but also to explain such effects as eclipses, phases of the Moon and the reasons why Earth experiences seasons (see King and Millburn, 1978).

In the sections that follow we shall describe in some detail the workings and construction of Desaguliers' machine, and we shall then briefly outline a few of the mechanical developments introduced by other instrument-makers.

2 A DEVICE AHEAD OF ITS TIME

While, as stated above, Desaguliers offered no particular name for the machine he demonstrated to the Royal Society, it may be reasonably described as a mercurium – that is, a device for illustrating the orbital motion of Mercury about the Sun. The association with Mercury arises not because of the orbital eccentricity being modeled but because the time-scale of the device was divided into 88 equal intervals, and this as Desaguliers (1732) pointed out was Mercury's period of revolution. No motivation for adopting the orbit of Mercury is given by Desaguliers, but in 1732 it was certainly the planet with the largest-known eccentricity and therefore also the planet with the greatest variation in its velocity upon moving from perihelion to aphelion. Recall that adherence to Kepler's second law requires that the velocity at perihelion be greater than that at aphelion. In addition we note that Mercury was due to undergo a solar transit on 1736 November 11, and was consequently an object of up-coming interest with respect to the determination of the astronomical unit (see Hughes, 2001).

While it seems clear that Desaguliers had the planet Mercury in mind when he constructed his device, he also suggested it could describe the orbital motion of a comet. This latter possibility is, in fact, historically rather interesting and indeed a potentially-controversial statement for Desaguliers to have made. When Desaguliers constructed his machine, circa 1732, it was neither clear how big comets actually were nor what they were made of. Nor, indeed, was it absolutely clear that comets orbited the Sun in elliptical orbits – that is, that comets were periodic. Certainly, Newton and Halley had argued that some comets moved in elliptical orbits, but it was not until 1758, with the first predicted return of Comet 1P/Halley, that the periodic nature (of at least one comet) was demonstrated. With respect to the nature of comets, Desaguliers (1734:409) noted in his *A Course of Experimental Philosophy* that "... comets are a sort of excentrick planets, which move in very long ellipses ... whose periodical revolutions take up such a long space of time that the same man has never yet seen the same comet twice." Later in his text Desaguliers (1734:410) noted that "... the comets are reckon'd not to be less than the Moon, nor much bigger than Venus." Desaguliers' views on the nature of comets in his book generally run parallel with those espoused earlier by Newton in his *Principia* (see e.g., Schechner-Genuth, 1997). It was presumably Desaguliers' unequivocal belief in the correctness of Kepler's laws of planetary motion and Newtonian gravitation theory[1] that lead him to suggest that his mercurium could also describe the orbit of a comet some twenty-six years before the fact was demonstrated observationally.

3 MERCURIUM MECHANICS

At best it is only the first two of Kepler's three laws of planetary motion that can be illustrated by mechanical means. Kepler's third law, which relates the square of the orbital period to the cube of the semi-major axis of the orbit, has no mechanical analog and is a result that stands by empirical measurement and Newtonian gravitational theory alone. Kepler's first law of planetary motion, on the other hand, which states that the planets move along elliptical orbits with the Sun at one focus, can be easily accommodated in any mechanical device by simply making a planet-marker move along an elliptical track. We note, however, that rather than fully accommodate the first law most early instrument makers simply had planet markers move along circular tracks with the Sun offset from the centre. A nice example of such an 'offset Sun' construction can be seen in the impressive Dutch planetarium constructed by Eisinga circa 1780 (see Figure 6 in Mulder de Ridder, 2002).

Figure 1 shows the front face of Desaguliers' mercurium. The Sun is located at focal point, S, and the planet-marker, P, is carried around in an elliptical track by drive arm SPO when the handle GH is turned. The circumference of the elliptical track is divided into 88 segments, each segment representing a day's worth of Mercury's orbital motion. The eccentricity of the elliptical track is 0.67, some three times larger than Mercury's actual orbital eccentricity ($e = 0.21$). This exaggeration of the orbital eccentricity was quite deliberate and introduced by Desaguliers (1732) "... to make the phenomena the more sensible." And indeed, this is a reasonable enough step, given that the device was designed solely to illustrate the effect of velocity changes at perihelion and aphelion.

The demonstration of Kepler's second law, which requires that the planet-Sun arm sweeps out equal areas in equal time, is a far more complex mechanical demonstration than that for the first law. The inherent engineering difficulty is that Kepler's second law requires that a non-constant orbital velocity be accommodated. Desaguliers was fully aware of this point and consequently developed an elliptical pulley system to deliver a non-constant rotation rate to the planet drive arm SPO (Figure 1).

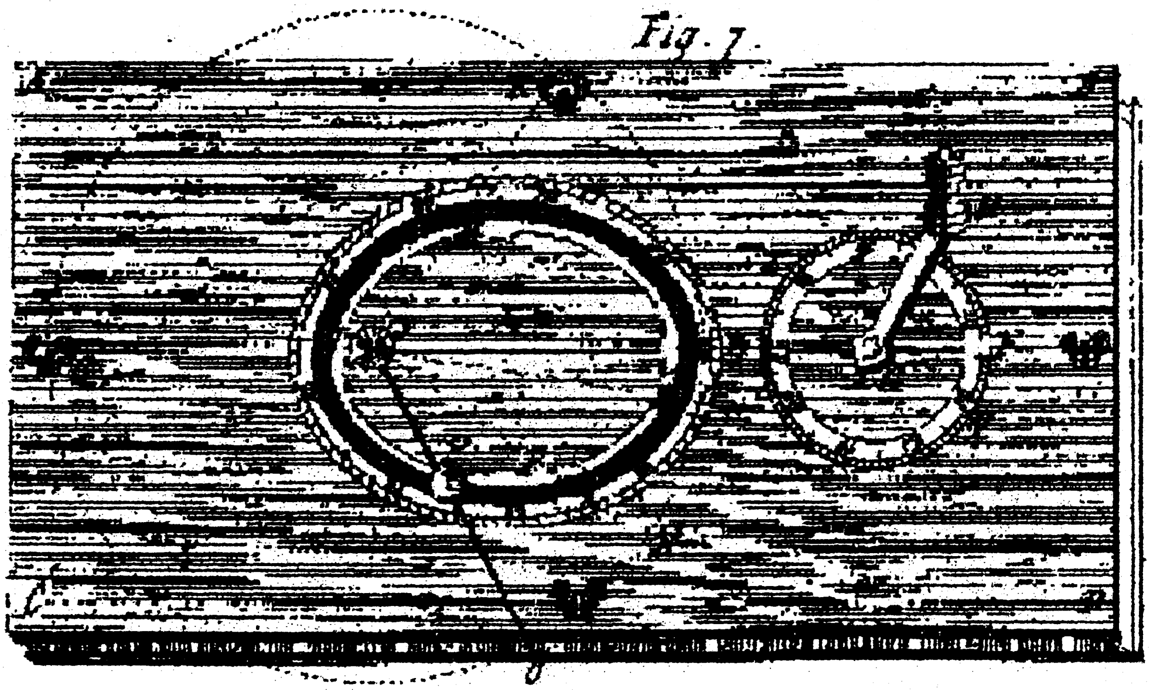

Figure 1. Frontal view of Desaguliers' mercurium (Photograph courtesy of the Royal Society).

Figure 2 shows the interior of Desaguliers' mercurium. The two elliptical formers are linked via a figure-of-eight cord and the constant rotation rate of the drive ellipse about focus I is transformed into the non-constant motion of the driven ellipse about S. The non-constant motion about focus S is directly transmitted to the drive arm SPO, and the planet/comet marker is correspondingly driven about the elliptical track with variable velocity (see, however, Appendix 8.2 for a mathematical description of what actually transpires).

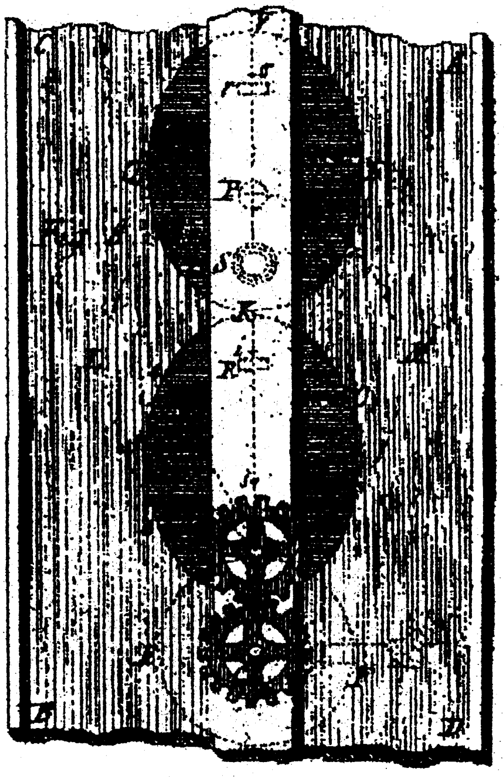

Figure 2. Interior view of Desaguliers' mercurium (Photograph courtesy of the Royal Society).

Desaguliers (1732) explained in his account to the Royal Society that his instrument was constructed to "... show the different velocities of a planet or comet in its motion around the

Sun, ... describing ... areas proportionable to the times, [with] the velocities of the revolving body being reciprocally as the distance from the central body." In his secondary statement about velocities, Desaguliers was referring to the 'inverse distance' form of Kepler's second law. Indeed, Kepler initially presented his second law in two forms. One form expounded the law of areas, while the other stated that the velocity (or as Kepler called it the 'delay' – see e.g., Martens, 2000; and Russell, 1964) of a planet varies inversely with heliocentric distance. Kepler initially believed that these two forms were equivalent statements of what we now call the second law, but in the general case they are not the same. For small values of the eccentricity, however, the inverse distance law is approximately true. We can see that this is so by expanding the velocity, V, into its radial and angular velocity components (see e.g., Szebehely, 1989, and Figure 3) such that $V^2 = (dr/dt)^2 + (r\ dv/dt)^2$. We may now argue that since the radial component of the velocity, dr/dt, will become small as the eccentricity approaches zero, so $V \approx r\ dv/dt$ in the small eccentricity limit. Further, given the equal area rule we have $r^2 (dv/dt) = \text{constant}$ (see e.g., Szebehely, 1989) and, hence, by substitution we find that V is inversely proportional to the radius, r. The point of this argument, of course, is that the inverse distance 'law' is only approximately true under the small eccentricity condition and is not as such equivalent to the conservation of angular momentum argument. Russell (1964) notes, however, that by the time that Kepler published his *Epitome Astronomiae Copernicanae* (in three parts between 1618 to 1621) he had realized that the inverse distance law only held true for small eccentricities.

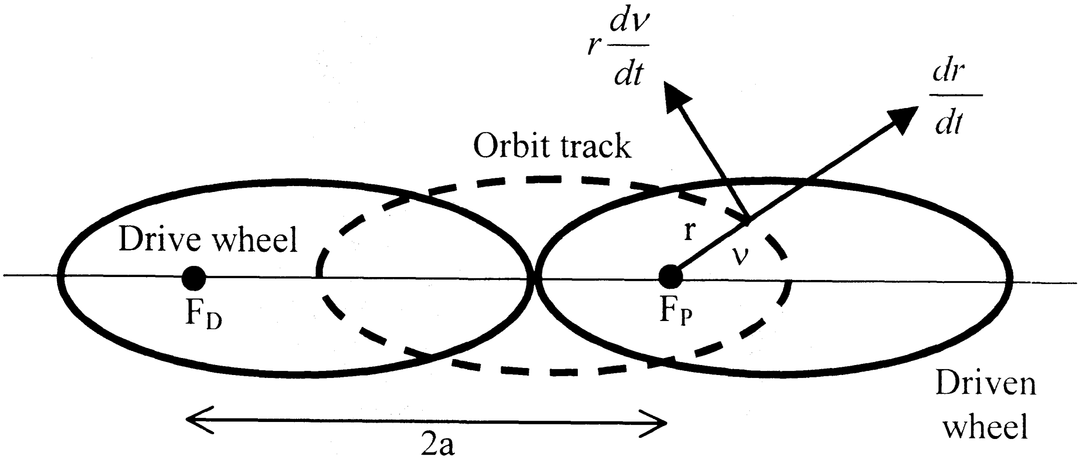

Figure 3. Elliptical former arrangement of a Desaguliers-type mercurium. The drive and driven formers are constructed to have the same semi-major axis (*a*) and eccentricity (*e*). The drive former rotates at constant angular velocity, ω_1, about F_D. The resultant motion of the driven former about F_P is the variable angular velocity, ω_2. A drive arm is attached to the driven focus support, F_P, and this carries a planet marker or bead around an elliptical track (shown as a dashed ellipse in the figure). The velocity, V, of the bead in its track about F_P can be expressed in terms of the radial and angular velocity components dr/dt and r(dv/dt) respectively.

Even though Kepler provided a clear statement of his second law, it was often ignored or rejected by his contemporaries for less accurate but more easily-applied approximations. Seth Ward (1617–1689), Savilian Professor of Astronomy at Oxford, for example, calculated planetary positions by considering the 'empty' focus of the orbit to be an equant point – an approximation that holds, in fact, to good accuracy for small eccentricities (see e.g., Evans, 1998). From an engineering perspective it would have been simpler to build a model under Ward's scheme, but it, of course, is not at all consistent with Kepler's laws which make no reference to the second, empty focus. While his calculating methods are now known to be suspect, Gunther (1967) argues that it is to Ward that we should attribute the idea that comets actually move about the Sun in closed orbits. All this being said, however, by choosing elliptical formers to modulate the rotation rate of the drive arm (SPO in Figure 2) in his mercurium, Desaguliers was at least able to demonstrate a marked variation in the bead's velocity between perihelion and aphelion. Interestingly (see Millburn, 1981), the elliptical formers only provide the correct perihelion-to-aphelion velocity ratio,

$$V_{per}/V_{aph} = (1 + e)/(1 - e) = Q/q,$$

where e is the orbital eccentricity, Q is aphelion distance and q is the perihelion distance (see Appendix 8.2). While the ratio of the velocities is correctly reproduced with elliptical formers, the actual perihelion and aphelion velocities are incorrectly modeled with respect to Keplerian motion. The perihelion and aphelion velocities are both, in fact, too small with respect to Keplerian motion in an elliptical former cometarium by a factor $\sqrt{(1 - e^2)}$.

4 DISCUSSION AND CONCLUDING REMARKS

In the written account of Desaguliers' demonstration to the Royal Society, no explanation is offered as to the genesis and development of the mercurium. It is clear, however, that in the early 1730s Desaguliers was experimenting with the design and construction of instruments for representing planetary motion. His new and innovative planetarium, described in 1733, for example, was built explicitly for use in his lecture courses and with "... the desire of giving a true notion of the celestial phenomena in the plainest and most expeditious mannor." (Desaguliers, 1733). While great attention was directed towards accurately representing the relative size of each planet's orbit, the relative orbital periods, the relative sizes of the planets themselves and their orbital inclinations, no attempt was made to illustrate Keplerian motion in the planetarium. One presumes that the Keplerian aspect was ignored in the planetarium model because of the complex mechanical requirements that it would call into effect. And indeed, it is only Mercury that has an appreciable orbital eccentricity, the other planetary orbits being well approximated by circles. After Mercury, Mars has the next most eccentric orbit (of the planets known in 1733), but with an eccentricity $e = 0.093$ it is some 2.2 times smaller than that of Mercury's orbit. Interestingly, Desaguliers (ibid.) comments that his planetarium could be fitted with bent wires to illustrate the parabolic figure of a comet's orbit, and that specifically the planetarium had been designed to show "... the orbits of several comets and the periods of three of them." The three periodic comets that were modeled presumably correspond to those studied by Halley (e.g., the comets of 1680, 1661 and 1682, although it should be noted that Halley's 'demonstration' of the periodic nature of the comets of 1680 and 1661 was incorrect). Desaguliers' planetarium has long been lost, and was apparently last on display, circa 1813, in the Royal Military Academy in London (King and Millburn, 1978:170).

It seems worth commenting at this stage that the problem of sensibly demonstrating cometary motion by mechanical means still exists to this day. In recent times, however, Hughes (1985) has suggested the construction of a large-scale model of Comet Halley's orbit around which 76 posts could be placed at separations corresponding to the distance travelled by the comet in successive one-year time intervals. In such a construction the 'crowding' of posts near aphelion would illustrate the slow motion of the comet when far from the Sun. Tattersfield (1984) in recent times has also described the construction of a detailed, static, three-dimensional card model of the orbit of Halley's Comet. Of course, in the most recent era, computers have been very successfully utilized in the study and visualization of complex dynamical behaviour, but such demonstrations are clearly not 'mechanical'.

When describing the mercurium in his *A Course of Experimental Philosophy* (1734:446), Desaguliers comments that it is a "... machine to show mechanically, how planets and comets, by a Ray drawn from the Sun, describe areas proportionable to the time." In this later work, we note that Desaguliers has dropped the inverse distance law for the velocity variation. We also note here, however, that as with the representation of orbital angular velocities, the arrangement of elliptical formers used by Desaguliers does not actually provide an equal area demonstration (see Appendix 8.2).

The term 'cometarium' was apparently first used by Benjamin Martin in the early 1740s. Specifically in his *Course of Lectures,* Martin indicates that the Copernican model of the Solar System will be explained by the mechanical orrery and cometarium (Millburn, 1973). Presumably prompted by the imminent return of Halley's comet (in 1758/9), Martin further built and marketed a cometarium with his book *The Theory of Comets Illustrated,* published in 1757 (Taub, 1998). Woodcut illustrations of Martin's cometaria are reproduced in Stephenson *et al.* (2000: 131) and Wheatland (1968:62).

James Ferguson, who actually sold his instrument-making business to Benjamin Martin in 1757 (Rothman, 2000), describes in detail the workings of a cometarium and equal-area machine in his 1756 book, *Astronomy Explained upon Sir Isaac Newton's Principles* (see pages

270-272). We note that the dial plate of Ferguson's cometarium is divided into 12 divisions, rather than Desaguliers' 88, and was, therefore, not specifically intended to illustrate the orbit of Halley's Comet or Mercury. We also note that Ferguson's cometarium is not an exact mechanical copy of Desaguliers' original. Specifically a worm gear is used to drive the elliptical pulleys and the time-display dial in Ferguson's machine. This innovation would have been useful during a lecture since it would enable the device to be hand-cranked from the side of the device as opposed to the front face as in Desaguliers' construction (see Figure 1). Henderson (1867:153) adds an interesting footnote to his commentary on Ferguson's cometaria, relating that "... cometariums constructed on this plan [using elliptical formers], and sufficiently large for the lecture room ... cost of about £2 10s.; when made with eccentric wheels (instead of pulleys and cat-gut strings), the price may rise to £4."

In similar fashion to Ferguson, it appears that Stephen Demainbray also used a cometarium device in his public lectures on planets and comets from about 1755 onwards. It does not appear, however, that Demainbray actually used the term cometarium to describe his model (Morton and Wess, 1995). The elliptical track in his cometarium is divided into 22 segments, so, again it was not intended to specifically illustrate the motion of Halley's Comet. The division into 22 segments is possibly a simple one-quarter reduction of the 88 day mercurium dial used by Desaguliers. Demainbray's extensive collection of scientific instruments (including his cometarium) now form part of the King George III Collection of scientific instruments at The Science Museum in London.

During the later part of the eighteenth century it appears that a number of scientific instrument-makers were constructing various forms of cometaria (Olson and Pasachoff, 1998). The early designs, as employed by Desaguliers, Martin, Ferguson, and Demainbray, used elliptical formers connected via a figure of eight cord. This arrangement was not entirely satisfactory, however, as the cord was prone to slip from the formers and the systems were apparently tricky to re-set. Interestingly, the choice of connecting cord material was one of the main problems encountered in the construction of a modern-day version of a Desaguliers-type cometarium (Millburn, 1981). To circumvent cord slippage, some instrument-makers employed meshed elliptical gears in their cometaria. An extant example of a geared cometarium built for classroom use is that held in the collection of the Royal Museum of Scotland, Edinburgh (Holbrook, 1992). The machine was built by scientific instrument-maker John Miller (see Bryden, 1972) in the late eighteenth century for the Department of Natural Philosophy at the University of Edinburgh. While the application of meshed gears solved the cord slippage problem it was a work-intensive (hence expensive) and technically-difficult way of correcting a somewhat trivial problem associated with the operation of the original machines.

Rather than cut expensive elliptical gears, William and Samuel Jones manufactured a cometarium which used an eccentrically-mounted circular gear with a sliding roller system to ensure constant mesh with the actuating pinion. A cometarium by W and S Jones is on display in The Science Museum, London (see, also, the illustration in Olson and Pasachoff, 1998:47). King and Millburn (1978) note that in Jones' 1855 catalogue the cometarium is listed as costing £5 6s 0d.

Perhaps the least complicated design of a meshed, circular gear cometarium is that described by Dean (1815). In his model, the varying rate of cometary motion is produced by allowing a variable-radius drive arm control the Sun-comet position arm. Interestingly, and unlike all of the other cometaria described in this article, the Dean cometarium could be set to accommodate a range of eccentricities. Sadly, no extant mechanical realization of Dean's cometatium is known at the present time.

Not quite one year on from the time that he presented his mercurium, Desaguliers described to the assembled Fellows of the Royal Society the workings of his new planetarium. By way of introducing this device, Desaguliers (1733) argued that "... machines and movements for representing the motions and appearances of heavenly bodies have been justly esteemed in all ages." While even to the modern day this statement can be readily defended, the golden age of mechanical orreries, planetaria, and cometaria, as valued scientific teaching tools, was relatively short-lived. Indeed just one hundred years on from the inaugural description of Desaguliers' mercurium, we find Sir John Herschel in his *A Treatise on Astronomy* (1833:287) describing such instruments as "... those very childish toys".[2] But, childish toys or not, we prefer to remember the cometarium and allied machines, out-dated as they presently may be, in terms of the lines

"When lately Jove the Orrery survey'd
He smiling thus to Gods in Council said
How shall we stint presuming Mortals Pow'r?"[3]

5 NOTES

1. Deasaguliers was both a good friend of Sir Isaac Newton and an important promoter of his work. And, reciprocally it was essentially upon Newton's suggestion that Desaguliers became 'curator' of experiments at the Royal Society (Hall, 1970). Finding much more than 'new physics' within Newton's *Principia*, Desaguliers suggested that Newton's ideas should be applied to all fields of human endeavour (including politics). In his *The Newtonian System, an Allegorical Poem*, published in 1728, Desaguliers made his feelings towards Newton's greatness very clear:

   "Newton the unparallel'd, whose name
   No Time will wear out of the Book of Fame,
   Coelestiall Science has promoted more,
   Than all the Sages that have shone before."

2. Sir John Herschel was a close friend of Charles Babbage, and at the time that he would have been writing *A Treatise on Astronomy* (circa 1832), the first, and only successfully-constructed and fully-functional piece of Difference Engine No. 1 was delivered to Babbage (Swade, 2000). The Difference and Analytic Engines of Babbage were certainly no toys, but were mechanical devices that pushed the then-available technology to its limits. Indeed, only small test segments of the various machines designed by Babbage were ever produced in his lifetime. In the light of these events, and given Herschel's close involvement with the political problems associated with the funding of Babbage's machines, his comments concerning orreries are more understandable.
3. These are the first three lines of a poem about the orrery, written in 1719 by "J.H a fellow of the RS". (Gunther (1967:269). The poem ends by suggesting that John Rowley should be 'transplanted' to heaven and made a 'star'. It was Rowley who made a lunarium (a Sun, Earth and Moon system) for Charles Boyle, Fourth Earl of Cork and Orrery, circa 1713 (King and Millburn, 1978:154), and by this act the name 'orrery' became synonymous with celestial mechanical models in general.

6 ACKNOWLEGMENTS

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7 REFERENCES

Bryden, D.J., 1972. *Scottish Scientific Instrument Makers (1600-1900).* Royal Scottish Museum (Information Series), Edinburgh.

Dean, J., 1815. Description of a cometarium. *Memoirs of the American Academy of Arts and Science*, **3**:344-345.

Desaguliers, J.T., 1732. Royal Society Record Book for 1732 (RBC 18.245).

Desaguliers, J.T., 1733. Royal Society Record Book for 1733 (RBC 18.395).

Desaguliers, J.T., 1734. *A Course of Experimental Philosophy. Volume 1.* Mears, Creake and Sackfield, London.

Evans, J., 1998. *The History and Practice of Ancient Astronomy.* Oxford University Press, Oxford.

Gunther, R.T., 1967. *Early Science in Oxford. Volume II.* Dawsons, London.

Ferguson, J., 1757. *Astronomy Explained upon Sir Isaac Newton's Principles.* Longman, London.

Hall, A.R., 1970. Desaguliers, John Theophilus. In C.C. Gillispie (ed.), *Dictionary of Scientific Biography. Volume IV.* Scribner, New York, pp. 43-46.

Henderson, E., 1867. *Life of James Ferguson, FRS in a Brief Autobiographical Account and Further Extended Memoir.* Fullarton, Edinburgh.

Herschel, J., 1833. *A Treatise on Astronomy.* Longman and Rees, London.

Holbrook, M., 1992. *Science Preserved: A Directory of Scientific Instruments in Collections in the United Kingdom and Eire*. HMSO, London.

Hughes, D.W. 1985. Year posts round the orbit of Halley's Comet. *Journal of the British Astronomical Association*, **95**:162-163.

Hughes, D.W., 2001. Six stages in the history of the astronomical unit. *Journal of Astronomical History and Heritage*, **4**(1):15-28.

King, H.C. and Millburn, J.R., 1978. *Geared to the Stars: The Evolution of Planetariums, Orreries, and Astronomical Clocks*. University of Toronto Press, Toronto.

Martens, R., 2000. *Kepler's Philosophy and The New Astronomy*. Princeton University Press, Princeton.

Millburn, J.R., 1973. Benjamin Martin and the development of the orrery. *The British Journal for the History of Science*, **6**:378-399.

Millburn, J.R., 1981. Demonstrating the motion of a comet. *Space Education*, **1**(2):55-58.

Morton, A.Q. and Wess, J.A., 1995. The historical context of the models of Stephen Demnainbray in the King George III Collection. *Journal of the History of Collections*, **7**:171-178.

Mulder de Ridder, J., 2002. Eise Eisinga and his planetarium. *Journal of Astronomical History and Heritage*, **5**(1):65-87.

Olson, R.J.M. and Passachoff, J.M., 1998. *Fire in the Sky: Comets and Meteors, the Decisive Centuries, in British Art and Science*. Cambridge University Press, Cambridge.

Rothman, P., 2000. By the light of his own mind: the story of James Ferguson, astronomer. *Notes and Records of the Royal Society*, **54**(1):33-45.

Russell, J.L., 1964. Kepler's laws of planetary motion: 1609-1666. *The British Journal for the History of Science*, **2**(5):1-24.

Schechner-Genuth, S., 1997. *Comets, Popular Culture, and the Birth of Modern Cosmology*. Princeton University Press, Princeton.

Stephenson, B., Bolt, M. and Friedman, A.F., 2000. *The Universe Unveiled: Instruments and Images Through History*. Cambridge University Press, Cambridge.

Swade, D., 2000. *The Cogwheel Brain: Charles Babbage and the Quest to Build the First Computer*. Abacus Books, London.

Szebehely, V.G., 1989. *Adventures in Celestial Mechanics: A First Course in the Theory of Orbits*. University of Texas Press, Austin.

Tattersfield, D., 1984. *Halley's Comet*. Blackwell, London.

Taub, L., 1998. Cometarium. In R. Bud and Warner D.J. (eds.), *Instruments of Science: An Historical Encyclopedia*. Garland, New York, pp. 125-126.

Wheatland, D.P., 1968. *The Apparatus of Science at Harvard: 1765-1800*. Harvard University, Cambridge, Mass.

8 APPENDICES

8.1 Orbital motion

The ratio of the variable rate of change, (dv/dt), of the true anomaly v of a planet in an elliptical orbit of eccentricity e to the constant mean angular motion, n, of an object in a circular orbit having the same period of revolution as the planet is

$$\frac{(\mathrm{d}\nu / \mathrm{dt})}{\mathrm{n}} = \frac{(1 + e\cos\nu)^2}{(1 - e^2)^{3/2}} \qquad (1)$$

where n = 2π/P, with P being the orbital period. Equation (1) is established by a straightforward application of the conservation of angular momentum.

8.2 Elliptical gearing

In a Desaguliers-type mercurium one of the two identical elliptical gears rotates at a constant angular rate, ω_1, about its focal point, F_D (see Figure 3). The second gear is thereby caused to be driven at a variable rotation rate, ω_2 = dv/dt, about F_P. The variable rotation, ω_2, is transmitted to a planet-marker, moving in an elliptical groove, by a drive arm attached to F_P. The ratio of the angular rates is given by the equation

$$\frac{\omega_2}{\omega_1} = \frac{Z^2 + 1 + \left(Z^2 - 1\right)\cos(\nu)}{2Z} \qquad (2)$$

where v is the angle through which the driven elliptical gear rotates about F_P, and where $Z = (1 + e)/(1 - e)$ is the ratio of the maximum and minimum distances from the focus. If the mercurium is to correctly model the orbital motion of a planet (or comet) then equations (1) and (2) will have to be identical. However, we find an error term, f(ν), in the mercurium, such that

$$\mathrm{f}(\nu) = \frac{\omega_2/\omega_1}{(\mathrm{d}\nu/\mathrm{dt})/\mathrm{n}} = \sqrt{(1-e^2)}\,\frac{1+2e\cos\nu+e^2}{(1+e\cos\nu)^2} \tag{3}$$

We can readily see from equation (3) that the ratio f(0) / f(π) is unity, which indicates that the mercurium provides the correct perihelion (ν = 0) to aphelion (ν = π) angular velocity ratio. The actual perihelion and aphelion velocities provided by the mercurium are smaller than the Keplerian orbital velocities, however, by the factor $\sqrt{(1-e^2)}$. In addition, we see from equation (3) that a Desaguliers-type mercurium provides the correct orbital angular velocity just four times per orbit at the positions corresponding to f(ν) = 1. The variation of f(ν) against ν, as given in equation (3) for various values of eccentricity, is shown in Figure 4.

In addition to the Desaguliers-type cometarium having a velocity variation error term f(ν), it also has an area swept out per unit time error term such that $(\mathrm{dA/dt})_{\mathrm{cometarium}} / (\mathrm{dA/dt})_{\mathrm{Kepler}}$ = f(ν), where A is the area swept out, f(ν) is again given by equation (3), and where $(\mathrm{dA/dt})_{\mathrm{Kepler}}$ is the constant appropriate to Kepler's second law.

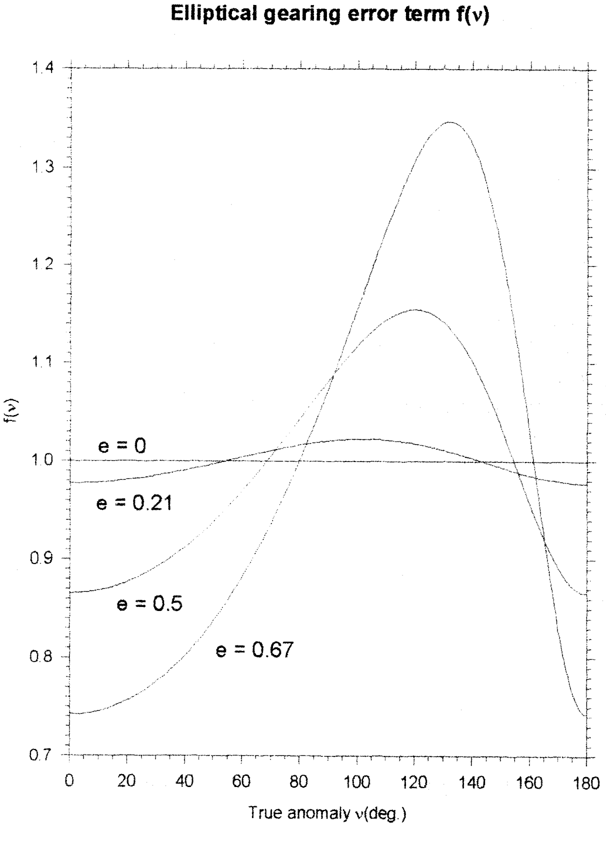

Figure 4. Elliptical former error term f(ν) plotted against true anomaly ν. Loci of f(ν) are shown for a selection eccentricities. Mercury has an orbit of eccentricity 0.21, while the eccentricity of Desaguliers' mercurium was 0.67. The loci for *e* = 0 (circular orbit) and 0.5 are for illustrative comparisons.

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Nineteenth century astronomy at the U.S. Naval Academy

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Abstract

During the 1850s the newly-formed U.S. Naval Academy in Annapolis, Maryland, acquired a small observatory featuring a 19.7-cm (7.75-in.) Clark refractor, transit telescopes, and an astronomical clock. The observatory was used as a base by staff to teach students the rudiments of nautical astronomy, but for a short time in 1869 the refractor was relocated to Des Moines, Iowa, as part of a U.S. Naval Observatory initiative to photograph a total solar eclipse. Although the Academy's observatory was demolished in 1908, courses and research in astrophysics were later introduced, and after more than 150 years astronomy continues to thrive at the U.S. Naval Academy.

Keywords: *U.S. Naval Academy, Alvan Clark refractor, astronomical education*

1 INTRODUCTION

Mention of astronomy and the U.S. Navy immediately conjures up images of the U.S. Naval Observatory (USNO) in Washington, proud owner of an historic 66 cm (26-in.) Clark refractor that for a short time was the largest refracting telescope in the world (see Dick, 2002). What is not so widely known is that the U.S. Naval Academy (USNA) in nearby Annapolis also boasted an observatory and a somewhat smaller Clark telescope during the nineteenth century. The USNA was founded in 1845 in order to provide formal training for future naval officers, and it is no surprise that nautical astronomy was an important area of the curriculum and the Observatory an indispensable teaching resource.

After briefly reviewing the founding of the Academy, this study discusses the USNA Observatory, its instrumentation, a solar eclipse expedition undertaken in 1869, Albert Michelson's foray into astronomical optics, and the astronomy training offered at the Academy during the nineteenth century, before ending with some brief remarks about its association with the USNO and more recent astronomy developments at the USNA.

2 FOUNDING OF THE ACADEMY

The USNA was founded in 1845, becoming fully collegiate (i.e. expanding from a two to a four year programme) in 1850. The impetus to create such an institution was an interesting one, and began some years earlier. The seeds were planted with the birth of the U.S. Navy during the Revolutionary War, and the need was further articulated by President John Quincy Adams in 1825 and again underscored in 1842 by U.S. Secretary of the Navy, A P Upshur. Yet it took an attempted mutiny on board a naval training vessel to have naval leadership reconsider the wisdom of immediate on-the-job training for future naval officers. The incident occurred on the American Brig *Somers* in 1842, and was orchestrated by a midshipman named Philip Spencer. Courts-martial were held, resulting in three hangings at the yard-arm (Park, 1900).

In response to this near-mutinous training travesty, succeeding Secretary of the Navy, George Bancroft, sought a schoolhouse to formalize the educational process, settling on a 'cramming school' called the Philadelphia Naval Asylum. In 1845 he moved it to the "... healthy and secluded location of Annapolis to rescue midshipmen from the temptations and distractions that necessarily connect with a large and populous city ...", and set up a school with fifty students and seven professors (King *et al.*, 1995:2). This Naval School, at Fort Severn in Annapolis, was renamed the 'U.S. Naval Academy' in 1850.

3. THE OBSERVATORY

3.1 Founding of the Observatory

The Observatory at the USNA (Figure 1) was begun on 1850 July 1 and completed by 1854 November 1 (Sweetman, 1979), just one year after the Department of Astronomy, Navigation and Surveying was established. However, manufacture of its principal occupant, a fine-quality 19.7-cm (7.75-in.) Clarke refracting telescope, took more time, and the Observatory only became operational in 1857 (Nourse, 1874b). The building cost $4696.75 (Lull, 1869), which at the time was a considerable sum given that the entire budget of the Academy in 1853 was just $48,044.22 (Todorich, 1984). The Observatory was located near the centre of the Academy grounds, close to the chapel and alongside the Severn River. In 1879, Spencer Baird from the Smithsonian Institution reported its longitude as $0^h\ 2^m\ 15^s.91$ east of Washington, D.C., and its latitude as 38° 58′ 53″.5 N.

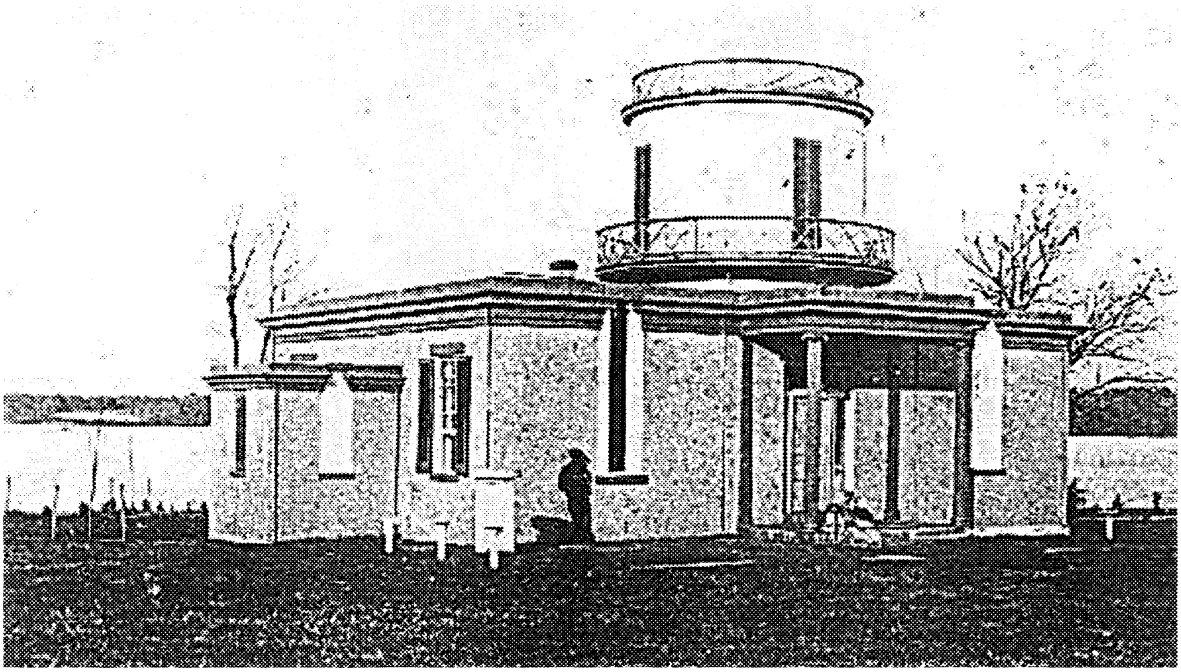

Figure 1. View of the USNA Observatory in 1868, looking north-east (Courtesy: Physics Department, USNA).

Figure 1, which was taken in 1868 looking north-east, reveals an Observatory with a modicum of architectural charm. The original building had overall dimensions of 9.45 × 4.88 metres (31 ft × 16 ft), and was constructed of brick in the shape of a cross (Marshall, 1862). It comprised a central room with entrance portico and a drum-shaped dome, plus adjacent 2.74 × 2.74 metre (9 ft × 9 ft) eastern and western transit wings (see Figure 2). At some date(s) between Marshall's report of 1862 and 1868, when the photograph in Figure 1 was taken, the western transit wing was substantially increased, and a small transit annex was added to it. Some time between 1868 and 1897 this annex was enlarged until its northern wall was flush with the wall of the main observatory building (see Figure 4). The two transit wings and the transit annex containing N-S aligned transit slits that extended across the flat roof and down the northern and southern walls are clearly depicted in Figures 1 and 3. The wooden drum, which on the basis of people shown in Figures 3 and 10 would have been 3.0 and 3.2 metres in diameter, housed the Clark telescope, and access to the sky was provided by a shuttered slit that extended across the flat roof and down one wall to the base of the drum (see Figure 10). The drum also contained two shuttered entranceways to an exterior catwalk, as shown in Figures 3 and 4. The likely reason for the selection of a drum rather than the more common hemispherical dome was its ease of construction and comparative cheapness.

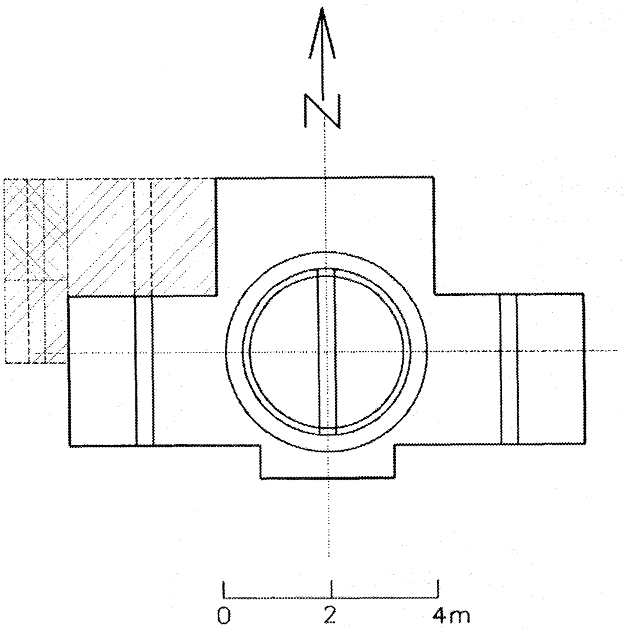

Figure 2. Reconstructed plan of the original Observatory, based on published accounts and archival photographs. The hatched areas were constructed sometime between 1862 and 1868, and the cross-hatched area between 1868 and 1897.

In terms of dimensions and overall design, the USNA Observatory was typical of other small United States observatories constructed during the first half of the nineteenth century. A central room with adjacent transit wings was the norm, and both the Hopkins Observatory and the Western Reserve Academy Observatory (Donnelly, 1973:75, 77), which were built in 1836

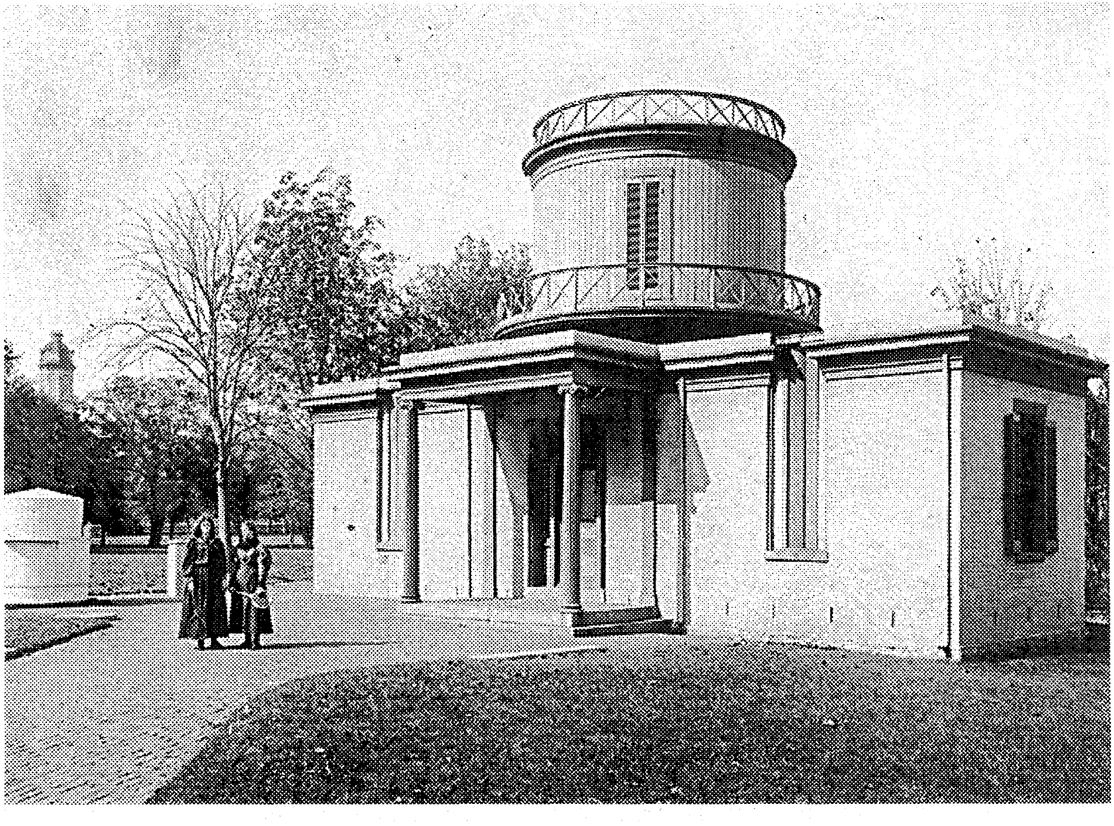

Figure 3. View of the Observatory in 1896, looking north-west (Courtesy: Physics Department, USNA).

and 1837 respectively, bear a close resemblance to the Observatory in Annapolis, while the original USNO and the Georgetown University Observatory, dating to 1842 and 1843 respectively, show the same basic design, even if on a much grander scale (see Donnelly, 1973:78, 81). However, the Hopkins Observatory (see Pasachoff, 1998) is the only one to possess a drum instead of a hemispherical dome, and this has led some at the USNA to speculate that it served as the prototype for their Observatory, even though Milham (1937) does not suggest this and there is no documentation in the USNA archives to support such a viewpoint. Furthermore, Robert Ariail (pers. comm., 2001) has pointed out that the two observatories were designed by different architects. Rather it would appear that generic aspects of nineteenth century observatory architecture influenced the design of the USNA Observatory.

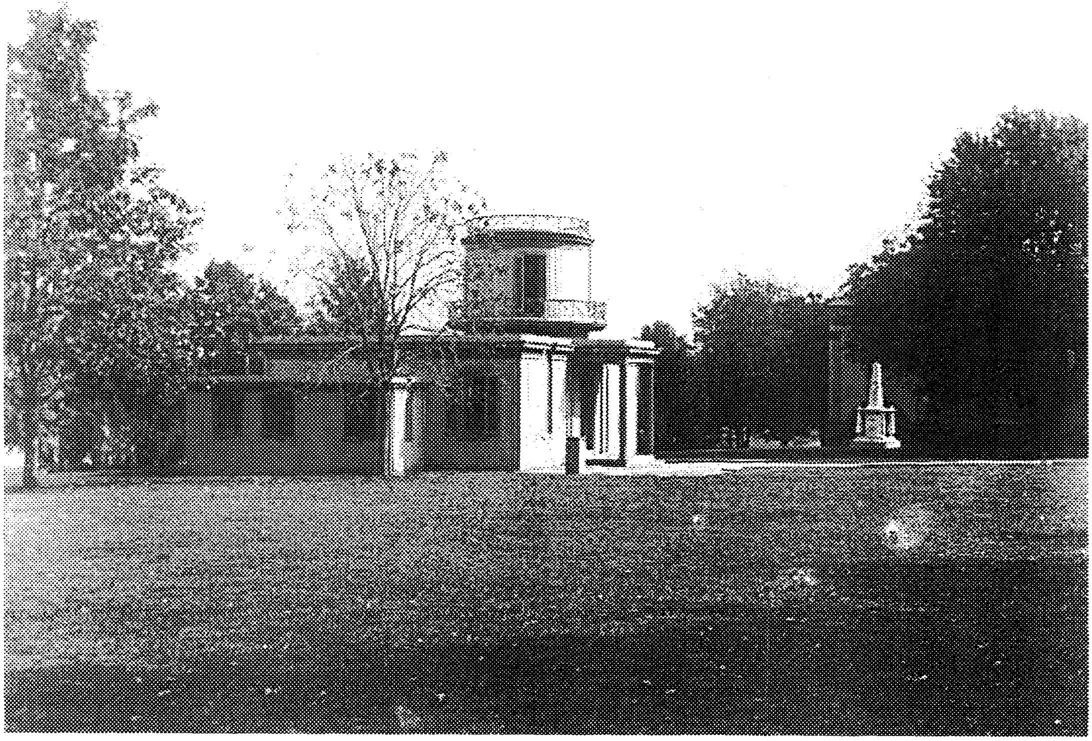

Figure 4. View of the Observatory in 1897, looking east (Courtesy: Physics Department, USNA).

3.2 The 19.7-cm Clark Refractor

The soul of the USNA Observatory was the equatorially-mounted achromatic Clark refractor (see Figure 5). The optics were completed in 1855, but because of funding issues and other delays the telescope only became operational in 1857. With a clear aperture of 19.7 cm (7.75 in.) and a focal length of 2.85 m (112.25 in.) the f/14.5 objective (Marshall, 1862) was the only known Clark lens of this exact size (see the listing in Warner and Ariail, 1995). In the eyes of USNA leaders, the telescope and its auxiliary instrumentation were prized educational accoutrements, and when the Academy moved to Fort Adams in Rhode Island during the US Civil War, the Superintendent penned a letter to his fellow Superintendent at the USNO requesting that they store the Clark telescope for safekeeping (*Letters* ..., 1845-1865).

Often compared to refractors of the '8-inch class', the lens was thought to be of exceptional quality (see Marshall, 1862; Phythian, 1869). In the 1850s, Clark approached lens-making in an holistic, almost aesthetic manner, his hands reportedly often gauging excellence merely by feel. Modern anecdotal evidence suggests this mythical ability attributed to Clark is perhaps wishful thinking. Nonetheless, Clark's revered lens-making techniques, as disclosed by Warner and Ariail (1995), involved crown and flint elements matched as unique, optimized pairs. Their confidence was such that the USNA objective was signed "Alvan Clark Cambridge, Mass. 1855" on the edge of the flint element, indicating that a highly-regarded hand was involved in its fabrication and that the company was willing to stake its reputation on the objective's excellence. The objective was of the Fraunhofer design, with little air spacing and a curve on the flint not equal to that on the convex crown. Recent investigations indicate approximate radii at R1, R2, R3, and R4 of 1.71 m (convex), 0.89 m (convex), 0.85 m (concave) and 2.69 m (convex), respectively, while both crown and flint elements were seen to contain the few small bubbles and internal glass imperfections that are typical of optical quality glass made in the mid-nineteenth century.

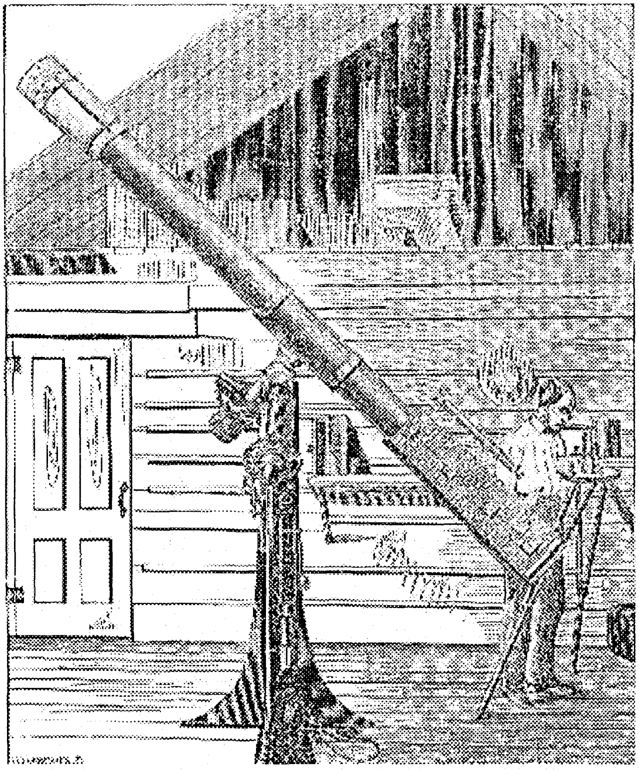

Figure 5. The 19.7-cm Clark telescope, as set up in Des Moines for the 1869 total solar eclipse (after Curtis, 1870:126).

The objective was originally mounted in what is believed to have been a wooden tube, complete with a dew-cap and a 4.4 cm (1.7 in.) aperture f/11.7 finder. The tube was supported by a clock-driven German equatorial mounting on a brick and cast iron pier, and the drive clock was regulated by a Bond spring governor. The telescope was supplied with seven different eyepieces and a filar micrometer (Soley, 1876). In an old USNA report dating to 1869, Phythian noted that the telescope was "... one of the best in the state ...", but these laudatory comments need to be taken in context given that there were very few 'competitors' in Maryland at that time with which to compare it.

The USNA telescope was manufactured early in Clark's career, and at that time was his second largest refractor, surpassed only by a 20.3 cm (8 in.) made for Dawes in 1853 (see Warner and Ariail, 1995:204). Meanwhile, by world standards the 19.7-cm Clark was respectable, but not outstanding. The largest refractor in existence in 1857 was the 39.4-cm (15.5-in.) Merz and Mahler instrument at the Harvard College Observatory, closely followed by its near-twin at the Pulkovo Observatory, and by 1859 there were at least fourteen refractors exceeding 24.1 cm (9.5 in.) in aperture world-wide, five of which were in the U.S.A. (see Table 1 in Orchiston, 2001). From a national perspective, the USNA Clark telescope therefore was in elite company.

3.3 Other Instrumentation

Observatory instrumentation which complemented the Clark varied in the course of the lifetime of the Observatory, but certain instruments are reported as principle appurtenances to the refractor. These included a very fine Repsold meridian circle of 2 arc seconds accuracy, with a 10.2-cm (4-in.) objective and a circle 72.9 cm in diameter, which was installed in the eastern transit wing. This instrument was used mainly for solar observation at 200 power, and was supplied with three eyepieces and four microscope circle-readers, and an observing couch (*Annual Register* ..., 1874; Baird, 1879; Boehmer, 1886).

At one time or another the following instruments were mounted on stone piers in the western transit wing and annex: a 7.6-cm (3-in.) Wurdemann zenith telescope with a focal length of 83.8 cm (33 in.); a 6.35-cm (2.5-in.) Stackpole broken-tube transit telescope; and a portable 5.1-cm (2-in.) Wurdemann meridian transit telescope with a focal length of 66 cm (26 in.) (*Annual Register* ..., 1874). The Stackpole transit telescope, which is of a distinctive design that was developed specifically for the US 1874 transit of Venus expeditions (see Dick *et al.*, 1998), was on loan from the USNO. In addition to housing these instruments, the western transit wing sometimes served as a lecture room (Marshall, 1862; Phythian, 1869).

Other instruments found at the USNA Observatory after 1874 included a portable 7.6-cm (3-in.) f/12 equatorial refractor by Plössl, a Wurdemann theodolite, an Ertel 'Universal Instrument', four surveyor's transits, 80 sextants, 34 artificial horizon, four reflecting circles, a level, five azimuth compasses, 20 comparing watches, and a plane-table (*Annual Register* ..., 1874), while a surveyor's compass and chain is also mentioned by Phythian (1869).

Timekeepers present were a sidereal clock by Arnold and Frodsham of London and an associated chronograph; five mean time chronometers by Dent, Hatton and Negus; and two Negus sidereal chronometers (*Annual Register* ..., 1874; Baird, 1879; Boehmer, 1886).

The Observatory was also furnished with charts, and a library of books, monographs, and scientific journals (Baird, 1879; Marshall, 1862). The library and instruments were housed in the large central room beneath the drum, and in the eastern transit wing, sometimes referred to as the 'Instrument Room' (Phythian, 1869).

3.4 The Demise of the Observatory

Despite its purportedly-inferior construction (Benjamin, 1900; Todorich, 1984), the Observatory stood defiantly for nearly half a century. Then in 1895 the Board of Visitors found the Academy's overall facilities to be "condemnable" (i.e run-down and ready for upgrade), and they recommended wholesale improvements. Among the building scheduled for demolition was the Observatory, and by the time that this actually occurred, in 1908, the telescope and many of the other instruments had been taken to the USNO for safekeeping (Durgin, 1975).

Meanwhile the new campus plan, prepared in 1895-6 by architech Ernest Flagg and Admiral Porter (the Superintendent), allowed for a replacement observatory. Architectural plans prepared by Flagg in 1896 show this observatory – complete with telescope – atop Mahan Hall, but when the final modified version of this major new building was constructed in 1907–10 the observatory was not included. In hindsight, perhaps this is not entirely surprising given that astronomy at the USNA could be more aptly described as celestial navigation, which did not really require the services of an observatory or the historic Clark refractor. Today Mahan Hall remains a stalwart of granite elegance, and instead of an observatory dome the elaborate central tower hosts a bell and a clock. No documentation has been found to explain why the Mahan Hall observatory was not constructed, but apart from its questionable usefulness, funding may also have been a factor. Furthermore, in the new scheme of things Mahan Hall housed an auditorium and the library, whereas the sciences (including astronomy) had to find other homes, and this may also have contributed to the decision not to build a new observatory there.

With the demise of the USNA Observatory, the Arnold & Frodsham sidereal clock remained at the Academy until it was loaned to the Smithsonian Institution for their Centennial Exposition. It subsequently was returned to the Academy, but was loaned to the Smithsonian again, in 1976, for their Bicentennial Exposition, and remains there (Cheevers, 1979-2001). Meanwhile, most of the other astronomical instruments in storage at the USNO were eventually disposed of or else mislaid (S. Dick, pers. comm, 2001), although the Clark objective was eventually identified and retrieved by the Academy.

4 ASTRONOMICAL RESEARCH

4.1 Introduction

Because the USNA Observatory was basically a teaching facility, it was not used to further positional astronomy – notwithstanding the research potential of the Clark refractor – and the only non-educational contribution made by this telescope was when it was relocated to Des Moines in 1869 to observe a total solar eclipse. The other notable research work that was carried out at the USNA during the nineteenth century was Michelson's investigation of the speed of light, and history would later prove the important astronomical implications of this. Further details of the 1869 eclipse and of Michelson's work are presented below.

4.2 The Solar Eclipse of 1869

In the second half of the nineteenth century solar physics was at a forefront of astronomy as spectroscopic analysis of the Sun opened new vistas on our nearest star. One of the most contentious issues during the 1860s was the true nature of the corona: was it a solar feature, or was it a terrestrial or even a lunar phenomenon? Spectroscopic analyses during solar eclipses offered a solution to this dilemma, and the eclipse of 1869 August 7 which was visible from the USA fell at precisely the right time in the history of solar astronomy. As a result of this fortuitous situation,

> ... never before was an eclipsed sun so thoroughly tortured with all the instruments of Science....
>
> The Government, the railway and other companies, and private persons threw themselves into the work with marvellous earnestness and skill; and the result was that the line of totality was almost one continuous observatory, from the Pacific to the Atlantic. We read in *Silliman's Journal*, "There seemed to be scarcely a town of any considerable magnitude along the entire line, which was not garrisoned by observers, having some special astronomical problem in view." This was as it should have been, and the American Government and men of science must be congratulated on the noble example they have shown to us, and the food for future thought and work they have accumulated. (Lockyer (1874:246).

One of the best-equipped observing stations was manned by staff from the USNO, and was located at Des Moines, Iowa. Recounted in meticulous detail in the 1870 printing of *Astronomical and Meteorological Observations Made at the United States Naval Observatory* (see Sands, 1870), this expedition was headed by Dr Edward Curtis (1870) and supported by Professors William Harkness (1870) and J R Eastman. Among the instruments was the USNA's 19.7-cm refractor, which was loaned so that it could be used to photograph the eclipse. It is interesting to note that this was the first time that Clark instruments were extensively used during a solar eclipse (Warner and Ariail, 1995).

The USNA telescope, original mounting and pier were all used, but the telescope had to be extensively modified in order to make it suitable for its intended photographic role. Accordingly, in 1869 May it was temporarily relocated to the Naval Observatory and set up in a wooden shed where it was fitted out with "... a wooden cross base for the pier, a camera box, plate-holders and diaphragm, new drive weights, and new pendulum components (to account for latitude changes). A Huyghenian [*sic*] eyepiece was used for projection to improve accuracy and measurement with cross-wires. The 7-inch plates were placed 4-inches behind the eyepiece for use." (Curtis, 1870:124). Figure 5 shows the telescope in final 'eclipse mode'.

A temporary observatory was erected on high ground near the north-eastern city limits of Des Moines, right on the central eclipse path, and comprised a 7.0 × 4.9 metre tent-like construction made from timber and canvas (Figure 6). This makeshift observatory included a floor, a darkroom, and the large observing room that housed the telescope and a chronometer.

There was some concern about the hoped-for performance of the telescope given that the achromat was corrected for visual use rather than for photography, so a number of preliminary focusing and timing tests were carried out. These experiments also allowed the astronomers to optimize their photographic techniques. These preparations were vindicated on eclipse day when the Clark telescope produced excellent photographs (despite water wash problems just prior to the event and tracking challenges during the eclipse). Eleven negatives of the Sun and 119 of the eclipse were taken, as well as 23 stereo views, and a drawing based on one of the photographs of totality is reproduced here as Figure 7.

Lessons that were learned from using the Clark refractor included a need for a flat-field eyepiece, a better means to ensure a sharp focus at the time of totality, and the aforementioned achromat concerns – to select an objective that was corrected for violet rather than white light. Curtis also reported a disconcerting flexure of the telescope's wooden tube, problems with the camera box (there were vibrations and shifts in tracking), and serious difficulty using the finder telescope with a white screen (see Sands, 1869). Most of these are not marks against the instrument, but simply reflect the adaptive employment of it.

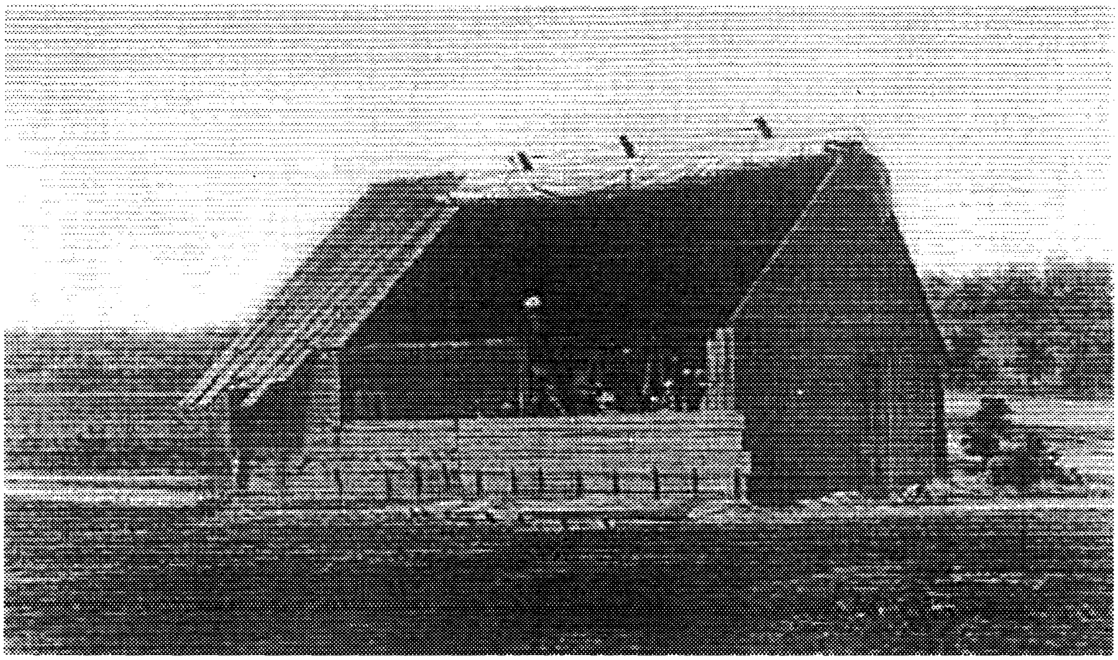

Figure 6. The temporary eclipse observatory set up at Des Moines for the Clark telescope (after Sands, 1870: Plate 1).

In the final analysis the Clark refractor performed well and contributed to forefront science, but the different observing teams across the nation produced conflicting results and the true nature of the corona remained in doubt (see Lockyer, 1874).

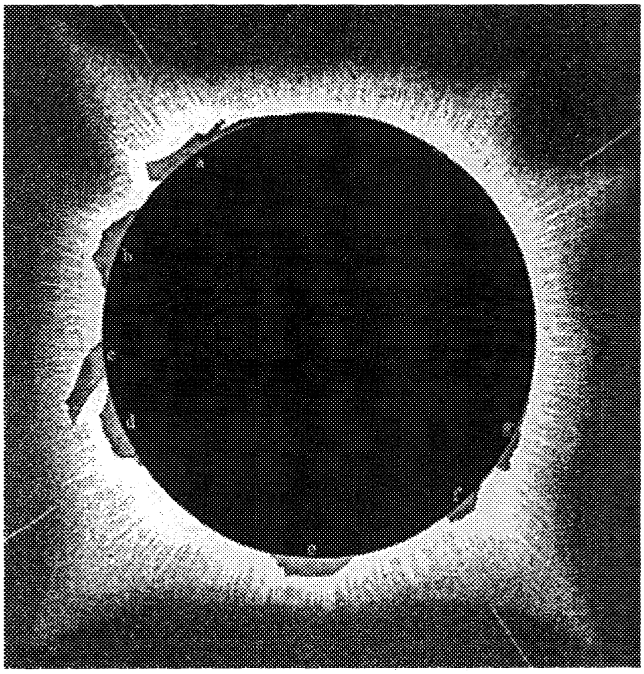

Figure 7. Drawing of the 1869 total solar eclipse, based on a photograph obtained with the Clark telescope. Individual prominences are indicated by letters a-g (after Lockyer, 1874:242).

4.3 Michelson and the Speed of Light

A discussion of research at the USNA is not complete without some consideration the influence that the United States' first Nobel laureate had on the institution, both as a student and as a teacher. Albert Michelson (1852–1931), a Polish emigrant, entered the Naval Academy at age 17 as a midshipman in the Class of 1873 (Figure 8). He did well in the sciences but poorly in seamanship, and after graduation and two years at sea he returned to the Academy and from 1875 to 1878 was an instructor in physics and chemistry. It was during this period that he began conducting his famous experiments into the speed of light. Not satisfied with the existing status quo, in 1878 Michelson created his own measuring device, which cost a mere US$10 (King *et al.*, 1995). This employed a 609.6 metre baseline along the shore of the Severn River bordering the USNA campus, and it was here that the result of 299,828 km/sec was obtained. This figure differs from the currently-accepted value by just 0.01%. Through this work, Michelson lent scientific credibility to the Academy's academics of the day, and his name is extensively honoured on campus today, as is the location of his historic research project.

Figure 8. Albert Michelson, 1852-1931, while a midshipman at the Academy (Courtesy: Physics Department, USNA).

In 1883, Michelson left the USNA for a Professorship at the Case School of Applied Science in Cleveland, and later he accepted a Chair at the newly-founded University of Chicago and taught there until his retirement in 1929. He died just two years later.

Michelson was awarded the Nobel Prize for physics in 1907, and his work of the speed of light and invention of the optical interferometer were to have a profound effect on the development of astronomy, cosmology, physics, and quantum mechanics.

5 TEACHING OF ASTRONOMY

5.1 Introduction

Astronomy was taught at the Academy from 1845, initially under the auspices of the Mathematics Department, and from 1853 by staff in the newly-created Department of Astronomy, Navigation, and Surveying (Phythian, 1869). There was also some interest in astronomy within the Physics Department. The respective roles of these three Departments in offering astronomy education at the Academy are discussed below.

5.2 The Department of Mathematics

Better officer education was prompted by the advent of steam propulsion, and actually motivated the creation of the USNA. With it came six foundation Departments, one of which was a Department of Mathematics headed by Professor William Chauvenet (Figure 9) who was destined to make a name for himself through his much-lauded book, *Spherical and Practical Astronomy*. Lankford (1997:126-127) records that "Chauvenet (1820-70) was born in Milford, Pennsylvania, and entered Yale at sixteen. Following an apprenticeship in geodesy and geophysics with Alexander Dallas Bache (1806-67) and astronomy under Seares Cook Walker (1805-53), Chauvenet was appointed … to the Naval Academy. An expert in astrometry and celestial mechanics, Chauvenet did much to make European ideas and methods available to American astronomers."

Figure 9. William Chauvenet, 1820-1870, founder of the USNA Observatory and the Department of Astronomy, Navigation, and Surveying (Courtesy: Physics Department, USNA).

Midshipmen enrolled at the Academy studied arithmetic, algebra, geometry, trigonometry, and descriptive geometry in the first two years of their course, and analytical geometry, calculus, astronomy, navigation, and surveying in their final two years (Benac, n.d.). Chauvenet was largely responsible for the creation of the Observatory, which was seen as an indispensable teaching aid when it came to astronomy, navigation and surveying. In 1853, courses in these last three subjects were transferred to the newly-formed Department of Astronomy, Navigation, and Surveying.

5.3 The Department of Astronomy, Navigation, and Surveying

While the Observatory was under construction, Chauvenet agitated successfully for a new Department of Astronomy, Navigation, and Surveying, and when this was established in 1853 he became the Founding Professor and Head of Department. In 1859, just two years after the Observatory became operational, Chauvenet resigned to accept a post at Washington University in St. Loius. He was succeeded Professor Coffin, who in turn was replaced by Lieutenant Commander R L Phythian in 1869. Later Phythian would become a captain, and in 1890 Superintendent of the Academy.

Very useful accounts of the nineteenth century astronomy, navigation, and surveying offerings at the Academy can be found in Boehmer (1886), Nourse (1874a), Phythian (1869), Soley (1876) and old Academy registers, and there is also a helpful summary in King *et al.* (1995). Core competencies in marine surveying were taught, including use of the azimuth compass and the sextant (see Figure 10), and students learned how to make time observations and determine latitude and longitude. White's *The Elements of Theoretical and Descriptive Astronomy* was used as a textbook, along with tomes on navigation by Bowditch and Coffin (Pythian, 1869).

Training in navigation was comprehensive, and included such topics as compass sailing, great circle sailing, compass deviation, charts, sextant use, circle of reflection, artificial horizon, azimuth compass, meridian time, latitude by celestial altitudes, longitude by chronometer, Sumner's methods, and spherical trigonometry. First class students (seniors) practised celestial

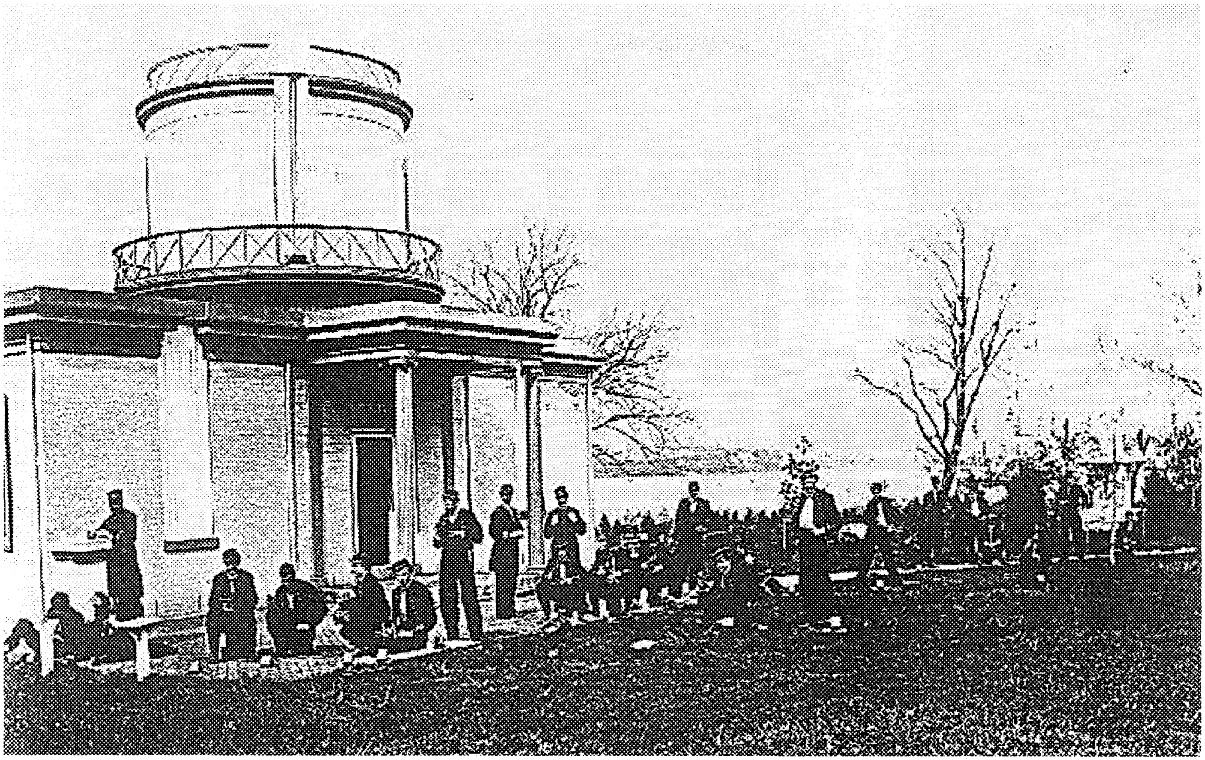

Figure 10. Midshipmen outside the Observatory engaged in a practical class on use of the sextant in 1869 (Courtesy: Physics Department, USNA).

navigation on a short cruise, and continued taking practical instruction for four hours per week throughout the academic year.

Phythian (ibid.) noted the Academy's requirement to focus on navigation, and he particularly lamented the limitations placed on astronomical observing and training in astronomy, but all second class students (juniors) took a first semester course in astronomy. Topics taught included physical and descriptive astronomy, the solar system, Kepler's Laws, Earth's motions and positional effects, weather and atmospheric effects, lunar astronomy, tidal theory, theory and calculation of eclipses and occultations, basic stellar astronomy, and time/equation of time. In addition, refraction, optical theory, and instrument construction were taught to upperclassmen. Cadet-engineers, who trained to become engineers on ships, also enrolled in a special astronomy course, but this focused on navigation. In addition, Phythian (ibid.) planned elective courses in pure astronomy, but no record exists of their implementation.

Although students were given basic instruction on how to use the Clarke refractor and the meridian circles at the USNA Observatory, there was inadequate time to teach any great proficiency let alone offer an opportunity to carry out research. But as the standards for preparation and appointment of midshipmen prior to entrance improved, less time was spent on the more basic training and slightly improved access to the main telescope was given in order to make students more proficient in carrying out and reducing astronomical observations. There was still no opportunity for research, and the hoped-for pure astronomy electives did not materialize (Phythian, 1869; Soley, 1876). Despite these perceived shortcomings, the USNA Observatory did perform a very valuable training role; but like other nineteenth century US college observatories, it suffered from a general lack of funding and academic staffing (see Lankford, 1995), although it did have ample military staff.

5.4 The Physics Department and its predecessor

The Physics Department was not formed until 1895, but its precursor, the Department of Natural and Experimental Philosophy, was one of the six Departments established when the Academy was founded. Through this Department, midshipmen were able to study various branches of physical science, but astronomy was confined to the Mathematics Department and later to the

Department of Astronomy, Navigation, and Surveying. As we have seen, the emphasis was very much on what we now commonly refer to as 'marine astronomy' or 'nautical astronomy' (see Cotter, 1968; May, 1973), and it was only during Michelson's tenure in the Physics Department that the concept of purist research and provocative thinking began to emerge. Clearly the Academy derived a certain amount of pride from its association with so pioneering a scientist, and the impact of Michelson's early work seems to have encouraged the administration to reconsider its policy of taking teaching in a more military and less academic direction. Michelson was able to show that pure science could be of value in an officer's education, and eventually this philosophy would allow courses in astrophysics to be introduced – but this development only occurred during the twentieth century (see Anderson, 1935).

6 DISCUSSION

6.1 The USNA and the USNO

The USNO began as the Navy's official Depot of Charts and Instruments in 1830, and only became the 'Naval Observatory' in 1844, shortly before the founding of the USNA. It quickly accumulated an impressive cache of world-class instrumentation, including what for a time was the largest refracting telescope in the world, and set the tone for positional astronomy in the United States during the remainder of the nineteenth century. But more than this, the USNO had a dominating and formative influence over much of American astronomy at this time (see Dick, 2002).

As part of this ethos, its influence extended to astronomy at the nearby USNA, but the relationship between the two institutions was more one of symbiosis rather than domination by the larger better-resourced Washington-based Observatory. Both were US naval institutions that enjoyed a common naval chain of command, a common scientific and academic arena, close physical proximity, and a focus on navigationally-oriented astronomy. Meanwhile, the U.S. Navy relied on the USNO for its time service and for nautical almanacs, and on the USNA for its officers. Both institutions were framed by common military requirements, and both were intent to expanding their astronomy regimes, in spite of the odds.

One particularly interesting common feature of the USNO and the USNA was the corps of U.S. Navy Professors of Mathematics that both institutions shared from 1848. This unique group of non-service academics, of whom William Chauvenet was one, was specifically created by Congress to teach at the USNA, with the sole restriction that they were hired with "... the requisite skills for the respective job." (Peterson, 1990). It was this vagueness which allowed a few Professors to be placed at other U.S. naval institutions, including the USNO. With the passage of time, the Academy increasingly-moved away from using these Professors, while the USNO came to depend upon them and fought hard to maintain the corps (see Peterson, 1990).

While the USNO may have benefited from the formation of this corps of academic mathematicians and from the loan of the Academy's Clark refractor for its 1869 solar eclipse programme, for its part the USNA acquired a Stackpole transit telescope and Arnold and Frodsham sidereal clock from the USNO, and was able to store its instrumentation there in complete safety during times of civil threat.

Before ending this section we should note that the USNO and the USNA were not the only US military establishments to take an active interest in astronomy and to maintain observatories during the nineteenth century: from 1839 the U.S. Military Academy at West Point, New York, boasted an observatory, which from 1856 housed a 24.8-cm (9.75-in) Fitz refractor (see André and Angot, 1877). And while observatories at overseas military establishments were by no means common, they did exist, perhaps the best-known example being the famous Pulkovo Observatory where Russian army and naval officers were trained in geodetic, astronomical, and nautical techniques (Nourse, 1874a).

6.2 Twentieth Century Developments at the USNA

Much has changed at the USNA since the first Observatory was demolished in 1908. Postgraduate programmes were begun in 1909, leading to the creation of the Naval Postgraduate School. Academic accreditation was granted in 1930, and in 1933 the first degrees were conferred (King, *et al.*, 1995).

The Academy now boasts a Physics Department that employs professional astronomers and offers undergraduate courses and post-graduate degrees in astronomy. Students have access to a computer-controlled DFM 50.8-cm (20-in.) reflector in a dome on the top of Michelson Hall, and faculty members are involved in astrophysical research, with emphasis on the photometric properties of certain types of variable stars, the nature of interstellar titanium, and radio emission from supernova remnants, radio galaxies, and quasars. Nautical astronomy, meanwhile, resides in a separate Department of Seamanship and Navigation.

From a heritage perspective, perhaps the most notable development during the twentieth century was the return of the historic 19.7-cm Clark objective to the campus, following its discovery by USNA Astronomy Club members during a visit to the USNO in 1986. After appropriate optical tests were carried out and various restoration options were reviewed, the USNA Alumni Class of 1941 elected to fund reconstruction of the Clark telescope, together with an observatory, as their fifty-year class gift to the Academy. On 1991 June 6, a formal ceremony marked the presentation of the new observatory and replica Clark telescope (but with an aluminium rather than wooden tube) to the Superintendent, Rear Admiral Virgil Hill. Since its opening, the telescope has provided celestial views for numerous groups of school students and Boy and Girl Scouts. Members of the USNA Astronomy Club have also enjoyed using it for casual observing, and for more serious projects (including sunspot counts, CCD imaging, and variable star photometry).

7 CONCLUDING REMARKS

In this paper we have provided an historical perspective on nineteenth century astronomy at the USNA. Along with an assessment of the USNA Observatory and the instruments it contained, we have summarized the nature of education, and in particular how the teaching of astronomy developed from the very founding of the Academy. In a bid to develop viable astronomy courses, there was competition between a more practical programme that served the Navy's nautical needs and a more concept-oriented academic system that emphasized critical-thinking. There was also a strong desire by those at the USNA for their institution to be compared favourably with the best US colleges (that has not changed!), where academic courses tended to be the norm. This struggle to find a viable balance can be likened to the conflicting approaches to life found in the ancient Greek cities of Athens and Sparta. While the mathematician-astronomer William Chauvenet and a number of early Superintendents stressed the practical line, Albert Michelson's eminence late in the nineteenth century encouraged a more academic approach. Even the venerable USNO had to grapple with similar conflicting philosophies, but in a research rather than educational context.

The founding of the Observatory at the USNA followed close on the heals of the Hopkins, Western Reserve Academy, West Point, USNO and Georgetown University Observatories, and although it took some architectural cues from the first of these observatories, its overall design – a central dome with adjacent transit wings – reflected common elements of observatory architecture in vogue at that time.

While by no means the nation's foremost astronomical facility, the USNA Observatory was reasonably well staffed and was an important element in nineteenth century American astronomy. It housed a respectable, if somewhat underutilized, Clark refractor of unique aperture, which served an important educational role by introducing thousands of future naval officers to the finer points of nautical astronomy. And for one brief moment it enjoyed a research role at Des Moines, Iowa, where the USNO set up an observing station for the total solar eclipse of 1869.

A major redevelopment of the campus at the end of the nineteenth century called for the demolition of the Observatory, and this occurred in 1908, bringing to an end exactly half a century of astronomical endeavours. Plans for a replacement Observatory atop Mahan Hall did not eventuate, perhaps through lack of money and changing priorities, and the Clark telescope and other instruments went into storage at the USNO. The Clark objective was only 're-discovered' in 1986, and a replica of the old telescope now offers USNA students and members of the public general sky-viewing opportunities, thereby continuing an educational tradition that was initiated back in 1857.

Throughout the life of the USNA, the competing benefits of academic education versus a professional military grounding have served to spawn interesting curriculum developments, and this is certainly true of astronomy. Courses in astrophysics and non-nautical astronomy were developed during the twentieth century; senior students now have access to a 50.8-cm reflector;

and staff are involved in forefront research. For more than 150 years, astronomy in one guise or another has continued to thrive at the U.S. Naval Academy. This is an institution that is truly rife with heritage and steeped in astronomical tradition.

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9 REFERENCES

The following abbreviations are used:
USNA = U.S. Naval Academy
USNO = U.S. Naval Observatory

Anderson, A.B. (ed.), 1935. 90th Anniversary, USNA. *US Naval Institute Proceedings*, **61**:1363-1365, 1394, 1417-1418.

André, C., and Angot, A., 1877. *L'Astronomie Practique et Les Observatoires En Europe et En Amérique, Depuis Le Milieu Du XVII^e Siècle Jusqu'a Nos Jours (Troisième Partie).* Gauthier-Villars, de L'École Polytechnique, Paris.

Annual Register of the United States Naval Academy, at Annapolis, MD. Twenty-Fifth Academic Year, 1874-1875. Government Printing Office, Washington (1874).

Baird, Spencer, 1879. Reports of American observatories. *Smithsonian Institution Annual Report*: pp. 535-539.

Benac, T.J., n.d. *A Brief History of the Department of Mathematics.* Mathematics Department, USNA, Annapolis.

Benjamin, Park, 1900. *The United States Naval Academy …* Putnam, New York.

Boehmer, George, 1886. Report on astronomical observatories. *Smithsonian Institute Annual Report*: pp. 367-371.

Cheevers, Jim, 1979-2001. Notes on the USNA Observatory and the sidereal clock. Unpublished personal reference notes, USNA Museum.

Cotter, C.H., 1968. *A History of Nautical Astronomy.* Hollis and Carter, London.

Curtis, Edward, 1870. Report of Dr Edward Curtis, U.S.A. In Sands:123-156.

Dick, Steven, 2002. *Sky and Ocean Joined. The U.S. Naval Observatory, 1830-2000.* Cambridge University Press, Cambridge.

Dick, S.J., Orchiston, W., and Love, T., 1998. Simon Newcomb, William Harkness and the nineteenth century American transit of Venus expeditions. *Journal for the History of Astronomy*, **29**:221-255.

Donnelly, Marian Card, 1973. *A Short History of Observatories.* University of Oregon , Eugene.

Durgin, H., 1975. Letter to William Jefferies, dated February 1. Original in the USNA Musuem.

Flagg, Earnest, 1896. Original architectural design drawings: Academic Group USNA Annapolis Md Serial 1153. Drawings of Mahan Hall [Library], indicating observatory dome plans for construction 1907-1910, Public Works Department, USNA.

Harkness, William, 1870. Report of Professor William Harkness, U.S.N. In Sands:25-67.

King, Randy, Cheevers, James, and Harmon, Scott, 1995. *The United States Naval Academy: 150 Years of History.* Public Affairs Office, USNA, Annapolis.

Lankford, John., 1997. *American Astronomy. Community, Careers and Power, 1859-1940.* University of Chicago Press, Chicago.

Letters Sent by the Superintendent of the U.S. Naval Academy 11. 1845-1865. National Archives and Records Service, General Services Administration, Washington, (1973).

Lockyer, J.N., 1874. *Contributions to Solar Physics.* Macmillan, London.

Lull, P., 1869. *Description and History of the U.S. Naval Academy, From Its Origin to the Present Time.* USNA, Annapolis.

Marshall, Edward C., 1862. History of the United States Naval Academy. *The North American Review*, **95**:57-58.

May, W.E., 1973. *A History of Marine Astronomy.* Foulis, Henley-on-Thames.

Milham, Willis, 1937. *Early American Observatories.* Williams College, Williamstown.

Nourse, J.E., 1874a. Observatories in the US. *Harper's New Monthly Magazine*, **48**:526-541.

Nourse, J.E., 1874b. Observatories in the U.S. *Nature*, **10**:209.

Orchiston, W., 2001. The English equatorial mounting and the history of the Fletcher Telescope. *Journal of Astronomical History and Heritage*, **4**:29-42.
Pasachoff, Jay M., 1998. Williams College's Hopkins Observatory: the oldest extant observatory in the United States. *Journal of Astronomical History and Heritage*, **1**:61-78.
Peterson, Charles, 1990. The United States Navy corps of Professors of Mathematics. *The Griffith Observer*, **54**(1):2-14.
Phythian, R.L., 1869. Report to the Superintendent: Department of Astronomy, Navigation, &c dated April 26. In Lull:33-35.
Sands, B.F, 1870. Appendix II. Reports on Observations of the Total Eclipse of the Sun, August 7, 1869. In *Astronomical and Meteorological Observations Made at the USNO During the Year 1867.* Government Printing Office, Washington.
Soley, James, 1876. *Historical Sketch of the United States Naval Academy. Prepared by Direction of Rear-Admiral C.R.P. Rodgers, U.S.N., Superintendent U.S. Naval Academy for the Department of Education at the International Exhibition.* Government Printing Office, Washington.
Sweetman, Jack, 1979. *The U.S. Naval Academy: An Illustrated History.* Naval Institute Press, Annapolis.
Todorich, Charles, 1984. *The Stribling Years. The Spirited Years: A History of the Antebellum Naval Academy.* Naval Institute Press, Annapolis.
Warner, Deborah, and Ariail, Robert, 1995. *Alvan Clark and Sons: Artists in Optics.* Willmann-Bell, Richmond.

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The IAU, astronomical archives and Commissions 41 and the ICHA*

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The year 1998 marked the 50th anniversary of the creation of International Astronomical Union Commission 41. It was formed in Zurich during the VIIth General Assembly (GA), the first one after the 1935 GA in Paris. The Commission was named *History of Astronomy* and it had less than 20 members. At the VIIIth GA in Rome in 1952 about a dozen new members joined the Commission, and three years later at the Dublin GA, reports and a bibliography were given for the 30 members.

The first apparent interest in astronomical archives was included in the Report of Commission 41 and in the sessions, under the proposal of Kulikovsky, at the Moscow GA in 1958, when "... the desirability of publishing short accounts of the archives of astronomical observatories and institutions, with special reference to letters from astronomers of their countries who have worked there ..." was discussed, but there was no follow-up at the GAs held in Berkeley in 1961 or Hamburg in 1964.

After the destruction of some papers and documents of a notable astronomer of high standing, Commission 41 submitted a resolution about instruments and documents of historical interest and this was passed by the GA in Prague in1967. The resolution included the following statement:

> "It laments the fact that the personal papers of some astronomers have been destroyed by those unacquainted with their value, and therefore urges individuals and observatories to protect and preserve such manuscripts and letters."

Forbes and others in Commission 41 supported the microfilming of documents on the history of astronomy.

From this time the number of members of Commission 41 began to increase, showing a growing interest in this field of astronomy. There were 54 members in 1970 (at the Brighton GA), 59 in 1973 (Sydney), 66 in 1976 (Grenoble), 73 in 1979 (Montreal), 79 in 1982 (Patras), and 102 in 1985 (Delhi). Meanwhile, "C41 consultants" were introduced in 1967 for those who were not IAU members but were actively involved in history of astronomy activities, and by 1976 their number had risen to 41. During these growth years of the 1970s and 80s, the "preservation of twentieth-century astronomy", "preserving written records" and "microfilming of documents in several countries" were mentioned at various times, and in 1982, "the use of historical records in astronomical research". Another important development was the founding of the *Journal for the History of Astronomy* in 1970, and almost from the start descriptions of important astronomical archives featured in its pages.

During meetings of Commission 41 at the Baltimore GA in 1988, Débarbat "... raised the question of library and archives conservation, and noted that despite our lamentations in 1967, and similar regrets expressed in 1977 by Commission 5 (Documentation and Astronomical Data) personal papers of great importance to the history of astronomy continue to be dispersed or destroyed." At that time it was resolved that she be invited to act on behalf of the Commission "... in setting up a working party to explore the problem jointly with Commission 5."

Three years later at the 1991 GA in Buenos Aires, a resolution proposed by Commissions 5 and 41 was passed after discussions between Débarbat and Hauck (President of Commission 5). The first objective was to stop the wholesale destruction of material of historical value, and

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[*] This is the first of what we hope will be a series of on-going reports by the various C41/ICHA Working Groups.

the second objective was to make the whereabouts of such material better known to scholars. Many instances were reported at this meeting of situations where directors of institutes, librarians, and others invested great care in the preservation of materials over a long time intervals, only to be followed by others who were entirely without any feeling for the past and were prepared to sell or destroy our astronomical heritage. Resolution C4 on "Astronomical Archives", which was endorsed by the GA, recommended that the Union supported the initiatives taken by Commissions 5 and 41

> "1 to establish a register of the whereabouts of all extant astronomical archives of historical interest;
> 2 to impress on observatories and other institutions their responsibility for the preservation, conservation, and where possible, cataloguing of such archives;
> 3 to search for an institution that will allocate space and funds for maintaining such a register and publishing it."

The following Working Group (WG) was established to action this resolution: S Débarbat (as the up-coming President of Commission 41), S J Dick (Commission 41), E Proverbio (Commission 41), B Hauck (President of Commission 5), D Dewhirst (Commission 5).

At the 1994 GA in The Hague, Débarbat reported that during the triennium the members of the WG were not able to meet, but information was circulated and the President of Commission 41 had discussions with a number of people responsible for astronomical archives. Meanwhile Professor Blaauw (a former President of the IAU) published a book titled *History of the IAU: The Birth and First Half-Century of the IAU*, and because some of the funds allocated for its preparation were unspent, Commission 41 successfully submitted the following resolution (B2) on "Funding the archival organization of the IAU":

> "Suggests to the Executive Committee that these remaining funds be used for the archival organization and cataloguing of the early IAU files in preparation for depositing them in a suitable archive."

The following related resolution (C4) on a "Search for an Inventory of Existing Archives", also proposed by Commission 41, was endorsed:

> "Noting that Professor Blaauw's recent "History of the IAU" shows the great value of astronomical archives, Encourages a search for an inventory for all archives related to the history of the IAU, to be undertaken by members at their home institutions and other places and reported to Commission 41."

It should be noted that during the 1994 GA, Commission 41 also organized the celebration of "Seventy-Five Years of the IAU" in the form of a Joint Discussion, and among those who attended were at least six past General Secretaries or Presidents of the IAU, all of whom were interested in the archives of the Union.

By the Kyoto GA in 1997, the number of members of Commission 41 had risen to 155, while at the 2000 GA in Manchester the President reported there were 179 members and 27 consultants, showing the increasing interest of astronomers in the history of their discipline.

At this last GA, Commission 41 joined an initiative of the Commission on Bibliography and Documentation of the Division of History of Science of the International Union for History and Philosophy of Science (DHS/IUHPS) in running a Special Session on "Inventory and Preservation of Astronomical Archives, Records and Artifacts". At this meeting it was announced that the archives of the IAU, which had been catalogued by Professor Blaauw as a result of the resolution taken in 1994, were now housed at the Archives de l'Académie des Sciences in Paris and were available to *bona fide* researchers upon the approval of the General Secretary of the IAU.

Drawing on the momentum generated by this Special Session, Commission 41 reactivated the Archives Working Group, with a new Committee comprising Suzanne Débarbat (Chair: France), Dan Green (USA) and Peter Hingley (UK). In 2002, two further Committee members, Wolfgang Dick (Germany) and Wayne Orchiston (Australia), were added. At the Manchester GA, Commission 41 also formed three other Working Groups (on Astronomical Chronology, Historical Instruments, and Transits of Venus), and another feature of this GA was a very successful Joint Discussion on "Applied Historical Astronomy", attended by more than 100 people.

During the last three years members of the Archives WG have continued to build up national inventories of astronomical archives in different countries, and to document, research and disseminate information on individual archives, and on individual archival records. Meanwhile, in 2001 the IAU and the DHS/IUHPS formed the Inter-Union Commission for History of Astronomy (ICHA), and it was decided that the four existing WGs would be shared by C41 and this new Commission.

The first archives initiative under this new structure occurred in 2002 July when the Archives WG joined with the Historical Instruments WG in organising a highly-successful four-day conference on "Astronomical Instruments and Archives from the Asia-Pacific Region" which was held in Cheongju, Korea.

The next opportunity for members of the C41/ICHA Archives WG to report on their work – either through verbal papers or poster papers – will be at the 2003 July GA in Sydney, when a half-day WG Meeting has been scheduled.

At the Korean Conference a number of our members highlighted the fact that archives underpin most historical research projects. This being the case, we hope that in the long run the activities of the Archives WG will prove to be of great benefit to the rank and file membership of C41 and the ICHA.

Society for the History of Astronomy founded in UK

Saturday 29th June 2002 saw the founding of the UK's new national Society for the History of Astronomy, in the glorious and historic surroundings of Wadham College, Oxford, England. The Society's principal aims are: To promote an academic, educational and popular interest in the history of the science of astronomy and related subjects . To encourage new research into the history of astronomy, especially amateur research at the local level, and to facilitate its collation, preservation, publication and dissemination both by conventional means and through the internet or such other new means as may subsequently become available. To bring together those with a common interest in the subject, whether amateur or professional researcher or general enthusiast, and to organize activities for the benefit and interest of the members.

Hosted by Dr Allan Chapman MA D(Phil) FRAS, well-known historian of astronomy, the Founding Meeting, chaired by Stuart Williams FRAS LRPS, took place in the Okinaga Room at 2 p.m., during which a formal Proposal and Constitution for the Society for the History of Astronomy were discussed and minor amendments made. These were then voted upon and accepted unanimously by a full meeting of more than fifty attendees.

A number of messages of goodwill were presented to the meeting, including a formal representation from the Royal Astronomical Society by Dr Helen Walker of Rutherford Appleton Laboratory, who is a Scientific Secretary of the RAS, and congratulations and good wishes sent by Professor F Richard Stephenson, President of IAU Commission 41 (History of Astronomy)and the ICHA, on behalf of the officials of those organisations.

During the meeting, the Society's first Council was elected, the candidates previously announced being formally and unanimously elected *en bloc*, without opposition. The Council now officially consists of: Hon. President – Dr Allan Chapman MA D(Phil) FRAS; Hon. Vice President – Sir Patrick Moore CBE FRS; Hon. Vice President – Dr Michael Hoskin PhD FRAS; Chair – Emily Winterburn MSc; Secretary – Stuart Williams FRAS LRPS; Treasurer – Kenneth J Goward; General Council Members – Roger Jones, Kevin J Kilburn FRAS and Dr Nicholas Kollerstrom MA Cantab PhD FRAS. They are now charged with the responsibility of setting up and managing the operation of the Society.

In addition, the Society's newly-appointed webmaster and newsletter editor, Callum Potter, and Archivist Mark Hurn and Librarian Madeline Cox were formally introduced to the meeting.

The Founding Meeting concluded with a Presidential Address by the new Society's Hon. President Dr Allan Chapman and the formal handover of the Chair to Emily Winterburn who then closed the meeting at a little after 4 p.m.

A group photograph was taken, followed by tea and an astronomy book raffle thanks to the kind sponsorship of publishers Springer-Verlag and booksellers Aurora Books who donated the prizes and have contributed to the Society's Library. Attendees departed at 5.30 p.m., all agreeing that a splendid and momentous occasion had taken place, making an excellent start to what will be a new chapter in the history of astronomy.

For general enquiries, please write enclosing a stamped s.a.e. (or two International Reply Coupons) to: Mr Stuart Williams FRAS LRPS, Secretary, SHA, Flamsteed Villa, 26 Matlock Road, Bloxwich, WS3 3QD, England. For membership details and a membership form, please send a stamped s.a.e. (or two International Reply Coupons) to Mr Ken Goward, Treasurer, SHA, 14 Keightley Way, Tuddenham St Martin, Ipswich, Suffolk, IP6 9BJ, England. Web site: http://www.historyofastronomy.fsworld.co.uk/

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The C41/ICHA Transits of Venus Working Group.
I: An introduction

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1 Introduction

Currently IAU Commission 41 (History of Astronomy) and the Inter-Union Commission for History of Astronomy have four active Working Groups (WGs):

- Archives (chaired by Dr Suzanne Débarbat, France)
- Astronomical Chronology (chaired by Professor Alex Gurshtein, Russia)
- Historical Instruments (chaired by Professor Il-Seong Nha, Korea)
- Transits of Venus (chaired by Dr Wayne Orchiston, Australia)

2 Formation of the Transits of Venus WG

Ever since Crabtree and Horrocks observed the 1639 transit of Venus, these rare events have captivated astronomers, none more so than in 1761, 1769, 1874 and 1882 when they were vital tools in determining that basic celestial yardstick, the 'astronomical unit'.

There is already a formidable transits of Venus bibliography which documents considerable scholarship, but at the 2000 General Assembly of the IAU in Manchester the following Resolution was adopted at the Business Meeting of Commission 41:

> "**Recognizing** the historical importance of previous transits of Venus and the numerous transit of Venus expeditions mounted by various countries, and

> **Noting** the rarity of the upcoming transits in 2004 and 2012
>
> Commission 41 **Recommends** that the sites of previous transit of Venus expeditions be inventoried, marked", and preserved, as well as instrumentation and documents associated with these expeditions."

In order to take this Resolution forward, a Transits of Venus WG was formed. In addition to inventorying, marking, and preserving the sites of previous transit of Venus expeditions and researching the instruments used at these sites and the observations made, the WG also aims to prepare a bibliography of existing publications relating to all transits of Venus, and encourage colleagues to carry out further research and to publish their results.

The following WG Committee was set up: Dr Wayne Orchiston (Australia – Chair), Dr Steven Dick (USA), Professor Alexander Gurshtein (Russia) and Professor Rajesh Kochhar (India). In 2002 July, Dr Luisa Pigatto (Italy) was added to the Committee.

3 Progress since Manchester

Since its formation, ICHA members in Australia, Brazil, Canada, Germany, Italy, Japan, South Africa, UK, and the USA have actively researched various transits and other means of establishing the solar parallax, resulting in a number of publications (e.g. see Hughes, 2001; Orchiston, Love and Dick, 2000; Pigatto and Zanini, 2001; Schaefer, 2001), and the WG Committee has begun preparing a list of post-1989 research papers on transits of Venus (see Section 5, below). In light of the up-coming 2004 and 2012 transits, a number of popular books have been published. One of these is co-authored by ICHA member, Sir Patrick Moore (see Maunder and Moore, 2000), while books by two other members, Michael Chauvin and William Sheehan (with co-author John Westfall), are due for release in 2003. In addition, Steven Dick's monumental history of the U.S. Naval Observatory contains a sizable chapter about the 1874 and 1882 transit programmes.

Meanwhile, much work is in progress. By way of example, Luisa Pigatto and her Italian colleagues are studying the various Italian expeditions, and preparing a list of transit of Venus publications. Hilmar Duerbeck recently presented a conference paper on "The German Venus expedition to Persia in 1874" and is developing this work and his research on the 1882 transit further; Herta Wolf is also researching German and other expeditions, with emphasis on photography. In the Netherlands, Rob van Gent, Al van Helden, Huib Zuidervaart, and other astronomers are busy writing papers and gathering texts and materials about Dutch transit of Venus observations, while Steve van Roode has established a fine web site (http://home.hetnet.nl/~smvanroode/venustransit/).

Jessica Ratcliff is studying the nineteenth century British transit of Venus programmes for a D.Phil. at Oxford University, while Peter Hingley (n.d.) has prepared a paper on the 1874 expedition to Kerguelen Island and Michael Chauvin's (2003) book focuses on the British expedition to Hawaii in 1874. Willie Koorts is investigating observations of the transit made in South Africa and monuments associated with the transit stations (see his excellent web site: http://canopus.saao.ac.za/~wpk/tov1882/tovwell.html), and Wayne Orchiston is carrying out similar studies for Australia and New Zealand.

Peter Broughton and colleagues from the Historical Committee of the Royal Astronomical Society of Canada are planning to install a monument near St. Johns, Newfoundland, where John Winthrop observed the 1761 transit, and Sara Schechner from the Collection of Historical Scientific Instruments at Harvard University is investigating the possibility of having someone construct a replica of the Short reflecting telescope used by Winthrop (that could be used by the Canadian group for an historic re-enactment, and then loaned to institutions for display purposes).

Further south, James Bryan is studying transit observations made from Texas, William Sheehan has researched Todd's expedition to Mt. Hamilton in 1882 and Robert Ariail is gathering information on 12.7-cm (5-in.) Clark refractors used by US expeditions in 1874, while R R de Freitas Mourão is researching Brazilian observations of the nineteenth century transits for a book.

On the display front, Harvard University is planning to show off the instruments used by Winthrop in their new museum gallery; Klaus Staubermann is organizing an exhibition about Dutch transit of Venus observations for the Utrecht University museum; and Nick Lomb is planning a display on Australian transit expeditions for Sydney Observatory. In addition, William Sheehan and Tony Misch are preparing a movie of the 1882 transit based on old plates they have located, and the much anticipated world premier is scheduled for the Sydney General Assembly!

Finally, Juergen Giessen has set up an excellent general transit of Venus web site, with a long list of links (see: http://www.venus-transit.de), and Stephen Johnston, Sara Schechner, and Steven Turner are in the process of creating a web site on behalf of the Scientific Instrument Commission of the International Union of the History and Philosophy of Science. The C41/ICHA WG looks forward to working closely with this group, and providing information and photographs for the web site and the associated database.

4 Concluding Remarks

Although a number of major unforeseen 'distractions' preoccupied those on the Committee of this WG following the Manchester General Assembly, much valuable progress has been made. However, we anticipate an exponential increase in activity as the date of the 2004 transit nears.

In the shorter term, WG members and other interested astronomers will be able to report on their transits of Venus research via oral and poster papers at a half-day WG meeting that is scheduled for the 2003 July General Assembly of the IAU in Sydney. In addition, Gordon Bromage is planning an international conference at Preston, U.K., in June 2004, which will include a sizable transits of Venus component.

5 References

Listed below are some papers and books that deal wholly or in part with transits of Venus, published since 1990. A further list will be provided in the next general report of the WG.

Chapman, A., 1990. Jeremiah Horrocks, the transit of Venus, and the 'New Astronomy' in early seventeenth century England. *Quarterly Journal of the Royal Astronomical Society*, **31**:333-357.

Chauvin, M., 1993. Astronomy in the Sandwich Islands: the 1874 transit of Venus. *The Hawaiian Journal of History*, **27**:185-225.

Chauvin, M., 2003. *Hokulo's: The British 1874 Transit of Venus Expedition to Hawaii.* Bishop Museum Press, Honolulu.

Dick, S.J., 1995. The American transit of Venus expedition of 1882, including San Antonio. *Bulletin of the American Astronomical Society*, **27**:1331.

Dick, S.J., 2002. *Sky and Ocean Joined. The U.S. Naval Observatory, 1830-2000.* Cambridge University Press, Cambridge.

Dick, S.J., Orchiston, W. and Love, T., 1998. Simon Newcomb, William Harkness and the nineteenth century American transit of Venus expeditions. *Journal for the History of Astronomy*, **29**:221-255.

Fernie, J.D., 1998. Transits, travels and tribulations. 4. *American Scientist*, **86**:422-425 [about the 1769 expeditions of d'Auteroche and William Wales].

Hingley, P.D., n.d. The priest and the stuffed penguin: the 1874 transit of Venus expedition to Kerguelen Island. MS.

Howse, D., and Murray, A., 1997. Lieutenant Cook and the transit of Venus, 1769. *Astronomy & Geophysics*, **38**(4):27-30.

Hughes, D.W., 2001. Six stages in the history of the astronomical unit. *Journal of Astronomical History and Heritage*, **4**:15-28.

Kollerstrom, N., 1991. Crabtree's Venus-transit measurement. *Quarterly Journal of the Royal Adstronomical Society*, **32**:51.

Macdonald, P., 1991. The transits of Venus in 2004 and 2012. *Journal of the British Astronomical Association*, **101**:176-178.

Maor, E., 2000. *June 8, 2004: Venus in Transit.* Princeton University Press.

Maunder, M., and Moore, P., 2000. *Transit: When Planets Cross the Sun.* Springer-Verlag, London.

Morikubo, S. (ed.), 1994. *Twentieth Anniversary of Building the Monument to the Transit of Venus of 1874.* Tokyo [in Japanese].

Muenzel, G., 2001. Ladislaus Weinel (1848-1913). *Acta Historica Astronomiae*, **13**:127-166. [In German]

Orchiston, W., 1998. From the South Seas to the Sun: the astronomy of Cook's voyages. In M. Lincoln (ed.). *Science and Exploration in the Pacific. European Voyages to the Southern Oceans in the Eighteenth Century.* Boydell Press, in association with the National Maritime Museum, Woodbridge, pp.55-72.

Orchiston, W., and Buchanan, A., 1993. Illuminating incidents in Antipodean astronomy: Campbell Town, and the 1874 transit of Venus. *Australian Journal of Astronomy*, **5**:11-31.

Orchiston, W., and Howse, D., 1998. From transit of Venus to teaching navigation: the work of William Wales. *Astronomy & Geophysics* **39**(6):21-24. Reprinted, with some elaborations, in *Journal of Navigation*, **53**:156-166 (2000).

Orchiston, W., Love, T. and Dick, S.J., 2000. Refining the astronomical unit: Queenstown and the 1874 transit of Venus. *Journal of Astronomical History and Heritage*, **3**:23-44.

Pigatto, L., and Zanini, V., 2001. Spectroscopic observations of the 1874 transit of Venus: the Italian party at Muddapur, eastern India. *Journal of Astronomical History and Heritage*, **4**:43-58.

Ponko, V., 1994. 19th century science in New Mexico: the 1882 transit of Venus observations at Cerro Roblero. *Journal of the West*, **33**:44-51.

Ponko, V., 1995. Cedar Key, Florida and the transit of Venus: the 1882 site observations. *Gulf Coast Historical Review*, **10**:47-65.

Schaefer, B.E., 2001. The transit of Venus and the notorious Black Drop Effect. *Journal for the History of Astronomy*, **32**:325-336.

Sellers, D., 2001. *The Transit of Venus. The Quest to Find the True Distance of the Sun.* Maga Velda Press, Leeds.

Smith, D.L. and Jetson, T., 1994. Samuel Tillman and the transit of Venus, Campbell Town, Tasmania, 1874. *Tasmanian History Research Association Papers and Proceedings*, **41**:141-153.

Stephenson, F.R., 1990. Historical evidence concerning the Sun: interpretation of sunspot records during the telescopic and pretelescopic eras. *Philosophical Transactions of the Royal Society*, **A330**:499-512.

van Helden, A., 1995. Measuring solar parallax: the Venus transits of 1761 and 1769 and their nineteenth-century sequels. In R. Taton and C. Wilson (eds.), *The General History of Astronomy. Volume 2. Planetary Astronomy from the Renaissance to the Rise of Astrophysics. Part B: The Eighteenth and Nineteenth Centuries*. Cambridge University Press, Cambridge, pp. 153-168.

Westfall, J.E., 1992. The 1769 transit of Venus expedition to San Jose del Cabo. In S. J. Edberg(ed.). *Research Amateur Astronomy.* Astronomical Society of the Pacific, San Francisco (Conference Series, Volume 33), pp.234-242.

Young, G., 1990. Two expeditions to Tahiti: 1769 and 1989. *Astronomy Now*, **4**(2):43-45.

Reviews

Gods in the Sky. Astronomy, Religion and Culture from the Ancients to the Renaissance by Allan Chapman. (London: Channel 4 Books, Pan Macmillan Ltd. 2002), ix + 342 pp., 240 × 155 mm, £18.99.

The author of *Gods in the Sky*, Dr Allan Chapman of Oxford, is an academic historian, well known for his researches in the history of astronomy. The historian's approach is central to the present book, which traces humankind's view of the cosmos from earliest times to the beginnings of modern science. It treats the subject in the context of general cultural developments at each stage, including quite particularly religious ideas and beliefs. It is Dr Chapman's basic premise, outlined in the first chapter, that the rise of monotheism – the belief in one rational, all-powerful Creator of the universe as held in the three great traditions of Judaism, Christianity and Islam – played a pivotal part in the foundation of modern science. He challenges the widely-held notions that science and religion are incompatible, or that in the past the Church was the enemy of scientific progress. He shows that the Middle Ages in Christian Europe were far from 'dark', and describes how centres of learning flourished in northern as well as Mediterranean countries.

The chapters that follow get down to copious historical details, beginning with the ancient civilisations of the Near East two or three millennia BC. These peoples acquired a considerable knowledge of astronomy, constructing calendars, and predicting eclipses, but these activities were carried out purely for the regulation of civil and religious life. The world of human beings was seen as subject to numerous capricious gods who inhabited a cosmos of the vaguest mythological origin. An exception to this primitive cosmology came from the Jews who in the first millennium BC developed their belief in a unique God who created the heavens and Earth from nothing. The story of the Creation in the book of Genesis, "one of the world's most far-reaching and influential narratives", was put on record in the sixth or seventh century BC. The same one God the Creator was carried through in the Old Testament to Christianity. It was also to be fundamental to the faith of Islam, founded in the seventh century AD. Dr Chapman finds it significant that these civilisations from which modern astronomy – and science generally – were to evolve would have in common a belief in one personal Creator God.

The cosmos of the Greeks in their great age of learning (beginning in the sixth century BC) did not include a Creator but was governed by principles of logic and mathematics which were absorbed by their monotheist successors. The Arab world was the principal inheritor of Greek science. Indeed, Arab astronomy, which began as early as the second century AD, was responsible for the longest and most detailed runs of celestial observations of all time, the era AD 900 to AD 1200 being its Golden Age. The fate of astronomy in Europe in the same period was more complex. Popular accounts of the history of science tend to skip from Ptolemy (second century AD) to Copernicus – well over a millennium – in one great leap.[1] Dr Chapman fills in this important interval. Though there was little research, practical astronomy, in the service of the Church, was never neglected. The Council of Nicea in AD 325 fixed the date of the equinox, important for the determination of the date of Easter. Within a few centuries the date had slipped again, and in AD 664 was corrected at the Synod of Whitby in Yorkshire, England. Education was fostered, monasteries flourished, and schools associated with Cathedrals were instituted. The great universities of Paris, Oxford, and Bologna were founded early in the new millennium. All used Latin as the common language, which encouraged the free movement of scholars and of ideas throughout Europe.

The twelfth and thirteenth centuries saw an amazing revival of European learning. The Crusades (*c.* AD 1100), aggressive though they were, had a beneficial effect on the conquerors, who were thus exposed to Arab culture and learning. Spanish Knights captured the city of Toledo with its magnificent library of Arabic books and of Arabic versions of Greek texts which were now re-translated into Latin and re-introduced to Christian scholars. In the field of science, the Greek and Christian traditions thus brought together appeared at first to be at odds: the Greek cosmos was ruled by a non-personal "first cause" and "prime mover", and was deemed eternal; the Jewish-Christian cosmos was created by God and had a beginning. Great minds endeavoured to reconcile these positions and succeeded in having Aristotle's works accepted as orthodox in the university curriculum. In the course of time, however, Aristotle's physics with its distinction between terrestrial and celestial matter, and Ptolemy's strict epicycles and crystal spheres, were to be challenged and eventually abandoned. Several factors contributed to this - the great fifteenth century sea voyages of exploration which fostered technology in navigation, geography and geophysics, the invention of printing (the "internet" of the day, as Dr Chapman aptly calls it), the re-discovery of original Greek material through refugee Byzantine scholars from the Ottoman Empire (1543), and to some extent the Protestant Reformation.

It was in the wake of these events that the scientific giants – Copernicus, Tycho Brahe, Kepler, and Galileo – carried out the labours that transformed astronomers' – and humankind's – view of the universe. Copernicus' theory of the Sun-centred solar system (though worked out years earlier) was published when he was on his deathbed (1543). Galileo's championing of that theory gave rise to his famous clash with the Inquisition in 1633 (an episode now candidly regretted by the Catholic Church). Dr Chapman's exposition of the ambiguous status of the Copernican theory at that period, and of the peculiar circumstances of the Galileo affair, provides informed enlightenment of a story that has been prone to bias, if not deliberate distortion, notably by the agnostic movement of the late nineteenth century.

The book ends with a brief look at the development of cosmology from that time until the present, and a recapitulation of the original proposition – that the emergence of a scientific picture of the universe is a result of the fusing of Greek modes of logical thought with monotheism or belief in one Creator God. It is certainly the case that the scientists responsible were all monotheists. The question is whether that revolution could have occurred otherwise. Dr Chapman argues powerfully that it could not; that the belief in a God who designed the universe was what motivated rational human beings, deemed to be created in His image, to observe and to endeavour to understand it. Contrary to popular notions, the scientific revolution of the sixteenth and seventeenth centuries did not represent a revolt against religious belief but against dogmatic classical philosophy. In fact, Church scholars, in late medieval times, had been the first to question that philosophy. On the general question of the relation between science and religion, Dr Chapman provides much food for thought. He counters the modern myth that would present science as "true" and "unprejudiced" by reminding us that science itself is not nature, but rather "a system of investigation which aspires to explore nature's inner logic, but which is itself invented and managed by fallible men and women". Both science and religion are branches of intellectual activity which are not fundamentally antagonistic to each other. He cites the traditional participation of the Catholic Church in scientific research, which is much to the fore in the present day; and the active academic collaboration growing up between modern scientists and theologians. (An example of the latter is the conference of distinguished scholars from Christian, Jewish and Islamic backgrounds held at the Pascal Centre for Advanced Studies in Faith and Science in 1998 whose published proceedings were reviewed in the last number of this journal.2) The book, for all that, is by no means entirely metaphysical. It can be read quite straightforwardly as a fascinating and instructive history of the development of cosmology from earliest times until the Copernican revolution. It is written in the author's highly readable jargon-free style, and contains much unexpected information, not encountered in the usual histories – from Egyptian mythologies, Islamic observatories, Gothic architecture, the medieval universities, to experimental physics in England in the Elizabethan age.

There is an excellent bibliography, divided into historical periods; and readers who as a result of Dr Chapman's analysis wish to delve further into, say, medieval science, will find expert "further reading" lists there. The book is well produced, with a set of interesting colour illustrations and some black and white drawings, and is very reasonably priced.

References

1 E. Theodossiou *et al.*, 2002. From Pythagoreans to Kepler: the dispute between the geocentric and the heliocentric systems. *Journal of Astronomical History and Heritage* 5(1):89-98. This excellent account, devoted specifically to the progress of astronomy, says: "The original Ptolemaic geocentric system remained unaltered and largely undisputed for more than fourteen centuries".

2 Clive Davenhall. 2002. Review of J.H.Brooke, M.J.Ostler and J.M. van der Meer (eds.) 2001. *Science in Theistic Contexts: Cognitive Dimensions. Journal of Astronomical History and Heritage* 5(1):100-101

Mary Brück

Karl Friedrich Zöllner and the Historical Dimension of Astronomical Photometry. A Collection of Papers on the History of Photometry, edited by Christiaan Sterken, and Klaus Staubermann (VUB Press, Brussels, 2000), 188 pp., ISBN 90 5487 254 3, paperback, US$30:00, 240 × 155 mm.

The application of spectroscopy, photometry, and photography to astronomy during the second half of the nineteenth century was to have a major impact and lead to the emergence of astrophysics. While Hearnshaw (1986, 1993) has done an excellent job summarizing major nineteenth century developments in astronomical spectroscopy and photometry, it has been left to others to provide more detail on some of the notable contributors.

One of these was Karl Friedrich Zöllner (1834-1882), a German physicist who introduced a new type of photometer in 1858, and this book reports the presentations and discussions that took place at a one-day workshop that was held at the Archenhold Observatory, Berlin-Treptow, on 1997 April 4. This was the first in a new series of workshops dedicated to documenting historical aspects of observational astrophysics in the nineteenth and early twentieth centuries.

The editors of this volume combine an interesting range of expertise and talent: Chris Sterken is a well-known variable star researcher, with a strong interest in historical aspects of astrophysics, while Klaus Staubermann is an historian who has built a working replica of Zöllner's famous 1858 photometer.

This book is divided into four parts. Part I deals with "Instruments of Zöllner's Era", and begins with an excellent review of nineteenth century visual photometers by Hearnshaw, followed by two chapters by Geyer on Zöllner's revision spectrometer and Schwerd's double-beam photometer. Batha provides a listing of Zöllner-type photometers in Hungarian institutions, and Staubermann ends Part I with two chapters relating to his replication of Zöllner's original photometer. The first of these has fourteen co-authors (one of whom is Sterken), and begins with details of Zöllner's original photometer, which is preserved in the Deutsches Museum in Munich.

There are three chapters in Part II, on "Zöllner's Photometric Data", the first two by Sterken and the last by Sterken and Staubermann. Sterken begins with a frustratingly short chapter on the applications of what he terms 'archeo-photometry', where he shows that ancient photometric catalogues can provide extremely useful data. For example,

> ... the historic light curve of ζ^2 Sco ... shows that two centuries ago the star was about 2 magnitudes brighter than today, while a millenium ago it was only 1 magnitude brighter than now, an indication that ζ^2 Sco should be regarded as a candidate Luminous Blue Variable." (page 79).

Sterken follows this chapter with a much longer one on the data contents of Zöllner's catalogue of 2216 photometric measures of 26 stars between magnitudes 1 and 6, which was published in 1861. In discussing Zöllner's derived magnitudes, he finds they are "... a consistent set ... [and Figure 8.7] shows that not a single of these stars deviates by more than one magnitude from their values of today and that thus none of these stars exhibits strong irregular variability." (pages 90-91). In another interesting analysis, Sterken compares Zöllner's photometric data for β Lyrae with visual magnitudes provided by other observers. In the third and final chapter in Part II, Sterken and Staubermann reproduce an edited version of Zöllner's catalogue of magnitude estimates, adding a sequence number, V magnitudes (drawn from the *Bright Star Catalogue*) and JDs.

Part III is about "Zöllner's Personality", and in three short chapters Dick and Münzel provide an interesting insight into Zöllner's contacts with other astronomers through surviving listings of his personal papers, and through letters that he wrote to his Berlin Observatory colleague and friend, Wilhelm Foerster. Some of these letters contain "... irreconcilable attacks on colleagues ... [indicating] an emotionally wounded person." (page 129), and Dick and Münzel conclude that "Many of Zöllner's reactions indeed manifest a narcissism ... which made him especially sensitive for insults. It would surely be helpful, if a psychologist or a psychiatrist with an interest in history could take care of Zöllner's biography ..." (ibid.). Further evidence of this instability comes through in Münzel's chapter on Zöllner's relations with staff at the Leipzig

University Observatory between 1862 and his death in 1882, although his political activism and emerging interest in spiritualism from 1877 may also have been factors in his growing unpopularity. At any rate, the University chose not to appoint a new Professor of Astrophysics following his death.

The final section of this book, "Studies on K.-F. Zoellner", contains just two chapters. The first is by that master astronomical historian and Zöllner expert, Dieter B. Herrmann, who over the years has published a succession of studies on this pioneering astronomer. Herrmann believes that "... Karl Friedrich Zöllner was one of the central figures in the early history of astrophysics in Germany. Without his work the genesis of the new scientific discipline of astrophysics cannot be understood." This is high praise indeed, but sums up Zöllner's vital role in the international development of astrophysics. Finally, Hamel brings this fascinating book to a close with a list of Zöllner's 87 publications, plus key biographical works about Zöllner.

Sterken and Staubermann are to be congratulated on producing a readable volume about one of the key figures in nineteenth century German astronomy – even if he is sometimes misunderstood, and I particularly recommend this book to anyone interested in the history of astrophysics.

Wayne Orchiston

References

Hearnshaw, J., 1986. *The Analysis of Starlight. One Hundred and Fifty Years of Astronomical Spectroscopy.* Cambridge University Press, Cambridge.

Hearnshaw, J., 1993. *The Measurement of Starlight. Two Centuries of Astronomical Photometry.* Cambridge University Press, Cambridge.

Queen of Science, Personal Recollections of Mary Somerville. edited and introduced by Dorothy McMillan. (Edinburgh: Canongate Classics 2001), xlii + 434 pp., 195 × 125 mm, £8.99 softback,.

Mary Somerville (1780-1872), mathematician, theoretical astronomer, and writer, is among the most celebrated women in the history of science. The daughter of an admiral in the Royal Navy, Somerville was brought up in a small seaport in Scotland. She received little formal education in her youth; yet she longed to learn and, mainly through her own persistence, became her own principal tutor. Later, with the help of sympathetic Edinburgh academics she mastered the calculus and was introduced to the works of the great continental mathematicians. She was married and widowed young, but in her second husband and first cousin William Somerville, an Army doctor, she acquired a partner who shared her enthusiasm for science and encouraged her studies. The Somervilles began their married life in Edinburgh among that city's liberal intelligentsia, but soon moved to London which was their home for over twenty years. Their English circle included a galaxy of scientists, most influential among whom was John Herschel who became a lifelong personal friend and adviser. Others were William Wollaston, the first to discover dark lines in the Sun's spectrum, and Charles Babbage of calculating machine fame. Early in her career Mary Somerville gained the friendship of the distinguished Paris school of scientists including the great Marquis de Laplace. When Mary was 58, her reputation well established, the family moved to Italy for the sake of her husband's health. There she was to live out the rest of her long life. She died in Naples at the age of 92 and is buried there. Mary Somerville first shot to fame with a theoretical treatise, *The Mechanism of the Heavens* (1831), a rendering in English of Laplace's monumental *Mécanique Céleste*. Two books addressed to a wider educated readership, *The Connection of the Physical Sciences* (1834) and *Physical Geography* (1848), were best sellers that went into several editions. In her old age she tackled a new field (biology) with *On Molecular and Microscopic Science* (1869) published in her ninetieth year. Towards the end of her life she also wrote her Personal Recollections, annotated and published after her death by her daughter Martha. It is from these Recollections that most of our knowledge of Mary Somerville's remarkable life is based. The original edition (1873) is now rare, and a new one is therefore to be warmly welcomed. The present re-issue, with the title *Queen of Science* (a sobriquet given by an obituarist), published in the Canongate Classics series of Scottish writing, is edited and introduced by Dorothy McMillan, head of English and

Scottish literature at the University of Glasgow. It is, however, considerably more than a reprint of the first: it includes not only the text as published at the time, but also Mary Somerville's own earlier drafts. Some passages from Mary's original version were modified by the daughter, evidently in order to give her mother a less forceful and more ladylike character such as would appeal to late Victorian British ideals. On the whole, however, the changes were not numerous or particularly drastic, and Dr MacMillan truly remarks that, even after editing, the Personal Recollections had "all the immediacy of a diary" and "the seeming freshness of youth". The editor has supplied explanatory notes to *Queen of Science*, and well over three hundred brief biographies of people – family members, friends, scientists, artists, public figures – recalled by Somerville's amazingly-retentive memory over an unusually long life. An appendix gives helpful translations of interesting letters in Italian or French which are interspersed among the Recollections. Thus, through the editor's care and undoubtedly laborious preliminaries, the way is cleared for the reader to enjoy these fascinating memoirs uninterrupted. The Introduction, though occupying only some 30 pages, looks at Mary Somerville the Scot, and surveys her place, as a woman and as a scientist, in the world – or worlds – in which she moved. In addition to its literary interest, *Queen of Science* will be an indispensable aid to students of Mary Somerville's work and an important source of information for historians of nineteenth century astronomy and of science generally.

Mary Brück

The Roman Cult of Mithras: The God and His Mysteries by Manfred Clauss, translated by Richard Gordon, 2000 (Edinburgh University Press: Edinburgh) 198 + xxiv pp, ISBN 0 7486 1230 0, hard cover, price £49.50, ISBN 0 7486 1396 X, soft cover, price £16.00, 234 × 158 mm.

> Mithras, God of the Midnight, here where the great bull dies,
> Look on thy children in darkness. Oh take our sacrifice!
>
> *A Song to Mithras*,
> Rudyard Kipling

The cult of Mithras was one of a number of 'mystery religions' which flourished under the Roman Empire. It began to spread during the first century AD, was at its peak during the second and was extinct by AD 400. The cult was only open to men and its adherents were mostly soldiers serving in the legions, merchants, freedmen, and slaves. The congregations were kept small and met in distinctive temples, *mithraea*, which have been found *in toto orbe Romano*, throughout the Empire. However, the cult seems to have been particularly strong in Rome itself, its port Ostia and the northern provinces on the Rhine and Danube. The origins of the cult are obscure, though, like some of the other mystery religions, it is usually thought to have come from the East. Attempts, more or less convincing, have been made to link the Roman Mithras with the Persian god of light, Mitra and with Zoroastrianism. Plutarch reports that the Cilician pirates defeated by Pompey in 67 BC worshipped Mithras, though any connection with the Roman cult is conjectural.

The doctrines of the cult were secret (that is, a 'mystery') and were revealed only to initiates. As far as is known they were never written down and thus were lost when the cult died out. Such few written descriptions of the cult as survive are fragmentary and come from authors, mostly Christians, who were opposed to it. However, what has survived are examples of the decorations which adorned the mithraea. These ornaments follow a fairly standardized iconography which is both distinctive and suggestive. They are often seen as the key to understanding the cult, though any interpretation of them must necessarily remain speculative.

Much of the supporting mithraic imagery undoubtedly contains astronomical elements: representations of the Sun, Moon, planetary gods, and zodiacal constellations are common. However, the central image of the cult, present in virtually every mithraeum, is the *tauroctony* or bull-slaying. Here Mithras, always in his distinctive phrygian cap and always with his eyes averted, slays a bull, usually surrounded by a supporting cast including a scorpion, a serpent, a dog, a raven, a lion and a drinking cup. Various explanations have been offered for the symbolic significance of this enigmatic and striking tableau, and some of these have been astronomical. In the late nineteenth century the German scholar K B Stark noticed that each of these figures corresponded to one of the Greek constellations and suggested that the tauroctony was a stylized constellation map. This idea fell from favour, but in the past twenty years has been revived by Ulansey, Beck, and others. In Ulansey's sophisticated and ingenious interpretation not only is the tauroctony a constellation map, but also the original inspiration for the motif came from Hipparchus' discovery of precession. These ideas, which remain speculative and controversial, are most fully described in Ulansey's *The Origins of the Mithraic Mysteries*.

THE BIRTH OF MITHRAS FROM HOUSESTEADS
Museum of Antiquities Newcastle upon Tyne Copyright

Mithras born from a cosmic egg. The remains of the eggshell can be seen above and below the god, who is surrounded by an ovoid ring inscribed with the symbols of the zodiacal constellations. The sculpture was found in Housesteads Mithraeum adjacent to Hadrian's Wall. (Courtesy of the Museum of Antiquities of the University and Society of Antiquaries of Newcastle upon Tyne.)

Inevitably the interest of historians of astronomy in the cult of Mithras will concentrate on these astronomical ideas. *The Roman Cult of Mithras* is a useful corrective to this tendency. It is a modern, general introduction to the cult, firmly grounded in the archaeological evidence and with little speculation beyond it. It is similar in scope and intent to Cumont's *The Mysteries of Mithra*, which is now seriously out of date (Cumont's book was first published in 1903 and is still in print, which gives an idea of its significance and influence). *The Roman Cult of Mithras* starts by placing the cult in the cultural and religious context in which it appeared and discussing its possible antecedents and origins. Subsequent chapters cover the external attributes of the cult: its growth and eventual decay, the type of person recruited and the role of the cult in Roman society. Additional chapters describe the physical appearance of mithraea and the utensils found in them. Later chapters cover more internal aspects of the cult, insofar as these can be deduced: its doctrines and rituals and the details of the seven grades of initiate (which seem to have corresponded to the seven planetary deities of antiquity). The final chapters consider the relation of the cult to other cults and religions practiced in the Roman Empire, including Christianity.

The Roman Cult of Mithras was originally published in German as *Mithras: Kult und Mysteries* during 1990. Both the author and translator are scholars well versed in the field. The author is now a Professor at Johann Wolfgang Goethe University, Frankfurt am Main. The text has been translated well and reads naturally and clearly. It is aimed at both the general and undergraduate reader and requires no specialist knowledge to follow. The translator has added suggestions for further reading in English. The book is well illustrated in black and white, and the paperback edition, at least, is reasonably priced. It is good on the archaeological evidence, but there is no separate discussion of the written sources, such as they are, which would have been useful. Because the book was originally published in 1990, and perhaps also because of the author's reluctance to speculate, there is little discussion of the astronomical symbolism of the cult, but the translator has included a section on this material in his suggestions for further reading. In summary, the book is a comprehensive and reliable introduction to the cult of Mithras. It can be read to gain a general understanding of the cult before following the more specialized (and speculative) literature about its possible astronomical symbolism.

Clive Davenhall

References

Cumont, Franz, 1903. *The Mysteries of Mithra* (Dover: New York; this edition 1956 and subsequently reprinted).

Ulansey, David, 1989. *The Origins of the Mithraic Mysteries* (Oxford Univ. Press: Oxford).

Walter Baade. A Life in Astrophysics, by Donald E. Osterbrock (Princeton University Press, Princeston, 2001), xiv + 270 pp, ISBN 0-691-04936-X, US$29:95, 240 × 160 mm.

It is a pleasure to read another book from the prolific pen of that master astrophysicist-historian, Donald Osterbrock, Professor Emeritus of Astronomy and Astrophysics at the University of California, Santa Cruz, and former Director of the Lick Observatory. His target on this occasion is Walter Baade, arguably the most influential observational astronomer of the twentieth century, and his aim is "... to present the known facts of Baade's life and scientific career in interesting and readable form and to let the reader draw his own conclusions ..." (page vii).

Wilhelm Heinrich Walter Baade was born in Schröttinghausen, Germany, in 1893, and trained at Göttingen University, receiving his Ph.D. in 1919 for a thesis on the spectrum and orbit of β Lyrae. Shortly afterwards he obtained a post at Hamburg Observatory where he built an international reputation through his photographic studies of variable stars, globular clusters and galaxies, and spectroscopic analyses of gaseous nebulae and selected stars. He also discovered a number of minor planets and a comet.

As an exciting interlude during this research work, Baade spent 10 days in the USA in 1925, visiting observatories in eastern states. This whetted his appetite to return and work there, which he did 1926-1927 when he held a one-year Rockerfeller Foundation fellowship, sharing his time between Harvard College, Yerkes, Lick, and Mount Wilson Observatories. After this "Wanderjahr in America", Baade returned to routine duties in Hamburg, but he hankered for a chance to work permanently in the States, using the world's largest telescopes.

In 1931 his dream came true when Adams offered him a post at Mt. Wilson Observatory. Although Baade was unquestionably well qualified for the position, Osterbrock suspects that Adams also wanted another bright, dynamic astrophysicist on staff – but this time a team-player – who could serve as a counterpoise to Hubble. Whatever the facts of the matter, Baade was in his element for "Mountain Wilson Observatory was unquestionably the most important observational astronomy research center in the world. Its 100-inch reflector was the largest telescope in existence; it and its 60-inch were both superb instruments at an excellent site ..." (page 50). Over the next decade he was involved in a range of research projects involving nebulae, globular clusters, supernovae and supernova remnants, clusters of galaxies, and he witnessed progress on the 200-inch reflector at Palomar, an instrument which he was destined to use with distinction.

Never a Nazi supporter but always a German at heart, it is perhaps ironic that Baade did some of his finest research, in America, during the Second World War, including the discovery of the existence of two distinct stellar populations, comprising young and old stars, respectively, which "... opened up the fields of study of stellar and galactic evolution that have made up so much of astronomy in our time, but which were sterile and unproductive before his discovery ..." (page 1).

One of the most interesting post-War phases of Baade's life was his involvement with radio astronomy, and this is recounted by Osterbrock in Chapter 6. From the end of the 1940s, Baade and his friend Rudolph Minkowski worked with Australian and British radio astronomers in identifying optical correlates for the newly-discovered 'radio stars', producing some fascinating results. While some sources were associated with well-known galactic objects (e.g. Taurus A with the Crab Nebula), others were linked to galaxies. Baade also investigated polarization in the Crab Nebula and the jet in M87, two well-known radio sources. In these critical formative years of radio astronomy, Baade was one of the few leading optical astronomers who from the very start was prepared – nay eager – to work with these strange new bed-fellows, radio engineers who knew surprisingly little about astronomy. With help from Baade, Greenstein, Minkowski, Oort, and a few others they quickly overcame this impediment.

Another of Baade's important post-War research results, and one that endeared him to readers of newspapers and scientific magazines, was his effective "doubling the size of the universe". This brought the apparent ages of Earth and the Universe into closer agreement, but with the benefit of hindsight Osterbrock feels that Baade's new distance scale was probably "... not as intrinsically important as his population concept ..., as his far-ranging work on supernovae, or as his leading the way in the identification of the radio sources ..." (pages 162-163).

Apart from his publications, another way Baade shared his research results with colleagues and interested members of the public was through conferences (including IAU General Assemblies and symposia), seminars, courses, and public lectures. He was an excellent speaker, and the passion of his involvement in forefront research generally rang loud and clear. Through his lectures, discussions, and letters he inspired a generation of graduate students and young astronomers to work on stellar issues, galactic research or nebulae, and he also had a profound impact on his contemporaries, in one way or another touching the lives and hearts of a great many astronomers world-wide. One of the features of Osterbrock's book is the way in which he interweaves research and the social fabric of Baade's relations with his colleagues. And in this context, the major falling out between Baade and Shapley over the new distance scale (pages 171-174) makes compelling reading.

As an Australian-based astronomer I was also fascinated by Osterbrock's account of Baade's six-month sojourn in Australia during 1959, the year after his retirement from the Carnegie Institution. Baade obviously enjoyed discussing forefront research with the optical astronomers at Mount Stromlo Observatory and the radio astronomers at the Division of Radiophysics in Sydney (where I begin work as a lowly Technical Assistant just two years later, straight after leaving secondary school), lecturing at the Australian National University, attending a conference in Perth and a symposia in Canberra, and observing the globular cluster NGC 6522 with the 74-inch reflector at Stromlo (even if this was "the most uncomfortable instrument with which [he] ever observed" – see page 205). But at times he also found the experience exhausting, as when he and Bok, the dynamic new director at Stromlo, spent a hectic week exploring Western Australia in a crowded automobile and sleeping in outback accommodation whilst in search of a suitable observatory site. As Osterbrock says, "Bok was a compulsive talker and doer; his heart was in the right place but he did not realize that he was wearing Baade down." (page 206). This comes through clearly in the photograph of him on page 207, taken somewhere in the Australian desert. He looks a tired old man!

This strenuous Australian experience undoubtedly contributed to Baade's rapid physical decline once he and his wife settled back in Germany in late 1959, and it was not long before he was bed-ridden and unable to write. In 1960 January he underwent an operation in Göttingen but never recovered and died suddenly in June of that year. According to Osterbrock, "Baade was born, lived, and died a German. He never wanted to be anything else. He loved his country, but best of all he loved his native region, Westphalia, where he was born, educated ...[and] buried." (page 212). But for Baade, astronomy always took precedence over his homeland, and this is why he made his greatest discoveries in America. Yet he never chose to become an American citizen, always planning to live in Germany after retirement, and he and his wife always spoke German at home. His death was a loss not just to Germany and America but to world astronomy.

All in all, this is a captivating book with that wonderful mix of science and sociology that we have come to expect from Osterbrock's pen. It is a veritable astronomical adventure, the story of one man's remarkable exploration of the Universe. And for those wishing to delve further into Baade's remarkable achievements there are 27 pages of notes and references.

2002JAHH....5..197N

Beautifully-written and well illustrated, this book is a bargain at just US$29.95, and it deserves to be on the bookshelf of every astrophysicist or historian interested in twentieth century astronomy.

Wayne Orchiston

La Carte du Ciel, Correspondance Inédite Conservée dans les Archives de Löbservatoire de Paris (*Unedited Correspondence Preserved in The Archives of Paris Observatory*), compiled by Ileana Chinnici (IAU and Observatory of Paris, 1999). Xviii + 475 pp., 80 plates,ISBN 2-901057-40-3, softcover, 245 × 172 mm.

The invention of the telescope in 1610 and two centuries later the application of photography revitalized astronomy. Warren De La Rue, a pioneer in sky photography at Kew Observatory England, devised in 1857 a concept to obtain photographic star charts and a catalogue of star positions for the whole sky. Realization of this intent was advanced by successful attempts in celestial photography by E C Pickering at Harvard and D Gill at the Royal Observatory, Cape of Good Hope. A permanent international Commission was formed and an astro-photographic Congress held at Paris Observatory in 1871 by invitation of the French Academy of Sciences. A second Congress in 1891 adopted a Working Plan and allocated regions of the sky to observatories in the northern and southern hemispheres to cover the entire sky from +90 to -90 degrees for stars down to around 13th limiting magnitude. This unique international project was from its inception organized by a permanent international Committee, presided over by the Director of Paris Astronomical Observatory, Admiral Ernest B Mouchez. However with the foundation in 1919 of the International Astronomical Union (IAU) for promotion of astronomy, this body assumed responsibility for this first truly international proposal. IAU Commission 23 for *Carte du Ciel* was much later assigned to conclude this effort and during 1964 provided financial support for publication of the entire 24 Volumes of the *Astrographic Catalogue*.

As the title indicates, this publication compiles original correspondence for *Carte du Ciel* received and archived at Paris Observatory between 1880-1923. These 732 letters between participants and Paris Observatory trace the concept and working plans for the *Carte du Ciel*. They reveal the historical development of astronomy in the second half of the nineteenth and first half of the twentieth centuries with improvements in photography and telescope technology, specifically the construction of optical lenses of large aperture and the design of telescopes to suit the particular photographic requirements of the proposed *Carte du Ciel*. An increase in sensitivity of photographic emulsion contributed to recording of fainter stars with shorter exposure times. Measuring equipment was designed and built to derive positions of celestial objects from photographic plates. To establish a Fundamental Star reference system of accurate positions, meridian transit circle telescopes were commissioned. Collaboration was developed between selected observatories to obtain more than 15,000 photographic plate exposures covering the entire sky. Essential elements and requirements were identified and discussed between participants. Each observatory was to secure the best possible observing equipment and to comply as far as possible with identical instruments and methods. They were at the same time to support other participants with advice and planning in order to achieve a library of photographic maps of the whole sky.

The author of this publication, Ileana Chinnici from Palermo University, Italy, received a scholarship to remain one year at Paris Observatory to research historical archived correspondence. She became familiar with the extensive and important *Carte du Ciel* correspondence received between 1880 and 1923. From the immense amount of letters preserved in this archive, she recognized the historical significance of this important first worldwide scientific collaboration. In preference to herself writing about the logistics and turmoil of this extremely large endeavour, the author decided to publish the text of the 732 letters as transcribed correspondence in their original languages. Her primary purpose was to compile material for other researchers. In this way, readers are presented with text of letters disclosing the struggle this venture would endure during the World War and other political and social uprisings of this historical period. The *Carte du Ciel*, although proceeding very tardily because of its great dimension and many unexpected obstacles, demonstrates that conflict, frustration, and disappointment could not compromise its uniquely-valuable contribution.

Advances in positional astronomy now render *Carte du Ciel* charts somewhat inadequate for most purposes. The *Astrographic Catalogue* has however gained new significance when the measurements of the photographic plates were reduced to the HIPPARCOS Celestial Reference System or HCRS, J2000.0. The United State Naval Observatory in Washington DC disclosed at the General Assembly in Kyoto 1997 its compilation on CD-ROM of the AC 2000 Astrographic catalogue around the epoch of 1900 and its distribution followed shortly thereafter. About two years later the CD-ROM AC 2000.2 was distributed, as a Revised Version of the AC 2000 Catalogue. It contains positions and magnitudes of 4,621,751 stars covering the entire sky at the Mean Epoch of Observation of 1900.0. These positions are also on the Hipparcos Celestial Reference System (HCRS, J2000.0) with improved photometry from TYCHO -2. Thus, the *Astrographic Catalogues* continue to contribute profoundly to present day astronomy.

The reviewed publication, co-sponsored by the IAU, is of great historical interest and therefore recommended to readers curious about the archives of astronomy. *La Carte du Ciel*, a pioneering design, demanded from participants the greatest commitment and endurance. The admirable outcome benefits us all; the historical example of *Carte du Ciel* remains a typical model for collaboration within contemporary extensive proposals.

Ivan Nikoloff

Author index

Subject index

GUIDE FOR AUTHORS

GENERAL

1. There are no page charges. All contributions must be in English language.
2. Manuscripts should be typewritten on one side only and single-spaced on A4-size paper with side margins of not less than 25 mm wide. Text should be justified.
3. First lines of each paragraph should be indented except for those immediately under a heading.
4. A line space should be left before headings and a half-line space before and after indented quotations. There is no space between a heading and the following text.
5. All pages – including references, tables and captions – should be numbered.
6. The Abstract should not be longer than 300 words. It should be intelligible in itself without reference to the rest of the paper.
7. Up to five key words for indexing should be listed under the Abstract.
8. The use of S.I. units is recommended.
9. Dates should be listed in the form "1857 September 16" or "1857 September".
10. The first page of the paper should include the title of the paper, and the name, postal address, and e-mail address of the author(s).
11. Where possible, papers should be e-mailed to the Papers Editor, Wayne Orchiston, at: wo@aaoepp.aao.gov.au Tables should be included, but it is not necessary, at this stage, to e-mail figures – only the list of figures. For those without e-mail facilities, three hard copies of the paper, including references, tables, figure captions, and photocopies of all figures, should be sent to:

    Dr Wayne Orchiston, Anglo-Australian Observatory, PO Box 296, Epping, NSW 2121, Australia

HEADINGS

1. The following hierarchical system of headings is employed:

    3 DISCUSSION
    3.1 Important Developments in Astronomical Spectroscopy
    3.1.1 Kirchhoff's Contribution

    Note that the 3 and 3.1 headings are in **bold** print (and that 3.1.1 is not).

2. Apart from the Abstract, all headings (including "Acknowledgements" and "References") should be numbered, and should be left-justified.

TABLES

1. Tables should be planned to fit the printed B5 format (135 mm wide and 200 mm high).
2. Each table should be typed on a separate sheet or sheets, and all tables should be collected together at the end of the text.
3. Tables should be numbered consecutively according to their position in the text.
4. Each table must be cited in the text.
5. Every table should have a short title.
6. Vertical lines are not required to separate columns; extra space is sufficient.
7. Zero must be placed before the decimal point in all values less than 1.0.
8. If references are used in tables, be sure to include them in the list of references.
9. Column headings should be brief with the units indicated in the line below between parentheses.

FIGURES

1. "Figures" include line drawings and half-tones (black and white photographs).
2. Line drawings must be clear and sharp. If they are draughted (rather than computer-generated) use Indian ink on white drawing paper or film.
3. On line drawings, lettering, line thickness, and other details should be large enough to be legible after reduction to a B5 page size.
4. Half-tone photographs should be on gloss paper with good contrast. Colour photo-graphs cannot be included (but black and white reproductions of them are acceptable).
5. Use bar scales to indicate size so that reduction is possible.
6. All figures should be planned to fit the printed B5 format (135 mm wide and 200 mm high) or part thereof.
7. Figures should be numbered consecutively according to their position in the text.
8. Each figure must have a caption. A list of "Figure Captions" should be supplied on a separate sheet(s) at the end of the manuscript.

INDICATIONS

1. Equations and symbols must be clear.
2. Equations should be numbered sequentially at the right hand margin.
3. Greek letters and unusual symbols should be identified by a pencil note in the margin.
4. Indicate clearly the difference between similar letters and numbers, for example., the letter "l" and the number "1"; the letter "o" and zero (0); the letter "u" and mu (μ); the letter "n" and eta (η).
5. Give the meaning of all symbols immediately after the equation in which they are first used.
6. Indicate clearly subscripts and superscripts.
7. Avoid root signs if possible and use fractional powers.
8. For simple fractions use the solidus (/) instead of a horizontal line.
9. Use standard symbols and notations whenever possible.

QUOTATIONS

1. Quotations of about 30 words or less should be set in the text within double quotation marks.
2. Longer quotations should be indented (left and right), without the use of quotation marks.
3. All underlining, italics, superscripts and subscripts that appear in the original sources should be faithfully reproduced in the quotations.
4. Any insert by the author within a quotation should be placed in square brackets.

REFERENCES

1. These should be cited in the text by author's name and date of publication in parentheses, appropriate pages may be included. Examples are: "Since Osterbrock (1990) has shown ..."; "... found by Dick (1992:15-17)"; "... later results have confirmed this (Warner, 1993)."
2. Publications written by more than two authors are referred to in the text by the first author plus "*et al.*"; however, in the reference list all authors should be included.
3. References in the text should be arranged alphabetically by author, for example., "... is well covered (see Batten, 1997; Dick, pers. comm., 1994; Gascoigne, 1992; Kochhar, 1990)."
4. All references to publications made in the text, tables, and figure captions should be put into a list, separate from the text.
5. The list of references should be arranged alphabetically by authors' names and chronologically if there is more than one reference for an author.
6. All references in the list must be cited in the text.
7. The following should be used as guides for references:

For periodicals

Andrews, A.D., 1997. Cyclopaedia of telescope-makers. Part 7: T-Z. *The Irish Astronomical Journal*, **24**:125-192.
Chapman, A., 1983. The accuracy of angular measuring instruments used in astronomy between 1500 and 1850. *Journal for the History of Astronomy*, **14**:133-137.
Obituary: Sir Joseph Norman Lockyer. *Monthly Notices of the Royal Astronomical Society*, **81**:261-266 (1921).

For newspaper entries

Tebbutt, J., 1861. The comet. *The Empire*, June 26.
The Comet. *The Empire*, June 28 (1861).

For edited symposia, proceedings, etc.

Jeffery, P.M., Burman, R.R. and Budge, J.R., 1989. Wallal: the total solar eclipse of 1922 September 21. In D.G. Blair and M.J. Buckingham (eds.), *Proceedings of the Fifth Marcel Grossman Meeting*. University of Western Australia, Perth, pp. 1343-1350.

For monographs, books, and chapters of books

Colonial Astronomer: Copies of all Correspondence Between the Governor General and the Secretary of State Respecting the Appointment of the Rev. W. Scott as Colonial Astronomer. Government Printer, Sydney (1857).
Howse, D., 1989. *Nevil Maskelyne. The Seamen's Astronomer*. Cambridge University Press, Cambridge.
Sullivan, W.T., 1988. Karl Jansky and the beginnings of radio astronomy. In K. Kellerman and B. Sheets (eds.), *Serendipitous Discoveries in Radio Astronomy*. National Radio Astronomy Observatory, Green Bank, pp. 39-56.

For unpublished sources

Airy, G., 1857. Letter to P.P. King, dated October 30. Mitchell Library, Sydney (AR 4216).
Berendzen, R., 1968. The career development and education of astronomers in the United States. Unpublished Ph.D. Thesis, Harvard University.
Tebbutt, J., 1860-61. Astronomical Observations. MS, Mitchell Library, Sydney (AR 3647).
Tebbutt, J., 1874. Untitled journal of transit of Venus observations. MS, Mitchell Library, Sydney (AR 3682).

For second-hand references

Lassell, W., 1847. Discovery of a new planet. *Monthly Notices of the Royal Astronomical Society*, **8**:83. Cited by J.L. Perdrix in *Journal of the Astronomical Society of Victoria*, **33**:86-92 (1980).

8. Note that the names of periodicals should be given in full.

FOOTNOTES AND ENDNOTES

1. Footnotes should be avoided if possible, but, if essential, they should be indicated by the following symbols: asterisk (*), dagger (†), double dagger (‡), section mark (§), and paragraph mark (¶).
2. If used, they should be kept as short as possible, and supplied on a separate sheet(s) at the end of the text. As most work is presented to the printer as camera-ready, it is best to avoid these and use endnotes.
3. Endnotes should be indicated in the text by superior figures (small figures placed above the line of text). The endnotes are gathered under a numbered heading immediately before the list of references.
4. If references are given in footnotes and/or endnotes, be sure to include full details in the list of references.

CHECK LIST AND ORDER

Title page, Abstract and key words, Text, References, Tables, Figure captions, Photocopies of figures

Journal of Astronomical History and Heritage

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CONTENTS

Cover illustrations show a series of images of the η Carinae area beginning with a drawing by John Herschel published in 1847, a black and white photograph taken by Ben Gascoigne with the MSSSO 40-inch reflector at Siding Spring, a colour photograph taken by David Malin with the AAO 150-inch at Siding Spring, and a view taken with the Hubble Space Telescope, courtesy J Morse (U. CO), K Davidson (U. MN), and NASA.