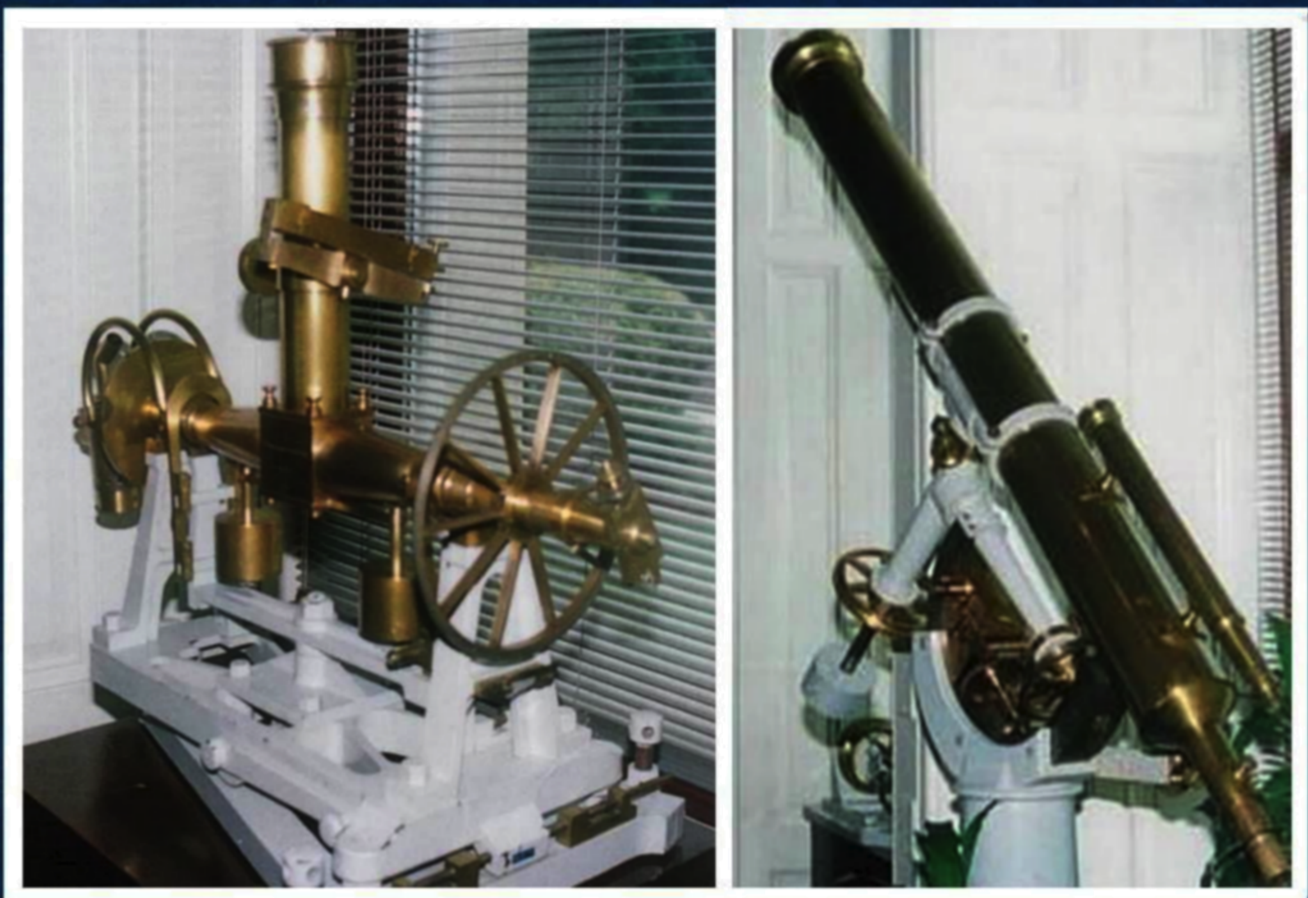
JOURNAL OF ASTRONOMICAL HISTORY AND HERITAGE



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

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COVER IMAGE

Two of the eight stations organized by the United States to observe the 1874 transit of Venus were in Tasmania, Australia. All the American stations were equipped with the same instruments, including a Stackpole broken tube transit telescope (left) and a 5-inch (12.7 cm) Alvan Clark refractor (right). Both of the telescopes pictured are on display at the U.S. Naval Observatory. For the results of an investigation of the relics still present at the Tasmanian sites in Barrack Square, Hobart, and The Grange, Campbell Town, see the article by Orchiston et al. which begins on page 149.

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A BRIEF HISTORY OF ERROR

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Abstract: Observational errors are inevitable in astronomy, and statements of results are not complete without some estimate of the uncertainties involved. While we always strive to reduce those uncertainties, we know that some will remain. There have been times in the history of science when errors have masked second-order effects and actually assisted in the process of scientific discovery.

Key words: Astronomical research, observational error.

1 INTRODUCTION

We are all familiar with observational errors in astronomy, and experimental errors in the laboratory sciences. We know that we cannot eliminate them entirely: Heisenberg's uncertainty principle assures us of that, and in practice the errors are much larger than that principle would predict. Obviously, we strive to reduce errors as far as possible but, at the end of an investigation, we try to estimate the uncertainty that those errors will inevitably produce in the final result. Indeed, a result without some indication of its uncertainty is now considered incomplete, but this was not always so in the history of science.

Observational errors can be of two kinds: systematic and accidental. Both occur in astronomy. The story of the unfortunate assistant of the then Astronomer Royal, Nevil Maskelyne (1732–1811; Figure 1) is well known. The poor man was dismissed because his observations of the transits of stars were consistently about half a second 'late'. Had the customs of the times permitted, the assistant could justifiably have retorted that Maskelyne's determinations were half a second early! Thus, the concept of personal error came eventually to be recognized. It is still with us. In the large cooperative programmes that used to be undertaken at the Dominion Astrophysical Observatory in Victoria, B.C., and which involved several people in the measurement of spectrograms, care was always taken that some of the spectrograms were measured by everyone concerned so that personal errors could be checked and evaluated.

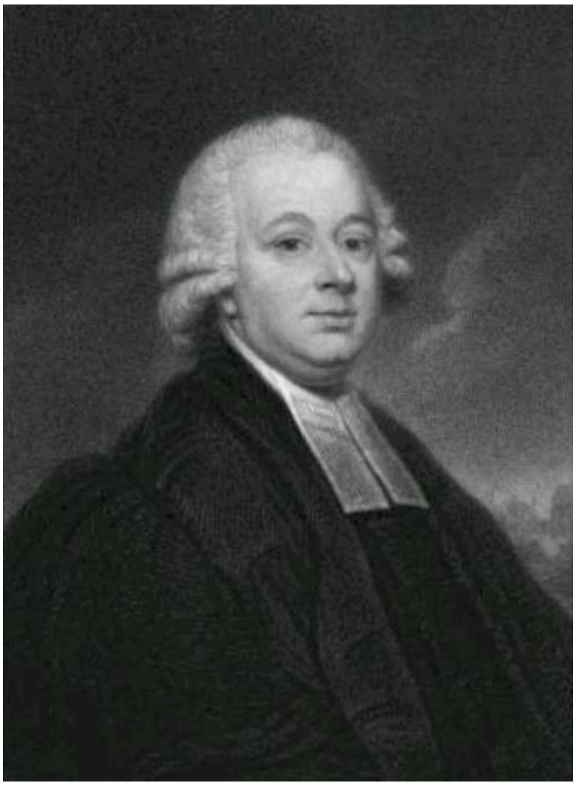

Figure 1: A portrait of the Reverend Nevil Maskelyne by Edward Scriven in 1836 (en.wikipedia.org).

While it is important to be aware of the existence of personal and other forms of systematic error, my chief concern in this paper will be with accidental errors. I will consider the work of Aristarchus of Samos, Tycho Brahe and Kepler, and Robert Boyle, and then go on to discuss some modern work in astronomy in which the evaluation of error is important.

2 ARISTARCHUS OF SAMOS

It is well known that Aristarchus (circa 310–230 BCE) devised a method for determining the relative sizes and distances of the Sun and the Moon and that by combining this with observations made during a total lunar eclipse he could, in principle, derive the absolute distances of the two bodies. The still extant text has been translated and annotated by Heath (1913).

Aristarchus' method was perfectly sound in principle, and his treatment of the geometry of lunar eclipses was superb. In practice, however, the method was flawed because it depended on assessing when the Moon was exacty half full. This is difficult to do; Neugebauer, as quoted by Mickelson (2007), claimed that it is difficult to determine the time of quadrature to within a day or two. My own attempts suggest one can do considerably better than that, but the ratio of the distances of Sun and Moon from the Earth is so sensitive that even an error of an hour or two can make a great difference to the derived result. When the Moon is exactly at quadrature, then the angle Sun-Moon-Earth

(SME) is 90° and the angle Moon-Earth-Sun (MES) can be measured, at least in principle. The ratio of the distance of the Sun to that of the Moon is the secant of MES. Unfortunately, since MES is also nearly 90°, the secant is large and varies rapidly as the angle changes, and the angle itself is difficult to measure. This misled Aristarchus into grossly underestimating the ratio of the two distances, an example of how an apparently small observational error can have very large effects. He found that the Sun was between 18 and 20 times as far away as the Moon. At first sight, this might seem like an attempt, however inadequate, to estimate the errors of observation. Aristarchus, however, assumed that the angle MES was exactly 87°, presumably on the basis of an attempted measurement, and the range of values he gives for the ratio of the distances of the Sun and Moon arises solely from approximations he was forced to make to the ratio of two lengths in his geometrical construction. He was clearly a superb geometer, and must have been well aware how sensitive his result was to any errors of observation, yet he assumed that his determination of the angle MES was correct. For all that, Aristarchus' result was a great advance on Anaxagoras' (circa 500–428 BCE) conclusion that the Sun was a fiery stone that was bigger than the Pelopennesos, still more on a culture that could believe that the Sun was close enough to scorch the Earth when the apprentice charioteer, Phaeton, took over the reins from the Sun-god Helios!

3 TYCHO BRAHE AND KEPLER

Before Tycho Brahe (1546–1601; Figure 2), the positions of planets were not measured systematically and the possibility that there might be errors in the measurements that were made was not taken into account. As is well known, Tycho took great care not only over the observations themselves but in the preparation of the graduated circles with which the observations were to be made. He achieved a precision of about two arcminutes in planetary measures (he could do better on stars—see Thoren, 1990), as did Ulugh Beg (1394–1449) before him, and Jai Singh (1688–1743) shortly after him. This is just about the limit of what can be achieved observationally without the aid of the telescope. The fund of data that Tycho obtained enabled his assistant and successor, Johannes Kepler (1571–1630; Figure 3) to demonstrate, after many false starts, that the orbits of the planets were elliptical. We know that Kepler rejected one false start because the orbit he obtained for Mars deviated systematically in one part by 8 arcminutes from Tycho's observations. Kepler knew that Tycho would not have made so great an error.

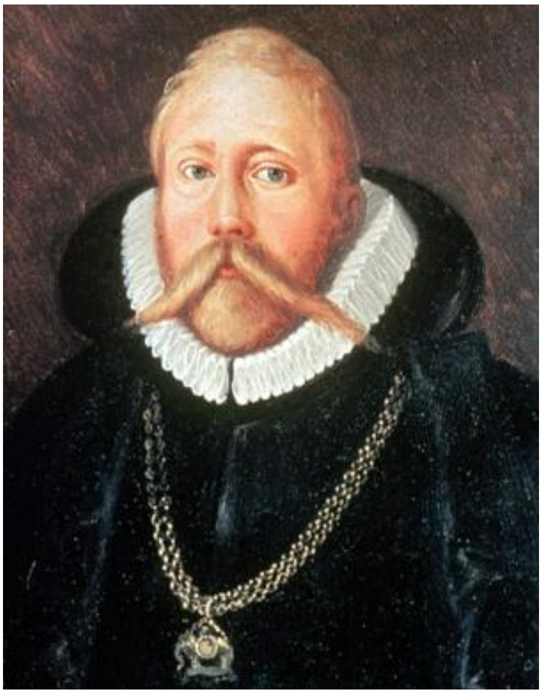

Figure 2: A portrait of Tycho Brahe by Eduard Ender (en.wikipedia.org).

What might have happened if Tycho's observations had been more precise? Suppose that he had been able to detect the deviations from simple ellipses caused by the mutual perturbations of the planets. Kepler, of course, was working before Newton and did not know that the inverse-square law of gravity would explain the three laws of planetary motion that he had discovered. Still less did he understand the possibility of the planets perturbing each other. Would he have been content to accept elliptical orbits as a first approximation with some un-

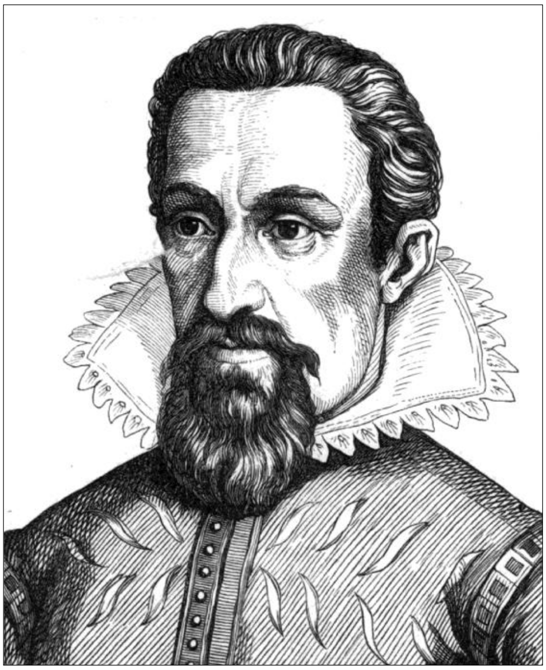

Figure 3: Johannes Kepler (thescienceclassroom.Wikispaces.com).

known force causing deviations from the ellipse, or would he have insisted on finding the 'true' orbit that would satisfy these supposed extremely precise observations obtained by Tycho? One suggestion (Kurth, 1959: 42–43) is that he might have arrived at a model for the Solar System rather like the early quantum theory of the atom. Kurth supposed that Kepler would have regarded the mean orbital motions of the planets as fundamental and, since his Third Law related these to the mean distances of the planets, which had only discrete values, he might have concluded that only discrete values of the mean motions were permitted in the Solar System. The satellite system of Jupiter and the later-discovered one of Saturn might seem to confirm this notion. Kurth argued that a completely consistent theory of the planetary motions could be constructed along these lines

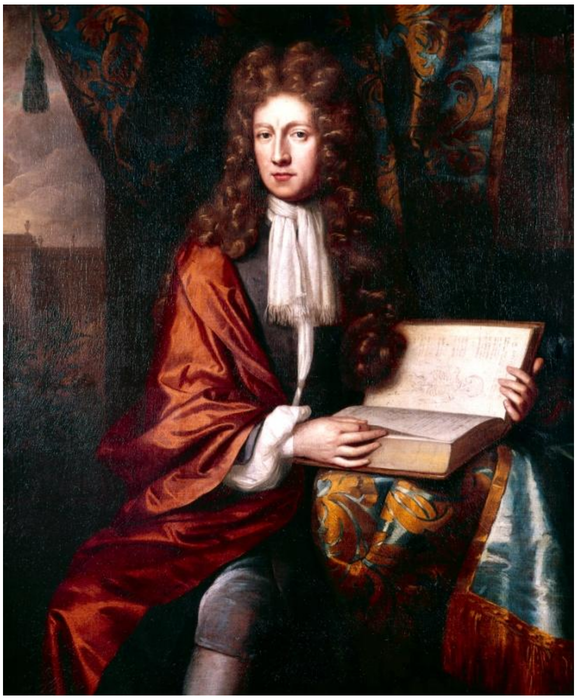

Figure 4: The Honorable Robert Boyle (http://wellcome images.org/).

and remarked that, had Kepler proceeded in this manner, "… physical science and philosophy would have developed in a completely different way." (ibid.). Whether or not one finds Kurth's argument convincing, it does draw attention to the fact that the limited precision of Tycho's observations is what enabled Kepler to derive elliptical orbits, which, in turn, enabled Newton to show that the one law of gravity would explain the falling of a stone to Earth and the motions of the Moon and planets.

4 ROBERT BOYLE

I learned in my schooldays that Robert Boyle (1627–1691; Figure 4) was the uncle of the Earl of Cork and the Father of Chemistry. He was not an astronomer, but his most famous discovery, that of the relation between the pressure and volume of a given mass of gas, combined with the later inclusion of temperature in the relationship, has proved to be of the utmost importance in the study of stellar structure and evolution and certainly deserves a place in the history of astronomy.

Boyle's law, of course, is that for a given mass of gas at a constant temperature, the pressure, P, and the volume, V, obey the relation

$$PV = \text{constant} \quad (1)$$

Boyle was well aware that his values of the product PV were not exactly constant and he wrote:

> Now although we deny not, but that in our table some particulars do not so exactly answer to what our formerly mentioned hypothesis might perchance invite the reader to expect; yet the variations are not so considerable, but that they may probably enough be ascribed to some such want of exactness as in such nice experiments is scarce avoidable. (Boyle, 1662: 159).

Here is a clear recognition that the results have been affected by experimental errors, a recognition that is repeated a few pages further on (Boyle, 1662: 162) together with a suggestion as to the cause of the error:

> In the meantime (to return to our last-mentioned experiments) besides that so little variation may be in great part imputed to the difficulty of making experiments of this nature exactly, and perhaps a good part of it to something of inequality in the cavity of the pipe, or even in the thickness of the glass …

This appears be one of the earliest discussions of experimental or observational errors in the literature of science. Once again, we are prompted to ask: what if Boyle had been able to make his apparatus more uniform and thus to reduce his experimental errors? If he had reduced those errors to a small enough value, then he would have become aware of real departures from the simple form of his law. It is doubtful, however, if, at that time, the van der Waals corrections could have been derived, or even formulated, and the insight given by the ideal form of the law might have been lost to science until well into the nineteenth century.

The lesson from both Kepler's work and Boyle's is that observational or experimental errors can be helpful in masking second-order effects and thus enabling scientists to concentrate their attention on the major factors at work in a given situation until they can develop the analytical tools needed to deal with the minor factors. Interestingly, a similar point was made by Airy (1850: 102) in an address to which I shall have occasion to refer later:

> In this, as in all other cases in natural philosophy, the more the accuracy of observations is increased, the greater becomes the complexity of the laws of nature which it is necessary to take into account; and the investigation, which at first was intended only for the purpose of correcting the numerical coefficients of a known theory, may lead to the discovery or verification of a subordinate theory of a totally different kind.

5 GAUSS

After Maskelyne's encounter with personal errors, the next step towards full recognition of the importance of observational errors came in the nineteenth century and, again, astronomers led the way. The discovery of the first minor planets early in that century created a need for a means of determining at least a preliminary orbit from a few observations in order that a newly-discovered planet might be recovered after its conjunction with the Sun. As is well known, Carl Friedrich Gauss (1777–1855; Figure 5) provided the answer (Gauss, 1809). Since six orbital elements have to be determined (the period, P, the major semi-axis, a, the orbital eccentricity, e, the inclination of the plane of the orbit to that of the sky, i, the longitude of periastron, ω, and the longitude of the ascending node, Ω), three observations, each giving a position and a time are just sufficient. Of course, if one proceeds with only three observations it is implicitly assumed that those observations are exact and the derived orbit may well be only an approximation to the true one—but a close enough approximation to serve the purpose of recovering the planet as it emerges from the glare of the Sun. Once sufficient observations have been obtained, then a more accurate orbit can be determined, but the orbital elements become over-determined and the question arises: what are their most accurate values given the inevitable errors of observation? Obviously, at best, only a few of the observations will lie exactly on the derived orbit.

Gauss provided the solution to this problem by showing that the best orbit was the one which made the sum of the squares of the residuals of the observations from the computed orbit a minimum. This applied to all problems in which it was required to find the best set of values of several variables to satisfy a given set of observations. In the special case of one variable, Gauss's solution reduced to the intuitively-obvious one of taking the arithmetic mean. Of course, he assumed a particular kind of distribution of the observational errors: the 'normal', or as we often say nowadays, the 'Gaussian' distribution—a point to which we shall return later. It became fashionable to supplement any numerical value with an estimate of its 'probable error' or 'mean error'. The quantity sought was equally likely to lie within the range of the probable error as outside it, while it was twice as likely to lie within the range of the mean error as outside it. I remember Erwin Finlay-Freundlich (1885–1964) once joking that British astronomers were more optimistic than their German colleagues, since the British quoted probable errors while the Germans quoted mean errors! In fact, the divide seems to be one of time rather than nationality. In the mid-nineteenth century, German astronomers often quoted probable errors, but perhaps they changed to mean errors more quickly than their British colleagues. Whichever value is preferred, it has precise meaning only if the observational errors do, in fact, follow a normal distribution.

Figure 5: A portrait of Carl Friedrich Gauss by C.A. Jensen in 1840 (en.wikipedia.org).

6 STELLAR PARALLAX

After Gauss had solved the problem of determining the orbits of the newly-discovered minor planets, the next major problem was the determination of stellar parallaxes. James Bradley (1693–1762) had given astronomers a pretty good idea of the size of the quantity they were looking for (about one arcsecond) and a number of claimed determinations were made in the subsequent years, although they failed to carry conviction.

As is well known, three astronomers succeeded in the period 1837–1840, namely F.W. Bessel (1784–1846; Figure 6), F.G.W. Struve (1793–1864; Figure 7) and T.J. Henderson (1798–1844). By that time, astronomers had had an opportunity to absorb Gauss's lessons on the theory of errors and all three of these men quoted probable errors for the parallaxes that they derived for 61 Cygni, Vega, and

Figure 6: A portrait of Friedrich Wilhelm Bessel by C.A. Jensen in 1839 (en.wikipedia.org).

α Centauri, respectively (see my discussion in Batten, 1988; 120–124). Some years ago, in conversation, Albert van Helden suggested to me that it was precisely because these three quoted probable errors that their determinations were accepted as convincing by their contemporaries.

An interesting commentary on that thought is the history of Struve's determination of the parallax of Vega. He published an initial value of

Figure 7: A portrait of Friedrich Georg Wilhelm Struve by C.A. Jensen (comons.wikimedia.org).

0.125 ± 0.055″ (Struve, 1837). Had this been accepted, it would have been the first successful determination of the parallax of a fixed star, but Struve himself regarded the probable error as too large. Shortly afterwards, Bessel (1838) published his parallax for the two components of 61 Cygni, giving the value of 0.3136 ± 0.0141″, and in the opinion of most of us became entitled to claim the priority to which Struve had come so close. Struve (1840) soon followed with a revised parallax for Vega of 0.2613 ± 0.0254″. He had much reduced the uncertainty of his result but, ironically, his first value for the parallax of Vega was considerably closer to the modern value (0.133″) than was his revised value. Perhaps we should be more aware that our estimates of uncertainty are themselves uncertain!

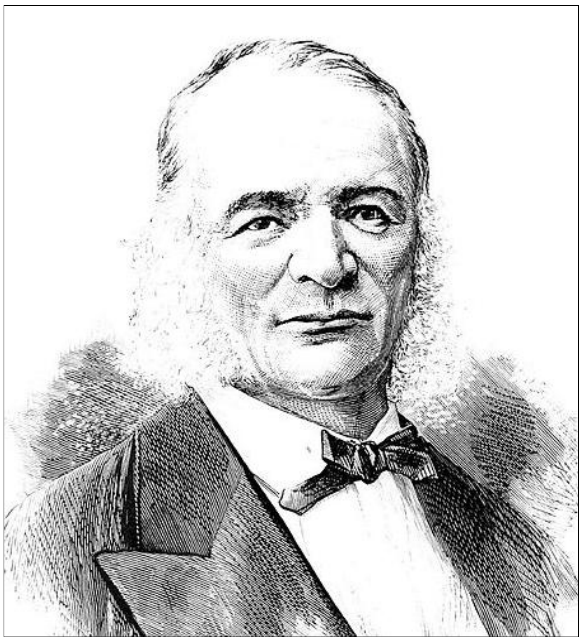

Figure 8: Otto Wilhelm Struve in 1879 (commons.wikimedia.org).

7 PRECESSION

One of the fundamental constants of celestial mechanics is the rate of precession of the equinoxes and Wilhelm Struve's astronomer son, Otto Wilhem Struve (1819–1905; Figure 8) won the Gold Medal of the Royal Astronomical Society in 1850 for his determination of the constant of precession and the solar motion with respect to nearby stars. The two quantities are linked observationally and are difficult to separate. G.B. Airy (1801–1892; Figure 9) was at that time the President of the Royal Astronomical Society, so it fell to him to deliver the customary address explaining the work that was so honoured and giving the reasons for awarding the medal. I have already quoted from this speech; in it Airy (1850: 108) singled out for special mention Otto Wilhem Struve's treatment of the uncertainties of his determinations:

> The two investigations which relate to the determination of the direction and magnitude of the solar movement are, in my opinion, very admirable; but the third, which exhibits the amount of uncertainty in the result depending on venial or probable errors of observation, is, in my judgment, even more valuable.

Modern astronomers undertaking a similar determination of these quantities would regard a discussion of the uncertainties as an essential part of the paper, but Airy's wording suggests that in 1850 such a discussion was still unusual. The derivation of the solar motion from the observations is so linked to that of precession that small observational errors, such as Airy thought could not be ruled out, can have a large effect on the final result for the apex of solar motion, as Otto Wilhem Struve himself pointed out. Just as with Aristarchus' method, the final result is very sensitive to the errors of observation.

8 DISCUSSION AND CONCLUDING REMARKS

Probable errors or mean errors are reliable guides to the actual uncertainties of derived quantities only if the residuals do indeed conform to a Gaussian distribution. I would like to discuss this in the context of the area of astronomy that I know best: the determination of orbital elements of spectroscopic binaries. Between 1970 and 1990 I obtained 52 spectrograms of the primary component of the wide visual binary 70 Ophiuchi, at a dispersion of 4 mm nm^{-1} (or 2.5 Å mm^{-1} in the older convention). I have excluded from consideration a number of spectrograms obtained at a lower dispersion, but included two values determined with a radial-velocity scanner. Figure 10 shows a histogram of the residuals from the velocity-curve eventually calculated from the orbital elements determined from these observations (Batten and Fletcher, 1991). The distribution approximates to a Gaussian one, but it is not clear that it is one. There is an asymmetry to the side of negative residuals and an apparent minimum just at the zero of the abscissae, where the maximum ought to be. These features are probably only statistical deviations inevitable when dealing with relatively small numbers of observations. I feel fairly confident that had I obtained two to four times the number of observations, the histogram would become much closer to a Gaussian distribution, but the point of this discussion is that observers often determine the orbital elements of a spectroscopic binary from many fewer observations than I have used for 70 Ophiuchi, and, even with over fifty observations, we still cannot be sure that the actual distribution of the residuals is Gaussian. The late D.M. Popper (1913–1999) many times commented that the true uncertainties of orbital elements were often appreciably greater than the published mean errors. This is probably true of many other areas of astronomy, and indeed of other sciences. Caution is necessary in dealing with all empirical results!

Figure 9: An undated print of Sir George Biddell Airy (commonswikipedia.org).

Another point of interest in the histogram is the outlying observation that shows a residual of +0.91 kms^{-1}. The next largest residual is no

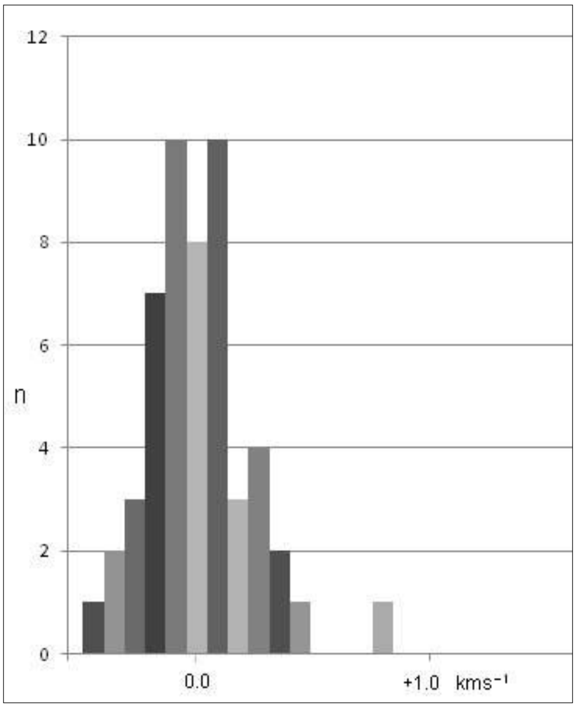

Figure 10: Numbers of residuals from the computed orbit of 70 Oph A. Each bar has a width of 0.1 kms^{-1} and the residuals run from –0.55 kms^{-1} to +0.46 kms^{-1}, plus an outlier (see text) at +0.91 kms^{-1}. The bar that contains 8 residuals is centred on 0.0 kms^{-1}.

more than -0.55 kms^{-1} and none of the others exceeds ± 0.5 kms^{-1}. We all have it drilled into us early in our scientific education that a discordant observation should not be discarded *just* because it is discordant. I can assure readers that the observation was included in the solution! It is legitimate, however, to examine a discordant observation to see if there is some reason for the large residual that might permit one to reject the observation. In the present case, the spectrogram is one of the best in the whole series. The internal (line-to-line) scatter of the plate is one of the smallest and the spectrograph seems to have been in perfect focus. The observation has to be accepted, even though it has a residual at least twice nearly all the others in the series. In the all-too-few years that I knew R.M. Petrie (1906–1966) before his untimely death, he more than once told me that he had often found that one of the best observations of a spectroscopic binary stood off the computed velocity curve by more than any of the others. Here is an aspect of observational error that has been neglected and deserves further investigation. Who knows to what it might lead?

Of course, there are many situations in which we know that the distribution of residuals will depart from a Gaussian one, and methods of estimating the uncertainties of derived quantities in these situations have been devised, although it is beyond my competence to discuss them in detail. In the context of determining orbital elements, however, the least-squares criterion has become so entrenched that I doubt if it will be forsaken in the foreseeable future.

This discussion has led to the conclusion that not only is error inevitable in our search for the truth, but that it may even play a positive role in helping us to reach that goal. Perhaps this is one of the most important lessons that we scientists can teach to others.

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THE SIZE AND SHAPE OF DANTE'S MOUNT PURGATORY

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Abstract: Where is Mount Purgatory? How high is it? How large is the island upon which it was situated? In the nineteenth century Rodolfo Benini and Ideale Capasso developed a series of hypotheses and calculations to find answers to these questions. Each used data derived from mathematics, astronomy, history of science and cartography, but they completely disagreed on the location and on the overall size and shape of the island. In this paper we review the main points of these two scholars, then we rework the calculations and estimates, according to a new astronomical hypothesis presented by Giulio Magli and Claudio Facciolo.

Key words. astronomy, cartography, geometry, Dante Alighieri, *Divine Comedy*, naval and maritime culture

1 INTRODUCTION

The authors of this paper are engaged in interdisciplinary research at the FDS Laboratory of the Politecnico di Milano, and, in particular, they are interested in contributing to projects that combine scientific data and artistic insights. The FDS Laboratory operates in mathematical training for teachers, science communication, education, experimental teaching and cultural heritage. These activities are developed in cooperation with universities and secondary schools. Some projects are developed in collaboration with astronomers at the National Institute for Astrophysics (INAF) in Rome.

This research paper is the second in an interdisciplinary research project, which began in 2013 with the publication of the paper "Galileo Galilei's location, shape and size of Dante's Inferno" (Angelini, Magnaghi-Delfino and Norando, 2014). Galileo (1564–1642) was called by the *Accademia della Crusca* to resolve the debated question about the shape and size of *Inferno*, opposing the views proposed by Antonio di Tuccio Manetti (1423–1497) and Alessandro Vellutello (b. 1473). In these lectures, Galileo (1588) combines a clear exposition of mathematics with his deep knowledge of Dante's *Divina Commedia* (*Divine Comedy*) and emphasizes that the geometry of Manetti's plan is based on evidence from the poem. Both plans are based on Dante's geographical knowledge and religious beliefs; the two arguments are identical as regards the general appearance of the *Inferno*, but are considerably different regarding the shape and the size. The learned men of the Renaissance based their mathematical knowledge on such ancient classical texts as the works of Euclid (367–283 BC) and Archimedes (287–212 BC). The Renaissance artists and scientists were deeply rooted in the mathematical and philosophical heritage of Classical Greece and the boundaries between scholarship, art, science and mathematics were inextricably intertwined.

Dante (1265–1321) may be considered the 'founding father' of Italian poetry and he stamped the mark of his lofty and commanding personality upon later literature. It can even be claimed that his works have played a direct role in shaping the aspirations and destinies of his native country. During the nineteenth century, Dante was the subject, at a European level, of a deep and heartfelt rediscovery, both literary and biographical. In the Risorgimento,[1] in particular, Dante becomes the symbolic reference of the aspirations and identity of the Nation, of which the Florentine poet is considered the ideal unifier, both linguistically and politically. In the twentieth century in Italy many authors wrote about the content and literary style of the *Divine Comedy*. The poem has achieved great fame, and many scholars study the *Divine Comedy* and try to explain and interpret its scientific content.

In this paper we examine the location, the height and the topography of *Mount Purgatory*. We consider two different points of view: the 1917 study of Rodolfo Benini (1862–1956) and the 1967 book of Ideale Capasso (1905–1992). Then we propose another calculation of the location, height and topography utilizing material in the 2010 thesis of Claudio Facciolo (b. 1962).

The notion expounded by Dante is that Earthly 'Paradise' was situated in the Southern Hemisphere at the summit of Mount Purgatory. The idea of its great altitude, above the reach of all atmospheric disturbances, so as to be fit for the secure abode of man, is commonly found in the works of other writers.

Benini and Capasso differ in their estimates of the size and the shape of the Mount. To Capasso, Mount Purgatory is ~11 km high, whereas Benini favours ~192 km high, much higher than medieval writers would accept; in fact, the maximum height of the Earth's atmosphere in Alfraganus' *Elements of Astronomy* (833) is 110 km, while Alhazen's figure (1972) is 79 km.

Capasso's shape is a truncated cone, the average slope of which did not exceed 30°, and the diameter of the base was about 3.5 times the height. These figures were derived from the verses of Dante.

In contrast, Benini's shape is similar to the structure of a ziggurat. Two examples, based on his concept, are shown in Figure 1.

In this research paper we review the main points of each work, then we rework the calculations using an alternative point of view, involving the position of the Southern Cross. We find a height for Mount Purgatory that is comparable to that of Capasso and a shape that is similar to that suggested by Benini.

Among surviving ziggurats, the inclination of the Aztec Pyramid of the Sun in Teotihuacan (Mexico) is greater than that of Mount Purgatory, as proposed by Capasso. The Mexican pyramid has a square base of 223.5 meters on each side, is 71.2 meters high and has an inclination of about 32° (Reynolds, 1999).

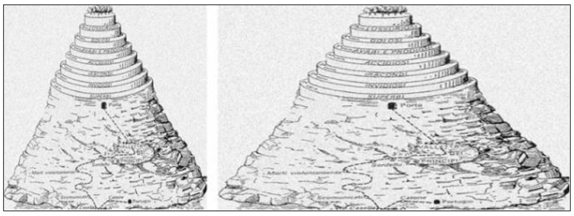

Figure 1: Two different versions of Mount Purgatory according to Benini (1917).

We consider the following verses in which Dante quotes some mountains that he knew of:

> One can walk to Sanleo and descend to Noli,
> one can mount Bismantova to the summit,
> with feet alone; but there a man must fly.
> (*Purgatorio*, IV, 25–27; Alighieri, 2005; 1977).[2]

'Bismantova' mentioned in this quotation is a geological formation in the Apeninne Mountains. It has the shape of a narrow plateau measuring 1 km × 240 m, whose steep walls rise ~ 300 m above the nearby hills. Moreover, in the Santa Maria del Fiore in Florence, Raphael Sanzio (1483–1520) painted a famous picture in which Mount Purgatory has the exact shape of a ziggurat.

Because there are no *Divine Comedy* manuscripts or records provided by Dante's contemporaries, none of these hypotheses can be considered as false. Each author highlights an aspect of Dante's scientific culture, which is often not sufficiently valued by scholars.

2 DANTE'S KNOWLEDGE

Because we do not have documentary data about Dante's culture, we have to reconstruct this from his works, *Divine Comedy*, *Convivio* (*The Banquet*) and *Quaestio de Aqua et Terra* (*The Question of the Water and the Land*). From these we derive an image of a scholar of theology, philosophy, physics, astronomy, grammar and rhetoric, which were all the disciplines in the *trivium* and the *quadrivium* at medieval schools and universities.

It is likely that Dante studied religious and secular topics in Florence, and we suppose that he took courses at the University of Bologna in 1287 when Guido Bonatti, the author of *Decem Continens Tractatus Astronomiae* (*Book of Astronomy*, 1851), taught in that city (*Inferno* XX, 118). Dante and Bonatti both learnt astronomy from the book *Elementa Astronomica* (*Elements of Astronomy*) by the ninth century astronomer Ahmad ibn Muhammad ibn Kathîr al-Farghânî, also known as Alfraganus. This book is a compendium of material from the *Almagest*, the great work of Ptolemy (who Dante places in Limbo). This work first was translated from Arabic into Latin in the twelfth century by Gerardo da Cremona (1114–1187), who also was the first to translate the *Almagest* into Latin; and again, a little later, by Johannes Hispaniensis of Seville, and would have been accessible to Dante. Alfraganus is quoted in Dante's *The Banquet* (II, xiv. 95) as his authority for the dimensions of the planet Mercury. Again, Dante quotes Alfraganus' work in *The Banquet* (II, vi. 134), under the title *The Book on the Clustering of Stars*. Most of the astronomical data, and sometimes even the comparisons and illustrations, given by Dante are found in Alfraganus, e.g. the graphic comparison of the revolution of the Sun as seen from the poles at the equinox (see *The Banquet*, III, v. 147) like that of a millstone. In Alfraganus' treatise (833) there are four chapters entirely devoted to geography, and a visual representation of the world that Brunetto Latini (1220–1294; n.d.) copies in his maps.

In order to discuss the location of Mount Sinai in ancient cartography we quote the work *Secreta* (or *Liber Secretorum*) *Fidelium Crucis* (*The Book of the Secrets of the Faithful of the Cross*) by Marin Sanudo the Elder (1270–1343; 1972), a Venetian statesman and geographer. This work occupies an important place in the development of cartography. It was begun in March 1306 and finished (in its earliest form) in January 1307, when it was offered to Pope Clement V as a manual for true Crusaders who desired to regain the Holy Land.

Colored maps accompany 9 of the surviving 19 complete texts, which are presumably presentation copies. They were designed specifically with the subject matter of *The Book of the Secrets …* in mind, and Sanudo made a contribution in selecting the illustrative material, even if he did not draw the maps himself.

Kretschmer (1891; 1909) showed that the fourteenth century Genoese cartographer Pietro Vesconte, who was active between 1310 and 1330, was the person who drew Sanudo's maps. Sanudo adapted the map of Palestine from a Florentine original, and produced the associated town plans of Jerusalem from Burchard of Mount Sion and the plan of Acre from his own memory of his visits in 1280. Conder (1881) noted that the map of Palestine is a rude and very inaccurate sketch, and is not to scale.

The official language of the medieval universities was Latin, hence Dante's humanistic studies were based primary on Latin authors, and Virgil, in particular, had a decisive influence on Dante's works. Dante learned the tradition of minstrels, the Provencal poets, and he had a particular devotion to Virgil:

> You are my master and my author.
> You alone are he from whom I took
> the fair style that has done me honor.
> (*Inferno*, I, 85 – 87; Alighieri, 2005; 1977).

So we can assume that at this time Dante was an up-to-date intellectual with worldwide interests.

3 THE LOCATION, HEIGHT AND TOPOGRAPHY OF MOUNT PURGATORY ACCORDING TO IDEALE CAPASSO

Mount Purgatory is at the antipodes of Jerusalem, which is at a latitude of 32° N so Mount Purgatory must be 32° S. According to modern maps, Jerusalem is at a longitude of 35° E, so Mount Purgatory would be 145° W, in the Pacific Ocean to the south of the archipelago of Tubuai (which has co-ordinates of 23° 27′ S and 149° 30′ W).

Dante imagined Mount Purgatory was the highest of all mountains, as can be seen from the following verses.

In the description of Ulysses' last voyage he writes:

> ... when there appeared to us a mountain
> dark in the distance, and to me it seemed
> the highest I had ever seen.
> (*Inferno*, XXVI, 133 – 135; Alighieri, 2005; 1977).

Here we have Dante's assertion:

> … and I turned my face to the hill
> that rises highest heavenward from the sea.
> (*Purgatory*, III, 14 – 15; Alighieri, 2005; 1977).

Finally, there is Adam's description:

> … on the mountain which rises highest from the sea.
> (*Paradise*, XXVI, 139; Alighieri, 2005; 1977).

The necessary information to determine the height of Mount Purgatory which is contained in the XXI, XXVII and XXVIII Cantos of *Purgatory*, is all astronomical and provides discordant results. In the XXI Canto, the Roman poet Publius Papinius Statius (AD 40 – 96) says that the gate of Purgatory is located at the very limit of the region of clouds and weather disturbances, above the three steps where the Guardian Angel rests. Also, *Matelda* (Canto XXVIII) says that Mount Purgatory is so high that earth and water cannot reach the point where the gate of Purgatory is located.

In order to find references to the height of that atmospheric region one can read the *Liber de Crepusculis* (*On Twilight*) (Alhazen, 1972; 2007) by al Hasan b. Hayman (965 – 1039), mentioned by Roger Bacon (1214 – 1294) in his *Opus Majus* (*Major Work*) (1962), and in the *Libro II* (*Book II*) (cap.23) of *Naturalis Historia* (*Natural History*) by Plinius (AD 23 – 79; 77).

In *On Twilight*, Alhazenus demonstrates mathematically that the Earth's atmosphere reaches a maximum height of 51⅔ miles (where 1 mile ≈ 1,764 meters),[3] on the basis of the following data: the Earth's circumference = 20,400 miles; the Sun's diameter = 5½ times the Earth's diameter; the Sun's distance from the Earth = 1,100 Earth radii; and the altitude of the Sun when dusk starts = 18°. In his *Meteora* (*Meteorology*), Aristotle (384–322 BC; 1931) says that the atmosphere extends to the limit between the air and fire, so (1962) suggests that we accept a figure of at least 51⅔ miles for the height (i.e. ~90 km).

In his *Natural History* Plinius (77) accepts the statement by Posidonius of Apamea (135 – 50 BC; n.d.), who estimated that the maximum height of the clouds was 40 stades (where 1 stade ≈ 185 meters, i.e. about 7.4 km). It must be said that Posidonius also believed that the Earth's circumference was only 16,100 miles.

In Dante's *Canto* XXVII we find useful quotes to determine the height of Mount Purgatory which are based on the difference in time between sunset at the base of the Mount and sunset at a certain height. The Sun sets when the Angel of Chastity appears to Dante. In pinpointing this moment, Dante gives the hours of the four simultaneous key meridians of this geographic system:

> As when it darts forth its first beams
> there where its Maker sheds His blood,
> while Ebro falls beneath the lofty Scales
> and the waves in the Ganges are scorched by noon,
> so stood the Sun, so that the day was departing
> when the glad angel of God appeared to us.
> (*Purgatory*, XXVII, 1 – 6; Alighieri, 2005; 1977).

As the Sun was in the sign of Aries and Libra was opposite, near the Ganges, where it was noon, Aries and the Sun were located together along the meridian. At the same time, at Ebro (in Spain), when Libra crossed the meridian it had to be midnight. So sunset at Mount Purgatory coincided with the rising of the Sun in Jerusalem, with noon to the Ganges with midnight in Spain.

At Mount Purgatory, Dante and Virgil began to climb the stairs that led to the Garden of Eden, but after a few steps they stopped, because the Sun had just set and it quickly became dark. Capasso (1967) estimates that the elapsed time from the start of the ascent to sunset was 15 minutes. Knowing the difference between the time of sunset at the base of Mount Purgatory and sunset at the height reached by Dante, one can find the height of the mountain. In the time interval ΔT between the two sunsets,[4] the Sun is lower than the astronomical horizon at this place relative to the marine horizon by an angle equal to the apparent depression (*AP*). This angle is given in minutes by the formula

$$AP = 15 \times \Delta T \times \sqrt{(\cos^2\varphi - \sin^2\delta)} \qquad (1)$$

where φ is the latitude and δ the declination of the Sun. For ΔT = 15 minutes and so 15 × ΔT arcmin, φ = 32°, δ = 6°, we have AP = 189′. Capasso (*ibid*.) assumes δ = 6° because he agrees with the calculations of Cantelli (1917) about the date of the arrival of Dante and Virgil at Purgatory. Cantelli asserts that the poets came to Purgatory on the night before 27 March 1301 (cf. Angelitti, 1897). On this day the declination of the Sun was +6°. Since the elevation, *e*, is approximately

$$e = (AP/1.8)^2 \qquad (2)$$

we get e = 11,000 meters. Since the entrance to the Garden of Eden (on the top of Mount Purgatory) is nearby, the mountain should not be much higher.

From the height of the mountain we can obtain the diameter of the base, knowing the inclination of the slope, which can be deduced from Dante's poetry. At the beginning, the climb is very steep and strenuous, greater than 45°, but not for very long because it only takes Dante and Virgil about 2 hours:

> We came meanwhile to the foot of the mountain.
> Here we found the cliff so steep that in vain would
> legs be nimble there …
> – Now we know on which side the hillside slopes
> said my master, stopping,
> –so that he can ascend who goes without wings?
> (*Purgatory*, III, 46–48; 52–54; Alighieri, 2005; 1977).
> So high was the top that it surpassed my sight,
> and the slope was far steeper than a line
> from mid-quadrant to the center.
> (*Purgatory*, IV, 40–42; Alighieri, 2005; 1977).

Then the slope becomes gentler, and on this part of the coast we can deduce the inclination from the instant when the Sun is hidden behind it. Placing such an instant between 3 p.m. and 4 p.m., we obtain an inclination of between 37° and 23°:

> And he [said] to me: "This mountain is such, that ever
> at the beginning down below it is toilsome,
> but the higher one goes the less it wearies [you].
> (*Purgatory*, IV, 88–90; Alighieri, 2005; 1977).

In Dante's Purgatory the slope is not exceptional:

> From its edge, bordering the void,
> to the foot of the high bank which rises sheer,
> a human body would measure in three lengths[5]
> (*Purgatory*, X, 22–24; Alighieri, 2005; 1977).

> and said "Come: the steps are at hand here,
> and henceforth the climb is easy."
> (*Purgatory*, XII, 92–93; Alighieri, 2005; 1977).

The slope for the hot-tempered is easier and even less inclined:

> With a glad voice he said, "Enter here
> to a stairway far less steep than the others."
> (*Purgatory*, XV, 35–36; Alighieri, 2005; 1977).

The climb for the extremely greedy is easy:

> And I, lighter than at the other passages,
> went on so that without any toil
> I was following the fleet spirits upwards …
> (*Purgatory*, XXII, 7–9; Alighieri, 2005; 1977).

Then the way that finally leads to the Garden of Eden is almost flat:

> In order that the disturbance which
> the exhalations of the water and of the hearth
> (which follow so far as they can the heat)
> produce below might do no hurt [harm] to man,
> this mountain rose thus high towards heaven,
> and stands clear of them from where it is locked …
> such movement strikes upon this height,
> which is wholly free in the pure air[6]
> (*Purgatory*, XXVIII, 97–102, 106–107; Alighieri, 2005; 1977).

If the average slope does not exceed 30° then the diameter of the base will be about 3.5 times the height (see Table 1). For a comparison of the size of Mount Purgatory island and other known islands see Table 2.

4 THE LOCATION OF MOUNT PURGATORY ACCORDING TO RODOLFO BENINI

Mount Purgatory is located on the Earth exactly opposite Zion (its antipodal point), and Virgil says to Dante:

> ... imagine Zion
> and this mountain to be so placed on the Earth

that they have one sole horizon
and different hemispheres; then you will see that
the way which Phaëthon,
unhappy for him, knew not how to drive,
must need to pass this mountain on the one side
when it passes that mountain on the other.
(*Purgatory*, IV, 68–74; Alighieri, 2005; 1977).

The myth of Phaethon was created by Publius Ovidius Naso (43 BC–AD 18) in *Metamorphoses* (*Metamorphosis*), and his term "… road of the Sun …" (Ovid, n.d.) can be interpreted as the ecliptic rather than a diurnal arc. Also, in another place, Dante (*Paradise*, X, 16) mentions the oblique circle that includes the Sun and the planets (the ecliptic), calling it "… their pathway." In this case, we can find Mount Zion on the Tropic of Cancer and Purgatory on the Tropic of Capricorn, and so Mount Purgatory must be at a latitude of about 23° 30′ S.

The subsequent response of Dante reinforces this interpretation:

That the mid-circle of celestial motion,
which is called the Equator …
… departs here
towards the north, as far as the Hebrews
used to see it toward the hot climes.
(*Purgatory*, IV, 79–80, 82–84; Alighieri, 2005; 1977).

Dante mentions the place where the Hebrews lived, not the Jews, and therefore in Benini's opinion he does not refer to Jerusalem, but to the Jewish people who lived in Egypt or wandered in the Sinai. According to the uncertain medieval geographers, the size of land masses to the south of the Sinai Peninsula was exaggerated, as we can see in the paper by Marin Sanudo the Elder (1270–1343), where the distance between the extreme south of the Sinai Peninsula and the angle southeast of the Mediterranean equals or exceeds all that section between the southeast corner and the northeast of the Mediterranean, while in reality it is less than half.

In conclusion, Benini (1917) claims that Mount Purgatory was at a latitude of about 23° 30′ S.

Benini's hypothesis can be confirmed in the following places in the *Divine Comedy*:

- the disappearance of Capricorn
- the setting of Ursa Major
- four circles and three crosses
- the navigation of Ulysses
- the duration of Ulysses' final the voyage.

Let us now examine each of these.

Table 1: Mount Purgatory's measurements according to Capasso (1967).

Height	h = 11 Km
Average slope	30°
Base diameter	d = 38.5 Km
Circumference of the base	C = π d = 121 Km
Island Area	$A = \pi d^2/4 = 1164\ Km^2$
Volume of Purgatory	$V = A\ h/3 = 4269\ Km^3$

5 ARGUMENTS IN SUPPORT OF RODOLFO BENINI'S HYPOTHESIS

5.1 The Disappearance of Capricorn

In *Purgatory* (II, 55–57; Alighieri, 2005; 1977) Dante writes:

The Sun was shooting forth the day on all sides
and with his deft arrows had chased Capricorn from mid-heaven.

If the expression "… from mid-heaven." is meant in the literal sense, then the constellation of Capricorn was in the middle of the sky when Dante was at the Tropic. However, according to Capasso (1967), the poet simply said that the first light of dawn obscured the stars in the sky, including those of Capricorn, which were close to the meridian.

5.2 The Setting of Ursa Major

In *Purgatory* (I, 28–31; Alighieri, 2005; 1977), Dante writes:

When I had withdrawn my gate from them,
turning a little to the other pole,
there whence the Wain[7] had already disappeared,
I saw close to me an old man alone.

From the latitude of the Tropic of Capricorn we can see, for varying periods, all the stars in the northern sky from the Pole to a declination of more than 23° 30′. Now in AD 1300, the seven stars of Ursa Major occupied a stretch of sky between 24° 30′ and 37°, so from the island of Purgatory, in the season when Dante made the journey, at a certain hour of the night they would all have been visible at the same time.

5.3 Four Circles and Three Crosses

After arriving at the top of Mount Purgatory, while Dante is already ascending into heaven of the Moon, he notices that the Sun shines from the first point of Aries, "Which joins four circles with three crosses." (*Paradisy*, I, 39; Alighieri, 2005; 1977).

Table 2: Purgatory Island and the sizes of some other known islands.

Island	Size (km^2)
Purgatory Island	1164
Rhodes	1398
Aracena (Chile)	1164
Grande Comore	1158
Martinique	1101
Elba	223
Ithaca	96

In the opinion of many scholars the four circles are the horizon, the celestial equator, the ecliptic the equinoctial colure,[8] and the three crosses are formed by the intersection of the three circles of the ecliptic, the equator and the equinoctial colure, with the circle of the horizon. Capasso (1967) considers this interpretation to be unsatisfactory because none of the angles is a right angle, and he proposes four other circles: the celestial equator, the horizon, the first vertical[9] and the first hour circle.

The interpretation proposed by Benini (1917) and other scholars is to replace the horizon with the circle of latitude passing through the equinoctial points; now we have two crosses at right angles: the cross formed by the equator and the equinoctial colure and the cross formed by the ecliptic with the circle of latitude. The third cross is the angular space between the celestial equator and the ecliptic and between the equinoctial colure and the circle of latitude (Figure 2).

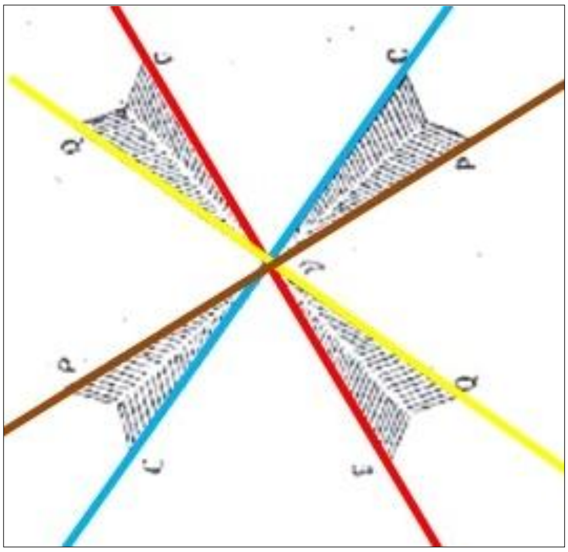

Figure 2: The three crosses. Yellow line = Equator; Red line = Ecliptic; Blue line = Colure; Brown line = Circle of Latitude.

If Mount Purgatory is on the Tropic of Capricorn, that is on the ecliptic, its horizon is the circle of latitude. Then the arms of the third cross form angles of equal amplitude, that is angles of 23° 30′. If Mount Purgatory is placed at the antipodes of Jerusalem, its horizon is not the circle of latitude and so we cannot get three crosses that are symmetrical in appearance (Cantelli, 1917).

5.4 The Navigation of Ulysses

Ulysses steers the ship “… diretro al sol …”, which means following the Sun, but not during the daily motion, but rather the annual motion from Cancer to Capricorn. In fact, when he arrives at the narrow passage where Hercules set his landmarks, Ulysses turns the stern towards the morning, and then he crosses the equinoctial circle and sails on until he only sees stars of the southern circumpolar sky.

Ulysses could not have passed the Tropic, otherwise he would have sailed beyond the Sun, instead of following the Sun. But if we judge that Mount Purgatory had a latitude of 32° S, we can assume that the voyage did extend beyond the Tropic. In fact, the ship would have to be at a latitude of 27° or 28° S for Ulysses to see the top of a mountain that was at least 10 miles high.

5.5 The Length of Ulysses’ Final Voyage

The duration of the voyage was ‘cinque lune’ (or 147 days). Ulysses sights Mount Purgatory, and shortly afterwards crosses the Equator:

> The night now saw the other pole
> and all its stars, and ours so low that
> it did not rise from the ocean floor.
> (*Inferno,* XXVI, 127–129; Alighieri, 2005; 1977).

In the fourteenth century, Ursa Major was in the sky between latitudes 24° 30′ and 37° S, so Ulysses stopped 7–8° south of the Equator (and 15° north of Mount Purgatory). The sailors had come a distance of 5,381 miles (8,660 km), if they had travelled about 36.6 miles/day (or 58.0 km/day) at an average speed of 3 knots.

This might seem an excessive duration, given that it took the Greeks and Phoenicians five days to voyage from Crete to the mouth of the Nile, travelling at almost double the speed of Ulysses’ vessel (Ferrara, 1998; Janni, 1996). But we must remember that these trips were accomplished by rowing day and night, with numerous, strong young oarsmen, whereas Ulysses’ companions only helped during the day and were *“…* old and slow.” (*Inferno*, XXVI, 106; Alighieri, 2005; 1977).

These comments do not contradict the hypothesis concerning the position of the island of Mount Purgatory.

6 ULYSSES’ FINAL VOYAGE IN THE *DIVINE COMEDY*

Although Dante knew Homer (he is quoted many times in the *Divine Comedy* and is mentioned in the *Limbo*, IV Canto), he would not have read the *Odyssey* in Greek. Nevertheless he knew the story of Ulysses from various Latin sources (e.g. Ovid’s *Metamorphosis* (n.d.) and *Odissey* by Livius Andronicus (284–c.204 BC; 1999)) and many medieval novels. Based on these sources, Dante virtually invents the story of Ulysses’ last voyage. The quest for knowledge was the aim of the voyage, as Dante reveals in *The Banquet*: “Naturally all the men desire to know …” (I, i, 1). Ulysses did not know the Graces, so his knowledge was confined to the purely terrestrial realm:

> … unto your senses … (v. 115) [and] … was able to defeat me the longing I have to gain experience of the world and of the vices and the worth of men. (vv. 97–99). (Inferno, XXVI, 106; Alighieri, 2005; 1977).

Nor does he direct this knowledge towards a useful goal (rather, it remains always an end in itself), and his desires therefore become negative, so much so that he involves his companions in evil (v. 119–120). Ulysses passes the Pillars of Hercules, beyond which men should not venture, and in breaking a divine prohibition he is defeated by God, and "…the sea closed over us." (*Inferno*, XXVI, v.142; Alighieri, 2005; 1977).

In some commentaries on Dante's *Divine Comedy* the authors suppose that Dante was inspired by the voyage Ugolino and Vadino Vivaldi made at the end of the thirteenth century. Let us now examine this voyage.

6.1 The Voyage of the Vivaldi Brothers

Vadino and Ugolino Vivaldi were two brothers and Genoese explorers and merchants. They were the first to embark on an oceanic voyage in search of a route from Europe to India. The Vivaldi brothers and Tedisio Doria organized an expedition with two galleys, which left Genoa in May 1291 under the command of Ugolino Vivaldi, accompanied by his brother and two Franciscan friars. Their objective was to reach India by sea, and return to Italy with useful items of trade. The two well-armed galleys sailed down the Moroccan coast to a place called Gozora (Cape Nun), at a latitude of 28°47′ N, after which nothing more was ever heard of them (Gianoli D'Aragona, 1968).

In 1315, Sorleone de Vivaldo (Ugolino's son) began a series of distant 'wanderings' in an unsuccessful search for his father, and it is said that he even reached Mogadishu on the Somali coast (*ibid*.).

In 1455 another Genoese seaman, Antoniotto Usodimare (1416–1461), sailing with Alvise Da Mosto detto Cadamosto or Ca 'da Mosto (1430–1483) in the service of Prince Henry the Navigator (1394–1460; Major, 1868) of Portugal, claimed to have met near the mouth of the Gambia River the last descendant of the survivors of the Vivaldi expedition. A letter by Usodimare reporting on this voyage is preserved in the University of Genoa Library (see Gråberg, 1802) and relates that the two galleys had sailed into the Sea of Guinea where one was stranded, but the other vessel continued and reached a place on the coast of Ethiopia-Mena or Amenuan, near the 'Gihon' (probably the Senegal River) where the Genoese were conducted to Priest Gianni who documented the story through a letter to the Emperor of Byzantium.

Jacopo Doria Cadamosto (1233–1290), the Genoese chronicler and contemporary of Vivaldi's brothers, wrote that the two galleys passed the Canary Islands. Alvise Ca 'da Mosto, the Venetian navigator who was on the same vessel as Antoniotto Usodimare, reported meeting a white man in a village situated between Gambia and Senegal who claimed to be the last descendant of those on the Vivaldi expedition (Prosperi, 2009).

6.2 Homeric Ships

Homeric ships are represented on Greek Geometric Pottery (e.g. see Figure 3). They had a sharp black hull, but as yet were not provided with a ram. The sides were held together by the thwarts, which formed the seats for the oarsmen. At the bow was a raised platform or deck, on which stood the fighting men of the ship; and there was a similar deck at the stern, on which the arms were kept, and under which there was room for stowage. The length of a fifty-oared galley is calculated to have been between 90 and 100 ft (27.4–30.5 m) from stem to stern, with

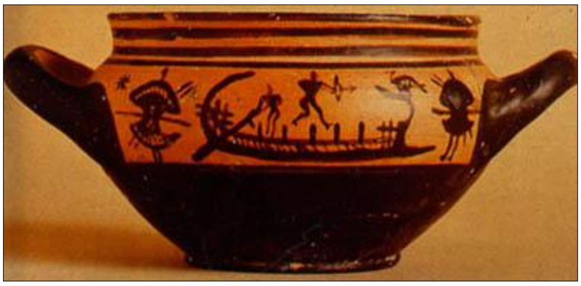

Figure 3: An example of an early Greek Geometric skyphos showing a Homeric ship (https://www.pinterest.com/pin/514184482429887300/).

a breadth amidships of 10–12 ft (3.05–3.65 m). The galley was propelled by oars and sails, the mast being raised or lowered as required. The ship was steered by paddles, and the master of the vessel had his place on the forward deck (Coates, 1989).

The mean speed of these galleys is estimated at 5–6 knots (~1.85 km/hr) when they were going downwind, and up to 10 or 11 knots during storms (*ibid*.).

During the night, the relative positions of the stars in different constellations were used for navigation. Associated with these constellations were mythical figures. Thus, in Homeric times navigators knew the Pleiades, Hyades, Orion, Ursa Major, Bootes, Arcturus and the brightest star in their sky, Sirius (see Theodossiou et al., 2011). They also knew that from the Mediterranean area Ursa Major was a circumpolar constellation.

In the first millennium BC the northern point of reference was the star Kochab in the constellation of Ursa Minor, also known as 'Stella

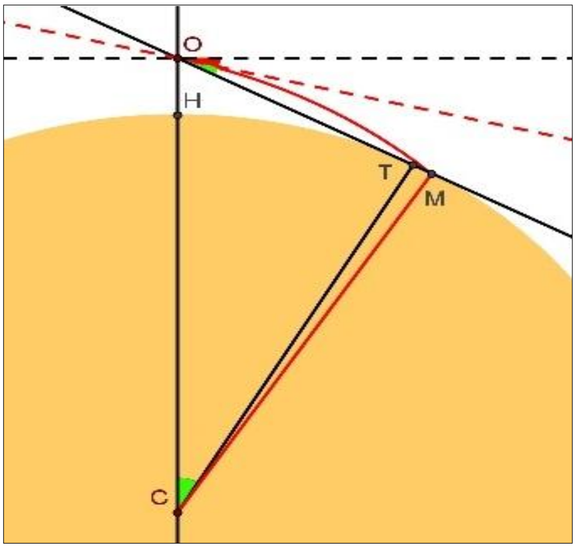

Figure 4: Calculation of the linear distance to the horizon.

Phœnicia', which was ~7° from the North Celestial Pole (Facciolo, 2010; Gianoli D'Aragona, 1968).

7 THE HEIGHT AND SURFACE OF MOUNT PURGATORY ACCORDING TO RODOLFO BENINI

As in Section 4, according to Rodolfo Benini Mount Purgatory is found opposite Zion, that is at a latitude of around 23° 30′ S.

Let us now investigate the height and surface of Mount Purgatory.

7.1 The Visible Horizon

Since the lookout on an Homeric ship was located on the bridge and the ship did not have a particularly deep draught, we can suppose that his eyes were around five braccia[10] above mean sea level.

From this height we can determine the linear distance to the horizon as follows. In reference to Figure 4, let *O* represent the eyes of the lookout, *H-C* the Earth's radius and *OT* the tangent line to the Earth's surface. The d_T (in radians) of the angle *OCT*[11] is given by

$$d_T = \sqrt{[(2 \times OH)/R]} = \sqrt{(2h/R)} \qquad (3)$$

Since in this case OH = 3 m and R = 5647 km (Ptolemy's measure), we have d_T = 0.00103, or about 3.5 minutes. Using the formula

$$HT = \sqrt{(2 \times h \times R)} \qquad (4)$$

we calculate HT = 5821 m, or about 3 nautical miles. Each minute is equivalent to 0.887 nautical miles on the Earth's surface. If we want to consider atmospheric refraction, it is enough to replace R by $1.168R$ in the above formulae.

We obtain for the angle *OCM* the measure d_M = 0.000954, that is 3.28 minutes, and HM = 6287 m, or about 3.4 nautical miles. Each minute is equal to about 1 nautical mile on the surface of the Earth.

7.2 The Height and Surface of Mount Purgatory

In reference to Figure 5, we can calculate the height of Mount Purgatory if we can measure the angle $d = FCT$. For this,

$$MF = (Rd^2)/2 \qquad (5)$$

We can determine the distance HF on the surface of the Earth between the ship and Mount Purgatory through the following formula:

$$HF = HT + TF$$
$$= \sqrt{(2 \times UH \times R)} + \sqrt{(2 \times MF \times R)} \qquad (6)$$

from which

$$HF = HT + TF = \sqrt{(2 \times UH \times R)} + R \times d \qquad (7)$$

In this case, d = 900 – 3.5 = 896.5 minutes and R = 5647.083 km (Ptolemy's measure), so we obtain MF = 192 km = 110 miles.

According to Benini (1917), who studied Dante's walk after conversing with Manfredi (*Purgatory*, IV), Mount Purgatory is a *perfect cone*, that is, the diameter of the basis is equal to its height (see Table 3). For a comparison of Mount Purgatory's size and two other well-known and similarly-sized islands see Table 4.

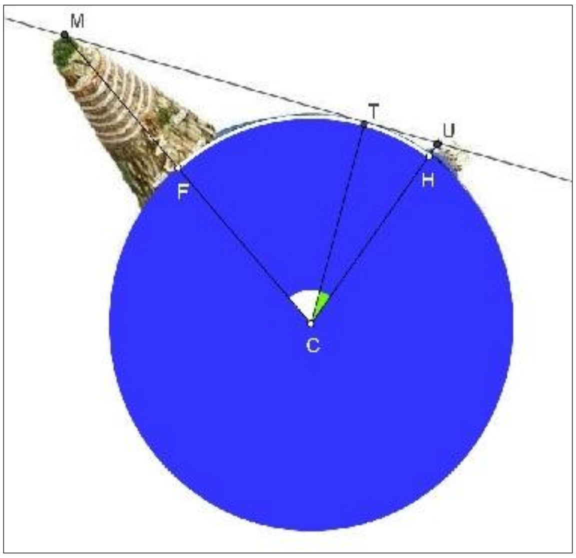

Figure 5: Determination of the height of Mount Purgatory.

8 THE LOCATION OF MOUNT PURGATORY THROUGH THE OBSERVATION OF THE SOUTHERN CROSS

> I turned to the right and gave heed
> to the other pole, and saw four stars never
> seen
> before save by the first people.
> the heavens seemed to rejoice in their
> flames. O northern widowed clime,
> that are deprived of beholding them!
> (Purgatory, I, 22–27; Alighieri, 2005;
> 1977).

The meaning that is usually attributed to the four stars is that they would be an allegorical representation of the four cardinal virtues: courage, temperance, wisdom and justice. In Dante's vision, the four stars are always visible from the summit of the Mount Purgatory, which is placed on the Earthly Paradise. The commentators do not deny that they may also be stars, that is, the four stars of the Southern Cross.

8.1 The Southern Cross

The constellation of Crux, the Southern Cross, is one of the most conspicuous features of the southern sky, and its principal star, Acrux (α Crucis) is the thirteenth brightest star in the sky. At the present time, the entire constellation is visible from latitude 27° north, while in the Southern Hemisphere it is circumpolar from temperate regions. Where it is visible every night of the year it can be used to locate south: by drawing a straight line from α Crucis to γ Crucis (Gacrux) and extending it approximately 4.5 times the distance between these two stars you reach a point that is very close to the South Celestial Pole, and by dropping a perpendicular from this point to the horizon you get due south. Crux lies on the southern part of the Milky Way, and its brightest stars (with the exception of γ Crucis) are part of the stellar association known as the Crux-Centaurus Association.

The first European to publish a description of this constellation in modern times was the Italian explorer Andrea Corsali (1487–1545), who described it as "… so fayre and bewtiful, that none other hevenly signe may be compared to it ..." (Corsali, 1516).

The first European cartographer who included the Southern Cross on a celestial atlas was Petrus Plancius in 1598.

On the other hand, the Southern Cross was known to the ancient astronomers, but as part of the constellation of Centaurus (which surrounded it on three sides while the fourth side 'bordered' the constellation of Musca). Some early European sailors who sailed to the southern hemisphere described the Southern Cross not as a 'cross' but as an 'almond' (e.g. see Vespucci, 1499).

However, due to the precession of the equinoxes (first described by Hipparchus of Nicea in 130 B.C.), the Southern Cross was observable in the Middle Ages by Venetian and Genoese merchants who frequented the port of Alexandria and sailed up the Nile for trade (Facciolo, 2010). It certainly was seen by Knights who participated in the Fifth Crusade (1217–1221) to Egypt under Duke Leopold of Austria, and later by those who took part in the Sixth Crusade (1248–1254) under King Louis IX of France,

Table 3: Mount Purgatory's measurements according to Benini (1917).

Height	h = 192 km
Base diameter	d = 192 km
Circumference of the base	$C = \pi d = 603$ km
Island Area	$A = \pi d^2/4 = 28953$ km^2
Volume of Purgatory	$V = A\,h/3 = 1852987$ km^3

also to Egypt (*ibid.*). Dante's teacher, Brunetto Latini, mentioned in the *Divine Comedy* (*Inferno*, XV), travelled to Spain and probably had a chance to see celestial maps drawn by Arab cartographers that included southern constellations. The Arabs were familiar with a large part of Africa and the Indian Ocean, as shown by a map dating to 1154 (Conder, 1881). During Dante's time, Crux was visible and known to Arab caravaners of the desert, and Arab voyages to the Indian Ocean were described by Rahmanj in 1184, as reported by the fifteenth-century astronomer and navigator Ahmad ibn Majid (Facciolo, 2010).

In *the Almagest*, the Southern Cross is not listed but its four main stars all appear as belonging to Centaurus. The Southern Cross could be identified in the constellation referred to as the throne of Caesar, which Plinius (77) described as no longer visible from Italy, but still visible from Egypt (*Natural History*, II: 68). The Southern Cross received its name at the time of the Emperor Augustus (Magli, 2009).

8.2 The Position of the Southern Cross in the Night Sky at the Time of Dante

If we know the declination (δ) of a celestial object and the latitude (φ) of the observer's location, we can calculate the maximum and minimum heights of that object relative to the local horizon. Using the derived co-ordinates of the four main stars of the Southern Cross in the fourteenth century, as listed in Table 5, we can calculate the maximum and minimum elevation (*h*) of Crux at the time of Dante (see Table 6). We find that this constellation was fully visible throughout the night at latitudes greater than or equal to 59° 12′ 02″ S. Therefore, Mount Purgatory must have been located at a latitude of at least 30° 47′ 58″ S.

9 THE HEIGHT AND SURFACE OF MOUNT PURGATORY THROUGH OBSERVATION OF THE SOUTHERN CROSS

Now we can proceed to estimate the height of Mount Purgatory by calculating the apparent depression (*dep*), as given in the thesis by Cap-

Table 4: The sizes of some comparable islands.

Island	Size (km^2)
Purgatory Island	28,953
Timor	28,418
Sicily	25,662

Table 5: The coordinates of the Southern Cross in the fourteenth century (after Facciolo, 2010).

Star	Right Ascension h:m:s	Declination degree (S)
α Crucis	11h 49m 48s	59° 12' 02"
β Crucis	12h 08m 54s	55° 49' 02"
γ Crucis	11h 54m 06s	53° 10' 10"
δ Crucis	11h 39m 38s	54° 50' 53"

Table 6: Maximum and minimum height of the Southern Cross.*

Star	*h* maximum	*h* minimum
α Crucis	149° 12′ 02″ + |φ|	−30° 47′ 58″ + |φ|
β Crucis	145° 49′ 02″ + |φ|	−34° 10′ 58″ + |φ|
γ Crucis	143° 10′ 10″ + |φ|	−36° 49′ 50″ + |φ|
δ Crucis	144° 50′ 53″ + |φ|	−35° 09′ 07″ + |φ|

* In this table we have ignored the effect of stellar extinction near the horizon, which is anyhow small for first magnitude stars. For instance, according to Thom's rule, a first magnitude star is first visible at an altitude of 1°.

asso (1967). For $\Delta T = 15$, $\varphi = 30° 30'$, $\delta = 6°$; there is a measure of *dep* = 192'. Since the elevation (*e*) of the human eye is estimated as $e = (dep/1.8)^2$, we get *e* = 11,429 meters. Since the entrance to the Garden of Eden is near the top of Mount Purgatory, the mountain cannot have been much higher than this.

We calculate the surface area and volume of Purgatory Island, using the average slope of Capasso (Table 7). This indicates that Purgatory Island had an area comparable to that of the island of Lolland in Denmark (1243 km^2).

Now we calculate the surface area and volume of Purgatory Island, following the direct calculations of Benini (see Table 8). In this instance, Purgatory Island had an area that was comparable to that of the island of Sant'Antioco in Italy (115.6 km^2).

10 CONCLUSION

The foregoing analysis indicates that Mount Purgatory was 11.4 km high and was structured like a ziggurat.

The most notable prehistoric ziggurat was the Etemenanki Temple of the 'foundation of heaven and earth', dedicated to Marduk, in the city of Babylon, which dates to the sixth century BC and the Neo-Babylonian Dynasty. This temple is described on a cuneiform tablet from Uruk dating to 229 BC and now in the Louvre in Paris, which is a copy of an older text. This tablet gives the height of the tower as seven stocks (i.e. 91 meters) with a square base of 91 meters on each side. The existence of this mud brick structure was confirmed by excavations conducted by Robert Koldewey from 1913 onwards (see George, 2005/2006; Schmidt, 1995). Large stairs were discovered on the southern side of the building, where a triple gate connected it with the Esagila, a temple dedicated to Marduk, the protector god of Babylon. A larger gate on the eastern side connected the temple with a road that was used for sacred processions.

Table 7: New measures according to Capasso.

Height	h = 11.4 km
Base diameter	d = 40 km
Circumference of the base	C = π d = 125 km
Island Area	A = π d^2/4 = 1257 km^2
Volume of Purgatory	V = A h/3 = 4775 km^3

Table 8: New measures according Benini.

Height	h = 11.4 km
Base diameter	d = 11.4 km
Circumference of the base	C = π d = 35.8 km
Island Area	A = π d^2/4 = 102 km^2
Volume of Purgatory	V = A h/3 = 388 km^3

It would seem that Dante had in mind a Mount Purgatory that was exactly this shape and contained seven terraces, just like the Etemenanki Temple.

11 NOTES

1. Italian unification (Italian Risorgimento, meaning 'the Resurgence') was the political and social movement in the nineteenth century that consolidated different states on the Italian peninsula into the single state of the Kingdom of Italy. The process began in 1815 with the Congress of Vienna and ended in 1871 when Rome became the capital of the Kingdom of Italy.
2. Dante's verses cited in this paper were translated into English by Charles Southward Singleton (see Alighieri, 1977). For another important English prose translation, by Dorothy L. Sayers, see Alighieri (1955).
3 We presume that this relates to the Florentine mile, which was used at the time of Dante (Benivieni, 1897).
4. Note that this mathematical use of ΔT differs from its conventional use in astronomy and Earth rotation studies.
5. Three times the average height of a typical human body would be about five meters.
6. Following the tradition established by the Fathers and the Scholastics, Dante attaches an immeasurable height to the Mount.
7. The 'Wain' were the seven brightest stars in the constellation of Ursa Major.
8. The equinoctial colure is the meridian or great circle of the celestial sphere which passes through the celestial poles and the two equinoxes.
9. The great vertical is a great circle of the celestial sphere whose plane is perpendicular to that of the horizon.
10. The 'Florentine braccio' (plural: braccia) is about 0.58 m.

11. $OC \times cos(d_T) = CT \rightarrow cos(d_T) = R/R + h) \rightarrow 1 - (d_T^2)/2 + o(1) = 1 - h/R + o(1)$

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ORIENTATIONS AND OTHER FEATURES OF THE NEOLITHIC 'GIANTS' CHURCHES' OF FINLAND FROM ON-SITE AND LIDAR OBSERVATIONS

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Abstract: The orientations and placement of 52 Neolithic stone enclosures in Finland known as 'Giants' Churches' were analysed. In addition, other characteristic features, such as cairns and standing stones in or near the Giants' Churches, were investigated. The axis and gate orientations of the structures were measured using both on-site and airborne laser scanning (lidar) observations. The results showed lidar observations to be useful in archaeoastronomical analysis as a complementary tool to be used with on-site measurements and observations. The Giants' Churches were found to be orientations towards certain solar and lunar events that could have acted as 'seasonal pointers'. The orientations of the gates of the GCs were found to replicate the axis orientations to a large degree. The majority (over 90%) of the GCs were positioned on the eastern or southeastern sides of the ridges on which they were built, indicating the interest of the builders in the eastern horizon and possibly the rising of celestial bodies. The orientations of large (>35-m long) Giants' Churches and small (≤35-m long) ones were compared. The observed differences in the orientations of these two groups suggested that the structures traditionally known as Giants' Churches may be a heterogeneous group consisting of at least two types of structures represented in this study by the two selected size groups. Many large GCs were found to have been oriented towards the solstices, while the smaller ones did not show this feature. It is possible that the smaller Giants' Churches were oriented towards the Moon, while the larger ones were associated to solar events. The smaller Giants' Churches could be the remains of large houses or otherwise belong to a different tradition of construction.

Keywords: Giants' Churches, Neolithic Finland, astronomical orientations, Neolithic astronomy, ancient calendars

1 INTRODUCTION

The Giants' Churches (Finn. *jätinkirkko*, a name originating in folklore; hereafter denoted also as the GCs) are Middle and Late Neolithic (ca. 3000–1800 BCE; Okkonen, 2003) stone enclosures found mainly in Ostrobothnia, on the northwestern coast of Finland. The monuments traditionally classified as GCs are from ~20–>70 metres long and ~15–>30 m wide, and most of them are rectangular or quadrangular; there are only two clearly oval or round GCs, and two so-called 'open' rectangular GCs, which have only three walls. Some of the GCs have double or even triple walls, i.e. smaller inner enclosures inside them (see Figures 1–3). The walls of most GCs are built out of the natural *rakka* boulder fields, with stones of about the size of a man's head and occasionally larger.

The GCs were originally built on the coast, on the tips and tops of capes, peninsulas or islands. Nowadays, these sites are situated on ridges and drumlins deep in the forest, 10–20 km inland, due to the isostatic land uplift caused by the post-glacial rebound phenomenon. The majority of the GCs have been dated by the land uplift method, where their altitude relative to the present sea level gives the date of their construction once the speed of the isostatic land uplift is known (Okkonen, 2003). This dating method has traditionally been used for dating the shore-bound Ostrobothnian Neolithic dwelling sites of the Comb Ceramic and Asbestos Ceramic Cultures, and its validity has been proven by comparison with radiocarbon dates (see Eronen, 2005; Okkonen, 2003). Also, the dates obtained for the GCs by this method are in accordance with the radiocarbon dates obtained for some GCs (see Okkonen, ibid., and various references therein).

Most of the GCs have 'gates', which are symmetrically-placed openings in the walls. Some of these are framed by larger stones termed 'pier stones'. Larger, even 2-m wide boulders are also found in the walls of some GCs and even inside of them. The largest GCs are often surounded by round stone cairns and some have standing stones, 'menhirs' around them. Some of the GCs are surrounded by the remains of Middle and Late Neolithic dwellings situated lower on the ridges (e.g. Kastelli and Kettukangas of Raahe, and Hiidenlinna of Kalajoki—see Koivunen and Okkonen, 1992; Okkonen, 2003; Okkonen and Ikäheimo, 1993).

The GCs may have included wooden parts, e.g. log walls that have long since decayed. The acidic soil of Finland does not generally preserve organic material; therefore, only burnt remains are usually found in excavations. The excavations of the GC at Honkobackharju in Kruunupyy have revealed possible signs of burnt wooden structures (Schulz, 2008). The double walls encountered in some GCs have led to the hypothesis that some of them may have enclosed a more complex inner structure, perhaps even wooden buildings (Ridderstad, 2014). However, the largest, >60-m GCs would have been impos-

Figure 1: The Giant's Church of Kastelli in Raahe. (photograph: Ismo Luukkonen).

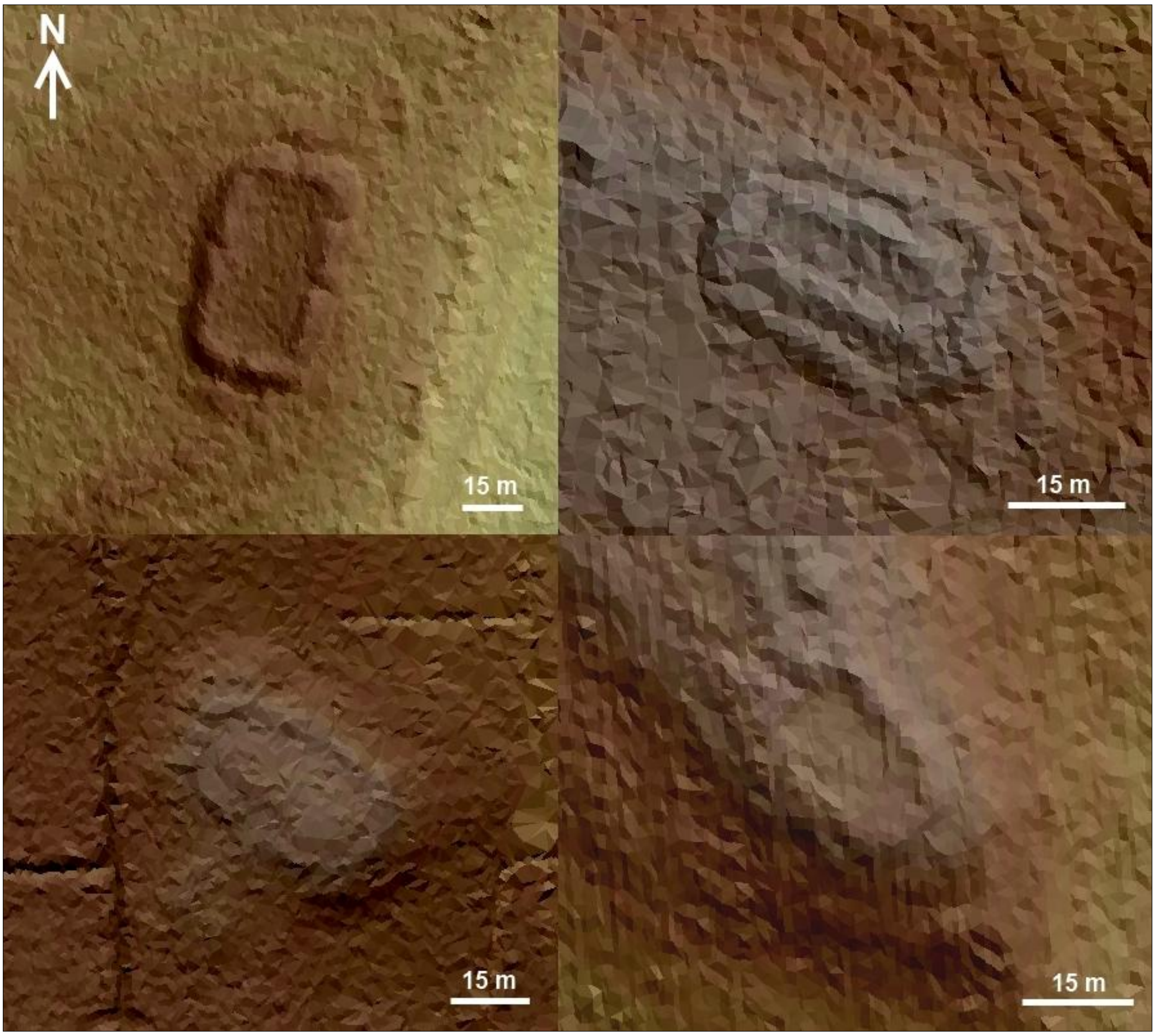

Figure 2: The Giants' Churches of Kastelli of Raahe (top left), Metelinkirkko of Oulu (top right), Rackle of Närpiö (lower left), and Kejsmolandsbacken of Pedersöre (lower right) as seen in the lidar observations. The original lidar data are courtesy of the National Land Survey of Finland (NLS, 2014).

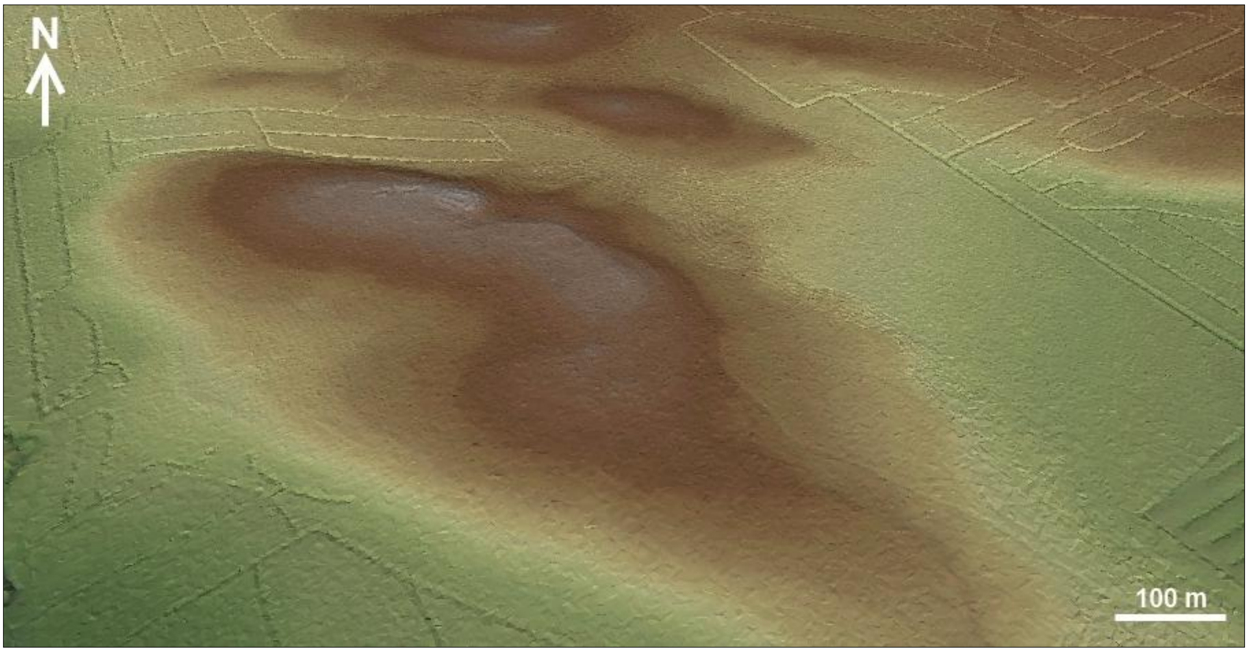

Figure 3: Metelinkirkko of Oulu was built on the top of a small ridge on an island, and to face primarily the eastern and southern directions, as most of the GCs. The original lidar data are the courtesy of the National Land Survey of Finland (NLS, 2014).

sible to cover with a single roof structure using the technology of the period.

The GCs have been associated with the culture that used the Pöljä style asbestos-tempered ceramics found on some GC sites (Forss, 1991; Okkonen, 2003). The builders of the GCs were hunter-gatherers living in marine environments (Okkonen, ibid.). Most of the bones from the Middle and Late Neolithic dwelling sites close to the GCs are from seals. Different kinds of fish and birds, elk, beaver and other game also were important. The average temperature was higher than today, and the living conditions were favourable, even at Ostrobothnia's latitude of between ~63° and 65° North (see Solantie, 2005). Agriculture was known, but at the time it did not contribute significantly to the diet (Alenius, et al., 2013; Cramp, et al., 2014; Vuorela and Hicks, 1996). There is also evidence of extensive foreign trade, possible protection of resources, and increased social complexity (see Costopoulos, et al., 2012; Koivunen, 1996; 2002; Okkonen, 2003; 2009; Vaneeckhout, 2008; 2010; Zvelebil, 2006).

The original function of the GCs is not known. Many different hypotheses have been presented to explain the existence of these kinds of monumental constructions in a hunter-gatherer society. In the various theories presented since the eighteenth century, the GCs have been seen for example as graveyards, temples, hunting enclosures and even as gigantic cold storages for seal meat (see, e.g. Okkonen, 2003, and references therein).

In previous studies of the orientations of the GCs, orientations to both solar and lunar events have been suggested (Okkonen and Ridderstad, 2009; Ridderstad, 2015; Ridderstad and Okkonen, 2015). Especially, the largest GCs seem to have orientations to the sunrises and sunsets of the solstices. Some orientations to the mid-quarter days, as well as to the full moon, risings or settings of the minor lunar standstill and the so-called 'megalithic equinox', have also been proposed.

In this study, the orientations of the axes and gates of the GCs were analysed using both on-site measurements and lidar[1] observations. The 52 GCs selected for the present study form a more complete sample than those of previous studies. The orientations of the smallest and the largest GCs were compared with each other to reveal possible similarities and differences. In addition to the orientations, other data gathered on-site during the fieldwork were examined and combined with the results of the orienttation analysis in order to help to refine the definition of what the GCs are and which purpose(s) they might have served.

2 OBSERVATIONS

The sample of the present study included 52 Neolithic stone structures classified or tentatively classified as GCs in the register of the NBA (2014).[2] However, in this study, some of the smallest constructions traditionally denoted as GCs in the NBA (2014) were left out, based on their apparently erroneous classification—Pentti Risla (pers. comm., 2009) has identified them as Neolithic housepits.

The orientations of the GCs were measured both on-site and from airborne laser scanning (lidar) data provided by the National Land Survey of Finland (NLS, 2014). Only one GC (Rackle

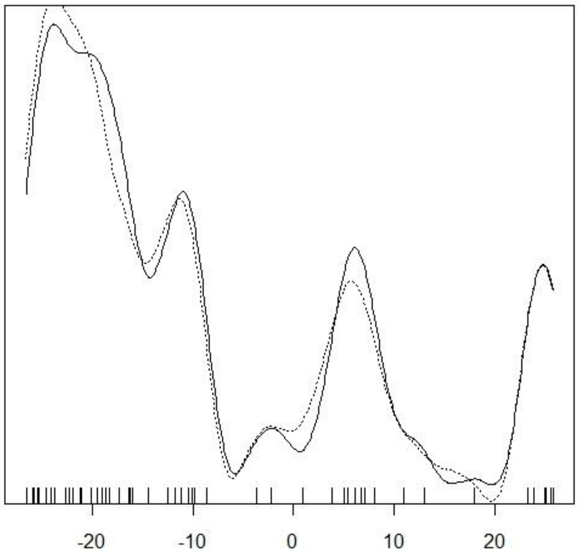

Figure 4: Declination distribution of the axes of the Giants' Churches towards the east. In this figure, north is right.

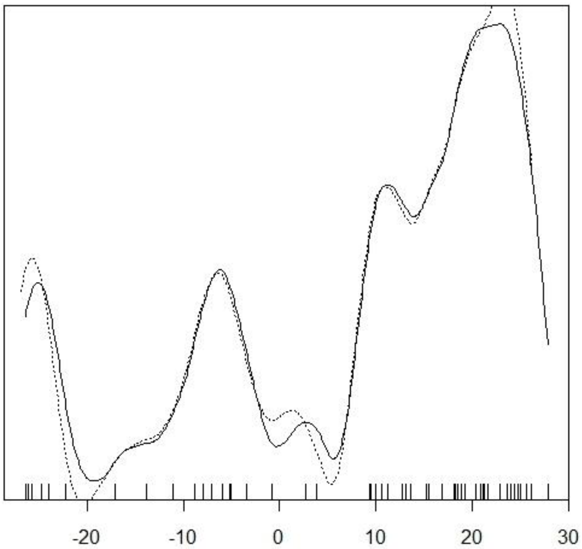

Figure 5: Declination distribution of the axes of the Giants' Churches towards the west.

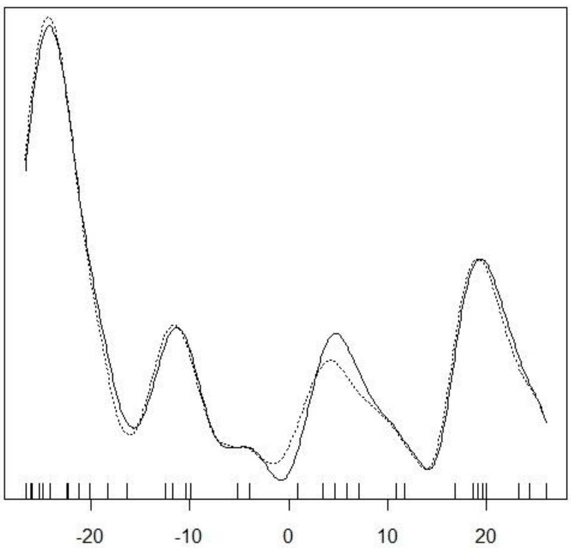

Figure 6: Orientations of the gates of the Giants' Churches to the east.

of Närpiö) was measured from lidar data alone, and one (Hautakangas of Tyrnävä) using both a site map by Sarkkinen (2009) and lidar data.

The on-site observations of this study were carried out in 2008–2014. The orientation measurements were made with a compass. The axis of a GC was calculated using the measured orientations of all walls and the general direction of the long axis, all measured towards both directions. The orientations towards the gates of a GC were measured outwards from the centre of the structure; for the two open-walled structures the centre was defined as the location of the centre of the GC as it would have been had the missing walls been in place to create a fully-rectangular enclosure. Also, many orientations towards prominent cairns and standing stones, as seen from the centres of the GCs, were measured during the project. Many sites were visited more than once, in which case the final result is the average of the measurements made at different dates, corrected for the respective magnetic declination value of each date separately. The average error of the compass measurements was estimated to be ±1.0° in azimuth. If available, the solar position was also used as a reference direction for each orientation measured; in practice, during the six years most of the orientations of the axes and gates were measured relative to the solar position at least once.

The axis orientations of 45 GCs were measured both on-site and from the lidar data. The average absolute difference between the orientations of the GCs measured from the lidar data and the measurements made *in situ* was 1.4°, of the same order as the estimated error of the compass measurements.

In addition to the orientation measurements, other kinds of data were collected during the fieldwork. A map of each GC was drawn, and the surrounding structures, such as cairns, standing stones, nearby dwellings, and the so-called rakka stone pits, which are ca. 0.5–1 m deep conical pits built into the rakka stone fields, were recorded. Also, the colours of the stones of the GCs and cairns, when observable under the thick cover of moss and lichen, were recorded. Finally, the exact locations of the GCs on the ridges upon which they were built were recorded, and then combined with geographical map data to estimate the views from the sites as they existed in the Neolithic.

Since the land uplift caused by the post-glacial rebound has moved the Neolithic shoreline and the related human-made structures 10 to 20 km inland and into deep forest, the original horizon height for the measured structures is in most cases no longer observable. Therefore, the horizon heights were estimated from map data provided by the National Land Survey of Finland (NLS, 2014). Since, for most of the GCs, the exact time of construction is still unknown, it is not known whether they were built on the small outer islands in the open sea or during a later 'archipelago stage', when the islands had grown bigger and were in a more sheltered location closer to the mainland coast. Therefore, two horizon models were used for the calculation of the orientations of the GCs:

(1) a model where the horizon height was estimated from the maps, with no contribution from possible treeline included; and

(2) the same as the model A, but with a 15-m high treeline included wherever the orientation would have been towards a land mass large enough to harbour a substantial tree cover.

It turned out that there were no great differences between the results obtained using the two models (see Figures 4–11). This is due to the fact that the GCs were often built on locations higher than their surroundings and on the tips of islands and capes, where the original nearest treeline would have been quite far away, usually on the other side of an area of open water. The results of the horizon models were also compared with the horizon heights in the present coastal areas and archipelago of southwestern Finland, which supported the validity of the modelled results obtained for the probable horizons visible from the GCs in Neolithic times.

In 2009–2013, partly side by side with the present project, a 'housepit observation project' was carried out. This involved measuring the orientations of Middle and Late Neolithic house remains in Ostrobothnia. Those observations provided important comparative data in the form of the features of the large housepits contemporaneous with the GCs. The results of that project, some of which are referred to in this paper, will be published in full in Ridderstad (2016).

3 RESULTS

The results of the orientation measurements for the 52 GCs are presented in Table 1 and Figures 4–11. In Figures 4 and 5, the declination distributions for the orientations of the axes of the GCs towards the eastern and western horizons are shown for both of the horizon models used (the rug plot is shown for the second model only).

In the eastern direction (Figure 4), at the large scale most of the axes are oriented towards the southeastern and southern segments of the horizon, roughly between the declinations of –10° and –26°. Separate groups of orientations can be observed around the declinations of ca. +6° or +7°; –10° or –11°, and –20°. There seem to be separate clusters at ca. +25° and –25°.

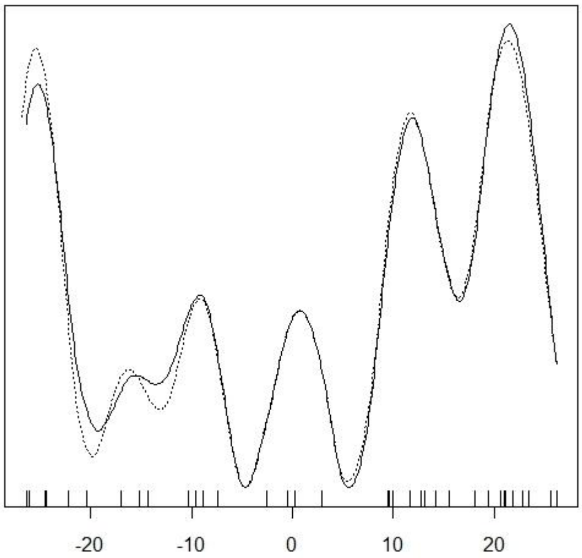

Figure 7: Orientations of the gates of the Giants' Churches to the west.

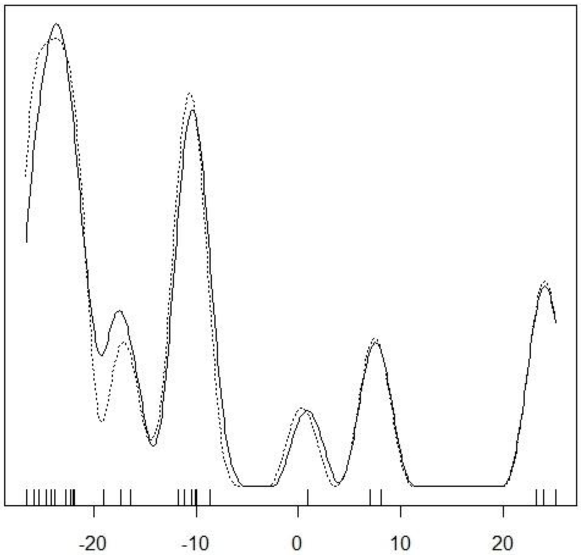

Figure 8. Orientations of the axes of the Giants' Churches >35 m towards the eastern horizon.

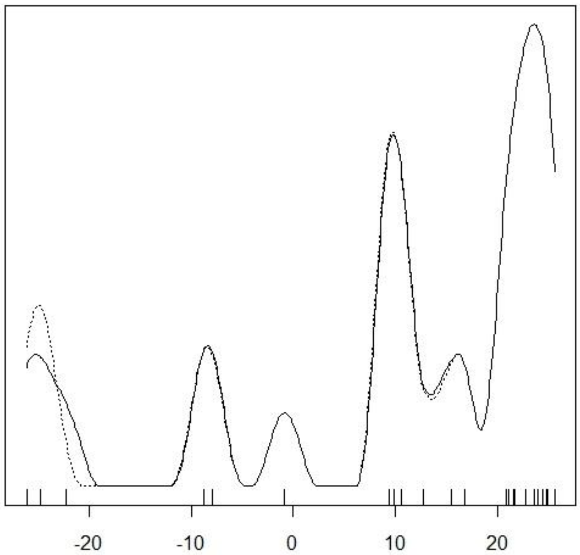

Figure 9: Orientations of the axes of the Giants' Churches >35 m towards the western horizon.

Table 1: Orientations and other features of the Giants' Churches of Finland.*

Name	Location	Latitude (deg)	HFSL (m)	Shape	Size (m)	Axis E (az/deg)	Axis W (az/deg)	Gates (az/deg)	Other feat.
Metelinkirkko	Oulu	65.36446228	52.5	Q2	38x29	114.8	294.8	75, 115, 165, 265, 295, 330	C?
Mäntyselkä	Oulu	65.26457281	62.5	Q	25x14	130.6	310.6		C, R
Rajakangas	Oulu	65.23128557	55	Q2	32x26	56.7	236.7	62.7, 271.7	C, M, T, D
Laivakangas NE	Oulu	65.18045354	55	Q	24x16	98.6	278.6	99.3	
Keskimmäisenkangas	Oulu	65.15976517	85	Q2	24x18	74	254		C, R
Luola-aho	Oulu	65.08633155	80	Q	30x20	94.8	274.8		R
Linnasaari	Oulu	65.05705135	55	Q	34x24	140.8	320.8	34.8, 249.8	R
Jättiläissaari	Muhos	64.92881914	82.5	Q	20x16	117.9	297.9	305.4, 327.4	R
Mustosenkangas	Liminka	64.74522394	52.5	Q2	37x23	149.2	329.2	60.3, 150.8, 234.8, 333.3	C
Metelinkangas	Tyrnävä	64.73165332	57.5	Q2	40x22	70	250	248	C
Linnakangas	Tyrnävä	64.71300365	52.5	Q	25x15	139	319	40.2, 144.2, 294.2	C
Kotakangas	Tyrnävä	64.712692	47.5	Q	26x14	150.3	330.3		C, T, R
Käyräkangas 1	Tyrnävä	64.70936823	50	Q2	33x15	75.1	255.1		C
Käyräkangas 2	Tyrnävä	64.70936823	50	Q	29x15	146.7	326.7	147.2, 329.2	C, T
Hautakangas	Tyrnävä	64.69602092	65	Q	47x39	170.1	350.1		D
Linnamaa	Liminka	64.64341865	57.5	Q2	40x28	130.2	310.2	130.2, 310.2	C, T, B, D
Pikku Liekokangas 1	Raahe	64.63746901	57.5	Q	18x13	83.2	263.2	84.2	C, B
Pikku Liekokangas 2	Raahe	64.63746901	57	Q	18x13	79.5	259.5		C
Kastelli	Raahe	64.63149319	57.5	Q	62x36	14.25	194.25	11, 46, 103, 168, 197	C, P, D
Linnankangas	Siikajoki	64.62834011	55	Oval	27x18	6.1	186.1	78.9	
Kiviojankangas	Raahe	64.62364796	52.5	Open Q	40x21	166	346	270	C, B
Pesuankangas	Siikajoki	64.61879234	52.5	Q	34x24	137	317	137, 317	C, M
Pikku Jakenaro	Raahe	64.58563819	78.5	Q	33x16	178.5	358.5	253.8	C
Kettukangas	Raahe	64.58233593	57.5	Q	30x20	48.6	228.6	193.6	C, M, P, D
Pirttivaara	Raahe	64.54814349	60	Q2(m)	44x32	175.2	355.2	179.4	C, R, M, D
Pirttivaara B	Raahe	64.54814349	60	Q	22x15	79.2	259.2		C, R, B, M, D
Pirttihaudankangas	Raahe	64.53984564	60	Q2	58x35	89.3	269.3	89.3	C, R
Miehenneva	Alavieska	64.26534801	52.5	Q2	40x25	111.7	291.7		
Hangaskangas	Kannus	64.0654465	60	Open Q	40x30	133.1	313.1	183	C, M, B
Hiidenlinna	Kalajoki	63.97554087	60	Q	46x29	72.9	252.9	72.9, 163, 182.1, 247, 337.8	C, R, D
Pahikaisharju	Kannus	63.96774947	57	Qm	40x20	116.1	296.1		C, M
Hautakangas	Kokkola	63.82688344	62.5	Q	32x20	2	182	230	B
Kirkkoharju	Kokkola	63.80259228	40	Q3	60x30	158.1	338.1		C, T, B
Pikku Hautakangas	Kokkola	63.77691769	70	Q	28x16	140.3	320.3		C, R
Tressunharju	Kokkola	63.72758928	60	Qm	40x18	146.7	326.7		
Honkobackharju	Kruunupyy	63.71442404	55	Q	25x18	176.8	356.8	177, 357	C
Kåtabacken	Kruunupyy	63.67821342	50	Q3	75x32	113	293	298.3	C, R
Högryggen	Kruunupyy	63.6498702	50	Q2	36x20	174.8	354.8	174.8, 354.8	
Snårbacken	Kruunupyy	63.58221987	65	Q	17x10	123.3	303.3	277.8	C
Hembacken	Pedersöre	63.57276641	42.5	Q	50x20	149.2	329.2	39.7, 277.8, 329.2	C, R, M
Tallbackharju N	Pedersöre	63.54038725	50	**Oval**/T	50x30	148.2	328.2	160.2, 192.7, 231.7	C, T
Tallbackharju N	Pedersöre	63.54038725	50	Oval/**T**	50x30	13	193		
Tallbackharju	Pedersöre	63.53451097	57.5	Q2	25x20	3.7	183.7	183.7	C, R
Svedjebacken	Pedersöre	63.51118357	57.5	Q2	58x34	112.9	292.9	113, 293	C, R, M, T, D
Storbacken 1	Evijärvi	63.47642094	66	Q	35x20	65.2	245.2		
Jäknabacken	Pedersöre	63.47382895	55	Q	65x35	147.7	327.7	148	C, M, P
Kejsmolandsbacken	Pedersöre	63.43456187	55	Q	28x20	138	318	42.9, 319.9	C
Bäckeshällorna N2	Vöyri	63.27022574	40	Q	35x20	121.8	301.8		C
Iso Mahosaari	Lieksa	63.26590478	97.5	Q2	23x18	160.6	340.6		C, R
Korkeamäki	Kauhava	63.25007553	65	Q2	60x30	163.4	343.4		C, T, B
Tavoma 1	Vöyri	63.15699536	62.5	Q	35x20	126.9	306.9	117.6, 301.6	R, M
Höjsaltträsk	Vöyri	63.11311806	62.5	Q2	38x20	27.2	207.2	27.2, 207.2	C, R
Rackle	Närpiö	62.67226913	40	Q	50x30	119.2	299.2	14.2, 119.2, 220.2, 299.2	?

Key: From left to right, the data columns show: the names of the GCs; locations; heights above mean sea level (HFSL); latitudes in degrees north; shapes; sizes; the axis orientations of the GCs towards the east in degrees of azimuth; the axis orientations of the GCs towards the west in degrees of azimuth; the gate orientations of the GCs in degrees of azimuth; and other features of the GCs. The shapes of the GCs are: Q = quadrilateral, usually a rectangle; Q2 = Q with double walls; Q3 = triple walls; Qm = Q divided into two, 1/3 and 2/3 sized 'rooms' by an inner wall; Open Q = Q with one wall missing; Oval; and T = triangular. The capital letters in the last column indicate the following features: C = cairn/s; R = rakka pit/s; M = standing stone/s; T = triangular standing stone; B = boulder/s inside the GC; D = dwelling remains around the GC; and P = piles of burnt stone. Notes: (1) Pirttivaara and Pirttivaara B may together form a Qm-type GC, with Pirttivaara B forming an extension of Pirttivaara; (2) the two values for the axis of Tallbackharju N result from the shape of the GC resembling a rounded triangle with one wall longer than the others, which leaves two possible definitions for the direction of the long axis.

Correspondingly, in the western direction the axes point mainly towards the northwestern and northern segments of the sky. Separate orientation peaks can be observed at the declinations of –25°, –6° or –7°, +10°, +19°, +21° and +25°.

The orientations of the gates of the GCs are shown in Figures 6 and 7. The distribution of the gate orientations towards the eastern horizon (Figure 6) has peaks at the declinations of ca. +19°, +5°, –11° and –24°; the latter seems to consist of two separate groups, one around ca. –20° and the other around –25°. Towards the west, the gate orientation distribution peaks at the declinations of +21°, +12° or +13°, 0°, –10° and ca. –25°.

Also the orientations of the smallest and the largest GCs were separately examined. The largest known single-room housepits (i.e. the remains of Neolithic semi-subterranean pithouses) are ca. 32 m long (Ridderstad, 2016). Therefore, the GCs were divided into two groups: those with their long axes >35 metres, and those with their axes ≤35 m in length. The sample size of the former group became 25 and the latter 27 (Pirttivaara B was left out, since it is connected by a cairn formation to Pirttivaara and its orientation may therefore have been affected by the position of the larger enclosure).

In Figures 8 and 9, the axis orientations of the GCs >35 m long are shown. Towards the eastern horizon (Figure 8), the orientation distribution has two tall peaks: one at –10° and another one at ca. –24°. Towards the western direction (Figure 9), the peaks are at +10° and +24°.

The orientations of the GCs with axes ≤35 m long are shown in Figures 10 and 11. The orientation distribution towards the east (Figure 10) has its largest peak around the declination of –20° or –19°. There are also peaks at the declinations of ca. +6° and –26°. Towards the western horizon (Figure 11), the largest peak is centred at ca. +19°. There is another peak at –5° or –6°, and also a cluster of orientations centred at ca. +13°.

In addition to the axis and gate orientations, also other features of the GCs were observed during the study. It turned out that the majority (>90%) of the GCs were positioned on the eastern or southeastern sides of the ridges upon which they were built. The dominant colour of the wall stones and particularly the large pier stones of the GCs was red: ca. 80% of the GCs for which it was possible to reliably determine the colour of the stones, turned out to be mainly red in colour. Most GCs were found to have in or around them additional structures that could be characterised as 'ritualising': cairns (perhaps used for burial or sacrifices—see Okkonen (2001) and standing stones. The orientations towards

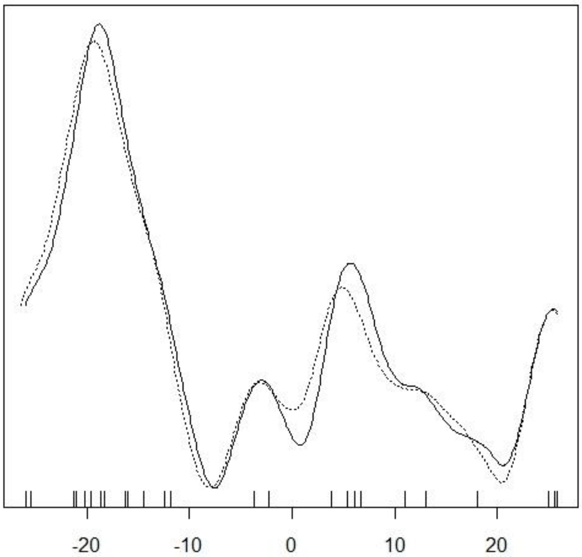

Figure 10: Orientations of the axes of the Giants' Churches ≤35 m towards the eastern horizon.

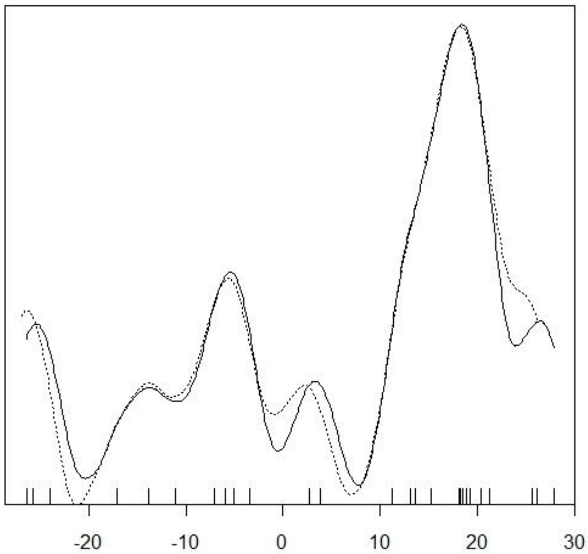

Figure 11: Orientations of the axes of the Giants' Churches ≤35 m towards the western horizon.

many prominent cairns and standing stones were measured during the project (see Section 4, below). The standing stones were ca. 0.5–2 m tall. Some were still in an upright position, while others had fallen next to a pit they had probably been standing in. The largest of the standing stones had anthropomorphic features (denoted with M in Table 1), while another special class of 'menhirs' were the red, triangular stones either protruding out of the easternmost walls of some GCs or at some distance outside of them (denoted with T in Table 1). In addition to these, some GCs had remains of dwellings and large piles of fire-cracked stones in their immediate vicinity (i.e. within a radius of about 100 m); the latter have been connected to the processing of seal blubber oil (see Okkonen, 2003).

The use of lidar data in the orientation analysis combined with the traditional method of on-site measurements provided some interesting results. The shapes of some GCs could be observed to be more complex than previously thought. The GC of Miehenneva that had been recorded as a J-shaped structure in some reports showed up as a double-walled fully rectangular GC in the lidar observations. Lidar observations also confirmed that the deviating orientation of the western wall of the Metelinkirkko of Oulu and the curved outer walls of Kåtabacken of Kruunupyy were true features of the structures and not observation errors (both structures are located in thick forest that effectively hampered long-sightline on-site observations). On the other hand, most gates and other small structures (cairns, standing stones and remains of small dwellings) surrounding the GCs could not be reliably observed with the presently-available resolution of the lidar data.

4 DISCUSSION

The present study included 52 Giants' Churches, providing a more complete sample than the previous studies (see Okkonen and Ridderstad, 2009; Ridderstad, 2015; Ridderstad and Okkonen, 2015). Also a new, more accurate horizon model was developed. The main purpose of the study was to further investigate the astronomical orientations of the Giants' Churches indicated by the previous studies, as well as to examine other characteristic features of the GCs to help address the question of their classification and, via that, their possible original functions. An additional aim of the study was to utilise a new investigative technique, lidar observations, in an archaeoastronomical orientation analysis of the GCs.

4.1 The Date for Calculating the Celestial Events

Once all GCs that had probably originally been built on the shores of inland lakes were removed from the sample, most of the structures investigated in this study had heights above sea level of between 40 m and 70 m (see the HFSL column in Table 1). The mean and the median values were 56 m and 57 m, respectively. The values of mean height above sea level for the smaller, ≤35-m long GCs and the large, >35-m long, GCs were 57.3 m and 54.7 m respectively.

In the somewhat different sample of GCs of Okkonen (2003), most of the GCs were located between 42 m and 70 m above sea level, with a mean height of 56.7 m. The dating of the seashore-bound GCs by Okkonen (2003) to ca. 3000–1800 BCE is thus applicable to the present sample of CGs as well.

The GCs at Kastelli and Kettukangas of Raahe that are 57.5 m above sea level have an average radiocarbon date of ca. 2900 BCE (see Okkonen, 2003 and references therein). Taking into account the effect of the lifetime of the dated material itself, the median height above sea level value of 57 m of the GCs in Northern and Central Ostrobothnia would thus correspond to ca. 2700–2800 BCE. Based on a combination of the height above sea level values and the radio-carbon dates, the year for calculating the celestial events for the GCs of this study was taken to be 2600 BCE.

4.2 Orientations Towards the Sun

The orientations of the GCs presented above in Figures 4–11 corresponded to various astronomical events in 2600 BCE. In Table 1 and Figures 4–11 it can be seen that some GCs have individual orientations towards the sunrises and sunsets of the solstices (declinations ±24°) and the solar mid-quarter days of early May, August, November, and February (declinations ±16°; see Ruggles, 2005). There are few values around the declinations close to 0° corresponding to the equinoxes, suggesting that the equinoxes were not as important as the solstices. Instead, the declination distributions indicate that the times about one month after and before the solstices and the equinoxes, corresponding to the declinations of ca. ±20° and ±10°, may have been especially important. The declinations between –25° and –27°, as well as those between +25° and +27°, are very close to the north-south direction and may thus indicate a deliberate orientation along the cardinal directions.

Most of the axis and gate orientations towards the eastern horizon belong to four main groups of declinations: (+5°, +6° and +7°), (–10°, –11°, –12° and –13°), (–19°, –20° and –21°) and (–24°, –25° and –26°). Towards the west, the signs are reversed, but the same relation holds. If the declinations very close to the north-south line (i.e. –25° and –26°) are left out, the average separations (17.5°, 8.5° and 4.0°) between the central declinations of the groups seem to be close to an exponential distribution. This is interesting, since it can be connected to the observation that the distances between the different groups correspond to roughly equal distances in solar days between the equinoxes and the solstices.

In 2600 BCE, 27 days after the autumnal equinox (AE) the Sun was at a declination of ca. –11°. About 42 days earlier, the Sun had been at a declination of +6°. One synodic month later (i.e. 29 or 30 full days after the Sun had been at the declination of –11°) the Sun reached a declination of –20°. And 30 days after the Sun had been at a declination of –20° it reached a declination of ca. –24° (i.e. it was only a few days away from the winter solstice). Considering that the daily variation in the movement of the Sun during the days around the winter solstice is so small that it cannot be detected by the human eye, the said date could in practise have been taken to be the time when the winter solstice started (for example, in Finnish folklore the days around the winter solstice were called the 'nesting days' of the Sun, i.e. the days when it stayed immobile in its 'nest'; Vilkuna, 1950).

The declinations of –11° and –20° also occurred about 30 days and 59-60 days before the vernal equinox, respectively. Or, counting from the winter solstice, the declinations of –20° and –11° would have occurred ca. 33 and 63 days, respectively, after the winter solstice. In the orientations of the GCs towards the western direction, a similar sequence of solar declinations can be observed with respect to the equinoxes and the summer solstice.

The period of 27 days can be compared to the length of one full synodic month, which is ca. 29.5 days. In a lunisolar calendric system, where a month starts with the appearance of the first crescent of the Moon, the full moon of the first full month starting at the autumn equinox or after it occurs on average ca. 27 days after the autumnal equinox. The difference of ca. 2 days results from the fact that the first crescent is not observable with the naked eye until it is ca. 16 hours old at the minimum, and is not easily visible until it is 2–3 days old.

The orientations towards the sunrises 27, 27+29, and ca. 27+29+30 days after the autumnal equinox thus point towards the existence of a lunisolar calendric system, where the month would started with observations of the first crescent Moon. The declination of +6°, on the other hand, can be connected to a different system of lunisolar markers: the Sun was at this declination 14–15 days, i.e. about half a synodic month before the autumnal equinox and also ca. 15 days after the vernal equinox. The 14-day period could be related to the average day of occurrence of the first crescent or the first full moon after the vernal equinox. The time of the second similar event would then be about one synodic month later, i.e. ca. 44 days after the vernal equinox, closely corresponding to the time of the solar mid-quarter day of early May.

The everyday practical calendar in the Neolithic probably was based on lunar phases, i.e. the synodic months. At least after the introduction of agriculture in early Neolithic Finland one might expect that a lunisolar calendric system that combined the tropical year of ca. 365 days and the synodic month of ca. 29.5 days was developed. A simple annual luni-solar calendar would probably have begun by starting to count the months in relation to a solstice or an equinox. It is well known from historical sources that ancient peoples often started a month by observing the last lunar crescent visible in the east before sunrise, the first lunar crescent in the west after sunset, or the full moon. The time of the full moon could, of course, be important in itself, especially at certain times of the year. The orientations seen in the GCs suggest that both the days of the start of the month at the sighting of the first lunar crescent and the time of the full moon may have been important, or that there may have been several different luni-solar calendric counts at use.

The 'seasonal calendric' orientations seen in the GCs can be compared to the medieval Nordic calendars, where the year was divided into four equal parts by four key dates: the Heart of Winter in the middle of January, the Summer Nights in mid-April, the Midsummer in mid-July, and the Winter Nights in mid-October. Originally, these days had corresponded to the times of the full moon, but became fixed in the Julian Calendar introduced after the arrival of Christianity. The four-divided year had been at use already in the Iron Age, and it has been suggested that it may be even older, having been established in hunter-gatherer times (Vilkuna, 1950). The Heart of Winter, for example, originally was the time of the full moon of the coldest month of the year, which would have been the first or second month, or the first full month after the winter solstice. In fact, it can be shown that the Heart of Winter and the Midsummer correspond to the times of the thermal minima and maxima of the year in Finland, and the Summer and Winter Nights approximately coincide with the permanent rise and decrease of the daily averaged temperatures above and below zero in the spring and in the autumn, respectively (ibid.). The equinoxes, on the other hand, do not coincide with any key dividing points of the annual temperature at the latitudes of Finland. This would have been the situation also in late Neolithic Ostrobothnia, even though the climate was slightly warmer than today. There, as in the Iron Age and historical times, the present month of April would have signified the start of spring time. The sunrise around the declination of +10° or +11° could thus have signified the start of the spring and summer period of the year. Correspondingly, the declination of –10° or –11° could be related to the start of the winter period, in a way similar to the calendric system of the Nordic Iron Age. In the same seasonal calendar, the sunrise at the declination of +20° would have corresponded to the annual thermal maximum in mid-July, and the declination of –20° at the time of the annual thermal minimum in mid-January. Together, the orientations of the GCs to the sunrises of specific days determined by the lunar phases in a lunisolar calendar could be viewed as a kind of permanent system of seasonal markers, eternalised in the most prominent stone monuments of the culture.

4.3 Orientations to the Moon

The declination of ±5° corresponds to a well-known lunar event: the so-called 'megalithic equinox' or the spring (or autumn) full moon, which is defined as the first full moon rising at a more southerly (northerly) declination than the Sun around the vernal (autumnal) equinox (see da Silva, 2004). Perhaps even the whole cluster of orientations of the GCs centred at ca. ±6° could correspond to that event, with the position of the highest peak slightly shifted.

The orientations to the declinations of ±19° correspond to the northernmost and southernmost full moons of the lunar minimum standstill every 18.61 years. On the other hand, the maximum and minimum declinations of the Moon at the time of the maximum lunar standstill are, at the latitudes of Ostrobothnia, well beyond the range of the declinations crossing the zero horizon line. Therefore, at those times, the Moon either does not rise or does not set at all, and orientations towards the rising or setting Moon are not possible. However, since the full moon is always opposite to the Sun, during the midwinter and the midsummer in the intermediate years of the 18.61-year cycle there still would often have been a situation where the full moon would have been seen at one end of a GC and the Sun at the other. The axis orientations of many GCs with gates at both ends could even be seen as well suited for this kind of 'double-orientation' towards a setting/rising Sun and a rising/setting full moon.

Recently, it has been suggested by Clausen et al. (2011) and Clausen 2014; 2015) that both the orientations of Scandinavian passage graves and West Iberian megalithic tombs could be explained by a combined distribution of orientations to the moon-rises of the spring full moon, the next full moon after the spring full moon (the 'sowing moon'), the southernmost full moon, the autumn full moon, and the full moon preceding the autumn full moon (the 'harvest moon'). The sowing moon would have happened from April to May and the harvest moon from August to September. The full moon would thus have acted as a seasonal marker in a way similar to what was suggested above for the Sun in the case of the GCs.

A possible lunar seasonal marker system for the GCs could have consisted of the spring (or autumn) full moon (the ±6° cluster) and the full moon at its annual extreme positions in midsummer and midwinter (the orientations peaking at ca. ±19°, but reaching to the north-south line near the maximum lunar standstill). This model, however, leaves the ±10° declination peak unexplained.

4.4 Orientations to Stars

Stellar orientations for the GCs were also considered, as it is well known that the heliacal and acronychal risings and settings of stars have been used as seasonal markers in ancient cultures. However, since there are so many bright stars that change declination relatively quickly with the precession of the equinoxes, any ancient monument has to be dated with an accuracy of a few hundred years to reliably suggest an orientation to a star. Currently, not enough radiocarbon dates exist for the GCs to suggest possible stellar orientations. Hopefully, the situation will change in the future.

4.5 Placement of the Giants' Churches

The fact that >90% of the GCs were positioned on the eastern or southeastern sides of the ridges upon which they were built, regardless of the direction of the ridge itself, may indicate that the eastern and southeastern directions were significant to the builders. This in turn may indicate that rising events were more significant than settings and/or that the winter Sun or the summer Moon may have been the intended targets of observation.

Bradley (2001) has suggested that the longhouses of the Central European Linear Pottery Culture (ca. 5500–4500 BCE) were oriented towards the ancestral lands of the builders. In comparison, it is perhaps significant that the eastern and southeastern directions also agree with the directions of the great river routes leading inland to the presumed ancestral lands of the Pöljä Ceramics Culture and other Middle and Late Neolithic Asbestos Ceramic Cultures in Finland and Karelia. The possibility that the GCs were oriented towards the ancestral lands of the builders does not contradict the existence of their astronomical orientations, but could be seen as a complementary feature: celestial events at specific, important times of the year would have also pointed towards the direction of the ancestral homeland.

4.6 Gate Orientations and Other Features

Not all GCs have visible gates at all and in some cases, the gates of the outer walls of a double-walled GC are not in the same places as those in the inner walls. In most GCs that have gates, these are found at the middle of the short-end walls of the structure, i.e. close to the axial direction. Therefore, the gate orientations resemble the orientations of the axes of the GCs; this relation was also found to be true for the gates of the >35-m and the ≤35-m GCs separately. However, the gate orientations towards the east are not concentrated so strongly on the southeast side of the horizon as the axis orientations of the GCs; the situation is similar towards the western horizon. Moreover, there are some peaks in the gate orientation distribution that are not seen in the axis orientations, and the locations of some peaks seem to be in slightly different positions relative to the axis orientation distributions.

Many orientations towards some of the most prominent cairns and standing stones, especially those positioned close to the axial direction in and around the GCs, were also measured. Most of the results of the orientation measurements towards the cairns from the centres of the GCs have been presented in a separate study (Ridderstad, 2013). The results also provided evidence in favour of further examination of the orientations towards the standing stones. At some sites, e.g. at Kotakangas and Korkeamäki (see Table 1) the orientation measured on-site from the centre of a GC towards the standing stone at the 'tip' of the GC could be connected to a solsticial event, while the axis orientation measured using the walls alone for each of these GCs was a few degrees off the direction of the standing stone. Most of those 'axial' stones were triangular and red in colour.

The slight differences between the axis orientations and the orientations towards the gates, cairns or standing stones close to the axial direction raises the question of which of these orientations were most important for the builders of the GCs. Moreover, in many cases, where a gate orientation of a GC was close to a certain event, but not quite towards it as seen from the exact centre of the structure, the event would have been visible through the gate if one moved just a few steps away: every gate of a middle-sized GC already has a window of visibility of more than 1° in azimuth, and a deviation of just 0.5 m in the location of the centre of the structure would make the 'observation window' at least 2° wide.

The possibilities provided by these kinds of wider observational windows call for new interpretations in the archaeoastronomical analyses of the orientations of ancient structures (see Silva, 2014). Instead of concentrating on just one line of sight and a single orientation, a wider 'sky-scape' analysis should be performed for each monument. In the case of the GCs, that kind of approach would preferably include not only the analysis of the celestial events observable via the full window of visibility of each gate, but also the analysis of all celestial events and prominent horizon features close to the axial direction, as well as the orientations towards prominent cairns and standing stones.

The suggested skyscape analysis could provide new opportunities also for the detection of stellar orientations that are now hampered by the lack of precise enough dates for the GCs. For example, in 3000–1800 BCE the rising positions of the Orion asterism grazed the southeasten horizon in Ostrobothnia. Orientations to its stars could have corresponded to some of the orientations of the GCs and possibly provided viable seasonal marker events for centuries if viewed through a wide enough physical window of visibility.

4.7 Orientations of the Small vs. the Large Giants' Churches

The initial sample included 52 large stone enclosures classified as Giants' Churches. It is possible however, that some small and middle-sized GCs might in fact be remains of unusually large Neolithic houses (see Mökkönen, 2011; Okkonen and Ridderstad, 2009; Ridderstad, 2015). Since currently no unambiguous definition of a Giant's Church exists and all of those structures fit the general characteristics (size, appearance, positioning in the landscape, etc.) of a 'traditional' GC, it was decided to keep these structures in the present sample and to try to bring out the mutual differences in the sample by comparing the GCs of different sizes. To accomplish this, the GCs were divided into two groups: those with their long axes >35 metres, and those with axes ≤35 m. The division was based on the fact that all of the suspected house remains are ≤35 m long, and, on the other hand, the length of the largest known Neolithic single-room semi-subterranean pithouse remains in Finland is ca. 32 m (Ridderstad, 2016).

It turned out that the largest GCs were oriented differently from the smaller, ≤35 m ones. For the largest GCs, orientations towards the solsticial declinations of ±24° and 'the ±10° peak', i.e. the sunrises and sunsets about one month before and after the equinoxes, are prominent (see Figures 8 and 9), while the orientations of the smaller GCs are concentrated in the declination groups around ca. ±6° and ±20° corresponding to the sunrises and sunsets about half a month before and after the equinoxes and one month before and after the solstices, or to seasonal lunar events (the autumn) full moon/spring full moon and the midsummer and mid-winter full moons). While some orientations of both the large and the small GCs can be connected to the sunrises and sunsets of the mid-quarter days, the smaller GCs have practically no orientations to the solstices. Neither have the smaller GCs orientations to the sunrises or sunsets about one month after the equinoxes (the ±10° peak), which are so prominent for the largest GCs.

While the orientations of the larger GCs to the declinations from ca. ±24° to ±26° could in principle be connected to the full moon near the solstices, an easily attributable lunar explanation for the ±10° peak has not been found. The orienttations of the smallest GCs, on the other hand, well suit a possible 'lunar seasonal pointer' calendric system: the orientations close to the declinations of ca. ±6° and centred at ±19° or ±20° could indicate the full moons near the equinoxes (the spring full moon and the autumn full moon) and the midsummer and midwinter full moons (of the minor lunar standstill). It is possible that the smallest GCs were oriented to the Moon, while the largest GCs were oriented to the Sun. Based on the height above sea level values, the group of the smaller GCs and thus the tradition of lunar orientations could be slightly older than the tradition of solar orientations, represented by the large GCs.

The younger age of the tradition of the solar orientations seen in the largest GCs could be related to the prominent role the Sun held in Bronze Age religion (for the Bronze Age solar cults see, e.g. Kristiansen and Larsson, 2005). The cultural practices in the late Neolithic Ostrobothnia could also have been affected by the arrival of the Corded Ware Culture that is known to have oriented its graves to the Sun (see Nordqvist and Häkälä, 2014; Schmidt-Kaler and Schlosser, 1984; Tranberg, 2001). However, there is some evidence of the ritual importance of the Sun already in the early Neolithic and possibly even late Mesolithic Finland: many circular stone disks have been found that are decorated with rayed patterns and apparent solar or stellar images; they were perhaps used as the headpieces of wooden staffs or hung from ropes (see Edgren, 1977, especially the Figures 7, 8, 10, and 16). To further address the question, the orientations of both Mesolithic graves and early Bronze Age monuments should be examined and compared with the orientations of Neolithic structures.

The smaller GCs could be remains of large houses or otherwise belong to a different tradition of construction. They could, for example, have been used for 'profane' activities, while the larger GCs may have been intended for ritual use. It is possible, though, that the largest GCs once enclosed one or more small buildings or even a whole former dwelling site, which then would have been ritualized by adding burial cairns, etc. (Ridderstad, 2015). The remains of the possible dwellings or perhaps mortuary houses would show up as the inner double or triple walls observed in many GCs. Unfortunately, none of the largest GCs has yet been excavated to the extent that the possible remains of buildings would have been exposed.

4.8 Lidar as an Archaeoastronomical Tool

The present study also demonstrated the usefulness of lidar observations as a tool in archaeoastronomical analysis. While they cannot replace the on-site measurements and observations, especially the shapes of very large structures can be effectively studied using lidar observations. Even though the current resolution of the lidar data did not enable the detection of the smallest details of the GCs, the axis orientation of a GC could generally be measured from the lidar images with an accuracy comparable to the compass measurements. Moreover, the shape of the local surrounding terrain also can be effectively viewed using lidar data, enabling efficient estimations of the views from a site and the inter-visibility of the surrounding sites and monuments. The latter property is especially important for sites located in boreal forests, where the use of lidar can overcome the blocking effects of the surrounding vegetation.

5 CONCLUSIONS

In this study, the orientations and placement of 52 Giants' Churches (GCs)—Neolithic stone enclosures located in Ostrobothnia and eastern Finland—were analysed. In addition, other characteristic features, such as cairns and standing stones, inside or in the immediate vicinity of the GCs, were investigated. The main aim of the study was to provide more information to help address questions of the defining characteristics, classification and original functions of the GCs. Also, the usefulness of lidar observations as a tool in archaeoastronomical analysis was examined. This study led to the following conclusions:

(1) The orientations of the GCs were found to be towards certain solar and lunar events that may have acted as 'seasonal pointers', i.e. lunisolar or lunar calendric markers related to changing seasons. Orientations to stars could also have acted as seasonal pointers, but the existence of stellar orientations for the GCs could not be validated at this stage of the research.

(2) The majority (>90%) of the GCs were positioned on the eastern or southeastern sides of the ridges upon which they were built, indicating that rising events may have been more significant than settings and/or that the winter Sun or the summer Moon may have been the intended targets of observation.

(3) The orientations of the gates of the GCs were found to resemble the axis orientations, which can be explained by the fact that the gates were usually located in the middle of the two end walls of a GC. However, often there were slight differences between the axis and the gate orientations of a GC.

(4) The observed small differences in the axis and gate orientations of the GCs, as well as the orientations towards standing stones located close to the axial direction of a GC on some sites suggest that, in the future, the orientations of each structure and its surroundings should be individually investigated further to determine whether the orientations towards the gates and/or prominent cairns or standings stones had been more important for the builders than the axial directions of the GCs. It is especially suggested that the reinvestigation should include a 'skyscape' analysis, where the full windows of visibility towards the horizon via the gates from the central parts of a structure should be taken into account.

(5) The large (>35-m long) GCs were oriented differently from the smaller (≤35 m) GCs. Many large GCs were oriented towards the solstices, while the smaller ones did not show this feature. The smaller GCs may have been oriented towards the Moon, while the larger ones were oriented to solar events.

(6) The differences in the orientations of the large and the small GCs suggest that the structures traditionally known as 'Giants' Churches' may be a heterogeneous group consisting of at least two types of structures, represented in this study by the GCs ≤35-m long and the ones >35-m long. The smaller ones may be remains of very large houses, or otherwise belong to a different tradition of construction.

(7) If the small GCs are indeed remains of houses, their orientations might be related to the orientations of the Middle and Late Neo-lithic housepits of Ostrobothnia. The differ-ences observed in the orientations of the largest and the smallest GCs thus provide another interesting direction for research.

(8) Lidar observations were shown to be useful in archaeoastronomical analysis as a complementary tool to be used with on-site measurements and observations, especially in the case of large and irregularly-shaped structures that are difficult to comprehensively observe at ground level.

6 NOTES

1. As the acronym suggests, Lidar (Light Imaging Detection and Ranging) is a remote sensing technique which uses a laser to measure the distance to a target. The measurements can then be used to create a 3-D model of the target (cf. radar).
2. The 'NBA' is the National Board of Antiquities of Finland.

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HIGHLIGHTING OUR INTERNATIONAL ASTRONOMICAL HERITAGE: TASMANIAN RELICS OF THE 1874 TRANSIT OF VENUS

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Abstract: Through the presence of two 1874 American transit of Venus stations, Tasmania played a key role in determining a value for the astronomical unit. But what makes these two stations even more important is that to this day they preserve relics associated with these historic observations. In this paper we summarise the surviving evidence found at Barrack Square in Hobart, and then revisit the Campbell Town site and provide a new interpretation of the field evidence preserved there. This is a revision of the problematic interpretation that was presented in Orchiston and Buchanan (2004), and is based upon more recent investigations.

Keywords: transit of Venus, US 1874 transit parties, Tasmania, Barrack Square, 'The Grange', Queen Victoria Museum and Art Gallery

1 INTRODUCTION

Observing the 1874 transit of Venus was a major international enterprise that helped solve one of nineteenth century astronomy's leading challenges: to derive a realistic value for the solar parallax and hence for the astronomical unit (i.e. the Earth-Sun distance).

The United States organised eight 1874 transit stations (Dick et al., 1998), and two of these were in Australia, where—weather permitting—the entire transit would be visible. Both U.S. transit stations were in the island state of Tasmania to the south of the Australian mainland. One was in Hobart, the Tasmanian capital (Orchiston, 2004), and the other was in Campbell Town (Orchiston and Buchanan, 1993; 2004),[1] a town ~130 km north of Hobart (for Tasmanian localities mentioned in the text see Figure 1).

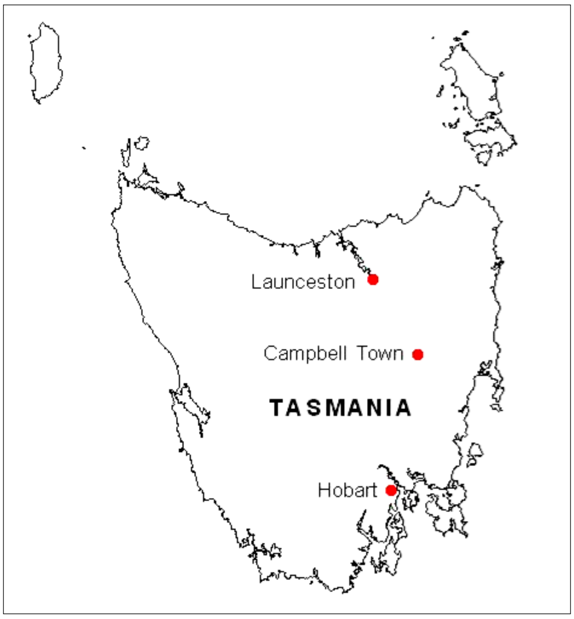

Figure 1: A map of the Australian island state of Tasmania showing locations mentioned in the text (map: Wayne Orchiston).

Both transit stations relied upon photographic and micrometric observations and consequently utilised the same instrumentation: a horizontal photographic telescope (Figures 2 and 3), a Stackpole broken-tube transit telescope (Figure 4), a 5-in (12.7-cm) equatorially-mounted Alvan Clark refractor (Figure 5), a Howard sidereal clock and Negus and Porter chronometers.[2] The Clark refractor, the transit telescope and the plate-holder that formed part of the photographic telescope all were housed in prefabricated 'Equator-

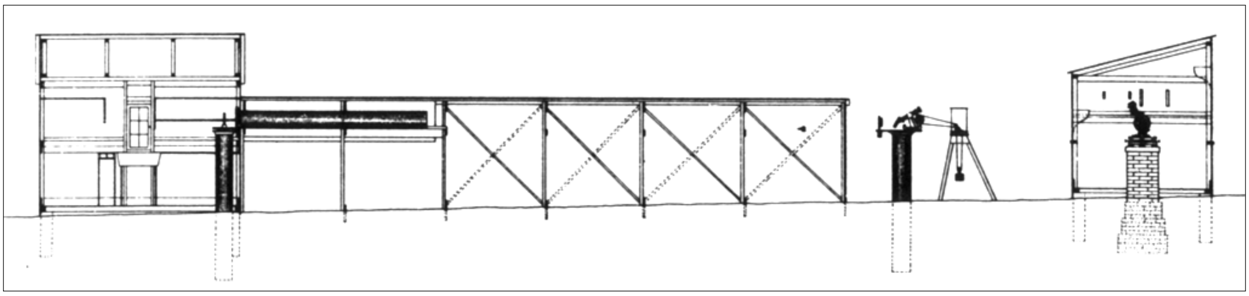

Figure 2: Schematic view of the photoheliograph, showing (from left to right) the Photographic House with the plate-holder and its supporting pier; framework shielding the incoming solar image; the heliostat and its supporting pier; the clock drive; and the nearby Transit House with its solidly-mounted broken-tube transit telescope (after Newcomb, 1880).

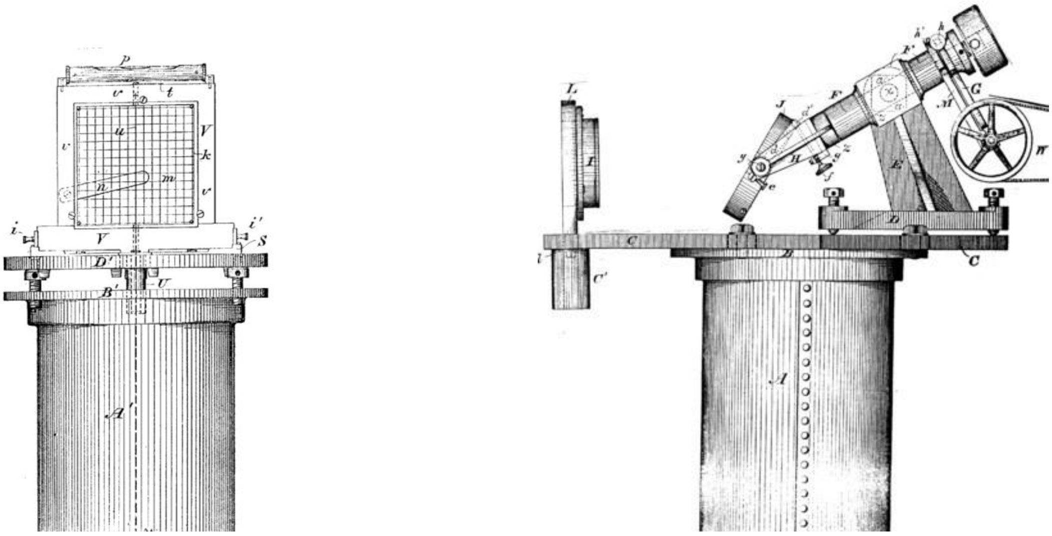

Figure 3: Close-up views of the photographic plate-holder and its pier (left), and the clock-driven heliostat and the collimator lens, *L* (right) (after Newcomb, 1880).

ial', 'Transit' and 'Photographic Houses' respectively that were brought out to the Antipodes from the United States.

Figure 4: One of the Stackpole broken tube transit telescopes used to observe the 1874 transit of Venus, and now at the U.S. Naval Observatory (photograph: Wayne Orchiston).

Figure 5: One of the 5-in Alvan Clark refractors used to observe the 1874 transit of Venus, and now at the U.S. Naval Observatory (photograph: Wayne Orchiston).

While there are no photographs or plans of the Campbell Town transit station, both exist for the Hobart transit station and are shown in Figures 6 and 7. Meanwhile, the personnel at the two transit stations are listed in Table 1.

2 TASMANIAN OBSERVATIONS OF THE TRANSIT

At Campbell Town the day of the transit, 9 December 1874, dawned cloudy, and soon it was raining heavily. However, about forty minutes after first contact[3] the rain suddenly stopped, and Venus could be seen on the face of the Sun. The photographers began exposing their plates, and continued doing this for the rest of the transit, except for those intervals when rain or heavy clouds returned. Dick (2003: 259) reveals that only 55 useable photographs were obtained, from the 120 images that were exposed on the day (The transit of Venus, 1874a). In addition, Raymond used the Clark telescope to try to observe the third contact, but clouds made Venus appear "… pear-shaped …; limb of Sun unsteady; not a satisfactory observation …" (Newcomb, 1880: 154). Despite the unpromis-

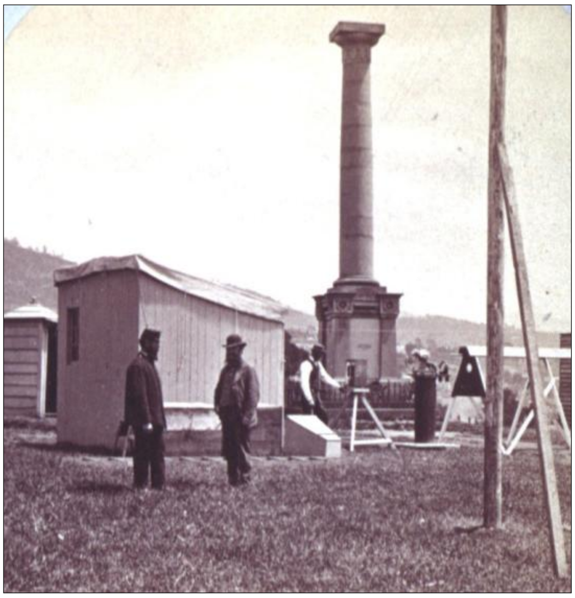

Figure 6: One of a stereo pair of photographs of part of the Hobart 1874 transit station, showing (left to right) the 'Transit House', heliostat drive, heliostat pier, and part of the wooden superstructure protecting the measuring rod (leading to the 'Photographic House'). In the background is the 'soldiers' monument' (courtesy: W.L. Crowther Library, Tasmania Archives and Heritage Office, ADRI:AUTAS001125299032).

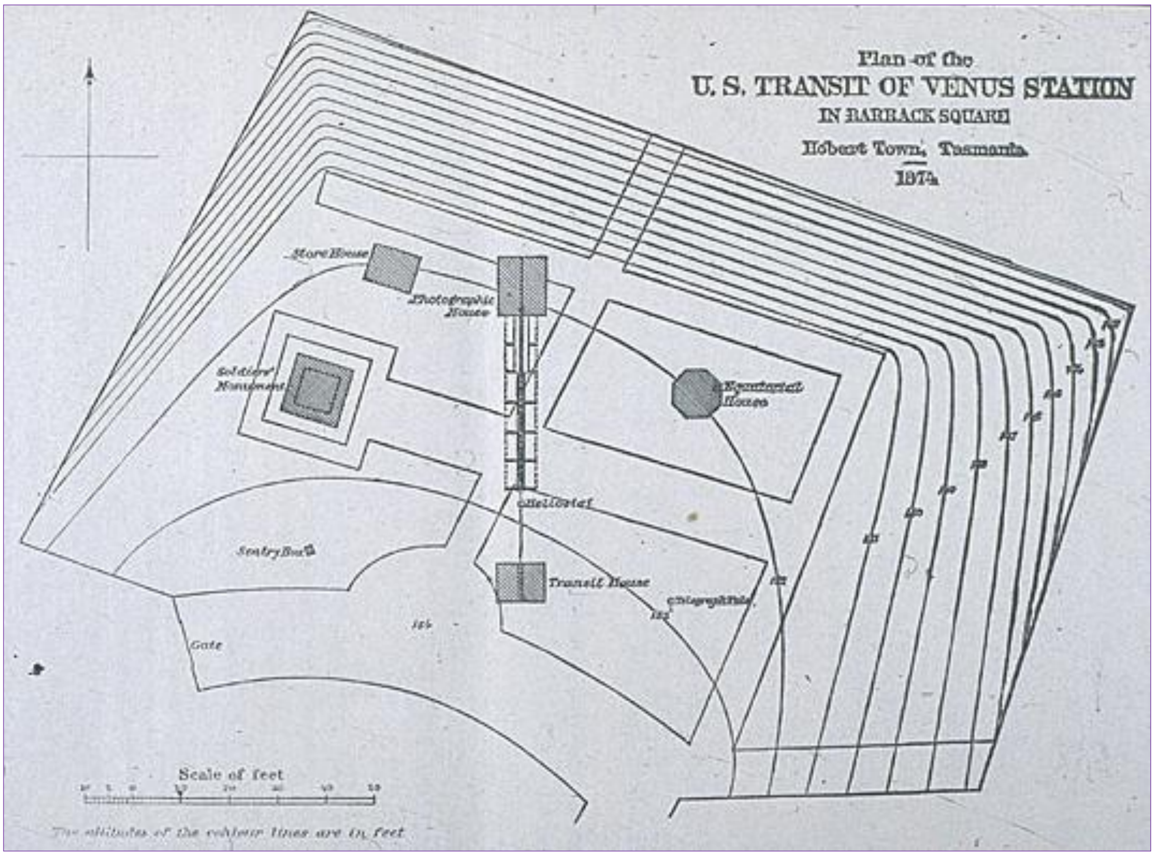

Figure 7: The Barrack Square transit station in Hobart, showing (left to right) the soldiers' monument, a store house, the Transit House, and above it the photoheliograph, and the Equatorial House (after Dick, 2003).

Table 1: The personnel at the two Tasmanian 1874 transit stations.

Personnel	Hobart	Campbell Town
Astronomer (in charge)	Professor William Harkness (1837–1903)	Captain Charles Walker Raymond (1842–1913)
Assistant astronomer	Leonard Waldo (1853–1929)	Lieutenant Samuel Escue Tillman (1847–1942)
Number of photographers	Three	Three
Number of local assistants	Four	Three (includes Alfred Barrett Biggs, 1825–1900)

ing start to the day, by the end of the transit Raymond felt that he "… had seized victory out of the jaws of defeat." (The transit of Venus, 1874b).

In Hobart transit day also was a disaster initially, but three hours into the transit the sky cleared enough for observations to begin. Altogether thirty-nine photographs were taken of Venus on the Sun's disk, then

> … the quick exposure apparatus was brought into use, and 74 pictures, including a photograph of the last contact, were taken between 10 minutes to 4 and 12 minutes past 4, when the final contact took place. (The transit of Venus, 1874b).

Another local newspaper elaborates slightly:

> The American party at the Barracks succeeded in taking 160 photographs by the wet collodion process, *of which 113 were considered first-rate*. (The transit of Venus, 1874a; our italics).

These figures refer to all photographs taken, but Dick (2003: 257–259) notes that just 39 of these were used in the final analysis. Clouds were quite dense by the time of the fourth contact, and Harkness could not see either of the egress contacts through the Clark telescope. Nonetheless, a local newspaper reported that he was "… very well satisfied with the results that were obtained, taking into consideration the unfavourable state of the weather." (The transit of Venus, 1874a). This contrasts with Newcomb's (1880) evaluation, which suggests that Harkness was profoundly disappointed with the overall scientific outcome of the expedition.

Table 2: Photographs from 1874 American transit stations used in deriving a value for the solar parallax (adapted from Dick et al., 1998: 246).

Transit Station	Number	% of Total
Vladivostok (Russia)	13	3.71
Nagasaki (Japan)	60	17.14
Peking (China)	90	25.71
Kerguelen Island (Indian Ocean)	26	7.43
Campbell Town (Australia)	55	15.71
Hobart (Australia)	39	11.14
Queenstown (New Zealand)	59	16.86
Chatham Islands (New Zealand)	8	2.29
Total	350	99.99

Now came the analysis of all of the observations, and the Americans relied on the photographic record. The task of measuring the plates obtained at the eight 1874 transit stations fell to U.S. Naval Observatory astronomer, William Harkness (1837–1903). Although the plates yielded "excellent results" for the interval when Venus was on the Sun's disk, photographs of the ingress and egress were of "no value", because of the black drop effect (Harkness, 1883).

Measurements of all of the American photographs were completed by the end of 1877, and then came the laborious task of establishing the longitudes of the transit stations. When this was accomplished, the official report of the 1874 American transit program was to have been published in a succession of volumes, but funding restrictions only allowed the appearance of the first of these (Newcomb, 1880). Unfortunately, this contained none of the results, as these were planned for subsequent volumes.

Further delays occurred, and in the end it was David Peck Todd (1855–1939) from the Nautical Almanac Office who published a provisional American value of 8.883 ± 0.034″ (Todd, 1881). The two Australian transit stations played an important role in contributing to this result: ~27% of the photographs used in deriving this solar parallax came from Hobart and Campbell Town (see Table 2). Nonetheless, Todd's result remained contentious,[4] because of certain concerns about the quality of the photographic images. These showed some limb-darkening, and there was also a difficulty in establishing plate scales (see Lankford, 1984).

Notwithstanding the importance of the 1874 transit of Venus as an international scientific enterprise, there are few tangible remains at the sites of the various American observing sites. Tasmania is a notable exception, however, as there are field remains in both Hobart and Campbell Town. In addition, the Queen Victoria Museum and Art Gallery in Launceston holds the only surviving photograph of the transit from any of the 1874 US transit stations. These important elements of our international astronomical heritage are discussed below.

3 THE TASMANIAN RELICS

3.1 The 'Observatory Paddock' at Campbell Town

At Campbell Town, the 1874 observations took place in what today is colloquially referred to as the 'Observatory Paddock', which is to the north and slightly east of Dr Valentine's homestead (see Figure 8). This more or less level paddock contains field evidence of three different features, that from their nature and positioning one would automatically assume relate to the 'Transit House', the heliostat pier (and drive) and the 'Photographic House'.

The most northerly of the three fetures is a solid brick pier that is rectangular in cross-section (see the right hand column in Figure 8), measures 717 mm × 616 mm, and extends 775 mm above ground level. There is no doubt that this is the transit telescope pier (see Raymond, n.d.; Newcomb, 1880). Approximately 38 m to the south there is a low two-tiered concrete and cement foundation which only extends ~15 cm

Figure 8: The 'Observatory Paddock', looking due north, and showing (from foreground to distance) a post hole, a concrete and cement foundation and the brick transit telescope pier. Close-ups of each of these are shown on the right (photographs: Alex Buchanan and Wayne Orchiston).

above ground level and measures 1.47 × 1.07 m, with the long axis oriented E-W. The most southerly field evidence is an area of cobblestones measuring approximately 3.05 × 3.35 m. Very near its southern boundary there is a conspicuous stone-lined depression that is the right diameter to accommodate the larger of the gatepost piers that were associated with the photographic telescope (see Section 3.2 below). Moreover, this depression is 12 m from the low concrete foundation, which just happens to be the distance that separated the two photographic telescope piers at the 1874 US transit stations. Initially, Orchiston and Buchanan (2004) tentatively identified the three structures from north to south as representing the locations of the 'Transit House', the 'Photographic House' and the heliostat pier (and drive) respectively. But they point-ed out that

> ... even if we accept the above identifications ... there is still a problem, and that is the anomalous positioning of the transit telescope pier. We have no 1874 photographs of the Campbell Town transit station or site descriptions by Raymond (n.d.) or Newcomb (1880) to judge from, so we must be guided by the configurations of other Southern Hemisphere US 1874 transit stations. Scaled layouts of the Hobart and Queenstown [New Zealand] ... transit stations show a consistent pattern of N-S aligned Photographic House, heliostat pier, and Transit House, in that precise order, with the pier of the transit telescope positioned 4.9 metres and 4.2 metres to the south of the heliostat pier respectively. A photograph of the 1874 Nagasaki transit station ... shows the middle of the Transit House ~4.7 metres from the heliostat pier, while Koorts (2003: 201) lists 4.27 metres as the distance of "... a typical southern station of an American observation post in 1882." If these figures are indicative, then the transit pier at Campbell Town should be anywhere from 4 to 5 metres *south* of the heliostat pier hole, not far to the north of this feature and the Photographic House foundation as is in fact the case. (Orchiston and Buchanan, 2004: 39–40; our italics).

Figure 9: Investigation of the two more southerly structures in the 'Observatory Paddock'. 'The Grange' homestead is just visible in the background, through the trees (photograph: Wayne Orchiston).

We then concluded:

> If the transit telescope pier is *in situ*, and has not been relocated since 1875 February (when the Americans sailed from Hobart), its current position cannot easily be explained. In fact it makes absolutely no sense ... (Orchiston and Buchanan, 2004: 40).

Thus in 2005 and 2006, two of us (AB and WO) teamed up with Gary Price (the co-owner of 'The Grange') and Professor Tony Sprent (University of Tasmania) to investigate this anomaly. First, we carried out an exploratory sondage that clearly established that the transit telescope pier was still in its original position. Next we carried out sondages at the other two field 'structures' (e.g. see Figure 9), but we could not find any evidence that clearly linked them to the 1874 transit station. To the contrary, the most southerly site coincided with the remains of a cow shed, where the conspicuous post-hole could be associated with one side of a cow bale. We could not identify a function for the foundation to the north of this cow shed, and we concluded that the fact these two locations were separated by 12.2 m, the precise separation of the two piers associated with the photoheliograph, was no more than an amazing coincidence.

We also concluded that the only field evidence of the 1874 transit station surviving in the 'Observatory Paddock' was the transit telescope foundation, and that any evidence that originally existed of the heliostat pier and drive and the 'Photographic House' would have been destroyed when site works were carried out in the northern section of this paddock in the early twentieth century and when the adjacent land was subdivided and houses were erected there.

3.2 The Photographic Telescope Piers at Campbell Town

When the Americans abandoned the Campbell Town transit station, they left the two photographic telescope piers *in situ*, and when the senior author last visited Campbell Town, in 2005, they served at the time as two rather novel gateposts at the entrance to 'The Grange' property from the Midland Highway (see Figure 10).

Reference to scaled drawings of the photographic telescope revealed that the heliostat pier was slightly larger in diameter than the pier in the 'Photographic House' that supported the plate-holder, and this was reflected when we measured the sizes of the two gate posts: the right hand gate post in Figure 10 had an external diameter of 309-mm and is the pier from the 'Photographic House', while the left-hand gate post, with an external diameter of 356-mm, was the pier that supported the heliostat. Both piers were made of riveted 9.5-mm steel plate. The date when they were relocated from the 'Obser-

Figure 10: Entrance to 'The Grange' homestead in 2005, showing the two photographic telescope piers serving as novel gate posts (photograph: Wayne Orchiston).

vatory Paddock' to the driveway entrance of 'The Grange' has not been documented, but Dr Valentine was a keen amateur astronomer, so it must have post-dated his death, which occurred in 1876, less than two years after the transit.

3.3 The Equatorial House at Campbell Town

Although the relative positions of the 'Photographic House', heliostat piers and 'Transit House' are predictable at the US 1874 transit stations, there was no 'standard position' for the 'Equatorial House'. Sometimes it was located due east or west of the 'Transit House', while at other times it was located between the 'Transit House' and the 'Photographic House', but to the east or west, as in Hobart (see Figure 7). Furthermore, because the Clark refractor sat directly on the floor of the Equatorial House and did not require a pier or foundation, we cannot expect to find any field evidence of the location of the 'Equatorial House' in the 'Observatory Paddock' at Campbell Town.

Yet we do know the current location of the 1874 'Equatorial House' at Campbell Town. Dr Valentine was a keen amateur astronomer, so when the Americans left Campbell Town they expressed their thanks for his genial hospitality by giving him the 'Equatorial House'. Valentine installed a 21.6-cm (8.5-in) Browning-With reflector in this observatory, and when he died soon after, in 1876, this instrument passed to Alfred Barrett Biggs (who had also assisted the American astronomers at Campbell Town). Subsequently, the 'Equatorial House' was converted into a summer house and was relocated to near the tennis court at 'The Grange', where it remains to this day (see Figure 11).

Currently it comprises five of the original eight octagonal wall units, constructed of Oregon Pine (*Pseudotsuga menziesii*) bottom plates, wall plates, studs and diagonal bracing, and clad with vertical planks of Sugar Pine (*Pinus lambertiana*). Both species of trees are endemic to the USA, and in the nineteenth century were common in the mountains of Oregon and California. Some of the pieces of framing timber have incised Roman numerals, that helped facilitate easy and rapid erection of these prefabricated buildings at the transit stations. One wall has a window, which mirrors exactly that shown on a photograph of the U.S. 1882 Equatorial House at the Santa Cruz transit station.

The nature of the triangular wooden domes that surmounted the 1874 Equatorial Houses is well documented, but at some stage the Campbell Town dome was removed and replaced by a more rustic roof which during the 1960s was clad with shingles. However, the basic design of the summer house, and the presence of a circular steel dome ring around the wooden plate above the octagonal wall units (see Figure 12) clearly betray its astronomical origins. The dome ring is 3-m in diameter, and made of 15 individual neatly-butted lengths of track, each with an inverted U-shaped cross-section.

Figure 13 shows the current location of the summer house, The Grange Homestead, the driveway in from the Midland Highway and the various structures in the 'Observatory Paddock'.

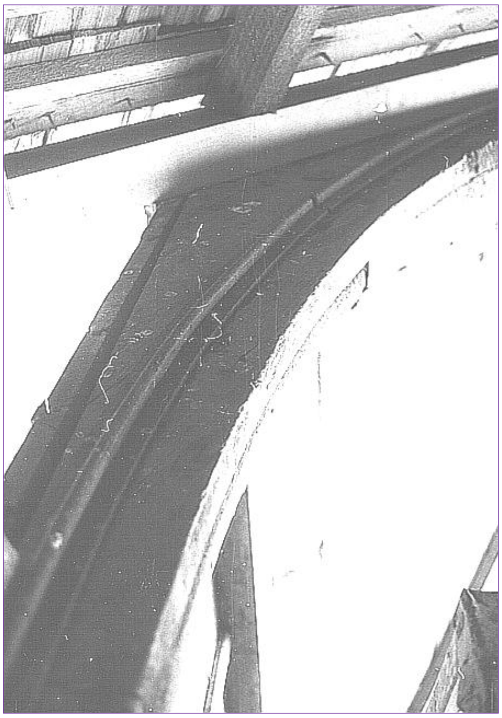

Figure 11 (left): The summer house at 'The Grange' showing the remains of the 'Equatorial House' and the distinctive window associated with the U.S. 1874 and 1882 transit station Equatorial Houses (photograph: Wayne Orchiston).

Figure 12 (right): A close-up showing the expanded wall plate carrying the metal track upon which the dome originally rotated (photograph: Alex Buchanan).

Figure 13: An aerial photograph of 'The Grange' homestead in 2006, showing the US 1874 transit of Venus relics and other structures (map: Tony Sprent).

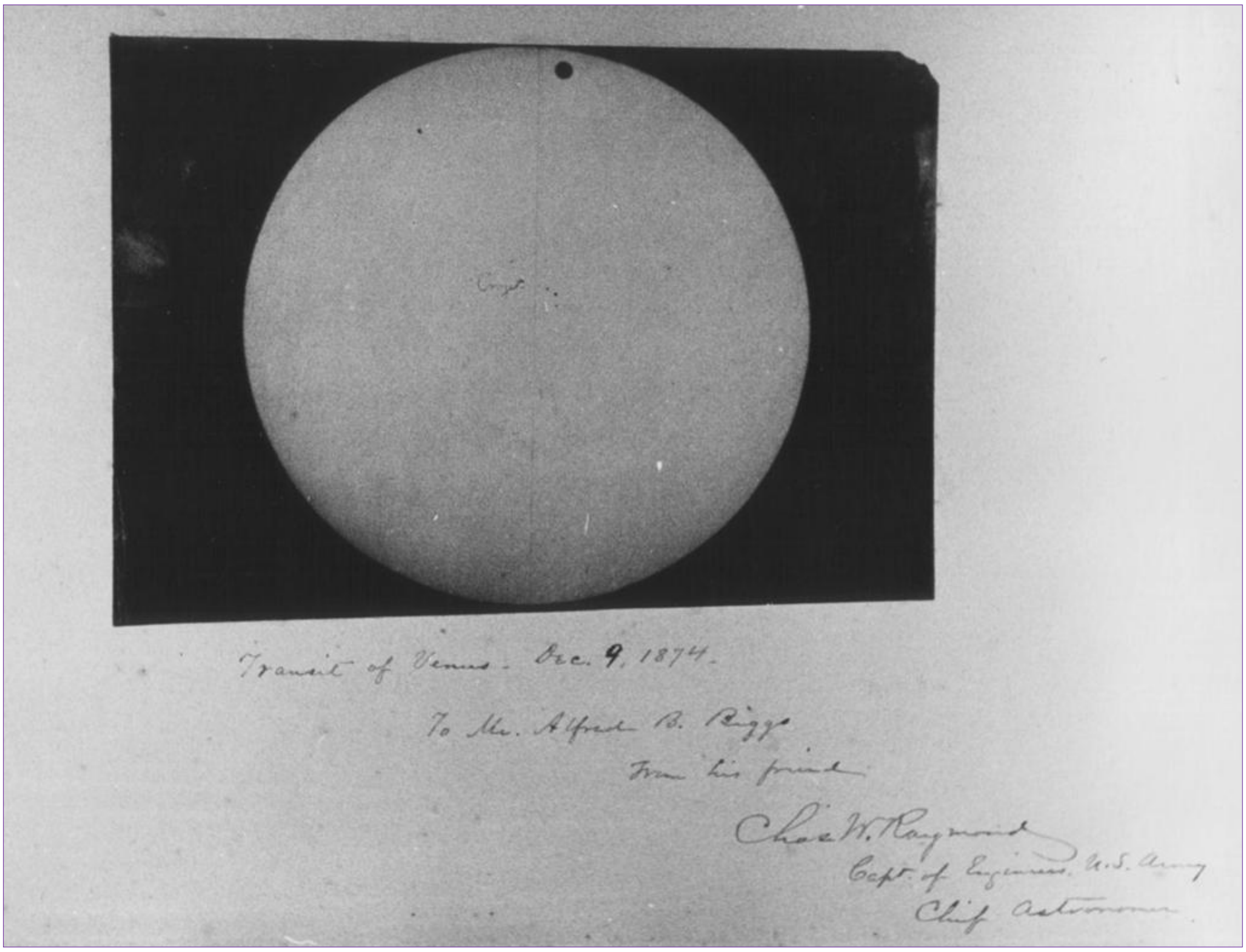

Figure 14: A print of one of the photographs of the 1874 transit of Venus taken at Campbell Town when the transit was in progress (courtesy: Queen Victoria Museum and Art Gallery).

3.4 The Photograph of the Transit at the Queen Victoria Museum and Art Gallery in Launceston

Back in the 1990s when researching the records and surviving relics relating to all of the U.S. 1874 transit stations, the then Historian at the U.S. Naval Observatory, Dr Steven Dick, and Wayne Orchiston were surprised to find that none of the original plates exposed at the eight transit stations has survived. The search then was on for surviving prints made from any of these plates, and their second surprise occurred when they discovered that only one such print is known to exist. This is in the Queen Victoria Museum and Art Gallery in Launceston, Tasmania, and is shown in Figure 14.

During the transit, the Campbell Town party succeeded in taking 55 photographs of Venus silhouetted on the solar disk and 77 photographs of the egress contacts, and the print in the Launceston Museum is from one of the 'disk' photographs.

Local school-teacher, Alfred Barrett Biggs (Figure 15), was one of the three volunteers, and he assisted in the Photographic House during the transit. The leader of the transit party,

Figure 15: Alfred Barrett Biggs, 1825–1900 (Orchiston Collection).

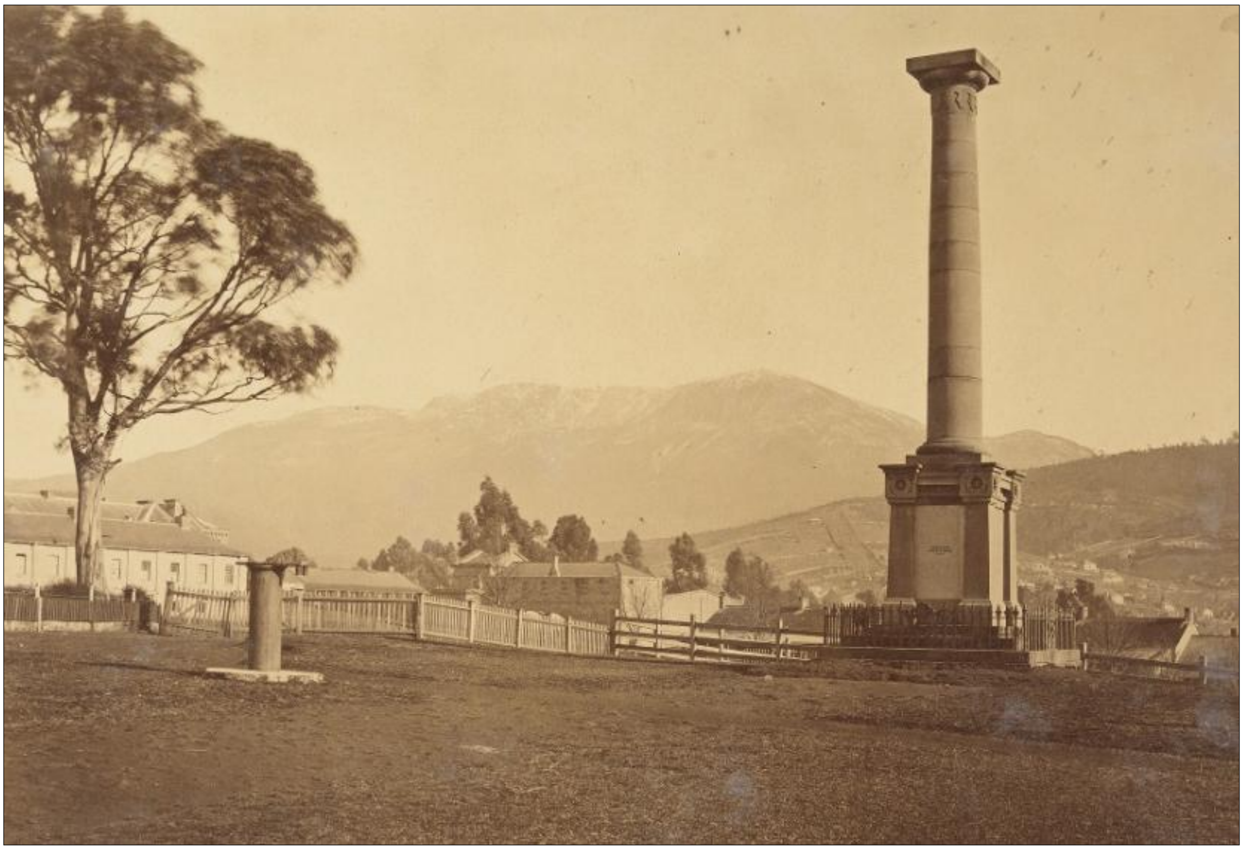

Figure 16: Photograph taken in 1885 showing the 'soldiers' monument' and the transit of Venus heliostat pier, which is still *in situ* (courtesy: W.L. Crowther Library, Tasmania Archives and Heritage Office).

Captain C.W. Raymond, sent him this photograph as a mark of his appreciation, and it contains the accompanying inscription:

> Transit of Venus. Dec. 9, 1874.
> To Mr. Alfred B. Biggs
> From his friend
> Chas. W. Raymond
> Capt. of Engineers, U.S. Army
> Chief Astronomer

Biggs probably was sent this photograph when the transit party was back in the USA, but immediately after the transit he was given the prefabricated wooden 'Transit House' and he subsequently erected this at his observatory complex in Launceston—see Orchiston (1985) for details. Despite extensive searches of historical photographic collections throughout Australia, no image of this small roll-off roof observatory building could be located, and the structure itself does not appear to have survived.

3.5 The Photographic Telescope Pier in Hobart

Barrack Square in Hobart, where the other Tasmanian U.S. 1874 transit station was located, is now part of a military base, but in a secluded area there is a conspicuous monument to British soldiers who died in the Maori Wars in New Zealand during the nineteenth century, and nearby is one of the two Photographic Telescope piers (see Figure 16). Two of the authors (AB and WO) paid a brief visit in 2005 but did not have a chance to measure the diameter of this pier to determine whether it was the plateholder pier or the heliostat pier, but if Figures 6 and 16 and the site plan shown in Figure 7 are any indication, this would appear to be the heliostat pier, which is still located in its original position.

4 CONCLUDING REMARKS

The island state of Tasmania, to the south of the Australian mainland, has a special claim to fame in the international history of the US 1874 transit of Venus expeditions. 'The Grange' at Campbell Town has pre-eminent status in this regard as home to both horizontal photographic telescope piers, an *in situ* brick pier that once supported the transit telescope and the remains of the Equatorial House (which now masquerades as a summer house). Meanwhile, Barrack Square in the Tasmanian capital, Hobart, boasts one surviving photographic telescope pier (that supported the heliostat), and this is still located in its original position. While field relics like these at other American 1874 and 1882 transit of Venus stations were still extant in the mid-twentieth century (e.g. see Koorts, 2003), these Tasmanian relics would appear to be the only ones that have survived through to the present day. But Tasmania has even greater significance, because the collections of the Queen Victoria

Museum and Art Gallery in Launceston include what would appear to be the only surviving print of any of the glass plates that were exposed at the eight US transit stations in 1874, and this assumes even greater importance given that not one of these plates has survived.

However, this study shows the importance of carrying out thorough investigations of historic astronomical sites and relics. Because of the known association of the 'Observatory Paddock' in Campbell Town with the 1874 US transit party, our initial supposedly-logical assumptions were made concerning the identification of the field monuments that were located there. However, further analyses showed most of these assumptions to be false, and that little remains in this paddock that is indeed associated with the 1874 transit (the only genuine relic being the transit telescope foundation). Instead, most of the original evidence was lost when the paddock was modified during the twentieth century and when the adjacent land—where the Photographic and Equatorial Houses are presumed to have been located—became a residential block and a house was constructed there.

Having said that, Tasmania still has a special place in the history of astronomy, and despite the passage of more than a decade, we can do little better than to repeat our earlier conclusion:

> Tasmania ... has a unique collection of 1874 transit of Venus relics. These are of international significance, and constitute part of our nineteenth century world astronomical heritage. As such, it is essential that their importance is fully recognized, and that they receive appropriate attention from those trained in the care and maintenance of historical and industrial archaeological remains. (Orchiston and Buchanan, 2004: 42).

5 NOTES

1. Actually this transit party was assigned to the Crozet Islands in the southern Indian Ocean, but when they arrived there inclement weather prevented a landing so the transit team continued on to Hobart, Tasmania, where they accepted an offer of hospitality from Dr William Valentine (1808/1809–1876) and established their transit station at his luxurious home, 'The Grange', in Campbell Town (see Orchiston and Buchanan, 1993).
2. For technical details of these instruments see Harkness (1877); Newcomb (1880); Orchiston and Buchanan (1993); and Orchiston (2004).
3. Following international convention, the two ingress contacts are referred to as 'first contact' and 'second contact', and the two egress contacts as 'third contact' and 'fourth contact', in that order.
4. We should note that Todd's result also differs somewhat from the currently-accepted figure of 8.794148 ± 0.000007″.

6 ACKNOWLEDGEMENTS

We are grateful to Robert Walch (Walch Optics, Hobart) for helping with the survey that led to the preparation of Figure 13, and the W.L. Crowther Library, Tasmania Archives and Heritage Office, (Hobart) and the Queen Victoria Museum and Art Gallery (Launceston) for kindly supplying Figures 6, 14 and 16.

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Professor Wayne Orchiston was born in New Zealand in 1943 and works as a Senior Researcher at the National Astronomical Research Institute of Thailand and is an Adjunct Professor of Astronomy at the University of Southern Queensland in Toowooma, Australia. He has a special interest in the historic transits of Venus, and in 2000 he was the founding Chairman of the IAU Working Group on Transits of Venus. He has published extensively on the 1769, 1874 and 1882 transits, and in 2014 he and former Ph.D. student, Stella Cottam, published the book *Eclipses, Transits and Comets of the Nineteenth Century: How America's Perception of the Sky Changed* (Springer). Wayne also has published on the history of meteoritics, historic solar eclipses and the development of solar physics, historic telescopes and observatories, the history of cometary and asteroid astronomy, and the history of radio astronomy. He is a co-founder and the current Editor of the *Journal of Astronomical History and Heritage*, and in 2013 the IAU named minor planet 48471 Orchiston after him.

Alex Buchanan was born in New Zealand in 1944, and is a retired botanist who formerly worked at the Tasmanian Herbarium, which is a section of the Tasmanian Museum and Art Gallery, in Hobart. His interest in the history of the natural sciences in Tasmania led him into several fields, including early botanical collections and Tasmanian astronomical history. His involvement in the study of the Campbell Town transit of Venus site began over thirty years ago, and culminated in the publication of two earlier papers, both written jointly with Wayne Orchiston. One appeared in this journal, and the other in the *Australian Journal of Astronomy*.

Gary Price and his wife June Tyzack purchased The Grange in Campbell Town in February 1999 and immediately set about trying to discover the rich history of this place. When tracing the history of the house and its original owner, Dr Valentine, it became increasingly obvious that the man himself was much more than just the local doctor. Dr Valentine's importance and involvement in bringing the U.S. transit of Venus observers to The Grange was immediately apparent and it became a quest to discover the mysteries that surround this event. Gary and June are pleased to remain as 'custodians' of what remains.

Dr Tony Sprent has a Ph.D. in physics, and taught surveying and spatial science at the University of Tasmania for 35 years before retiring in 2003. He is currently an Adjunct Senior Lecturer in the School of Mathematics and Physics at the University. After graduating, he was closely involved with the design of high precision scientific instrumentation for various Tasmanian organisations. During this time, he became involved with a not-for-profit organisation, TADTAS, concerned with the design and construction of technical aids for people with disabilities, in 2004 becoming Chairperson of its Board of Management. In addition, he is currently the site engineer with the University of Tasmania's new 1.3-m optical telescope being erected at Bisdee Tier near Melton Mowbray. For relaxation, Tony sings with the Tasmanian Symphony Orchestra Chorus. In 2011 he was appointed as a Member of the Order of Australia (AM) for his contributions to the development of technical aids for people with disabilities, spatial science and astronomy.

FOLLOW THE INFORMATION: COMETS, COMMUNICATIVE PRACTICES AND SWEDISH AMATEUR ASTRONOMERS IN THE TWENTIETH CENTURY

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Abstract: The aim of this paper is to demonstrate that important insights into the historical development of amateur astronomy can be gleaned through studies of its communicative practices, particularly organised means of circulating information. The case discussed here concerns the tradition of Swedish amateur astronomy in the twentieth century, with the focus on cometary astronomy.

Keywords: Amateur astronomy, Sweden, cometary astronomy, communicative practices, observational networks

1 INTRODUCTION

In 1944 the Swedish amateur astronomer Thorvald Eriksson sent the following question and complaint to Knut Emil Lundmark (1889–1958; Figure 1), Professor of Astronomy at Lund Observatory (Holmberg, 1999; Smith, 2009; Kärnfelt, 2014) and a well-known public figure in Swedish astronomy:

> Isn't there a journal where I can read about new findings about approaching comets, etc.? Last year, when the great comet in Ursa Major was seen, I first read about it in a newspaper after it had already been visible for a whole month, which was annoying. It would have been interesting to follow it the entire time. (Eriksson, 1944).[1]

If we assume that Eriksson is asking for a journal in Swedish, the answer to his question is 'no', for at that time no such journal was available. Until the 1960s amateurs were generally left in the dark when it came to comets, with the exception of the few times that approaching comets were predicted to be so bright that newspapers took an interest.

Eriksson's frustration illustrates the main argument of this paper: that amateur endeavours are largely dependent on the accessibility of vital information about celestial events. If you do not have access to relevant information, you cannot, for example, engage in amateur cometary astronomy. From that perspective, the aim of this paper is to demonstrate that important insights into the historical development of amateur astronomy can be gleaned through studies of its communicative practices, particularly organised means of circulating information.

Swedish amateur astronomy emerged rather late, the first practitioners appearing just after the turn of the twentieth century. Even though the number of active amateurs subsequently increased, it has always been a relatively small enterprise, currently involving approximately 1,000 Swedes. To put this number into perspective, it has been suggested that there are approximately 10,000 counterparts in the UK (British Astronomical Society, 2013) and at least 200,000 in the United States (Fraknoi, 2013). For our purposes, the relatively-modest Swedish tradition is an advantage since it permits an overview of the many communicative practices involved. Still, we need a focus for the argument. As it so happens, the very nature of comets makes them an excellent point of departure.

Figure 1: Professor Knut Lundmark (after *Dictionary of Swedish National Biography*).

From an observational point of view, there are three categories of comets. First there are the spectacular 'Great Comets' (e.g. see Burnham, 2000; Seargent, 2008). Big and bright, but few and far between, they attract the interest of not only professionals and amateurs, but also the general public due to reports in the media.

The appearances of Comet 1P/Halley in 1910 and 1986, Comet Hyakutake (C/1996 B2) in 1996 and Comet Hale-Bopp (C/1995 O1) in 1997 are good examples. Reading the daily newspaper is more than sufficient to find the information needed to observe comets like these. Since they are big and bright, fairly general information about their position is good enough. Comets belonging to the second group are not as spectacular as the Great Comets but are still visible to the naked eye, and it is much more difficult to track down information about them. One example is Comet Whipple-Fedtke-Tevzadze (C/1942 X1; Figure 2), which is mentioned above by Eriksson. This comet reached a maximum visual magnitude of 3.5 before fading (Ashbrook, 1943). Newspapers generally ignore such comets, so amateurs have to rely on other sources. Since these comets are not so bright, more precise information about their right ascensions and declinations is required in order to locate them. The third group, representing the lion's share observed by amateurs, are those comets that are only visible in a telescope. To track these comets, access to detailed finder charts (or ephemerides) is required and positions must be specified in increments of 24 hours or less.

This is the background that makes cometary astronomy a suitable starting point for studying the circulation of information. Eriksson was not able to observe the 1943 comet before the newspaper happened to mention it, simply because he did not know about it. Amateur astronomy devoted to comets requires that someone distributes the necessary information through channels that are accessible to its practitioners.[2]

Before we continue, a few words need to be said about the nature of the amateur endeavour. The basic quality that defines amateur astronomy is the do-it-yourself attitude that permeates the domain (Holmberg and Kärnfelt, n.d.). In contrast to someone who passively 'consumes' popular astronomy from the comfort of their favourite armchair, amateurs take action. They build telescopes, run observatories, engage in various kinds of observation projects and so on. For the purpose of this paper, and drawing on the work of Dr Tom Williams (2000), a second distinction needs to be made—between amateurs who actively contribute to science and those who engage in astronomy for recreational purposes. Within the Swedish tradition, the majority of amateurs fall into this second category—they pursue astronomy just for the fun of it, without any ambition to make a scientific contribution. Of today's 1,000 Swedish amateurs, no more than 10% occasionally contribute to science (cf. Gada, et al., 2000).

Returning to cometary astronomy, the two types of amateurs described above have quite different requirements when it comes to information infrastructure. Recreational amateurs, to the extent that they take an interest in comets, can settle on being at the receiving end of a flow of information that alerts them to approaching comets and gives them the means of locating them in the sky. Scientifically-inclined amateurs, on the other hand, need access to channels through which they can submit their reports. The latter case gives rise to a more complicated communicative practice that might be called an *observation network*. Drawing on the work of Jeremy Vetter (2011a: 259), an observational net-

Figure 2: Two photographs of C/1942 X1 (Whipple-Fedtke-Tevzadze) taken by Cuno Hoffmeister on successive nights in March 1943 showing the changing nature of the tail (courtesy: Patrick Moore Collection).

work—in his case a *field network*—can be defined as "… a mode of knowledge production in modern science that has linked together geographically dispersed lay people whose activities are co-ordinated and directed from a central location …" Vetter uses Kansas weather-watchers in the early twentieth century as his case, but his argument can easily be extended to include other kinds of amateurs who actively contribute to science (cf. McCray, 2008; Macdonald, 2002; Vetter, 2011b).

Astronomical observational networks emanate often, but not always, from the needs of professional astronomers. Amateurs with the proper discipline are invaluable resources when astronomers need to collect certain kinds of data, such as magnitude estimates of variable stars (e.g. see Williams and Saladyga, 2011), meteor counts (e.g. Kärnfelt, 2014; Littmann and Suomela, 2014) or data on comets (e.g. Sekanina and Fry, 1991). The success of the enterprise hinges on the ability of the experts, or their proxies, to attract interest, circulate information and relevant protocols, and maintain an infrastructure that allows amateurs to provide feedback in the form of observational reports.

Turning to Swedish amateur cometary astronomy, a fully-developed observational network is the culmination of our history, and was achieved in the 1990s. In the following Section we start in the early twentieth century, and see how amateurs first gained access to basic information about comets. Then we follow the information.

2 CHRONICLES

Swedish amateur astronomy did not enjoy the same stature at the beginning of the twentieth century as the British or American traditions (cf. Chapman, 1998; Williams, 2000), but was limited to a handful of isolated individuals (Holmberg and Kärnfelt, n.d.; Kärnfelt, 2004). No organisations promoted astronomy or recruited amateurs. No astronomical journals were available to lay readers. No observatories offered the general public the opportunity to glimpse heavenly bodies. The fourteenth Scandinavian Scientists' meeting in Copenhagen in 1892 first addressed this deficit, and Nils Christoffer Dunér (1839–1914; Figure 3), Director of the Uppsala Observatory, proposed the establishment of a Scandinavian society devoted to astronomy. The Royal Astronomical Society in Britain and the newly-formed British Astronomical Association were sources of inspiration. Dunér (1892) envisaged a similar organisation in Scandinavia and suggested that its chief aim be to recruit amateurs in the service of professionals. Even though the proposal was well received, the only immediate result was a resolution of support. The astronomical societies that eventually emerged were outside the aegis of the Scandinavian Scientists' meetings and operated on a national rather than international level. The Danish Astronomical Society was inaugurated in 1916. The Swedish Astronomical Society followed suit in 1919 at the initiative of Nils Viktor Emanuel Nordenmark (1867–1962; Figure 4), one of Dunér's students. The Ursa Astronomical Association in Finland was founded in 1921 and the Norwegian Astronomical Society in 1938.

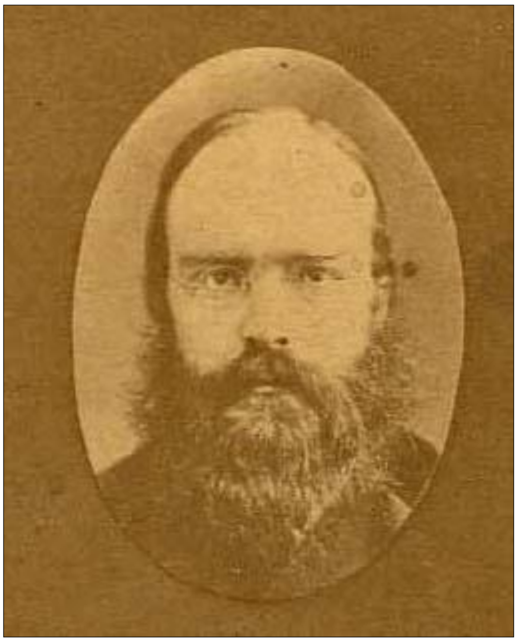

Figure 3: Nils Dunér (en.wikipedia.org).

Like its counterparts in other Scandinavian countries, the Swedish Astronomical Society had a dual purpose: to serve both professionals (approximately 20, including geodesists and Ph.D. students) and members of the general public who

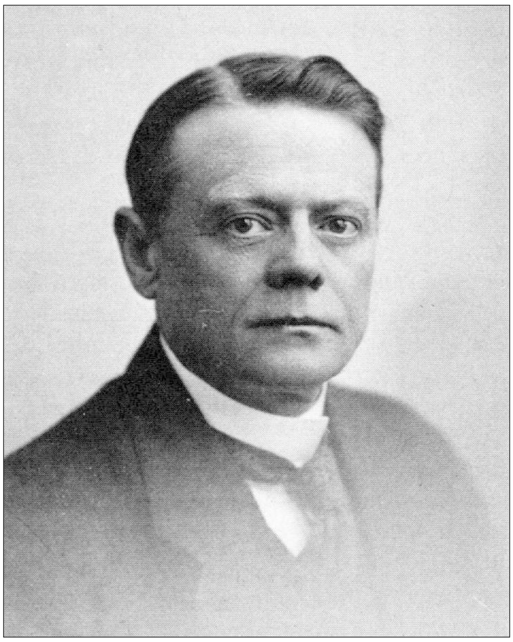

Figure 4: Nils Nordenmark (after *Dictionary of Swedish National Biography*).

were interested in astronomy, especially those who might become active amateurs (Kärnfelt, 2004). The Society launched a number of projects, the most important one being the publication of *Populär Astronomisk Tidskrift* (*Journal of Popular Astronomy*), which started in 1920. This biannual magazine included a number of articles, often popularized versions of presentations at Society meetings, along with an extensive section of miscellaneous news, book reviews, professional updates, obituaries, etc.

After a few years, the Society had managed to attract approximately 250 members, most of whom joined not as active amateurs, but out of an interest in astronomy. In general, the journal targeted this larger group of interested lay persons, but during the first few years, the Society also tried to arouse interest in amateur astronomy. The *Populär Astronomisk Tidskrift* included articles about ways of making various kinds of observations suitable for amateurs, about amateur observatories and about the basics of astrophotography. The results were limited, with the number of active amateurs in the Society increasing to about 20 (Kärnfelt, 2004). After a few years, and despite these partial results, the Board (which was dominated by professional astronomers) felt that the amateur initiative was not worth the effort and abondoned it altogether. The journal would not address the needs of the amateurs again until the 1940s (see below).

From the very first issue of the *Populär Astronomisk Tidskrift*, and continuing for half a century, the miscellaneous section contained quite informative 'comet chronicles'. Edited by a succession of professional astronomers, the chronicles were the first reliable source of cometary information for the few interested amateurs who were around. Each of the 1–2 page chronicles reviewed appearances during the previous six months, and listed the periodic comets that were due to return during the coming year. The first chronicles named seven periodic comets that were expected to appear in 1920, and the author claimed that 10P/Tempel had the greatest potential (Anonymous, 1920a). Contrary to his expectation, this comet peaked at the eleventh magnitude (Anonymous, 1920b)!

Swedish amateur astronomers who read the comet chronicles during the 1920s were at the receiving end of a quite straightforward information structure (Figure 5). Whether new or periodic, and discovered by professionals or amateurs, comets were reported to the Central Bureau for Astronomical Telegrams, which was located in Copenhagen (Denmark) from 1922 (Sperling, 1991). Swedish-Danish astronomer Elis Strömgren (1870–1947; Figure 6) compiled the reports and circulated them through a telegram service and printed notices. Swedish and other observatories subscribed to the service, which enabled astronomers to keep up with the latest developments. Swedish astronomers used the information in the circulars to put together the bi-annual comet chronicles for the benefit of the Society's members.

These comet chronicles might have sparked interest in comet observations among Swedish amateur astronomers had it not been for one important fact: the chronicles did not provide the information required to actually locate any of the comets. Let us take a typical example dating to 1922:

> The orbital period of comet Perrines (1896 VII) is 6.45 years. It was observed in 1909 and should also be visible this year. At the perihelion passage, around 10 October, the comet will be six hours (1.17 astronomical units) away

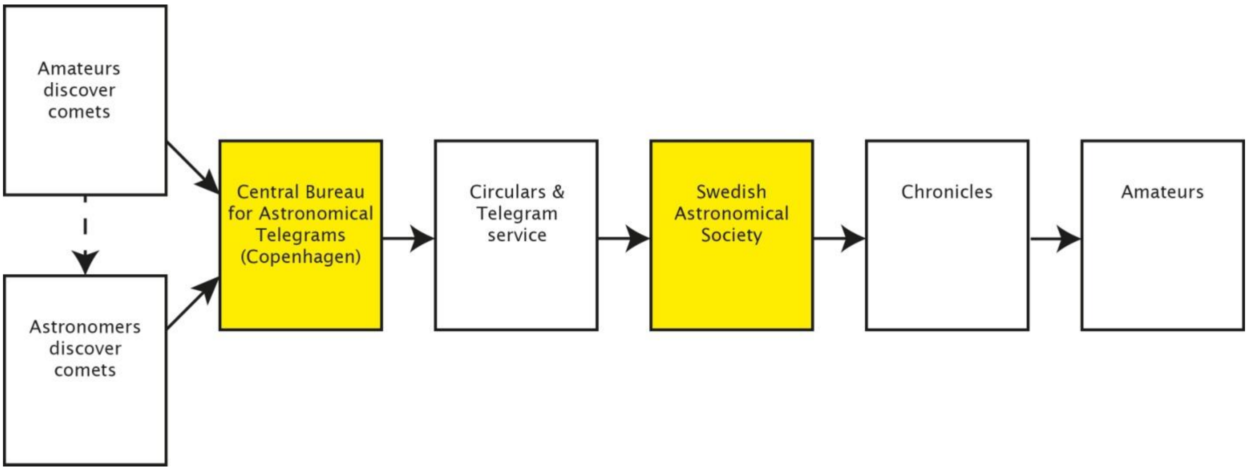

Figure 5: Circulation of comet information around 1920. The Central Bureau for Astronomical Telegrams, located in Copenhagen as of 1922, was the hub for information regarding comets. Both amateurs and professionals reported new discoveries to the Bureau, which distributed information about them to astronomers around the world by means of a news service. Astronomers at the Swedish Astronomical Society used the telegrams and circulars from the Bureau to put together the comet chronicles published in the society's journal. Up until the 1950s, this was the only organized source of comet information available to Swedish amateurs. During this period, amateurs were not encouraged to actually observe the comets, and there were no organized means for them to report.

> from the sun. It should be observable even with small telescopes. The comet will pass through the constellations of Perseus, Auriga and Gemini from July to November. (Anonymous, 1922: 80).

This announcement is typical of the information contained in the comet chronicles. The trajectory of the comet is described in very general terms, which would have been useless to anyone who may have wanted to track it. There were no finder charts or ephemerides, not even the orbital elements. The main reason for this shortcoming seems to have been that the delivery dates of the chronicles were too few and far between, given the transient nature of comets. Without access to the actual telegrams from Copenhagen, amateurs could not benefit from the information that the Central Bureau supplied.

There is no evidence that the Society debated the issue, as successive editors of the chronicles stuck to the original format. It was only in 1939 with the discovery of Comet Jurlof-Achmarof-Hassel (C/1939 H1; Figure 7), which was fairly bright, that the chronicles actively encouraged observations by amateurs. One of the reasons that this particular comet attracted the attention of astronomers was because it was independently discovered by three amateur astronomers, one of whom was the deaf-mute Norwegian Olaf Hassel (1898–1972; Figure 8; Darsenius, 1961). Another reason was because the summer issue of the *Populär Astronomisk Tidskrift* was about to be printed, and the editor managed to insert a note about the comet, which already was at magnitude three, along with instructions about how to locate it. He did not include a full ephemeris, but specified the position on 18 April, as well as the estimated daily motions in right ascension and declination for the weeks to come (Anonymous, 1939).

The extent to which amateurs actually observed Comet Jurlof-Achmarof-Hassel is not clear. There were no reliable means of providing feed-back, and the journal did not publish any reports. But Nils Tamm (1876–1957), who was then one of Sweden's most sophisticated amateurs (see Figure 9), managed to image it with the Schmidt camera at his observatory which was located on the Kvistaberg estate (Tamm and Wallenquist, 1942).

After the 1939 event, when comets appeared around the time that the journal was about to be published, the chronicles might encourage amateurs to observe them. But the Society did not set up a distribution channel better suited for the task until two decades later.

3 CIRCULARS

Until the late 1950s, amateur astronomy devel-

Figure 6: Svante Elis Strömgren (courtesy: Neils Bohr Institute, Copenhagen).

Figure 7: Comet C/1939 H1 (Jurlof-Achmarof-Hassel) imaged by Nils Tamm at the Kvistaberg Observatory (after Tamm and Wallenquist, 1942: 79).

Figure 8: Olaf Hassell (www.twu.edu/dsc/hassell.htm).

Figure 9: Nils Tamm's observatory, which housed a 13-cm (5-in) equatorially-mounted Zeiss refractor (from www.astro.uu.se/history/images/kvistaberg_tamm_obs.jpg).

oped slowly in Sweden. The number of members of the Swedish Astronomical Society (most of whom were not active amateurs) rose from 250 before World War II to 500 in 1950. In 1955 the first local amateur association—the Gothenburg Astronomical Club—was formed, soon to be followed by many others (Holmberg and Kärnfelt, n.d.). Meanwhile, the Society once again took an interest in amateur astronomy, this time successfully promoting the North American amateur telescope making movement (Holmberg and Kärnfelt, n.d.; cf. Cameron, 2010). Starting in the mid-1940s, in just a few years, they managed to raise the number of amateurs with access to telescopes to a couple of hundred. As always, these telescopes were mostly used to marvel at the Great Orion Nebula, the globular cluster in Hercules and other spectacular objects, while the handful of more sophisticated amateurs tended to focus on variable star observing. Comets still attracted little attention. Then, in the words of Professor Gunnar Larsson-Leander (b. 1918) from Lund University, in 1957 "… one of the most remarkable comets ever observed …" turned up (Larsson-Leander, 1957: 115; cf. Anonymous, 1957a). This was Comet Arend-Roland (C/1956 R1), which became famous for its remarkable anti-tail.

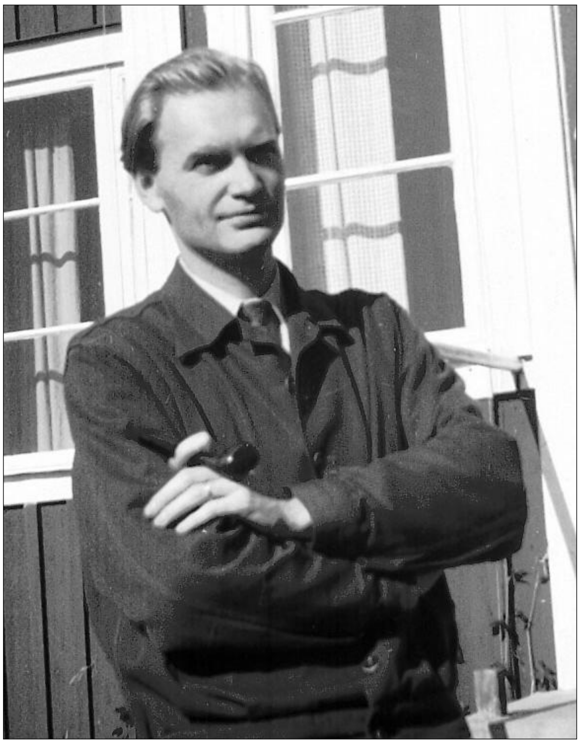

Figure 10: Rune Fogelquist (courtesy: Rune Fogelquist).

Figure 11: Comet C/1956 R1 (Arend-Roland) imaged by Rune Fogelquist on 22 April 1957 at UT 21:00-22:00. The image was acquired by means of an anastigmatic lens with a focal length of 120 mm and an aperture of 25 mm (courtesy: Rune Fogelquist).

This time the telegram from Copenhagen arrived just days after the latest issue of the journal had been circulated, and to make matters worse the comet would reach perihelion and start on its way back to the depths of space well before the next issue was due out. An obvious solution would have been to post a notice out to interested members, but Larsson-Leander, the editor of the chronicles, did nothing, and when C/1956 R1 (Arend-Roland) turned out to be one of the most memorable comets of the twentieth century his oversight became somewhat of an embarrassment to the Society.

Despite the Society's reluctance to communicate with amateurs, some of them received the information anyway. Rune Fogelquist (1924–2013; Figure 10), later to become one of the most influential amateurs, was not a member of the Swedish Society but of the Danish organisation, which posted a circular. The service, which started in the 1930s (Anonymous, 1933), informed members about all kinds of transient events, including interesting comets like Arend-Roland. As soon as Fogelquist learned of the approaching comet, he passed the news on to some of his fellow amateurs, and when the comet became visible to northern observers after its perihelion passage in mid-April 1957 they were prepared. At least four amateurs observed the comet before Swedish professional astronomers got around to it (Larsson-Leander, 1957, 117). On 22 April, Fogelquist took what would become an iconic image of the comet, showing its anti-tail (Figure 11). He reported his observations directly to the Central Bureau in Copenhagen (cited in Brahde and Brekke, 1957: 27), and a couple of months later the image was published as part of a photo collage in *Sky & Telescope* (see Anonymous, 1957b).

The Arend-Roland event made Swedish astronomers aware that amateurs could also be useful when it came to comet observations.[3] Later that spring, while the comet was still visible in the western sky, the Society decided to start its own news service. The service was announced in the summer 1957 issue of the journal: the notice stated that there "… seems to be a general desire amongst the Society's amateur astronomers to receive news about new comets, novae, especially interesting variable stars, etc., as fast as possible …" (Anonymous, 1957c: 75). As it turned out the service met a real need, and by the end of that year it had more than 150 subscribers (Elvius, 1957). A couple of years later the number had almost doubled (Malmquist, 1961).

Figure 12: Comet C/1957 P1 (Mrkos) photographed by Alan McClure on 13 August 1957 (http://stony-ridge.org/AlanMcClure.html).

The first circular, announced the approach of Comet Mrkos (C/1957 P1; Figure 12) in August 1957 (Anonymous, 1957d; cf Anonymous, 1957e), and marked the beginning of a new era in Swedish cometary astronomy (Figure 13). At

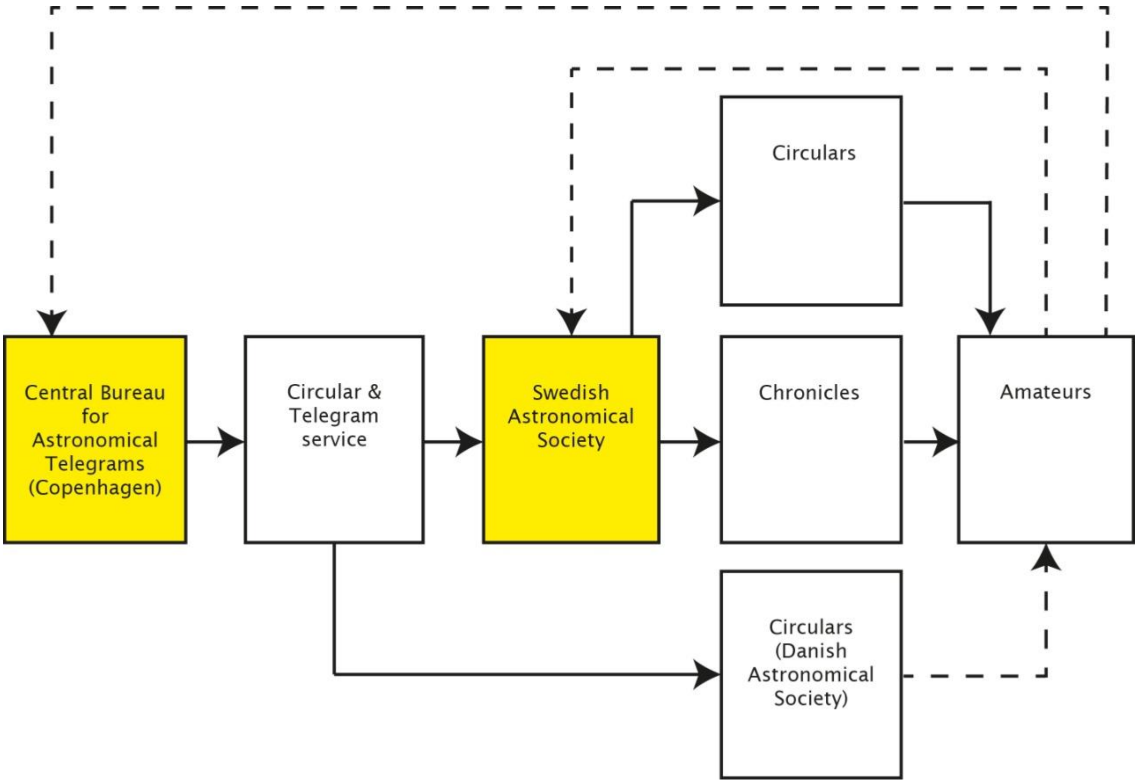

Figure 13: Circulation of comet information around 1960. The basic source of comet information was still the Central Bureau in Copenhagen, but Swedish amateurs could now access it from several different sources. The comet chronicles were still being published but did not contain the information needed to actually observe any of the comets. As of 1957, that information could be found in the Society's circular (some Swedish amateurs also subscribed to the Danish Society's circular). Even though some amateurs submitted reports, either directly to the Central Bureau, or to the Society, it was still very much a one-way street.

last amateurs had access to a rapid, reliable and affordable source of information about comets. About one-third of the circulars concerned comets, normally specifying the orbital elements and ephemeris spanning at least one full month. Meanwhile, the speed with which the information was distributed increased dramatically. Comet Mrkos is a good example. This comet was discovered by Antonín Mrkos (1918–1996) at the Skalnaté Pleso Observatory in Slovakia on the morning of 2 August 1957.[4] He immediately sent a telegram to the Central Bureau in Copenhagen, which communicated the discovery later that morning through its news service (Hendrie, 1996). The telegram reached Larsson-Leander at Saltsjöbaden Observatory the very next morning, and he sent out the first Swedish circular later that day. Allowing time for postal delivery, the information reached amateurs three or four days after the comet was discovered.

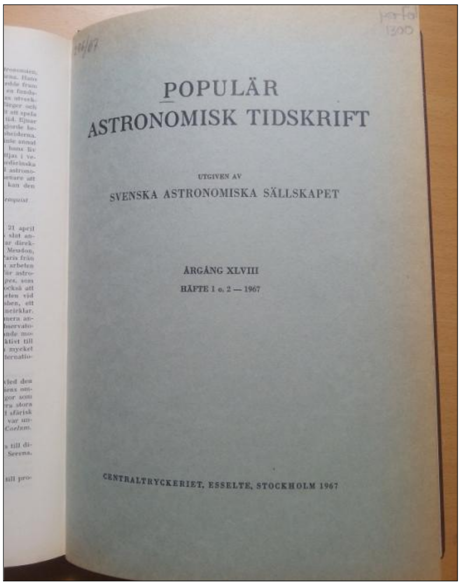

Figure 14: The 1967 issue of the *Populär Astronomisk Tidskrift*. By this time the journal had more or less abandoned amateur astronomy in order to focus on professional astronomy.

Even though amateurs suddenly had access to information that allowed them to observe new comets, they still had no organised means of reporting their observations, since the Society's approach was very much a one-way street. Thus, the comet circulars (or the chronicles for that matter) never once suggested that amateurs might submit a report. The most advanced amateurs found their own channels: Fogelquist and others reported directly to the Bureau in Copenhagen, while some wrote to Swedish astronomers, but they were exceptions.[5] The Society did not fill the gap. Then by the end of the 1960s, it appeared to have lost interest in amateur astronomy altogether (Figure 14). The news service was discontinued in 1968, and around the same time the ambitious amateur observing sections formed back in 1960 were discontinued.[6] A shift towards a more professional orientation was formalised in 1968 when the journal was restarted as a joint venture of the Danish, Norwegian and Swedish societies. To mark this transition the adjective 'Popular' was dropped from the title—henceforward it was known as *Astronomisk Tidskrift* (*Astronomical Journal*). The era of 'top-down amateur astronomy' was ending, and a new era of 'bottom up astronomy' started to develop, prompted by the specific needs of Sweden's amateur astronomers. One of the areas that would soon be reformed was cometary astronomy.

4 NETWORKS

Swedish amateur astronomy matured in the 1960s and 1970s. Associations modelled after the very successful Gothenburg Astronomical Club started in many cities and towns. They mimeographed bulletins, arranged lecture series, conducted telescope-making workshops, held congresses, organised star parties and embarked on major observation projects. The number of active amateurs now ran into the thousands.

One of the new organisations was the Malmö Astronomy and Space Exploration Society. Started in 1962 as an upper secondary school club, it quickly evolved into a dynamic amateur association with international connections. Ulf R. Johansson (b. 1945), one of its leaders, befriended Patrick (later Sir Patrick) Moore (1923–2012) and in 1969 helped him launch the International Union of Amateur Astronomers (IUAA) (Johansson and Moore, 1966; cf. Moore, 1967).[7] Besides hosting the second IUAA World Congress in Malmö in 1972 (Figure 15), Johansson and other members began collaborating with amateurs in Denmark.

Eventually this initiative led to a new multilateral amateur association when the Scandinavian Union of Amateur Astronomers (SUAA) was founded in 1973. According to the rules of procedure as published in the *Scandinavian Amateur Astronomer* (*Scanam*), the aim of the union was to act as an "… organ for communication and coordination …" among amateurs in Denmark, Finland, Iceland, Norway and Sweden, and "The most important activities of the union are to be carried out by the sections. They are to coordinate, collect, edit and forward observations and studies conducted by Scandinavian amateurs." (Anonymous, 1973a: 15). The novelty of the Union was not so much Scandinavian collaboration as the consequences of the four verbs, *coordinate*, *collect*, *edit* and *forward*. These activities manifested the spirit of the observational networks.

Most of the Union's ten sections had an observational orientation, notable exceptions being amateur telescope making and the history of

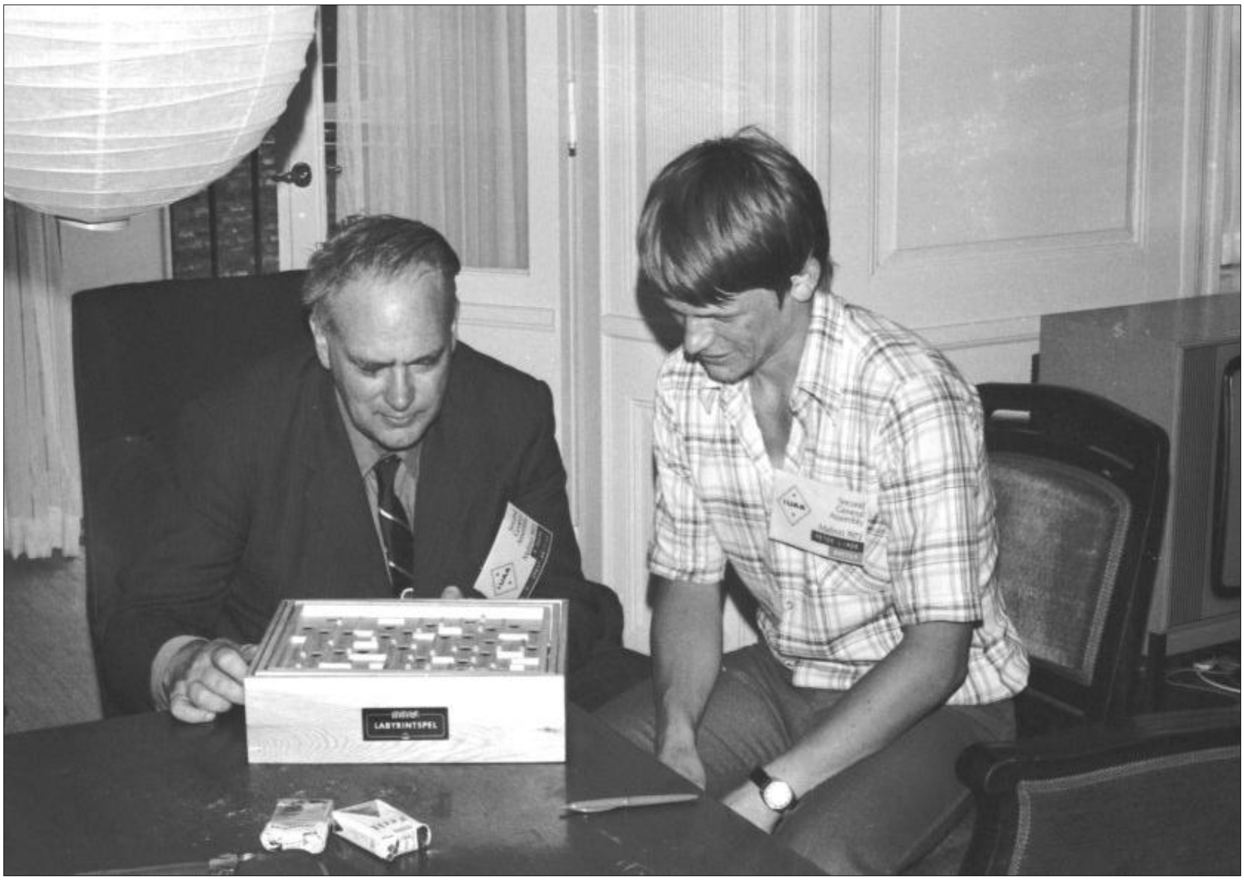

Figure 15: Patrick Moore and Peter Linde at the 1972 Congress of the International Union of Amateur Astronomers in Malmö (courtesy: Peter Linde/ASTB).

astronomy. Ideally the observing sections were organised in accordance with the rules of procedure, and their leaders were supposed to establish contact with international organisations and networks in order to access information, protocols and communication channels. Then they were to set up relevant programmes for their sections, distribute information and protocols, and encourage participation. Members were to submit reports (according to international standards) of their observations to the leaders, who would edit and forward them to the American Association of Variable Star Observers (AAVSO), American Meteor Society (AMS), Association for Lunar and Planetary Observers (ALPO) and other international clearing houses. The background and objectives of the individual section leaders had a major impact on the activities of their observational networks, and some sections were more successful than others (Holmberg and Kärnfelt, n.d.).

One of the Union's observing sections focused on comets. Founded in 1972, a year before the Union was formally started, it was first coordinated by Tor Nørretranders (b. 1955) and Michael Krogsgaard (b. 1953), who were then two young, enthusiastic but rather inexperienced Danes. The lack of experience was to some extent compensated by a thorough study of the American magazine *Sky & Telescope*, which became an important source both for inspiration and information. The journal had become available to Scandinavian amateurs in the late 1940s and from that time on played a vital role in developing the field. Nørretranders and Krogsgaard used the reports on comets in the American magazine to write similar articles for *Scanam*, and the account of their first observing project, which concerned C/1973 E1 (Kohoutek) (see Krogsgaard, 1973b), was based entirely on material taken from an article in *Sky & Telescope* (Anonymous, 1973b).

Unfortunately, these early initiatives produced few results. Members did not flock to the Comet Section, and few reports were submitted. Even Comet Kohoutek, which initially was predicted to become the 'comet of the century', failed to engage them. A few images by Scandinavian amateurs were published in the journal (Anonymous, 1974), but not a single report was dispatched to the Association of Lunar and Planetary Observers, the intended recipient. Not only did the Section have little status, but the Comet's appearance was far below expectations. On top of this, a huge low pressure area covered most of Scandinavia during the weeks after perihelion, making observations difficult or impossible.

In 1976 the Comet Section was reactivated under the auspices of Karl Gustav Andersson (b.

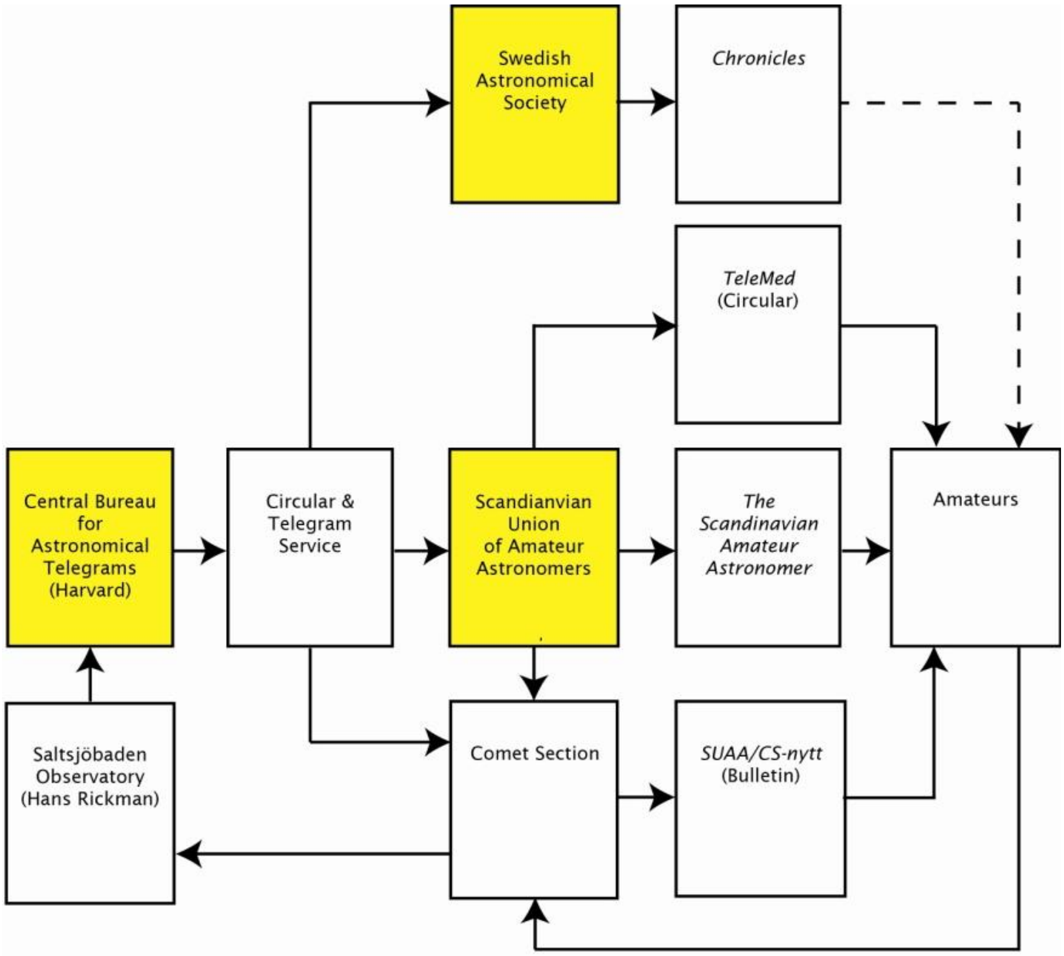

Figure 16: Circulation of comet information around 1975. With the foundation of the Scandinavian Union of Amateur Astronomers in 1972, a more complex pattern of communication emerged. The Central Bureau was still the basic source of information, but now the Union, or rather its Comet Section, acted as a go-between. Both the quality and the quantity of information reaching the amateurs increased. The Section also managed to create the first hierarchical observation network, for which amateur reports were collected by the Section leader and submitted to Dr Hans Rickman at the Saltsjöbaden Observatory, who later resubmitted them to the Central Bureau. Still the level of activity was low, and only occasional reports were sent off to Dr Rickman. The Society still published its 'Comet Chronicles', but ceded its previous role in practice.

1950), and he established the first proper observational network for comets. He contacted Dr Hans Rickman (b. 1949), a cometary expert from the Saltsjöbaden Observatory, who promised to act as a go-between, forwarding comet reports to Brian Marsden at the Central Bureau for Astronomical Telegrams, which was relocated to Harvard College Observatory in 1965. Andersson also arranged for the Section to subscribe to comet circulars from the Bureau (Andersson and Jürisoo, 1975). Thus the landscape of comet information changed significantly.

The Swedish Astronomical Society was still publishing its comet chronicles in the 1970s but had essentially ceded its previous role. Amateurs relied on their own channels for accessing cometary information (Figure 16), and the circulars from the Bureau were edited and distributed directly to the 100 members of the Comet Section. In addition, the Union's *TeleMed*, a general newsletter launched in 1974 (Krogsgaard, 1973a) and aimed at all members, included a good deal of information about comets. Eventually the Comet Section started its own bulletin under the name *SUUA/CS-Nytt*, and Swedish amateurs now had easy and reliable access to the information they needed in order to pursue cometary astronomy. They were encouraged not only to observe, but also to submit reports to the Section. After being edited by Andersson, the reports were forwarded to the Central Bureau in the United States with Rickman's assistance. Finally, the information channels of Swedish cometary astronomy had come full circle.

5 INTERNET

Despite ten successful years, the Scandinavian Union of Amateur Astronomers did not last. Mainly because of language issues, the Finns started to leave the organisation. As a consequence, the Union more or less came into the hands of Swedish amateurs, who from the start had comprised the largest national population group in the association. Eventually it was decided to disband the Union, and to carry on the activities on a national basis (Minutes …, 1982). The Swedish Amateur Astronomical Society was founded in 1982, the surviving Sections were restarted, and *Astro*, a new journal, was launched. The new Society and its Comet Section marked the last chapter in this story, and the dawn of the digital era.

In 1988, Anders Lindquist (b. 1953), an amateur astronomer and professional computer technician, set up a Bulletin Board System on a spare computer and invited amateurs to start using it (Lindquist, 2012). The system required that users had access to a computer and modem, which was not very common in the late 1980s. Nevertheless, it was a success among a small group of advanced amateurs, who immediately realised its potential. In just a few years, Astrobase (*Astrobasen*) became the hub for all kinds of information about amateur astronomy, not the least about comets, linking practitioners and their clubs with international networks (Danielsson, 1989).[8]

One of the amateurs who made good use of the new information technology was Jörgen Danielsson (b. 1947; Figure 17), for several years the leader of the new Comet Section. Danielsson (1996) had become interested in comets during the 1986 appearance of 1P/Halley, and he evolved into an enthusiastic, skilled observer. He was also among the few amateurs who realized the potential of the new 'information highways', and under his supervision the Comet Section more or less moved to Astrobase.

During the era of the Scandinavian Union, the basis for the activities of the Comet Section had been the dispatches from the Central Bureau of Astronomical Telegrams. Judging by the many posts in Astrobase's 'comet meeting', the sources had now multiplied (Figure 18). Starting in the 1990s, the circulars from the Bureau were down-

Figure 17: Jörgen Danielsson (after Danielsson, 1984).

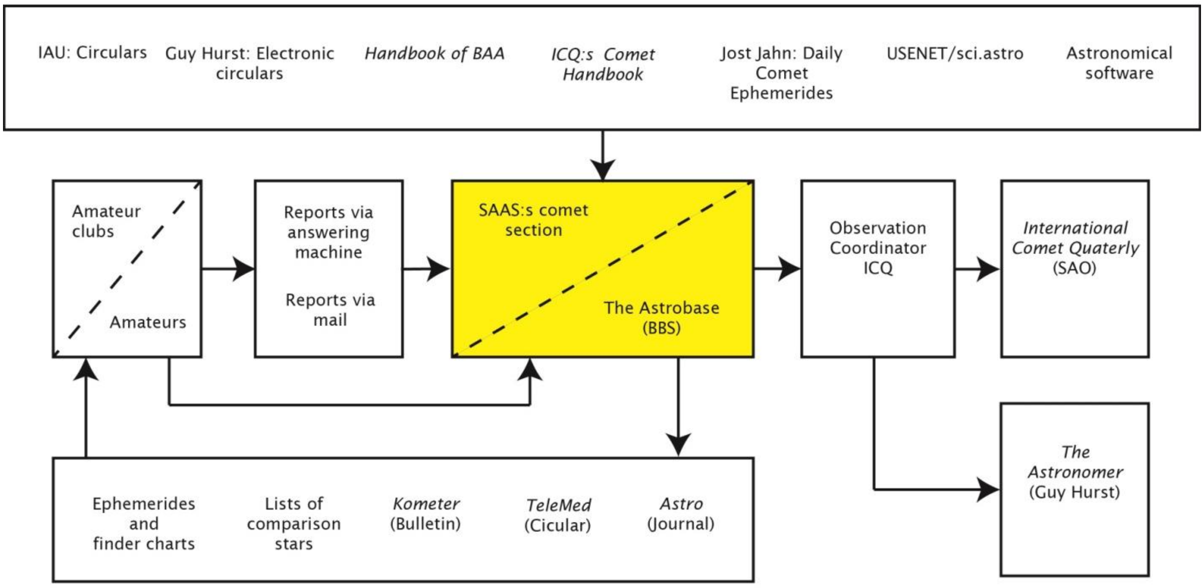

Figure 18: Circulation of comet information around 1990. With the launch of Astrobase, a Bulletin Board System, communicative patterns changed dramatically. The Swedish Amateur Astronomical Society's Comet Section, to a large extent administered inside the Astrobase, utilised a variety of sources for comet information, including electronic circulars from the Central Bureau of Astronomical Telegrams and *The Astronomer*. Together with other sources, they were used to put together information distributed by various channels directly to the amateurs or to their local clubs. With the assistance of the information, amateurs could observe comets and submit reports. The reports were either submitted directly to Astrobase via an answering service or by filling out a special form and sending it to the Section leader. Later the reports were edited and submitted to the *International Comet Quarterly* and to *The Astronomer*.

loaded to Astrobase in digital format. They were supplemented by the *Electronic Circulars* produced by Guy Hurst, editor of the British amateur journal *The Astronomer*. In addition, the Section frequently used information from the annual handbooks of the British Astronomical Association and from the editors of the newly-launched *International Comet Quarterly* (ICQ). While these four sources became the basic building blocks of the new information structure, they were accompanied by a variety of others. Discussions in various USENET groups, especially *sci.astro*, trickled down to Astrobase. The Section also relied on efforts of amateurs in other countries. Starting in 1991, they downloaded the daily ephemerides produced by German comet enthusiast Jost Jahn (Danielsson, 1991a). The introduction of astronomy software like *Megastar* (Willmann-Bell), *Superstar* (Pico Science) and *Dance of the Planets* (ARC Software) also

Figure 19: The naked eye appearance of Comet C/1996 B2 Hyakutake as sketched by Hans-Göran Lindberg early in the morning on 3 March 1996 (courtesy: Hans-Göran Lindberg).

had an impact, allowing Swedish amateurs to generate their own finder charts, ephemerides, lists of comparison stars and predictions of comet light curves (Bengtsson, 1994).

In the mid-1990s, the wealth of information in Astrobase was still for the chosen few. It needed to be made available to the majority of amateurs. As a result, Jörgen Danielsson and his successors published *Kometer*, a mimeographed monthly that described Section activities, distributed protocols for observations and reports, and announced approaching comets by means of ephemerides, finder charts, etc. The bulletin had about 80 subscribers (Anonymous, 1991). Some of the material was also published in the Swedish Amateur Astronomical Society journal *Astro*, thereby reaching practitioners who were not members of the Comet Section. Much of the information in Astrobase was recirculated in the bulletins of many local amateur clubs. There were also sources not under the control of the Section, especially magazines like *Astronomy* and *Sky & Telescope* that had become popular with Swedish amateurs.[9]

Due to the plethora of channels, amateurs now had access to an abundance of information about comets. Many of them were content to track a particular comet, especially if it was among the brighter ones, but more scientifically-minded amateurs also needed channels through which they could submit reports. Several such channels were available. The easiest way for those who could log in to Astrobase was to file the report directly to the comet meeting. Others could either phone in a report to an answering service, which would transcribe it to Astrobase or fill out a special form and post it to the Section (Danielsson, 1990; 1991b). Later, all the reports were compiled by the Section leader and forwarded to *The Astronomer*, and to the *International Comet Quarterly* (which from 1990 was the global clearing house for cometary observations).

The information infrastructure needed for serious cometary astronomy was in place by the early 1990s. Swedish amateur astronomers had strong links with international networks of comet observers and thereby with some professional astronomers who conducted research on comets. That did not change the fact that Swedish amateur astronomy still was a rather small enterprise. The number of amateurs who actually submitted reports was even smaller. In 1991, for example, the Section forwarded a total of 57 observations to the *International Comet Quarterly,* which were supplied by just nine amateurs. Half of the reports concerned the rather unassuming Comet 4P/Faye, which peaked at magnitude 9 (Schlyter, 1992). The next year's results were similar: in total 60 observations were submitted by seven observers; half of the observations concerned Comet 109P/Swift-Tuttle (Danielsson, 1992; Schlyter, 1993). A few years later, Comet Hale-Bopp (C/1995 O1) became one of the most observed comets of the 1990s, generating close to 150 reports submitted by ten observers.[10] It was followed soon after by Comet Hyakutake (C/1996 B2). Needless to say, many amateurs simply enjoyed making naked eye (see Figure 19) or telescopic observations of these comets without feeling the need to formally report their observations.

6 DISCUSSION AND CONCLUDING REMARKS

Swedish amateur cometary astronomy arguably was born in August 1957 when the Swedish Astronomical Society distributed its first circular.

Two decades later, fully-operational observational networks emerged, enabling amateurs to join forces with their counterparts in other countries as a means of promoting astronomical research. The relationship between Swedish amateurs and professionals was transformed in the process. While the Society was still in charge of comet information, a handful of astronomers acted as rather strict 'gatekeepers'. The information circulated in the comet chronicles was fairly useless, at least for someone who wanted to make observations. With the advent of the circulars later on, the Society encouraged amateurs to observe comets. Not until amateurs themselves started to organize the flow of information, however, did the situation really improve. They essentially sidestepped Swedish professionals and hooked up directly with international organisations. New 'gatekeepers' emerged, and starting in the 1970s, the Section leaders controlled the flow of information.

There was also an increase in the frequency of information delivery. The comet chronicles of the 1920s had two delivery dates per year; while the circulars of the 1950s and 1960s had about ten. The Comet Sections of the 1970s and 1980s upped the pace, and Astrobase in the early 1990s generated daily or hourly posts. But changing patterns of communications also impacted on the speed of information. A major breakthrough in this respect was the Society's circular, which reduced the amount of time it took for amateurs to find out about the discovery of a new comet from several months to about one week. Then hooking up with international networks through Astrobase accelerated the process further.

Cometary astronomy is but one of many branches of amateur astronomy that is very dependent upon information. Another striking example is variable star observing, which hinges on infrastructure maintained by organisations such as the American Association of Variable Star Observers, the Association Française des Observateurs d'Etoiles Variables (AFOEV) and Variable Stars South (operated by the Royal Astronomical Society of New Zealand, and the international clearing house for observations of variable stars in the southern sky). This is also true to a lesser degree of planetary, solar and deep sky observing.[11] Thus one important driving force for the development of amateur astronomy, regardless of context, has always been its information infrastructure. In the case of Swedish cometary astronomy, a number of technologies were used in the service of the amateurs—printed journals, telegrams, circulars, mimeographed bulletins, answering machines, computers, software, BBS systems and the Internet—enabling more sophisticated activities, and links to international networks.

The history of amateur astronomy obviously needs to focus on the evolution of organisational structures, not just on telescopes and other instrumentation, and on observational efforts. As previous research has shown, clubs, societies, sections and the like have played a vital role in promoting astronomy, recruiting and organising new generations of amateurs, and negotiating the relationship between amateurs and professionals (e.g. see Lankford, 1981; Chapman, 1998; Orchiston, 1988; 1989; 1998a; Orchiston and Bhathal, 1991; Rothenberg, 1981; Williams, 2000). Moreover, such a history also needs to pay attention to instrumental developments. Recent research has demonstrated that new technologies and manufacturing techniques were fundamental in facilitating amateur astronomy well into the twentieth century (Cameron, 2010). History, as I have tried to show in this paper, also needs to address changing communicative practices. Particularly in an observational context, access to relevant information (or lack thereof) largely determines what amateurs can or cannot accomplish.

7 NOTES

1. All quotes from primary sources have been translated into English by the author.
2. Obviously access to, and the speed and reliability of, information infrastructure comes to the forefront when discoveries of new comets are made (e.g. see Orchiston, 1997), but since Swedish amateurs have not been very successful in comet hunting I will not discuss this matter further (see Note 4 below). A case in point, though, is discussed by Wayne Orchiston in a research paper about early twentieth century Australian and New Zealand cometary astronomy. He shows that drawbacks in communicative structures became a major source of tension between amateurs and professionals with respect to reporting on newly-discovered comets (Orchiston, 1999b). In addition to this research paper, Orchiston has written extensively on the history of amateur cometary astronomy (including Orchiston, 1982; 1983; 1993; 1998b; 1999a; and 2003).
3. Three years later, Gunnar Larsson-Leander (1960) published an research paper on the physics of the anti-tail and Fogelquist's observations represent part of his empirical material.
4. Mrkos is so far the only comet discovered by a Swedish amateur. Georg Hugo Neumann at the Institute for Meteorology in Stockholm discovered it independently the day after Mrkos, but unfortunately, his report did not reach relevant parties in time to be considered when naming the comet (Lodén, 1957: 143).

5. One of these exceptions was Erik Alexandersson who submitted several observations to the Society. Five of them concerned Comet Burnham (C/1959 K1) and six concerned Comet Seki-Lines (C/1962 C1) (Alexandersson, 1960; Alexandersson, 1962). Astronomer mer Per-Olof Lindblad replied positively, but apparently did not forward the observations (Lindblad, 1960; Lindblad, 1962).
6. After a couple of years the circulars appeared at increasingly long intervals. They still had many subscribers, so the reason seems to have been of an organisational nature. A total of 30 circulars was distributed between 1957 and 1968. The amateur sections mentioned were launched in 1960. There were sections for the Sun, Moon, meteors, artificial satellites, Aurora Borealis, variable stars, astrophotography, mirror grinding and telescope construction, as well as a Junior Section, but not for comets. The development of the sections follows a similar pattern as the circulars: they were quite active the first year but eventually the organization fell apart and their activities basically ceased.
7. Although the Union initially managed to attract amateurs from around the world, for a number of reasons it failed to prosper. It never officially closed down and traces of it could still be found on the Internet until recently. However, its website is no longer active.
8. With the development of the web and html-based forum engines, Astrobase became obsolete. After several years of inactivity, the system was permanently discontinued in 2006. Astrobase has been preserved in its entirety, and the author has a complete digital copy. The database consists of about 9,000 posts from 1988 to 2001. The posts are organised in different meetings or sub-forums, one of the largest of which is the comet meeting. During its first year, Astrobase had about 20 active members who logged in 2,000 times (Danielsson, 1989).
9. How many Swedish subscribers these journals had is not clear, but according to an article in *Astro* in 1995, about 200 single copies of *Astronomy* and 150 of *Sky & Telescope* were sold every month (Nilsson, 1995).
10. Numbers obtained by counting the many reports posted in Astrobase. See for example Warell (1997).
11. Except for beginners, any amateur can readily point out the brighter planets, but they might need finder charts or ephemerides for the fainter ones like Uranus and Neptune. Obviously you do not need access to specialised information to find the Sun, but you need channels for submitting reports if you are counting sunspots. A case can also be made for deep sky observing. The number of visible galaxies, nebulae and clusters is determined by the aperture of your telescope, your visual accuity and the quality of the local sky, as well as the objects that happen to be plotted on the star charts that you use.

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THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 3: ELLIS, REBER AND THE CAMBRIDGE FIELD STATION NEAR HOBART

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Abstract: Low frequency radio astronomy in Tasmania began with the arrival of Grote Reber to the State in 1954.[1] After analysing ionospheric data from around the world, he concluded that Tasmania would be a very suitable place to carry out low frequency observations. Communications with Graeme Ellis in Tasmania, who had spent several years studying the ionosphere, led to a collaboration between the two in 1955 during which year they made observations at Cambridge, near Hobart. Their observations took place at four frequencies between 2.13 MHz and 0.52 MHz inclusive, with the results at the higher frequencies revealing a clear celestial component.

Keywords: Australian low frequency radio astronomy, Tasmania, Grote Reber, Graeme Ellis, Cambridge.

1 INTRODUCTION

The science of what would later be termed radio astronomy began in 1931 with the discovery by the American physicist Karl Jansky (1905–1950) of radio-frequency radiation of celestial origin. Grote Reber (1911–2002) followed this up, and in 1937 he constructed the world's first dedicated radio telescope at Wheaton (Illinois, USA) and used it to create a 160 MHz map of the sky (Reber, 1940; 1944).

After WWII, Reber maintained a strong interest in this field of research, and was aware of the important work being performed in Australia, in and near Sydney by staff from the CSIR's Division of Radiophysics (Orchiston and Slee, 2005; Robertson, 1992; Sullivan 2009). By the early 1950s Reber was working atop Mount Haleakala in Hawaii, attempting to observe discrete sources using a sea interferometer (see Reber, 1959). His inspiration came mainly from the pioneering work carried out at Dover Heights in Sydney and sites near Auckland, New Zealand, by John Gatenby Bolton (1922–1993; Robertson, 2015), Gordon John Stanley (1921–2001); Kellermann et al., 2005) and Owen Bruce Slee (b. 1924; Orchiston, 2004; 2005b). Their research revealed that the concept of 'radio stars' was a misnomer, and that these discrete sources were associated either with prominent optical objects in our own Galaxy (such as the remnant of SN 1054) or with anomalous extragalactic objects (see Bolton et al., 1949; Robertson et al., 2014).

Reber's interest turned increasingly to low frequency radio astronomy (Reber, 1977), but he was well aware that the ionosphere imposed a lower limit, albeit a variable one, on the frequencies that could be observed. He therefore collected ionospheric data from many locations around the world, which made it clear to him that

> The lowest electron density was found to be near the minimum [of] solar activity, during winter at night between latitudes 40° and 50°, near the agonic line where [the] compass points true north. (ibid.).

Tasmania (Figure 1), therefore, offered excellent prospects for making low frequency observations of celestial sources. Although similar conditions existed in the USA and Canada in the region of the Great Lakes, the fact that the Galactic Centre was at a southerly declination clearly was appealing to Reber (ibid.). As early as 1949 he had indicated that he was interested in making observations in the Southern Hemisphere (Reber, 1949), and the fact that the best observing conditions occurred during winter would have been an additional factor in selecting Tasmania rather than the USA-Canada region as Tasmanian winters, even at sites well inland, were far less severe.

In Tasmania, the seeds of a potential future

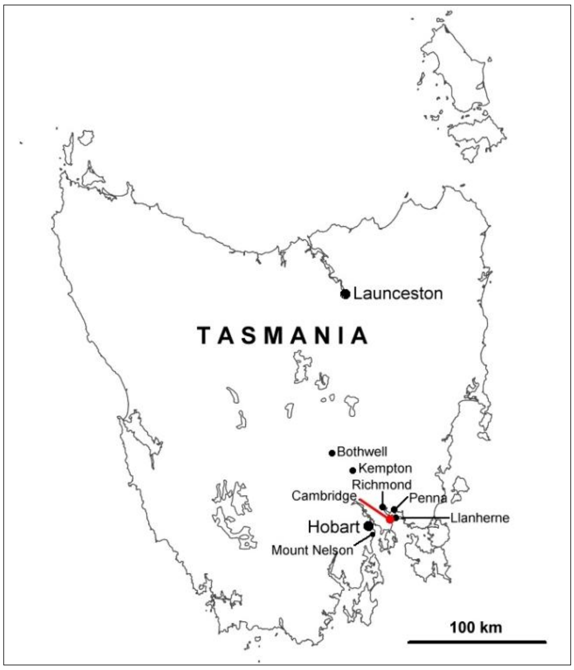

Figure 1: The Australian island State of Tasmania, showing the two largest cities (Hobart and Launceston) and important radio astronomy sites.

in radio astronomy were already being sown. By about 1952, Gordon Newstead (1917–1987), then a Senior Lecturer in Electrical Engineering at the University of Tasmania, had succeeded in making observations at about 90 MHz from a site on Mount Nelson, near Hobart (Ellis, 1954a; Haynes et al., 1996), and Graeme Ellis (1921–2011) was performing important ionospheric research as an officer of the Ionospheric Prediction Service (IPS) and at the same time working toward a Ph.D. Ellis' collaboration with George T. Goldstone (1925−2012) from the IPS was of major importance in ionospheric studies in Tasmania; indeed, Susan Ellis (pers. comm., 2007) recalled that Goldstone

> … assisted him [Ellis] during his Ph.D. work, and was at the Physics Department all those years and even after they both retired, Dad and George used to go to The Lea [a later IPS station].

Reber (1954a) was prompted to contact Ellis after reading Ellis' (1953) research paper on 'Z echoes', and during the first half of 1954 they exchanged several letters. It seems that the first suggestion of a cooperative effort in Tasmania came in a letter by Reber (1954b) in which he discussed the conditions in which 'cosmic static' of exceptionally low frequency would easily pass through the ionosphere via an ionospheric Z hole. Clearly, was aware that at frequencies of around 1 MHz or even lower, the best chance was to observe through such a hole. He concluded that the declination from which the radiation would most easily reach observers on the ground was equal to the latitude of the observer plus the dip of the Earth's magnetic field less 90°. For Hobart (latitude S 43°, dip angle 72°), this is equal to 25°—that is, a declination of –25°. This was close to the declination of the Galactic Centre (–28° 55′ in 1950.0 coordinates). Reber (1954c) described this as a 'Z hole experiment', referring to the mode by which this radiation would reach the ground,[2] in addition to offering the opinion that observations at 2 to 2.5 MHz would be possible in general when f0F2[3] was sufficiently low. Reber then made a clear request to Ellis:

> If the circumstances look auspicious, I will be interested in making some arrangement with the University of Tasmania to conduct experiments for measuring Cosmic Static from the galactic center at frequencies in the range 0.5 to 1.5 megacycle. My sponsor, the Research Corporation, will cover the expenses of the proposed tests.

Ellis' reply (1954a) was very welcoming and positive. Reber made further detailed enquiries to Ellis about the scientific equipment that was then


Figure 2: The Ionospheric Prediction Service building on Mount Nelson, erected in 1954 (after *The Mercury*).

available at the IPS field station, and conditions at the site.

This amicable correspondence between Reber and Ellis, and Reber's acceptance of the suitability of making observations from Tasmania, led him to decide to spend a period of time in the island State from late 1954. During his initial correspondence with Ellis (which began in January 1954) and up until the time he travelled to Tasmania, Reber was living in Hawaii.

Although the IPS field station had recently been transferred to Mount Nelson (Figure 2),[4] the site to which Ellis referred in his correspondence with Reber was the original one at Cambridge, close to Hobart Airport.[5] Further details of the site, and the observations made by Reber and Ellis, are discussed below in Sections 3 and 4.

2 BIOGRAPHICAL NOTES

2.1 Grote Reber

Grote Reber (Figure 3) was born in Chicago, USA, on 22 December 1911. At an early age he developed a great interest in radio and obtained his amateur radio licence, W9GFZ, at the tender age of 16 (Kellermann, 2005). He also showed an aptitude for mechanics, as evidenced by a note written at the age of 13 giving instructions to his father as to how to repair his bicycle. He graduated from the Armour (now Illinois) Institute of Technology in 1933 with a degree in electrical engineering.

Reber took a great interest in the work of Karl Jansky, who in the early 1930s was employed by the Bell Telephone Laboratories to investigate radio interference in transatlantic telephone links. In the process he serendipitously discovered radio emission from our Galaxy (see Sullivan, 1983; 1984b).

There was very little progress in this field in the 1930s and Reber decided to investigate the phenomenon further (Sullivan, 1984b). To this end, in 1937 he constructed the world's first purpose-built radio telescope. It was built with his own funds adjacent to his home in Wheaton, Illinois, just west of Chicago, and it was of the now-familiar paraboloid 'dish' design. It was such an unusual object that local residents would walk along different streets in order to avoid getting too close to it.[6]

Reber (1940; 1944) used his radio telescope, which had a diameter of 9.75 metres (32 feet), to map galactic emission at a frequency of 160 MHz—a wavelength of 1.9 metres. This was the first detailed radio map of the sky. It showed the Milky Way, and revealed for the first time the presence of the Galactic Centre in Sagittarius, and the radio source which later became known as Cassiopeia A.

Reber maintained his interest in radio emission from celestial sources and he published several papers on the subject in the 1940s. For example, in September 1943 he succeeded in detecting radio emission from the Sun (Reber, 1944), which was first identified by the British radar researcher, James Stanley Hey (1909–2000), in 1942 but made public only after the war (see Hey, 1946).

After leaving Wheaton in early 1948, Reber (1983) worked for a while at the National Bureau of Standards in Washington, before moving to Hawaii and conducting radio astronomy experiments from the summit of Mount Haleakala, on the island of Maui. Then in 1954 he moved to Tasmania, and began to observe at lower frequencies. Although he returned to the USA on many occasions, he effectively made Tasmania his home for the second half of his life. Accordingly, in 1982 he wrote:

Figure 3: Grote Reber in 1957 (courtesy: George Swenson).

> During the past quarter century I have greatly enjoyed Tasmania, and its mild climate. I've travelled around the state, engaged in projects in botany, archaeology and cosmic rays. The natives have been very friendly. (Reber, 1982).

Reber involved himself in many other scientific pursuits. Among his activities, he built an energy-efficient house in Bothwell; he was fascinated by plants, in particular the direction in which beans entwined themselves around poles; and he was particularly keen on studying energy-efficient transport, being very proud of his electric car, which he called *Pixie*.

Reber was well known for his independent thoughts and activities, and he held controversial views on various topics, including his opposition to the widely-accepted Big Bang Theory.

He was awarded a number of prizes, including the Astronomical Society of the Pacific's 1962 Bruce Medal, and an honorary D.Sc. from Ohio State University in the USA.

Grote Reber died in Tasmania on 20 December 2002, two days before his 91st birthday.

2.2 Graeme Ellis

Graeme Reade Anthony Ellis (Figure 4) was born in Launceston, Tasmania, on 20 December 1921. During his early childhood he came to be called 'Bill' by his sister, and the name stayed with him for the rest of his life (Susan Ellis, pers. comm. 2007).

Ellis took a great interest in science from an early age, experimenting with gunpowder and flying model aeroplanes (McCulloch and Delbourgo, 2013). During WWII he enlisted in the army, but not long after joined the Royal Australian Air Force, following which went to England and served as a navigator with the Royal Air Force.

Figure 4: Graeme Ellis at the Ionospheric Prediction Service Station on Mount Nelson, near Hobart, in 1954 (courtesy: *The Mercury*).

After the war, Ellis returned to Tasmania and enrolled at the University of Tasmania, completing a B.Sc. with First Class Honours in 1949. While working as a Senior Officer with the Ionospheric Prediction Service, he worked on his Ph.D., submitting his thesis in 1955. His work with Grote Reber, in 1955, began a long-term interest in low frequency radio astronomy.

After a brief period in Queensland and then New South Wales, Ellis returned to Hobart in 1960 to take up the Chair of Physics at the University of Tasmania. His great interest in radio astronomy led to significant developments in the field in the ensuing years, with many installations in the Hobart area and several of his honours and Ph.D. students excelling in the subject. These aspects will be discussed in later papers in this series.

Ellis also maintained a keen interest in the properties of the ionosphere—a subject closely aligned to low frequency radio astronomy because of the ionosphere's poor transmission of low-frequency radiation. Indeed, in his physics lectures at the University, he would often include a mention of the subject, which was an important part of the courses on "Electrodynamics" and "Advanced Electrodynamcs" that he taught third-year and fourth-year physics students.

As well as being an eminent physicist, Ellis was a very practical person who liked to ensure that equipment was working efficiently and without undue fuss. His aim was to obtain results quickly and perform a rigorous analysis.

Ellis was a driving force behind radio astronomy in Tasmania, making important contributions especially to ionospheric physics, low frequency Galactic radio astronomy, and the study of Jovian decametric radio emission. He continued his work well beyond his official retirement in 1982. He was also supportive of amateur astronomy, serving as Patron of the Astronomical Society of Tasmania from 1960 for two decades. He attended many meetings of the Society, and presented talks on his research work and occasionally on other topics. The latter included the search for intelligent life in the Universe, which was of special interest to him.

In 1963 Ellis was awarded the Thomas Ranken Lyle Medal by the Australian Academy of Science, and elected a Fellow of the Academy in 1965. In 1984 he was honoured when made an Officer of the Order of Australia (OA).

3 INSTRUMENTATION

The installation at Cambridge used by Reber and Ellis in 1955 was at the former IPS station, which was relocated to Mount Nelson in 1954. In reference to the Cambridge site, in March 1954 Ellis informed Reber:

> Should you wish to make your measurements here, I shall be pleased to assist all I can. I have available a 10 acre site about 11 miles from Hobart. There is a 10′ × 10′ building with power and telephone, and some aerials, including a full wave 2.2Mc/s Berkner dipole.[7] The site is not at present being used and was originally established for the P′f recorder[8] which is now situated nearer Hobart. (Ellis, 1954a).

In addition, Ellis (1954b) wrote to Reber:

> The site is about 650′ square and is oriented N.E-S.W. It is flat and the land slopes gently upwards S.W of it, ending in a row of hills a couple of miles away.

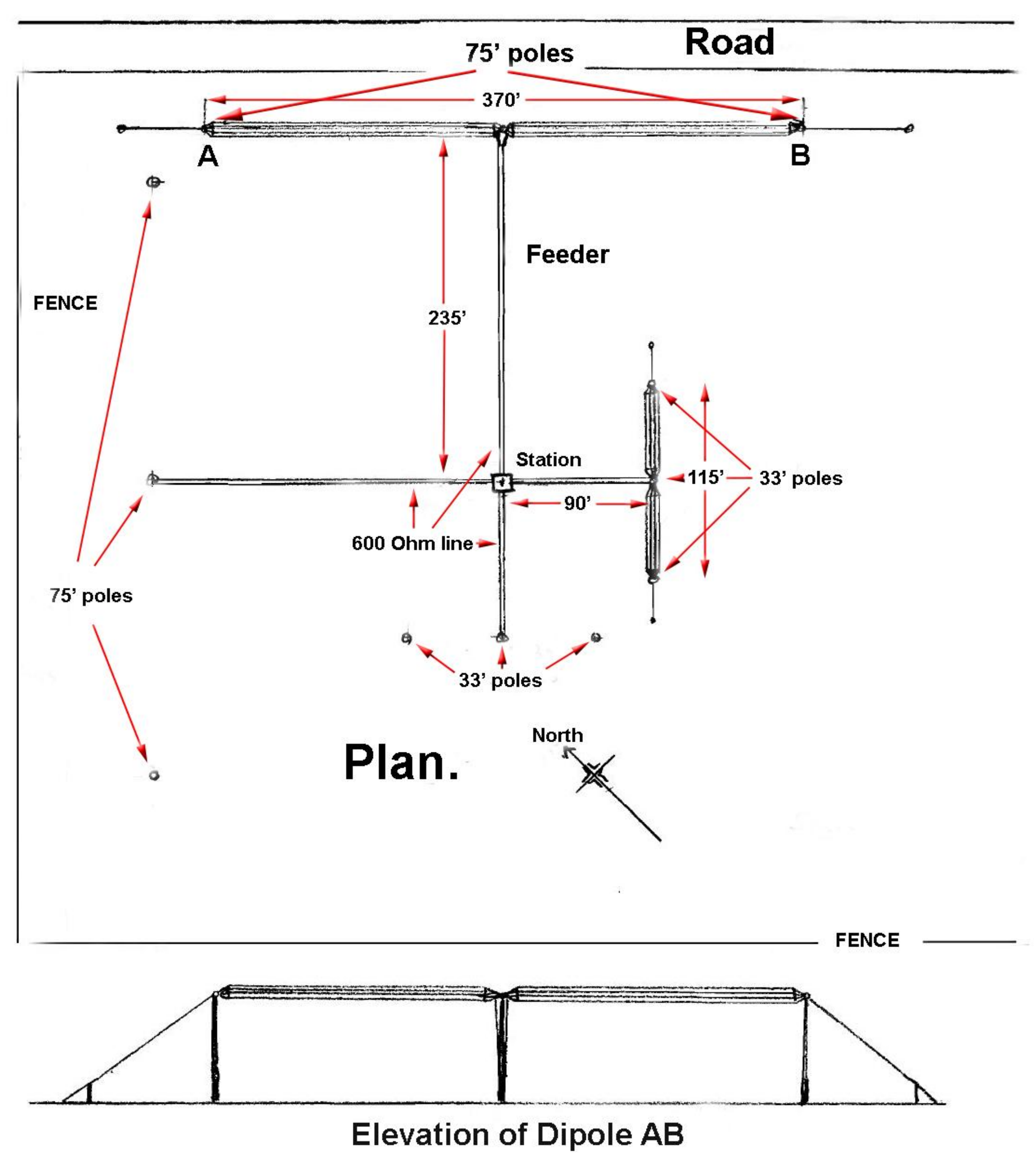

Figure 5: A plan (top) of the Cambridge site as at mid-1954, and an elevation drawing (bottom) of the 374-foot dipole (adapted from a diagram in Ellis, 1954c).

From an interview with Dr Geoff Fenton (pers. comm., 2008) in combination with a diagram (see Figure 5) in Ellis (1954c) and the only known surviving image of the site—an aerial photograph taken in 1957 (Figures 6a, 6b)—one of us (MG) has identified the location of the Cambridge site as being at longitude 147° 28.6′ E and latitude 42° 50.7′ S, adjacent to what is now known as Acton Road. MG visited the site on 21 September 2013 and noted, as expected, that the area has been subdivided into modern blocks of land that contained post-1950s houses. No trace could be seen, or imagined, of the 1955 setup.

Reber was pleased with the proposed site and that some equipment remained there, but he brought some of his own to supplement what was available. His letters to Ellis during 1954 made this intentions clear, but his arrival in Sydney on 1 November 1954 (after leaving Honolulu 17 October) was far from satisfactory:

> Eventually I arrived in Sydney on 1st November, 1954 aboard the *"Orion"* with ten cases of electronic apparatus in the hold. The wharfies promptly struck. Only passengers and personal baggage were unloaded by the crew and the *"Orion"* left for New Caledonia with my cases. I reached Hobart toward the end of November and my cases followed in a few weeks. (Reber, 1982).

Figure 6a: The Cambridge field station (centre), photographed on 27 May 1957 (two years after the 1955 observations discussed in this paper). The relatively new Hobart Airport (Llanherne) is at the extreme upper left. The photograph was found amongst Reber's collection and was probably taken by Reber himself (courtesy: Archives, National Radio Astronomy Observatory/Associated Universities, Inc.).

Reber's enthusiasm for the observations and his clear intention to make the most of his visit to Tasmania were evident in his questions to Ellis about the local conditions (Reber, 1954c), as he was naturally keen—because of the low frequencies at which he and Ellis would be observing—to understand the likely level of artificial radio interference. He also enquired as to the possibility of extending the aerials onto adjacent land. Ellis' reply (1954b) included maps, and a comment that adjacent land to the south and west could indeed be used if necessary.

To record their observations, Reber and Ellis (1956) made use of a cathode ray indicator.[9] The indicator was photographed with a film moving at a rate of 1.5 inches (3.8 cm) per hour. At such low frequencies, this was far preferable to using a pen recorder. The advantage of the cathode ray indicator method was that its smaller time constant resolved the appearance of atmospherics[10] so that the background celestial signal could be isolated.

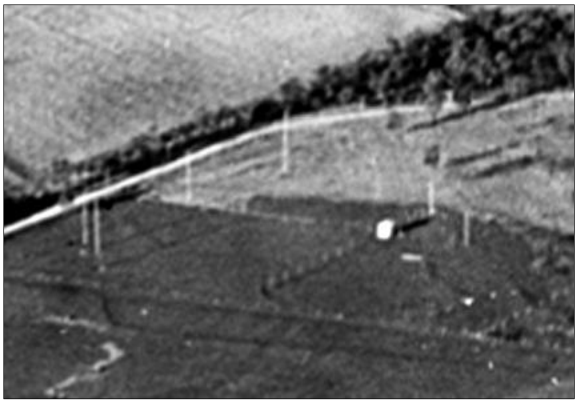

Figure 6b: A close-up of the central region of Figure 6a, enhanced to show the remaining artefacts on the site. North is to the left. The position of the white shed in relation to several poles clearly matches the diagram by Ellis (cf. Figure 5).

4 THE OBSERVATIONS: RADIO ASTRONOMY AT CAMBRIDGE IN 1955

Because Reber had arrived in Australia in the lead-up to the summer of 1954–1955, he and Ellis decided to wait until mid-March 1955 to commence their observations (Reber, 1982). This was, of course, because of the well-understood advantage of observing during winter when the conditions for low-frequency radio astronomy would be best. However, although there are no detailed records of their activities between November 1954 and March 1955, Reber and Ellis would in any case have needed to use this time to set up and test equipment at Cambridge and plan their observations. In particular, Reber (1954c) had mentioned to Ellis that before any observations could be commenced or more poles erected, he wished to carry out 'listening tests' to ensure that man-made electrical interference did not dominate.[11]

Originally, Reber (ibid.) had told Ellis that he intended to observe at two main frequencies:

> I expect to bring with me duplicate equipments (*sic*) and make simultaneous recordings at two main frequencies. One frequency will be in the region of 500–1000 kc where the Z hole phenomenon should occur. The other frequency will be in the region 2000 to 2500 kc where the ionosphere should be reasonably transparent when f0F2 is between 1000 and 1500 kc.

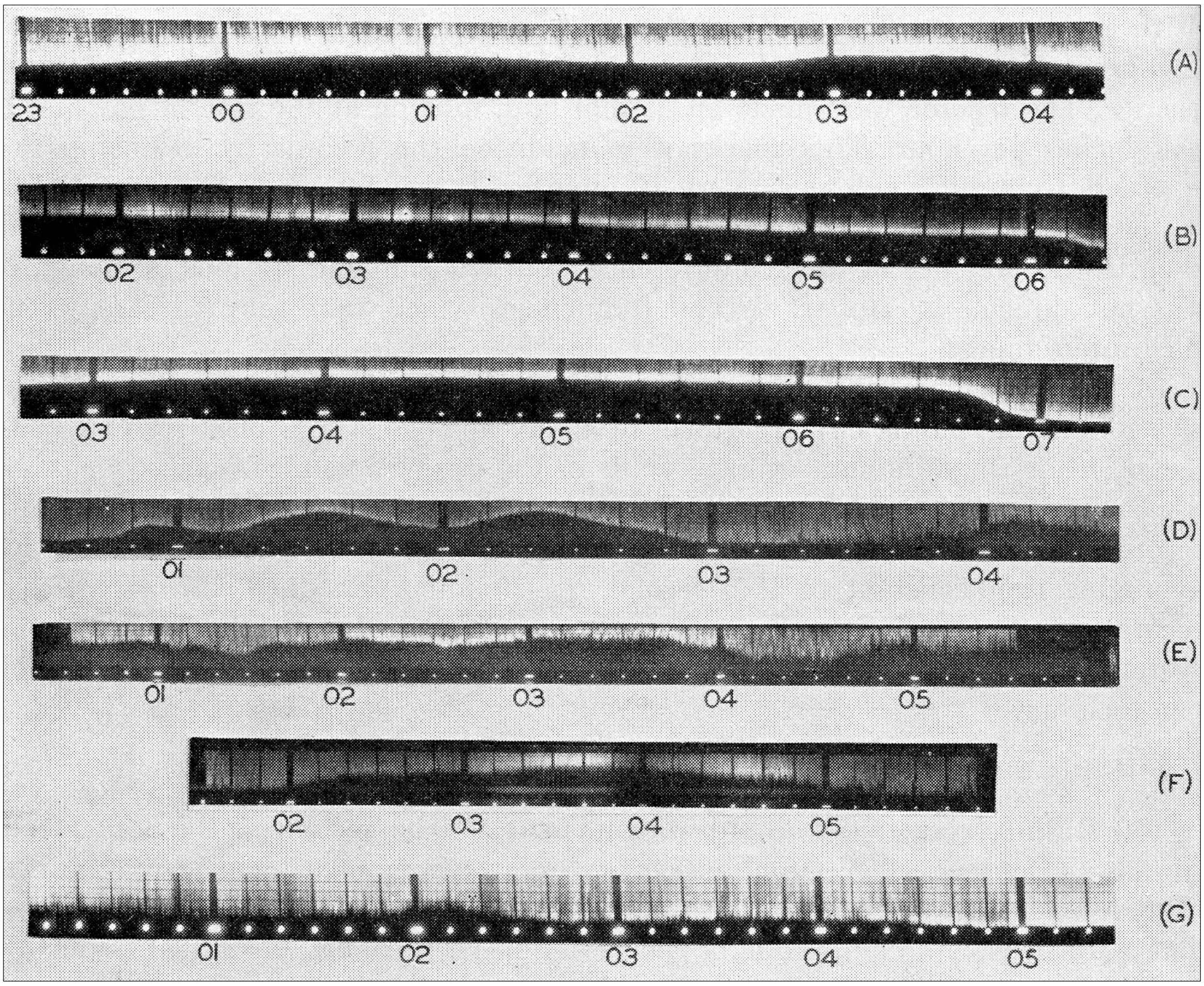

Figure 7: Records of observations made at Cambridge in 1955. The upper three (A, B and C) were at 2.135 MHz, followed by two (D and E) at 1.435 MHz, and one each at 0.9 MHz (F) and 0.52 MHz (G), respectively (after Reber and Ellis, 1956).

However, the 1955 observations were actually made at four different frequencies: 2.13, 1.435, 0.9 and 0.52 MHz (see Figure 7). Note that at the time these were by far the lowest frequencies ever attempted in radio astronomy: prior to this, the lowest frequency at which celestial radio emission had been observed was 9.15 MHz by Higgins and Shain (1954) at the Radiophysics Hornsby Valley field station near Sydney (see Orchiston et al., 2015).

In mid-March 1955, Reber and Ellis set the equipment to an "… apparently empty frequency near two megahertz …" (Reber, 1982), using a pen recorder. It was left operating for three days. Over that period they noticed that

> Daytime readings showed low level station interference which increased in magnitude along with atmospherics toward evening. About 1 a.m. on the first night, the electron density decreased enough so that a transparent hole in the ionosphere appeared at that frequency. The pen on the chart rose to a high level, about three-quarters full scale, and continued there until sunrise when the hole closed due to increasing electron density ... During the first night, when the hole was open, all man-made interference and atmospherics went out through the hole into space. Luckily for us the cosmic static came in without attenuation and had unexpectedly great strength. Here was a new and interesting aspect of radio astronomy which should be followed up. (Reber, 1982).

In their landmark paper titled "Cosmic Radio-Frequency Radiation Near One Megacycle", Reber and Ellis (1956) describe the results of the observations made at the four different frequencies.

4.1 The 2.13 MHz Observations

This series of observations ran from March to October, and includes the very first trial observations mentioned above. At this frequency, the 374-foot cage dipole was used (see Figure 5a). The authors mention (ibid.) that at this frequency and at 0.52 MHz (see 4.4 below), "… specially built battery-operated receivers with a bandwidth of 6 kc/sec were used." However, they do not indicate whether Reber brought these with him when he came to Australia, or whether he built them in Hobart.

In relation to the 2.13 MHz observations, Reber and Ellis (ibid.) noticed that

> On almost every night, strong continuous radiation was observed for periods which ranged from approximately one hour to 12 hours.

Both researchers were in no doubt that the radiation was of extraterrestrial origin. They also noted that when the critical frequency was lower than about 1.6 MHz, the amplitude increased to a limiting value. The clear implication of this is that the ionosphere was by then so transparent (at this frequency) that they were observing relatively, or nearly completely, unattenuated radiation.

4.2 The 1.435 MHz Observations

These, and the observations at 0.9 MHz, ran from April to September 1955 and were conducted using single half-wave dipoles placed 60 feet above the ground. Although the researchers make no other reference to the particular antenna used, it is reasonable to assume that they constructed new dipoles for this purpose, as Ellis (1954c) in his diagram of the site makes no reference to 60-foot poles, and Reber (1954c) discusses the possibility of erecting extra poles.

On only five nights, when the critical frequency was ~1MHz, did the radiation reach a limiting value. Nevertheless, Reber and Ellis (1956) still were able to identify a maximum at ~17h right ascension (close to the Galactic Centre), although the results were clearly less distinct than at 2.135 MHz.

4.3 The 0.9 MHz Observations

A significant difference now existed with the observations, as the equipment used to measure the critical frequency operated only down to 1 MHz. Therefore, the important observation of extraterrestrial radiation reaching a maximum when the critical frequency dropped below a certain level was not possible with these observations, nor was it possible at the lowest frequency of 0.52 MHz (see Section 4.4 below). However, based on the observations they did obtain between June and October 1955 the critical frequency was *inferred* to have been below 1 MHz on four occasions.

Nevertheless, at this frequency the cosmic component of the radiation was far less clear. Reber and Ellis (ibid.) commented that they did observe a rise and fall in the cosmic radiation, but that it also was characteristic of the rise and fall in the transparency of the ionosphere.

4.4 The 0.52 MHz Observations

This was the lowest of the four frequencies at which Reber and Ellis attempted observations. They observed on 80 nights between late May and early September 1955, and noted that only three nights produced records that could "… reasonably be interpreted as cosmic radiation." However, their comment that on two of these same nights they also observed radiation at 0.9 MHz (which, they imply, was assumed to be cosmic radiation), is an indication that they were convinced that they had observed extraterrestrial radiation at this frequency. Indeed, they commented that

> Although observations were made at lower frequencies at various times, 520 kc/sec was the lowest frequency on (*sic*) which there was any reason for believing that the cosmic radiation was detected. (ibid.).[12]

They came to the interesting conclusion that it was possible that all the records at 0.52 MHz were due to a region of low electron density passing overhead.

5 DISCUSSION

5.1 Reber and Ellis' Cambridge Observations

This was the first time that radio astronomers had attempted to observe at such low frequencies. From the letters exchanged by Reber and Ellis, and in particular Reber's assessment of the Z hole situation and his appreciation of Ellis' understanding of the subject, it is clear that Reber saw the potential for making observations at these frequencies being twofold. Firstly, the observations at the lower frequencies would make use of the Z hole phenomenon, and secondly, at the higher frequencies (particularly at 2.13 MHz) use would be made of the generally low values of the critical frequency.

As it turned out, Reber and Ellis made their observations a little later than the optimum time. The solar minimum of the 1950s, which occurred in June 1954, was very deep (e.g. see Hathaway, 2015; Meeus, 1983), with the mean Zurich sunspot numbers for both January and June 1954 reaching as low as 0.2.[13]

The mean of the Zurich sunspot numbers for the whole of 1955 was 38.0, with the lowest value of 4.9 occurring in March. It may therefore have been quite fortuitous that Reber and Ellis began their observations in March, rather than in the following months. This would have been a major factor that allowed the researchers to detect strong radiation on "… almost every night …" (see Section 4, above).

In their 2.13 MHz results, Reber and Ellis (1956) show a clear rise and fall centred on the region between 16h and 20h right ascension, and they noticed a similar maximum at 1.435 MHz. Later, when high-resolution low frequency arrays were utilised, the centre of our Galaxy showed up in absorption (e.g. see Shain, 1957), but we would not expect to see this with the wide-field Cambridge antenna, where the radiation was observed through an ionospherioc hole of ~1°, so the maximum in emission observed between 16h and 20h right ascension almost certainly was real.

There is little doubt that from amongst their selected frequencies, Reber and Ellis' 1.43 MHz results would have been close to the lower limit of reliable and consistent results. So the fact that they claim to have seen a possible celestial component at 0.9 MHz, and even at 0.52 MHz, is remarkable. Rather than being a record of the intensity as a function of right ascension, the success or otherwise of any such observations would have been very strongly dependent on ionospheric conditions, including the existence and size of an ionospheric hole. Supporting this view is the suggestion by Reber and Ellis (1956) that when regions of low electron density were passing overhead it was possible that all of the records obtained at 0.52 MHz were due to phenomena of that kind.

We can only speculate as to what the result would have been had Reber and Ellis chosen to carry out their initial observations during the exceptional year of 1954 instead of in 1955. Today this may be viewed as a 'lost opportunity', but at the time neither Reber nor Ellis made any comment about this. Indeed, although Reber was aware that solar activity was increasing, this did not deter him from making further low frequency observations before the consistent level of solar activity became too high. When they detected strong signals in March 1955, Reber and Ellis (1956) made the point that "… here was a new and interesting aspect of radio astronomy which should be followed up." This clearly resonated with Reber, whose subsequent research—and especially at Kempton in 1956–1957—will be the focus of a future paper in this series.

We also should note the comment by Reber and Ellis (1956) that their 1.435 and 0.9 MHz observations were made between 1 am and 5 am in order to avoid interference from local radio stations. At the time, and for some years afterwards, it was common for these radio stations to cease operating around midnight and start again at 6 a.m. or 7 a.m. (see Table 1). Even by the early 1970s, Hobart radio station 7HO, an AM station broadcasting at 0.86 MHz, and possibly others, still did not recommence their daily transmissions until 5 a.m.

In November 1955, not long after the completion of the observations at Cambridge, Reber (1955) left Australia, only to return a few months later so that he could begin observing at Kempton.

5.2 Other Early Observations

In addition to the observations made by Reber and Ellis at Cambridge, two research papers were published that relate to low frequency observations made after Reber's departure. One was by Ellis alone (1957) and the other by Ellis and Newstead (1957). As we saw on page 178, Gordon Newstead (Figure 8) from the Department of Electrical Engineering at the University of Tasmania was the first local person to conduct radio astronomical research in Tasmania, in 1952,[14] and it is interesting to see him team with 'Bill' Ellis from the Physics Department and carry our further research in this exciting new field after a hiatus of several years.

Table 1: The broadcast times of Hobart radio stations in 1954 (after *The Mercury*, 1954).

Station	Daily Broadcast Times	
	Start	End
7HO	6 a.m.	11 p.m.
7HT	6 a.m.	11 p.m.
7NT	6 a.m.	not listed
7ZL	7 a.m.	not listed
7ZR	6 a.m.	not listed

Unfortunately, as with many of the Tasmanian low frequency radio astronomy papers, the exact location of these observations by Ellis and Newstead is not recorded. It is a matter of speculation as to whether they were made at Cambridge or the IPS station on Mount Nelson, but Ellis (1957) states that a dipole was directed 38° east of north. Measurements along Acton Road at Cambridge show that the section of the road immediately adjacent to the Cambridge field station and parallel to the large antenna had an azimuth bearing of 127°. A line perpendicular to this has an azimuth of 37°, very close to the angle mentioned, and from both the diagram by Ellis and the aerial photograph of the site, it is significant that the dipoles

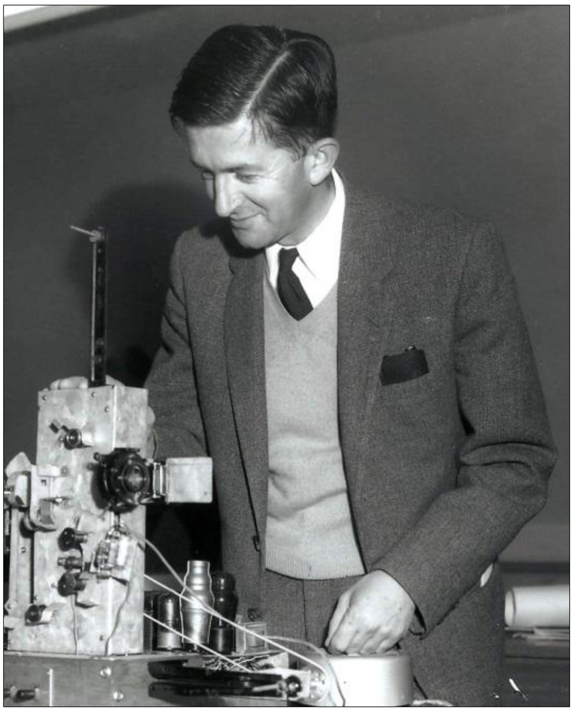

Figure 8: Gordon Newstead in the 1950s (courtesy Kim Newstead).

were very close to being parallel to or perpendicular to the road.

Regardless of the site of these observations, it is clear that although they were made at low frequencies, they were not made at the *extremely* low frequencies employed by Reber and Ellis in 1955. Indeed, Ellis and Newstead (1957: 185) reveal that their joint observations were made at 10.05 and 18.3 MHz, and that

> Six [discrete] sources were observed at both frequencies. Four of the sources were weaker at 10.05 Mc/s than at 18.3 Mc/s and two were stronger.

Although these observations did not form part of the collaboration by Reber and Ellis discussed in this paper, nonetheless they are an important component of early Tasmanian radio astronomy.

Figure 9: Examining a test recording at Eaglehawk Neck immediately prior to the 1949 partial solar eclipse. From left to right are John Murray (Division of Radiophysics), Graeme Ellis (standing) and N. Gerrard. At the time Ellis and Gerrard were research students in physics and electrical engineering at the University of Tasmania (courtesy: *The Mercury*).

6 CONCLUDING REMARKS

The 1955 observations at Cambridge by Reber and Ellis were a successful pioneering attempt to demonstrate that celestial radiation could be detected at significantly lower frequencies than had previously been thought possible, and they were aided by relatively low solar activity even though this was one year after the very deep solar minimum of that decade.

The combination of Reber and Ellis' ionospheric knowledge and Reber's drive to investigate this exciting new area of radio astronomy worked well, the eventual outcome being a very significant paper that they published in 1956. Although Reber knew that Tasmania was ideally located for such research, and this influenced his decision to relocate to Hobart, his appreciation of the ionospheric research carried out by Ellis clearly also was a contributing factor.

Future papers in this series will show that the success of the 1955 research by Reber and Ellis led to the blossoming of low frequency radio astronomy in Tasmania during the 1960s as Reber and Ellis went on to build a succession of new low frequency radio telescopes and Ellis developed a vibrant graduate program at the University of Tasmania.

7 NOTES

1. This is the third paper in a series that aims to document the early history of low frequency radio astronomy (<30 MHz) in Australia. The first paper (Orchiston et al., 2015) overviewed the activities of the CSIRO's Division of Radiophysics in Sydney at the Hornsby Valley and Fleurs field stations, and the second paper (George et al., 2015) summarised the research carried out in Tasmania during the 1950s and 1960s.
2. The O, X and Z modes are the three wave propagation modes that can pass through the ionosphere (Reber and Ellis, 1956). The 'Z hole', described by Ellis (1955), is a relatively small ionospheric region that allows the Z mode to pass through. Ellis had found that for Hobart this region had an angular diameter (as observed from the ground) of <0.84°. Despite the interest in this hole, Ellis and Reber (1956) note that only the O mode was important in the observations they recorded.
3. The term f0F2 refers to the lowest frequency that will pass through the F2 ionospheric layer at vertical incidence. It is also called the *critical frequency*. The F2 ionospheric layer is the most important layer limiting the detection of low-frequency celestial radiation. The value of f0F2 varies according to location, time of day and season.
4. This new site was located on University of Tasmania property on Mount Nelson, near the road known as Olinda Grove, at longitude 147° 18.9′ E and latitude 42° 54.8′ S. Ellis (1954b) comments that the Mount Nelson site includes "… the usual equipment of an ionospheric station, supplemented by close co-operation with the University."
5. Until 1956, Hobart's airport was located close to the small township of Cambridge. The current Hobart Airport (now known as Hobart International Airport), is several kilometres to the east and began operations in 1956. It is also known as 'Llanherne Airport' after the name of an important local property.
6. This comment is based on discussions one

of us (MG) had with Wheaton (Illinois) residents on 16 August 2008. Some of these residents were children at the time when Reber built his 'dish', and they recalled that in walking home from school they used a route that by-passed Reber's radio telescope.

7. When Reber asked Ellis what a 'Berkner dipole' was, Ellis (1954c) explained that it was a cage dipole, as shown in the diagrams he sent to Reber (see Figure 5).
8. A P′f record for an ionospheric layer is a plot of virtual ionospheric height against frequency. By 'virtual height' is meant the equivalent (single) altitude from which reflection appears to come.
9. These bore some similarity to cathode ray oscilloscopes, but were simple display devices that often were dedicated to particular applications.
10. The term 'atmospherics', sometimes simply called 'spherics', is used to describe radio noise arising from atmospheric sources, rather than external radio-frequency radiation that passes through the ionosphere. It occurs most predominantly at low frequencies. Lightning is the main cause.
11. Reber was always keen to optimise his use of time. Therefore it is clear that his arrival date in late 1954 was planned in order to allow sufficient time to prepare for the winter 1955 observations, including conducting the 'listening tests.' Indeed, he commented (Reber, 1954c) that "The earliest I can leave here [Hawaii] will be October or November ..." Later, he thanked the University of Tasmania's Vice-Chancellor, Professor T. Hytten, for the use of laboratory and shop facilities, which "... greatly expedited the work, particularly in its early stages." (Reber, 1955).
12. As far as is known, no further records or comments about attempted observations below 0.52 MHz were made, probably because they produced no useful results other than to show that these frequencies were far too low to produce anything meaningful.
13. The Zurich Relative Sunspot Number for an observer is calculated using the formula

$$R = k(10g + f) \qquad (1)$$

where k is a constant which is dependent on the observer (to remove systematic differences between observers), g is the number of sunspot groups and f is the number of individual sunspots. A typical value of R at the time of solar maximum is between 100 and 200. The monthly mean of 0.2 was an exceptionally low value; indeed, 1954 as a whole saw the lowest yearly mean (4.4) since 1901. A lower monthly mean value was not documented until a value of 0.0 was recorded in August 2008 during the unexpectedly prolonged solar minimum.
14. It is important to note, however, that Newstead was not the first to carry out radio astronomy experiments in Tasmania, as teams from the CSIR's Division of Radiophysics observed partial solar eclipses from Strahan (on the west coast) and Eaglehawk Neck (near Hobart) in 1948 and 1949 respectively (see Orchiston et al., 2006; Wendt et al., 2008). The former eclipse was observed at 600 MHz, and the latter at 1,200 MHz. It is interesting that Bill Ellis was a member of the 1949 eclipse team (see Figure 9). At the time he was completing his B.Sc. Honours degree, and this was his very first escapade in radio astronomy.

8 ACKNOWLEDGEMENTS

We wish to thank Elizabeth Ellis, Susan Ellis, Dr Geoff Fenton (University of Tasmania), David Goldstone (Hobart), Dr Ken Kellermann (National Radio Astronomy Observatory, USA), Kim Newstead and Dr Harry Wendt (Sydney) for assisting with this project. We also are grateful to the National Radio Astronomy Observatory, Kim Newstead, George Swenson and *The Mercury* newspaper for kindly supplying Figures 2–4, 6, and 8.

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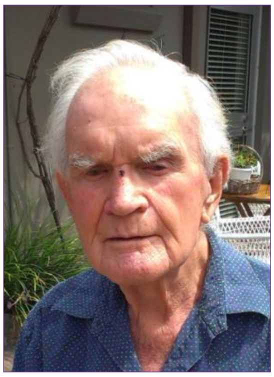
Professor Wayne Orchiston was born in New Zealand in 1943 and works as a Senior Researcher at the National Astronomical Research Institute of Thailand and is an Adjunct Professor of Astronomy at the University of Southern Queensland in Toowoomba, Australia. In the 1960s Wayne worked as a Technical Assistant in the CSIRO's Division of Radiophysics in Sydney, and forty years later joined its successor, the Australia Telescope National Facility, as its Archivist and Historian. He has a special interest in the history of radio astronomy, and in 2003 was founding Chairman of the IAU Working Group on Historic Radio Astronomy. He has supervised six Ph.D. or Masters theses on historic radio astronomy, and has published papers on early radio astronomy in Australia, England, France, Japan, New Zealand and the USA. He also has published extensively on the history of meteoritics, historic transits of Venus and solar eclipses, historic telescopes and observatories, and the history of cometary and asteroidal astronomy. He is a co-founder and the current Editor of the *Journal of Astronomical History and Heritage*, and in 2013 the IAU named minor planet 48471 Orchiston after him.

Dr Bruce Slee was born in Adelaide, Australia, in 1924 and is one of the pioneers of Australian radio astronomy. Since he independently detected solar radio emission during WWII he has carried out wide-ranging research, first as a member of the CSIRO's Division of Radiophysics, and then through its successor, the Australia Telescope National Facility. After working with Bolton and Stanley on the first discrete sources at Dover Heights, he moved to the Fleurs field station and researched discrete sources with Mills using the Mills Cross, and radio emission from flare stars with the Shain Cross and the 64-m Parkes Radio Telescope. He also used the Shain Cross and a number of antennas at remote sites to investigate Jovian decametric emission. With the commissioning of the Parkes Radio Telescope he began a wide-ranging program that focussed on discrete sources, and radio emission from various types of active stars. He also used the Culgoora Circular Array (*aka* Culgoora Radioheliograph) for non-solar research, with emphasis on pulsars, source surveys and clusters of galaxies, and continued some of these projects using the Australia Telescope Compact Array. Over the past two decades, he also has written many papers on the history of Australian radio astronomy, and has supervised a number of Ph.D. students who were researching the history of radio astronomy. .



Professor Richard Wielebinski was born in Poland in 1936, and moved with his parents to Hobart, Tasmania, while still a teenager. Richard completed B.E. (Hons.) and M.Eng.Sc. degrees at the University of Tasmania. In his student days he met Grote Reber and was involved in the construction of a low frequency array at Kempton. After working for the Postmaster General's Department in Hobart he joined Ryle's radio astronomy group at the Cavendish Laboratory, Cambridge, and completed a Ph.D. in 1963 on polarised galactic radio emission. From 1963 to 1969 Richard worked with Professor W.N. (Chris) Christiansen in the Department of Electrical Engineering at the University of Sydney, studying galactic emission with the Fleurs Synthesis Telescope and the 64-m Parkes Radio Telescope. He also was involved in early Australian pulsar research using the Molonglo Cross. In 1970 Richard was appointed Director of the Max-Planck-Institute für Radioastronomie in Bonn, where he was responsible for the instrumentation of the 100m radio telescope at Effelsberg. In addition, he built up a research group that became involved in mapping the sky in the radio continuum, studying the magnetic fields of galaxies, and pulsar research. Further developments were the French-German-Spanish institute for millimeter-wave astronomy (IRAM), and co-operation with the Steward Observatory, University of Arizona, on the Heinrich-Hertz Telescope Project. Richard holds Honorary Professorships in Bonn, Beijing and at the University of Southern Queensland. He is a member of several academies, and has been awarded honorary doctorates by three universities. After retiring in 2004 he became involved in history of radio astronomy research, and is currently the Chairman of the IAU Working Group on Historic Radio Astronomy.

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THE SAPTARISHIS CALENDAR: 'THE INDIAN TROPICAL ZODIAC'!

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Abstract: The Saptarishis Calendar of ancient India is based on precession of the equinoxes. It employs the tropical zodiac of the Greeks and the precessional rate of Hipparchus. The Saptarishis era has to be determined by naked eye observation of the sky. The line of reference goes through the stars Dubhe and Merak in the constellation of Ursa Major, touching both of them, and crosses the ecliptic in the sidereal Purvaphalguni Nakshatra[1] of Simha Rashi at a point close to the star 59 Leonis. The angular difference between this 'Saptarishis pointer' and the vernal equinox gives the tropical lunar mansion in which Saptarishis resides at a given point in time.

Keywords: India, the Saptarishis Calendar, Dubhe, Merak, 59 Leonis, precession of the equinoxes, tropical zodiac

1 INTRODUCTION

There are numerous references in ancient Indian literature to a kind of time keeping using the star group known as Saptarishis (the Seven Sages). Saptarishis has been identified as the brightest seven stars in the constellation Ursa Major (the Big Bear), constituting the asterism known as the Big Dipper (Figure 1).

The seven stars of Ursa Major take the shape of a cart or a bowl with a handle. The Sanskrit names of these stars can be recognized by following the description given in the *Brihat Samhita* of Varahamihira (Iyer, 1884: 80):

> The east-most of the group is Bhagavan Marichi; the next to him is Vasishtha; the next is Angirasa and the next two are Atri and Pulastya. The next in order are the Rishis Pulaha and Kritu. The chaste Arundati chastly attends her husband the Sage Vasishtha.

Details of the principal stars in Ursa Major are given in Table 1.

2 USES OF THE SAPTARISHIS CALENDAR

The Saptarishis Calendar is based on the discovery by the ancient Greek astronomers that in different periods of time the Seven Sages resided in different lunar mansions of the tropical zodiac. The lunar mansion in which Saptarishis resided was noted when significant events occurred. This must have been done by direct observation of the

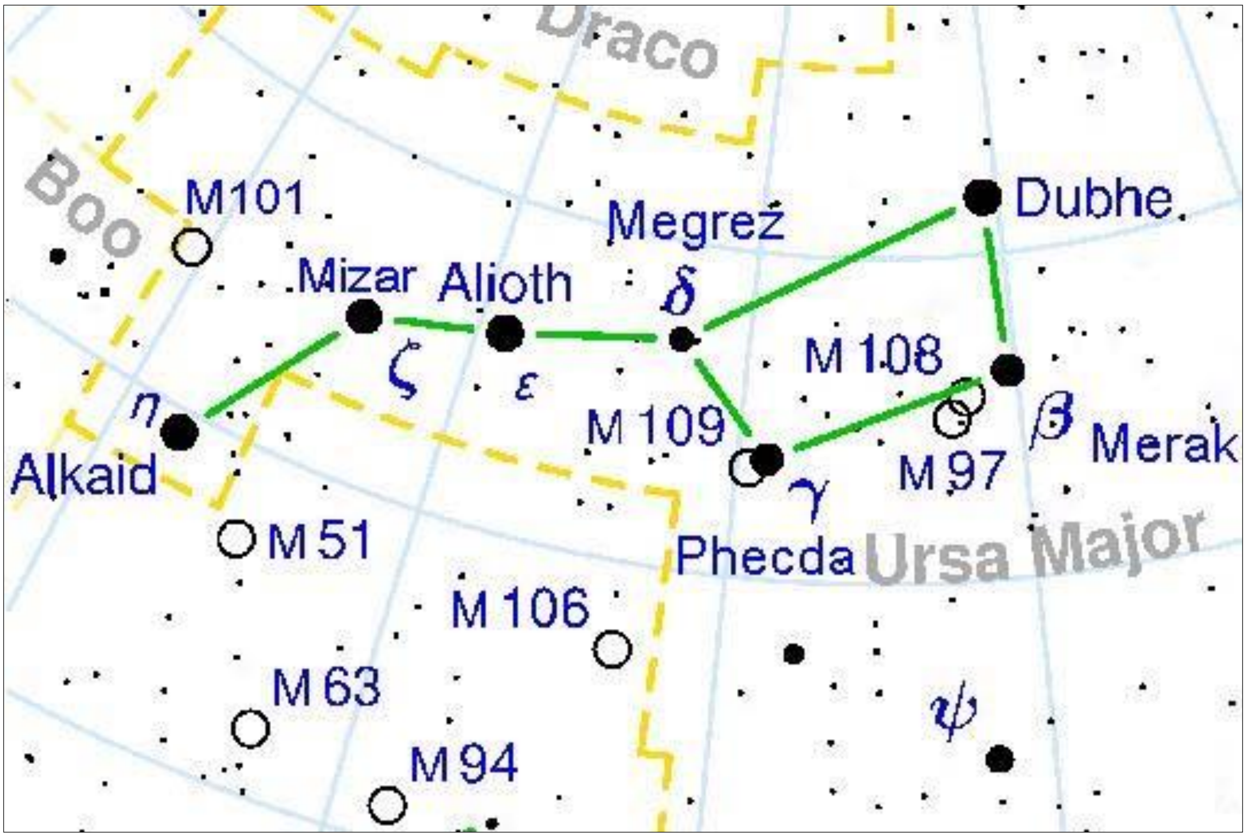

Figure 1: A map showing the brightest stars in the constellation of Ursa Major (http://en.wikipedia.org/wiki/Big_Dipper).

Table 1: The main stars in the constellation of Ursa Major.

Bayer Code	Common Name	Sanskrit Name	Magnitude (v_m)	Sidereall Longitude	Right Ascension	Declination (N)
α UMa	Dubhe	Kratu	1.79	20° 36′ 02″Cancer	11h 03m 43s	61° 44′ 49″
β UMa	Merak	Pulaha	2.37	24° 50′ 12″ Cancer	11h 01m 50s	56° 22′ 43″
γ UMa	Phecda	Pulasthya	2.44	05° 52′ 42″ Leo	11h 53m 49s	53° 41′ 29″
δ UMa	Megrez	Atri	3.31	06° 28′ 01″ Leo	12h 15m 24s	57° 01′ 45″
ε UMa	Alioth	Angiras	1.77	14° 20′ 06″ Leo	12h 54m 00s	55° 57′ 24″
80 Uma + ζ UMa	Alcor-Mizar	Vasishta + Arundhati	4.01 2.27	21° 16′ 29″ Leo 21° 06′ 04″ Leo	13h 25m 12s 13h 23m 54s	54° 59′ 07″ 54° 55′ 21″
η UMa	Alkaid	Marichi	1.86	02° 19′ 53″ Virgo	13h 47m 31s	49° 18′ 40″

night sky and locating the Saptarishis pointer in relation to the tropical zodiac. This was not a method that could be done by simple calculation. It was like a 'clock' in the sky. To tell the time one had to look at the sky and note the position of the Saptarishis pointer. Since there is only slight, if any, movement of stars relative to each other, the sidereal zodiac or the stars themselves could not be used in this method. With respect to a star or sidereal Nakshatra, there is hardly any movement of Saptarishis.

Given below are some of the events that the ancient Indian astronomers noted using the Saptarishis Calendar.

1) "At the birth of king Parikshit they were in Magha and the Kali Yuga then began." (*Vishnu Purana 2*; see Dutt, 1896: 312).
2) "When Seven Rishis will be in Parvashadha, then Nanda will begin to reign and thenceforth the influence of Kali will increase." (*Vishnu Purana 2*; see Dutt, ibid.).
3) "During the reign of Yudhishtira 2526 years before the commencement of the Vikrama Saka the seven Rishis were at the constellation of Magha (Regulus)." (*Brihat Samhita*: Sloka 3, Chapter XIII; see Iyer, 1884: 80).

3 THE SAPTARISHIS POINTER

Ursa Major includes the seven bright stars shown in Figure 1. Since these span an angular distance of >42°, it is impossible to fit all of them within one lunar mansion (which spans only 13° 20′). Instead, in order to locate the lunar mansion an imaginary line connecting two particular stars in Ursa Major is extended towards the ecliptic. This line of reference is described in the *Vishnu Purana* as follows:

> When the first two stars of the seven Rishis rise in the heavens and some lunar asterism is seen at night at an equal distance then the seven Rishis remain stationary in that conjunction for a hundred years of man. (Dutt, 1896: 31).

The meaning of "equal distance" in this translation should be understood as the distance from the North Celestial Pole to Ursa Major and a similar distance from Ursa Major towards the ecliptic. Ursa Major lies approximately midway between the North Celestial Pole and the ecliptic. The point where the imaginary line crosses the ecliptic is the place where Saptarishis resides.

The first two stars that rise in Ursa Major are the two stars that form the pouring edge of the bowl (i.e. Dubhe and Merak). The Dubhe-Merak axis when extended towards the ecliptic goes parallel and close to the Zosma and Chort stars in the constellation of Leo that form a triangle with Denebola (Purvaphalguni Nakshatra). The point where this imaginary line cuts the ecliptic is not static because of the slight proper motion of the stars, which is significant over several centuries.

4 ZODIACAL CONSIDERATIONS

Does Saptarishis move? In accordance with the Saptarishis Calendar, yes it does. It moves at a rate of one conjunction in 100 years, and it moves through the whole zodiac in one cycle, "... the seven Rishis remain stationary in that conjunction for one hundred years of man." (*Vishnu Purana;* Indrasena, 2014). Is this true? The answer to this question is both yes and no, depending on how the zodiac is defined.

The zodiac consists of 12 Rashis (signs) and 27 or 28 Nakshatras (lunar mansions), and is stationary and star based in Vedic astronomy. By definition the first Rashi, Mesha (Aries), begins at a point which is approximately diametrically opposite to the location of the star Chitra (Spica). This starting point of Mesha is fixed. In Greek astronomy the zodiac is based on equinoctial and solstice points, with Aries starting from the point of the vernal equinox and Libra the autumnal equinox. This is known as the tropical zodiac. The astrological tropical zodiac is not astronomically correct (ibid.). Because of the precession of the equinoxes the vernal equinoctial point drifts backwards along the ecliptic at a rate of 50.3″ per year. Therefore, the tropical zodiac is not stationary but moves backwards along the ecliptic among the background of stationary stars at a rate of 1° in 72 years.

4.1 The Sidereal Zodiac

Stars hardly move except for proper motion, which is only a few arc minutes over many centuries. Figure 2 and 3 show the arrangement of stars in CE 100 and CE 3000. The sidereal zodiac is also shown along the ecliptic. Simha (Leo) and Kanya (Virgo) Rashis (constellations) can be - seen in these figures. The sidereal zodiac starts

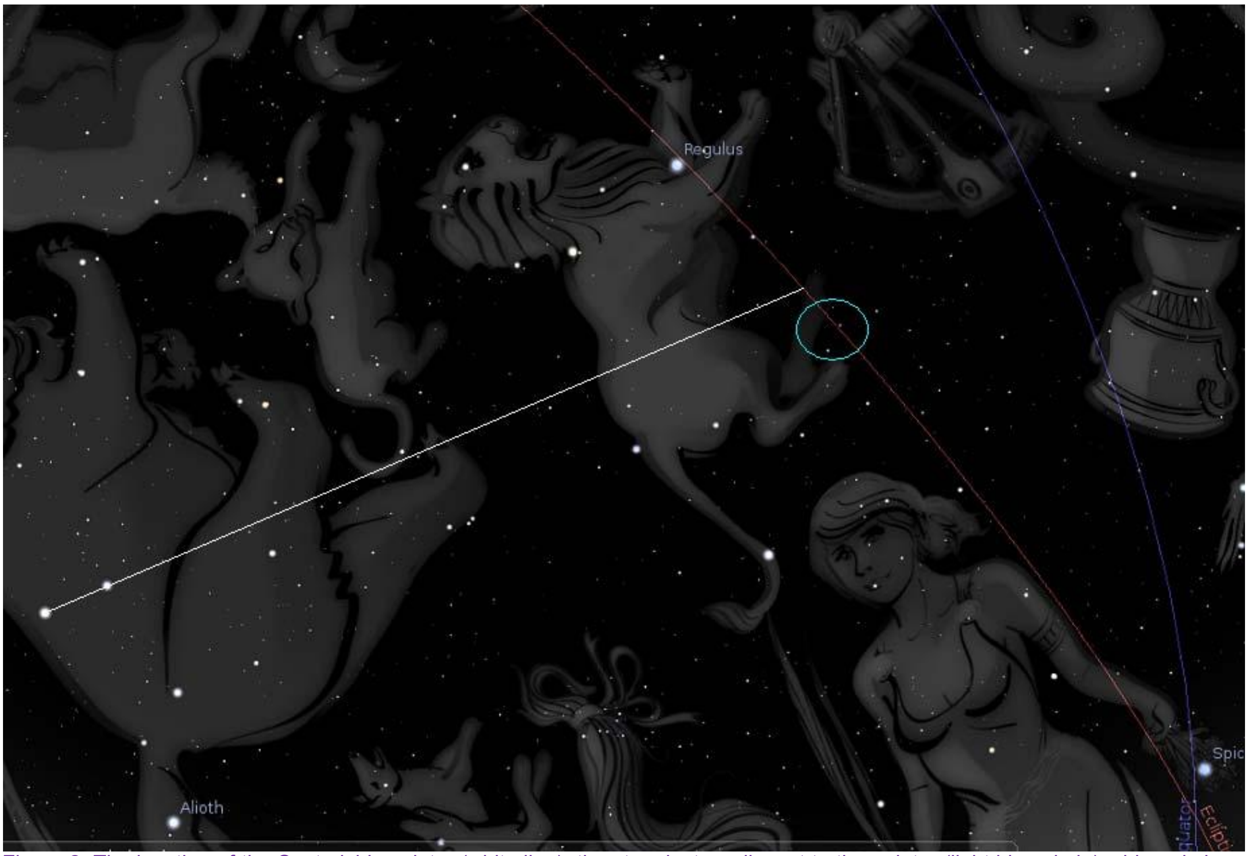

Figure 2: The location of the Saptarishis pointer (white line), the star cluster adjacent to the pointer (light blue circle), sidereal signs Simha and Kanya, and the autumnal equinox [the meeting points of the red (ecliptic) and blue (equator) lines] in CE 100.

Figure 3: The location of the Saptarishis pointer (white line), sidereal zodiac and autumnal equinox [the meeting points of the red (ecliptic) and blue (equator) lines] in CE 3000.

Table 2: The approximate Saptarishis era at the beginning of each millennium.

Year	Tropical Longitude of the Saptarishis Pointer (° ′ ″)	Tropical Lunar Mansion of the Saptarishis Pointer	Sidereal Longitude of the Saptarishis Pointer (° ′ ″)
10000 BCE	27 19 59 Pisces	Revati	17 25 01 Simha
9000 BCE	11 55 14 Aries	Ashwini	18 23 32 Simha
8000BCE	26 08 30 Aries	Bharani	19 00 48 Simha
7000 BCE	10 06 27 Taurus	Rohini	19 22 53 Simha
6000 BCE	23 54 35 Taurus	Margasir	19 34 38 Simha
5000 BCE	07 37 07 Gemini	Ardra	19 39 42 Simha
4000 BCE	21 17 55 Gemini	Punarvasu	19 41 24 Simha
3000 BCE	04 58 17 Cancer	Pushya	19 40 34 Simha
2000 BCE	18 40 10 Cancer	Ashlesa	19 38 43 Simha
1000 BCE	02 25 24 Leo	Magha	19 37 22 Simha
CE 01	16 14 06 Leo	Purvaphalguni	19 36 23 Simha
CE 1000	00 04 50 Virgo	Uttaraphalguni	19 35 00 Simha
CE 2000	14 00 18 Virgo	Hasta	19 34 11 Simha
CE 3000	28 00 04 Virgo	Chaitra	19 34 18 Simha
CE 4000	12 03 05 Libra	Swati	19 34 24 Simha
CE 5000	26 09 42 Libra	Vishakha	19 35 00 Simha
CE 6000	10 21 12 Scorpius	Anuradha	19 37 36 Simha
CE 7000	24 38 02 Scorpius	Jyeshta	19 42 55 Simha
CE 8000	09 01 39 Scorpius	Moola	19 52 43 Simha
CE 9000	23 34 09 Scorpius	Purvashadha	20 09 32 Simha
CE 10000	08 18 30 Scorpius	Uttarashadha	20 36 41 Simha

with reference to a star. Commonly a point diametrically opposite to Spica is taken as the starting point of Aries by Indian astrologers (Lahiri Ayanamsha). In the West, the Fargan-Bradely Ayanamsha is commonly used, but I prefer the Dulakara Ayanamsha (Indrasena, 2015), which is obtained by eliminating the refraction error imparted by the atmosphere in the location of Spica. It should be understood that throughout this research paper the Dulakara Ayanamsha has been used, and the zodiac has been fixed at CE 232.[2]

It can be seen that there is hardly any change in star positions with respect to each other between CE 100 and CE 3000. The stars are also more or less stationary with respect to the sidereal zodiac. The Saptarishis pointer, which is the Dubhe-Merak axis, cuts the ecliptic in sidereal Simha (Leo) close to the star 59 Leonis in both CE 100 and CE 3000. There is only 2 arc minutes movement of the pointer along the ecliptic over 2,900 years because of the proper motion of Dubhe and Merak (see Table 2). Therefore, over 2,900 years Saptarishis has hardly moved with respect to the sidereal zodiac.

4.2 The Tropical Zodiac

What is the situation with respect to the tropical zodiac? In Figures 2 and 3, the starting point of tropical Libra can be identified as the point of interception of the ecliptic and the celestial equator. Tropical Aries starts from the point of the vernal equinox. In CE 100, the Saptarishis pointer cuts the ecliptic at tropical Leo but in CE 3000 it will happen in tropical Libra because the starting point of tropical Libra has progressed backwards by about 40° along the ecliptic towards sidereal Leo. Clearly there is movement of Saptarishis along the tropical zodiac although there is hardly any absolute movement against the stationary stars. This movement is due to the precession of the equinoxes. The rate is approximately 1.5° in 100 years.

5 DISCUSSION

5.1 The Indian Tropcial Zodiac

A Nakshatra-based zodiac is unique to Indian astronomy. Indian astrology uses both signs and lunar mansions, whereas Western astrology hardly uses lunar mansions. The first lunar mansion is Ashwini and starts at Aries zero. As noted previously, one lunar mansion spans 13° 20′; these mansions are distributed equally along the zodiac. Since tropical Aries starts at the vernal equinox, the vernal equinox also is the starting point of tropical Ashwini. A tropical lunar mansion-based zodiac starting from the vernal equinox is the basis of the Saptarishis Calendar.

5.2 What Others Say About the Saptarishis Calendar

The Saptarishis Calendar is an ill-understood phenomenon thus far, and as a result it has been dismissed by saying it is non-astronomical (Dikshit, 1969). It is considered more as a convention rather than a true phenomenon (see Ravilochanan, 2007). This misunderstanding is such that the Saptarishis era is calculated by adding or subtracting 100 years serially from a known point. But it is clear from the above description that the Saptarishis Calendar is astronomical and is real. It cannot be calculated by adding 100 years serially but must be identified by observing the pointer in the night sky.

The only research paper available thus far that describes the astronomical basis of the Saptarishis Calendar is the one by Sule et al. (2006).

They noted that the Saptarishis pointer actually migrated from one star or star cluster to another star or cluster. However, they placed major emphasis on the North Celestial Pole and always had the pointer starting from the Pole. Rather than focussing on the alignment of the first two stars in Ursa Major that rise, Sule et al. used a line that went through the North Celestial Pole. In a computer programme it is possible to do so, but in practice it is not always possible to locate the Pole by looking at the sky. Nowadays, the North Celestial Pole is within 1° of Polaris, but Polaris was not always at the Pole. Because of precession, different stars marked the position of the Pole at different times in the past. In 3000 BCE it was Thuban that was close to the North Celestial Pole. In ~320 BCE there was no star visible to the naked eye near the Pole, and by CE 3000 Polaris will cease to serve as the Pole Star. Figure 4 shows how the location of the North Celestial Pole changes among the background stars in the course of one precessional cycle.

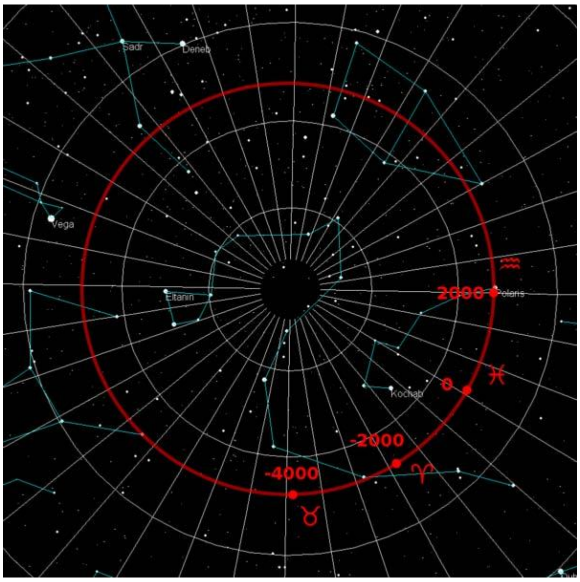

Figure 4: A plot (the red circle) showing how the position of the North Celestial Pole changes with time.

Since the North Celestial Pole cannot always be identified by a star it is not practical to draw imaginary lines that go through the Pole. Furthermore, when emphasis is placed on the Pole rather than Ursa Major, it can be seen that the line can miss the stars Dubhe and Merak altogether. For example, although in CE 2000 the line passes through these two critical stars (Figure 5), in 2000 BCE the line from the North Celestial Pole (very near the star Thuban) missed both Dubhe and Merak but went in between them, violating the principle given in the *Vishnu Purana* (see Figure 6). When the North Celestial Pole is devoid of a star and no stars in Ursa Major are used, it is virtually impossible to trace lines accurately to the ecliptic. Although this can be done with the help of a computer, without a computer it is a challenge.

All in all it can be said that the Saptarishis Calendar is an ill-understood phenomenon. This is because it is tempting to move the Saptarishis pointer along the ecliptic. Rather than moving the pointer from one star to another what actually happens is that the tropical zodiac—which is not dependent on the stars—moves against the star-based Saptarishis pointer.

5.3 The Rate of Motion of Saptarishis

Since the Saptarishis Calendar is a direct projection of the precession of the equinoxes the position of Saptarishis should change at the precessional rate. The major drawback in understanding the true nature of the Saptarishis Calendar and the rate of change is the ambiguity of the descriptions and translations of the verses that mention the rate of movement of Saptarishis.

There are different versions presented in the *Vishnu Purana* and in the *Brihat Samhita*. In the *Vishnu Purana* there is no reference to lunar mansions: "... seven Rishis continue stationary in that conjunction for a hundred years of man." (Dutt, 1896: 312). In contrast, the *Brihat Samhita* states that "The Sages in their course remain for a period of 100 years in each lunar mansion." (Sloka 4, Chapter XIII; Iyer, 1984: 80). The meaning of the term "conjunction" in the *Vishnu Purana* quotation is often misinterpreted as Nakshatra (lunar mansion) but it should not be. 'Conjunction' can be understood better as the meeting point of the Saptarishis pointer with the ecliptic. In other words, the Seven Sages remain at a particular point for nearly 100 years, and this is exactly the case when the *Vishnu Purana* verse is looked into closely. The verse says "Whichever Nakshatra out of Ashwini etc. this line meets; it will remain in the same for 100 human years." The verse is actually referring to the point where the lines meet in a lunar mansion rather than the whole of the lunar mansion. This has been wrongly interpreted as the whole lunar mansion instead of one point. This point has to span either 1°, as per the Greek tradition, or 1.5°, as per the Vedic tradition, if it lasts for 100 years. Since it was the Greeks who popularized the tropical zodiac, the span of the 'conjunction' has to be taken as 1° rather than the whole lunar mansion.

The afore-mentioned quotation in the *Brihat Samhita* must be interpreted cautiously because at the beginning Varahamihira says that what he was writing about Seven Sages was merely what was known to Vriddha Garga: "I shall describe according to the theory of Sage Vriddha Garga ..." (Slokas 1/2, Chapter XIII; Iyer, 1884: 80). It is not clear who Vriddha Garga was. Although it is tempting to assume that he was an ancient Indian writer, his name does not appear in any Indian books, so perhaps he was not an Indian sage. Since Varahamihira and later Indian astronomers followed the zodiac of Ptolemy, relating the signs to solstices and equinoxes, it is possible that Vriddha Garga was none other than Ptolemy.

Since Varahamihira does not take responsibility for what he says in the *Brihat Samhita* about the Seven Sages it is clear that either he had doubts about it or it was not well understood by him. Therefore Varahamihira's account of the Seven Sages residing in one Nakshatra for 100 years must be treated with caution.

It is impossible for the Saptarishis pointer to traverse one lunar mansion in 100 years. A lunar mansion spans 13° 20′, and since Saptarishis moves along the tropical zodiac at the rate of the precession of the equinoxes, in 100 years it is impossible to move more than 1.38° at the current rate of precession. As per the Vedic tradition the rate of precession is 54" per year; in 100 years this will be 1.5°. As per the Greek tradition of Hipparchus the rate of precession is not less than 1° in 100 years. The rate of change of the Seven Sages as given in ancient Indian texts is closer to the rate of precession as discovered by Hipparchus. Therefore, it seems that the Saptarishis Calendar is the application of the rate of precession found by Hipparchus, and the meaning of the term 'conjunction' in the *Vishnu Purana* or Nakshatra in the *Brihat Samhita* is simply a span of 1° along the ecliptic.

5.4 Origin of the Saptarishis Calendar

It is unlikely that the Saptarishis Calendar was in use in India earlier than the time of Ptolemy (i.e. the second century CE). The earliest text that mentions his calendar is the *Vishnu Purana*; the earliest possible date for its composition is the first century BCE and the latest is the fourth century CE. Vriddha Garga is said to have lived in the third century CE, and Varahamihira lived in the sixth century CE. Saptarishis is mentioned in the *Matsya Purana* (CE 250–500), the *Vayu Purana* and the *Bhagavata Purana* (CE 500–1000) (see Sule et al., 2006), all of which postdate the Hipparchus-Ptolemaic era. Hipparchus discovered that the rate of precession was 1° in not less than 100 years, while Ptolemy popularized the tropical zodiac. It is clear that what was known as the Seven Sages' movement by the ancient Indian seers was nothing more than the adoption in India of the tropical zodiac of Ptolemy and the rate of precession of Hipparchus.

Ironically, though, by this time Indian astronomers were aware that the actual rate of precession was 54" per year, as mentioned in the *Surya Siddhanta* (Indrasena, 2015: 87). This is equivalent to 1° in 66.7 years, a more realistic value than Hipparchus' figure. This must have been the reason why Varahamihira was so cautious about the movement of Saptarishis when he said it traverses one lunar mansion in 100 years and placed the responsibility for this claim on Vriddha Garga.

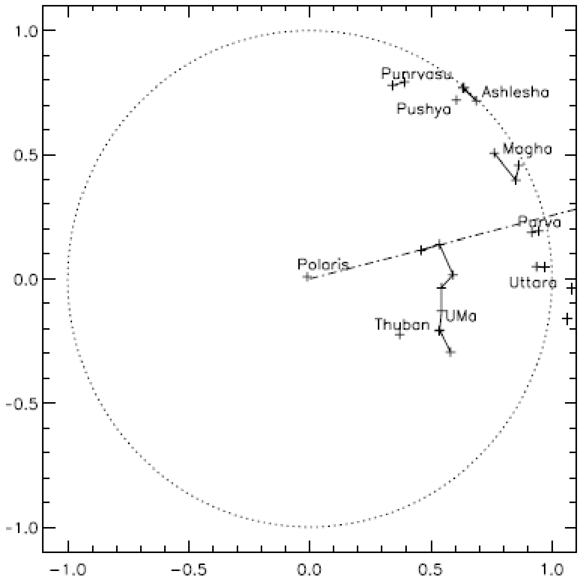

Figure 5: In CE 2000 the Saptarishis pointer passed through the two Ursa Major stars (after Sule et al., 2006).

That the Saptarishis Calendar came to India from Greece is also supported by the fact that this calendar was widely used only in the northern parts of India (i.e. in Kashmir and Nepal). In Kashmir it is still in use today whereas the rest of India emphasizes the Kali era.

In Kashmir, Varahamihira's teachings are still very popular and it is clear from his writings that he supported the Saayana (tropical) zodiac of the ancient Greeks.

5.5 The Sky Clock

The ancient Indian astronomers did not pay much attention to the exact rate of change of the Saptarishis pointer. This was because they relied

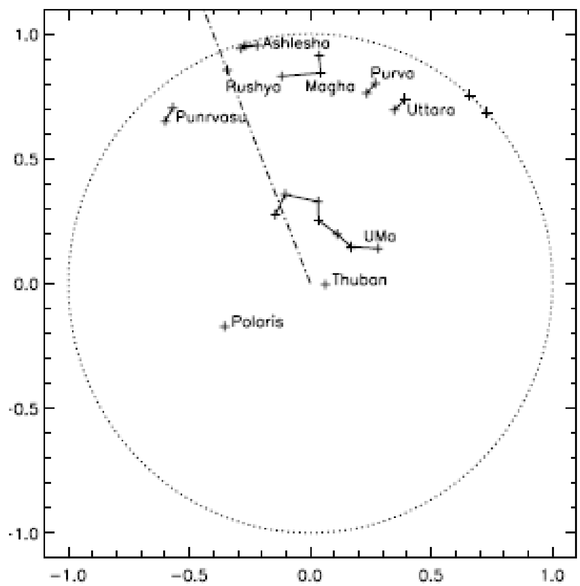

Figure 6: In 2150 BCE the Saptarishis pointer passed between the two 'marker' stars in Ursa Major (Sule et al., 2006).

Table 3: The approximate Saptarishis era by lunar mansion.

Tropical Lunar Mansion	Tropical Longitude (° ′)	Year of Commencement	Sidereal Longitude of the Saptarishis Pointer (° ′)
Asvini	00 00	9821 BCE	17 37 22 Simha
Bharani	13 20	8903 BCE	18 27 58 Simha
Krittika	26 40	7964 BCE	19 01 50 Simha
Rohini	40 00	7009 BCE	19 22 44 Simha
Mrigasira	53 20	6043 BCE	19 34 17 Simha
Ardra	66 40	5291 BCE	19 38 48 Simha
Punarvasu	80 00	5071 BCE	19 39 35 Simha
Pushya	93 20	3120 BCE	19 40 25 Simha
Ashlesa	106 40	2147 BCE	19 39 03 Simha
Magha	120 00	1177 BCE	19 37 42 Simha
Purvaphalguni	133 20	210 BCE	19 36 18 Simha
Uttaraphalguni	146 40	CE 753	19 35 05 Simha
Hasta	160 00	CE 1711	19 34 46 Simha
Chaitra	173 20	CE 2667	19 34 11 Sinha
Swati	186 40	CE 3617	19 34 04 Simha
Vishakha	200 00	CE 4563	19 34 55 Simha
Anurdha	213 20	CE 5506	19 36 03 Simha
Dhanishta	226 40	CE 6442	19 39 31 Simha
Mula	240 00	CE 7373	19 45 56 Simha
Purvashadha	253 20	CE 8297	19 56 51 Simha
Uttarashadha	266 40	CE 9211	20 14 16 Simha
Shravana	280 00	CE 10113	20 40 35 Simha

on observing the Seven Sages rather than using any method of calculation that depended upon their specific rate of movement. Therefore, they did not need to know the exact rate: whether it was 1° per century or one Nakshatra per century was immaterial just so long as the pointer was observed and recorded at the time of a specific event. Even today if somebody wants to find out where Saptarishis is, this must be done by direct observation rather than by calculation. Anybody looking at the sky will see that Saptarishis is now in Hasta of the tropical zodiac. It can be said that when Jawaharlal Nehru was the President of India the Seven Sages were in Hasta, whereas when Parikshit was the ruler it was in Magha. This conclusion cannot be arrived at by any method of direct calculation.

5.6 The Saptarishis Era

The placement of the Saptarishis pointer against the tropical and sidereal zodiac is given in Tables 2 and 3. In the sidereal scale the pointer can be seen always to be in the Purvaphalguni Nakshatra (between 13° 20′ 00″ and 26° 40′ 00″) of Simha (Leo) Rashi (sign) between 10000 BCE and CE 10000. It is not easy to determine the exact point where the Saptarishis pointer crosses the ecliptic, but it is somewhere near the star cluster that is located between the two hind feet of the lion (i.e. within the light blue circle included in Figure 2). Out of the three stars, 56 Leonis, 59 Leonis and χ Leonis, 59 Leonis is the closest to the ecliptic, and its radial velocity also is closest to the radial velocity of Dubhe and Merak. Therefore, for practical purposes 59 Leonis is used as the reference point on the ecliptic in this research paper, although this is not the precise point. The sidereal longitude of 59 Leonis has been given using the Dulakara Ayanamsha, and the zodiac fixed as at CE 232. A slight change in the sidereal longitude is due to the proper motion of Dubhe and Merak (which have radial velocities of –9.40 ± 0.30 and –13.10 ± 0.01 km/s respectively; see Gontcharov, 2006). The proper motion of 59 Leonis (its radial velocity is –11.70 ± 1.30 km/s; ibid.) is very simlar to those of the other two stars.

Although against the sidereal zodiac the Saptarishis pointer is always in Purvaphalguni Nakshatra, the pointer migrates rapidly along the tropical zodiac at a rate of about 950 years per lunar mansion as a result of precession of the equinoxes (see Tables 2 and 3). It is obvious that this migration of the Saptarishis pointer along the tropical zodiac is the principle behind the Saptarishis Calendar.

5.7 Use of the Saptarishis Calendar for Dating Historical Events

The Saptarishis Calendar can be used to date important events in history, as the folowing examples demonstate.

5.7.1 The Mahabharata War and the Yudhishtira-Parikshit Era

The most famous statement regarding use of the Saptarishis Calendar is that Emperor Yudhishtira, who led the Pandava side to victory in the Kurukshetra War, ruled when Saptarishis was in Magha (Sloka 3, chapter XIII, *Brihat Samhita*). In the *Vishnu Purana*, it is said that at the birth of King Parikshit, the successor to Yudhishtira, Saptarishis was in Magha. According to Table 3, the Saptarishis pointer was in Magha between 1177 and 210 BCE.

It has been estimated by Witzel (1995) that the Kuru Kingdom existed between 1200 and 800 BCE. Pargiter (1922: 180–182) arrived at an approximate date of 950 BCE for the Bharata battle, and from a combination of archaeological and literatary evidence Lal (2012) came up with a figure of 900 BCE.

Elsewhere the author of this paper has concluded that the onset of Kali Yuga was in 951 BCE (Indrasena, 2015: 89). It is said in the *Mahabharata* that Kali Yuga commenced soon after Krishna's departure but actually it had already begun astronomically by the time of Krishna's death. Professor Narahari Achar (2010) has established that Krishna's demise occurred 36 years after the Mahabharata War. Accordingly, the year of the War can be dated to a couple of years later than 987 BCE.

5.7.2 Chronology of the Nanda Dynasty

The *Vishnu Purana* states that when Saptarishis was in Parvashadha, the Nanda Dynasty began. This statement cannot be explained by the principles outlined in this paper because Saptarishis cannot be expected to be in Purvashadha lunar mansion in the tropical zodiac until CE 8300. It is possible that this verse actually refers to Purvaphalguni rather than Purvashadha when it says 'Parvashadha'. If this is the case then the relevant time period would be after 210 BCE. Historians say that the Nandas were in power in the fourth century BCE, which approximately tallies with the Saptarishis era as outlined in Tables 2 and 3.

5.7.3 The Duration from Parikshit to Nanda

According to the *Vishnu Purana* (4th Amsa, 24th Adhyaya, 104th Sloka), 1,015 years elapsed from the birth of King Parikshit to the installation of King Nanda (Wilson, 1840). According to Wilson (ibid.) three copies of the *Vayu Purana* and five copies of the *Matsya Purana* give this interval as 1,050 years, and one copy of the *Matsya Purana* mentions 1,500 years. Meanwhile, the *Bhagavata Purana* gives 1,115 years.

As indicated above, King Parikshit must have been ruling around 950 BCE, and since the start of the Nanda Dynasty is dated to 345 BCE by historians (e.g. see Panda, 2007: 28), there is a gap of about 600 years between these two figures. This figure is much less than the gap mentioned in the *Puranas*, which is variously mentioned as from 1,015 years, to 1,500 years.

It has to be understood that when the *Vishnu Purana* says that the gap between Kings Parikshit and Nanda was 1,015 years, this is in terms of 'Saptarishis Years', since this gap has been given in the paragraph where the ages of Kings Parikshit and Nanda are given in relation to the Saptarishis Calendar. Since the Saptarishis pointer moved at a rate of 1° in 100 years, the duration of one 'Saptarishis year' was 0.01°. When King Parikshit ruled it was Magha and when Nanda ruled it was Purvaphalguni. The difference is one lunar mansion of 13.33°. With the rate of precession of ≤1° in 100 years this amounts to not more than 1,333 years. This is compatible with the gap given in the *Puranas* which ranges between 1,015 and 1,500 years.

5.7.4 The Saka Era in the *Brihat Samhita*

Another perplexing question that baffles scholars the world over is Varahamihira's claim in the *Brihat Samhita* that the year of King Yudhisthira's reign can be obtained by adding 2,526 years to the Saka era:

> The Seven Sages were in the lunar mansion Magha when king Yudhisthira was ruling over the earth, the period of that king being 2526 years before the commencement of the Saka era. (Sloka 3, Chapter XIII; Iyer, 1884: 156).

This quotation should also be understood in the same context as above because the figure 2,526 is in 'Saptarishis years'. This gap is approximately equivalent to two Sapatarishis Nakshatras. Since by the time of Yudhisthira it was Magha, the Saka era that Varahamihira mentions in the *Brihat Samhita* must have been when the Seven Sages were in Uttaraphalguni. As seen in Table 3, the Saptarishis entered Uttaraphalguni in about CE 700. Therefore, the Saka era mentioned in the *Brihat Samhita* is clearly different from the commonly-known Saka era that is said to have begun in CE 78.

A Saka era that began in CE 638 is currently in use in Southeast Asia (see Eade, 1995; Irwin, 1909). It is known as Chula Sakarat, meaning 'small Saka'.[3] At present, the Chulasakarat Calendar is used in Thailand and in other Southeast Asian countries, and the Shalivahana era that began in CE 78 is known as the Mahaskaraja era in these countries. The Chula Sakarat Calendar is a variation of the Hindu Calendar, which also incorporates the Metonic cycle of the Greeks.

Accordingly, it is clear that the Saka era that is mentioned in the *Brihat Samhita* refers to the Chula Saka era that is still in use in Thailand and certain other Southeast Asian countries. Since the Chula Saka Calendar is a combination of both Vedic and ancient Greek astronomy it can be concluded beyond any reasonable doubt that the Saptarishis Calendar was based on both Vedic and Greek astronomy.

6 CONCLUSION

The Saptarishis Calendar is a reality: it is not just a convention but is an astronomically-explainable phenomenon. It followed the precessional rate and tropical zodiac of the ancient Greeks. Saptarishis (the Seven Sages) moves forwards from one lunar mansion to the next, covering all 27/28 lunar mansions in one precessional cycle. The axis of the Saptarishis pointer always passes through the stars Dubhe and Merak in Ursa Major, and crosses the ecliptic at a point that can be identified using the tropical zodiac. The pointer does not move with time but the tropical zodiac does in a backward direction against the Saptarishis pointer, which paved the way for the time-keeping system known as the Saptarishis Calendar in ancient India.

7 NOTES

1. A Nakshatra is a lunar mansion.
2. This date was chosen because the Dulakara Ayanamsha assumes that the year CE 232 is the Ayanamsha year zero, when the tropical and the sidereal zodiacs coincided exactly.
3. In the Pali language the meaning of 'Chula' is 'small'.

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WILLIAM HERSCHEL AND THE 'GARNET' STARS: μ CEPHEI AND MORE

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Abstract: Although William Herschel's 'Garnet Star' (μ Cephei) is a prominent object, the story of the discovery of this famous red star is not well documented. Prior to and after Herschel, the identification of this star was the subject of confusion in various catalogues and atlases. The case is complex and involves other stars in southern Cepheus, including double stars, found by Herschel in the course of his star surveys.

It is also fascinating to learn that μ Cephei is not the only star called "garnet" by him. This study reveals that there are 21 in all, resulting in a "Herschel Catalogue of Garnet Stars"—the first historical catalogue of red stars. Among them are prominent objects, which in the literature are credited to later observers. This misconception is corrected here, for Herschel was the true discoverer of all of them. The most interesting cases are Hind's 'Crimson Star', Secchi's 'La Superba', John Herschel's 'Ruby Star' and Schmidt's V Aquilae.

Finally, we discussed whether Herschel speculated about the physical nature of his garnet stars, many of which are now known to be variable.

Keywords: William Herschel, Herschel's 'Garnet Star', John Herschel, Jérôme Lalande, red stars, variable stars, double stars, star catalogues, star atlases, spectroscopy

1 HERSCHEL'S DISCOVERY IN 1782

The fourth magnitude star μ Cephei (Erakis), commonly known as 'Herschel's Garnet Star', is one of the most prominent naked eye red stars in the sky. The standard reference to this is William Herschel's paper "On the proper motion of the Sun and Solar System", which was published in the *Philosophical Transactions of the Royal Society* (Herschel, W., 1783a: 257). Therein, a special section mentions "Stars newly come to be visible …", where nine examples are listed. The third of these, which impressed the ethnic German astronomer because of its peculiar colour, is described as follows:

> A very considerable star, not marked by Flamsteed, will be found near the head of Cepheus. Its right ascension in time is about 2′ 19″ preceding Flamsteed's 10th Cephei, and it is about 2° 20′ 3″ more south than the same star. It is of a very fine deep garnet colour such as the periodical star o Ceti [Mira] was formerly, and a most beautiful object, especially if we look for some time at a white star such as α Cephei, which is near at hand [4° northwest], before we turn our telescope to it.

When did Frederick William (later Sir William) Herschel (1738–1822; see Figure 1) discover the 'Garnet Star'? The exact date can be found in his "Journal No. 4", covering the period of his 'third star review' in which all Flamsteed stars were inspected (and this campaign resulted in the discovery of many new double stars). Herschel's telescope was a reflector of 6.2 inches aperture and 7 feet focal length (the very instrument with which he found Uranus on 13 March 1781; see Figure 2). The Journal entry for 27 September 1782 reads:

> A very considerable star not marked in Fl[amsteed's] Atlas, its place should be there about 45′ past 21^h. 32½ Deg Polar distance. It is of a very deep fine garnet. This must be looked at often. Very beautiful indeed. (Herschel, W., 1782a: 32; see Figure 3).

Figure 1: William Herschell (after Holden, 1881: Title Page).

Thus we know that Herschel discovered the 'garnet star' in Cepheus on 27 September 1782, and that the observation was made from Datchet. He later copied the note into the third folder on the "Fixt Stars" (Herschel, W., 1782b: 238).

On that same September night Herschel discovered seven double stars: I 48, I 49, III 70, III 71, III 72, IV 78, IV 79 (designated by class and

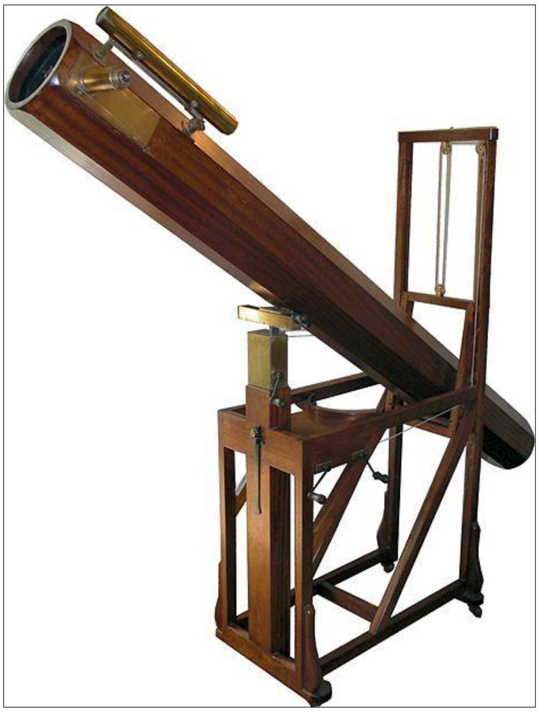
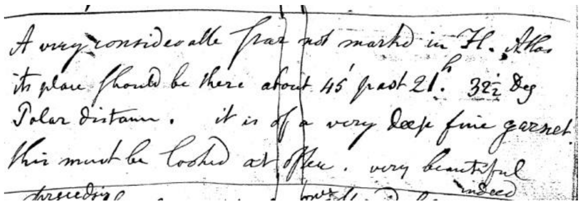


Figure 2: A replica of the telescope that Herschel used to discover Uranus and his Garnet Star in Cepheus (en. wikipedia.org).

number; Herschel, W.,1785). All are in Cepheus, and four of them (I 49, III 71, III 72, IV 79) are near the Garnet Star in the southern part of the constellation. Herschel (1782–1783a: 349) again surveyed the area on 16 March 1783:

> New Garnet Star Cephei, uncommonly beautiful [magnification] 460. With 932 finely distinct, seems of a larger diameter[1] than stars of that size as generally seen in the finder. With 1504 very well defined. The diameter is not larger than that of 10 Cephei with the same power. The colour continues the same with all the powers, with the naked eye rather larger than the 9th Cephei.



A very considerable star not marked in Fl. Atlas
its place should be there about 45' past 21h. 32½ deg
Polar distance. it is of a very deep fine garnet
this must be looked at often. very beautiful

Figure 3: Herschel's note about the discovery of the Garnet Star in Cepheus, dated 27 September 1782 and contained in "Journal No. 4" (Herschel, W., 1782a: 32). The two vertical lines indicate that the text was later copied to another folder ("Fixt Stars No. 3").

On 24 March 1783, Herschel (1782–1783a: 351) revisited the double stars III 71 and III 72, located 1.3° southwest of the Garnet Star. Another observation followed on 5 April 1783:

> Garnet Star Cephei. With the 20ft reflector is a most beautiful object; the colour being very vivid & the same as before described. There are great many stars about it. (Herschel, W., 1782–1783a: 363).

The reflector in question is the 'small 20-ft' with an aperture of 12 inches (Figure 4). On 21 May 1783 the Garnet Star was the target of a 'prismatic experiment' at the 10-ft reflector. Herschel used a prism at the eyepiece and described the colours seen in the continuous spectrum; of course, due to the low dispersion, no lines were seen, and the red part of the spectrum dominated, which showed the lowest refraction. Herschel (1782–1783a: 385) wrote:

> The spectrum of α Cephei with 10ft reflector power about 100 gave the colours r o y g b p v [red, orange, yellow, green, blue, purple, violet]. The Garnet Star gave only r y g perhaps o may be there in some small degree. I repeated the experiment several times on both stars but could find no b p v in the Garnet Star.

On 29 September 1783 Herschel (1782–1783a: 443) showed the Garnet Star to his friends Alexander Aubert and Charles Bladgen, using the standard 7-ft reflector and the brand-new 'large 20-ft' reflector with an aperture of 18.7 inches (Figure 5).

The star also appeared in two of his sweeps for nebulae, made at Slough. Sweep 768 (16 October 1787): "7 m. of a deep orrange [*sic*] colour, or pale garnet. Very different from all the stars in this neighbourhood. U^{794}" (Herschel, W., 1787–1790). Because the star was not in Flamsteed's catalogue it was entered in a list of 'unknown stars', getting the number 794 (hence 'U^{794}' in the quotation). The reference star for the position was 14 Cep, which was 2.5° to the southeast. And in sweep 875 (1 November 1788) we have: "6 m. garnet colour. U^{794}." with the reference star 10 Cep, 2.4° to the north. It is interesting that Herschel does not mention his earlier observations; perhaps he thought the garnet-coloured star was a new object. It seems that he was not expecting to encounter this object in these sweeps. Table 1 lists all eight obser-

Table 1: Herschel's observations of the Garnet Star. Sources: J = Journal, F = Fixt Stars (with page number; see References).

Date	Source	Telescope	Remarks
1782, September 27	J4, 32; F3, 238	7-ft	"very deep fine garnet"
1783, March 16	J5, 43; F4, 349	7-ft	"New Garnet Star Cephei"
1783, March 24	J5, 46; F4, 351	7-ft	double stars near Garnet Star (III 71, III 72)
1783, April 5	J6, 5; F4, 363	small 20-ft	"Garnet Star Cephei"
1783, May 21	J6, 17; F4, 385	10-ft	"prismatic experiment"
1783, September 29	F5, 443	7ft, large 20-ft	visitors: Alexander Aubert, Charles Bladgen
1787, October 16	sweep records	large 20-ft	sweep 768, U^{794}
1788, November 1	sweep records	large 20-ft	sweep 875, U^{794}

vations of the Garnet Star that Herschel made over a period of six years.

2 OTHER OBSERVERS, VARIABILITY AND CATALOGUING

The next to observe Herschel's Garnet Star was Guiseppe Piazzi (1746–1826; Figure 6) in late August 1799, using the 3-inch Ramsden refractor at the Palermo Observatory. It is listed in his star catalogue (Piazzi, 1803) as an anonymous star of magnitude 6 in Cepheus (Hora XXI). The English translation of the separate note reads:

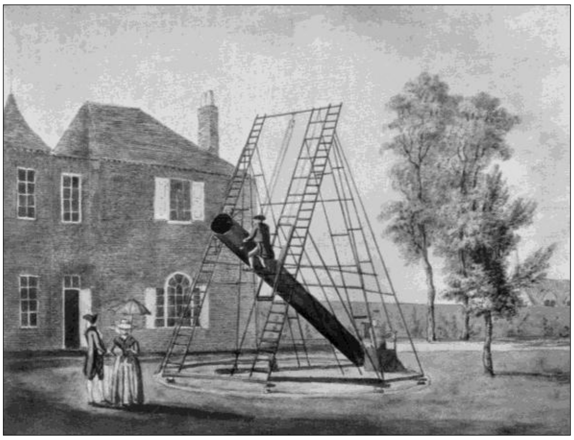


Figure 4: Herschel's 'small 20-ft' telescope at Datchet (after Dreyer, 1912: Volume 1, Plate B).

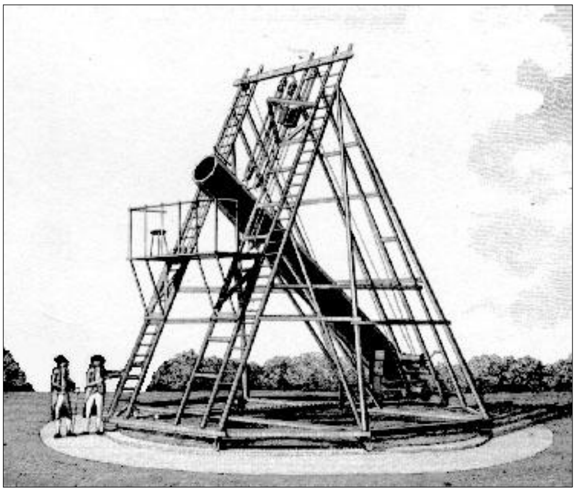


Figure 5: Herschel's 'large 20-ft' telescope (http://faculty.humanities.uci.edu/bjbecker/ExploringtheCosmos/week6d.html)

"Star of this obscure red colour supposedly first appeared around 1782."[2] Piazzi refers to Herschel's publication of 1783. In the second edition of his catalogue Piazzi (1814) refers to the star as 'Garnet Sidus'. All entries are numbered now, and Herschel's star is number 285 in Hora XXI, which led to the later designation 285 P. XXI (but the terms XXI P. 285 and P. XXI. 285 also were used).

It is interesting that the Garnet Star was not observed by Joseph Jérôme Lefrançois de Lalande (1732–1807) in the course of his measure-

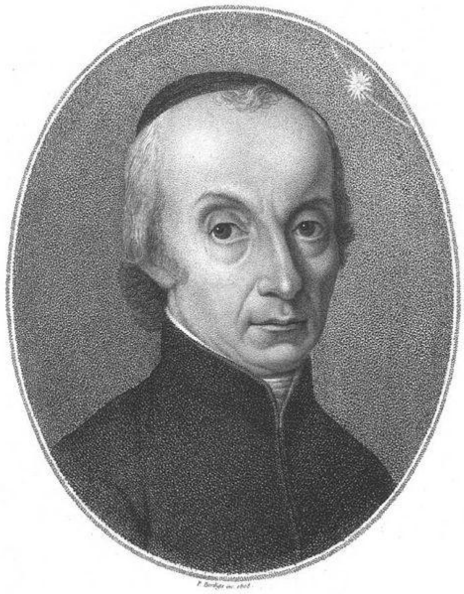


Figure 6: Giussepe Piazzi (en.wikipedia.org).

ments at Paris in the late eighteenth century, when he recorded 47,390 stars down to visual magnitude 9. Thus, the object is missing from his great catalogue *Histoire Céleste Française* (Lalande, 1801; cf. Baily, 1847). Magnitude and colour could not have been the reason, for Lalande did observe comparable red stars (see below).

Herschel's Garnet Star is anonymously listed in the zone observations made by Friedrich Wilhelm August Argelander (1799–1875; Figure 7) at the Bonn Observatory from 1841 to 1844. The measurement was made on 11 September 1842. Argelander listed the position for 1842 and noted it as "… very red." (see Oelzen, 1852). The magnitude was estimated as 3, which is surprisingly bright, and this led John Russell Hind (1823–1895; Figure 8), the observer at Bishop's Observatory in Regent's Park (London), to speculate about its possible variability: "The remarkable

Figure 7: F.W. Argelander (en.wikipedia.org).

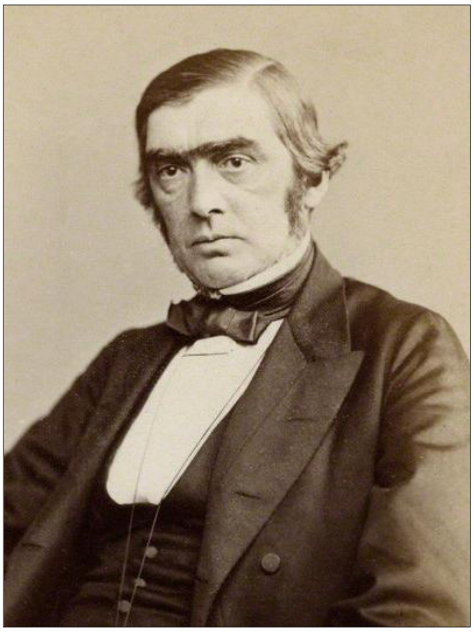


Figure 8: J.R. Hind (en.wikipedia.org).

garnet-stars [*sic*] in Cepheus appears to be fluctuating in brilliancy." (Hind, 1848a). Intrigued by this remark, Argelander—who was very interested in variable stars—watched this star from 1848 to 1864 (Argelander, 1869: 371–372), and it became clear to him that the red colour created difficulties when it came to making magnitude comparisons with nearby stars. During the early years that he monitored this star Argelander was supported by his assistants, Johann Friedrich Julius Schmidt (1825–1884) and Eduard Schönfeld (1828–1891).

In 1861 the young George Frederick Chambers (1841–1915) published a list of 99 variable stars in his influential *Handbook of Descriptive and Practical Astronomy* (Chambers, 1861). Herschel's Garnet Star is no. 92, and is listed as: "μ Cephei, Sir W. Herschel 1782." That he cites 1782

Figure 9: Eduard Schönfeld (en.wikipedia.org).

is interesting, because it is not mentioned in Herschel's 1783 publication (and Piazzi only noted "… circa annum 1782."). What was Chambers' source? It must have been Herschel's second catalogue of double stars where we find the following entry:

> III. 71. Tiaram Cephei praecedens.[3] Sept. 27, 1782. Treble. About 1½ degree preceding the *Garnet Star*, in a line parallel to ι and ζ Cephei ... The place of the *Garnet Star*, reduced to the time of FLAMSTEED'S Catalogue, is about AR 21 h. 45′. P.D. 32°½. (Herschel, W., 1785: 83).

We know from Herschel's unpublished Journal that this is one of the double stars that was discovered on the same night as the Garnet Star. Chambers therefore must have concluded that the date "Sept. 27, 1782" was when the Garnet Star also was discovered, though this is not mentioned explicitly. An enlarged version of Chambers' list of variable stars subsequently appeared in *Astronomische Nachrichten* (Chambers, 1864), but no additional information is given about the Garnet Star.

In the same year Eduard Schönfeld (Figure 9) published a catalogue of 119 variable stars, which included μ Cepheus as no. 112, with a magnitude range of 4–5:

> Sir W. Herschel's Garnet Star, thought to be new by him; but, as Argelander has shown, it already appears in the Almagest. In 1848 Hind called attention to the variability of the star; however, the reasons were not sufficiently convincing at that time, thus Argelander had doubts. But later the latter could confirm the variability by comparisons over several years. Among all naked eye northern stars the Garnet Star has the most intense red colour. (Schönfeld, 1864).

In Schönfeld's second catalogue the star is no. 135 (Schönfeld, 1875).

In 1872 Julius Schmidt (Figure 10), by now Director of the Athens Observatory, published a report of his observations, titled "μ Cephei, Herschel's 'Garnet Star'." (Schmidt, 1872). The variability was later studied by several astronomers (e.g. Hassenstein, 1938; Percy at al., 2001). The star in fact varies with a semi-regular period of 800–1000 days around a mean visual magnitude of 4.5, with Δv ~1.

The Garnet Star is also listed in the first comprehensive catalogue of 280 red stars, published by the Danish astronomer Hans Carl Frederik Christian Schjellerup (1827–1887) and titled "Catalogue of red, isolated stars which became known before 1866" (Schjellerup, 1866). Here no. 253 is "W. Herschel's *Granatstern*". It also appears in the red star catalogues of George Chambers (1867: 591; 1887) as no. 266 and no. 656, respectively, and John Birmingham (1816–1888) as no. 594 (Birmingham, 1877).

Herschel's Garnet Star was also featured by the great Victorian popularisers of astronomy in their observing guides: William Smyth (1788–1865; 1844), Thomas Webb (1807–1885; 1859) and William Darby (1864). All three used the Piazzi designation 285 P. XXI. It is interesting that there is no reference to μ Cephei. The first to publish the Bayer designation was Chambers (1861); hence it is also present in his update of Smyth's *Cycle* (Chambers, 1881: 639).

3 WILL THE REAL *μ* PLEASE STAND UP!

The identification of μ Cephei was a problem that extended over centuries. The case looks like a cabinet of curiosities. Five other stars are involved, including ν Cephei (2.3° north of μ and variable too) and Herschel's double star IV 79 (3.2° southeast of the Garnet Star). It is interesting to compare some important star catalogues and atlases of the time. Table 2 below shows all six relevant stars (see Figure 11 for their positions). The correct identification is given in the second row.

Johann Bayer (1572–1625) created the designation "μ Cephei" in his famous *Uranometria* (Bayer, 1603; Berberich, 2010). This work uses Claudius Ptolemy's star catalogue, given in the *Almagest*, but adds many new stars. Ptolemy lists 11 principal stars in Cepheus, and two additional ones under "Informatae" (Peters and Knobel, 1915). The first of them ("Precedens tiaram"), given as magnitude 5, is Bayer's μ Cephei; the second is the famous variable star δ Cephei ("Sequens tiaram"). Alas, Bayer reverses Ptolemy's sequence in assigning the numbers 13 and 12 for μ and δ in his star list (instead of 12 and 13); the chart, however, shows the correct order. Only two of the six stars in Cepheus listed in Table 2 were known to Bayer: μ and ν (chart A of Figure 12). Although no coordinates are given in his star list, a celestial grid marks the position.

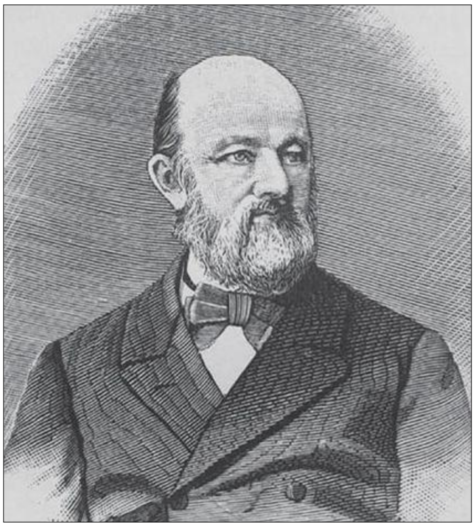


Figure 10: Julius Schmidt (en.wikipedia.org).

The next relevant observer is John Flamsteed (1646–1719; Figure 13). His British Catalogue (Flamsteed, 1725) contains a Cepheus star called μ (Figure 14): the 13th entry in that constellation (thus later designated 13 Cephei). But the position for 1690 is incomplete: a polar distance of 34° 50′ 10″ is given, but no right ascension (AR). However, the PD does not match Bayer's star! Thus, 13 Cephei is a different object, 2.6° southeast of Bayer's μ. A similar case is the nearby star ν Cephei: Flamsteed erroneously lists it as 15 Cephei, located 2.6° southeast of ν.

Curiously, the first to present a map of all stars of the British Catalogue was not Flamsteed.

Table 2: Problematic stars in southern Cepheus (shown in Figure 2) and their appearance in some important historic works. Wrong or incomplete identifications – relative to the correct one in the second row – are marked in bold italics.

Star	μ	13	IV 79	14	ν	15
Correct identification	μ = Garnet Star	13 Cep	IV 79 = N. 57	14 Cep	ν = 10 Cep	15 Cep
Bayer 1603	μ	--	--	--	ν	--
Flamsteed 1725/29	--	***μ = 13 Cep***	--	14 Cep	***10 Cep***	***ν = 15 Cep***
Harris 1727	--	***μ = 13 Cep***	--	14 Cep	***10 Cep***	***ν = 15 Cep***
Herschel 1782	***Garnet Star***	--	***IV 79 = μ = 13 Cep***	14 Cep	***10 Cep***	***ν = 15 Cep***
Bode 1782	(μ)	***μ = 13 Cep***	--	14 Cep	***10 Cep***	***ν = 15 Cep***
Wollaston 1789	***Garnet Star***	***IV 79 = μ = 13 Cep ?***	***N. 57***	14 Cep	***10 Cep***	***ν = 15 Cep***
Bode 1801	-	***154 = IV 79 = μ = 13 Cep***	147	165 = 14 Cep	***139 = σ = 10 Cep***	***171 = ν = 15 Cep***
Piazzi 1814	***285 = Garnet Sidus***	***347***	--	385 = 14 Cep	***297 = 10 Cep***	***399 = ν = 15 Cep***
Baily 1835	***--***	***2997 = μ = 13 Cep***	--	3016 = 14 Cep	2984 = ν = 10 Cep	3025 = 15 Cep
Baily 1845	***7582***	***7643 = μ = 13 Cep***	7631	7683 = 14 Cep	7595 = ν = 10 Cep	7696 = 15 Cep
Argelander 1843	***XXI P. 285***	--	--	***385 = μ = 14 Cep***	297 = ν = 10 Cep	399 = 15 Cep
Argelander 1859	+58 2316	+55 2644	+55 2638	+57 2441	+60 2288	+59 2456
Heis 1872	μ	13 Cep	--	14 Cep	ν = 10 Cep	15 Cep

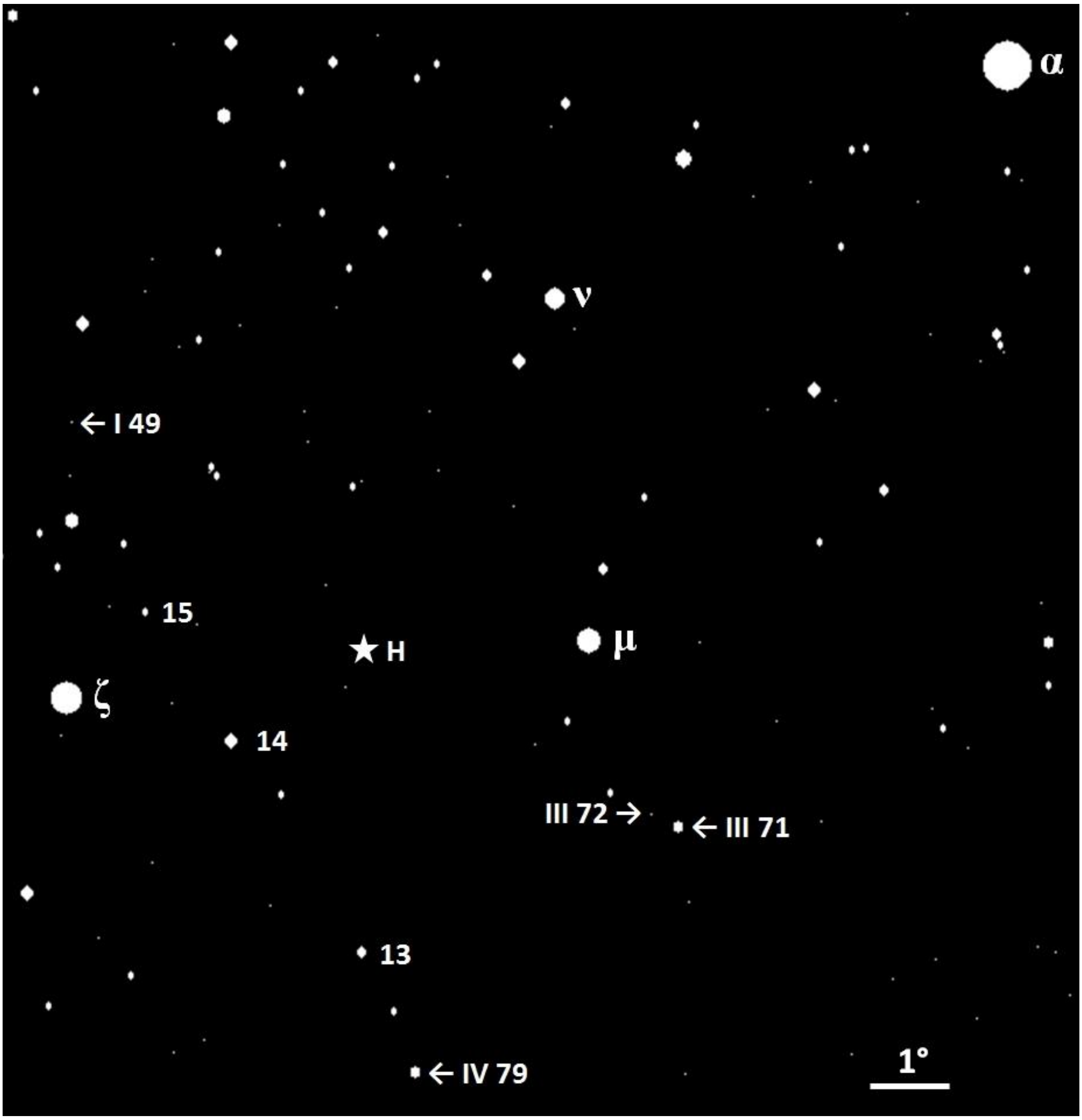


Figure 11: Map showing the stars listed in Table 2 (area around μ Cephei). Herschel's position of the Garnet Star is marked by an 'H', and the locations of his double stars I 49, III 71 and III 72 also are given.

Two years before Flamsteed published his *Atlas Coelestis* (1729), the Welsh astronomer, Joseph Harris (1702–1764; Steincke, 2014), produced a pair of single-sheet charts, showing the skies of the northern and southern hemispheres (Harris, 1727). Due to the missing AR and wrong PD, 13 Cephei is incorrectly labelled μ in Harris' northern map and the position of the true Bayer star is blank! For ν it is analogous: 15 Cephei is labelled ν, while the true Bayer star is 10 Cephei (Figure 12, chart B). Flamsteed's *Atlas Coelestis* shows the same, but there is no label "ν" (Figure 12, chart C).

Now William Herschel comes into play. At the time of his third star review he was using Flamsteed's British Catalogue and *Atlas Coelestis*. For quick identifications, he still had Harris' star maps at hand. The discovery night of the Garnet Star (27 September 1782) brought a lot of confusion. When Herschel tried to identify the "… very beautiful …" object, he saw that it was "not marked by Flamsteed" (actually it was Caroline Herschel who did this job). There is no object at the position of the Garnet Star (Bayer's μ Cephei) in the British Catalogue and the related charts. But the data reduction brought an error too! The calculated position "… relating to the time of Flamsteed …" (1690) led to RA = 21^h 45′ and PD = 32° 30″ (Herschel, W., 1782b). This is strange, for while the PD is that of Bayer's μ Cephei, the RA is that of Flamsteed's 13 Cephei (see Figure 11, "H")—a curious mix! When preparing his *Philosophical Transactions* paper "On the proper motion of the Sun …", which was read

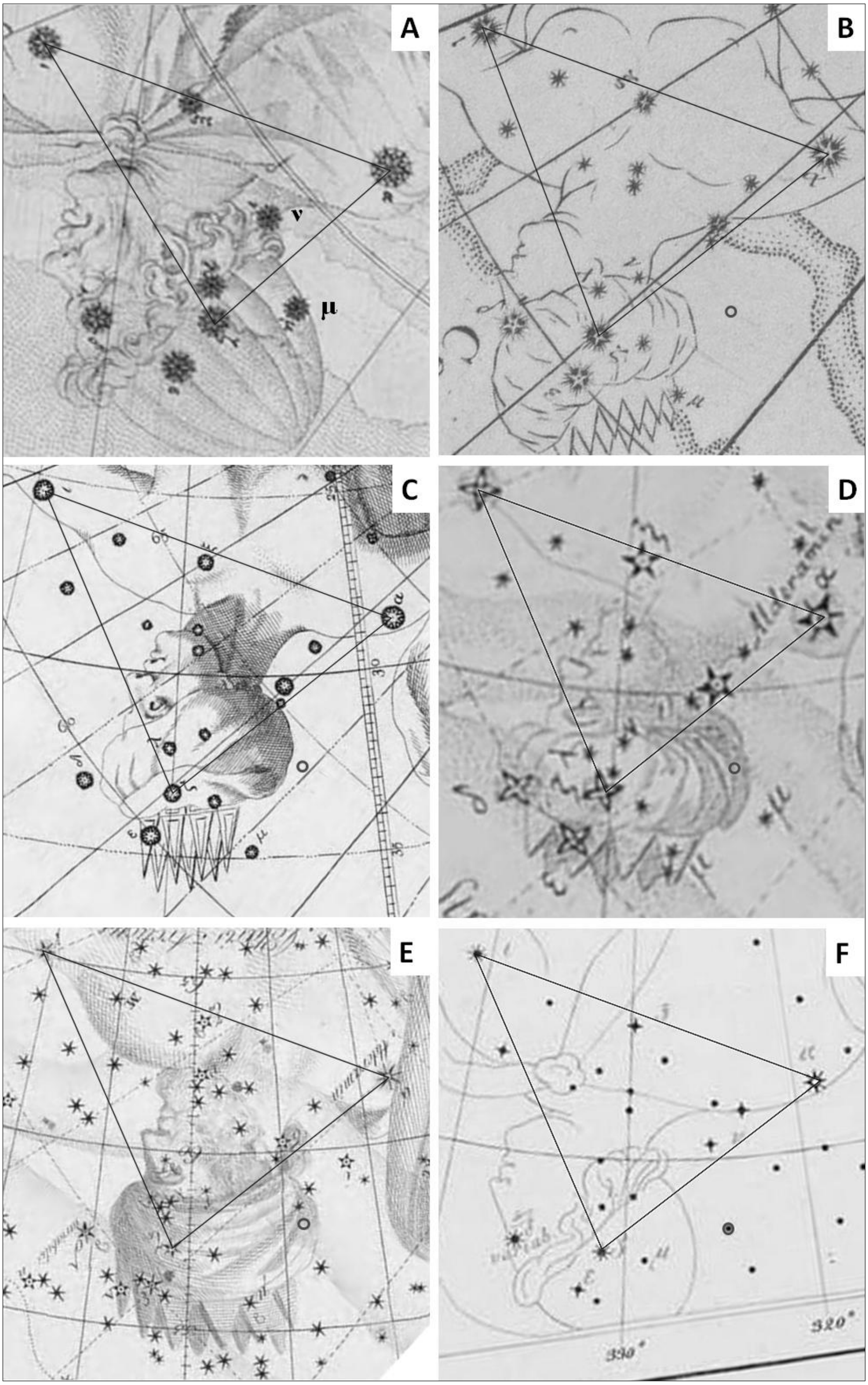


Figure 12: Comparison of the southern Cepheus area in six important atlases or maps: A = Bayer, B = Harris, C = Flamsteed, D = Bode 1782, E = Bode 1801, F = Argelander. For orientation all charts are rotated to have north up and equally scaled (the triangle connects α, ι and ξ Cephei). The position of Bayer's μ Cephei is marked by a small circle (right below centre).

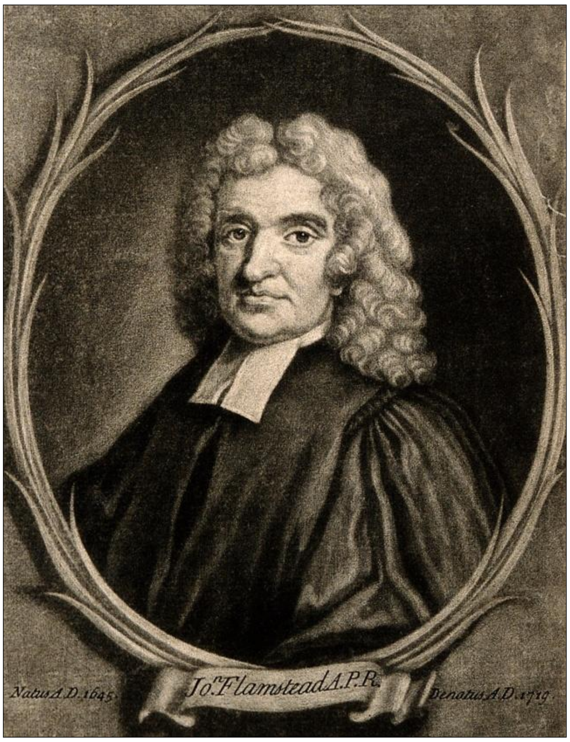


Figure 13: John Flamsteed (en.wikipedia.org).

on 6 March 1783, Herschel became aware of this error. Therein the place of the Garnet Star is correctly given relative to 10 Cephei: 2′ 19″ preceding, 2° 20′ 3″ south!

Further confusion is demonstrated when Herschel announces a new double star (IV 79, see Figure 11), which was found later that same September night: "μ Cephei. Fl 13. double. 4th Class." He not only equates μ Cep with 13 Cep, but also identifies Flamsteed's star with the new pair, athough located about 1° southwest (the magnitudes matched). Herschel had no reliable data for 13 Cep. This is reflected in Caroline Herschel's list of the Flamsteed stars with positions for 1690, arranged in zones of constant polar distance (Herschel, C., 1786). The star μ 13 is listed in zone 30–35°, but only the PD is given. In her compilation of all double star observations, we still have "μ Cephei Fl. 13", and three observations are listed: 27 September and 21 December 1782 and 16 August 1783 (Herschel, W., 1776–1781: 202). But in William Herschel's second catalogue of double stars (Herschel, W., 1785) we read for IV 79: "Prope μ Cephei Fl. 13", where "prope" means "near to". Thus he must have noticed the error. There is no observation of the true 13 Cephei, neither in the reviews nor during the sweeps.

During sweep 765 on 14 October 1787 Herschel discovered a new double star, and it was observed again two days later during sweep 768 (which also marked his last observation of the Garnet Star). Later this object was named N. 57 in a list of 145 new double stars that were found during the sweeps (Herschel, W., 1822). Around the end of 1787, Herschel described 15 of the new double stars (N. 57 and 58 being the last) in a manuscript that he would send to Francis Wollaston (1731–1815) for inclusion in his new star catalogue (see below).[4] Herschel did not identify IV 79 and N. 57, and the first to do so was Friedrich Georg Wilhelm von Struve (1793–1864), who published it in his *Catalogus Novus* (Struve, 1827). This double star is no. 2840 (modern designation Σ 2840), and is identified with Cephei 147 (see below) and H. N. 57 =

In Conſtellatione CEPHEI.

Ptol.											
1	10	Quæ in Crure dextro eſt	κ	304 30 0	13 14 35	♉ 28 51 22	75 28 30	B	27 40	13 32	5
6	8	Sub Ancone dextri Brachii	θ	306 0 30	28 2 0	♈ 0 37 40	73 57 30		18 48	14 1	5
5	7	Ad dextri Brachii Anconem	η	309 39 0	29 21 5	0 12 58	71 46 22		22 25	15 10	4
			4	309 41 30	24 27 30	14 55 55	74 7 3		14 43	15 17	6
4	2	Tangit dextrum Humerum	α	317 43 30	28 42 20	8 30 33	68 56 20		25 45	17 37	3
			6	318 9 40	26 25 30	14 18 38	69 59 30		23 1	17 45	6
			7	320 20 30	24 31 40	20 30 18	70 2 55		21 42	18 22	6
		In Cingulo ad dextrum latus	β	321 3 0	20 47 35	♉ 1 17 53	71 9 0		15 40	18 32	3
3	1		9	322 19 0	29 17 40	♈ 10 42 10	66 47 28		29 0	18 52	6
			10	324 5 0	30 17 40	10 5 8	65 29 3		31 0	19 17	5
			11	324 14 30	20 6 50	♉ 4 13 47	70 16 30		17 7	19 22	5
			12	324 29 30	30 44 10	♈ 9 35 5	65 2 35		31 42	19 25	7
			μ		34 50 10						6
			14	327 51 0	33 28 56	7 41 48	61 52 50		35 47	20 10	6
			ν	328 23 0	31 40 20	10 58 16	62 54 22		34 38	20 16	7.6
			16	328 34 30	18 17 25	♉ 10 26 48	69 24 0		17 33	20 23	5.6
7	9	In Pectore	ξ	328 38 30	26 52 0	♈ 19 54 39	65 45 5	B	30 33	20 21	5
			14		28 23						

R

Figure 14: Extract from Flamsteed's British Catalogue. μ Cephei is the 13th entry in Cepheus. Note that Flamsteed numbers are inserted by hand where no Bayer letter is present. Owen Gingerich (private communication) conjectures that this could be Bode's copy (the original is at the Bayerische Staatsbibliothek).

H. IV. 79. The situation is clarified by the note: "μ Cephei itaque non est H. IV. 79." Later John Herschel (1867) copied this result in the synopsis of his father's double star observations.

On that remarkable September night Herschel found three other double stars in the same area as the Garnet Star:

> Preceeding the new Garnet Star in Cepheus. Treble. One of the 3rd Class the other of the 4th Class. [III 71, and] … Just following the above treble star. Double 3rd Class. [III 72].

Two of these were ~1.4° southwest of the Garnet Star, and the third star was a "Double 1st Class" (I 49), although the described location does not match the star that was referred to (Figure 11 shows the locations of III 71, III 72 and I 49). No doubt, to Herschel southern Cepheus was a confusing area!

In 1782 the Berlin astronomer Johann Elert Bode (1747–1826; Figure 15) presented an astonishing version of the case in his popular star atlas *Vorstellung der Gestirne* (Bode, 1782). We are now faced with two stars labelled μ Cephei (Figure 13, chart D)! One is at the position of 13 Cep and the other is 1.3° southwest of the Garnet Star (and therefore it accidentally matches the position of Herschel's double star III 71). However, Bode's star catalogue, with positions for 1780, only lists one μ (which corresponds to 13 Cep), and the identification of ν Cephei is still wrong.

The next relevant person is Herschel's friend Francis Wollaston. In his zone catalogue, giving positions for 1790, the situation for μ Cep is similar to Herschel's view (Wollaston, 1789). The Garnet Star is included: "… mentioned by Hersc. as supposed to be new 1782±, a pretty considerable Star." However, Herschel's identification of IV 79 with 13 Cep and μ is now doubted. Thus, Wollaston's note for 13 Cep reads:

> Whether this be the same as *μ Cephei*, N° 13 of Flamsteed, is uncertain; since this is an imperfect observation. Herschel sets *μ* down as a double star (IV. 79).

It is not clear what is meant by "imperfect observation". Herschel's record does not mention any problems. Wollaston also lists the new double star N. 57 (the true IV 79): "a double star (Hers. M.S.) Oct. 1787."

In 1801 Bode published his *magnum opus*, the *Uranographia* (Bode, 1801a), showing stars down to magnitude 8. Unlike in 1782, there is now only one μ at the 13 Cep position (see Figure 13, chart E), but curiously, in the accompanying catalogue (Bode, 1801b), with positions for 1801, this star is listed as no. 154 in Cepheus and identified with Herschel's double star IV 79 (whereas the true IV 79 is no. 147 in Cepheus)! Later, Caroline Herschel (1750–1848; Figure 16) identified N. 57 with "No. 147 Cephei of Bode's Cat." in the final copy of the sweep records, without mentioning IV 79 (Herschel, W., 1786–1787: sweep 765). The situation for ν Cep had changed too: to make matters worse, the false ν (10 Cep) was called "σ Cephei", even though there is no such star in Bayer's *Uranometria*!

Figure 15: J.E. Bode in about 1802 (en.wikipedia.org).

How does Piazzi manage the case? He lists the Garnet Star as no. 285 (Hora XXI) in his Palermo star catalogue of 1814 (but μ is not mentioned). Meanwhile, star no. 347 (13 Cephei) is

Figure 16: Caroline Herschel in 1829 (after Clerke, 1895: f. 114).

Figure 17: Francis Baily (en.wikipedia.org).

referred to as a Hevelius star and no. 299 is incorrectly called 15 ν Cephei, while the true ν is no. 297 (10 Cephei).

Eventually, Francis Baily (1774–1844; Figure 17), an expert in producing star catalogues, would correct some of these errors. In his revision of the British Catalogue (1835) the star 13 Cephei μ is listed as no. 2997 (with the position for 1690). There is an interesting remark in the notes about Flamsteed's observation:

> It was observed on Sept. 28, 1692, at about 8h 47m; but the time of transit is only approximately noted; and I have therefore left the right ascension doubtful.

The reason for the missing AR of 13 Cep is clear now, but it is surprising that the wrong identification of μ as 13 Cep remains, even though Baily had compared Flamsteed's catalogue with Bayer's atlas. However, the puzzle of ν Cephei was solved: for star no. 2984 we have "10 Cephei ν", and Baily's note reads: "Flamsteed has erroneously annexed the letter ν to 15 Cephei, instead of this star, to which it properly belongs." The true 15 Cep is no. 3025. The corrections also were transferred to Baily's *British Association Star Catalogue* (BAC) of 1845, with positions for 1850. Herschel's Garnet Star is included (no. 7582), without any comment. It is interesting that this star is even featured in Alexander von Humboldt (1769–1859) in his monumental *Kosmos* (Humboldt, 1850), where it is called "Granat-stern" (Garnet Star), with a reference to Baily's BAC 7582.

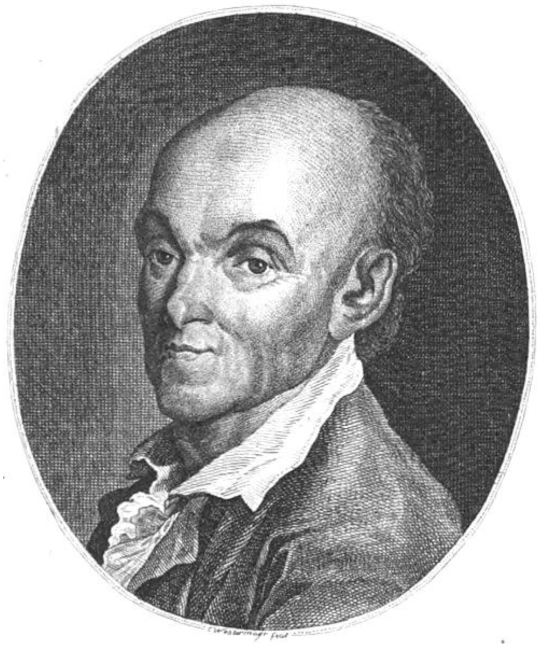


Figure 18: An engraving of Jerôme Lalande by Conrad Westermayr (en.wikipedia.org).

One would think that only the identification of the Garnet Star with μ Cep and the assignment of 13 Cep as a separate star were left, were it not for Argelander's account in his *Uranometria Nova* (1843). This catalogue and atlas contains all naked-eye stars with positions for 1840. During his zone observations he had noticed the "red star" in Cepheus, correctly identifying it with Piazzi's XXI P. 285. However, Bayer's μ Cephei is now placed at the position of 14 Cephei = XXI P. 385, while 13 Cephei is missing altogether! However, it also was Argelander who eventually would clear up the remaining puzzle some years later in his report on variable stars:

> I now come to the star P. XXI. 285, Garnet sidus, to which the elder Herschel first called attention, due to the deep garnet colour and because he thought it to be new. This is a mistake, for, on the contrary, it is known a very long time, namely 1 informium circa Cepheum in the Almagest. Reducing the position for 1800 … one gets AR 324° 38′, Decl. +57° 51′ in close agreement with Piazzi … only Flamsteed deviates … The star is definitely Bayer's μ Cephei, and only his slightly wrong plot of the position had induced me to take 14 Fl. [14 Cephei] for μ. (Argelander, 1849).

This also implies that 13 Cep is a different star.

From this date on, all of these stars in Cepheus are correctly designated. Argelander's *Bonner Durchmusterung* lists all six stars shown here in Table 1 with precise positions for 1855, but no identifications are given (Argelander, 1859). An example of correct naming is the *Catalogus Stellarum* of Eduard Heis (1872) with positions for 1855. The first to identity the Garnet Star with μ Cephei is Chambers in his 1861 *Handbook*: "μ Cephei, Sir W. Herschel 1782." Being familiar with astronomical literature, he obviously knew Argelander's result. All later catalogues of variable or red stars—except for Schjellerup (1866) with "W. Herschel's *Granatstern*"—followed this view.

4 THE FIRST PUBLISHED CATALOGUES OF RED STARS AND HIND'S DISCOVERY

The earliest published compilation of red stars is by Jérôme Lalande (Figure 18; 1804) and contains 33 "Étoiles rouges" (Figure 19). The table gives AR and zenith distance for 1800; to get the PD one has to combine this with the latitude of Paris (41.2°). Lalande found these red stars during his observations for the *Histoire Céleste Française* (1801). Subsequently, his list was reprinted by Baron von Zach (1822b) in his *Correspondence Astronomique*.

John Frederick William Herschel (1792–1871; Figure 20) is the author of the second published catalogue of red stars, listing 76 objects. It is based on his observations at Slough and the Cape of Good Hope, covering the northern and southern skies, respectively. The table appears as Appendix D in his tome *Astronomical Observations* (1847), and is headed "Approximate places of seventy-six ruby coloured, or very intensively red, insulated stars, noticed in the course of observation, in either hemisphere." It gives position for 1830, magnitude and a des-

Figure 20: A photograph of Sir John Herschel taken by Julia Margaret Cameron in April 1867 and now in the Metropolitan Museum of Art in New York (en.wikipedia.org.).

TABLE des Étoiles rouges.

ASC. DR.	DISTANCE AU ZÉNIT.			ASC. DR.	DISTANCE AU ZÉNIT.		
2h 23′	72d	12′	Midi.	12h 34′	2d	17′	
3. 40.	11.	31.	Nord.	13. 7.	71.	0.	
4. 41.	34.	58.	Midi.	13. 16.	60.	29.	68 ν Vierge.
4. 43.	46.	38.	5 Orion.	14. 7.	31.	32.	
4. 44.	41.	23.		14. 22.	17.	32.	25 ρ Bouvier.
4. 54.	47.	56.		14. 25.	11.	17.	
5. 19.	50.	4.	31 Orion.	19. 0.	24.	57.	
5. 20.	30.	22.	119 Taureau.	20. 5.	70.	42.	
5. 44.	2.	56.	35 π Cocher.	20. 15.	77.	40.	
6. 22.	10.	13.		21. 7.	10.	21.	Nord.
6. 58.	60.	26.		21. 35.	51.	57.	
8. 44.	30.	49.		21. 37.	28.	48.	Nord.
8. 58.	17.	2.		22. 49.	75.	1.	
10. 0.	56.	13.		22. 56.	40.	34.	ι Pégase.
10. 28.	61.	7.		23. 36.	46.	27.	
10. 41.	68.	57.	Bien rouge.	12. 28.	79.	41.	Un peu terne.
11. 7.	14.	37.	54 ζ Lion.				

Figure 19: Lalande's list of red stars. For 'Nord' the zenith distance must be taken as negative.

cription for each star (but no discovery date). Herschel uses the term 'ruby', but one object is described as 'garnet': an anonymous 9th magnitude star in Cassiopeia (no. 3). On 15 March 1834, during sweep 432, he discovered the reddest star in the sky: DY Crucis (no. 41):

> In the field of β Crucis. The fullest and deepest maroon red; the most intense blood red of any star I have seen. It is like a drop of blood, when contrasted with the whiteness of β Crucis.

The strongest rival to DY Crucis was found by Hind in October 1845. Using the 7-inch refractor at Bishop's Observatory, he discovered an extraordinary star in Lepus. However, he did not publish the find until April 1850 in the *Astronomische Nachrichten* #712. Hind reported on the "Position of a Scarlet Star between Orion & Eridanus" (Hind, 1850a). In the next issue (#713) he provided a little more detail: "I may mention also a remarkable crimson star in Lepus of about the 7th. magn. the most curious object I have seen." (Hind, 1850b). In a letter to William H. Smyth dated 14 January 1850 Hind wrote:

> … in October 1845, I remarked a most fiery or scarlet star on the confines of Lepus and Orion … This is by far the most deeply-coloured of any that I have yet seen, and in striking contrast with a beautifully white star preceding it one minute. (Smyth, 1864).

Another description reads:

> Of the most intense crimson, resembling a blood-drop on the blackground of the sky; as regards depth of colour, no other star visible in these latitudes could be compared to it. (Chambers, 1881: 121).

The unusual object is commonly known as 'Hind's Crimson Star'. It is variable (as discovered by Schmidt in 1855), has the designation R Lep; and m_v varies between 5.5 and 11.7 with a period of 427 days. Chambers (1865) wrote:

> Its light was of a very intense crimson colour, greatly surpassing in depth several of Sir J. Herschel's 'Ruby' stars, called by him 'intense', &c., and also Piazzi's garnet *sidus* in Cepheus.

5 A HERSCHEL CATALOGUE OF GARNET STARS

A thorough study of William Herschel's unpublished reports, impeccably edited by Caroline, recently revealed that Herschel's Garnet Star μ Cephei is not a singular case as there are more stars described as 'garnet'. The search produced surprising results.

Perhaps of greatest importance is the fact that the credit for the discovery of 'Hind's Crimson Star' must go to William Herschel! He discovered this object during sweep 365, on 4 February 1785, at about 7 p.m., from Datchet. At this time the star was 20° above the horizon, and Herschel noted: "A bright garnet star about 9 m. a most beautiful colour." (Herschel, W., 1784–1785). The position was determined relative to 60 Eridani, which was 2.7° to the southwest. There were no further observations, and this 'garnet star' was later referred to as U^{450} in his list of 'unknown' stars.

Another interesting object is known in the literature as 'Herschel's Ruby Star'. However, here 'Herschel' refers not to William but to his son, John. The star in question is no. 70 in his list, and as a variable star was later designated RT Capricorni. He found this beautiful object during sweep 298 on 22 February 1830, using the 18.25-inch reflector at Slough, and described it as "A fine ruby star. Pure ruby colour. This is perhaps the finest of my 'ruby stars'." (Herschel, J., 1847: 449). However, John Herschel was not the first to catalogue this star as Lalande observed it on 19 July 1795 and entered it as "étoile rouge" no. 25 in his list.

There are two more red stars observed by John Herschel that are interesting. No. 19 is the variable star BL Orionis, seen on 23 January 1832 during sweep 393 and described as "vivid red" (Herschel, J., 1830–1832). Two days later he saw no. 27 during sweep 395, writing: "Very fine red, between ruby and orange. Brick red." This was the variable star X Cancri.

In fact, John Herschel's 'ruby stars' RT Cap, BL Ori and X Cnc were all recorded earlier by William Herschel at Datchet. The first to be discovered was X Cnc, on 31 December 1782, with the 7-ft telescope, and Herschel (1782–1783a) noted in his report: "68 (·) [Cnc] 6 more [stars] one garnet towards δ [Cnc]." Alas, there is a problem with the magnitude of Flamsteed's 68 Cnc: Flamsteed lists it as 6 but Baily says 8, which is correct. Thus, most star catalogues omit this star. It is located about 5° east of δ Cnc. Right in between we find Herschel's garnet star X Cnc. RT Cap was discovered on 8 August 1784 during sweep 246, using the 18.7-inch reflector. At the time, Herschel (1784) noted: "A star of very deep, fine, garnet colour. 9 m." (U^{203}). Finally, BL Ori was seen on 15 October 1784 during sweep 293: "A most beautiful garnet coloured star. 8 m." (U^{327}; Herschel. W., 1784–1785).

At first sight it is remarkable that John Herschel was not aware of these discoveries made by his father, as he had access to all the records at Slough, but this can be explained. Caroline, his aunt, was the bookkeeper, managing the records, lists and catalogues, and making various copies, extracts and compilations. Obviously, John was fully dependent on this perfect bureaucracy, and largely benefitted from his aunt's activities. Perhaps the best example of this was

Caroline's "zone catalogue" of 1825, which listed all Herschel nebulae and clusters with positions for 1800 in zones of constant PD. This work 'won' her the Gold Medal of the Royal Astronomical Society in 1828, and John used it as the basis for his plan to reobserve the Herschel objects. Obviously, he did not need to inspect the original data, except for doubtful cases. At the Cape of Good Hope the situation was quite different, as here John had to concern himself with all tasks and was in full control.

Finally, let us look at 19 Piscium, another celebrated red star in the literature. This is Lalande's "étoile rouge" no. 32 and identical with the variable TX Psc. William Herschel saw it on 8 October 1785 (during sweep 461 at Clay Hall) as "deep orange red or pale garnet". This is the only case where the master was pre-empted, for the discovery credit goes to Tobias Mayer at the new Göttingen Observatory. This German astronomer observed the star on 14 September 1756, describing it as "rubicunda" (Zach, 1822a). 19 Psc also was seen by Piazzi (182 P. XXIII), who referred to it as a "Stella subrubei coloris".

An examination of William Herschel's records revealed 21 single stars that he called 'garnet' (see Table 3). For this task, Caroline Herschel's "Temporary Index", which lists "Coloured Stars", was helpful (Herschel, C., 1802: 29). Although some objects are called 'garnet', the compilation is not complete and sometimes differs from the observational records. For instance, Caroline

Table 3: A Herschel catalogue of garnet stars; 15 of the 21 objects were found in the sweeps (see text). Antares, though described as "pale garnet", is ignored here. Except for γ CMi, 6 Aur and 5 Lac, all of these stars are variable.

Star	V	B–V	Date	Ref	Sweep	Colour	U	Lal	JH	Schj	Birm	'Discoverer'	Name
o Ceti	6.5	1.1	1780, Sep. 8	F1, 74	280	rather garnet; garnet but not deep			8	19	40	W. Herschel 1780	Mira
γ CMi	4.3	1.4	1782, Feb. 9	F2, 189		fine garnet						W. Herschel 1782	
6 Aur	6.5	2.7	1782, Mar. 5	F2, 196		garnet					91	Birmingham 1876	
μ Cep	4.0	2.4	1782, Sep. 27	F2, 238	768; 875	very deep fine garnet; garnet colour	794			253	594	W. Herschel 1782	Herschel's Garnet Star
5 Lac	4.4	1.7	1782, Oct. 4	F3, 247		fine garnet					612	Birmingham 1876	
119 Tau	4.3	2.1	1782, Dec. 28	F3, 288		garnet		12		59	111	Lalande 1797	CE Tau
X Cnc	6.4	2.1	1782, Dec. 31	F4, 295		garnet			27	115	211	J. Herschel 1832	
W Ori	6.1	3.4	1784, Jan. 23		99; 526	claret coloured; garnet coloured	13	6		50	96	Lalande 1794	
RT Cap	8.9	4.0	1784, Aug. 8		246	very deep fine garnet colour	203	25	70	238	545	Lalande 1795	J. Herschel's Ruby Star
χ Cyg	4.4	1.8	1784, Sep. 6		258	beautiful garnet	220			232	518	Schmidt 1856	
BL Ori	6.0	2.3	1784, Oct. 15		293	most beautiful garnet coloured	327		19	74	144	J. Herschel 1832	
W CMa	6.6	2.4	1785, Jan. 31		363	deep garnet coloured	440	11		89	166	Lalande 1797	
R Lep	7.8	5.8	1785, Feb. 4		365	bright garnet...most beautiful colour	450			49	94	Hind 1845	Hind's Crimson Star
19 Psc	5.0	2.6	1785, Oct. 8		461	deep orange red or pale ganet		32		273	648	Mayer 1756	TX Psc
RY Mon	7.5	4.4	1786, Feb. 24		529	deep garnet colour	637			88	165	Bessel 1824	
U Hya	4.8	2.7	1786, Mar. 19		541; 997	deep garnet colour; very deep coloured ...almost garnet		15		132	242	Lalande 1798	
W Hya	7.7	1.3	1786, Mar. 28		550	deep garnet colour	657				313	Argelander 1851	
S Cep	7.4	4.7	1787, Oct.10		762	deepest and most brilliant garnet colour	787	29		250	588	Lalande 1789	
RY Dra	6.3	3.1	1790, Mar. 20		954	deep garnet colour	939			155 b	298	d'Arrest 1874	
V466 Per	8.1	4.0	1790, Dec. 28		989	very deep garnet colour	976					Espin 1895	
6 Gem	6.3	2.6	1792, Feb. 17	R5, 1		deep garnet					139	Birmingham 1876	BU Gem
V419 Cep	6.6	2.3	1794, Oct. 14		1060	very deep garnet colour	1040	27		247	579	Lalande 1797	

lists μ Cephei as "7 m. deep orrange [*sic*] & c. S[weep] 768", where the term "garnet" is missing Herschel (1814) himself gives the number of garnet and red stars found in the sweeps in his paper "Astronomical observations relating to the sidereal part of the heavens":

> In my sweeps are also recorded the places of 9 deep garnet, 5 bright garnet, and 10 red coloured stars, of various small magnitudes from the 7th to the 12th. (Herschel, W., 1814).

However, the current study lists 15 single garnet stars instead of Herschel's 14. Alas, he does not identify the stars, so the "10 red coloured stars" are not analysed here (Caroline mentions only 8, two of which were later catalogued by Birmingham). Also ignored are the 16 stars found as a component of a double or multiple system and described as "garnet". Among them is a pair with a red star and a garnet star, observed on 30 July 1780: VI 18 = v1 and v2 Coronae Borealis (m_v = 5.2 and 5.4, and separation 6′).

Table 3 may be called the "Herschel Catalogue of Garnet Stars". The stars are sorted by discovery date. Columns 2 and 3 give the mean visual magnitude (most of the stars are variable) and the colour index. These data are from the SIMBAD (2015) database as available on the internet. The reddest stars have the largest B–V values (for a variable star B–V changes too and the value is highest at minimum brightness); Hind's Crimson Star (R Lep) reaches 5.8. Herschel's second reddest star is S Cephei with 4.7 (found during the northern sweep 762). Column Ref gives the number of the "Fixt star" folder (F plus page); R5 is "Review No. 5" (Herschel, W., 1792–1800). Next are the sweep numbers (three stars were seen twice; the date refers to the first sweep) and Herschel's colour description. Only eight stars were known to him (from the British Catalogue); unknown stars were later numbered (U). Lal, JH, Schj and Birm give the number in the lists of red stars by Lalande (1804), John Herschel (1847), Schjellerup (1866) and Birmingham (1877). The column titled 'Discoverer' names the astronomer credited with the discovery of the red star in the literature (plus the year). Of course, the Bayer and Flamsteed stars were already observed and catalogued earlier, but the colour was not recorded—or in most cases probably was not perceived with the naked eye or a small instrument. Indeed, for a fainter star a sufficient magnification is needed to detect the red colour (the eye is not very sensitive to faint red light). For his star reviews Herschel used magnifications of 227× and 460× (using the 7-ft), and in the sweeps the standard was 157× (with the large 20-ft telescope). The last column gives the common name or variable star designation.

Looking at the date, we see that μ Cephei was not Herschel's first 'garnet star'. This honour goes to o Ceti (Mira). On 8 September 1780 he noted:

> The colour was very remarkable being darker red (or rather garnet colour) than any I remember to have seen before among the fixt stars. (Herschel, W., 1775–1781: 74).

There are five more colour descriptions of Mira (Herschel, W., 1777–1810: 15–21): "garnet" (22 October 1781), "fine garnet" (21 August 1783), "garnet but not deep" (sweep 280, 20 September 1784) and "deep garnet colour" (2 December 1790). Meanwhile, John Herschel entered Mira in his list as "very fully ruby" (no. 8). Probably the redness of Mira was perceived by other observers, before William Herschel, but was not reported (Argelander, 1869: 320–326). Herschel's second garnet star, γ Canis Minoris, might be a similar case.

The first garnet star mentioned during a sweep is W Orionis, 7° west of the stars in the Belt. However, during the early sweep 99, performed on 23 January 1784 at Datchet, Herschel did not get a reliable PD. This was corrected in sweep 526 (on 22 February 1786). This star is no. 6 in Lalande's list. Herschel's last garnet star, the variable V419 in Cepheus, is also mentioned by Lalande (no. 27), and was found on 14 October 1794 (from Slough) during northern sweep 1060. Piazzi later noted: "Rubei coloris" (61 P. XXI).

Table 4, below, lists all important early catalogues of red stars.

6 TWO OTHER EXCEPTIONAL STARS

There are two other interesting discoveries, hidden in Herschel's handwritten observing notes, although the term 'garnet' is not used for these exceptional stars.

On 18 November 1781, shortly after "5^h in the evening", Herschel saw a red star. His note in Journal No. 3 sounds cryptic: "the trefoil is north

Table 4: Important early catalogues of red stars, including the new compilation of Herschel's garnet stars.

Author	Publ.	Objects	Number	Remarks
Herschel, W.	--	"garnet stars"	21	observations 1780–1794, northern sky
Lalande	1804	"Étoiles rouges"	33	obervations 1793–1798, northern sky
Herschel, J.	1847	"ruby stars"	76	observations 1827–1836, whole sky
Schjellerup	1866	"rothe, isolierte Sterne"	280	supplements 1866, 1874
Chambers	1867	"red stars"	293	
Birmingham	1877	"red stars"	713	observations
Chambers	1887	"red stars"	719	
Birmingham, Espin	1890	"red stars"	766	observations

following κ & colour reddish" (Herschel, W., 1781–1782a: 40). Fortunately, a later copy in "Fixt Stars No. 4" is more detailed:

> … in the trefoil near k Aquilae. The trefoil is north following, colour inclining to red. Too low for other observations and the colour not to be trusted to. (Herschel. W., 1781–1782b: 171).

What is this "trefoil near k Aquilae", and which "reddish star" is meant? The star 9 Aquilae (now η Scuti) was called 'k' by Flamsteed in the British Catalogue; it is labelled with this letter in the *Atlas Coelestis*; there is no 'k Aquilae' in Bayer's *Uranometria* (Baily, 1835: 622, note for no. 2552). Herschel used the term 'trefoil' for a triangle of stars with comparable magnitudes. The triangle north following k (i.e. to the north-east) is framed by 12 (i), 14 (g) and 16 (λ) Aquilae; a fourth star, 15 (h), lies between 14 and 16 (see Figure 21). Is there a red star in or near this asterism? Yes, there is a very remarkable exemplar: V Aquilae, one of the reddest stars in the sky! There is no doubt that Herschel saw this conspicuous object, even though the observation was difficult: at 5:30 p.m. the southern part of Aquila was about to set and the red star was only ~15° above the horizon.[5] Herschel never viewed this red star again.

Usually the discovery of V Aql is credited to Julius Schmidt (1872), but it has been shown (see Steinicke, 2011) that already Bessel had observed this red star in 1823 during his zone observations. William Herschel's observation is mentioned in Caroline's compilation under the heading "Low situations not proper observing the colours of stars" (Herschel, C., 1802: 29). There is no doubt that if he had been able to view it at a higher altitude Herschel would have applied the term 'deep garnet' to this very red star (which has a maximum visual magnitude of 6.9, and B–V = 4.3). V Aql was later catalogued as no. 222c by Schjellerup (1874) and no. 483 by Birmingham (1877).

Finally, we come to the remarkable red star, commonly known as 'La Superba'. The name was created by Angelo Secchi (1818–1878; Figure 22) and belongs to the variable star Y Canes Venatici, which is identical to Schjellerup 152 (Secchi, 1872; 1877). The Italian astronomer and pioneer of spectroscopy was fascinated by the strange spectrum, belonging to his rare spectral class IV (now called 'carbon stars'). 'La Superba' was Secchi's prototype. In the literature, Lalande is credited with the discovery; he observed this star on 3 April 1791 and entered it as no. 18 in his list of "étoiles rouges". However, three years

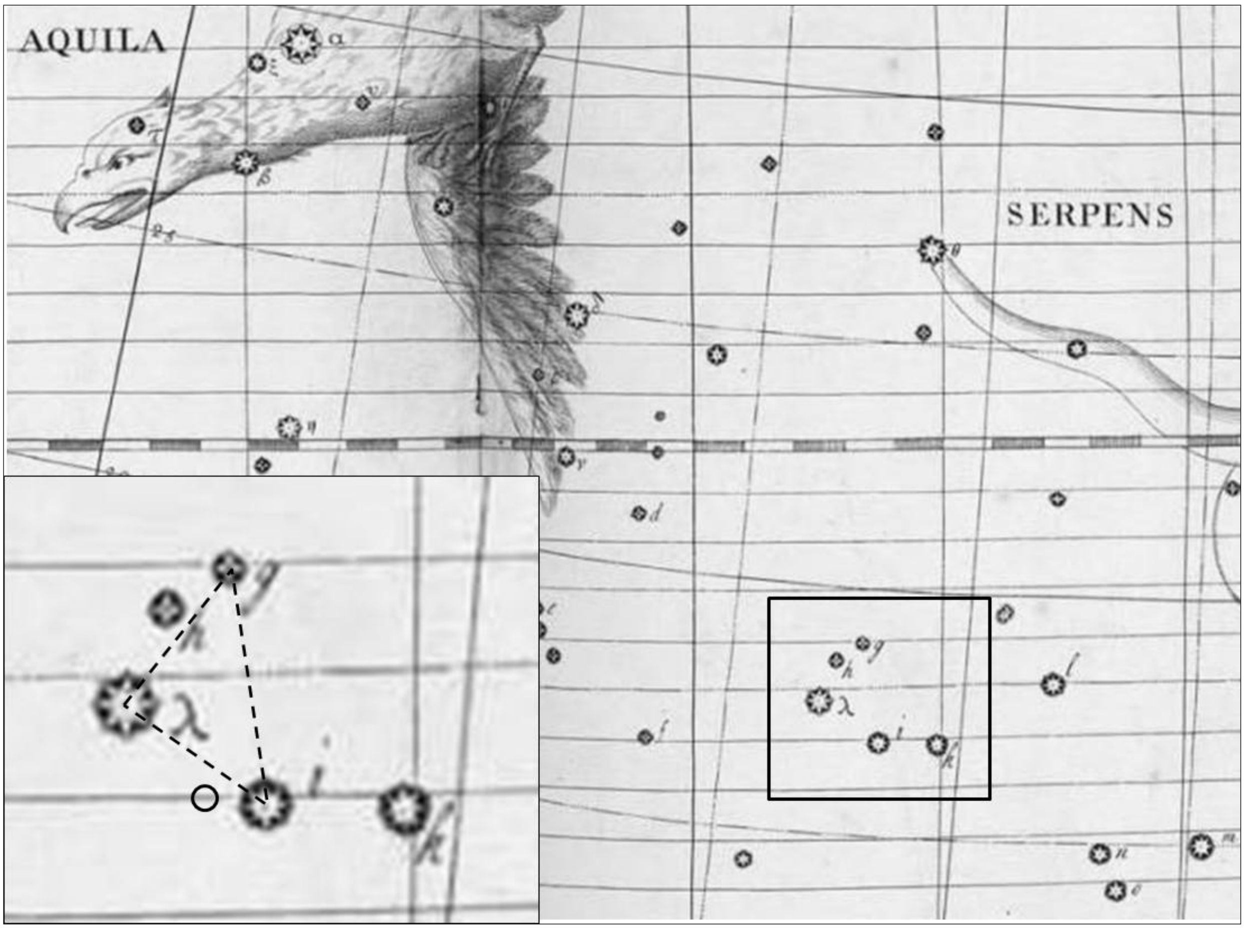


Figure 21: An extract from Flamsteed's *Atlas Coelestis* showing the southern Aquila with Herschel's trefoil northeast of *k* Aquilae. The circle in the inset marks the position of the red star V Aquilae.

earlier, on 27 April 1788, William Herschel discovered this object during sweep 833 at Slough, noting: "7 m. Deep red." It was later listed by Caroline as 'unknown star' U[817]. Y CVn appears in Birmingham's catalogue as no. 290; the maximum visual magnitude is 4.9 and the B–V is 2.5. Herschel's catalogue contains three stars, later classified as spectral class IV by Secchi (1869): RT Cap, W CMa and U Hya. The stars μ Cep, Mira and X Cnc belong to class III (Betelgeuse type).

7 THE PHYSICAL NATURE OF RED STARS AND CRITICAL VOICES

Even though Herschel was more interested in nebulae and star clusters (see Steinicke, 2010), did his observations of red stars cause him to speculate about the physical reason for star colours? Although his experiments with heated metals and the detection of the Sun's infrared radiation would imply that he did, in fact there is little indication of this. Only in 1814 did he write:

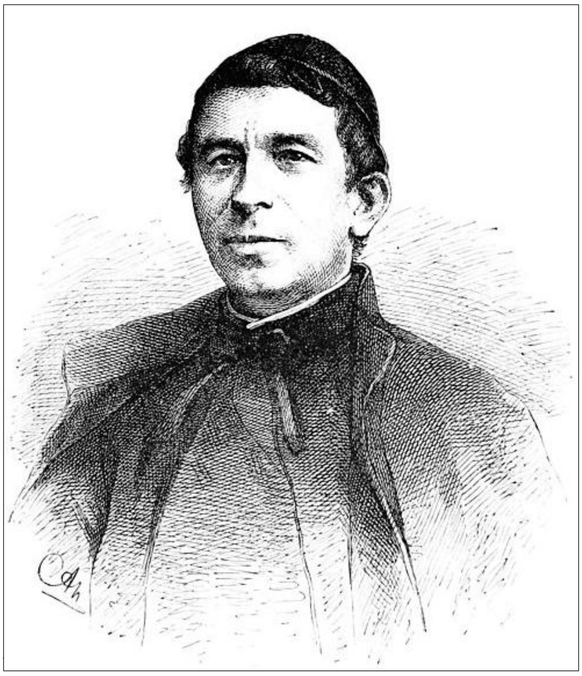


Figure 22: Angelo Secchi (*Popular Science Monthly*, 1877–1878).

> They [the stars] also, like the planets, shine with differently coloured light. That of Arcturus and Aldebaran for instance, is as different from the light of Sirius and Capella, as that of Mars and Saturn is from the light of Venus and Jupiter. A still greater variety of coloured star-light has already been shewn to exist in many double stars, such as γ Andromedae, β Cygni, and many more … By some experiments, on the light of a few of the stars of the first magnitude, made in 1798, by a prism applied to the eye-glasses of my reflectors, adjustable to any angle and to any direction, I had the following analyses. (Herschel, W., 1814).

A few remarks follow on the colour of the light from Sirius, Betelgeuse, Procyon, Arcturus and Vega, but there is no attempt to explain the associated physics, and he then turns to variable stars. However, at a much earlier date Herschel (1782b: 258–259) did mention the effect of atmospheric refraction on star colour: "The atmosphere will colour the stars." He also noted that especially at low elevations objects would appear redder. It would seem that to William Herschel the garnet stars were probably only a curious phenomenon.

Similarly, John Herschel did not remark on the physical nature of 'ruby stars' in his various publications. However, he discussed the case with Hind, who had written in a letter dated 6 September 1848 (one day after Hind announced the variability of Herschel's Garnet Star):

> … a very great proportion of the changeable stars I have discovered are red, in fact, I have learned to be suspicious of all ruddy stars. (Hind, 1848b).

Later, Argelander took over and developed the new field of variable star astronomy. But the physical explanation for the red star phenomenon had to wait for the development of astrophysics. Secchi was a pioneer in this field, creating an innovative spectral classification (Hearnshaw, 2014). But from the observational point of view, the case was still open around 1880 (for a review on the history of carbon stars see McCarthy, 1994). However, the strong connection between red and variable stars was accepted. In 1877, the British astronomer, John Birmingham wrote:

> The Red Stars must be considered as a class of heavenly bodies particularly worthy of attention; for not alone, as compared with the other stars, do they seem to differ most widely in constitution from our own sun, but they show a peculiar inclination to periodic change, while some of the most noted Variables are found amongst them … The redness of a star has given rise to the singular conceit that it shows a cooling down, or, as we might say, an approach to a final snuffing out of the luminary; but one might think that the fact of periodic variation of tint in many of the Red Stars ought to go far in disproving this proposition. (Birmingham, 1877: 249).

Another point was the visual redness of the stars. Birmingham commented on this, referring to eminent observers:

> It has been well remarked by Schmidt that no stars have been found of a perfectly red, or blood colour, such as may be seen in the solar protuberances: even stars like the "crimson" in Lepus, or Herschel's "garnet star," are no exceptions; and the reddest star that we see still shows a mixture of yellow. This perfectly agrees with my own observations; and in stars even described by myself as deep red, I must

be understood to use the term only in a conventional sense and in comparison with the other stars classified along with them.

One example is his find of 22 May 1881, using a 4.5-inch Cooke refractor: the "deep red or crimson star" V Cygni, 2.8° north of Deneb (Birmingham, 1881). This star is variable with a visual magnitude of 7.7 at maximum and an exceptional B–V value of 6.4 (at minimum). Even though William Herschel scanned the region on 27 September 1788 (during sweep 866), he missed this star.

Birmingham also mentions Wilhelm Struve, who had doubted the redness of several double star components observed by William Herschel. Birmingham lists 13 examples, where Herschel attributed a red colour but Struve saw a white star. Struve speculated that the reason might be the telescope that Herschel used: speculum mirror reflectors "… as is well known had a reddening tendency." But Birmingham was not convinced, and he presented various counter-examples (i.e. of stars seen as white by Herschel but redder by Struve).

Finally, it is historically interesting that William Herschel discovered many of the prominent red stars, and his celebrated 'Garnet Star', μ Cephei, was only the opener. It has been shown that the Herschel collection, as presented here, is the forerunner to the later catalogues, and that full credit for the master is long overdue!

8 NOTES

1. The term "diameter" means the size of the optical image in the eyepiece, which depends on the magnification.
2. All English translations from foreign sources are by the author.
3. "Tiaram Cephei praecedens" in this quotation means that the double star precedes the crown of Cepheus.
4. In fact, the number of new double stars might have been 16 according to a note in Caroline's double star compilation (Herschel, W., 1784–1802).
5. This was Herschel's second object of two seen during this observing session. The first was 17 Draconis (a double star that he found on 8 August 1780). Thus, starting at 5 p.m., he turned his telescope from Draco to southern Aquila, 66° across the sky!

9 ACKNOWLEDGEMENT

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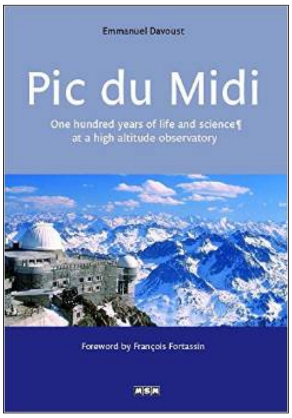
Dr Wolfgang Steinicke, FRAS, studied physics, astronomy and mathematics in Aachen and Freiburg, receiving his Ph.D. at Hamburg University with a study of the history of the New General Catalogue (NGC). Since early youth he has been an active visual observer, which triggered his interest in the nature and history of deep-sky objects like nebulae and star clusters. He is the head of the History Section of the VdS, Germany's largest association of amateur astronomers, a member of the Working Group for the History of Astronomy of the Astronomische Gesellschaft, a core team member of the international NGC/IC Project and committee member of the Webb Deep-Sky Society and Director of its Nebulae and Clusters Section. He has written seven books (three in English), contributes to various astronomical magazines and frequently gives conference papers and courses.

BOOK REVIEW

***Pic du Midi. One Hundred Years of Life and Science at a High Altitude Observatory*, by Emmanuel Davoust. Translated by Barbara Jachowicz. (Vic-en-Bigorre, MSM, 2014), pp. 478 + [ii]. ISBN 978-2-3508-0143-8 (paperback), 140 × 205 mm, €29.95.**

Mention of the Pic du Midi immediately conjures up childhood memories of this mystical observatory nestled high in the Pyrenees Mountains where some amazing observations of Mars were made during a particularly favourable opposition in the 1950s. But upon reading the recent English translation of Emmanuel Davoust's book, *Pic du Midi. One Hundred Years of Life and Science at a High Altitude Observatory*, I quickly discovered it was much more than this.



I also discovered that the idea of a French high-altitude observatory was born not with Jules Janssen but much earlier, in the 1860s, when a number of local enthusiasts founded the Ramond Society. Among its objectives was the erection of an astronomical observatory at the summit of the 2,876-m high Pic du Midi. In the early 1870s the idea emerged of combining meteorology with astronomy. Following its defeat by Prussia in the recent war, France was seeking projects that would contribute to its 'moral recovery'. Davoust notes that French astronomers used this tactic

> ... to obtain the creation or funding by the State of six Provincial astronomical observatories ... [But he stresses that] the creation of Pic du Midi Observatory owes nothing to French astronomers, except for some encouraging words. This was a project of pure Pyrenean regionalism, very active in the 19th century, and it fit perfectly into the spirit of the time, when people everywhere were ready to explore uncharted territory. (Page 21).

Construction began in 1875, and six years later the Pic du Midi Observatory was functioning. As Chapter 1 clearly documents, the driving force throughout the challenging construction phase was General Charles de Nansouty, a former career military officer.

In 1882 the Ramond Society succeeded in transferring the ownership and operation of the Observatory to the State: its budget was attached to the Ministry of Public Education, and its primary function was to be meteorology (not astronomy). "The Observatory's first ten years" is the title of Chapter 2. However, during this decade visiting scientists also carried out experiments on atmospheric electricity and on the chemical composition of the atmosphere, and in 1883 the Observatory was designated a first order geodetic station in France's national network.

Astronomy, meanwhile, was not entirely ignored. In 1882 Paris Observatory sent Pierre and Prosper Henry to the Pyrenees in order to observe the 6 December transit of Venus from the Pic du Midi Observatory, but the winter was so severe that they could not reach the Observatory. So they tried to observe the transit from a lower altitude but failed because it was snowing. Three of the porters in the party carrying their equipment perished during an avalanche. The following year, Paris Observatory Director, Admiral Mouchez, sent two other astronomers to the Pic, to explore the posibility of establishing an astronomical station there. Although they reported exceptional seeing both day and night, Mouchez was unable to gain support for his plan.

During the first decade, two other astronomers carried out significant observations from the Observatory. In August 1890 Professor Charles André, Director of the Lyon Observatory, and his colleague, Emile Marchand, successfully observed lunar occulations and Jovian satellite phenomena using 6-in (15-cm) and 8-in (20.3-cm) refractors that had been lent by Paris Observatory in 1884.

The Pic du Midi Observatory's inaugural Director, Célestin-Xavier Vaussenat, lobbied relentlessly to have an astronomical facility added to the Observatory, but he died on 16 December 1891 before this could be accomplished.

Astronomy at the Observartory only came of age under the second Director, Emile Marchand. Under his guidance, the Pic du Midi Observatory

> ... would truly play the role it had been destined for by its founders – progressively becoming a centre of multidisciplinary scientific observations, where daily data were gathered in the fields of meteorology and atmospheric physics, seismology, astronomy and botany. (Page 59).

This metamorphosis is recounted in Chapter 3, while Marchard's own research is described in Chapter 4.

Marchand began his Directorship on 1 August 1892, and in September and October spent six weeks at the Observatory organising the expansion into astronomy. The following year the 8-in refractor was housed in a hexagonal wooden observatory and he began to visually monitor the Sun and selected planets: between 1893 and 1914 he and Sylvain Latreille made 2,800 solar sketches and 1,400 drawings of Venus, Mars, Jupiter and Saturn. They also observed Jovian satellite phenomena and variable stars, and made visual observations of meteor showers. In 1910 Comet 1P/Halley attracted their attention. But despite these 'successes', Marchard's attempts to develop astronomy further were frustrated, and he is now remembered for developing meteorology and geophysics at the Pic and elsewhere in the Pyrenees. Perhaps he is best known for 'Marchand's Law', which states:

> There exists a series of terrestrial or atmospheric phenomena: magnetic storms, aurora borealis, electric storms, waterspouts, cyclones, strong barometric depressions with violent wind, strong rain, earthquakes, … all of which tend to occur when an area of activity on [the surface of] the Sun passes at the central meridian; but, furthermore, for certain of these phenomena to be produced, various local conditions (atmospheric or geological) must be met. (Page 79).

Davoust notes (page 76) that between 1894 and 1912 Marchand published more than 100 research papers, 12 in astronomy, about the same number in botany and 77 in meteorology and geophysics, plus a biographical monograph about Jérôme Lalande. Yet, despite this output he

> … never managed to become well known during his career. One of the reasons for this was that he was often satisfied with a limited audience, such as readers of the *Bulletin de la Société Ramond*, or the proceedings from meetings in which he participated.

As the subtitle foreshadows, *Pic du Midi* … is about more than science, and Chapters 5 and 11, titled "Daily life in Bagnères and at the Pic" and "Daily life at the summit", illustrate this. We also are reminded that this book is about more than astronomy and meteorology when we encounter Chapters 6, 12 and 19 on "The botanical garden at the summit", "Geophysics" and "The cultivation of potatoes", respectively. There are also chapters (9 and 15) about the Observatory's activities during World Wars I and II.

For those with a passion for astronomy, the book really starts with Chapter 7 ("The beginnings of the Baillaud telescope") on page 117. Despite Marchand's frustrated efforts, it was Toulouse Observatory Director Benjamin Baillaud who first succeeded in installing a telescope at the Pic capable of producing research results. This was a 50-cm (20-in) reflector with a 23-cm (9-in) guidescope, which was installed in a new purpose-build dome and became operational in 1909. This marked the start of a close association between the two observatories, which caused Marchand more worry. Initially the Baillaud Telescope was used to obtain a series of impressive photographs of Mars, and in 1910 observations of Comet 1P/Halley followed, and it quickly became apparent that when the sky was clear the seeing was usually exceptional, but for much of the year the uncooperative high-altitude weather prevented any observing. Even when observing was possible, there were problems with the telescope and dome, and there was also the hardship of daily life at the summit to contend with. So the Baillaud Telescope saw little use.

All this hardly impressed Marchand and

> As the years went by … [he] became ever more bitter. His career did not progress, he had health problems, his scientific work did not receive the recognition it deserved and the administration of the Pic by Toulouse University brought only worries." (Page 137).

This sorry situation finally came to an end on 25 April 1914 when Marchand died. He was just 61 years of age.

With almost undue haste, just three months later the Council of Toulouse University abolished the Director's position at the Pic, leaving only an Assistant Director there who would take orders from Toulouse. The new Assistant Director was Joseph Rey who had a background in meteorology, terrestrial magnetism and atmospheric electricity, but not astronomy. Like his predecessor, Rey became embittered by his situation at the Pic, and he resigned in February 1920.

The Pic du Midi Observatory entered a new era with the appointment of a Toulouse school teacher, Camille Dauzère, as Assistant Director on 31 August 1920. Dauzère had a doctorate in physics. His first priority was to renovate the Observatory, and to improve access and living conditions there. Meanwhile, political considerations forced him to devote all of his research efforts to geophysics, as outlined in Chapter 12 (where the achievements of other scientists based at the Pic also are discussed).

Despite Dauzère's research interests, during the period between the two World Wars,

> Three astronomers, each in his own way, would contribute to turning the situation around and putting the Observatory on the path that would soon lead it to the forefront of planetary and solar astronomy … (Page 201).

They were Jules Baillaud, Benjamin's son, who worked at the Paris Observatory, used the Baillaud Telescope for stellar spectrophotometry, and would become Director in 1937; Bernard Lyot from Meudon Observatory (who perfected and used his new invention—the coronagraph—while based at the Pic); and Henri Camichel, who joined the staff at the Pic in December 1936 and used the Baillaud Telescope for planetary observing. Their stories are recounted in Chapter 13, which appropriately is titled "The return of astronomy". Also mentioned in this chapter is the work of other visiting astronomers, including Emile Paloque (Toulouse Observatory), Gilbert Rougier (Strasbourg Observatory) and Louis Roy (Toulouse University). For me, this chapter and the following one, on Jules Baillaud's directorship (from 1937 to 1947), were among the most interesting chapters in the whole book. Davoust justly describes the Baillaud decade as "… an exceptional period in the history of Pic du Midi Observatory, after which it became a nationally important centre in many fields of research." (page 223).

After describing life at the Observatory during WWII, the next three chapters (16–18) are devoted to telescope projects that occurred during the war years: "The transformation of the Baillaud telescope", "The large telescope project" and "The domeless telescope project". The refurbished Baillaud instrument was a refracto-reflector with a 60-cm (24-in) objective, while the 'large telescope' and the 'domeless telescope' projects related to a mooted 1.5-m reflector, and a large Schmidt, neither of which was constructed (although much later, in 1964, a 1-m telescope was installed—see Chapter 28).

Jean Rösch took over as Director of the Pic du Midi Observatory in 1947, and remained in office for 34 years. A key innovation during his 'reign' was the opening of a cable car service in 1952 which dramatically facillitated ease of access to the Observatory, and significantly increased the number of scientists, visitors and support staff at the Pic, especially in summer. Apart from those who came from Britain and from France to study cosmic rays, there was an influx of astronomers:

> First, British astronomers came to observe the Moon and scientiists from Meudon Observatory to observe the Sun. The International Geophysical Year (1957-1958) brought renewed activity to the Pic, both in studies of the upper atmosphere and of the Sun. (Page 310).

Another major innovation was the formal merging of the Pic du Midi and Toulouse Observatories in 1971.

Rösch was a dynamic Director, and his constant efforts soon gave the Pic an international reputation (especially after 1954 when he was finally able to return to his own research). Postwar research at the Pic on cosmic rays, the Sun, the Moon, and the planets and their satellites occupy Chapters 23 through 26.

After these welcome astronomical treats we are exposed to a short chapter on "The alpine biological laboratory" before returning once more to astronomy. In Chapter 27, "A wide range of activities", we are reminded that although best known for research on the Sun, Moon and planets, the Pic also contributed in other areas of astronomy, as well as high altitude medicine and radioactivity caused by nuclear explosions. Davoust notes (page 398) that

> This eclecticism was not typical of traditonal research institutes, but the Pic's location and its status as a de facto assignment observatory favoured a multitude of research projects in diverse fields …

The penultimate chapter brings us back to telescopes, rather than the research accomplished with them. Titled "The large noctural telescopes", it documents the long and very difficult path followed by those who made the Pic's largest telescope, a 2-m reflector, a reality. Although conceived in the 1960s, first light only occurred in July 1980.

Rounding out this long and very detailed book is a short (3-page) concluding chapter; 32 pages of black and white photographs and a locality map; acknowledgements; two pages about the sources used in researching this book; and an 8-page "Index of proper names".

So how should I rate this book? *Pic du Midi* … is a long book, with a great deal of reading that has nothing to do with astronomy. I found this a little overpowering, although some of the human drama associated with those who chose (or were coerced) to work at this rather inhospitable high-altitude observatory, especially in winter, was captivating. *Pic du Midi* … is well illustrated, and it is good value at just €29.95. I believe that it belongs on the bookshelf of everyone interested in French astronomy or the pioneering efforts required to establish and then conduct research at a high-altitude observatory.

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