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COVER IMAGE

A painting of "The Creation of Trowenna" [the island of Tasmania] by Trawlwoolway artist Lisa Kennedy, who is a descendent of Woretermoteteyer (ca 1797–1847), one of the Aboriginal people who accompanied George Augustus Robinson when he recorded data on Tasmanian Aboriginal astronomical knowledge during the 1830s. This project, and others that aimed to capture details of Tasmanian Aboriginal astronomy, are discussed by Michelle Gantevoort, Duane Hamacher and Savannah Lischick in a paper titled "Reconstructing the star knowledge of Aboriginal Tasmanians" on pages 327–347.

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HIGHLIGHTING THE HISTORY OF JAPANESE RADIO ASTRONOMY. 4: EARLY SOLAR RESEARCH IN OSAKA

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Abstract: For about two years, from late 1949, Minoru Oda and Tatsuo Takakura carried out solar observations from Osaka, initially with a hand-made horn and later with a small parabolic antenna connected to a 3.3 GHz receiver, but they only published one short paper on this work. At about the same time, Ojio and others at Osaka City University presented the concept of a solar grating array at a meeting of the Japan Physical Society, but this was never built. In this paper, we provide brief biographical accounts of Oda and Takakura before examining their radio telescopes and the observations that they made. We also briefly discuss the proposed Japanese solar grating array.

Keywords: Japan, solar radio astronomy, Osaka University, Osaka City University, Minoru Oda, Tatsuo Takakura, solar grating array

1 INTRODUCTION

Japanese radio astronomy was launched on 9 May 1948 when Koichi Shimoda (b. 1920) observed a partial solar eclipse from Tokyo (see Shimoda, 1982; Shimoda et al., 2013), and by 1952 four different groups of Japanese researchers were actively pursuing solar radio astronomy, in Hiraiso, Osaka, Tokyo and Toyokawa (see Orchiston and Ishiguro, 2017). This short paper is about the Osaka initiative, which commenced in November 1949.[1]

For Japanese localities mentioned in this paper see Figure 1.

2 SOLAR RADIO ASTRONOMY AT OSAKA UNIVERSITY AND OSAKA CITY UNIVERSITY

2.1 Introduction

Radio astronomy blossomed in the years immediately after WWII, largely as a result of the development of radar during the War, and by 1950 Australia, Canada, England, France, Japan, New Zealand and the USA all had made valuable contributions, but with Australia and England the ‘stand-out’ nations (e.g. see Sullivan, 2009).

At the end of WWII

> The U.S. Initial Post-Surrender Policy prohibited research which might contribute to a revival of Japan’s war-making potential; that included all activities relating to atomic energy. Research facilities were closed until the headquarters of the Supreme Commander for the Allied Powers (SCAP) could ascertain that their activities were of a “peaceful” nature. SCAP gave instructions to destroy or scrap “enemy equipment”—arms, war vessels, aircraft, and military installations. It exempted equipment considered “unique and new development” desirable for “examination, intelligence or research;” equipment deemed useful for U.S. army or naval operations; and equipment suitable for peacetime civilian use. (Low, 2006).

Figure 1: Japanese localities mentioned in the text. Key: 1 = Hiraiso; 2 = Tokyo University; 3 = Tokyo Astronomical Observatory (Mitaka); 4 = Toyokawa Observatory; 5 = Nagoya University; 6 = Osaka; 7 = Shimada (Map: Wayne Orchiston).

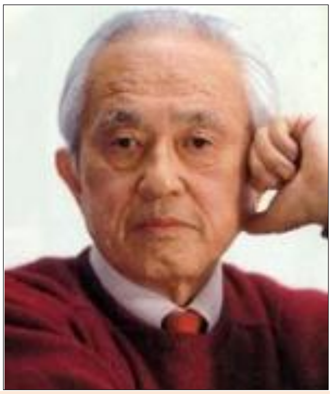

Figure 2: Professor Minoru Oda (www.casinapiova.va/content/academia/en.academicians/deceased/oda.html).

Although radio astronomy was a non-military field of science and technology, its association with war-time radar research and development (as in other countries) meant that in Japan it was very difficult to obtain suitable equipment and stable power supplies for radio telescopes. The simplest option was to focus on 'solar noise studies' using modest instrumentation.

This is precisely what two young graduate students in the Physics Department at Osaka University did in November 1949 when they began researching solar radio emission, encouraged by their supervisor, a newly-appointed Professor of Physics, the cosmic ray expert Yuzuru Watase (see Oda, 1985). They were 26-yr old Minoru Oda (1923–2001) and 24-yr old Tatsuo Takakura (b. 1925).

After graduating with a B.Sc. in Physics from Osaka University in 1944, Minoru Oda was involved in magnetron research at the Shimada Naval Research Laboratory (see Figure 1) for the remainder of WWII, and this focus on microwaves provided his entré to radio astronomy. However, his commitment to this new field was short-lived, for in 1953 he went to the USA, and became involved in research on cosmic rays. After returning to Japan in 1956 he proceeded to build an international reputation in this field and subsequently in X-ray astronomy (Pounds, 2004). He achieved great success as Director of the Institute of Space and Astronautical Science (ISAS) and later the Reiken Institute (see Maddox, 2001), and long before he died (Figure 2) was widely regarded as the 'founding father' of space astronomy in Japan (Clark et al., 2001). One has to wonder if he would have achieved such international eminence had he remained in radio astronomy.

Tatsuo Takakura (see Figure 3) also worked on microwave radar during WWII (Takakura, 1985), but in stark contrast to Oda, he stayed true to radio astronomy throughout his career. After leaving Osaka City University in 1953 he joined the vibrant young radio astronomy group at Tokyo Astronomical Observatory (TAO) in Mitaka (see Nakajima et al., 2014), and remained there for the rest of his working life. At first he was devoted to solar research, but later he turned his attention to non-solar projects (see Takakura, 1985).

2.2 Osaka University

From November 1949 Oda and Takakura observed solar noise at 3.3 GHz using the hand-made metallic horn shown in Figure 4, which was supported by a damaged military searchlight mounting (Takakura, 1985). Apparently, the use of a horn rather than a parabolic dish was inspired by Japanese WWII radar technology. Much later, Takakura (1985: 163; our English translation) explained how this project came about:

Figure 3: A meeting of the Japanese National Commission V of URSI held at Toyokawa Observatory in 1954. T. Takakura is in the back row, third from the left. Also shown in the back row are some of Takakura's TAO colleagues: Akabane (2nd from the left), Suzuki (2nd from the right) and Hatanaka (extreme right). Oda is absent because by this time he was in the USA and no longer worked in radio astronomy (adapted from Tanaka, 1984: 345).

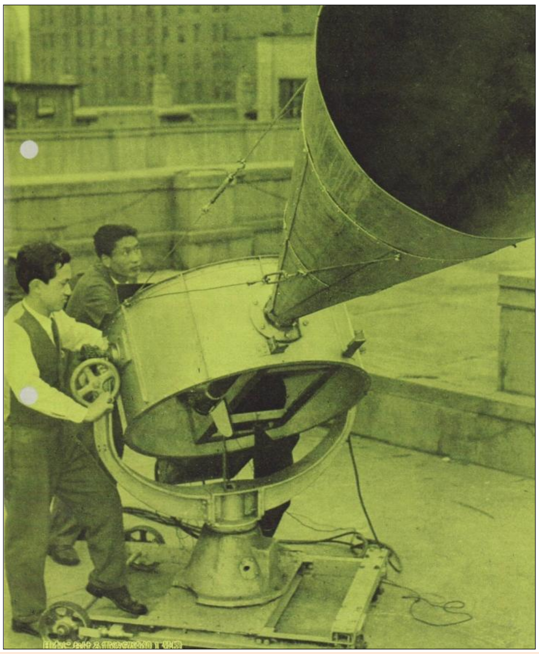

Figure 4: Oda (left) and Takakura (right) with their simple horn radio telescope at Osaka University in November 1949 (after Takakura 1985: front cover).

> One day in 1948, Minoru Oda happened to come to the lab where I worked, and said that he recently heard a rumour that a new field called radio astronomy had recently been born in overseas countries. He wanted me to work with him in this new field. This was my first opportunity to start research on solar radio astronomy.

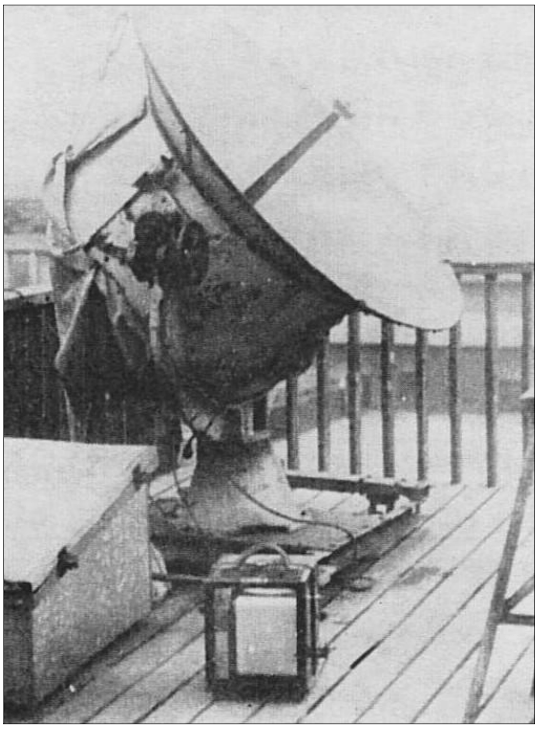

Figure 5: After they moved to Osaka City University Oda and Takakura replaced the horn feed with a 1-m parabolic reflector, and installed a new receiver, but they retained the chart recorder and the original mounting (after Takakura, 1985: 163).

As a result, the horn shown in Figure 4 was fabricated in the University's workshop, and Oda and Takakura found an abandoned 3.3 GHz radar receiver designed for use in submarines, and they modified it so that it coud be used with the horn. However, they did not know if the length and aperture of the horn were appropriate for a 3.3 GHz receiver (Takakura, 1985)!

We see that Oda and Takakura's decision to use a 3.3 GHz receiver also was motivated by their prior war-time experience working with microwave radar.[2] Towards the end of WWII the Imperial Japanese Army and Navy maintained metre-wave radar stations around the coasts of Japan (see Nakagawa, 1997; Nakajima, 1988), and the Navy also operated significant numbers of microwave radar units (Wilkinson, 1946a, 1946b). As we have seen, this to some extent lightened the burden of trying to source suitable electronic equipment during this difficult post-war period.

Takakura recalls that their initial attempts to detect solar radio emission with this simple radio telescope were frustrating:

> We used to manually point it [the horn] at the Sun, but could not detect any signal even after we had improved the sensitivity of the receiver. One day by mistake the antenna drifted away from the Sun, and then Oda noticed that the pen on the chart recorder recorded a strong signal … (Takakura, 1985: 163; our English translation).

Regrettably, they never suggested an explanation for this pointing error. Akabane (1986: 12–13; our English translation) also aludes to the difficulties that Oda and Takakura encountered at this time, prior to the introduction of the chart recorder:

> Since they pointed it [the horn antenna] on and off the Sun manually and read the needle of the current meter, I heard they spent lots of effort and time trying to detect solar radio emission …

Sometime in 1949—presumably towards the end of that year—Osaka City University established a new Faculty of Science and Technology, and Physics staff from Osaka University moved *en masse* to this innovative new facility, where Yuzuru Watase was appointed to a Chair in Physics (see Oda, 1985). Early in 1950 Oda accepted an Assistant Professorship in the same Department, and Takakura also transferred there, as a Research Assistant (Maddox, 2001; Takakura, 1985).

2.3 Osaka City University

Once settled at Osaka City University Oda and Takakura replaced the horn feed with the 1-m parabolic metal dish shown in Figure 5 (Tanaka, 1984), and they installed a new 3.3 GHz receiver (Takakura, 1985). They also constructed a metallic quarter-wave rotary polarization screen that was inserted directly in front of the dish when they wished to study the circular polarization of solar radio emission. In his report titled *Radio Astronomy in Japan*, Akabane (1986: 13) includes a photograph of this antenna with the polarization screen in place.

Strangely, in their 1-page published report on the research that they did carry out, Oda and Takakura (1951) say nothing about polarization, just that

> Solar radio noise at 3300 m.c. was observed from April to Oct. 1950 for every two hours per day [i.e. two hours every day]. Attention was paid to the average intensity and its fluctuations during [the] two hours.

Although they recognised that "… the period of observations was too short to arrive at any decisive conclusions …" (ibid.), Oda and Takakura did offer "… some crude results …" The first of these was:

> The intensity of solar noise at 3300 m.c. *is approximately proportional to the whole disk sunspot number*, reported from the Tokyo Astronomical Observatory, and shows no clear relation to the central zone sunspot number or whole disk sunspot group number. (ibid., their italics).

They also noted fluctuations with a period of ~20 minutes regardless of the intensity of the received emission, and that

> The mean fluctuation of the intensity is approxmately proportional to [the] square root of the intensity. (ibid.).

Towards the end of their short paper, Oda and Takakura (ibid.) suggested that:

> … it is most probable that the solar noise comes from the sunspots, but it should be noted that the period of a source is rather short. Then it may be supposed that the magnetic field in the sunspot might have [an] important role in the generation of radio waves.

This 1-page paper, or short communication, was the only publication issued by Oda and Takakura about their solar radio astronomy program, even though Tanaka (1984) indicates that they continued monitoring the Sun at 3.3 GHz for another 10 months—i.e. until August 1951. Tanaka (ibid.) also states that Oda and Takakura discovered there was a linear correlation between solar flux density and sunspot numbers, but he does not elaborate on this.

Perhaps Oda and Takakura did not write any further papers on their solar work because they felt there was nothing new to report. By 1951, radio astronomers in Australia (Lehany and Yabsley, 1949; Minnett and Labrum, 1950; Piddington and Hindman, 1949; Piddington and Minnett, 1949), Canada (Covington, 1947; 1948), England (Sander, 1947; Stanier, 1950), France (Laffineur and Houtgast, 1949) and the USA (Dicke and Beringer, 1946; Southworth, 1945) had published a succession of research papers on microwave solar radio emission, and Oda and Takakura would have been familiar with at least some of this literature.

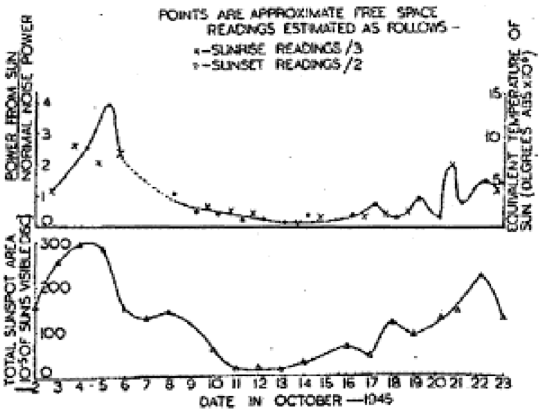

Figure 6: Plots of solar radio emission at 200 MHz (top) and total sunspot area (bottom) in October 1945 (after Pawsey et al., 1946).

They would have learnt that it was already well known that at frequencies above ~1 GHz burst emission was minimal and the solar flux density mimicked sunspot intensity. For example, in 1947 the Canadian, Arthur Covington began to regularly monitor solar radio emission at 10.7 cm (very close to the wavelength used by Oda and Takakura), and

> … this wavelength … turned out ideal as an index of solar activity, although its original choice [as in Japan] was dictated strictly by radar technology. Indeed, after only six months Covington (1948) could see his 10.7 cm data points rise and fall in perfect synchronism with the sun-spots .... (Sullivan, 2009: 213).

In fact, this correlation was first suggested by Pawsey et al. (1946), on the basis of October 1945 metre-wave data (Figure 6; cf. McCready et al., 1947), but it soon was confirmed to be a feature also of microwave solar emission—as shown in the lower two plots in Figure 7.

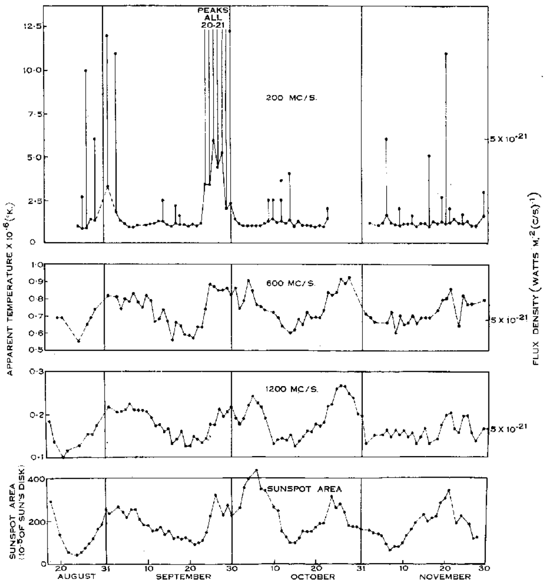

Figure 7: Variations in total sunspot area and solar radio emission at three different frequencies during a 4-month period in 1948. Note the obvious correlations at both 600 and 1200 MHz (after Lehany and Yabsley, 1949: 56).

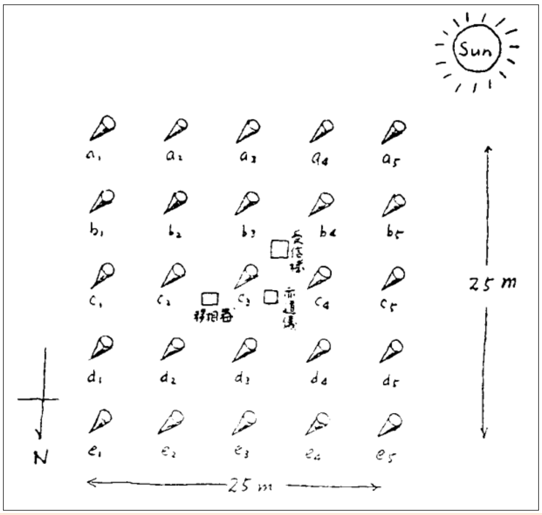

Figure 8: The solar grating array that was designed by Oda's group in 1950 but was never built (after Tanaka, 1984: 338).

Meanwhile, in 1946, Appleton and Hey (1946) in England and Martyn (1946) in Australia published papers on the polarization of solar radio emission, even if their studies focused on metre-wave emission. Presumably, Oda and Takakura did not obtain any new results that were meaningful at microwave wavelengths.

But another likely reason for Oda and Takakura's decision not to publish further papers was Oda's growing research interest in cosmic rays, at the expense of radio astronomy.[3] By this time it also was apparent that the optimal 'scientific mileage' in solar radio astronomy came from studying the metre-wave burst emission, and this became even more of a major international focus once Wild and his colleagues invented the solar radio spectrograph (see Wild, 1950a, 1950b; Wild and McCready, 1950) and could study solar bursts simultaneously across a wide range of frequencies. This somewhat reduced the research potential of single-frequency observations, and radio spectrographs quickly were adopted world-wide (including by Japan)

3 DISCUSSION

3.1 Takakura's Move from Osaka City University

When it became obvious that radio astronomy had no future at Osaka City University, Takakura was forced to move if he wished to remain in this field, or else he had to change his research direction and focus on cosmic rays. In choosing to continue in radio astronomy his options were limited: he had either to join Tanaka's vibrant Nagoya University group based at Toyokawa or Hatanaka's equally-impressive team at Tokyo Astronomical Observatory. At this time, both research groups were researching solar microwave emission (see Akabane, 1986; Nakajima et al., 2014; Tanaka, 1984), and for reasons that remain obscure Takakura chose to join the Tokyo group, where he went on to build a distinguished career as a radio astronomer (e.g. see Takakura, 1967; 1985).

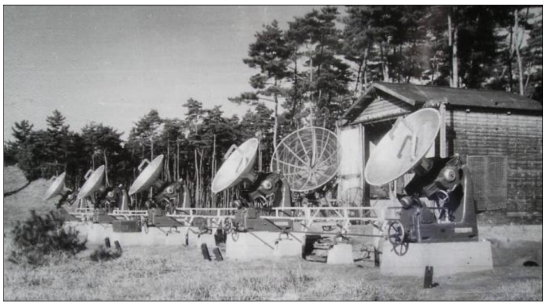

Figure 9: A view of the 4 GHz five-element grating interferometer installed at Toyokawa in 1953 (courtesy: Tanaka Family).

3.2 The Osaka Solar Grating Array Concept

By 1950 it was apparent that there were three very different types of solar radio emission:

(1) Energetic non-thermal bursts and outbursts;
(2) Thermal emission from the quiet Sun; and
(3) A slowly-varying component, correlated with the total area of sunspots visible on the solar disk.

The second and third components dominated at microwave wavelengths, and in order to study these more effectively than a small single dish would allow Oda's group at Osaka City University independently developed the concept of a grating interferometer. This would operate at 4 GHz, and would be used to identify the locations of the sources responsible for the solar noise. The interferometer would consist of 25 circular horns each 50-cm in diameter and arranged in the configuration illustrated in Figure 8. This interesting concept was proposed in an 8-page paper that was presented at the annual assembly of the Physical Society of Japan in 1950 (see Ojio et al., 1950), but it was never acted on. Had it been, then possibly Japan rather than Australia may have hosted the world's first solar grating array (see Christiansen, 1953; Christiansen and Warburton, 1953; Wendt et al., 2008).

The 1950 Ojio et al. paper was never published and thus far our attempts to locate a copy of it have been unsuccessful, so we cannot provide technical details of this innovative radio telescope. If we do eventually track down this paper we will prepare a separate paper in this Early Japanese Radio Astronomy series just about this array.

Meanwhile, Professor Haruo Tanaka from Nagoya University was inspired by the Ojio et al. paper, which led him to construct Japan's first solar grating interferometer at Toyokawa in 1953 (see Figure 9). This interferometer, and other radio telescopes designed and constructed by the Toyokawa researchers will be the subject of a later paper in this series.

4 CONCLUDING REMARKS

For less than two years, starting in November 1949, graduate students Minoru Oda and Tatsuo Takakura monitored solar radio emission at 3.3 GHz, initially from Osaka University with a simple horn antenna and subsequently from Osaka City University with a small metallic parabolic reflector. Although they particularly wished to investigate the polarization of the solar emission, they ended up publishing just one short solitary research paper, which merely contained general comments about microwave solar emssion but nothing about its polarisation properties.

Oda then turned to other fields of astronomy, but Takakura was able to transfer to the vibrant Tokyo Astronomical Observatory radio astronomy group at Mitaka and make an important life-long contribution to solar and non-solar radio astronomy. The limited and short-lived Osaka experiments therefore served as his radio astronomical 'apprenticeship', and should be viewed in this light—notwithstanding the paucity of publications that he and Oda produced at this time.

5 NOTES

1. This is the fourth paper in a series that aims to document early Japanese radio astronomy. The first paper was an overview (Ishiguro et al., 2012), and it was followed by papers about the first solar radio observations made from Japan, by Koichi Shimoda in 1948 (see Shimoda et al., 2013), and a review of the early solar radio astronomy carried out at the Tokyo Astronomical Observatory (Nakajima et al., 2014).
2. Akabane (1986: 12; our English translation) notes that at this time Japanese scientists

   > … were stimulated by the news that US and Canadian physicists started observing celestial bodies in the microwave radio band …

   This was quite different from the early solar radio astronomy research conducted in Australia, England and New Zealand, which was at metre wavelengths.
3. This was nurtured by Professor Watase, and it is significant that when Oda went to the USA in 1953 he made this his sole research interest.

6 ACKNOWLEDGEMENTS

We wish to thank Ms Junko Oguri at the National Astronomical Observatory of Japan Library for providing copies of old research papers; the Tanaka Family for kindly supplying Figure 9; and Professor Ray Norris and Drs Peter Robertson and Harry Wendt for commenting on the original dfraft of this paper. The first author (WO) also is grateful to the NAOJ for helping fund this project.

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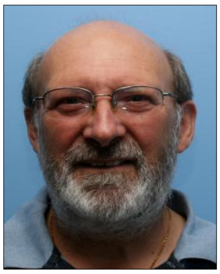

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A LUNAR ECLIPSE VOLVELLE IN PETRUS APIANUS' *ASTRONOMICUM CAESAREUM*

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Abstract: The workings and theory of an eclipse volvelle in Petrus Apianus' *Astronomicum Caesareum* is investigated. This paper also tries to explain how the volvelle was implemented from the theory and what values were given to the parameters that were used for the calculations. Results from model computations are presented.

Keywords: volvelle, lunar eclipse, Petrus Apianus

1 INTRODUCTION

Petrus Apianus (Figure 1; also Peter Apian), whose surname is a Latinized version of his original family name Bienewitz, was born the son of a shoemaker in Leisnig (Germany) in about 1501 and died in Ingolstadt (Germany) in 1552 (Galle, 2014). He began his studies at the University of Leipzig in 1516 but moved to the University of Vienna in 1519 where he studied mathematics, astronomy and astrology. In 1527 he was appointed a Professor of Mathematics at the University of Ingolstadt and soon achieved fame as an astronomer and astrologer. He published several works on comets and instruments for the calculation and astronomical observation, and he observed Halley's Comet. But his masterpiece was *Astronomicum Caesareum* (Apianus, 1540a), which was dedicated to the Roman Emperor Charles V (1500–1558). It is based in the Ptolemaic model of the Universe and the fundamental parameters are the same as in the Alfonsine Tables (1518) although it seems from preliminary computer calculations that I have made that Petrus Apianus in some cases made some small modifications. *Astronomicum Caesareum* contains a large set of ingeniously-constructed volvelles for computing the true locations of the Sun, Moon and planets, as well as an extensive set for different kinds of eclipse calculations. His work earned him an appointment as Imperial Mathematician.

Petrus Apianus (1540b) also published a manual in German for *Astronomicum Caesareum*. A review of *Astronomicum Caesareum* has been given by Gingerich (1971). At that time, about 120 copies of the original work were still extant. In 1967, a facsimile of *Astronomicum Caesareum* was published (Apianus, 1967).

There is a very complete compilation on different aspects of Apianus' life and work edited by Karl Röttel (1995) in connection with an exhibition on Apianus that was held in Leisnig in 1996 and Landrats-amt Neumarkt in 1997.

In this paper we study one of the volvelles (Figure 2) that Apianus (1967: 73) used for lunar eclipse calculations. As with all the other volvelles in Petrus Apianus' work, one cannot help but be impressed by the amount of mental and manual effort and skill that was used in creating this volvelle. Here, we try to investigate how this volvelle was constructed.

2 OVERVIEW OF THE VOLVELLE

At the top of the volvelle there is a panel for setting up the volvelle, given the anomalies of the Moon and the Sun. There are then four separate panels grouped clockwise around the centre, the first for determining the size of the eclipse, N. PVNCTA ECLIPTICA, the second one for determining half the time of the totality, MORA MEDIA, the third one for determining the time of partiality, TEMPVS CASUS, and finally the last one for determining the angular movement of the Moon during the eclipse, MINVTA GRA. MOTVS LUNE. Each of these panels ex-

Figure 1: Petrus Apianus (courtesy: Instituto e Museo della Sciencia, Florence).

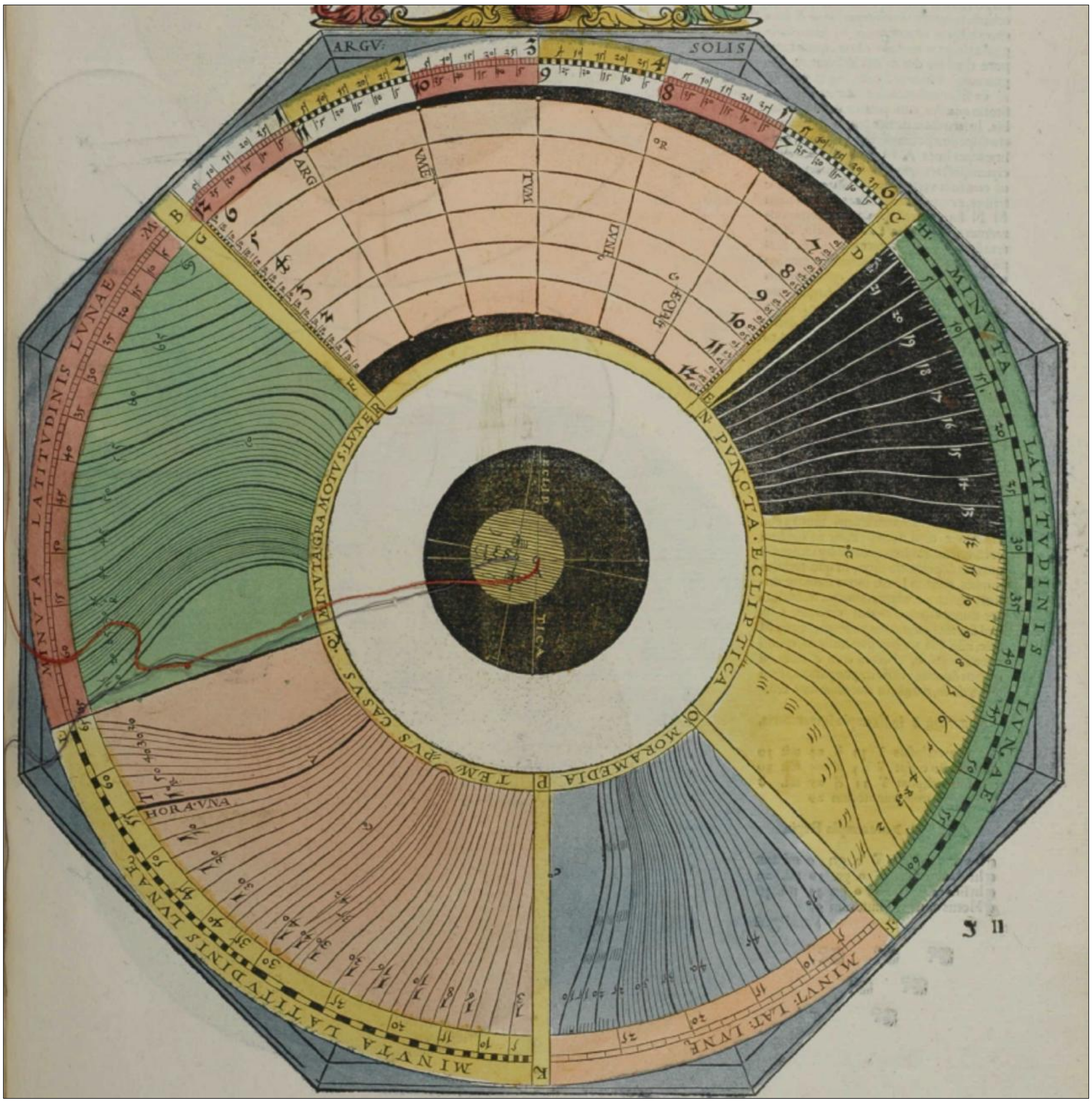


Figure 2: The eclipse volvelle (Photograph: Lars Gislén).

hibits an intricate set of curves. In the case of the size of the eclipse, each curve represents a certain eclipse size, for the *mora media* and *tempus casus* the curves show the half duration in hours and minutes of the totality and partiality respectively, for the *minuta motus* panel, the movement of the Moon in arc minutes during the eclipse.

The lunar anomaly is set in the top panel on the left and right hand scales, graduated from sign 1 to 6 and 7 to 12 respectively. The solar anomaly is set by the top scale along the edge of the volvelle. There are two different threads, red and blue, attached to different centres A and B. Centre A is the centre of the entire volvelle while B is slightly displaced to the left. The two threads presumably had small beads that could slide along the threads with some friction. You first use the blue thread and stretch it along the left scale, setting the bead at the given anomaly of the Moon. For lunar anomalies with signs 7 to 12 the right hand scale is used. The red thread is then stretched and set against the solar anomaly on the upper scale. The blue thread is rotated until its bead crosses the red thread and the bead on the red thread is fixed at that point. Finally, the red thread is rotated to the respective panels and set against the given lunar latitude and a value is read off from the curve under the bead, possibly interpolating between two curves.

The volvelle raises some questions. It is evident that the lunar and solar anomalies are not independent. So for instance a setting with lunar anomaly zero signs, solar anomaly zero signs gives the same result as a setting of lunar anomaly 11 signs 10°, solar anomaly 6 signs. For this reason, I have treated the volvelle as having solar anomaly zero and refer the inclusion of the solar anomaly to the discussion at the end of the paper.

3 NOTATION

The lunar latitude is denoted by β. All angular measures are made in minutes of arc. The Moon’s apparent radius is r and the radius of the shadow is R. As in the *Almagest* (Toomer, 1984: 254), it is assumed that $R = 2.6r$. The radius is a function of the Moon’s distance from the Earth, which in turn is a function of the lunar anomaly, γ_M. Figure 3 comes from the Alfonsine Tables (1518: 234) and shows the apparent radii of the Sun, the Moon and the shadow as a function of their respective anomalies. Note that the Alfonsine Tables use sexagesimal notation for the anomaly, for instance 1:30 in the first column is 60 + 30 = 90. The last column in the table shows the correction to the radius of the shadow as a function of the solar anomaly γ_S. The shadow becomes slightly smaller as the Sun gets closer to the Earth, the largest shadow correction being –56″, see the Appendix at the end of this paper.

The very small influence on the theory from the inclination of the Moon’s orbit is neglected.

4 THE DIFFERENT PANELS OF THE LUNAR VOLVELLE

4.1 Theory

4.1.1 *Puncta Ecliptica*, *p*, the Size of the Eclipse

This is expressed as the fraction of the lunar diameter that is obscured, in units such that a total eclipse has size 12 or larger. The mathematical expression is:

$$p = 12(R + r - \beta) / 2r = 21.6 - 6\beta / r \tag{1}$$

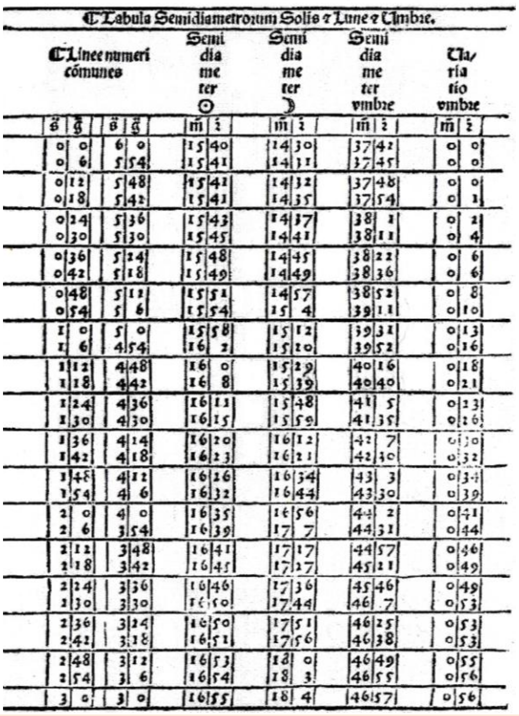
It is easy to see that if $\beta = R + r$, the size of the eclipse is zero, while if $\beta = R - r$, the size is 12, the lower limit for a total eclipse. The maximum possible eclipse will be for $\beta = 0$ when the size is 21.6.

4.1.2 *Mora Media*, the Half Duration of the Totality, t_m

From Figure 4 the distance AB is seen by the Pythagorean theorem to be

$$m = \sqrt{(R - r)^2 - \beta^2} \tag{2}$$

In time units (minutes) $t_m = 60m / (\nu_M - \nu_S)$, where ν_M is the angular speed of the Moon per hour and ν_S the corresponding angular speed of the Sun. These speeds are a function of the respective anomalies. For the Sun this dependence is quite small and can be taken as constant as in the *Almagest* (Toomer, 1984: 306) where $\nu_M - \nu_S = \nu_M / (1+1/12)$.



Tabula Semidiametrorum Solis ⁊ Lune ⁊ Umbre.

Linee numeri cõmunes				Semi dia me ter ☉		Semi dia me ter ☽		Semi dia me ter vmbre		Va/ria tio vmbre	
s	g	s	g	m	2	m	2	m	2	m	2
0	0	6	0	15	40	14	30	37	42	0	0
0	6	5	54	15	41	14	31	37	45	0	0
0	12	5	48	15	41	14	32	37	48	0	0
0	18	5	42	15	41	14	35	37	54	0	1
0	24	5	36	15	43	14	37	38	1	0	2
0	30	5	30	15	45	14	41	38	11	0	4
0	36	5	24	15	48	14	45	38	22	0	6
0	42	5	18	15	49	14	49	38	36	0	6
0	48	5	12	15	51	14	57	38	52	0	8
0	54	5	6	15	54	15	4	39	11	0	10
1	0	5	0	15	58	15	12	39	31	0	13
1	6	4	54	16	2	15	20	39	52	0	16
1	12	4	48	16	0	15	29	40	16	0	18
1	18	4	42	16	8	15	39	40	40	0	21
1	24	4	36	16	11	15	48	41	5	0	23
1	30	4	30	16	15	15	59	41	35	0	26
1	36	4	14	16	20	16	12	42	7	0	30
1	42	4	18	16	23	16	21	42	30	0	32
1	48	4	12	16	26	16	34	43	3	0	34
1	54	4	6	16	32	16	44	43	30	0	39
2	0	4	0	16	35	16	56	44	2	0	41
2	6	3	54	16	39	17	7	44	31	0	44
2	12	3	48	16	41	17	17	44	57	0	46
2	18	3	42	16	45	17	27	45	21	0	49
2	24	3	36	16	46	17	36	45	46	0	49
2	30	3	30	16	50	17	44	46	7	0	53
2	36	3	24	16	50	17	51	46	25	0	53
2	42	3	18	16	51	17	56	46	38	0	53
2	48	3	12	16	53	18	0	46	49	0	55
2	54	3	6	16	54	18	3	46	55	0	56
3	0	3	0	16	55	18	4	46	57	0	56

Figure 3: A table from the Alfonsine Tables.

4.1.3 *Tempus Casus*, the Half Duration of the Partiality t_c

This is the difference between the half the total time for the eclipse, AC, and half the time of the totality, AB. Again using the figure above we get

$$c = \sqrt{(R + r)^2 - \beta^2} - \sqrt{(R - r)^2 - \beta^2} \text{ if } \beta < R - r \tag{3a}$$

$$c = \sqrt{(R + r)^2 - \beta^2} \text{ if } \beta < R - r \text{ (no total eclipse)} \tag{3b}$$

In time units (minutes) $t_c = 60\, c / (\nu_M - \nu_S)$.

Figure 5 shows a sketch of the *tempus casus* function. The function is here drawn with $r = 1$, $R = 2.6$. The slope of the curve gets infinite for $\beta = R - r$ with $c = 2\sqrt{(Rr)}$. Petrus Apianus’ volvelle panel effectively shows a contour plot of the ‘mountain ridge’ in the figure as the Moon’s anomaly varies.

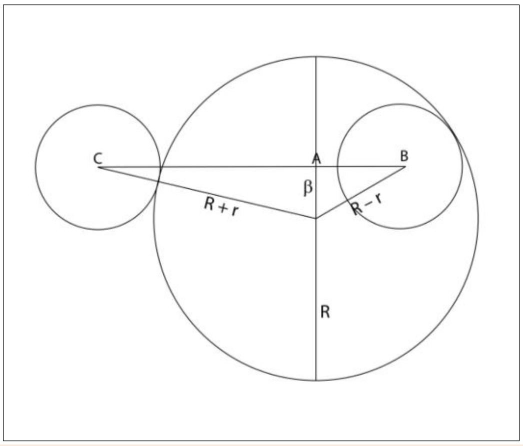


Figure 4: Eclipse geometry.

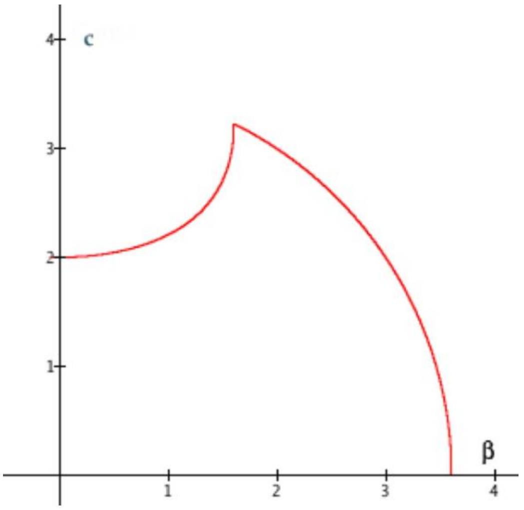


Figure 5: The *tempus casus* function.

4.1.4 *Minuta Motus*, the Moon's Movement During (Half of) the Eclipse

The Moon's angular movement, a, relative to the shadow disk is

$$a = \sqrt{((R + r)^2 - \beta^2)} \qquad (4)$$

The corresponding time is calculated as above by dividing this by the relative speed of the Moon and the Sun. Multiplying this by the Moon's angular speed will give the Moon's movement,

$$\delta = a\, v_M \,/\, (v_M - v_S) \qquad (5)$$

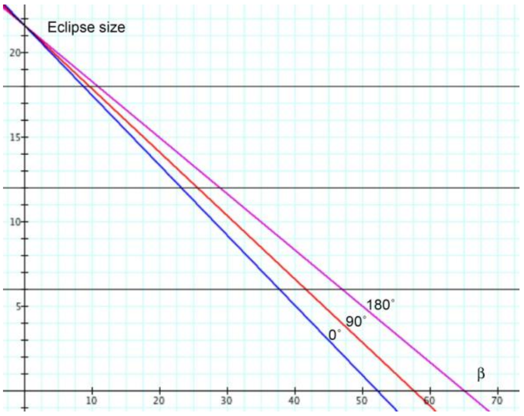


Figure 6: The eclipse size graph.

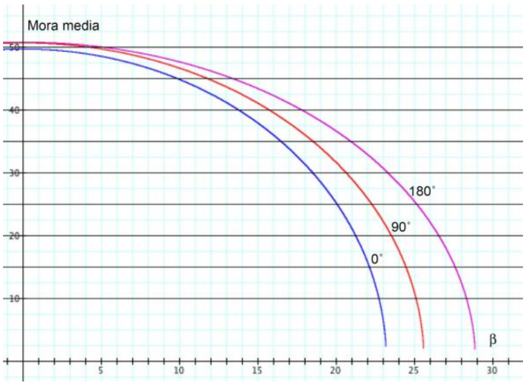


Figure 7: The *mora media* graph.

4.2 The Implementation of the Theory

The mathematical expressions above are somewhat complicated, especially for the *tempus casus* case. In order to draw the panel curves we want the variation of the lunar latitude as we move along a curve with constant value of for instance the duration of the totality. This means that we would have to invert relations (1)–(4), something that in the case of the *tempus casus* function is mathematically quite difficult. A much simpler—and I believe for Petrus Apianus more natural—procedure would be to graph the respective functions, select a value for the parameter of interest and read off corresponding β value manually. It is rather easy to plot curves for different R and r as the Moon's anomaly varies. It would also be enough to plot curve points in the volvelle panels for a few values of this anomaly and then connect these points by hand. In the graphs below I have only computed results for lunar anomalies 0°, 90° and 180°, in some cases where the panel curves are less linear I have also used intermediate lunar anomalies of 45° and 135°.

4.2.1 *Puncta Ecliptica*, the Size of the Eclipse

The three lines in Figure 6 were constructed by taking the values for r from the Alfonsine Tables for anomaly 0° (14′ 30″), 90° (15′ 59″) and 180° (18′ 4″) and inserting them in expression (1) and plotting the resulting three straight lines.

If we follow the line of, for instance, eclipse size 12 to the magenta curve (anomaly 180°) we get $\beta = 29'$. The red curve (anomaly 90°) gives $\beta = 26'$, and the blue curve (anomaly 0°) gives $\beta = 23'$. This corresponds excellently with the curve on the volvelle.

4.2.2 *Mora Media*, the Half Duration of the Totality

Again I have plotted three curves (Figure 7) using the tabular values of R and r and the formula (2) for anomaly 0°, 90° and 180°. A problem here is that I also need values of the lunar angular speed that depends on the anomaly. There is a table for these values in the Alfonsine Tables (1518: 190–191). However, using these values does not give a perfect fit, especially for the *mora media* panel.

I am not sure which version of the Alfonsine Tables was used by Petrus Apianus; there quite a few that are possible, with slightly different tabular values. Instead I have made a weighted least square fit of the curve values in the panels and the theoretical values. The fit has to be weighted because the β scale in the panels is in many cases non-linear, for the *tempus casus* panel very much so. Table 1 shows the best fit values for $v_M - v_S$ in the *mora media* and *tempus casus* panels.

The values do not deviate very much from these you get from the Alfonsine Tables that I have consulted, except for lunar anomaly 180° (see Figure 7).

4.2.3 *Tempus Casus*, the Half Duration of the Partiality

In Figure 8, it should be mentioned that where the curves are more or less horizontal, the point where the curves cross a horizontal line is not very well defined and the value of β is not very precise. This is the case when the lunar latitude is small.

4.2.4 *Minuta Motus*, the Moon's Movement During Half of the Eclipse

Here (Figure 9) the ratio v_M / (v_M – v_S) is essentially constant—its variation with the lunar anomaly is very small. I used values of v_M from the Alfonsine Tables and v_S = 2.38, the tabular value for solar anomaly 0°. Thus, the only important dependence comes from the variation of R and r.

5 RESULTS

Figure 10 shows the volvelle with some calculated points (red) using the procedures above. For the size panel I have calculated points for eclipse sizes 6, 12, and 10. In the *mora media* panel points are for times 45 and 25 minutes and in the *tempus casus* panel for times 1 hour and 1 hour 20 minutes. The white points mark the 'crest' of the *tempus casus* curve. In the *minuta motus* panel, points are calculated for 20, 45, 55, 60 and 65 minutes.

6 TWO EXAMPLES

In *Astronomicum Caesareum* there are two examples of eclipse calculations. The first is related to the year of birth of Emperor Charles V and was a partial lunar eclipse on AD 5 November 1500. Petrus Apianus gives the solar anomaly as 4 signs 23° 29′, the lunar anomaly as 9 signs 22° 59′, and the Moons latitude as 29′ [south]. The anomaly entry is marked by a small letter C that can be seen in the top panel of Figure 2. Moving to the *puncta ecliptica* panel we find the letter C marked corresponding to the Moon's latitude 29′ and the eclipse size can be read off as 10. In the *mora media* panel the corresponding point shows that there was no totality. In the *tempus casus* panel, point C gives the half duration of the partiality as 1 hour 35 minutes and finally the *minuta motum* panel shows that the Moon moved 49′ during this time. I checked the result with a modern ephemeris program: eclipse size 10.6, half duration 1:36, and Moon's movement 56′.

Table 1. Parameter values of $v_M - v_S$ for best fit.

Lunar Anomaly	0°	90°	180°
Mora media	28.05	30.3	34.11
Tempus casus	27.38	30.32	34.43
Alfonsine Tables	27.92	30.32	33.41

The second example in *Astronomicum Caesareum* is the partial lunar eclipse on AD 15 October 1502, preceding the birth of King Ferdinand I, one of the brothers of Charles V. The solar anomaly was 4 signs 2° 12′, the lunar anomaly 6 signs 15° 33′, and the Moon's latitude 55′ north. The entry point is marked in the top panel by the letter R. This gives the eclipse size as 3, no totality, half duration of partiality 56 minutes, and Moon's movement 34′. The modern values are respectively 3.4, 56, and 37.

7 DISCUSSION

The above procedures explain and give results that agree very well with the different curve sets in the volvelle panels. So far, however, the influence of the solar anomaly has been neglected This will influence two things: the apparent angu-

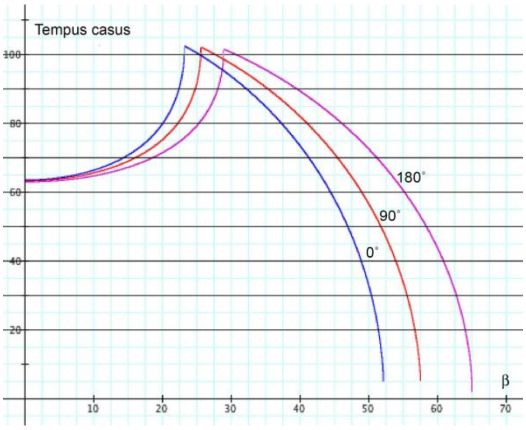


Figure 8: The *tempus casus* graph.

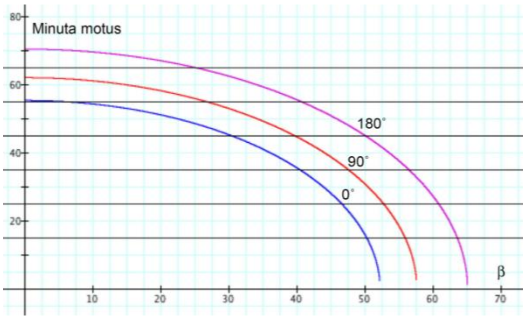


Figure 9: The *minuta motus* graph.

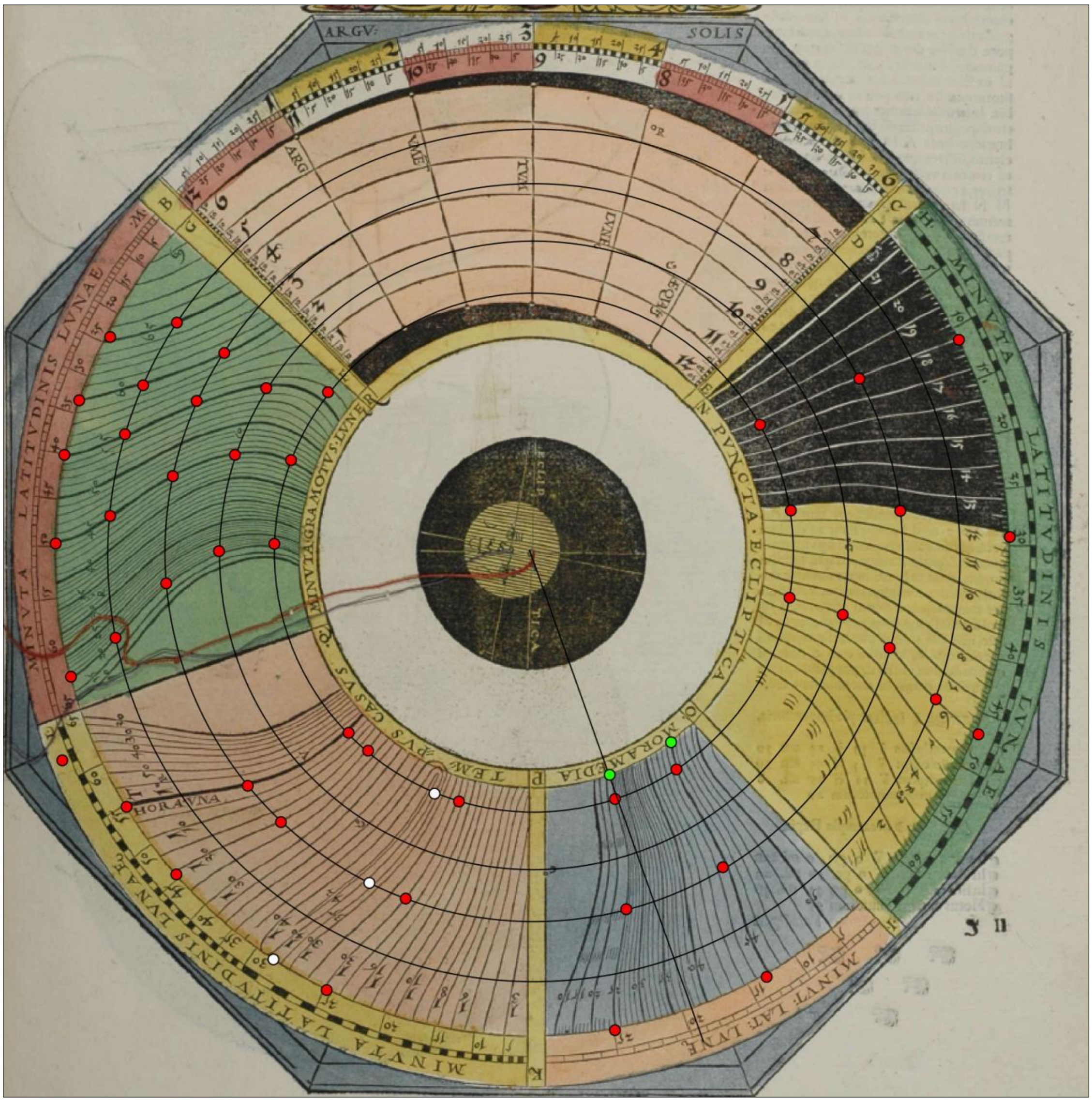


Figure 10: Simulation results.

lar speed of the Sun and also the size of the shadow. The variation of the solar speed makes a very small impact on the results and I believe that it was purposely neglected by Petrus Apianus. The change in the radius of the shadow is also rather small but if neglected one would ask why the volvelle required a scale for setting the solar anomaly. However, the volvelle curves can be extremely well simulated for most of their extent, with the influence of the solar anomaly entirely neglected. Only the strip nearest to the centre of the volvelle is still undetermined. I will now consider in more detail the *mora media* panel.

As the solar anomaly increases from 0° to 180°, the shadow radius shrinks, slowly to begin with, more rapidly after 90° and has finally decreased by 56″ ≈ 1′ at 180°. As the elongation speed is of order 30′ per hour, the time of the totality for β = 0 will be shortened by about 60·1/30 = 2 minutes. For larger values of β this time correction will be larger but even at β = 20′ it is only about 3 minutes. We also notice that, as the lunar and solar anomalies are set in the volvelle, they are not independent. If we examine the volvelle it is evident that the panel curves in general show a rather abrupt small change of direction towards smaller values of β in the strip closest to the centre. I believe that the solar anomaly correction was only implemented by Petrus Apianus in this strip. I have simulated this by points corresponding to lunar anomaly 0° and solar anomaly 180° at the inner border of the *mora media* panel where for instance the point on the curve representing a 45 minute duration has been calculated for 47 minutes, lunar anomaly 0° and solar anomaly 180°, and then corrected by 2 minutes, 47 – 2 = 45. The simulated point is marked by a green dot. A similar procedure gives another green dot on the 25 minutes curve. Both these points agree very nicely with the panel curves.

In the *tempus casus* panel, the curves are the result of the difference between two square roots and we expect the time correction to be smaller. A similar, but slightly more involved, computation as for the *tempus casus* panel, indeed shows that the time correction in this case is very small, in general much less that one minute. This is also evident from an inspection of the panel curves, there is no or very small change in the direction of these curves in the strip closest to the inner border of the panel. The only panel posing a problem is the *minuta motus* panel where the curves in the strip deviate in the wrong direction—the curves on the volvelle indicate that the Moon moves a larger angular distance as the shadow radius shrinks, which must be wrong. I cannot explain this, although a possible explanation may be that there was an error in the layout of the curves in this part of the panel.

8 ACKNOWLEDGEMENTS

I am grateful to the Instituto e Museo della Sciencia in Florence for kindly supplying Figure 1.

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10 APPENDIX: THE SHADOW CORRECTION

We refer to Figure 11 showing the Sun, the Earth and the shadow plane where the Moon is located. D is the Sun-Earth distance, d the Earth-Moon distance, and x the distance from the shadow plane to the shadow apex. R is the radius of the Sun, r the radius of the Earth, and S the radius of the shadow. The apex angle is small, of the order of 0.5 and we can use the approximation that the sine of this angle is equal to the tangent of this angle and also equal to the angle itself, expressed in radians. We also see that the shadow becomes smaller when the solar distance decreases.

From equal triangles we have

$$(D + d + x) / R = (d + x) / r = x / S$$

The first equality gives $x = D \cdot r / (R - r) - d$

Inserting this in the last equality we get

$$S = r - (R - r)\, d / D$$

The apparent angular size of the shadow (in radians) as seen from the Earth is

$$\alpha \approx S / d = r / d - (R - r) / D$$

At the maximum distance of the Sun where the Sun-Earth distance is D_0 we have

$$\alpha_0 = S / d = r / d - (R - r) / D_0$$

The change in angular size is $\Delta\alpha = \alpha_0 - \alpha = (R - r)\,(1/ D_0 - 1/D)$

In the Ptolemaic model $D = D_M \cdot \surd(1 + e^2 + 2e \cos \gamma) = D_M\,(1 + e)\,\surd(1 - 4e \sin^2(\gamma/2) / (1 + e)^2)$.

where D_M is the mean solar distance and e the eccentricity of the Sun, and γ the anomaly of the Sun.

At maximum distance where $\gamma = 0$ we have $D_0 = D_M\,(1 + e)$. This gives

$$\Delta\alpha = (R - r)\,(1 - 1/\surd(1 - 4e \sin^2(\gamma/2) / (1 + e)^2)) / (D_M\,(1 + e)).$$

The eccentricity is a small quantity and we can Taylor expand the second term in the bracket skipping higher orders of e:

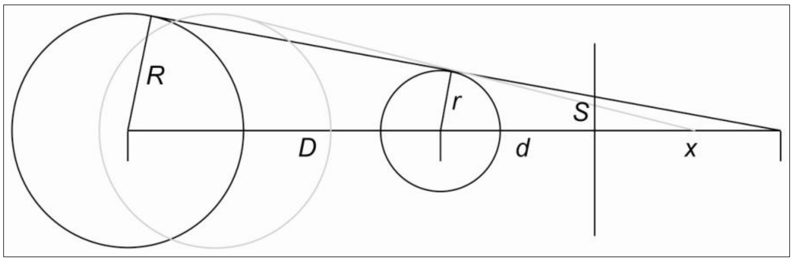

Figure 11: The eclipse shadow.

$1/\sqrt{(1 - 4e \sin^2 (\gamma/2) / (1 + e)^2)} \approx 1 + 2e \sin^2 (\gamma/2) / (1 + e)^2$

Thus we finally get

$\Delta\alpha = -2e\,(R - r) \sin^2 (\gamma/2) /(D_M (1 + e)^3)$.

We now insert Ptolemy’s values $R = 5.5$, $r = 1$, $D_M = 1210$, $e = 2.5 / 60 = 0.0417$ (Toomer, 1984: 158, 257) and convert to arc seconds by multiplying with the factor $3600 \cdot 180/\pi$

$\Delta\alpha = -56.6'' \sin^2 (\gamma/2)$.

The value used in the Alfonsine Tables in Figure 2 is a rounded down value of 56″.

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ON THE LOST PORTRAIT OF GALILEO BY THE TUSCAN PAINTER SANTI DI TITO

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Abstract: We study here the first established image of Galileo from the engraving made by Giuseppe Calendi at the end of the eighteenth century after a lost portrait of 1601 by Santi di Tito. We show that the engraving cannot be an exact copy, as it contains several inaccuracies which are unlikely to have been present in the original painting. A recent claim of the discovery of the painting by Santi di Tito is examined, and some reasons for suspecting it to be a forgery are outlined.

As an alternative, we suggest a connection between the engraving and a portrait attributed to Tintoretto (which is currently in the collection of the Padua Civic Museum). The engraving and the Padua painting look quite different but can be traced to a common origin if we assume that Calendi added the half body, copied the painting onto copper plate directly, and adjusted the shading slightly. In this way, several features and details of the engraving find a plausible explanation.

Finally, we note a remarkable similarity between the Padua portrait and a figure included in a Cologne painting by Rubens dating to about 1602–1604, which was suggested by Huemer to be Galileo.

Keywords: Galileo Galilei, Santi di Tito, Giuseppe Calendi, Peter Paul Rubens

1 INTRODUCTION

> The most experienced Italian Painters wanted to have the honor of portraying Galileo. Santi di Tito represented him in 1601 in a small painting at the age of thirty-eight, not long before he [Santi di Tito] passed to the other life. (de Nelli, 1793: 872; my English translation).

The above passage is taken from the biography of Galileo by Giovanni Battista Clemente de Nelli (1725–1793), which contains the first—albeit incomplete—iconography of the scientist. In a brief footnote on the same page of his book, de Nelli adds that he also possesses the Santi di Tito painting:

> This portrait is the one preserved in my private library, and the engraving made by Mr. Giuseppe Calendi I posted at the beginning of this Istoria [biography]. (ibid.).

The engraving by Giuseppe Calendi (1761–1831) taken from the frontispiece of de Nelli's book is reproduced here as Figure 1. At its base, the engraving bears the following inscriptions: "Galilaeus Galilaei Patricius Flor. / aet. suae / Annum Agens Quadragesimum"; below it on the left, "Sancti Titi pinxit"; in the center, "Ex Pinacotheca Nelliana", and on the right the signatures, "Joseph Calendi sculp. / Raph. Morghen direxit". The inscriptions thus state that Galileo was painted by Santi di Tito (1536–1603) when the scientist was aged 40 and that the engraving was made by Calendi under the direction of Raphael Morghen (1758–1833).

Favaro (1914–1915) already noted that the age of Galileo reported in Calendi's engraving could not be accurate since Santi di Tito died in Florence on 25 July 1603 when Galileo was 39. This inconsistency continued in the work of de Nelli, wherein he suggests the painting was executed in 1601 when Galileo was 38 years old; in actuality, though, he would have been 37. However, we suggest that the latter could be resolved by assuming that de Nelli refers to the Florentine calendar for the date of the painting. The painting is probably undated, according to the custom of the times, and it is possible that de Nelli had drawn its date from some lost document. The Florentine calendar, used until 1750, set the beginning of the year at 25 March. Thus, if according to the Florentine calendar the painting was executed before 25 March 1601, in the calendar then current the year would be 1602. This interpretation could explain de Nelli's imprecision, and converge towards a very precise date for the picture that therefore must have been painted between 15 February—Galileo's birthday—and 25 March 1602. Conversely, unless the age of 40 indicated in the engraving has a symbolic meaning for maturity it indicates a certain inaccuracy by the engraver, or else a lack of communication between Calendi and de Nelli. However, what de Nelli writes about the most experienced Italian painters applies certainly to late portraits of Galileo made by painters of his time such as Sustermans, Leoni or Furini, but it can hardly be applied to the portrait of Santi di Tito because in 1601 Galileo was not the renowned scientist he was to become in a few years time.

2 THE CALENDI ENGRAVING OF GALILEO IS NOT A FAITHFUL COPY

In the engraving (Figure 1) Galileo is depicted in half-length format with his right hand holding a telescope. The telescope first made its appearance in the Netherlands in October 1608 and was

Figure 1: Giuseppe Calendi's engraving after Santi di Tito on the frontispiece of *Vita e Commercio Letterario di Galileo Galilei*, by G.B.C. de Nelli (1793).

reproduced and improved by Galileo in 1609. Discarding imaginative reconstructions, we assume that the telescope was not present in Santi di Tito's original portrait, but was added by Calendi in his engraving made in the late eighteenth century. It is likely that Calendi deemed it appropriate to depict the scientist with the symbol of his most important discoveries. Along with the telescope we cannot exclude the possibility that the entire half-body of Galileo could have been added. In the engraving Galileo is slightly cross-eyed with a pointed nose which turns sideways to the direction of the face. The haircut is quite unnatural and does not end symmetrically along the forehead. Moreover, the engraving lacks a well-defined light source. The shading of the hand holding the telescope indicates that the light comes from the right, while the shadowing on the face indicates that the light comes from above. But the right side of the collar is in shadow while the left side is clearly illuminated, and there is no visible shadow of the head. We note that Galileo turns his shadowed face towards the observer, which is quite unusual for the portraiture of the time. Such inaccuracies are hardly attributable to a painter of the quality of Santi di Tito. They are more likely due to the transposition of the painting into the engraving. The engraving appears of mediocre quality. It is also difficult to understand the role played by Raphael Morghen, who was an excellent draftsman and printmaker himself and author of good portraits of some of the greatest Italian writers of the time, such as Dante, Petrarch, Ariosto, Tasso, Guicciardini and Boccaccio, which were printed in the frontispieces of books.

Santi di Tito was a pupil of Bronzino and probably one of the greatest painters of the Florentine School of the late sixteenth century, during the transition from Mannerism to the Baroque art style (Spalding, 1982). Vasari (1568) dedicated a biography to Santi di Tito in his *Lives of the Artists* where he emphasizes his ability in portraiture, mentioning that of Michelangelo in the painting for Michelangelo's funeral of 1564, which is now lost. Filippo Baldinucci (1770) gives a full account of the numerous Santi di Tito portraits, and in his *Delle Notizie de' Professori del Disegno da Cimabue in Qua* writes:

> … by his genius, no less his desire for gain, was he led to do portraits, like those who, possessing an extraordinary security in the drawing, he did with great ease ... He was painting mostly the head and perhaps the hands, and leaving to his young collaborators to paint the hair, if they were females, and all the clothes of females and males ... Of portraits, however, of his own hand there are many and beautiful, but many are somewhat battered. (Baldinuuci, 1770: 69; my English translation).

Most of the portraits mentioned by Baldinucci are lost.[1] By 1602, Galileo was a respected Professor at the University of Padua, but he was struggling with economic problems (Drake, 1978) and could hardly afford a costly commission to a famous painter like Santi di Tito—who was at the peak of his career. When translated into English, Santi di Tito's motto was literally "I have brushes of all prizes", meaning that he could create cheap or expensive paintings, thereby catering for 'all pockets'. We may therefore speculate that the Galileo painting was executed on a small remnant of canvas as a gesture of friendship or by the intercession of Ludovico Cardi (also known as Cigoli), who was one of Santi di Tito's pupils, and also a close friend of Galileo since the time when they both took perspective lessons together from Ostilio Ricci in Florence (Chappell, 1975; Reeves, 1999). We also note that according to Viviani (1711: 3), Santi di Tito's tutor, Bronzino, was close to Galileo, but it is possible that Viviani was wrong since Bronzino died in 1572.

We do not know how the painting of Galileo came into de Nelli's possession. After Viviani died, his collection of mathematical portraits was sold by Viviani's heirs to Professor Thomas Perelli, de Nelli, and other assorted buyers. It is thus possible that the picture, and various Galileo documents, belonged to the collection acquired by de Nelli at this time (see Favaro, 1912–1913). De Nelli's Galilean collection was later bought, in 1818, by Ferdinand III, the Grand Duke of Tuscany and, after various vicissitudes, first passed to the Palatine Library and then to the National Library of Florence. However, during all of these moves there is no mention of the Galileo painting.

3 THE REPORTED DISCOVERY OF THE SANTI DI TITO PAINTING

A Santi di Tito painting of Galileo owned by a Florentine antique dealer was reported by Federico Tognoni in 2013, and details subsequently were presented in an article published in the *Academia Patavina* (Tognoni, 2014–2015, see also Figure 2 in Molaro 2016). If the painting is genuine, this discovery would be extraordinary because it would represent one of the first portraits of Galileo to be executed by one of the Tuscan painters of his time. However, as highlighted by Tognoni, the total absence of any information on the provenance of this painting casts a shadow on this important discovery. On the top of the painting there is a written statement "GALILEUS GAL: NOVOR./ORBIUM R.. [unreadable] … R" which identifies Galileo as the discoverer of worlds. This inscription could not have been made by Santi di Tito in 1601 (or

1602) since Galileo only reported on his discoveries of ‘new worlds’ in the *Sidereus Nuncius* in 1610. As noted by Tognoni (2014–2015), this inscription is similar, though not identical, to the one present in a copy of the Sustermans portrait of Galileo painted in 1640.

There are also other peculiarities that I would like to point out, and that require some explanation. In the painting of the Florentine antique dealer shown in Tognoni (ibid.), the light comes from above with no trace of shadow on the right side of the face, which is present in the engraving. Galileo’s coat also is different in the two works. Moreover, the coat in the painting resembles that of the Galileo portrait painted by DomenicoTintoretto (1519–1594) a few years later. Could Tintoretto have been inspired by Santi di Tito’s earlier painting? But why then did Calendi decide to change the garments? We also note that the light reflections on the coat are very similar to those present in the digitally–manipulated image of Tintoretto’s painting released by the National Maritime Museum, Greenwich a few years ago. The manipulated image is reproduced in Tognoni (2013), while the true original is shown by Molaro (2011). Other differences concern the nose, which is pointed in the engraving but rounded in the painting, and the mustache which is parted in the middle in the engraving. While the painting and engraving are perfectly identical in the contours, quite surprisingly they differ in such an important anatomical feature as the nose. We note that the nose in the engraving is not natural while that in the painting closely resembles that of the famous portrait of Machiavelli by Santi di Tito. Both are far from the characteristic, broad sloping nose which is seen in the other portraits of Galileo. We also note that this painting made its appearance in the same year (2010) as the sensational forgery of the *Sidereus Nuncius* (Wilding 2011, Schmidle 2013). In this book, the illustrations of the Moon were not printed but hand painted, and according to the seller they were made by Galileo himself. The author of the drawings is still unknown, and the Florentine antique dealer’s painting of Galileo could have been conceived in the same context.

4 A NEW PROPOSAL

While awaiting proof of the authenticity of the painting discussed by Tognoni (2014–2015) we propose here the identification of Santi di Tito’s portrait of Galileo with another painting. This painting is the *Portrait of a Bearded Man* in the collection of the Museum of Medieval and Modern Art of Padua (Inventory Number 772), and attributed to Tintoretto.[2] This painting, which is reproduced here as Figure 2, was acquired by the Museum in 1888 as a legacy of Ferdinand Cavalli (1810–1888). Cavalli, the eldest son of the Earl of Sant ‘Orso and Elisa Renier, was an important politician and Italian economist. Through his maternal line he was the grandson and universal heir of Paolo Renier (1710–1789), the penultimate doge of Venice. However, the attribution to Tintoretto is recent. Initially Vittoria Romani (1991) attributed it to the Titian School and dated it around the middle of the sixteenth century, but on the occasion of the exhibition “The Spirit and the Body. 1550–1650. One Hundred Years of Portraits in Padua in the Age of Galileo”, which was linked to the International Year of Astronomy, the attribution was reconsidered by Paola Rossi (2009) in favor of Tintoretto, on stylistic grounds. Radiographic and reflectographic analyses showed a pictorial layout characterized by the technical mastery of a great painter. The attribution relies on comparisons with other portraits, such as *Testa d’Uomo* from the National Gallery of Scotland (Edinburgh, catalogue number 689) and the *Busto di Gentiluomo* in the Kunsthistorisches Museum (Vienna, inventory number 701), which are unanimously assigned to Tintoretto from the period between 1549 and 1555. However, in my humble opinion, the definition of the design, the color palette and the artistic style are quite different in the two paintings. The temporal separation between the attributions to Tintoretto and Santi di Tito is approximately half a century, and should be verifiable with advanced dating techniques. In addition, the spectroscopy of pigments might provide new elements for proper stylistic evaluation of the painting and a more robust attribution of this potentially-important work. We asked Jack Spalding, who is an authority on Santi di Tito for an opinion, and after examining the Padua painting, which is currently attributed to Tintoretto, he informed me that it “… certainly could be made by Santi …” because of its style (pers. comm., April 2016).

At first sight the painting is quite different from the engraving. However, we argue that these differences are exactly the reason why, over the years, the correspondence between the two works has been lost. The painting is an oil-on-canvas of 35 × 30 cm, a size that is well suited to the *piccolo quadro*, i.e. small picture, as described by de Nelli. The painting reproduces only the face, with the head partially incomplete at the top and looking left. In the engraving, Galileo is depicted in half body and is turning his gaze towards the opposite side. We will see that in the event that the engraver was granted some freedom, the two works could be traced to a common origin, thus providing a plausible explanation for the several anomalies we have highlighted in the engraving.

Already determined to amend the original subject by completing the figure of the scientist and adding a telescope, Calendi probably did

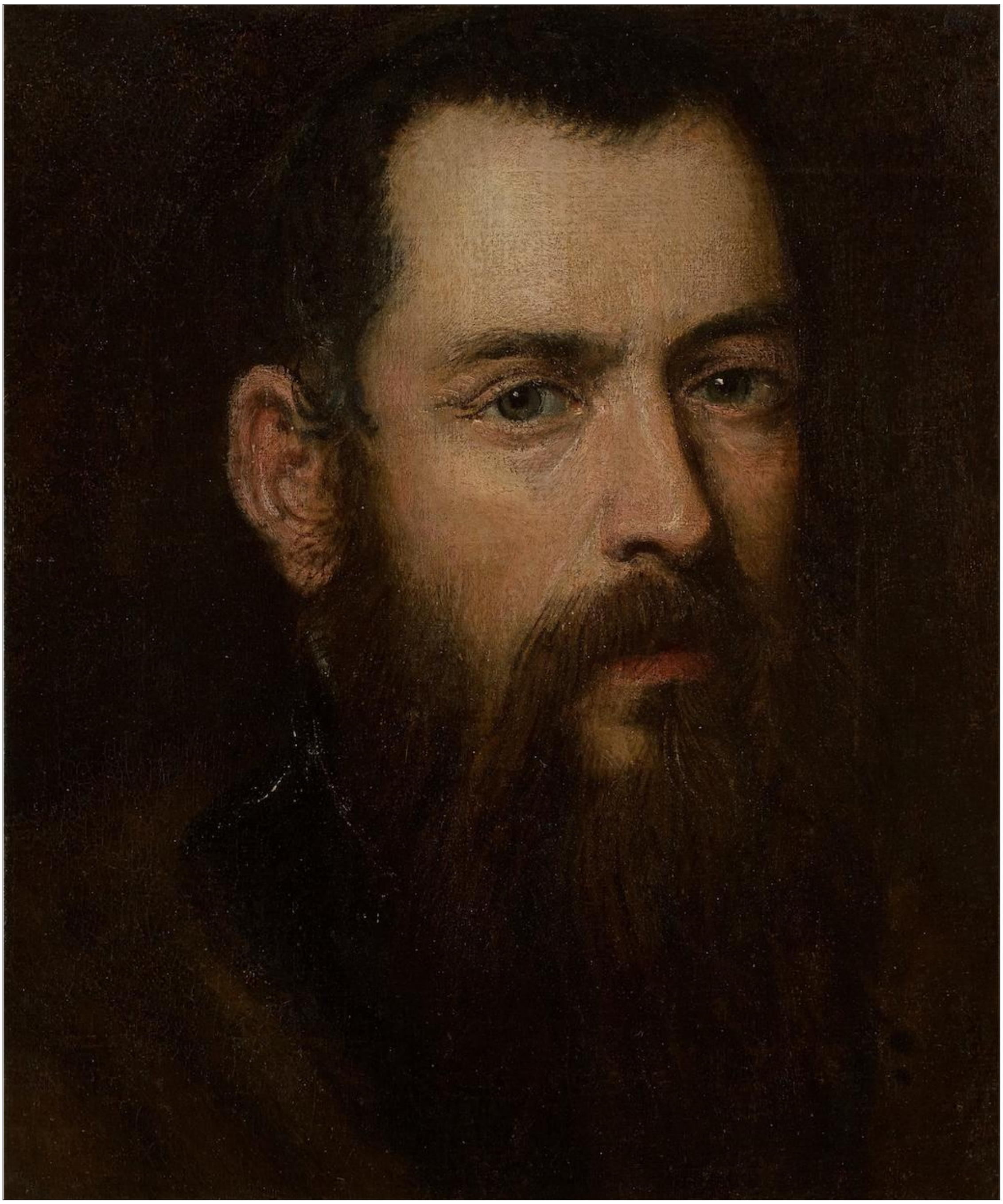

Figure 2: *Portrait of A Bearded Man*, attributed to Tintoretto (Museum of Medieval and Modern Art, Padua, Inventory number 772).

not feel obliged to produce an entirely-faithful reproduction of the Santi di Tito's painting. Therefore, he likely decided to draw a direct reproduction onto the copper matrix, without reversing the image first. In doing so, the face of Galileo would be turned from left to right in the final printing process. This *modus operandi* simplifies the design. It is interesting to follow the mole on the face of Galileo. In the Padua painting the mole is either not present in the painting or partially hidden on the shaded side of the face. If Calendi had made a direct copy the mole should have been placed on the side fully exposed to light and entirely visible. With the aim to hide the mole, Calendi probably proceeded to shade this side of the face as well as the sides of the face and nose facing the observer. In Figure 3 the reversed portrait of a bearded man and the detail of the face of Galileo by Calendi are placed next to each other in an attempt to illustrate the process adopted by Calendi. This is the reason why in the final

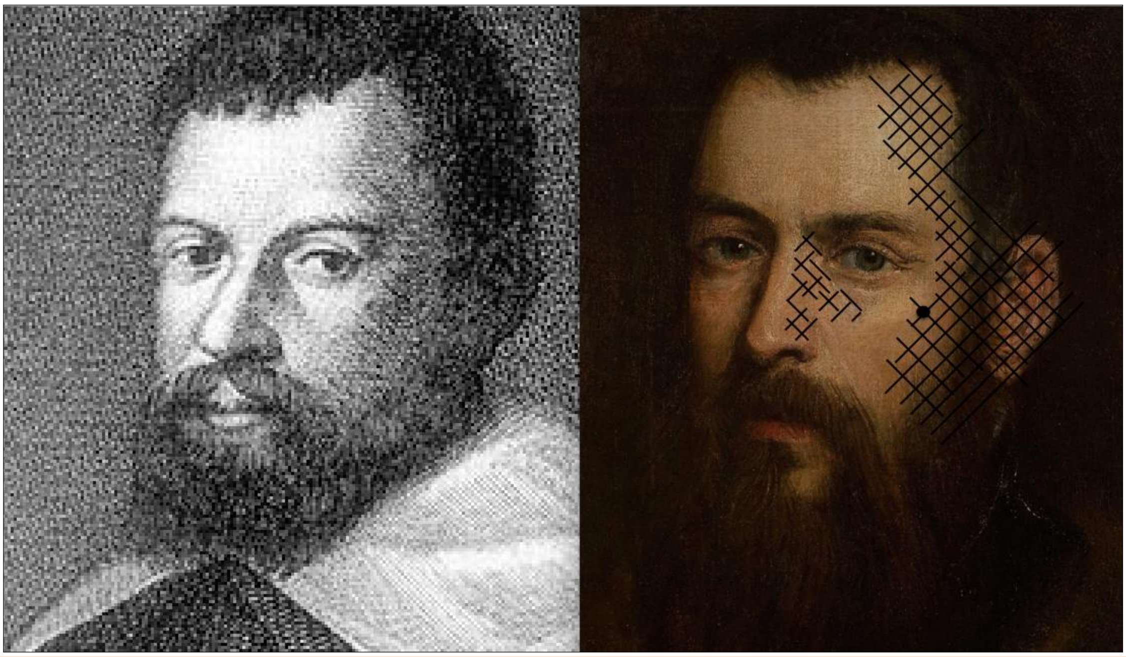

Figure 3: A comparison of Calendi's engraving and the Padua painting inverted horizontally. The shadowing of the illuminated side of the face is, I argue, added by Calendi in order to hide a mole.

printing the sitter shows the dark side of his face to the observer, while the absence of a clear light source in the engraving also can be explained quite easily.

The Padua portrait and Calendi's engraving are superimposed in Figure 4. The fundamental traits of the face are similar and in particular the shape and location of the ear. However, some differences can be noted, such as the position of the eyebrows and the shape of the beard. They could also be due to the procedure described above. In Calendi's engraving, the two eyebrows and eyes are at the same height making them invariant to the reversal of the image.

Moreover, it may also be noted how the outline of the nose in the engraving seems to incorporate both the nose and its shadow as depicted in the painting. A similar thing occurs in the hairline. How this happened is not clear, but it has to do with the way the engraver extracted his depiction of Galileo from the painting.

We already noted a certain lack of communication between Calendi and de Nelli regarding Galileo's age. The mistakes mentioned above reveal that we are dealing with a non-perfect copy, and we think that these inaccuracies offer a logical reconstruction of what could have happened.

5 GALILEO AND THE COLOGNE PAINTING BY RUBENS

In 1600, at the age twenty-three, the young Flemish artist Peter Paul Rubens (1577–1640) began travelling through Italy to study Art, and he remained until 1608. He travelled to Venice and to Rome, where he met Elsheimer, and also to Mantua where he was seeking a position. Around 1602–1604 Rubens painted the *Self Portrait with Friends in Mantua*, an oil on canvas measuring 77.5 × 101 cm that is now in the Wallraf-Richartz Museum in Cologne. Frances Huemer (1983; 2004) and Eileen Reeves (1999) suggested that one of the prominent figures represented in the painting, and reproduced here in Figure 5, is Galileo Galilei, but there is no consensus on this identification as de Maegd (1998) identified this figure as Jean Richardot II.

Galileo probably met Rubens for the first time in Padua in 1602 when the painter spent several months in Venice and again a second time in Mantua which, according to Stillman Drake (1978), Galileo visited twice in 1604. We know Rubens was fond of astronomy. Together with Jan Bruegel the Elder, he painted the *Allegory of Sight* (1617) where several astronomical instruments belonging to the Archduke Albert VII were depicted, including perhaps a telescope made by its unknown inventor (Selvelli and Molaro, 2010; Molaro and Selvelli, 2011). In a letter dated 1 April 1635, Nicolas Fabri de Peiresc wrote to Galileo that Rubens was a "... great admirer of your genius." The astronomical image of the planet Saturn with three bodies as descibed by Galileo is included in *Saturn Devouring One of His Children* (1637–1638), which is in the Museo del Prado in Madrid. In the last part of his life over a period of five years Rubens worked and reworked the *Landscape by Moonlight* (1635–1640) now at the

Figure 4: Overlay of the negative of Calendi's engraving inverted horizontally and the Padua painting, with a reduced opacity to highlight similarities and differences.

Courtauld Gallery, London, where a natural sky is depicted. Reeves (1999) connects Rubens' Cologne painting with Galileo's Lectures on the nova of 1604 and a possible Stoic and anti-Aristotelic interpretation of the natural world. Lipsius (1547–1606) was the founder and most representative neo-Stoic philosopher, and although he was not present in Mantua, he appears in the painting together with his followers, including Rubens' brother Philippus and two other students (ibid.). It was a subject that Rubens elaborated again in the painting of the *Four Philosophers* around 1611 on the occasion of the death of his brother. Huemer (1983; 2004) notes several similarities with the authentic portraits of Galileo done before 1642. The characteristic elements of Galileo's face are a large forehead with receding reddish hair and deep-set narrow and intense eyes. These elements are also found in the possible new portrait of Galileo (Molaro, 2012; 2017). Huemer (2004) also noted that all these portraits show Galileo dressed in the simple black costume with a white collar. In Figure 5 we show the

Figure 5: A comparison of A Bearded Man (left) and one of the individuals in Rubens' *Self Portrait with Friends in Mantua* now in the Wallraf-Richart Museum in Cologne.

Padua painting next to the detail of the Cologne one to emphasize the several similarities between the two portraits once the different styles of the two painters are taken into account. Santi di Tito was the last representative of Tuscan Mannerism at the end of his life, while Rubens was at the start of his career and at the dawn of the Baroque age.

It would be interesting to perform a facial-recognition analysis, such as that performed by Conrad Rudolph and his collaborators on other portraits, to determine objective elements of these identifications (see Srinivasan et al., 2015).

6 NOTES

1. A notable exception is the one of Machiavelli, now in the Palazzo Vecchio, which must have been painted without its living model since Machiavelli died in 1527.
2. Tintoretto's birth name was Jacopo Comin, but he also was known as Jacopo Robusti.

7 ACKNOWLEDGEMENTS

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Finally, this work is dedicated to the memory of my friend and astronomer Francesco Palla with whom I shared the early ideas behind this paper.

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NŪR UD-DĪN JAHĀNGĪR AND FATHER KIRWITZER: THE INDEPENDENT DISCOVERY OF THE GREAT COMETS OF NOVEMBER 1618 AND THE FIRST ASTRONOMICAL USE OF THE TELESCOPE IN INDIA

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Abstract: The year 1618 in astronomy was a unique one in that it presented three bright cometary apparitions in quick succession. The comets created a sensation, and belonged to an era when Galileo's telescopic observations had created a paradigm shift in our perception of the heavens and Johannes Kepler was introducing a fundamental change in mathematical astronomy by redefining orbits of planets around the Sun. This paper is an account of the observations of two of the three great comets of 1618, made from India. This turned out to be a unique occasion because these same targets of opportunity were followed independently by astronomers from two very different 'schools', and their observations were recorded quantitatively. Jahāngīr, the fourth Mughal Emperor of India, recorded in the *Tūzūk-i Jahāngīrī* (*The Memoirs of Jahāngīr*), the appearance of two comets during a Royal journey from the town of Dohad in Gujarat to Agra, the capital city of the Empire, in the thirteenth year of his accession. From the recorded dates, Jahāngīr turns out to be an independent discoverer of two great comets that appeared one after the other in November 1618. Meanwhile, Father Venceslaus Kirwitzer and fellow Jesuits observed these comets from Goa, and their first observations also correspond to the discovery dates of the comets. These same comets also were followed by Father Antonius Rubinus from Cochin. Fr. Kirwitzer collated and published these observations in 1620 in a short treatise where he states that he also viewed these comets with a 'tubo optico'. This is the first recorded use of a telescope in India.

Keywords: India, Goa; Jahāngīr; Kirwitzer, Rubinus; Mughal chronicles; Great Comets of 1618; first astronomical use of a telescope in India

1 INTRODUCTION

The thirteenth century was a turning point in the history of astronomy in India with the entry of Islamic astronomy and its adoption, which flourished along with Hindu astronomy until around the nineteenth century. It led to an amalgamation of the observational techniques and instruments of the former and the computational techniques of the latter that paved the way for accurate astronomical observations. This overlapped with several stray instances of telescope use during the seventeenth and eighteenth centuries for celestial events and geographical surveys, and the establishment of a modern astronomical observatory at Madras (now Chennai) in 1786.

In the Middle Ages, astronomy in northern India was mostly under the patronage of the Delhi Sultanate (1206–1526 CE) and Mughal emperors (1526–1858 CE), and some of these rulers were interested in astronomy. In the celebrated Mughal writings of the sixteenth and seventeenth centuries, such as the *Akbarnāmā*, the *Tūzūk-i Jahāngīri* and other chronicles of the same period, there are several accounts of unexpected celestial and terrestrial phenomena, such as comets, eclipses, meteors and earthquakes. Just as in other cultures, these were regarded as ill omens for rulers and emperors and so were routinely monitored by historians and chroniclers. Astronomical observations mainly were required for astrological purposes, to precisely determine the auspiciousness of events and their timings, like Royal births, or when to embark on missions or campaigns, etc. Some of these records have little astronomical content, but they underline how these types of events got rulers seriously concerned about their auspiciousness and possible consequences, so they even sought counsel for remedial measures. At this time, generally there was no clear distinction between astrology and astronomy, and superstition remained entwined with both. Many medieval scholars considered astrology as a part of astronomy, while others were opposed, saying that this did not conform to the principles of Islam.

So, what does one say when a ruler records, virtually in own hand, accounts of some 'evil' celestial phenomena that occurred during his reign but with hardly a reference to their ominous nature? Nūr ud-Dīn Jahāngīr (1569–1627), the fourth Mughal Emperor of India (who ruled from 1605 to 1627) was such a person. He was only eight years of age when the Great Comet of 1577 (C/1577 V1) appeared, and he probably witnessed it. Jahāngīr was a great naturalist, a gifted author and in his writings he displayed an excellent command of language. We note how his father, Emperor Akbar, "… paid very great attention to the education of his sons and grandsons, and appointed learned men of very high reputation to superintend their studies." (Law, 1916: 160). Apart from ornithology, biology and lexicography, Jahāngīr had an interest in astronomy, and he maintained records of his observations in his journal *Tūzūk-i Jahāngīrī* (*Memoirs of Jahāngīr*; see Rogers and Beveridge 1909;

1914). In the other memoir that he wrote, the *Wākī'āt -i Jahāngīrī*, we find very similar descriptions (Elliot, 1867–1877; 1975). In these *Memoirs*, we find descriptions of a few solar and lunar eclipses, a meteorite impact and the two Great Comets that he observed.

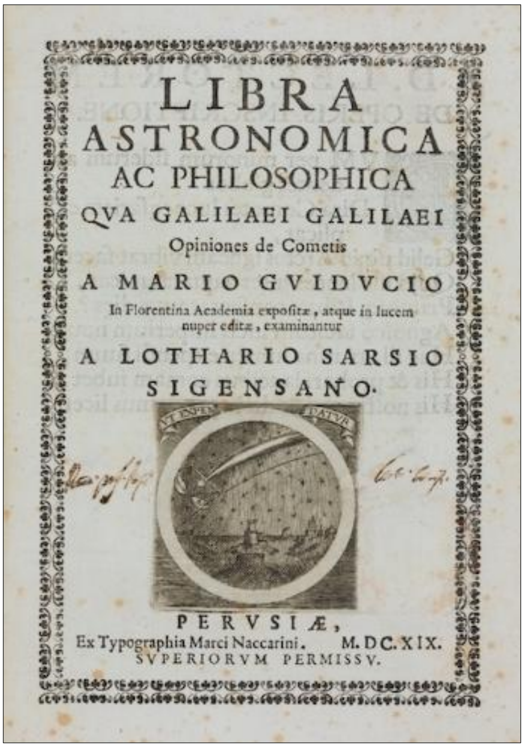
In this paper we present the story of the observations of the two Great Comets of 1618 from India. Jahāngīr recorded these comets in the course of a journey from Dohad (also known as Dahod) in Gujarat to Agra, the capital of the Mughal Empire, via Ujjain, in the year 1027 A.H. (or 1618 CE);[1] for Indian localities mentioned in the text see Figure 1. The comets in question are those designated 1618 III and 1618 II, and they appeared in that order. Considering the account and the dates entered in his *Memoirs*, Jahāngīr turns out to be an independent discoverer of these two Great Comets of November 1618. If so informed later, Jahāngīr would have been amused, but his records indicate that he had the ability to carry out accurate astronomical observations, and the requisite scientific equipment.

Strikingly, India's tryst with the telescope also began at this time, when a number of Jesuit missionaries observed these same comets. Fr. Venceslaus Pantaleon Kirwitzer (1588–1626) observed Comet 1618 III from Goa, and he was soon joined by other Jesuits in Goa and in Cochin, and then in quick succession they observed the second bright comet of November 1618. Their initial observations also coincide with the discovery dates of these comets. While giving details of the observations, Fr. Kirwitzer also mentions that he used an optical device, a 'tubo optico' (telescope), to view the comets. We cannot say for certain that it was a Galilean telescope with a mounting that the group had brought from Europe, together with other astronomical instruments and books, to be carried further east to Macao. Fr. Kirwitzer and others deserve credit on several counts, as independent discoverers of the two Great Comets in succession; as the first independent users of an optical device for observing comets outside Europe; and for the first modern astronomical observations from India with telescope, and within a decade of its invention in Europe.

2 THE COMETS OF 1618

When hardly any theory of comets existed, Tycho Brahe's observations of the Great Comet of 1577 marked a milestone in the history of astronomy when he placed it at a supra-lunar location, settling the important question of the distance to comets through the parallax method. This challenged the Aristotelian perception that comets were atmospheric phenomena. The comets of 1618 belong to the era when Galileo's telescopic observations created a paradigm shift in our perception of the heavens, and Johannes Kepler introduced a fundamental change in mathematical astronomy by redefining the motions of the planets around the Sun. After Halley's Comet of 1607, here were the first significant comets to appear in the skies.

Figure 1: Indian localities mentioned in the text (Map: Baba Varghese).



LIBRA
ASTRONOMICA
AC PHILOSOPHICA
QVA GALILAEI GALILAEI
Opiniones de Cometis
A MARIO GVIDVCIO
In Florentina Academia expoſitæ, atque in lucem
nuper editæ, examinantur
A LOTHARIO SARSIO
SIGENSANO.

PERVSIÆ,
Ex Typographia Marci Naccarini. M.DC.XIX.
SVPERIORVM PERMISSV.

Figure 2: Oratio Grassi's *Libra Astronomica* …, a follow up to his *De tribus cometis Anni MCDXVIII* (1619), is a critique of Galileo's ideas on the nature of comets; Grassi used Lotario Sarsi as a pseudonym. Grassi was the leading astronomer in Rome and a Professor at the Rome College (Collegio Romano). As a Jesuit, Grassi was charged with teaching nothing in science contrary to Aristotle, who said that comets were vapors located beneath the Moon. Yet Grassi's analysis demonstrated that these comets moved beyond the Moon (after *Galileo's World* … 2015).

The year 1618 was a unique one in that three bright comets were visible in the sky within a short span of just three months. That year also saw the novel use of the telescope for the observation of these three Great Comets. In order of occurrence and with their respective modern designations and dates of perihelion passage, the comets were 1618 I (C/1618 Q1; perihelion August 17.627 UT), 1618 III (C/1618 V1; October 27.9) and 1618 II (C/1618 W1; November 8.851). The last two were sighted within a short span of time in the same region of the sky and were visible together for several successive nights. All of these comets were naked eye objects, with tails and motion direct, and were noticed after their perihelion passages.

Figure 3: German ducat of 1618 (adapted from Faintich; http://www.symbolicmessengers.com/newfin di.htm).

With three apparitions in quick succession, these comets created a sensation among astronomers, and even drew Galileo Galilei (1564–1642) into a controversy with the Jesuit mathematician Fr. Horatio Grassi (1583–1654) over the nature of comets (Figure 2). Grassi stressed the apparitions were against the Copernican world-view. Galileo was indisposed at the time, so he responded through the work *Discorso delle comete di Mario Guiducci*, which was published under the signature of his disciple Mario Guiducci (1585–1646). As Whipple (1985) put it, Galileo tried to wriggle out with a carefully-worded "… technically conformist comment." This dispute involved Galileo Galilei, Horatio Grassi, Mario Guiducci and Johannes Kepler, and it is discussed in a thought-provoking book by Drake and O'Malley (1960).

The three bright comets of 1618 generated grave concern among the general population, and also left an indelible imprint on people's minds. Figure 3 shows a German ducat (0.986 gold weighing 0.110902 oz) featuring one of the comets of 1618. The comet is depicted passing from right to left and so was a morning object. Which one of the three comets of the year does the ducat depict? According to Faintich (2007), the ducat was issued on 19 November 1618 to commemorate Comet 1618 I. The celebrated comets of 1577 and of 1680—the latter being the first to be discovered with telescope—also were commemorated with medals.

Comet 1618 III even was observed by a young John Milton (1608–1674) when he was ten (see Cunningham, 2016). How this comet made an indelible impression in Milton's young mind is reflected much later, in his poem *Paradise Lost* (1667; 1674(II): 706–711):

> On the other side,
> Incensed with indignation, Satan stood
> Unterrified, and like a comet burned,
> That fires the length of Ophiuchus huge
> In the arctic sky, and from his horrid hair
> Shakes pestilence and war.

King James I (1566–1625) registered Royal reaction to the 'Angry Starr' of late autumn of 1618 (apparently, Comet 1618 II) in what is now a famous poem that aimed to alleviate the fear that people then had that it was a sign of God's wrath (see Maclean, 1987). However, what is more interresting is what the King actually exclaimed before the Reverend Thomas Lorkin, as recorded by Sir Thomas Puckring on 1 December, 1618 (11 December Greg.; Birch 1849(II): 110):

> Concerning the blazing star, his majesty, they say, swears it is nothing else but Venus with a firebrand in her ___.

In a footnote provided by Thomas Birch (1705–1766) on the same page as this quotation he explains:

> 'The word omitted [at the end of above quotation], if proper for a king to utter and a clergyman to repeat – of which we can not entertain doubts – is certainly too objectionable to be printed.' More importantly, he adds that 'Mr. Briggs conceives it to be a perfect comet and therefore above the moon (so mathematicians have demonstrated Aristotle's tenet in this point to be false) …'

The afore-mentioned 'Mr. Briggs' was the English mathematician Henry Briggs (1561–1630), well-known for his pioneering work on common (base 10) logarithms.

The sighting of the comet of late November 1618 was, in prognostications and in retrospection, also linked to the Great Thirty Years War of 1618–1648, a religious war according to some scholars that greatly affected life in the Holy Roman Empire.

2.1 A Description of the Three Great Comets of 1618

A brief description of the three comets is in order, but for detailed accounts of the observations and contemporary discussions, one should refer to Kronk (1999), Vsekhsvyatskii (1964) and The comets of 1618 (1878).

Comet 1618 I (C/1618 Q1) was discovered at Caschau in Hungary on 25 August in the morning skies at magnitude 2−3, and by Johannes Kepler (1571–1630) at Lintz on 27 August. On 1 September, its tail was up to 5° long. It passed closest to the Earth at 0.5162AU on 19 August and was last seen on 25 September. This comet holds the distinction of being the first recorded comet to be observed with a telescope, on 6 September. This observation was made by Kepler, who described the comet as a large object that resembled a cloud. Those orbital elements of direct interest here are listed in Table 1.

Comet 1618 II (C/1618 W1; Great Comet) probably was first seen on 23 or 24 November by Garcia de Silva y Figueroa (1550−1624) from Isfahan in Persia toward the east as a diffuse object and having the colour of Venus (Kronk, 1999: 338−341). Garcia de Silva, who had travelled extensively throughout the country, including to the city of Shiraz and the ruins of Persepolis, was the Ambassador of Philip III (the King of Spain and Portugal) to the court of the renowned ruler Shāh Abbās (1571–1629; ruled 1587–1629). Some of the orbital elements of this comet are included in Table 1.

There is some confusion about the discovery date of this comet. In 1619, Fr. Horatio Grassi argued that among the most popular dates, namely 14, 26 and 29 November, the earliest observations that fitted well could be of 26 November only, although there were independent reports of its discovery on 24 November. The Danish astronomer Longomontanus also had some reservations about the correct date and the chronology presented by Garcia de Silva y Figueroa.

The first to record the comet were the Chinese who found it in the constellation of Libra on 25.9 November with a tail more than 10° long. Elsewhere, the comet was observed amongst others, by Fr. Johannes Cysatus, John Bainbridge, Johannes Kepler, the Koreans and the Japanese. It passed closest to the Earth (0.358 AU) on 6 December. Four days later it exhibited an unusually-long tail, which Longomontanus measured to be 104° (Hind, 1852: 15, 106; The comets of 1618, 1878: 247). During the month of December its brightness reached first magnitude, and subsequently it dropped to the third magnitude (Vsekhsvyatskii 1964: 113). François Arago, the French mathematician and astronomer, mentioned that the head of the comet split into several parts during December, a phenomenon observed by Cysatus (Hind, 1852: 10; Lynn, 1889: 408) and also by Wendelin and Christoph Scheiner. It then appeared as a cluster of bright stars, each with its own tail and travelling together. Comet 1618 II was last seen on 22 January 1619, by which time it had faded to between magnitude 5 and 6 (Kronk, 1999: 338−341).

Table 1: Some orbital elements* of the three Great Comets of 1618 (after JPL, 2015).

Comet	*q* (AU)	*i*	*e*
C/1618 Q1 (1618 I)	0.51298	21.494°	1.0
C/1618 W1 (1618 II)	0.38594	37.196°	1.0
C/1618 V1 (1618 III)	0.744	08.4°	1.0

* *q* = perihelion distance
i = inclination of the orbit to the plane of the ecliptic
e = eccentricity

Fr. Johann Cysatus (1587–1657), then at Ingolstadt, was the first to use a telescope to observe this comet, and he detected structure in the comet's head. He could resolve it into a nucleus surrounded by a nebulous envelope (coma), with yet another luminous, though relatively fainter, appearance around that. He also noticed unusual movement in the tail, and he noted that the path of the comet began to deviate from the stipulated straight line:

> This curvature (of the orbit) would be a phenomenon of great importance, if it could be confirmed by more observations. (Schreiber, 1904: 100).

One may gauge the significance of this observation from the fact that cometary orbits are so acutely elliptical or parabolic that Kepler and Galileo believed that comets travelled in straight lines. From his observations of Halley's Comet in 1607, Kepler drew in his 1619 work *De Cometis Libelli Tres* the inference that this comet travelled in a straight line (Yeomans et al., 1986: 82). For a perspective, we may recall that in 1609 Kepler had published the first two of his famous laws of planetary motion. According to these, a planet orbits the Sun in an ellipse with the Sun at one of the foci, and the area swept out by a line connecting the planet to the Sun is always the same in a given time interval irrespective of its position in the orbit. The third law, relating the average orbital distance of a planet from the Sun to its orbital period, was published in his book *Harmonica Mundi* in 1619. It was only in 1687 that Isaac Newton (1642–1727) showed that cometary orbits took the form of a conic section, other than a rectilinear one. However, Jeremiah Horrox (1619–1641) was the first to conclude that the comet of 1577 followed a curvilineal path: "… in an elliptical figure or near it." (Whatton, 1859: 15–16).

Now to the third Great Comet of 1618, Comet 1618 III (or C/1618 V1). This was spotted earlier than 1618 II, on 11.04 November by Garcia de Silva y Figueroa (1550–1624) from Isfahan in Iran. It was visible in the southeastern sky, and had a tail that was about 60° long (Kronk, 1999: 335–338). These observations are mentioned in Pingré's celebrated *Cometographie* of 1784. However, Comet 1618 III is not listed in Vsekhsvyatskii (1964). It also does not figure in the lists of comets given by Hind (1852: 128), although it is mentioned on page 21. The Roman College Jesuits followed the traverse of this comet across the sky from 28 November until 9 December, during which time it may have been visible for a large part of the night (Kronk, 1999: 337). This comet also was observed by Kepler from Linz, from 20 to 29 November. On the latter date he saw it share the morning skies with the third bright comet of the year, 1618 II. Orbital elements of Comet 1618 III that are of direct interest here are included in Table 1.

Kennedy (1980) mentions a book titled *Tanbīhāt al-munajjimīn* (*Admonitions to Astrologers*) by Muzaffar b. Muḥammad Qāsim Junābādī (Gunābādī) that refers to several comets seen in history and also provides a classification. The author of the book cites Arabic, Egyptian, Greek, Indian and Iranian sources. The Indian works mentioned are:

> *Barahi (?), an Indian book, No. 17, f. 192r; Bistiham (?) the Indian, No. 25,ff. 197v, 200r*. is a name otherwise unknown to us. The author reports his views on the motion of tailed stars; Brahma and the Indian astrologers, ff. 184r, 192v.

Barahi, mentioned above, is probably the Indian astronomer Varāhamihira (485–587), and *Brahma* is Bṛhmagupta (b. 598).

Junābādī points out that he witnessed the great comet of 1577 that appeared in the west towards "… the latter part of Sha'ban (ca. 2–12 November, 1577)." Lastly, he refers to two consecutive comet sightings in the year 1027 A.H. The reference is made at two places. The first one reads as follows:

> … in the beginning of Dhu al-Hijja 1027 H. (ca. 21 November 1618), while the royal court was at Qazwin (northwest of Tehran), a *harbah* appeared in the east, in the sign of Libra.

Then in a later chapter, the author describes how

> On the morning of Monday, 8 Dhu al-Hijja (26 November 1618) of the above-mentioned year, a comet (*Au dhawaba*) appeared in the east in the middle of the sign of Scorpio and lasted for about forty days.

The Royal Court referred to above is that of Shāh Abbās of Iran to whom *Tanbīhāt al-munajjimīn* was dedicated. As for the 1027 A.H. dates, Kennedy (1980) observed that

> The two dates are practically the same, and the zodiacal signs are adjoining, but different names are used for the category of tailed star observed. We have no explanation.

We find that the references in the book *Tanbīhāt al-munajjimīn* are correct and made in respect of two different comets, which are now designated 1618 III and 1618 II.

3 JAHĀNGĪR'S INTEREST IN ASTRONOMY

Jahāngīr's *Memoirs* clearly demonstrate his interest in astronomy and the level of accuracy reached in the observations. We find the recorded information in excellent agreement with modern computations. Jahāngīr's astronomers used instruments such as *ghati-yantra* (water-driven clocks; clepsydras), astrolabes, sundials and hour-glasses. One can find depictions of many of the astronomical instruments then in use on a number of Mughal miniature paintings of the sixteenth and seventeenth centuries. One such example is presented here in Figure 4, a margin drawing from the folio of Jahāngīr's Album depicting an astrologer surrounded by his equipment.

Jahāngīr has written in the *Tūzūk-i Jahangīrī* about the circumstances of fall of an iron meteorite in a village in Jalandhar district in the Punjab on 30 Farwardin, in the 16th regnal year, i.e., 19 April, 1621 Greg. (but Howe, 1896: 296 cites the year as 1620—also see, A forgotten Indian meteorite, 1935). The iron that was extracted from the site weighed 1.93 kg (Blochmann, 1869: 167–168), and the meteorite broke under the hammer. The sword-maker got the Emperor two sword blades, a dagger and a knife using three parts of the meteorite for metal, to which the sword-maker added one part of terrestrial iron. One of these artifacts, the coveted dagger, can be seen in the Smithsonian Institution's Freer and Sackler Galleries (Sabri Ben-Achour, 2012).

There is mention in the *Tūzūk-i Jahāngīrī* of the total lunar eclipse of 1018 A.H. (Rogers and Beveridge, 1909–1914(I): Chapter 6), and the solar eclipses of 1019 A.H. and 1024 A.H. (15 December 1610 and 29 March 1615 Greg respectively, both annular) also were duly recorded. Jahāngīr put down his thoughts about them and recorded details during the eclipses. For instance, in the matter of the solar eclipse of 1024 A.H., he states that on the occasion

> Alms of all kinds, and things in the shape of metals, animals, and vegetables, were given to fakirs and the poor and people in need. On this day the offering of Rāja Sūraj Singh was laid before me; what was taken was of the value of 43,000 rupees. The offering of Bahādur Khān, the governor of Qandahar, was also laid before me on this day; its total value came to 14,000 rupees. (Rogers and Beveridge, 1909–1914(I): Chapter 12).

In connection with such marches too, an auspicious hour mattered. About the march of an advance of *Lashkar* (troops) from Gujarat to Agra in the year 1027 A.H., Jahāngīr writes:

> On Thursday, the 7th, with great joy and congratulation, the advance camp was started towards Agra. The astrologers and astronomers had already fixed the auspicious hour for the march. As excessive rain fell, the main camp could not cross the river of Maḥmūdābād (the Vātrak) and the Mahī at this hour. Out of necessity, the advanced camp was started at the appointed hour, and the 21st Shahrīwar was fixed for the march of the main camp. (Rogers and Beveridge 1914 (II): 25).

The Mahī flows north from Vadodara and eventually enters the Arabian Sea whereas the Vātrak flows through Kheda, a district bordering Ahmedabad and Vadodara. The first date above corresponds to 29 August, 1618 (Greg.). That is just

Figure 4: An early seventeenth century margin drawing from the folio in Jahāngīr's Album showing an astrologer surrounded by his equipment—an astrolabe, zodiac tables and an hour glass (courtesy: Werner Forman Archive/Naprestek Museum, Prague).

days after the bright comet 1618 I was discovered on 25 August. It is surprising that no chronicler mentions this object in his writings. No one recalled it either when later on two bright comets appeared during the month of November.

Zodiacal gold coins and silver rupees struck in the names of Jahāngīr and his queen Nūr Jahān, respectively, were issued from the thirteenth year of his reign (in the year 1027 A.H.). These coins have a zodiacal sign on the obverse and a Persian verse on the reverse. Jahāngīr ordained that rather than carry his name on the obverse and the name of the place and the month and year of his reign on the reverse, each coin should feature a zodiacal symbol for the name of the solar month it belonged to, with the Sun emerging from this symbol (Brown, 1922: 95−96). On the obverse these symbols are depicted, with the (rising) Sun in the background. These coins, which clearly reflect Jahāngīr's inclinations, are fine examples of numismatic art, and quickly became collectors' items.

Some very fine Mughal miniatures were made by Jahāngīr's court artists, like the one by Bichitr reproduced here in Figure 5 where the Emperor is shown proffering a Sufi Shaikh to kings. Jahāngīr is seated on an hour-glass throne, and the halo behind his head has a golden Sun and a crescent Moon.

4 MUGHAL WRITINGS ABOUT THE NOVEMBER 1618 COMETS

Of the numerous comet apparitions during the Mughal period, we find brief accounts of only the great comets of 1577 and 1618, namely, in the *Akbarnāmā*, in the *Tūzūk-i Jahāngīri*, and in a few chronicles. These references assume significance in view of the fact that observations from Europe of the very same comets made a decisive impact on the course of astronomy there. Abū'l Faḍl (1551–1602), the celebrated Prime Minister of the Mughal Emperor Jalāl ud-Din Muḥammad Akbar (1542−1605; ruled 1556−1605), has recorded in the *Akbarnāmā*, the highly-acclaimed biographical account of the Emperor, and the appearance of a comet during the 22nd year of his reign, in 985 A.H. From the recorded date, Abū'l Faḍl turns out to be an independent discoverer of one of the most famous comets in history–the Great Comet of 1577 (C/1577 V1). We have discussed this in detail in an earlier paper (Kapoor, 2015), and here we confine ourselves to the two great comets of November 1618.[2]

In 1910, when Halley's Comet was yet to reach naked eye visibility, it had already stirred up the *cognoscente* of India. Jivanji Jamshedji Modi (1854−1933), a renowned scholar of Sanskrit, Persian and the *Avesta* carried out a comprehensive examination of accounts by Muslim scholars and those in the books of ancient Persians of the records and sightings of comets over the ages, and on 9 February 1910 he presented his findings at meeting of the Bombay Branch of the Royal Asiatic Society. Modi (1917) gave a remarkable exposition on the "Mahomedan view of comets", and he listed comets that the Muslim scholars of the Middle Ages came to know about through historical documents, literary works and records, or they had actually observed during their own lifetimes. Modi (1917: 84–86) discussed at length Abū'l Faḍl's discourse on comets, his record in the *Akbarnāmā* of the appearance of the great comet of 1577, and, Jahāngīr having recorded two comets that occurred in the year 1618. Modi consulted Hind's (1852) book on comets and *Ferguson's Astronomy* (Brewster, 1811(II): 360) to identify the comets described in Jahāngīr's *Memoirs*. Modi identified the first of the comets as the one seen in November 1618 with perihelion on 8 November. For the other, the only candidate he could find was the comet of August 1618. These comets respectively are 1618 II (C/1618 W1) and 1618 I (C/1618 Q1). However, comet 1618 I had appeared months before Jahāngīr's dates of observation; it was discovered on 25 August and last observed on 25 September, by Kepler. The period of visibility does not match Jahāngīr's whereabouts at the time and his sighting of the two comets within a span of sixteen days.

Both Mousavi (2000: 114−115) and Ansari (2002: 257) mention that Jahāngīr recorded a comet that was visible in early November 1618, and their references correspond to comet 1618 III. Ansari (ibid.) cites the period of Jahāngīr's observations as 11 November−9 December, 1618 whereas Mousavi (2000: 115) cites the date of first observation as "… a few days before 18 Ābān 13 R.Y. [= 3 November 1618, Greg.]." The converted date of 3 November although a Saturday—just as in Jahāngīr's account—is not consistent with the course of comet 1618 III. On 3 November 1618, comet 1618 III was still an evening object whereas Jahāngīr's are morning observations. Ansari's (2002: 257) first recorded date (11 November) is acceptable, except that it is a Sunday.

So, which of the three comets of 1618 did Jahāngīr observe and on which dates? As the present study concludes, the comets in question are the ones designated 1618 III and 1618 II, appearing in that order and that the right dates of Jahāngīr's first record are, respectively, 10 November for comet 1618 III and 26 November for comet 1618 II. Muslim historians are acknowledged for their chronological precision, and Jahāngīr's dating can be relied upon. In what follows, we shall deliberate upon Jahāngīr's de-

Figure 5: *Jahangir Proffering a Sufi Shaikh to Kings*. This shows Jahāngīr seated on an hour-glass throne and presenting a book to the Sufi. This miniature by Bichitr is part of an album made for the Emperor circa 1615–1618; from the St. Petersburg album—Google Art Project.jpg (Wikimedia Commons).

scription. We then move on to the observations made by other observers from India (at times with a telescope), and then to India-related stories of the two great comets.

4.1 The Many Versions of Jahāngīr's Observations

The following passage from Jahāngīr's *Memoirs Wāki'āt-i Jahāngīrī* (Elliot, 1867–1877: 363; Elliot, 1975: 88–89), pertains to the account of the thirteenth year of his reign, i.e., 1027 A.H.:

> Saturday, 17th Zi-l Ka'da: Several nights before this, a little before dawn, a luminous vapour, in the form of a column, had made its appearance, and every succeeding night it arose half an hour earlier than on the preceding night. When it had attained its full development, it looked like a spear with the two ends thin, but thick about the middle. It was a little curved like a reaping-sickle, with its back towards the south, and its edge towards the north. On the date above mentioned, it rose three hours before the sunrise. The astronomers measured its size with their astrolabes, and, on an average of different observations, it was found to extend 24 degrees. Its course was in the empyrean heaven, but it had a proper motion of its own, independent of that firmament, as it was retrograde—first appearing in the sign of the Scorpion, then in that of the Scales. Its declination was southerly. Astrologers call such a phenomenon a spear, and have written that it portends evil to the chiefs of Arabia, and the establishment of an enemy's power over them. God only knows if this be true!
>
> Sixteen nights after its appearance, a comet appeared in the same quarter, having a shining nucleus, with a tail in appearance about two or three yards long, but in the tail there was no light or splendour. Up to the present time, nearly eight years have elapsed since its first appearance, and when it disappears, I shall take care to record it, as well as the effects which have resulted from it.

Modi (1917: 86) interpreted the above translation in Elliot (1867–1877) to mean that it is not that the comet continued to be seen for eight years, rather the reference alludes to the supposed disastrous and unlucky influences the comet had lasting as long. However, the mysterious 'eight years' appear elsewhere too, in an account of the apparitions by another historian. Modi (1917: 78) cites an account of the sighting of the two comets of 1618 from Mū'tamad Khān's *Iqbālnāmā-i Jahāngīrī* that also is available in Elliot's *History of India* (Elliot, 1867–1777(VI): 406–407). Mū'tamad Khān's description matches Jahāngīr's in the *Wāki'āt-i Jahāngīrī*. Only the date, "On the 16th of De …", differs. According to Modi (1917: 86), this may have arisen from Mū'tamad Khān mistaking the "… Mahomedan month Zi-l Kada for the 'Ilahi De'." The mismatch also could be result of paraphrasing, or translation. However, Mū'tamad Khān adds the evil aspects of the comet's appearance:

> It was in consequence of its appearance that a pestilential disorder (*waba-o-ta aun*) spread throughout this extensive country of Hindustan, which exceeded everything known and recorded in former ages, nor is there any mention made of such in the authentic works of the Hindus. The pestilence arose in the county one year before the appearance of the phenomenon and continued to rage for eight years, It was also through the effects of this phenomenon that a misunderstanding arose between His Majesty and the fortunate Prince Shah Jahan. The disturbances which thus originated lasted seven or eight years. What blood was shed in the country! and what families were ruined!

Mū'tamad Khān (d. 1049/1639) was a courtier and favourite of Jahāngīr and had taken up the task of continuation of the Royal *Memoirs* after the seventeenth regnal year, under the Emperor's supervision. *Iqbālnāmā-i Jahāngīrī* is his independent work finished in 1029/1620 (Nabi Hadi, 1995: 443).

From Rogers and Beveridge (1914(II): 48; see also Baber, 1996: 83), a translation of the part on the sighting of the comets from the *Tūzūk-i Jahangīrī* is reproduced below that does not contain the confusing 'eight years' in the crucial part of the narration:

> On Saturday the 18th (Aban), the camp was at Ramgarh. For some nights before this there appeared, at three *gharis* before sunrise, in the atmosphere, a luminous vapour in the shape of a pillar. At each succeeding night it rose a *ghari* earlier. When it assumed its full form, it took the shape of a spear, thin at two ends, and thick in the middle. It was curved like a sickle, and had its back to the south, and its face to the north. It now showed itself a watch *(pahar)* before sunrise. Astronomers took its shape and size by the astrolabe, and ascertained that with differences of appearance it extended over twenty-four degrees. It moved in high heaven, for it was first in Scorpio and afterwards in Libra. Its declination (*harakat-i-arz*) was mainly southerly. Astrologers call such a phenomenon a spear (*ḥarba*) in their books, and have written that its appearance portends weakness to the kings of Arabia, and points to their enemies prevailing over them. God knows! Sixteen nights after this phenomenon, a star showed itself in the same quarter. Its head was luminous and its tail was two or three yards long, but the tail was not luminous. It has now appeared for eight nights; when it disappears, the fact will be noticed, as well as the results of it.

A *ghari* (*ghati*) as a unit of time is equivalent to 24 minutes (1 *ghati* = 1/60 of a day). It is obvivous from the above quotation that the observations refer to the sighting of two comets in quick succession.

4.2 The Royal Traverse and the Dates of the First Observations

Let us ascertain the Gregorian dates of the observations from the chronology of the traverse of the Royal *Lashkar* as entered in the *Memoirs*, keeping in mind the paths of the comets and how their positions changed, and see if these reconcile with the observations made elsewhere. The recorded dates differ but 'Saturday' is common in the English translations of both the *Memoir* extracts. A clue to the chronology could come from another part of the *Tūzūk-i Jahangīrī* wherein, while referring to a particular day, Jahāngīr enters in the same passage a date according to two calendars together. He notes that:

> On Saturday, the 11th, the auspicious equipage alighted in the pargana of Dohad … On the eve of Sunday, the 12th of the Ilāhī month of Ābān, in the thirteenth year from my accession, corresponding with the fifteenth Z̲ī-l-Qa'da of the Hijrī year 1027, in the nineteenth degree of Libra, the Giver of blessings gave my prosperous son S̲h̲āh-Jahān a precious son by the daughter of Āṣaf K. I hope that his advent may be auspicious and blessed to this everlasting State. (Rogers and Beveridge 1914(II): 47).

That is about the birth of Aurangzeb who would be the sixth Mughal Emperor in the times to come (ruled 1658–1707) and where Āṣaf K is Abdul Hasan Āṣaf Khān, the father of Arjumand Bānu Begum (Mumtāz Mahal). Corresponding to the date *15*, *Dhu-al-Qa'dah*, *1027 A.H.*, not only the day is *yawm as-sabt* (Saturday), the equivalent Persian date 12 Ābān, 997 also is a *Shanbeh* (Saturday). The corresponding Gregorian date is 3 November 1618 CE, Saturday (24 October 1618 Julian). It was a Full Moon on the night of 2/3 November, 1618. Making 12 Ābān a Sunday would be in conflict with the timetable. As for the phrase "… in the nineteenth degree of Libra …" that should be about the Ascendant. Note that while a "… formidable sign …" appeared in the heavens in a week of the Royal birth, followed sixteen days later by another one and as the two went on to dominate the morning skies, neither the Emperor nor any chronicler connected these to the Royal birth.

We see that the double entry of the crucial dates in the *Memoirs* still leaves some ambiguity. Considering that the date 15 *Dhu-al-Qa'dah*, 1027 A.H. can still be our reference, the dates in the *Memoirs* help us follow the course of the Royal traverse from Ahmedabad to Agra, through Ujjain in Madhya Pradesh. Beginning with Dohad (Saturday, the 11th day of Ābān), the Royal party halted on the way at the villages of Samarna (or Samarni/Tamarna; on the 15th day), Ramgarh (on the 18th), Sitalkhera (or Sambhalkhera; on the 20th), the parganas of Madanpur (Badhnur or Badnawar; on the 22nd) and Nawari (on the 25th), the banks of the Chambal River (on the 26th) and the banks of the Kahnar River (on the 27th) (Rogers and Beveridge, 1914(II): 48–49). Jahāngīr further notes:

> On Tuesday, the 28th, the royal standards were raised in the neighbourhood of the city of Ujain. From Ahmadabad to Ujain is a distance of ninety-eight *kos*. It was traversed in twenty-eight marches and forty-one halts—that is, in two months and nine days.

The first observations of the comet would have been made in this period. Some of the halts mentioned in the foregoing account are not readily identifiable. Dohad, about 200 km east of Ahmedabad and about the same distance from Ujjain by road (see Figure 6), is where Jahāngīr's grandson, Aurangzeb, was born. It is near the border of Gujarat and Madhya Pradesh. In the Survey of India's State Map of Madhya Pradesh (scale 1:1,000,000; 1978), Ramgarh, Nawari and and the Kahnar River do not figure but we do find the Chambal and Gambhir Rivers near Ujjain, on the stipulated route. Notably, the *Memoirs* do not refer to the Kshipra (Sipra) River that flowed to the immediate west of the city of Ujjain and lay on the royal route.

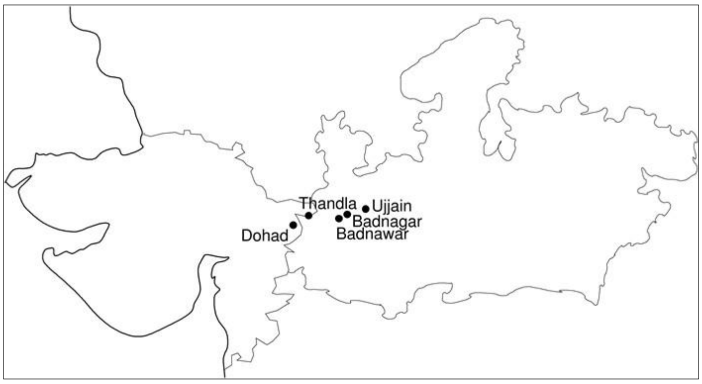


Figure 6: A map showing certain modern locations in the states of Gujarat and Madhya Pradesh that might have been on or near the route Jahāngīr took from Dohad to Agra through Ujjain in 1618.

We have looked at the *District Census Handbooks* (DCH) of the *Census of India 2011* released in 2015 by the Registrar General & Census Commissioner, India, for the districts of Dohad in the State of Gujarat and Jhabua, Dhar and Ujjain in western Madhya Pradesh. It is these districts, spread along a more-or-less west-east corridor, through which the stipulated route must lie. These DCHs list every village and town in the districts, along with the census data.

We did not find any place of interest in the DCH of Dohad. There is a state highway, SH 18, running through the last three districts and this connects to its counterpart in the State of Gujarat. We cannot say if this highway, or a part or parts of it, actually represent the medieval route between Dohad and Ujjain but we can identify two major places where halts may have occurred. SH 18 passes by the Thandla *Tehsil* (a block of a district) of Jhabua and the Badnawar *Tehsil* of Dhar, eventually reaching Ujjain. In the respective census listings, there is a Ramgarh in Thandla (DCH *Jhabua*, p. 60) and to its east is Semal Kheda (khera). The latter is joined in the east to Badnawar (DCH, *Dhar*: 66) by SH 18. On the west side of Jhabua, SH 18 stretches from the town of Thandla to join a road at the State border with Dohad. The names Madanpur and Nawari as such do not appear in any of the DCHs. However, Rogers and Beveridge (1914: 49) suggest that Madanpur is present day Badhnawar, which does fit into the sequence.

Incidentally, there is a Ramgarh in the Nalchha block of Dhar (DCH, *Dhar:* 144) and also one in the Ghatiya block of Ujjain (DCH, *Ujjain*: 134), but these are a long way from Badnawar. The Chambal River splits into the Chamla and the Chambal Rivers in the Khachrod *Tehsil* in the northern part of Ujjain district. The western component, the Chamla River, passes close to Badnagar in the district of Ujjain, and the eastern component, the Chambal River, flows between Badnagar and Kharent. The latter is situated ~10 km west of Ujjain on SH 18. Considering the geography of the region, we suggest Badnagar can be identified with Nawari. The Gambhir River passes Kharent. Finally, Samarna cannot be identified. It should be either in Dohad or in Jhabua. Both of these districts have hilly, undulating terrain.

While Figure 6 shows certain modern locations that lie on or near the route that Jahāngīr's Royal party would have followed in 1618, only modern on-site explorations, coupled with a more detailed analysis of the place names involved and the route, will allow us to confirm the identifications suggested above.

In Jahāngīr's *Memoirs*, the celestial positions of the comets are given zodiac-wise only but the comets' ephemerides generated from their orbital elements can help us fix the dates of the first sightings. Following the *Tūzuk-i-Jahangīri,* we take the first date of observation to be Saturday, 21 *Dhu-al-Qa*ʻ*dah* 1027 A.H. (corresponding to the 18th of Ābān, Saturday) at Ramgarh. The date converter www.islamicfinder.org gives this as Friday 9 November 1618 (Greg). The converter indicates that there is a small probability of a one day error in the conversion, but this date is the same as those derived using other converters (such as www.imcce.fr, www.iranchamber.com and CalendarHome.com). The last converter also gives the corresponding Persian date as Jomeh 18, Ābān, 997. As the date 21 *Dhu-al-Qa*ʻ*dah* begins at sundown (still Friday 9 November until midnight) and the observation was made ~12 hours later, the morning of 21 *Dhu-al-Qa*ʻ*dah* 1027 A.H, Saturday, corresponds to the morning of Saturday 10 November 1618 (Greg). The observation was made before the Sun rose at Ramgarh.

Since Ramgarh was located between Dohad (22º.87 N, 74º.25 E) and Ujjain (23º.18 N, 75º.78 E), we chose to use Thandla's coordinates (23.016º N, 74.579º E), and any discrepancy in the chosen latitude and longitude will be too small to influence the scenario we now present.

Comet 1618 III passed perihelion, on 27.9 October (q = 0.744 AU), about two weeks before its discovery. Jahāngīr records that the comet moved westwards from Scorpio into Libra. On 10 November, computations place the Sun in the middle of the constellation of Libra (which is ~17º in the sign of Scorpio) and a few degrees east of α Librae. The sky view shown in the Figure 7 corresponds to Saturday 10 November 1618 at sunrise (01:13 UT) at Thandla; north is at the top. The field of view is 45° and the bullseye at RA 14h 59h 24.09s and Dec. –19º 13′ 46.3″ is the apparent position of the comet with respect to the true equator and equinox of date at that moment as computed with the Horizons system (JPL 2015).

Using John Walker's *Solar System Live* and the Horizons system, we generate positions of the Sun and the comet in the sky for two crucial dates as in the Table 2.

In the Table 2, RA is for Right Ascension, Dec. for declination, r the heliocentric and Δ the geocentric distance, both in AU; the Moon's distance is in Earth radii (ER). The comet positions are apparent right ascension and declination. Also included in this Table are the computed values of the ecliptic coordinates (λ and β) of the Sun and the comet and the precessed position of Spica. In Figure 7, a line through the stars ζ Herculis, the Sun and ε Centauri (not shown) roughly defined the eastern horizon at the time of

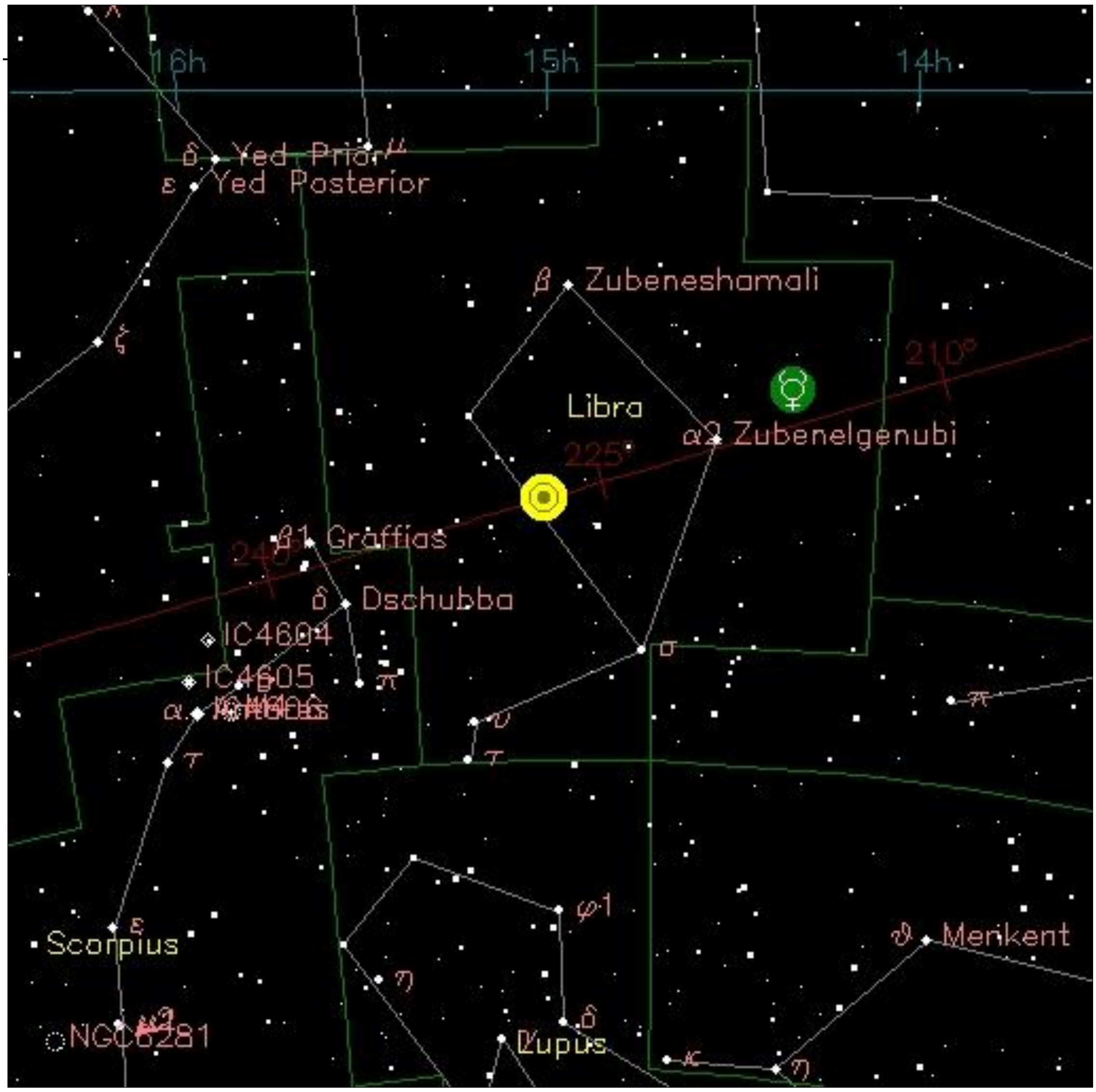


Figure 7: The bullseye at RA 14h 59m 24.09s and Dec. –19º 13′ 46.3″ is the computed position of Comet 1618 III (C/1618 V1) on Saturday 10 November 1618, 01:13 UTC, field 45°; the blue line is the equator and the red line the ecliptic; north is at the top (generated from John Walker's *Your Sky*).

Table 2: Details for the Sun, Comet C/1618 V1, the Moon, Mars and Spica on 10 and 11 November 1618 at 01.13 UT

	RA			Dec			*r*	Δ	Alt	Az (S-E)	Elong
	h	m	s	°	′	″					
10 November 1618											
C/1618 V1	14	59	24.09	–19	13	46.3	0.788	0.200	–1.10	–70.03	2.13L
	λ 227.945			β –2.099							
Sun	15	00	27	–17	06	54		0.989	–0.67	–71.65	Rising
	λ 227. 598										
Mercury	14	16	59	–12	04.5			0.734	10.99	–71.70	Up
Moon	09	53	10	+10	05.2			60.2 ER	75.69	–26.47	Up
Mars	10	43	22	+09	59.5			1.721	67.67	–57.44	Up
Spica									27.55	–66.13	Up
11 November 1618											
C/1618 V1	14	47	14.10	–19	39	02.7	0.795	0.194	2.53	–68.83	4.68L
	λ 225.319			β –3.335							
Sun	15	04	31	–17	23	48		0.989	–0.81	–71.40	Rising
	λ 228. 606										
Mercury	14	14	56	–11	39.9			0.754	12.49	–71.39	Up
Moon	10	39	38	+04	42.8			61.0 ER	65.38	–44.55	Up
Mars	10	45	25	+09	47.8			1.712	67.91	–56.28	Up
Spica									28.38	–65.55	Up

sunrise. The ecliptic (passing through the Sun) is roughly vertical to the line defining the eastern horizon; on location, the ecliptic would be inclined southwards.

A computation with the Horizons system shows that the comet began to lead the Sun from 9 November at 23:34 UT. At this time, the Sun was below horizon, at altitude –22º.75. As nautical twilight passed, in a dark sky[3] the comet's tail would begin to be noticeable. At sunrise, by which time the UT had changed to 10 November, the comet, about 2º south of the Sun (S-E azimuth –71º.58) was ~1º below the horizon and, as per the *Memoirs*, its tail would have been curved and located in the northwestern quadrant of the sky.

This scenario can be better visualized by referring to an observation of this comet by an observer in Rome on 11 November where the head was not noticed but the tail extended to the constellation of Corvus and remained visible until twilight. However, see Kronk (1999: 335) on ascertaining a date according to the convention of the beginning of an official day in those times, and also Section 7.2 below. The elongation of the star, say, β Corvi from the Sun that morning was ~40º, which about points to the length and position angle of the tail. In fact, between 10 November and 11 November, the PA of the tail, and its length, would change noticeably. However, the perceived length depended in part on haze and twilight. At sunrise on 10 November, the star β Crv had reached altitude 30º and azimuth –47º. With the head of the comet still very near the Sun, the tail had to be bright and intense in order to fit the description that it was long and magnificent.

In 1985, Landgraf computed the orbital elements of the Comet C/1618 V1 on the basis of observations made from 11 November to 9 December 1618. He assigned 225º and –3º to the ecliptic position of the comet's head for the observation of 11.15 November. Landgraf also claimed that the perihelion date could be wrong by ±2.5 days (Kronk, 1999: 335–337). The traverse of the comet computed with the Horizons system that uses Landgraf's orbital elements is as follows: in Libra (November 10), Libra (November 14), Libra-Virgo-Hydra (November 15), Virgo-Hydra-Corvus (November 19), Corvus (November 23), Crater-Hydra (November 29) indicating that it moved mainly westwards. In the orbit determination, Jahāngīr's observations are not part of the initial data on the comet and could affect its elements, even though by a trifling amount. Ravene (1897: 205) remarked, while presenting elements of the comet of 141 CE on the basis of the Chinese records, that diminishing the dates of observation by about one third of a day to about one day would bring the computed orbit closer to the Halley's.

The epoch of the observation, as read off the *Memoirs* account, is 72 minutes before sunrise. Since the Sun rose at 01:13 UT at Thandla (read Ramgarh) that day, this would make the observation at 00:01 UT, 10 November 1618. The observation is possibly linked with the *Al Fajr* prayer that is offered when the sky begins to lighten (with the Sun 19.5º below the horizon; see Bobrovnikoff, 1984: 18). The prayer is offered facing the direction of the *Ka'aba* and lasts about five minutes. The refraction effect is ~35 arcmin, so that the Sun would have risen about 2 minutes earlier, but this has little consequence here.

Sixteen nights after the 18th of Ābān, and therefore on the morning of 26 November, Jahāngīr observed a second comet, now designated 1618 II (C/1618 W1). It then lay in Libra. This also was a 'Great Comet' and was the third Great Comet of the year. According to Yeomans (2007), it was brightest on 29 November at magnitude 0–1. Kronk (1999: 338) gives its path as follows: Libra when discovered, Virgo (December 2), Bootes (December 5), Ursa Major (December 22) and Draco (December 31).

On 28 Ābān (19 November) Jahāngīr's party camped near Ujjain. Five days later, on 3 Azar, he marched from Kāliyādaha in Ujjain. The month following Ābān is Azar and the date Jahāngīr observed the second comet would be 5 Azar, 997 (8 *Dhu-al-Hijjah*, 1027 AH) which is 26 November. We can only guess the spectacle it may have been when another bright comet was already under observation.

The two Figure 8 images, which were generated with the Horizons System, are views of the inner Solar System from the top, and they allow us to pin-point the two comets when they were in the morning sky on 26 November 1618. At that time, Comet 1618 II moved faster in its orbit (direct motion) than Comet 1618 III, and began to lead the Sun on 16 November at 15:00 UT, the moment of its inferior conjunction, while 0.587 AU from the Earth. It passed closest to the Earth, at 0.358 AU, on 6 December at 15:00 UT.

4.3 Viewing Comets on a Bright Morning

If a comet is visible in the sky when the nucleus is below the horizon this is because it has: (1) an active nucleus; (2) the right combination of the r and Δ values; and; (3) an absolute magnitude H_{10} that should be on the brighter side. To that we can add the enhancement in brightness as a result of forward scattering of sunlight off the comet's dust grains when the comet passes between the Earth and the Sun (Marcus, 2007: 119). Post-discovery, Comet 1618 III was

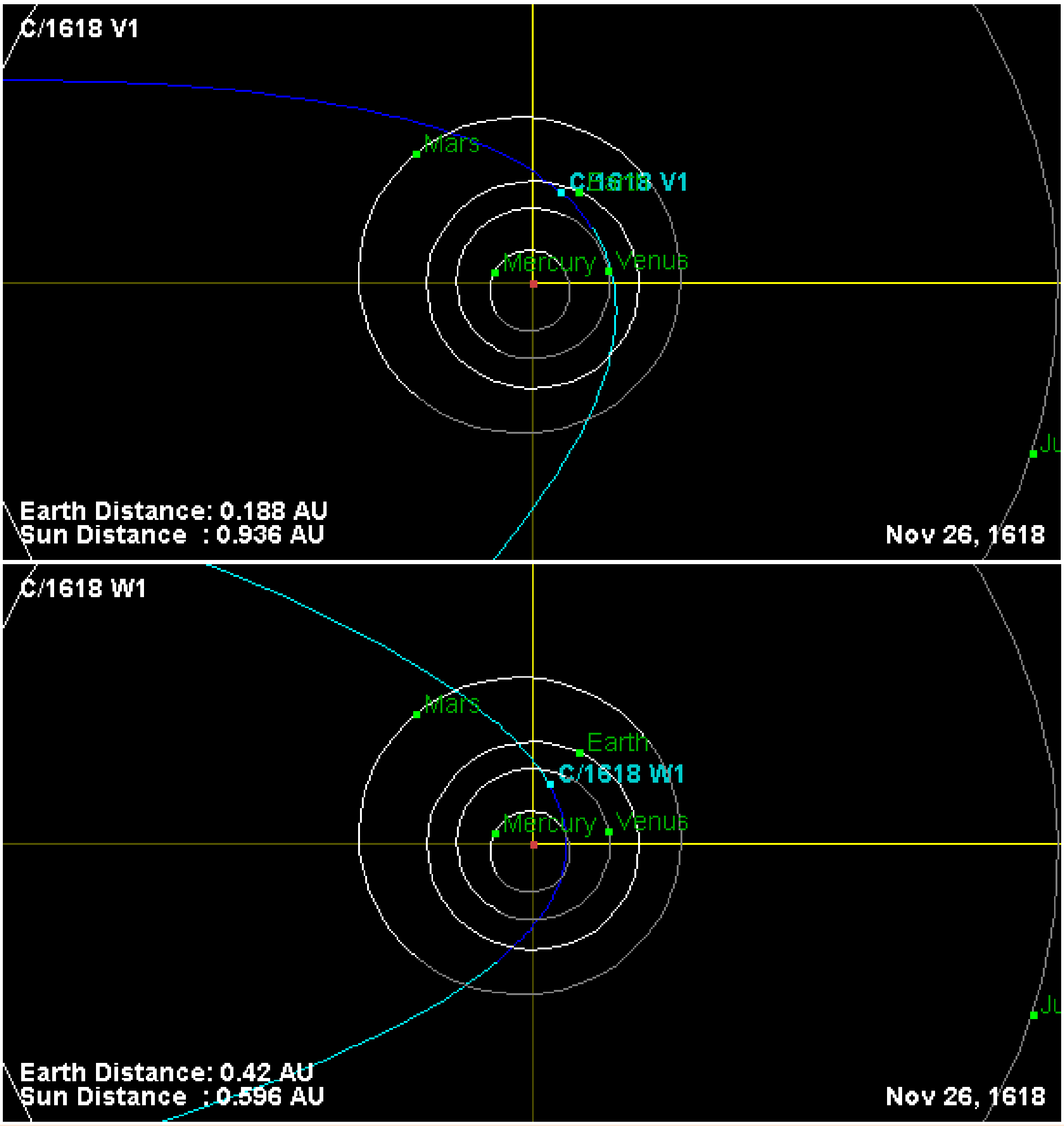


Figure 8: Comets 1618 III and 1618 II as on 26 November 1618; a bird's-eye view (generated from JPL's Horizons System).

nearing the Earth and growing into a spectacular object. It passed the closest by the Earth from 0.1706 AU on 18 November at 21:00 UT.

There are various examples in the cometary literature of comets seen just around the time of their solar conjunction. For example, Marsden (2005) writes about the comet of 1668 (C/1668 E1):

> Cassini (1668) was the first in the western world to publish observations—made from Bologna soon after sunset in March 1668—of what appeared to be the bright tail of a comet extending to more than 30° above the southwestern horizon. Neither he nor other observers located farther to the south (including some in Brazil and South Africa) were able to locate the comet's head, which evidently passed very close to the sun.

Other well-known comets seen in bright twilight are the sungrazer X/1702 D1, Great Comet C/1927 XI, Seki-Lines C/1962 C1 and Ikeya Seki C/1965 S1 (see Bortle (1998). According to R. Vasundhara (personal communication, December 2012),

> At twilight, there is surface brightness gradation from horizon to zenith. Fainter regions of the distant parts of the 60 deg tail should show up against the relatively darker (compared to horizon) sky. At the horizon the sky is brighter but the tail closer to the head is more dense (larger surface brightness) and should show up despite bright sky. In case the comet head is close to the Sun, in my opinion, the inner region will be washed out in the glare, however the rest of the tail should be visible out to great distances. Comet 1618 III (C/1618 V1)

> appears to be similar to last year's comet 'Comet Lovejoy' which had grazed the sun and then was visible in the morning … Elevation of 60 deg can be closely approximated to the zenith under conditions of negligible air pollution, as in 1618.

Figure 9 shows Comet Lovejoy (C/2013 W3) post-perihelion.

An idea of the precision that Jahāngīr's astronomers reached in their observations can be formed from the following few examples. In the *Akbarnāmā*, Abū'l Faḍl underlines Emperor Akbar's interest in the study of astronomy. A "… part of the Astronomical Tables of Ulugh Beg that we have noticed in Bābar's reign was translated under the supervision of Amīr Fatḥullāh Shīrāzī …" (Law, 1916: 150), while

Figure 9: Comet Lovejoy (C/2011 W3) after its perihelion passage in December 2011 (adapted from: http://astronomy-vlm.blogspot.in/2011_12_01_archive.html).

> Maulāna Chānd, the astrologer … was possessed of great acuteness and thorough dexterity in the science of the astrolabe, in the scrutinizing of astronomical tables, the construction of almanacs and the interpretation of the stars. (Beveridge, 1897–1939(1): 69).

Maulāna Chānd's astronomical tables, *Tahsilāt-i-Akbar Shāhī*, later were used by Sawāi Jai Singh II (Beveridge, 1897–1939(1): 69). Sheikh Alāhā-dād's family in Lahore flourished during the period 1570–1660 CE, and was acclaimed for the production of high-precision astrolabes and other equipment (e.g. see Figure 10). An astrolabe has plates to address different latitudes; each plate is engraved with a grid marked with degrees from 0º to 90º.

Muslim astronomers measured time by measuring altitudes of the Sun or Moon or a bright clock-star that they reduced to local time using astrolabes and the *zījes*. Re an individual instrument's precision, Stephenson and Said (1991: 196–197) cite an account of the solar eclipse of 17 August 928 CE where the observers were able to measure the altitude of the eclipsed Sun, observing its reflection in water, to a third of a division of the measuring ring that itself was graduated in thirds of a degree. We may also note that medieval Muslim astronomers were able to make eclipse predictions from *zījes* accurate to a fraction of an hour (Yazdi, 2008: 79). The eclipse magnitude would be expressed as the maximum proportion of the Sun's disc obscured, and astronomers could calculate this with great accuracy, with errors averaging 0.05 of the solar disk (Stephenson and Said, 1991: 206).

In the matter of the solar eclipse of 1024 AH (29 March 1615 Greg) that he observed from Agra, Jahāngīr wrote that the maximum eclipse magnitude attained was four out of five parts of the Sun (0.8) and lasting 8 *gharis* (3h 12min) (Rogers and Beveridge, 1909–1914(I): Chapter 12). These figures are very close to those calculated using Espenak's (2015) eclipse predictions, namely, 0.794 for the magnitude and nearly three hours duration as seen at Agra. One cannot help but admire Jahāngīr's astronomers for their observational abilities, and for their attempt to 'measure' astronomical objects other than the Sun and the planets.

To conclude, we deduce from Jahāngīr's records that Comet 1618 III was first sighted on 10 November around 00 UT and Comet 1618 II on the morning of 26 November, both post-perihelion. These dates make Jahāngīr an independent discoverer of the two comets in succession. In case the Islamic date converters err by a day, for the pair of dates 11 and 27 November 1618, Jahāngīr is still an independent discoverer of the two comets, notwithstanding the fact that the week days do not suggest this. However, we believe that there is lesser room for ambiguity about the pair of dates 10 and 26 November. The sunrise times on 10 November and 11 November 1618 at Isfahan (32.6577º N, 51.6692º E) were 3:01 and 3:02 UT respectively, so Jahāngīr would have sighted Comet 1618 III several hours before de Silva y Figueroa.

4.4 The Comets in Jahāngīr's Perception

The heliocentric worldview of Copernicus (*De Revolutionibus*, published in 1543) arrived in India much later. This knowledge was known to the Jesuits missionaries at the time but, involved as they were in their missions at several places in India, their primary goal was to spread the Christian faith. When Jahāngīr ascended the throne in 1605, Father Jerónimo Xavier, a grandnephew of St. Francis Xavier, had already spent ten years in the Royal Court as head of their mission (Guerreiro and Payne, 1930: xvi). Jahāngīr interacted with them on matters of faith and even joined in the sessions between his Moors and the priests. In fact, Abd us-Sattār ibn Qāsim Lahori, his courtier since Akbar's times, had been asked by Akbar to learn the language of the Franks. Abd us-Sattār closely interacted with Fr. Xavier with a view to translating into Persian certain Latin and Greek works about science, including astronomy, while in 1606 Jahāngīr had shown interest to establish a printing press to print books in Persian, and he was assured by Fr. Xavier on this matter (Hadi, 1995: 28; Alam and Subrahmanyam, 2009: 471, 477).

The cometary sightings of 1618 provided a rare opportunity for widespread discussions among astronomers and other scholars. While various past apparitions were recorded in many Muslim texts, here is nothing in Jahāngīr's *Memoirs* to suggest tthat there was any interaction between Jahāngīr's astronomers and the Jesuits in 1618. To Islamic astronomers, comets and meteors were regarded as atmospheric rather than heavenly phenomena, and so usually they were ignored. However, Ja'far b. Muḥammad Abū Mash'ar (787–886 CE), the famous Persian astronomer, astrologer and philosopher, considered comets to be celestial. Whether Jahāngīr' knew about this or not, on the conceptual side his writings take an exceptional departure from the conventional viewpoint. There is no concern expressed for any untoward consequences due to the apparitions, and so the Royal traverse continued.

For the first comet, Jahāngīr observed that

> It moved in high heaven, for it was first in Scorpio and afterwards in Libra. Its declination (*harakat-i-arz*) was mainly southerly …. and it had a proper motion of its own, independent of that of firmament, as it was retrograde – first appearing in the sign of the Scorpion, then in that of the Scales.

An orbital calculation indicates that the comet entered the Libra (the sign of the Scales) on 16 November. Jahāngīr's reference to the positions is according to the tropical system, and he also took due notice of the retrograde nature of the movement. It is clear that he and his astronomers conducted observations on various dates in addition to 10 and 26 November.

There are no *manāzil* or bright stars or planets mentioned by Jahāngīr near the comet's position, and nor could the position angle of the tail or its length be ascertained. While the comet's tail was rising above the horizon, bright objects like *Simāk* (Spica), *Al Ḥāris al Simāk* (Arcturus), *Al Jabhah* (Regulus), Mars and the Moon were all in the sky, whereas Mercury was hovering near the horizon. Jahāngīr also wrote that "At each succeeding night it rose a *ghari* earlier …", and that the comet had appeared a few nights prior to that date (i.e., 18 Ābān/10 November). Those 'few nights' the comet actually was trailing the Sun. For example, on 8 and 9 November calculations give its altitudes at sunset (12:18 UT, at Thandla) as ~ 4° and ~1° respectively (see also Table 2). On 10 November, around 00 UT, the comet transitted the Sun, passing ~2° below it, and was spectacular in appearance. Therefore, the word translated to mean 'night' may also mean the dark phase before twilight, and what Jahāngīr observed earlier could also mean the evening sightings of the same object. The key question is why there are no reports of evening sightings from anywhere else, even though the comet would have been nearly as bright, the change in r and Δ values through the few days being small only. Georg Dorffel, a student of Hevelius, first suggested that the two bright comets, seen in quick succession in late 1680 and early 1681, were the same comet (now designated C/1680 V1). By saying that the comet made its appearance before *and* after its perihelion passage and that it followed a parabolic path with the Sun at one

Figure 10: An astrolabe by Alāhādād, ca. 1601, at the Art Institute of Chicago (Wikimedia Commons).

focus, Dorffel provided an explanation for the pair of comets (Festou et al., 1993: 366). Even earlier, Peter Apian (1495–1552) had noted the disappearance of comets as they orbited close to the Sun and their subsequent reappearance (Hellman, 1944: 90). Jahāngīr also noticed the same thing

Jahāngīr had no knowledge of the developments that were taking place in astronomy in Europe at the time. He used astrolabes for his observations, but he did not use the prospective glass [telescope] gifted to him by Sir Thomas Roe in early 1616—see below. Jahāngīr had ascended the throne a week after Akbar's death on 17 October 1605 (Julian; Majumdar et al. 1967: 450, 456). He had been taught astronomy by Abū'l Faḍl's brother, Abū'l Faiẓ Faiẓī (d. 1595), a scholar and poet-laureate in Akbar's court. Jahāngīr had access to astronomical literature in the *Kitābkhānā* (the Royal Library), including the *Akbarnāmā* and the *Ā'in-i Akbari*—where Abū'l Faḍl gave a scholarly exposé on astronomical phenomena, his own sighting of the Great Comet of 1577, and current knowledge and his views on the nature of comets. Ironically, Abū'l Faḍl was assassinated in 1602 at Jahāngīr's instance (see Elliot, 1975: 13–14), much to his father's anguish. As a keen student of astronomy, we must wonder why he missed noting Kepler's Nova in 1604, the appearance of Halley's Comet in 1607 and the first bright comet of 1027 A.H. (1618 I) that appeared only a few days before Jahāngīr's entourage left Dohad for Agra.

Figure 11: Edward Terry (after Foster, 1921: 288).

Apart from Jahāngīr, there were others who observed the November 1618 comets from India.

4.5 The Reverend Edward Terry on the Two Bright Comets

In his travelogue *A Voyage to East India* that originally was published in 1655 the Reverend Edward Terry (1590–1660; Figure 11) records occurrence of the two comets of 1618. Terry came to India during the reign of Jahāngīr, and was the "… then Chaplain to the Right Hon. Sir Thomas Row, Knt, Lord Ambassador to the Great Mogul." (Terry, 1655: 393). He reports:

> In the year 1618, when we lived at that court, there appeared at once, in the month of November, in their hemisphere, two great blazing stars, the one of them north, the other south; which unusual sight appeared there for the space of one month. One of these strange comets, in the north appeared like a long blazing torch, or launce fired at the upper end; the other, in the south, was round, like a pot boiling over fire. The Mogul consulted with his flattering astrologers, who spake of these comets unto the King, as Daniel sometimes did of Nebuchadnezzar's dream … (ibid.).

5 INDIA'S TRYST WITH TELESCOPE

The invention of a device to see an enlarged version of objects at a distance is attributed to the German-Dutch spectacle-maker Hans Lippershey in 1608, who lived in the Netherlands. It consisted of a concave eyepiece and a convex objective lens. By the end of 1608 the so-called Dutch 'perspective glass' had entered the public domain, and in April 1609, perspective glasses magnifying 3× could be purchased in spectacle-makers' shops in Paris, and soon after in Italy.

Here was one of the most important inventions in history, which in the hands of Galileo Galilei, the Professor of Mathematics at the University of Padova, would soon evolve into a high-powered instrument (*occhiale* as he called it) and usher in an unimaginable revolution in science. It transformed our world-view forever. News of the device and Galileo's exciting findings—described in his book *Sidereus Nuncius* (*The Starry Messenger*), published on 12 March 1610—spread more quickly than anyone could have imagined at that time. The term 'telescope' was coined in 1611 by the Greek poet and theologian Giovanni Demisiani (d. 1614) from two Greek words, *tele* (far away) and *skopeo* (to look).

In August 1610 Johannes Kepler (1571–1630) acquired a telescope, and he confirmed Galileo's observations of the Jovian satellites (see van Helpern et al., 2010). In 1611 he went on to propose in his book *Catoptrics* a variation to the optics by using only convex lenses, which would produce an inverted image but give a wider field of view. Based on this innovation, the first astronomical telescope in the true sense was developed by the German Jesuit mathematician Christoph Scheiner (1573–1650) between 1613 and 1617 (Mitchell, 1915: 345). The telescope found favour with astronomers by 1630, but it was only when the English astronomer William Gascoigne (1612–1644) inserted a crosswire in the eyepiece and installed a micrometer (by 1640) that it was transformed into an astronomical measuring instrument.

Early in 1616 Emperor Jahāngīr also came to possess a telescope. One of the most important visitors to the Mughal Empire at that time was Sir Thomas Roe (1581–1644) who came to Jahāngīr's Court as Ambassador of King James I for the years 1615–1619. Sir Thomas landed at Surat in September 1615 and proceeded to have an audience with the Emperor who was then at Ajmer in Rajasthan. Sir Thomas arrived in Ajmer at Christmas and was first presented to Jahāngīr on 10 January 1616 (Wheeler, 1881: 68). Of the many valuable gifts that he had brought to India was a 'spyglass', which he presented to the Emperor (Huff, 2010: 12). A spyglass is actually a small hand-held telescope that extends when pulled out and can be adjusted to the viewer's eye (see Warner, 1998). Sir Thomas' exotic gift apparently did not impress Jahāngīr very much, so he passed it to Āṣaf Khān (the brother of Nūr Jahān and father of Mumtāz Mahal) in his court. This device then joined Khān's collection of other fascinating optical objects, like spectacles and prospective glasses [sic.] that had been purchased from a Venetian merchant in 1616 (Foster, 1928: 83). Although he was a scholar of astronomy (Khan Ghori, 2000: 33), apparently Āṣaf Khān did not realize the astronomical potential of this gift.

However, a telescope was eagerly sought after by a Jesuit missionary in India soon after news of the invention reached Indian shores. We will meet him below, but first let us learn something about the history of the Jesuits in the Indian Subcontinent and in the Far East.

Jesuit missionaries belonged to the 'Society of Jesus', which was founded by St. Ignatius of Loyola, a Spanish soldier, in 1540. Its roots were in Rome, and its purpose was to propagate Roman Catholicism. The Collegio Romano (*Collegium Romanum*) that would become the Society's main scientific centre, was founded by him in 1551, and the present-day Pontifical Gregorian University is the heir to the College. The Society has male members only, called Jesuits. During the sixteenth century, many of the Jesuits were trained in mathematics, geography and astronomy, and they carried the latest developments in European science to their missions worldwide. Missionaries heading for the Far East needed to set sail from Lisbon, with a stopover at Goa, the capital of Portuguese India, and Macao, the Portuguese commercial base further east in China. Voyages from Lisbon to Goa took six months, and Jesuits heading for Macao had to stopover in Goa for a further six months until winds became favourable again.

In due course, the city of Goa became the headquarters to many religious orders, the Franciscans, Jesuits and Dominicans being the main ones, so much so that in 1554–1555 the Portuguese King assigned different parts of Goa to them, namely Baldez (Bardez) in the north to the Franciscans, Salcete in the south to the Jesuits, with the contiguous islands of Divar and Chorão to be shared by the Jesuits and the Dominicans. The Dominicans had come to Goa in 1548, and they soon established houses in various places; the Augustinians arrived much later, in 1575 (de Mendonça, 1958: 80–81). Goa is landscaped with innumerable churches, which are affiliated with various congregations and reflect exquisite architectural splendour. An interesting feature of the Portuguese-style Goan churches built in the sixteenth and seventeenth centuries is that they incorporated certain astronomical aspects in their design. There were sundials for timekeeping, while an east-west orientation allowed sunlight to enter the eastern or western entrances at sunrise or sunset on the day of the equinox or the solstice, or on some other important day (Borkar, 2016).

The first Jesuit mission in India was established in Goa in 1542 under St. Francis Xavier (1506–1552), one of the co-founders of the Society of Jesus. In due course this was followed by more missions, which were established at various places in India, but initially in coastal regions in the south, such as Malabar, Cochin and the fishery coast of Tamil Nadu. However, missions soon spread inland. A member of the mission in Goa from 1606 was the cartographer Giovanni Antonio Rubino (Antonius Rubinus, 1578–1643), who perhaps was the first Jesuit in India to show an interest in astronomy. On 2 November 1612 after learning about the invention of the telescope, Rubino wrote to Christof Grienberger (1561–1636), a Jesuit astronomer at the Collegio Romano and a Galileo sympathizer, asking for astronomical literature and other equipment (Sharma, 1982: 346). This letter makes wonderful reading, as it shows the excitement of the Jesuits to scientific developments and the pace with which the news of these spread. This was at a time when communication with Europe took anywhere from six months to 2–3 years. An English translation of an excerpt from Rubino's letter, originally written in Italian, follows.

> Somebody wrote me from Italy that certain occhiali (eye-pieces) have been invented by means of which objects 15 or 20 miles away are seen clearly and many discoveries have been made in the heavens, particularly in the planets. Your Reverence will do me a great favor by sending me these, together with a little treatise on such occhiali, if there is demonstration of the things one sees by them. But if Your Reverence does not have the occasion or the money to send me these, please send me in writing and in figures, as clearly as possible, the manner of their construction, so that I may have them made in this land of many officials and abundance of crystals. (Leitao, 2008: 118).

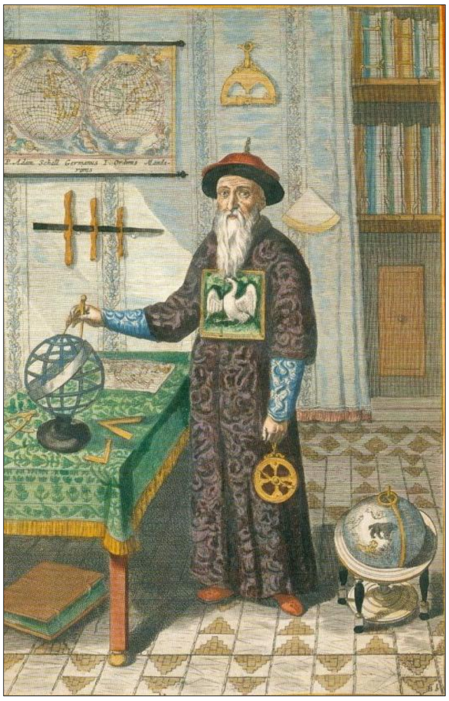


Figure 12: A portrait of Johann Adam Schall von Bell wearing mandarin attire while missionary to China during 1622–1666 and accompanied by an astrolabe, a celestial globe and an armillary sphere (Wikimedia Commons).

On the basis of this letter, Father Rubino has been credited with introducing the telescope to India (Udias, 2003), but in fact we do not know if his request was successful.

6 OBSERVATIONS OF THE COMETS OF NOVEMBER 1618 BY THE JESUITS IN INDIA

6.1 Father Trigault's Mission to the Orient, with a Passage Through India

In its astronomical column on 24 January 1878 *Nature* carried a contribution titled "The comet of 1618" by an unnamed author stating that the Jesuit astronomer Giovanni Riccioli (1598–1671) had mentioned observations made from Goa, India, by another Jesuit astronomer named Kirwitzer of the comets of 1618. Riccioli taught in Bologna, and is acknowledged for his star catalogue, the book *Almagestum Novum* and a detailed map of the Moon. Wilhelm Olbers (1758–1840) also had received from H.G. Brandes a work by Fr. Kirwitzer which by then had become scarce, about the observations of the second comet of 1618 (The comet of 1618, 1878). Olbers was a German physician and astronomer who discovered Comet 13P/Olbers and the minor planets Pallas and Vesta. He also was the first to devise a suitable method for calculating cometary orbits. However, he is best known in astrophysics for posing the fundamental question "Why is the sky dark at night?", the famous 'Olbers Paradox', that led to great debates in astronomy. In 1821 Olbers wrote to Franz Xaver von Zach (1754–1832) about Kirwitzer's account of the comet, adding that the work he had received from Brandes unfortunately was in too bad a shape due to copying or printing for him to deduce a realistic orbit. One should consult Zach (1822: 369–371) for more on this.

The exchanges above were about the missionary and astronomer Father Venceslaus Pantaleon Kirwitzer (1588–1626), originally from Kadaň in Bohemia (present-day Czech Republic), who first saw the second comet of 1618 on 14 November and noted down his observations. He was joined in the observations on 26 November by the German Jesuit missionary Johann Adam Schall von Bell, S.J. (The comets of 1618, 1878). Fr. Adam Schall (1591–1666; Figure 12) was a mathematician and astronomer, and an expert on calendrical science. Olbers knew that in his work, Zach had stated that fourteen volumes of Fr. Schall's works were available in the library of the Vatican. Believing that these might contain information on the second comet of 1618, Olbers urged Zach to examine that aspect. However, subsequently, a search by Conti revealed nothing of the sort. Further, the paper in *Nature* noted that

> It does not appear that a more accurate copy of Goa observations has been found since Olbers wrote on the subject. There are two works by Kirwitzer in the British Museum, but they afford no assistance. It thus happens that there is as yet no orbit of the comet in question. (The comets of 1618, 1878).

Father Kirwitzer was a member of the *Collegium Romanum* at the time when in May 1611 Galileo Galilei was in Rome to state his case for the Heliocentric vs. Ptolemaic systems. The *Collegium* was then open to the Copernican views and was warm to Galileo. Father Kirwitzer was among a group of missionaries led by Nicolas Trigault (1577–1628) destined for China that included Giacomo Rho (1592–1638), Johannes Schreck-Terrentius (also Terrenz; 1576–1630) and Adam Schall. In April 1618 they set sail from Lisbon aboard the *San Carlos* (Leitao, 2008: 107), and braving the rigours of the voyage, sickness and the death of five of the twenty-two China missionaries, they sailed into Goa on 4 October 1618. The group was carrying a few telescopes and some measuring instruments, along with a large number of books. Incidentally, when he was on tour to Milan in 1616 Terrenz had received a Galilean telescope from Cardinal Federico Borromeo, and eventually he would take this precious gift to China. Along with Terrenz and Adam Schall, Kirwitzer subsequently proceeded to China, setting sail on 15 May 1619 and reached Macao on 22 July 1619 (Zettl, 2008: 29−36). In 1621, Terrenz presented the Emperor with a telescope as a gift (Udias, 1994: 467).

What kind of instruments did the Jesuits bring with them? Baichun (2003) has provided illustrations of several astronomical instruments taken to China by Trigault et al., as well as those that subsequently were made there. One may also refer to Bolt and Korey (2010) for examples of early seventeenth century telescopes, starting with the earliest-known surviving one, which dates to the year 1617 (Figure 13). This consists of a main tube and a number of draw tubes.

In Figure 14 we reproduce the sketch of a Galilean telescope that Fr. Adam Schall drew in his book *Yi Hai Zhu Cen* (*Pearl Dust of Artistic Sea*). The inscription says "Compiled by Tang Ruowang", which was his Chinese name, and his preface is dated 1626. The book is about astronomy, and discusses Galileo's findings on the Solar System and the Milky Way made with such a device. It also delves into general optics, optics of concave and convex lenses and their combinations, and the making and use of telescopes. The telescope that is illustrated has an altazimuth mount; recall that telescopes with equatorial mountings lay in the future.

Christoph Scheiner, who had been using an altazimuth-mounted telescope to follow sunspots, found it difficult to follow them properly, so on a suggestion from his brother Christof Grienberger, he constructed what is regarded as the forerunner of the equatorial mounting. With it Christoph Scheiner was able to observe sunspots and determine their position and motion conveniently and with precision. As outlined in the *Rosa Ursina* (1630), his great work on sunspots, Scheiner put the device to use from 4 March 1627 (Mitchell, 1916: 347–348; Woods, 2005: Chapter 5).

Figure 13: The world's oldest-known surviving telescope, which is securely dated to 1617, is now in the Kunstgewerbemuseum/Staatliche Museen zu Berlin. The maker is unknown. This cloth and paper telescope comprises a main tube, and five draws of pasteboard. Each draw is covered in marbled paper. The end tube and ring stops are in silk velvet embroidered by gold thread. When collapsed the end tube and rings have a common outer diameter of 48mm (after http://dioptrice.com/telescopes/782).

6.2 Father Kirwitzer's Treatise on his Observations

Father Kirwitzer presented a detailed description of his observations of the spectacular comets that first appeared in the morning skies in November 1618 in a monograph titled *Observationes Cometarvm Anni 1618. In India Orientali Factae a Societatis iesv Mathematicis in Sinese Regnum Nauigamtibus ex Itinere eo Delatis* that was published in 1620 (Figure 15).

The treatise is short, consisting of 24 pages only and signed *ex* "Goæ in India Orientali 11. Febr. 1619." In his *Preface*, Fr. Kirwitzer refers to being assigned to India by Muzio Vitelleschi

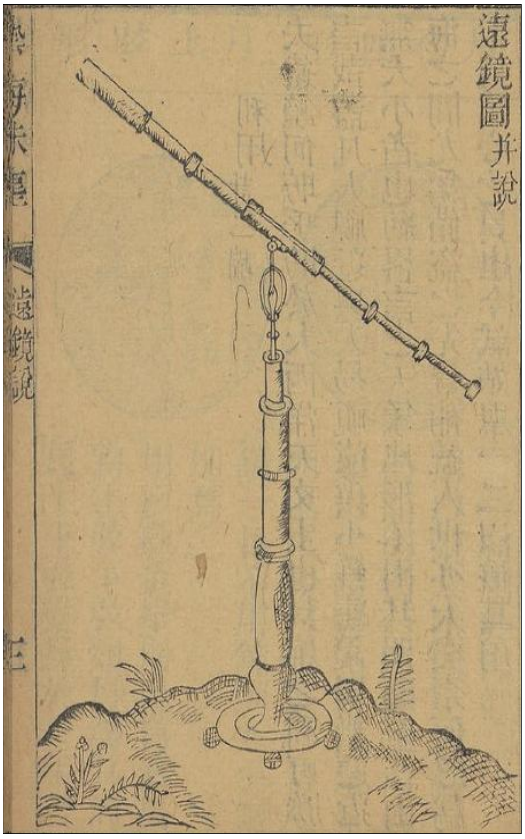
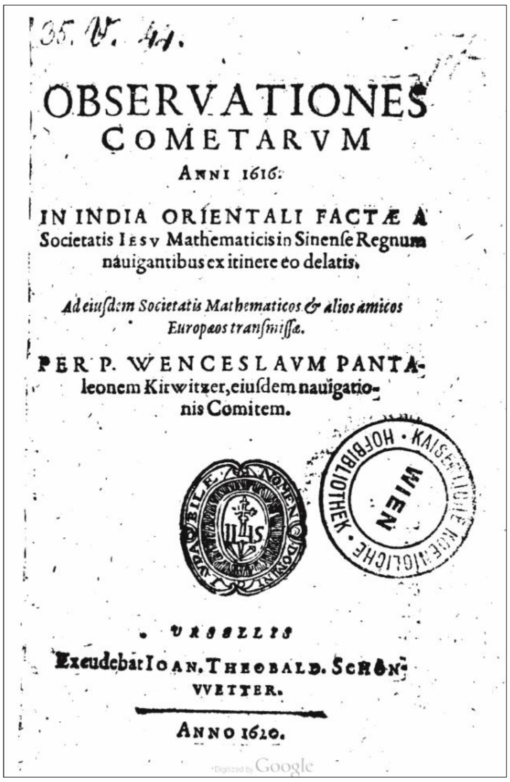


Figure 14: A drawing of a Galilean telescope by Adam Schall (after World Digital Library http://www.wdl.org/en/item/11434/).



OBSERVATIONES
COMETARVM
ANNI 1616.
IN INDIA ORIENTALI FACTÆ A
Societatis IESV Mathematicis in Sinenſe Regnum
nauigantibus ex itinere eo delatis.

*Ad eiuſdem Societatis Mathematicos & alios amicos
Europæos tranſmiſſæ.*

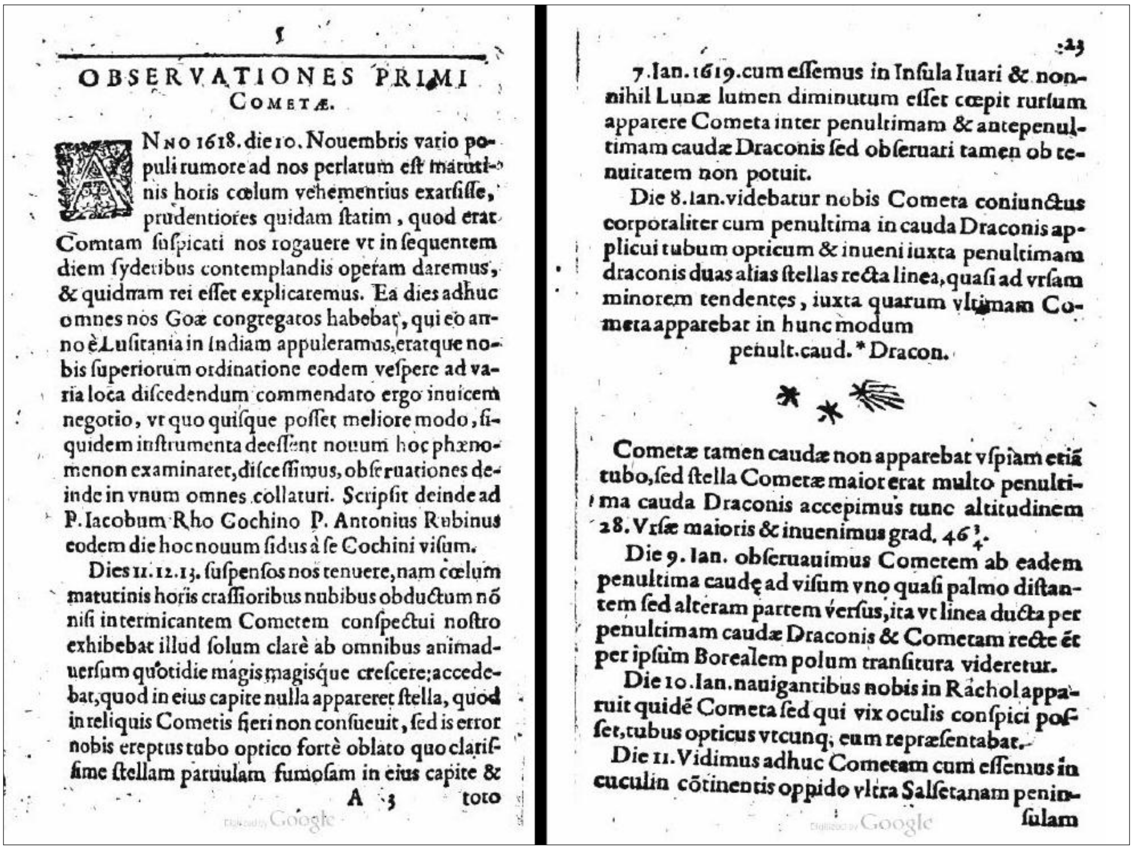
PER P. WENCESLAVM PANTALEONEM Kirwitzer, eiuſdem nauigationis Comitem.

VRSELLIS
Excudebat IOAN. THEOBALD. SCHÖNWETTER.
ANNO 1620.

Figure 15: The cover page of Fr. Kirwitzer's treatise, which was digitized in 2014 by The Austrian National Library (after Google Books).

(1563–1645), the Sixth General of the Society through 1615–1645, to bring the light of the Gospel to the great Empire of the Chinese. Fr. Kirwitzer (1620) also mentions how fellow Jesuit astronomers met with very unkind circumstances (also see Golvers, 1992: 391).

The significance of Fr. Kirwitzer's treatise lies in the fact that it reports the first-ever modern astronomical observations carried out in India and the first-ever use in India of the telescope for astronomical observations, soon after its introduction in Europe (see Figure 16). Hereinafter, the description closely follows certain relevant parts of the treatise, and we cite the dates just as given in the treatise. These match the dates given in *Nature* (The comets of 1618, 1878) and also agree with the chronology presented in the *Tūzūk-i Jahangīrī*. We shall return to this topic in Section 7.2, where we investigate the dating conventions then in use. In the following account, references to the 'first comet' and the 'second comet' refer specifically to the November 1618 comets, just as Fr. Kirwitzer described them (i.e. to Comet 1618 III and 1618 II respectively).



5

OBSERVATIONES PRIMI
COMETÆ.

ANNO 1618. die 10. Nouembris vario populi rumore ad nos perlatum eſt matutinis horis cœlum vehementius exarſiſſe, prudentiores quidam ſtatim, quod erat Comtam ſuſpicati nos rogauere vt in ſequentem diem ſyderibus contemplandis operam daremus, & quidnam rei eſſet explicaremus. Ea dies adhuc omnes nos Goæ congregatos habebat, qui eo anno è Luſitania in Indiam appuleramus, eratque nobis ſuperiorum ordinatione eodem veſpere ad varia loca diſcedendum commendato ergo inuicem negotio, vt quo quiſque poſſet meliore modo, ſiquidem inſtrumenta deeſſent nouum hoc phænomenon examinaret, diſceſſimus, obſeruationes deinde in vnum omnes collaturi. Scripſit deinde ad P. Iacobum Rho Cochino P. Antonius Rubinus eodem die hoc nouum ſidus à ſe Cochini viſum.

Dies 11. 12. 13. ſuſpenſos nos tenuere, nam cœlum matutinis horis craſſioribus nubibus obductum nō niſi intermicantem Cometem conſpectui noſtro exhibebat illud ſolum clarè ab omnibus animaduerſum quotidie magis magiſque creſcere; accedebat, quod in eius capite nulla appareret ſtella, quod in reliquis Cometis fieri non conſueuit, ſed is error nobis ereptus tubo optico fortè oblato quo clariſſime ſtellam paruulam fumoſam in eius capite &

A 3 toto

23

7. Ian. 1619. cum eſſemus in Inſula Iuari & nonnihil Lunæ lumen diminutum eſſet cœpit rurſum apparere Cometa inter penultimam & antepenultimam caudæ Draconis ſed obſeruari tamen ob tenuitatem non potuit.

Die 8. Ian. videbatur nobis Cometa coniunctus corporaliter cum penultima in cauda Draconis applicui tubum opticum & inueni iuxta penultimam draconis duas alias ſtellas recta linea, quaſi ad vrſam minorem tendentes, iuxta quarum vltimam Cometa apparebat in hunc modum

penult. caud. * Dracon.

Cometæ tamen caudæ non apparebat vſpiam etiā tubo, ſed ſtella Cometæ maior erat multo penultima cauda Draconis accepimus tunc altitudinem 28. Vrſæ maioris & inuenimus grad. $46\frac{3}{4}$.

Die 9. Ian. obſeruauimus Cometem ab eadem penultima caudę ad viſum vno quaſi palmo diſtantem ſed alteram partem verſus, ita vt linea ducta per penultimam caudæ Draconis & Cometam rectè ét per ipſum Borealem polum tranſitura videretur.

Die 10. Ian. nauigantibus nobis in Rachol apparuit quidē Cometa ſed qui vix oculis conſpici poſſet, tubus opticus vtcunq; eum repræſentabat.

Die 11. Vidimus adhuc Cometam cum eſſemus in cuculin cōtinentis oppido vltra Salſetanam peninſulam

Figure 16: Pages 5 (left) and 23 (right) in Fr. Kirwitzer's book, which discuss his observations of the two bright comets that appeared in November 1618. Both pages mention that a telescope was used for viewing the comets (after Google Books).

In the *Præfatio*, Fr. Kirwitzer (1620) states that he was not prepared to make any observations when two bright comets suddenly appeared in the sky in the early morning hours. His first record is dated 10 November where he says that many people from the locality approached him to tell him about and seek an explanation for this strange apparition in the sky. Fr. Kirwitzer suspected that it was a comet, and he told everyone that he would explain about it on the following day after first observing it. He also felt that if it was to be examined the new phenomenon demanded suitable instruments, and that it warranted a joint effort with others, so the very same day he wrote to Fr. Jacobus Rho and to Fr. Antonius Rubinus at Cochin, 660 kilometres south of Goa, about the newcomer. Unfortunately, at that time their baggage was still on the ship, and no instruments or books were to hand, but later this would change.

6.3 The Jesuit Observing Sites

Where in Goa and Cochin were the Jesuits stationed?

In the sixteenth century Goa (Figure 17) initially was an important centre of long distance trade, but it soon became the political, cultural and religious 'central engine' of Portuguese India. The activities of all the religious orders that arrived in India in quick succession to spread the Christian faith received the backing of the Portuguese Government. The Jesuits, who were in Goa from 1542, developed an economic framework and acquired land and houses so that they could continue their mission to spread the faith and pursue scientific interests. In his treatise Fr. Kirwitzer refers to a few places from which the Jesuits made astronomical observations. One named Rachol (pronounced Rashol) is mentioned as being 5 leagues from Goa (i.e., Old Goa). It is a town on the Salcete Peninsula south of Panjim (now Panaji) and 7 kilometres north-east of Margao. The Portuguese occupied Salcete in 1543, and they fortified Rachol and placed Salcete in the care of the Jesuits. The Jesuits took up residence in a small house in Rachol where the present-day parish church is situated. Rachol has been home to the Patriarchal Seminary of Rachol since 1610, which was built by the Jesuits atop a small hillock. With the passage of time the Seminary evolved into a multipurpose institution (see Patriarchal Seminary of Rachol, 2016).

As for his own location, Fr. Kirwitzer writes of being at 'Insula Ivari' and sometimes at 'S. Paul'. Insula Ivari must be Divar Island (Figure 18), which is in North Goa 10 km north of Panjim, and was among the first places in Goa that the

Figure 17: An 1719 pictorial map of Goa by Pieter Boudewyn van der Aa (1700–1750), Divar Island is in the middle of the lower half of the image and Chorão Island is to its right; the Mandovi River flows from left to right into the Arabian Sea (adapted from British Library Online Gallery http://www.bl.uk/onlinegallery/ onlineex/apac/other/019pzz000002417u00000000.html).

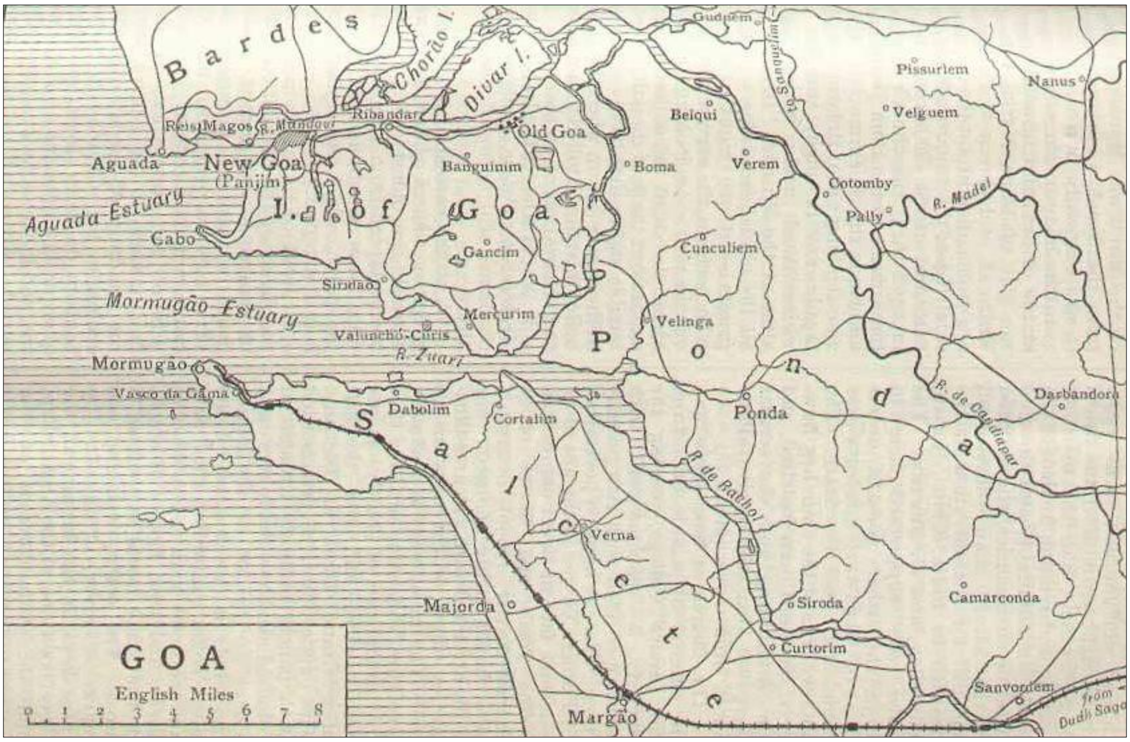


Figure 18: A map showing the Island of Goa, 'Old Goa' (centre, near the top) and above it Divar Island (after Poyntz, 1924).

Portuguese strove to spread the Catholic faith. A major portion of the island is rather flat and thickly forested, with a 49-m high hillock. At the base of the hillock is a Goan village named Piedade. On the hilltop is the Church of Our Lady of Piedade that was founded in 1541 and was rebuilt in 1625 (Lourenço, 2005: 158). The hilltop, which overlooks Old Goa, may have served as an observation point. The Mandovi River surrounds Divar Island, and the Jesuits used canoes to reach the island.

'S. Paul' would be the famous New College of St. Paul in Old Goa, east of Panjim. On the other side of the Convent of St. Augustine, it was situated on the western slopes of the hill, overlooking Divar Island. The New College was an institution of higher learning in theology, philosophy and many other disciplines. This magnificent four-storeyed building was greatly admired for its vastness and architecture. It was erected on the ruins of a house on the hill of Nossa Senhora de Rozario that the Jesuits had acquired in 1578. Initially it was known as the Convent of St. Roch, but in 1610 was changed into a college and given the name New College of St. Paul (for details see da Fonseca, 1878: 315–320), to distinguish it from an older College of St. Paul. The latter, with its church, was completed in 1542 and has been described as

> … the chief institution of the disciples of Loyola in India, to which more than three hundred churches with their colleges in different parts of Asia were subject. (da Fonseca, 1878: 262).

It is worth mentioning that the first printing press in India was introduced by the Jesuits, in Goa in 1556, at the colleges of St. Paul and Rachol (da Fonseca, 1878: 58). Because of an epidemic in 1570 that afflicted those in this locality, including 58 priests, in 1578 the Jesuits decided to move to a new house in a healthier location so that they could more effectively care for their sick. Activity at the Old College then reduced, although it remained the prime institution of the Jesuits for some time (da Fonseca, 1878: 264). All that remains today of the New College of St. Paul is a magnificent gateway on a small road south of St. Cajejan's Church in Old Goa (Figure 19). A sign board describes this as the Arch of Conception. Fr. Kirwitzer mentions S. Rochi a few times in his treatise.

After Goa, Cochin became a stronghold of the Catholic faith. The residence of the Society of Jesus was erected in Cochin in 1550 and the College of Mother of God (*Madre de Deus*) and the Seminary were established in 1560. Later, both grew to become major cultural centres. Fr. Antonius Rubinus, who carried out the astronomical observations in Cochin, probably was based here, although there is no corroborating evidence for this.

6.4 The Instruments Used by the Jesuits

Fr. Kirwitzer records in detail what the observers saw and measured, namely, the altitude and aziimuth of the comet; its angular distance from stars like Spica etc. in *grad* (degrees). He also reports the observers' visual impressions, sometimes gained with difficulty because of illumination by the Moon or sunlight. The observations are presented systematically and are divided into two sections for each comet, incorporating those by brother-priests at the other Jesuit establishments.

In those times, astronomers observed the position and direction of the tail, and they determined the position of the comet with respect to many nearby fixed stars whose positions were already known. The main objective was to determine the position of the comet on the ecliptic, and its motion. Whilst indicating the positions, Fr. Kirwitzer also refers to *informi* (unformed), which are field stars that at that time had not been grouped into designated constellations.

Astronomical instruments that these Jesuits were able to access were an astrolabe (*astrolabium*) and an astronomical radius or cross-staff (*radium astronomicum*) belonging to Goa College. A cross-staff consists of a staff with a smaller, sliding transverse arm, generally made of wood but sometimes of brass, and bearing a scale that could be read directly in degrees. One measured altitudes and angular separations between two objects by pointing it at the object and moving the transversal arm until the angle was covered. The cross-staff was introduced by the Portuguese in the mid-sixteenth century as an aid to navigation. The earliest depiction of the device that I have located is in the 1552 work on navigation, *Regimento de Navegacion* by Pedro de Medina (Figure 20; see Goldstein, 2011 for details). Even Tycho Brahe (1546–1601) used one. The instrument was handy for seafarers and astronomers of the time even though viewing added to errors that limited the precision. Notably, the measurements given by Fr. Kirwitzer were to a fraction of a degree, or minutes of arc. At this time, astronomers determined time by measuring the altitude of the Sun or Moon or a bright clock-star that they then reduced to local time by using astrolabes and astronomical tables.

Finally, these were not the only astronomical instruments that Fr. Kirwitzer and his colleagues used. Most importantly, a telescope (*tubo optico*) also was used by him to view the comets.

6.5 Observations of the First Comet of 1618 (i.e. 1618 III)


Figure 19: The Arch of Conception in Old Goa (photograph: R.C. Kapoor, 24 February 2016).

As Fr. Kirwitzer writes, dark clouds that were present before sunrise on 11, 12 and 13 November prevented them from making any observations, but providence intermittently showed the comet growing day-by-day. Fr. Kirwitzer looked for a star in the head as was typical of comets, but found none. However, when he used the telescope it clearly revealed a star, with a little 'smoke' in the head that appeared pale in colour. The comet's form was best described as like a palm leaf, and it stretched as a straight smoky column from the east to the midst of heaven, with the tip a little turned to the north.

For this comet, the observations extend from 10 to 30 November, with no observations possible on 19, 20, 22 and 25 November due to clouds.

Figure 20: The cross-staff, as depicted in Pedro de Medina's 1552 treatise *Regimento de Navegacion* (Wikimedia Commons).

The date 10 November is included here since the mysterious object was first noticed that morning and Fr. Kirwitzer (rightly) suspected it to be a comet. Observations were made by Fr. Kirwitzer at Divar Island and at S. Rochi and by Fr. Jacobus Rho at Rachol and at S. Rochi. Fr. Rho used a cross-staff for his measurements. The altitude and azimuth of the comet and the first magnitude star Spica (*Alpha Virginis*), along with the length of the comet's tail, were given to the fraction of a *grad*. At times, there is reference to the constellations of Corvus, Crater, Hydra, Crux and Centaurus, with information about how the angles to these varied. On page 7 in the treatise, Fr. Kirwitzer depicts the position of Comet 1618 III on 17 November with respect to two nearby stars (which, unfortunately, are not readily identifiable). Nowhere does Fr. Kirwitzer mention the time when the observations were made, even though he refers to "… the clock of our College …"

Detailed observations began on 14 November. At Rachol that morning the altitude of the comet was recorded as 11°, the horizontal distance to the sunrise position as 14°, while at the same time *canicula* (Sirius) was 44° above the horizon. We take the word *ab ortu* in the text, the reference point for azimuth, to mean the point of 'sunrise', not east. On 15 November, Fr. Kirwitzer refers to the use of star charts:

> The comet was near the same horizon 5 degrees, but 17 degrees from sunrise. The tail ran until the second star of the *Corvi* in the right wing, counting the stars in the celestial constellations, according to the figures published by P. Christopher Gruenberger [*sic*], famous mathematician of our Society. In fact, they were on hand for the event outside of the luggage and of which we made use throughout the duration of our observations.

Christopher Grienberger (1561–1636; MacDonnell, 2014) was an Austrian Jesuit and Professor of Mathematics at the Collegio Romano. His acclaimed work on the constellations, *Catalogus veteres affixarum Longitudines, ac Latitudines conferens cum novis. Imaginum Caelestium Prospectiva duplex ...*, was published in 1612. It was illustrated, and contained astronomical tables and maps relating to 21 numbered northern constellations, 12 zodiacal constellations and 15 numbered southern constellations. It also included the new northern constellations of 'Antinous' and 'Berenices Crinis'; these, however, were not numbered (see Stoppa, 2016). These new constellations were first added to the existing 48 Ptolemaic constellations by the cartographer Casper Vopel (1511–1561) in 1536, but Antinous was later abandoned (ibid.). Fr. Kirwitzer uses the term 'Crines Berenices' several times in his treatise when describing the location of the second comet. Figure 21 depicts the constellation of Draco (numbered 3) as in the *Catalogus* …

On 26 November, Fr. Adam Schall joined Fr. Kirwitzer in observing the comet from Divar Island while Fr. Rho observed it on the 27th from Goa. The observing campaign continued until 30 November. From that day, "… the light of the moon obscured the comet and we could not observe it more." Fr. Antonius Rubinus' first measurement of this comet from Cochin was made on 28 November, when he noted a tail 40° long and a maximum width of ~3°. His last measurements were on 18 December when he noticed that the tail had increased in length from an initial 25° to 44°.

The word '*canicula'* mentioned in the observation of 14 November refers to the Dog-star (Sirius). On 14 November 1618 at Rachol (15º 18′ 29″ N, 74º 00′ 19″ E), this (precessed) star reached an altitude 44º at 00:20 UT (sunrise was at 01:08 UT). The Sun's altitude at this time was –11.38º, and the comet's apparent position, computed with the Horizons system, suggests that its altitude at that time was 4.3º. However, this does not agree with the observed value. In the Section 7.2, we shall discuss the convention of time-keeping in those days. For the moment, if we take 15 November as the first date of the measurements, then at 00:16 UT when Sirius reached an altitude of 44º, the comet was 7.7º high and the Sun was at an altitude of –12.4º. On both dates, the comet was found further away from the Sun than its orbital elements suggested. Similarly, the comet's elongation from Spica as measured by Fr. Rho with the cross-staff on 18 November, while at S. Rochi, was 15.30 *grad*, but with the Horizon's system we have the two separated by 11.6º that morning.

6.6 Observations of the Second Comet of 1618 (i.e. 1618 II)

In the second section of the treatise, Fr. Kirwitzer begins with:

> On 24 November this comet was visible from Divar Island in the dawn sky before sunrise. Its nucleus was obvious and comparable to Venus, and it had a short tail. Meanwhile, a straight line from Arcturus to Mars passed through the comet's nucleus, and the distance between Arcturus and Mars was three times that between the comet's nucleus and Mars.
>
> On the same day, Fr. Joannes Terrentius saw the comet from the fields of Rachol College. The next day before the sunrise, Fr. Kirwitzer and many other Jesuits saw it clearly, and it already had a longer tail. They also admired the sky, which was filled with many new stars Fr. Rho at S. Rochi, Goa, first noticed the comet on 25 November, and Fr. Antonius Rubinus in Co-

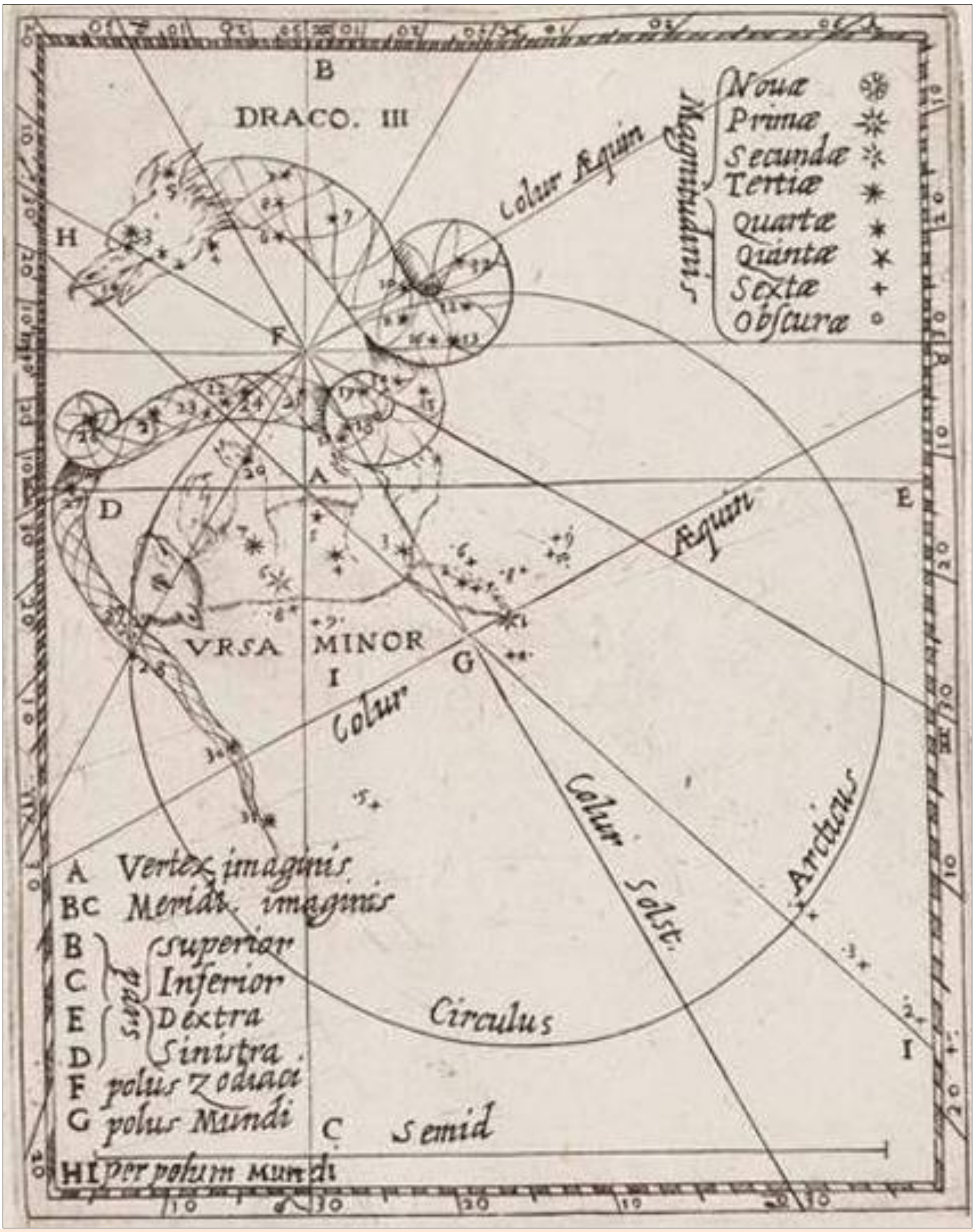


Figure 21: The constellation of Draco as depicted in Christopher Grienberger's *Catalogus … 1612* (after Stoppa, 2016).

chin saw it first on the 26th. Fr. Kirwitzer writes:

> While we watch the new comet, it appears to us in the East, another very bright star not much different from Venus, similar in color and magnitude, consider this not a little confusion many bore.

Venus was then the 'Evening Star' while Mercury was visbile in the morning sky, and confusion arose because it was close to the comet. Fr. Kirwitzer sought to explain this by quoting the *Prutenic Tables* (see below) wherein on that day Mercury was at 14° in Scorpio. The comet's magnitude was definitely much brighter than Mercury so there was no doubt about its identity.

On 26 November, Fr. Rho observed the comet from Goa as a bright object, with a tail ~2°

long and similar to a beard. Its right ascension was 225° and declination –11°, and it was "… in the sign of Sagittarius …" and nearly 29.12° from Spica. The phrase "… in the sign of Sagittarius …" (my English translation) does not quite fit as that constellation was not even up, unless it refers to the Sun that actually was in Sagittarius at that time. Just to illustrate this, on 26 November at 00 UT the Horizons system gives the comet's right ascension as very close to 225º but with the declination at –17.35º. As per the calculation, at that time the comet had just risen and Mercury was 2º above the horizon and about 3º from the comet. Meanwhile, Spica (precessed) was 27.9º from the comet, close to the value Fr. Rho noted down.

From 28 November 1618 two sets of observations for each comet were being taken from a given location, and the comets were observed together until 30 November. The Jesuits continued to make angular measurements of Comet 1618 II until 12 January 1619, but from the end of December they could not observe it because of the bright Moon and they only recommenced their observations on 7 January. Angular distances from the comet to Mercury, Mars, Spica, Arcturus and certain stars in Crux, Corona Borealis, Ursa Major and Minor, Draco, Coma Berenices also were measured. On 7 January 1619 while Fr. Kirwitzer was on Divar Island the light of the Moon somewhat diminished and he noticed that the comet was positioned between the penultimate and ante-penultimate stars in the tail of Draco, though it could not be easily observed because it was too faint.

On 8 January 1619 the comet seemed to be joined to the penultimate star of the tail of Draco. Upon viewing it through the telescope Fr. Kirwitzer found two new stars near the penultimate star of Draco directed towards Ursa Minor, and the comet appeared close to one of these, as depicted on page 23 in his treatise (see Figure 17, where the comet's tail extends to the right from a star-like nucleus). At this time the comet's tail was not visible in the telescope, but the 'star' in the nucleus seemed much brighter than the penultimate star in Draco's tail. The apparent position of the comet computed with the Horizons system suggests that it was only 0.5° away from the star κ Draconis (precessed), and, just as stated in the treatise, the two new stars are nearly on a line directed towards Ursa Minor. Further observations were made with the telescope on 10 January (Kirwitzer, 1620: 23).

The *Prutenic Tables* that Fr. Kirwitzer refers to are an ephemeris that was prepared by the astronomer Erasmus Reinhold (1511–1553) in 1551 to compute planetary positions, eclipses, phases of the Moon etc., based on Copernicus' Heliocentric Model of the Universe as portrayed in *De revolutionibus Orbium Coelestium*. The tables helped to substantiate the Copernican model but as circular orbits were used, accuracy was limited. Elliptical planetary orbits were introduced in Kepler's *Rudolphine Tables* in 1627, which enabled one to compute solar and planetary positions in the sky for any date. It was the *Rudolphine Tables* that led to the prediction and successful observations of the transits of Mercury and Venus in the years to come.

Inclined towards astronomy as the Jesuits were, one wonders if anyone noticed the Leonid meteor shower earlier in the month, which would have peaked on about 8 November (in 1618). Dick (1998: Table 1) has shown that the Leonids can be traced back to 902 CE, while Table 1 in Brown (1999: 289) provides details of Leonid showers between 1799 and 1999, where a shift by three days in the epoch of the peak every hundred years can be easily noticed.

6.7 Fr. Kirwitzer's Concluding Remarks

Althrough Fr. Kirwitzer's treatise contains observations and descriptions of the two comets, there is no theorizing about comets or where they belong in the Universe. While summing up, Fr. Kirwitzer (1620: 24) notes that

> For a fuller understanding of those observations, it remains to make known the true longitude and latitude of the places where the observations have been made. However, we have not seen yet any lunar eclipse and from others nothing we learned that we can accept with confidence, so we will work diligently in order that no latitude and longitude of this or other places of Asia remains unknown. In the meanwhile we will respond to this lack and any other: we will rely on Johannes de Barros, the prince of Portuguese Historians.

In fact, a lunar eclipse did take place on 31 December 1618. However, it was penumbral, but with the shadow over India. Whether the Jesuits were aware of this up-coming eclipse is not clear, although among them was Fr. Adam Schall who, years later in Macao, would determine the precise details of the lunar eclipses of 8 October 1623 and 9 September 1624 (Udias, 1994: 467). As we know, eclipse and certain other records were used by astronomers to refine eclipse computations and determine longitude differences between the places of observation of the predicted eclipses.

In the indented quotation presented above, Fr. Kirwitzer refers to 'Johannes de Barros'. João de Barros (1496–1570) was the Portuguese Royal Historian, and he is best known for his multi-volume classic *Décadas da Ásia*, which was published in 1552 and describes the early history of the Portuguese in India and in Asia. Fr. Kirwitzer quotes from his work a solar eclipse that was seen in Cochin

> … in the Year of Christ 1506, 13 January, series 4, the time prior to the second half and it was so clear that although it was daytime we saw the stars.

In fact, there *was* an eclipse on 13 January, but in 1507, and it was annular and not total. The path of annularity passed across Sri Lanka, not India, and from Cochin it was a partial eclipse with a magnitude of 0.83 (see eclipse predictions by Espenak, 2015), which was too bright to show stars in the daytime (except possibly for Venus at maximum eclipse, and only if one looked hard for it). However, Fr. Burke-Gaffney (1944: 127–128) adds an interesting dimension to this eclipse reference:

> In 1618 Remus wrote to Kepler that he had heard from Father Schreck that when Venus was observed in conjunction with the moon on June 6, 1617, it was further from the moon than Kepler predicted. "This observation," Father Schreck wrote from Lisbon, "was made by Father Lembo, who is now in Naples, and by Father Pantaleon, who is sailing with me to China." Father Pantaleon's full name was Wencelas Pantaleon Kirwitzer; in his signature, he omitted his surname. He, too, was a bit of a thorn in Kepler's side. He wrote to Father Ziegler (who was European Procurator for the Chinese Mission), from Goa, in February, 1619, saying that he had seen a comet in India, and, going back a hundred years, telling of an eclipse seen in Cochin on January 13, 1507. It was this eclipse which bothered Kepler. He was not sure of the facts. Father Kirwitzer's authority was Joao de Barros's *History of the Portuguese in India*. Kepler had not heard of de Barros or his history. In his *Rudolphine Tables*, he harped back on the possibility of the eclipse reported by Father Kirwitzer.

As for the Venus-Moon conjunction, it really was on 6 June 1617, when the two bodies came within 16′ of each other at around 19:30 UT. It would be interesting to find out what kind of difference was noted by Fr. Kirwitzer from the prediction in Kepler's *Ephemerides Joan. Kepleri annorum 1617, 1618, 1619 et 1620*. The ephemerides appeared in 1617, and were more accurate than any other astronomical tables available at that time.

7 FATHER CRISTOFORO BORRI'S WORK

7.1 Fr. Cristoforo Borri on the 1618 Comets

In the Indian part of the story of the comets of 1618 we also must refer to Father Cristoforo Borri S.J. (1583–1632). He was an Italian Jesuit missionary known for his magnetic observations in Asia (that came to provide an ingenious way of determining longitudes) and astronomy, as acknowledged by his peer Athanasius Kircher (1602–1680), himself an acclaimed mathematician and astronomer (Dror and Taylor, 2006: 40). Borri entered the Society of Jesus in 1601, and could speak Latin and Portuguese with ease. He left Lisbon in April 1615 for Macao, stopped over at Goa for six months, and arrived in Macao in 1617. The mission soon faced unfavourable circumstances, and he moved to Cochin-china (the southern region of Vietnam). It is from here that he observed the two bright comets of 1618. Unfortunately for him, Fr. Borri could not adapt to the local circumstances, so he decided to return to Europe. He went to Macao in 1622, and later that year left for Goa. He stayed in Goa until February 1624, when he eventually set sail for Lisbon, together with Garcia de Silva y Figueroa (Dror and Taylor, 2006: 42).

While he was in Goa in 1623, Fr. Borri befriended a well-to-do and knowledgeable Roman nobleman, Pietro della Valle (1586–1652), who had travelled far and wide and knew many languages. The celebrated traveller described Borri as a great mathematician who shared with him the Tychonic worldview and also his own perception on the three heavens. Fr. Borri had been developing his theory of tenuous heavens and recorded his views and observations in a book. An impressed Pietro translated this work into Persian in 1624, with the title *Risalah- i Padri Khristafarus Burris Isavi dar tufiq-i jadid dunya* (*Compendium of a Tractate of Father Christoforo Borri Giesuita on the New Model of the Universe according to Tycho Brahe and the Other Modern Astronomers*—see Figure 22). Later, in 1631, he was in Rome and he proceeded to translate Borri's work into Italian: *Compendio di un Trattato del Padre Christoforo Borro Giesuita della Nuova Costitution del Mondo secondo Tichone Brahe e gli Altri Astologi Modern*.

This book is preserved in the Vatican Apostolic Library (*Vat. pers. 10 fols. 7 recto - 6 verso orient18 IGH.06;* http://www.ibiblio.org/expo/vatican.exhibit/overview.html) and carries a depiction of Tycho's hybrid Universe with the planets revolving around the Sun and the Sun round the Earth. A few comets in orbits are depicted too, with tails pointing away from the Sun to demonstrate that comets could not be carried by the crystalline spheres. According to Fr. Borri, the book was well received by scholars in Persia, Armenia and Arabia. He also refers to his observations of the two comets of 1618 in a letter to Mutius Vitelleschi, General of the Society of Jesus, stressing that his precise observations substantiate

> … the tenuousness and corruptibility of the Heaven, which I already in Europe demonstrated for the sake of modern observations. This phenomenon was observed not only by myself but also by Father Giovani Vremano in China, and Father Manuel Dias in India …

and by mathematicians in Europe (Dror and Tay-

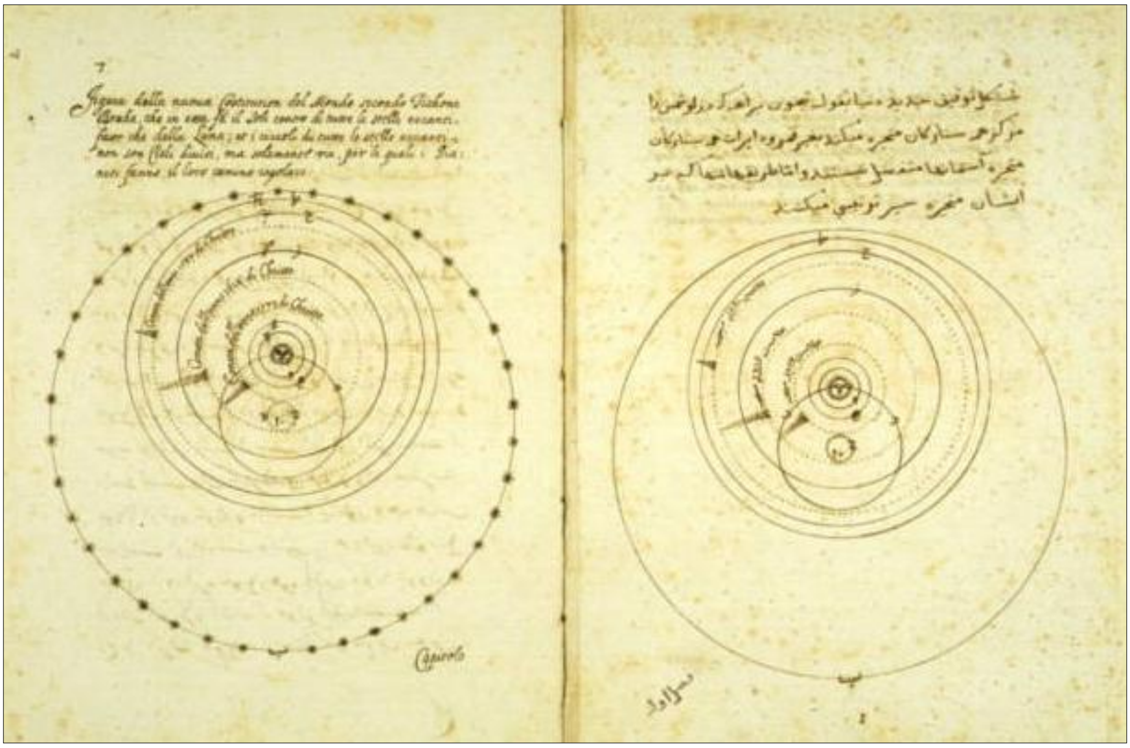


Figure 22: Two pages from the Italian version of Pietro della Valle's (1631) book (Adopted from the Library of Congress exhibition 'Rome Reborn: The Vatican Library & Renaissance Culture'; http://www.loc.gov/exhibits/vatican/images/orient18.jpg; accessed 30.11.2015).

lor, 2006: 40). Fr. Borri (op. cit.) was confident of his precision, which according to him provided "… the unique proof of truthfulness of observations, when it is found in different territories and countries, far from each other." Fr. Borri had received accounts of observations of the first comet made by the Jesuit astronomer Vremano (Jan Wremann; 1583–1621) from Macao, and by Fr. Emmanuel Diaz (Manuel Dias) of the Society of Jesus and a Portuguese philosophy professor who according to Borri had observed the first comet from the city of Cochin in India. In these accounts, the Jesuits concurred with Borri about the comet: that it was undoubtedly a celestial phenomenon (Borri, 1631: 116; Carolino, 2007: 190). Fr. Borri refers to this communication in his 1631 work *Collecta Astronomica ex Doctrina*, where he speaks of the first sighting of the comet on 9 November (Borri, 1631: 115; my English translation): it "… started to appear on 9 November and lasted up to 22 December …" This date for the first sighting account needs revision—see Section 7.2 below. Fr. Borri (ibid.) does not refer to an evening sighting, and he states that the comet was in Libra and Virgo, and with the Sun in Scorpio this would have to be a morning observation. There are no further details provided, and Fr. Borri quickly focuses his discussion on the comet's position in the sky with respect to the Moon.

From his parallax estimations derived from triangulation calculations of the observations of the comets of 1618, Fr. Borri argued that comets were located far beyond the Moon, which immediately cast doubt on the impervious nature of the celestial spheres. Borri thus tried to combine mathematical astronomy and canonical cosmology, fruitfully using it in carrying forward the Tychonic worldview that he later put forth in his work, written while in India, *De Nova Mundi Constitutione juxta Systema Tychonis Brahe aliorumque recentiorum mathematicorum* (Carolino, 2007: 190).

Here doubt arises because we come across references to Father Manuel Dias Sr. (1561–1639) and Father Manuel Dias Jr. (1574–1659). Father Dias Sr. was a Portuguese philosopher who was in Macao at the time we are discussing (see Pina, 2007: 90). Fr. Dias Jr., also a Portuguese philosopher and well known for his 1615 work *Tianwenlue* (*Epitome of Questions on the Heavens*), was in Goa during 1601–1604 and Macao in 1604–1610, before entering China in 1610. So, which Fr. Dias was Fr. Borri referring to? If Fr. Dias was also a Jesuit and was at Cochin, he and Fr. Antonius Rubinus would have known each other and about their respective cometary observations. But Fr. Kirwitzer only wrote to Fr. Rubinus, whom he knew was in Cochin and carrying out cometary observations. In the communications from Cochin, only observations by Fr. Rubinus feature in Fr. Kirwitzer's treatise.

Incidentally, in the extensive account of his travels, Pietro Della Valle too refers to sighting Comet 1618 III on 21 November, while he was journeying through Persia.

7.2 The Time Convention

The date of 9 November as given by Fr. Borri for the earliest sighting of the first comet does not align with the dates of first sighting the contemporary European astronomers came to accept. Therefore, the convention of the division of time that Fr. Borri used needs to be ascertained. In an early nineteenth century guide for navigators (Moore, 1807: 218), we do find reference to a particular convention where the civil day begins at midnight and the astronomical day begins at the noon of the civil day. Kronk (1999: 335) has used this convention when giving dates for the Great Comets of 1618. We also should apply this convention to the dates reported by Fr. Borri and Fr. Kirwitzer.

To recall: the Catholic countries of Europe were the first to adopt the Gregorian Calendar, which was introduced in 1582. As is clear from his description, Fr. Borri (1631: 115) used Gregorian dates. Any correction to the dates needs care and therefore we have cited the dates just as they are reported in the original treatises. There is no ambiguity when we convert the dates reported in Jahāngīr's *Tūzūk-i Jahāngīrī*.

8 CONCLUDING REMARKS

In this paper I have presented India-related accounts of two exquisite comets that were visible in November 1618. These observations, and those made elsewhere of the bright comet of August 1618, had an important impact on our thinking about the nature of comets. In the Indian context their significance relates to the first-ever use of an optical device, a *tubo optico* (telescope) for astronomical observations, within a decade of its invention in Europe. This was a time when the telescope was a fascinating gadget and a wonderful present—only later would it become an indispensible astronomical tool.

The Latin phrase (*tubo optico*) in Fr. Kirwitzer's (1620) treatise translates as telescope, but was it a Galilean telescope that the Jesuits had brought from Europe, like the one Fr. Adam Schall depicted in his 1626 book (see Figure 14)? In the 'Preface' to his treatise, Fr. Kirwitzer mentions that their baggage, with instruments and books, remained in the ship in unsafe condition, but they could use an astrolabe and a cross-staff from the local Jesuit establishments. That explains how the angles that they measured came to a fraction of a degree. Fr. Kirwitzer does not mention the instruments that Fr. Antonius Rubinus used in Cochin. Whether he also used a telescope to view the comets is not stated, but we do know that he was eager to obtain one. Fr. Kirwitzer also does not mention the bright comet of August 1618 (1618 I) that the missionaries would have noticed while still at sea. Once he was in Goa and armed with a telescope, Fr. Kirwitzer may have used it to demonstrate Galileo's observations to fellow-Jesuits and others.

Until now, the credit for the first use of a telescope in India for astronomical observations has rested with Jeremiah Shakerley (1626–1655) who specially came to Surat in Gujarat to observe the transit of Mercury of 3 November 1651. The following year he also observed a comet, most probably C/1652 Y1. However, we know nothing about his telescope, timing device or observing methods (Kochhar, 1989: 188). While these seventeenth-century examples did not prove to be trend-setters for modern astronomy in India, they were the first ones nevertheless.[4]

The orbits of the November 1618 Great Comets were determined on the basis of observations that were made elsewhere between 11 November and 9 December for Comet 1618 III and between 30 November 1618 and 22 January 1619 for Comet 1618 II (JPL, 2015). As we have seen, Jahāngīr's and Fr. Kirwitzer's observations were largely unknown at the time, and thus did not form part of the initial datasets assembled for these two comets. Whether their observations can be suitably used now needs to be evaluated, in order to see if they alter the orbital elements, even minutely. Equally desirable is a translation of Fr. Kirwitzer's treatise into English, supported by notes.

9 NOTES

1. Most dates listed in this paper are Gregorian and the years are CE or BCE. However, some dates, like 1027 A.H., are given using the *Hijri* or Islamic Calendar. This is a lunar calendar that consists of 12 months in a year of 354 days. The first year (1 A.H.) of the *Hijri* Calendar began in CE 622, when Muhammad moved from Mecca to Medina. For example, the Islamic year 1437 A.H. is from 14 October 2015 to 2 October 2016.
2. This study is part of the author's ongoing research since 2009 into the cometary sightings and observations from India from antiquity until 1960, where available data, however minimal, permit identification of a comet. Some of the Indian sources that are available have received little or no attention in the cometary literature.
3. To refresh, morning civil twilight commences when θ_s, the elevation of the centre of the Sun's disc, is 6° below the horizon, and lasts

until its top shows. During civil twilight the Sun is down but the sky is lit by the sunlight scattered from the upper layers of the Earth's atmosphere, and the brightest stars and planets can be seen. It is nautical twilight when θ_s lies between –6° and –12°. The sky is deep blue, the horizon is still visible and navigator's guide stars can be sighted. It is astronomical twilight when θ_s lies between –12° and –18°. When θ_s is <–18°, it is night and the sky is dark for regular astronomical observations to be made (U.S. Naval Observatory, 2012). These definitions are for a geometrical horizon that is 90° from the zenith. The length of the twilight depends on latitude and the time of the year.

4. An astronomically-significant incident in the history of Indian and international astronomy was the discovery that the brightest star in the constellation of Centaurus, α Centauri, was a double star. This discovery was made by a French Jesuit priest, Fr. Jean Richaud (1633–1693), on 19 December 1689 from Pondicherry, with a 12-ft long telescope. Although Shakerley's was an innovative use of the telescope whilst in India, Fr. Richaud made a systematic effort to introduce telescopic astronomy. He practiced and taught astronomy at the Jesuit school in São Tomé in Madras until his death (Kameswara Rao et al., 1984). Fr. Richaud also was one of the independent discoverers of the comet of 1689, a sungrazer now designated C/1689 X1. He made his discovery on 8 December1689 from Pondicherry (Vsekhsvyatskii, 1964: 121).

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12 APPENDIX: AN INTERESTING PAINTING

In 2009, while beginning a search for old records of comet observations from India, I came across an interesting painting on the website of the Amateur Astronomers Association, Delhi. This is shown in Figure 23, and it depicts the Emperor Jahāngīr observing a comet during October 1618. According to Dr C.B. Devgun (personal communication, March, 2010), the painting featured in a book by Dr Nirupama Raghavan that was published around the time when Comet Hale-Bopp made its appearance. However, as the research presented in this paper indicates, the depiction in Figure 23 does not agree with the observations mentioned in the *Tuzuk-i-Jahangiri*.

For a feel of the style of Jahāngīr's court artists, one may look at Bichitr's 'Jahangir Profferring a Sufi Shaikh to Kings' (Figure 5) or Abū'l Hasan's 'Jahangir Embraces Shāh Abbās While Standing on a Globe'. Abū'l Hasan painted some of the best-known illustrations of the Emperor in the year 1618, and several of these are reproduced and discussed in Bailey's (2001) paper.

Figure 23: "Jahangir observing a comet in the skies in October 1618. It sported a tail of 24 degrees and was observed for 16 days." (http://delhiamateur.tripod.com/anc_refs.htm)

Professor Ramesh Kapoor began his career in 1971 at the Uttar Pradesh State Observatory (now the Aryabhatta Research Institute of Observational Sciences, ARIES) at Naini Tal, India, in observational astronomy where his main interest was flare stars. From March 1974 until September 2010, he was with the Indian Institute of Astrophysics (IIA) in Bengaluru, where he worked on various topics in relativistic astrophysics centred round the observational aspects of black holes, white holes, quasars and pulsars, etc. He has participated as an observer and as an organizer in a few solar eclipse expeditions mounted by the IIA. Ramesh has published in international journals and presented papers at national and international conferences. His current research interest is history of astronomy, particularly comet sightings and observations from the Indian region. In addition, he has been active in popularizing astronomy, and he also has published on Indian systems of medicine. Ramesh is a member of the International Astronomical Union and a Life Member of the Astronomical Society of India.

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INTRODUCING ASTROGEN: THE ASTRONOMY GENEALOGY PROJECT

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Abstract: The Astronomy Genealogy Project ("AstroGen"), a project of the Historical Astronomy Division of the American Astronomical Society (AAS), will soon appear on the AAS website. Ultimately, it will list the world's astronomers with their highest degrees, theses for those who wrote them, academic advisors (supervisors), universities, and links to the astronomers or their obituaries, their theses when on-line, and more. At present the AstroGen team is working on those who earned doctorates with astronomy-related theses. We show what can be learned already, with just ten countries essentially completed.

Keywords: Academic genealogy, astronomers, Ph.D. theses, dissertations

1 INTRODUCTION

AstroGen is coming. The Astronomy Genealogy Project will soon appear on the website of the American Astronomical Society (AstroGen: https://astrogen.aas.org/). Under construction since early 2013, the project will list the world's doctoral theses (dissertations) on astronomy-related topics, along with information about the theses and their authors.

The original goal was to emulate, and possibly improve upon, the highly successful Mathematics Genealogy Project (MGP: http://www.genealogy.ams.org/), which has been underway since 1996 and currently holds information about more than 200,000 'mathematicians'. This number includes more than a thousand whose 'math subject area' is listed as 'astronomy and astrophysics' and several thousand classified in at least eight fields of physics.

Note that in academic genealogy one's parent is one's thesis advisor (also known as supervisor, *directeur, Doktorvater, promotor* …). Academic genealogy sites allow a scholar to trace his or her academic ancestors, and many find this enjoyable. I found my academic grandfather listed in the MGP, so I entered my academic father and myself, even though our degrees are in physics, and now a visitor to the MGP can trace my academic ancestry back 29 generations to the year 1360. Of course most of the early generations lacked doctorates, and the information about them is sketchy. Before the seventeenth century nearly all the degrees were in medicine, theology, or law, and many were not doctorates. Many scholars did not even take degrees.

The modern doctorate, usually called a Doctor of Philosophy, or Ph.D., began in Germany in the early nineteenth century. It gradually spread to most countries over the next century, although it did not become popular in some places, notably the United Kingdom, until after World War II. The first granted in the ten countries we have studied (listed in Section 3) went to Arthur Williams Wright (Figure 1), who became the first person outside Europe to earn a Ph.D. in science and one of the first three Ph.D.s in any subject in the United States. His thesis, *Having Given the Velocity and Direction of Motion of a Meteor on Entering the Atmosphere of the Earth, to Determine its Orbit about the Sun, Taking into Account the Attraction of Both these Bodies,* was submitted to Yale College in 1861. A man of many talents, Wright earned a law degree, tutored Latin, and ended up as a professor of physics at Yale, where he made some of the earliest experiments with X-rays.

Figure 1: Arthur Williams Wright (1836–1915). Photographer unknown (after Kingsley, 1879: 431).

2 WHAT ARE WE DOING?

We have been filling in a spreadsheet to be converted to a proper database by the IT experts who work for the American Astronomical Society. It has 30 columns for each dissertation, and almost every one of them causes questions and conflicts and forces us to make arbitrary decisions.

The biggest question is whom to include. For now we are including every astronomy-related thesis. We use this word because *thesis* is widely understood worldwide, although the proper term in our own country, the United States, is *dissertation* for the Doctorate, while *thesis* is used for the Master's degree. Some countries follow the reverse convention. We define 'astronomy-related' to include the scientific study of anything that is or comes from outside the Earth, and the development of tools to facilitate such study. We find that such theses are earned in a variety of academic departments—Astronomy and Physics of course, but also Aerospace Engineering, Chemistry, Computer Science, Earth Science, Electrical Engineering, Geology, Mathematics, Mechanical Engineering, Meteorology, Space Science, and others. In seeking such theses we often find it convenient to search for 'astronomy or astrophysics or cosmology or planetary science'. Note that we exclude theses on ethnoastronomy, archaeoastronomy, history of astronomy, and education in astronomy, even though degrees on such topics are occasionally awarded by Astronomy Departments.

There are grey areas. How much of cosmology should we include? Observational cosmology for sure, but what about theoretical theses? We have included most while trying to exclude those that are so purely theoretical that they show no connection with observations (e.g., brane theory, string theory), but it may be impossible to be completely consistent. We have included searches for dark matter in nature, but excluded attempts to make it in accelerators. Another big problem area is near-Earth geophysics. Sometimes we have to resort to the arbitrary definition that space begins 100 km above the ground. We have included the study of the ionosphere and beyond. We exclude studies of the interior of the Earth unless they compare it with some other planet or planets. The inclusion of the development of tools for astronomy is another complicated area. Design of a new optical telescope or spectrometer? Yes. Lightning protection and radio frequency interference mitigation for a new radio telescope? Yes, for now, but we are not sure. Design of a rover for planetary exploration? No, for now, but we are uncertain.

There are many other places where we have made somewhat arbitrary decisions. Some may yet be changed.

3 WHAT HAVE WE ACCOMPLISHED SO FAR?

As of November 2016 we have entered more than 20,000 theses, including nearly complete coverage of ten countries—Australia, Canada, Chile, Ireland, the Netherlands, New Zealand, South Africa, Sweden, the United Kingdom and the United States. We have started with theses in the language we know best. (The last Dutch thesis on an astronomy-related subject in a language other than English was submitted in 1962. Of the 37 Chilean theses, 31 are in English. All post-1800 theses from Sweden that we have found are in English.)

Here are the items we have attempted to record, with some of the questions that have arisen for each.

3.1 Name

People change their names for a variety of reasons. For example, women in the Western world have long changed their surnames on marriage, and sometimes again on divorce. While this is becoming less common, it still leads to difficulties in identifying some. Astronomers from east Asia, where the family name comes first, study in the West, where they reverse name order for the thesis and a few publications. Some then return to their home-lands and change the order of their names back. Scholars in Spanish-speaking countries use their full, formal names, consisting of given names followed by father's surname and then mother's surname, on their theses, but many then omit the mother's surname on their websites and publications (and just to make it more confusing, some combine father's and mother's names with hyphens). And not a few immigrants change their names to make them easier for residents of their adopted country to remember and pronounce. A few change their given names because of changing genders. Some have other personal reasons. We have tried to put the last-used name at the top of this category, but to include other names for those who wish to trace publications and careers. There is also the problem of two or more astronomers with identical names. This is especially common among those of Chinese or Korean origin. The practice of including only initials and surname on a thesis, while waning, is still a pernicious one from our perspective. 'Y. Wang' publishes more than ten scientific papers per day (Butler, 2012). Of course there are many Y. Wangs (does anyone know how many?), which is why it is important that scientists acquire and use identification numbers such as those of ORCID (2016).

3.2 Years of Birth and Death

We have recorded these when we have come across them, but we do not intend to make birth years public for living persons.

3.3 University Granting the Degree

Universities change their names; they merge; they split. Some use different names in different languages. This becomes complicated. On a person's page, we will have a link from the name of the university granting the degree (at the time, but in English) to a page for that university. There we will give the other names used by the university, including those in its own language(s). We will also give the current name, the country where the university is now located, and a link to the university's website if it exists. (A small number of universities have ceased to exist.)

3.4 Name of the Degree

How do we translate doctorates in other languages? At present we are using 'Ph.D.' for nearly all earned doctorates, even though they may be called 'Doctor of Physical Science', 'Doctor of Astronomy', or something else. This appears to be the custom for those who earn doctorates nowadays in countries where a different title is used. Then there is 'D.Sc.' At one time several American universities awarded it interchangeably with the Ph.D. This was done at the Massachusetts Institute of Technology as recently as 1992. Many universities, especially in Australia, award a D.Sc. as an honorary degree, but they request a 'thesis', which consists of a bundle of previously-published papers. This has served a valuable purpose in recognizing distinguished senior scientists, including several who were too busy founding radio astronomy after WWII to bother earning a doctorate. We are including those awarded this degree with submission of a 'thesis' if they did not have a previous doctorate. If a D.Sc. was awarded with no thesis, we exclude it, as it is usually the kind of honorary degree awarded to donors.

3.5 Year of the Degree

We have tried to use the year the degree was awarded, but that is not always available. We find theses in libraries, and librarians are more interested in copyright dates. The date on the thesis is often the date the thesis was submitted or defended. If this is late in the year, the degree may well have been awarded the following year. In a few cases we have found that the degree was awarded two or more years after the thesis was defended, presumably because some other degree requirement was not met. We expect it to be impossible to please everyone with the years we have listed.

3.6 Thesis Title

We intend to include the original title and an English translation for those in other languages. This assumes we can find volunteer translators.

3.7 Advisors and Mentors

Until recent decades, most thesis research was directed by a single advisor (supervisor). A few students had two. Now it is not uncommon for a student to have three or even four advisors, and it is quite common for a new Ph.D. to thank many, many scientists for being very helpful in the research that led to the thesis. We have been including mentors as a separate category, restricting the title of mentor to those who are called unofficial or *de facto* advisors in the acknowledgement pages of the thesis. Yes, we have read thousands of such pages. It is sometimes difficult to separate the official advisors from the mentors. We have obtained the names of the advisors of more than 82% of the Ph.D.s we have recorded in the ten countries mentioned above, in a few cases by examining the theses in libraries, but in the great majority from on-line sources.

3.8 A Link to the Thesis if it is On-line

Some readers may be surprised at how many theses are on-line. Of the 18,923 theses we have recorded for doctorates awarded in the ten countries from 1861 through November 2016, 37% are freely available to everyone on the world wide web, and another 28% are on ProQuest (2016), a database to which a great many academic libraries subscribe. ProQuest is the successor to University Microfilms, which microfilmed most American theses for many decades. It now includes other countries as well, and most theses have been digitized. Starting at various dates since the mid-1990s, most universities have required that all theses be submitted in electronic format. It is quite possible that many American theses never see paper, while in the Netherlands they are printed and bound with handsome covers despite the fact that they are submitted electronically. Some universities make all or nearly all their theses freely available on their websites, while others limit viewing to members of their own campus communities. Of course the author, as copyright holder, has to give permission, and some authors embargo their theses for a year or two or three.

Table 1: Progress through November 2016. The second column is the current population in millions. The third column is the number of institutions in a country that have awarded two or more doctorates with astronomy-related theses. (In this column we ignore institutions that have awarded just one, but their output is included in column 5.) The number of degrees is from 1861 through late 2016, but is more up-to-date for some universities and countries than others. The last two columns are the year of the first modern doctorate and the median year for production of doctorates. Populations are from Wikipedia (2016). Degrees awarded by two universities for one thesis are counted only once. Subtraction of duplicates is done within country totals where the two universities are in the same country, but one degree was awarded by universities in two different countries and the duplication was subtracted in the total, which is why the number of degrees for all countries is one less than the sum of the column above it.

Country	Population (million)	No. of Instns	Instns/ pop	Number of Doctorates	Degrees/ pop	Degrees/ Instn	First Year	Median Year
Australia	24.2	17	0.70	702	29	41	1953	2001
Canada	36.5	23	0.63	829	23	36	1926	2001
Chile	18.2	3	0.16	37	2	12	2004	2012
Ireland	4.8	6	1.25	103	21	17	1967	2010
Netherlands	17.0	8	0.47	939	55	117	1863	1999
New Zealand	4.7	4	0.85	84	18	21	1957	2004
South Africa	55.7	7	0.13	97	2	14	1972	2009
Sweden	9.9	8	0.81	363	37	45	1853	2005
United Kingdom	65.1	35	0.54	2890	44	83	1904	2002
United States	324.3	153	0.47	12880	40	84	1861	1997
All ten countries	**560.4**	**264**	**0.47**	**18923**	**34**	**72**	**1861**	**1999**
California	39.1	11	0.28	2442	62	222		

3.9 A Link to the Author's Web Page or Obituary

This may be foolish, as web pages change so frequently, especially in early careers. Yet we are trying it, and we hope that astronomy graduates will send us updates once we are on-line.

4 WHAT HAVE WE LEARNED?

As we look over the results we discover that AstroGen can be used for much more than tracing one's academic ancestry. It can be valuable to historians and sociologists of science who will be able to compare universities, countries, and eras. For examples of such research, see Gargiulo et al. (2016) and references cited therein. (There are other uses as well. A significant use of the MGP has been by editors wishing to avoid sending papers for review to the advisors or students of authors.)

I have compiled some information for the ten countries which are nearly complete. It is of interest to compare their astronomy-related degree production with their populations and the number of universities granting these degrees. Table 1 shows this for the ten countries, plus one subdivision, the U.S. state of California.

The number of universities that have granted two or more astronomy-related doctorates per million population is highest in the least populous countries—Ireland, New Zealand, and Sweden. South Africa and Chile have far fewer degrees per capita than the other countries. This is readily understood since (1) they are poorer countries, and (2) most of their universities did not start awarding doctorates until fairly recently—South Africa in 1972, Chile in 2004. Both have taken advantage of the fact that they provide sites for major optical and radio observatories that are funded and operated by institutions and governments in the rich world. Their astronomers are entitled to some of the observing time at these observatories, and the backers of the observatories have agreed to help them build communities of local astronomers to use this time. In both cases their degree production is increasing rapidly.

A more surprising outlier is California, which with a population just a little (9%) greater than that of Canada has fewer than half as many universities producing nearly three times as many doctorates. However, California is not extreme among the states in any category other than population and total number of degrees: Arizona has produced a whopping 298 doctorates per institution (of which there are only two), and Massachusetts has 171 per million residents.

In terms of doctorates per million population, the Netherlands is the highest among the ten nations, with the U.K. second and the U.S. third, which is not surprising as all three attract a lot of foreign students, while the Netherlands produces the most degrees per institution. The productivity of California institutions is far greater than that of any of the countries, with 222 doctorates per university. It will even be first among the states soon, as Arizona is starting a third doctoral program in astronomy, at Northern Arizona University, and will drop below it. Will China dwarf these numbers? What about universities in other countries? We know that the Department of Physics and Astronomy at the University of Heidelberg currently produces about 100 doctorates per year (Heidelberg, 2016), but we don't yet know how many of these are astronomy-related. It will be better to make such comparisons when we have more countries in our database.

Another interesting fact is how greatly the production of astronomy-related doctorates has increased over time (Figure 2). Although the first

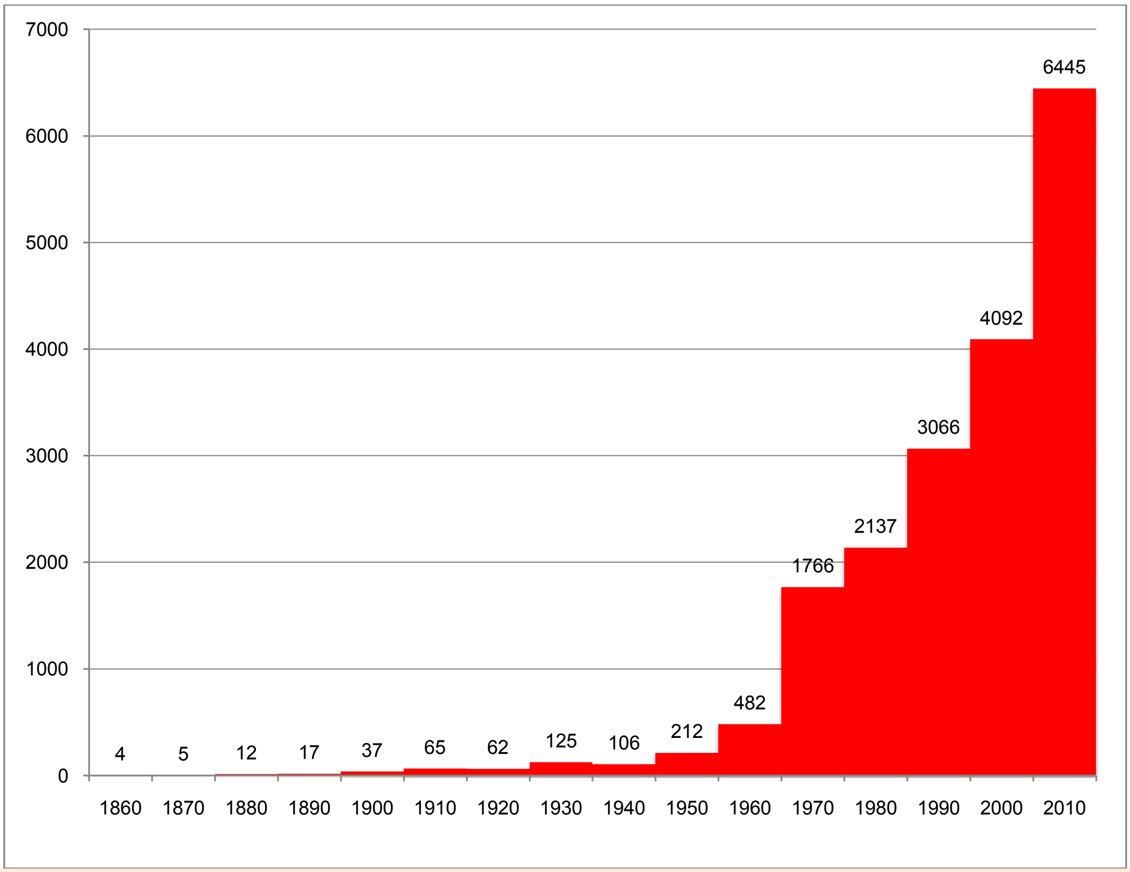

Figure 2: Earned doctorates with astronomy-related theses by decade. The label '1860' means 1856 through 1865, etc. Degrees awarded in 2016 are excluded here (and only here). Data are from the ten countries listed in Table 1. The only decreases were caused by the two World Wars.

U.S. doctorate in astronomy was in 1861, one half of the American degrees have been awarded since 1997. For the other countries listed above, the median year ranges from 1999 (Netherlands) to 2012 (Chile). For the ten countries combined, it is 1999. Of course the Netherlands and the U.K. have been educating astronomers for centuries, but they did not award Ph.D.s in the field until 1863 and 1929 respectively. At least that is the earliest we have found. We would be delighted to learn of earlier such degrees. We are aware of one earlier doctorate: J. Norman Lockyer was awarded a D.Sc. by the University of Cambridge in 1904 for previously-published work. The data for the U.K. are less complete than for the other countries. Some British universities have not yet put their complete catalogues on-line. On the other hand, the University of Manchester's on-line catalogue does not distinguish between Doctoral and Master's degree theses, so we have probably included some of the latter and therefore overcounted

British academics long resisted the Ph.D., considering it an unnecessary foreign invention. Many of the great British astronomers of the twentieth century, including Ralph Howard Fowler (1889–1944), Arthur Stanley Eddington (1882–1944), Fred Hoyle (1915–2001; Figure 3), Hermann Bondi (1919–2005), Martin Ryle (1918–1984), Freeman John Dyson (b. 1923) and Edward Robert Harrison (1919–2007), never earned Ph.D.'s, although some received honorary doctorates late in life.

An excellent example of this attitude is given by Hoyle (1994: 127) in elaborating on his decision to become a student of Rudolph Peierls at Cambridge:

> The situation proved ironic, for, if it had ever been my intention to seek the Ph.D., it was [Maurice] Pryce who persuaded me out of it. He had a dislike for the degree, which he regarded as a debasement of the academic currency. He showed his opinion by fulfilling all the technical requirements but then omitting ever to go to the Senate House to formalize the situation in an official ceremony. As it turned out, I did the same, but only partly for doctrinaire reasons. I discovered the Inland Revenue distinguished between students and nonstudents by whether or not you had acquired the Ph.D., and, since the distinction affected my tax quite substantially in the period 1939–1941, I had a more earthy motive for avoiding an official ceremony in the Senate House.

Hoyle continues with a denunciation of the Ph.D. that includes: "The mere fact that government bureaucracy demands the Ph.D., and has demanded it pretty well from the first moment it was was introduced from America, is sufficient to condemn it." (ibid.)

This illustrates a reason not to keep track of doctoral work only. In fact, AstroGen will eventually include many without doctorates, especially those who were academic ancestors of those who did earn the Ph.D. or equivalent. We already have some. Otherwise most family trees would be short, and none would go back beyond the nineteenth century.

The above information was easily obtained from the spreadsheets. Those historians willing to spend more time with the database will be able to learn how subjects, such as X-ray astronomy, planetary exploration, exoplanets, or gravitational wave astronomy, grew in popularity over time while celestial mechanics and astrometry declined. (The latter has enjoyed a resurgence in recent years with the European Space Agency's *Hipparcos* and *Gaia* missions.) They will also be able to compile information as to the careers of Ph.D. astronomers. For example, in the twenty-first century the number of astronomers using their expertise with 'big data' in such fields as internet companies, financial institutions and retailers may exceed the number who have obtained research positions in physical science. This is certainly true for the graduates of some universities.

It is also possible to compare universities. While 264 universities in the ten countries have awarded a total of 18,923 doctorates with astronomy-related theses, more than three-eighths of these have come from the seventeen largest producers, listed in Table 2. These are the universities that have produced more than 300 doctorates each.

We have not compiled any quantitative information about the careers of those who have earned doctorates with astronomy-related dissertations, but I can make a few comments from reading thousands of acknowledgements in theses and finding and reading current web pages.

In the 1970s and 1980s it was almost unthinkable for a graduate student to express religiosity in a thesis. It has become increasingly common in recent years, both in the United States and in some parts of Europe. Although by no means a large percentage of theses, there are now many in which the author expresses his or her religious views, sometimes at considerable length. This is always done in the acknowledgements section.

Figure 3: Fred Hoyle at Caltech in 1967 (Courtesy: Clemson University and Donald D. Clayton).

Individuals who survive graduate school in the physical sciences are an enterprising lot. As the fraction who obtain research positions in the field has decreased, graduates have made careers in many fields that one might not expect, as doctors, lawyers, entertainers, fiction and non-fiction writers, clergy of all faiths, public speakers, photographers, entrepreneurs, and in many other areas. Of course most have found ways to use their educations more directly. Those whose degrees are in electrical engineering, computer science or the earth sciences usually work in those areas. Many astronomy graduates go into defense industries and government laboratories. Some teach in secondary school or colleges. Some make their livings as communicators of science to the public. And, as mentioned above, many use their skills at manip-

Table 2: The seventeen universities in our ten countries that have produced 300 or more Ph.D.'s with astronomy-related theses as of November 2016. This is slightly more up-to-date for some universities than for others.

University	Doctorates
University of California, Berkeley	652
California Institute of Technology	565
University of Cambridge	536
University of Arizona	512
Harvard University	496
University of Chicago	458
University of Texas at Austin	412
University of Maryland, College Park	399
Princeton University	389
University of Colorado Boulder	379
Massachusetts Institute of Technology	366
Cornell University	342
University of Leiden	333
University of Wisconsin-Madison	321
University of Michigan	320
University of Manchester	318
University of California, Los Angeles	316

ulating 'big data' in fields such as finance.

Another qualitative observation is that ethnicity and gender matter. A graduate student with an Asian, Hispanic, Middle Eastern or Slavic name is more likely to choose a thesis advisor with the same background than would be expected by chance, and a female student is much more likely to choose a female professor. This observation is difficult to quantify, as we would need to know the ethnic and gender distributions of the department at the time of the thesis.

5 WHAT NEXT?

It may take a while before the programmers have completed the necessary work to convert our spreadsheets to a polished website. In the meantime we are anxious to correct errors (there are certain to be some in what we have gathered from the web), add more information, such as the names of advisors of those whose theses are not on-line, and, especially, expand from ten countries to the world. (Since submitting the first version of this paper we have completed Norway and a good portion of Spain.) We are seeking volunteers. If you know the language and something of the academic culture of another country, we would very much like to have you join us and gather information on some of the theses from that country. If you would like to work on our list of universities, that would also be helpful. If you can go into a university library, get old theses out of storage, and photograph the page listing the advisor and the acknowledgements section or copy the necessary information, then you could make a major contribution to the Project. We also welcome comments and suggestions. Please contact me at astrogendirector@aas.org.

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POSTSCRIPT

The author has very recently discovered several hundred more doctorates, mostly in the UK, which he is currently adding to the database. While it is too late to update this paper, note that University College London will join the list of universities that have awarded more than 300 astronomy-related doctorates.

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WILLIAM HERSCHEL'S 'HOLE IN THE SKY' AND THE DISCOVERY OF DARK NEBULAE

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Abstract: In 1785 William Herschel published a paper in the *Philosophical Transactions* containing the remarkable section "An opening or hole". It describes an unusual vacant place in Scorpius. This matter falls into oblivion until Caroline Herschel initiated a correspondence with her nephew John in 1833. It contains Herschel's spectacular words "Hier ist wahrhaftig ein Loch im Himmel" ("Here truly is a hole in the sky"). About a hundred years later, Johann Georg Hagen, Director of the Vatican Observatory, presented a spectacular candidate for the 'hole', discovered in 1857 by Angelo Secchi in Sagittarius and later catalogued by Edward E. Barnard as the dark nebula B 86. Hagen's claim initiated a debate, mainly in the *Journal of the British Astronomical Association*, about the identity of Herschel's 'object'.

Though things could be partly cleared up, unjustified claims still remain. This is mainly due to the fact that original sources were not consulted. A comprehensive study of the curious 'hole' is presented here. It covers major parts of the epochal astronomical work of William, Caroline and John Herschel. This includes a general study of 'vacant places', found by William Herschel and others, and the speculations about their nature, eventually leading to the finding that dark nebulae are due to absorbing interstellar matter. Some of the 'vacant places' could be identified in catalogues of dark nebulae and this leads to a 'Herschel Catalogue of Dark Nebulae'—the first historic catalogue of its kind.

Keywords: William Herschel, Caroline Herschel, John Herschel, Johann Georg Hagen, Angelo Secchi, Edward E. Barnard, Herschel's 'hole in the sky', sweeps, star gages, dark nebulae

"Of the great modern philosophers, that one of whom least is known, is William Herschel. We may appropriate the words which escaped him when the barren region of the sky near the body of Scorpio was passing slowly through the field of his great reflector, during one of his sweeps, to express our own sense of absence of light and knowledge: *Hier ist wahrhaftig ein Loch im Himmel*." (Holden, 1881: 1).

1 THE CORRESPONDENCE BETWEEN CAROLINE AND JOHN HERSCHEL

The achievements of William Herschel (1738–1822; Figure 1) in observational astronomy are unrivalled. He discovered numerous double stars, nebulae and star clusters during his epochal survey of the northern sky (Steinicke, 2010). Occasionally peculiar objects came into view, firing his imagination, like 'garnet stars' (Steinicke, 2014) or even 'non-objects', i.e. fields in the sky which appeared absolutely devoid of stars. The latter are subject of this paper.

The starting point is a correspondence between Caroline Herschel (1750–1848; Figure 2), when living at Hanover, and her nephew John. There are several sources. The first is *Memoir and Correspondence of Caroline Herschel* (Herschel, Mrs J., 1876), published by John Herschel's wife Lady Herschel, née Margaret Brodie Stewart (1810–1884). A German translation appeared just a year later (Scheibe, 1877). The second is *The Herschel Chronicle* (Lubbock, 1933), published by John Herschel's daughter, Constance Anne Lubbock (1855–1939). A third source, from John's perspective, is *Herschel at the Cape: Diaries and Correspondence of Sir John Herschel, 1834–1838* (Evans, 1969). The author is the British astronomer David Stanley Evans (1916–2004).


Figure 1: William Herschel (Steinicke Collection).

On 1 August 1833 Caroline Herschel sent a letter to Lady Herschel at Slough. At that time 41 year old John Herschel (1792–1871; Figure 3) was preparing his South Africa expedition to survey the southern sky; it started in November.

Figure 2: Caroline Herschel (www.spacerip.com/women-astronomy-caroline-herschel/).

In a P.S.S. addressed to him, Caroline wrote (Herschel, Mrs J. 1876: 258; her italics; Lubbock, 1933: 372):

> Dear Nephew, as soon as your instrument is erected I wish you would see if there is not something remarkable in the lower part of the Scorpion to be found, for I remember your father returned several nights and years to the same spot, but could not satisfy himself about the uncommon appearance of that part of the heavens. It was something more than a total absence of stars (I believe). But you will have seen by the register, that those parts could only be marked *half swept*. I wish you health and good success to all you undertake and a happy return to a peaceful home in old England. God bless you all!

Figure 3: John Herschel (Steinicke Collection).

The meaning of the terms 'register' and 'half swept' will be explained in Section 4. Beside his sweeps, made at Feldhausen near Cape Town, John Herschel roughly checked the region and replied on 6 June 1834 (Herschel, Mrs J. 1876: 266; his italics; Lubbock, 1933: 373; Evans, 1969: 72): "I have not been unmindful of your hint about Scorpio. I am now *rummaging* the recesses of that constellation and find it full of beautiful globular clusters." Caroline, not happy with John's answer, wrote on 11 September 1834 (Herschel, Mrs J. 1876: 269; Lubbock, 1933: 373):

> I thank you for the promise of future accounts of uncommon objects. It is not *Clusters of Stars* I want you to discover in the Scorpion (or thereabout), for that does not answer my expectation, remembering having once heard your father, after a long, awful silence, exclaim: 'Hier ist wahrhaftig ein Loch im Himmel!', and, as I said before, stopping afterwards at the same spot but leaving it unsatisfied, &c.

It is remarkable that Caroline, at the age of 84, remembers this case so well after about 50 years. Forced by his insistent aunt, John checked his records, and found that observations made on 29 July 1834 in sweep 474 match the query. On 22 February 1835 he wrote another letter. It lists "blank spaces" with positions for 1830 (right ascension RA; north pole distance NPD = 90° – declination). John wrote (Evans, 1969: 143–144; his italics):

> I have swept well over Scorpio and have entries in my sweeping books of the kind you describe – viz: blank spaces in the heavens *without the smallest star*. For example
>
> RA 16^h 15^m NPD 113° 56′ – a field without the smallest star
>
> RA 16^h 19^m NPD 116° 3′ – *Antares* (α Scorpii)
>
> RA 16^h 23^m NPD 114° 25′ to 114° 5′ – field entirely void of stars
>
> RA 16^h 26^m NPD 114° 15′ – not a star 16 m. – Nothing!
>
> RA 16^h 27^m NPD 114° 0′ – not a star as far as 114° 10′
>
> and so on – then come on the Globular Clusters – then more blank fields – then suddenly the Milky Way comes on as there described (from my Sweep 474. July 29. 1834).

We will see later that this matches the region of Herschel's 'hole'. Obviously, Caroline was satisfied with this information, and the correspondence about the issue terminated here.

2 HAGEN'S CANDIDATE: BARNARD 86

What is this obscure 'hole in the sky'? In the literature we encounter the claim that Herschel saw the striking dark nebula Barnard 86 in Sagittarius, and it was located about 6′ west of the small open cluster NGC 6520. This cluster was discovered by William Herschel on 24 May 1784 and later catalogued as VII 7 (Herschel, W., 1784d: 496). John Herschel observed the same object from Feldhausen on 15 July 1836 and catalogued it as h 3721 (Herschel, J., 1847: 116). Father and son do not mention the dark nebula 6′ to the west, and later neither would return to this region of the sky.

The identification of Herschel's 'hole' with Barnard 86 is due to the Jesuit astronomer Johann Georg Hagen (1847–1930; Figure 4), Director of the Vatican Observatory. In 1928 he published a paper "Die Geschichte des Nebels 'Barnard 86'" ("The History of the nebula 'Barnard 86'") in *Sitzungsberichte der Preussischen Akademie der Wissenschaften* (Hagen, 1928); of course, not one of the common astronomical publications. Hagen was directed to this case by the science journalist Agnes Mary Clerke (1842–1907; Figure 5) who made a notable remark in her book about the Herschels. She wrote that William

> … adverted to a black opening, four degrees wide, in the Zodiacal Scorpion, bordered on the west by an exceedingly compact cluster (Messier's No. 80), possibly formed, he thought, of stars drawn from the adjacent vacancy. The chasm was to him one of the most impressive celestial phenomena. His sister preserved an indelible recollection of hearing him, in the course of his observations, after a long awful silence, exclaim, "Hier ist wahrhaftig ein Loch im Himmel!" (Here truly is a hole in the sky); and he recurred to its examination night after night, and year after year, without ever clearing up, to his complete satisfaction, the mystery of its origin. (Clerke, 1895: 67–68).

Triggered by these words, the Vatican astronomer searched for the source, which, unfortunately, was not given. But with the aid of William Alfred Parr (1834–1936), a friend of the Herschel family at Slough, he received a copy of Caroline's letter dated 11 September 1834. In his paper Hagen quotes the relevant part (he was not aware of the earlier correspondence). Concerning size and position of the object, as given by Clerke (4° wide, east of M 80), he wrote: "In saying this, however, she appears to be merely stating her own conviction, as no source is quoted."

To get an impression of the region, Hagen could use an imposing work, published a year before by the American astronomer Edward Emerson Barnard (1857–1923; Figure 6): *A Photographic Atlas of Selected Regions of the Milky Way* (Barnard, 1927). It particularly features 370 'dark nebulae', designated as B 1 to B 370. The globular cluster M 80 is seen on Plate 13 "Region of the Great Nebula ρ Ophiuchi" (Figure 7).

Hagen finds that

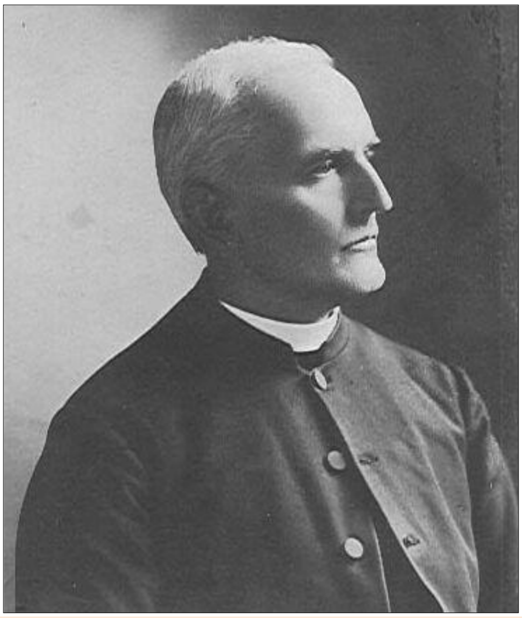


Figure 4: Johann Georg Hagen, Director of the Vatican Observatory (Steinicke Collection).


Figure 5: Science journalist Agnes Mary Clerke (wikimedia. commons).

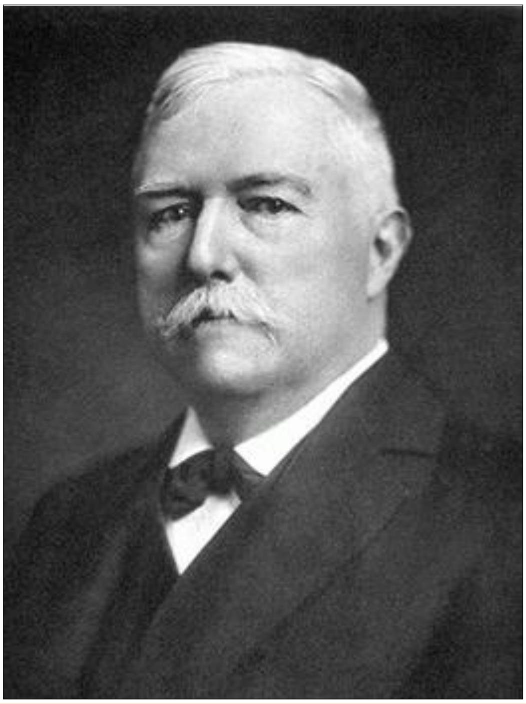


Figure 6: American astronomer Edward Emerson Barnard (en.wikipedia.org).

> … the opening mentioned [B 42] is not 'black' but filled up by the bright nebula ρ Ophiuchi ... [and] For this reason, another astronomer has placed the 'opening' further towards the East [B 44], where three starless tracts extend for more than four degrees beyond the nebula.

Alas, Hagen does not tell which astronomer is meant. He concludes that

> Neither explanation fits Caroline's account. Messier 80 lies in Scorpion, it is true, and the nebula in Ophiuchus adjoining, but Herschel could not see both at the same time, for they lie half a degree apart. Herschel calls this starless region 'an opening or hole' (Scientific Papers I, p. 253), but we might have found more than a hundred openings of equal extent, and it is not easy to see why he should have repeatedly come back to this particular spot, as Caroline suggests, and why this starless region rather than any other should have evoked his exclamation of wonder.

Hagen's statement that M 80 and ρ Ophiuchi "… lie half a degree apart …" is incorrect; the true distance is ~2°. Anyway, he presents an unexpected candidate for Herschel's hole: a "… perfectly dark spot …" found in the summer 1857 by the former Director of the Vatican Observatory, Angelo Secchi (1818–1878; Figure 8). It is located about 2° north of γ Sagittarii. The Jesuit astronomer discovered the object when observing John Herschel's cluster h 3721 (NGC 6250) with the fine 10-in Merz refractor at Collegio Ro-

Figure 7: Part of Plate 13 "Region of the Great Nebula ρ Ophiuchi" from Barnard's *Photographic Atlas of Selected Regions of the Milky Way*. It shows the striking region around ρ Ophiuchi (267). Note the dark nebulae B 42 and B 44 south and southeast of the star. M 80 (248) is west of the star; also seen at the bottom are M 4 (261) and NGC 6144 (268).

mano. Secchi wrote (1857: 10): "… a perfectly dark spot of the shape of a pear, about 4^m large. This spot, by its contrast, shows that the galaxy in that region is quite strewed with stars, which give a white aspect to the firmament." However, the reported size of 4^m in RA (i.e. 53′ at that declination) is rather exaggerated; visually the spot is not larger than 5′. Perhaps Secchi meant 4′. Hagen also celebrates his predecessor as initiator of the idea that 'dark masses' exist in space. He writes: "Secchi was the first astronomer to recognise the dark spots in the Milky Way as nebulous masses, rather than merely as starless regions, or holes." This will be discussed in Section 7. About two decades later, Secchi's pear-shaped object in Sagittarius was independently discovered by two other visual observers.

On 12 August 1876 the French astronomer Étienne Trouvelot (1827–1895; Figure 9) noticed the 'dark spot' with the 26-in Clark refractor of the U.S. Naval Observatory, Washington, and made a drawing. However, the observation is not recorded in the annual report of the Observatory, but it was published 1882 in his book *Astronomical Drawings*. He wrote (Trouvelot, 1882: 133):

> I have myself detected such a dark space devoid of stars and nebulosity in one of the brightest parts of the Milky-way, in the constellation Sagittarius, in about 17h. 45m. right ascension, and 27° 35′ south declination. It is a small miniature coal-sack or opening in the Galaxy, through which the sight penetrates beyond this great assemblage of stars. Close to this, is another narrow opening near a small, loose cluster.

Trouvelot does not present the drawing in his book. It eventually appeared 1884 in a French magazine (see Section 4).

The French astronomer was followed by Barnard in Nashville. He found the object in July 1883 with his 5-in Byrne refractor. The observation is described in a short note, written for the new magazine *Sidereal Messenger* (Barnard, 1883–84):

> It is a small triangular hole in the Milky Way, as black as midnight. It is some 2′ diameter, and resembles a jet black nebula. There are one or two faint stars in the following part of it with a small cluster following [NGC 6520]. A small bright orange star is close north preceding [HD 164562], on the border of the opening. Numerous larger dark openings are in its neighbourhood but none is as small and decided as this.

A paper in the common *Astronomische Nachrichten*, titled "Small black hole in the Milky Way", soon followed (Barnard, 1884). He coined the popular name 'Ink Spot' (Barnard, 1913: 500): "It is a very striking object in a 5-inch telescope, where it looks like a drop of ink on a luminous sky." Barnard photographed the region on 1 August 1889 with the 6-in Willard lens


Figure 8: Angelo Secchi, the former Director of the Vatican Observatory (en.wikipedia.org).


Figure 9: French astronomer Étienne Trouvelot (www.fs.ed.us/ne/morgantown/4557/gmoth/trouvelot/).

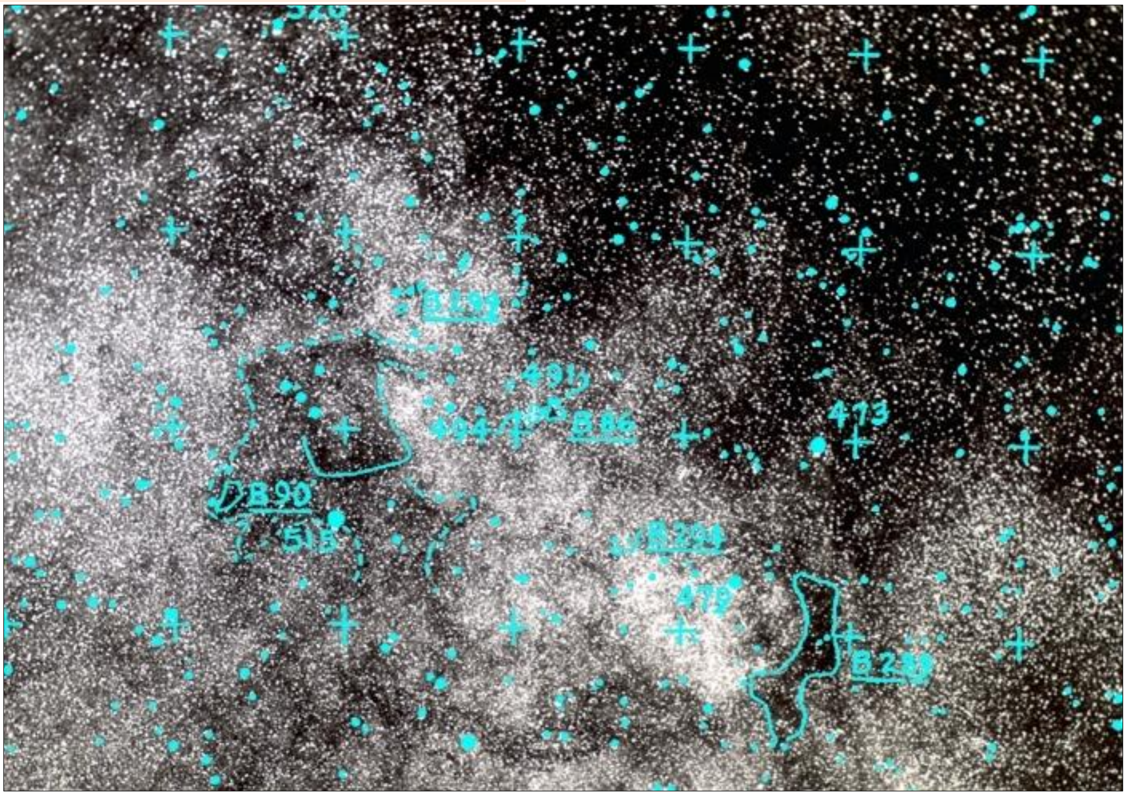


Figure 10: Part of Plate 26 "Great Star Clouds in Sagittarius" of Barnard's *Photographic Atlas of Selected Regions of the Milky Way*. It shows the region and the tiny dark nebula B 86 in Sagittarius (centre of the photograph).

at Lick Observatory (Barnard, 1890). Later he entered the object as no. 86 in his first catalogue of 182 dark nebulae (Barnard, 1919); there a diameter of 5′ is given. B 86 is shown as a small spot on Plate 26 "Great Star Clouds in Sagittarius" (see Figure 10) of his *Atlas of Selected Regions of the Milky Way* (Barnard, 1927).

Hagen's citation "Scientific Papers I, p. 253" points to a paper, published in 1785 by Herschel in the *Philosophical Transactions* and reproduced in John Louis Emil Dreyer's (1852–1926) monumental 2-volume work *The Scientific Papers of Sir William Herschel* (1912: 253). It is titled "Construction of the Heavens" and contains the remarkable section "An opening or hole". Here Herschel gives all relevant facts about the case:

> … in the body of the Scorpion is an opening, or hole … [It is] at least 4 degrees broad … the 80th *Nebuleuse sans étoiles* of the *Connoissance des Temps*, which is one of the richest and most compressed clusters of small stars I remember to have seen, is situated just on the western border of it.

Obviously, this is the source of Clerke's short review (together with the Herschel correspondence). However, Hagen's treatment of this paper is telling.

The essential evidence for his claim is due to the open cluster NGC 6520, about 6′ southeast of B 86. Hagen (1928: 484) has observed the pair with the 16-in Zeiss refractor at the Vatican Observatory, reporting a diameter of 15′ for the dark object. He doubts that the globular cluster M 80 was meant because Herschel "… could not see both [hole and cluster] at the same time, for they lie half a degree apart." He also stresses that Herschel is the discoverer of the open cluster, catalogued as VII 7, and quotes his description: "Considerably rich but pretty coarsely scattered, little more compressed in the middle (*Scientific Papers* I: 291)." Hagen adds:

> Herschel's attention was thus concentrated on this spot [cluster] for some time, and would naturally extend to the neighbouring vacuity, by reason of its small size and the chain of stars encircling it—but chiefly on account of the contiguous star cluster, favoured his theory in a way scarcely to be found elsewhere. An exclamation of wonder in such circumstances is thus comprehensibly enough.

Here Hagen refers to Herschel's theory of the formation of clusters by gravity, leaving places of less matter (holes). This idea will be discussed later. Based on the presented 'facts', the Vatican astronomer comes to the conclusion that Herschel's 'hole in the sky' is identical with Secchi's 'dark spot':

> This star cluster [NGC 6520] lies on the confines of the three constellations Sagittarius, Ophiuchus and Scorpio, i.e. within the region which Herschel's sister indicated from mem-

> ory. If, now, we consider that Barnard described the dark nebula connected with this star cluster as 'one of the most impressive objects in the Milky Way', and if we compare the two impressions received by Herschel and Barnard respectively—of a 'hole in the sky' in the one case and of a 'black hole' in the other—there can scarcely be any doubt whatever that the nebula now known as B 86 was the one which evoked the famous exclamation from Herschel. This remarkable object was thus discovered three times within a century, viz., by Herschel, by Secchi, and by Barnard.

Of course, critical remarks about this claim are necessary. To distinguish the arguments, Table 1 might be useful. It compares the facts as presented by

(1) the Herschel Family, supported by Flammarion, Chambers, Clerke and Gore; and
(2) Hagen, based on the observations of Secchi, Trouvelot and Barnard.

Hagen does not explain why Herschel has not mentioned the dark object in the description of the cluster VI 7, worth for an exclamation. Also there are problems concerning the distance to the cluster and the size of the hole. Herschel never has claimed to have seen "… both at the same time". Moreover, the true distance is not "… half a degree …" but about 2°. Hagen's conclusion of a small distance, favouring the close pair B 86/NGC 6520, is not justified. He also did not recognise Secchi's wrong size of 4^{m} in RA, which is nearly 1°. This would imply that NGC 6520 lies inside the 'black hole', for the separation is only 6′. Herschel even speaks of a size of 4° for his hole.

The identification of Herschel's hole with B 86, located nearly 25° east of M 80, is essentially Hagen's claim. Secchi, Trouvelot and Barnard never mentioned a connection with it, although they might have known Herschel's paper in the *Philosophical Transactions* of 1785, a standard publication in every observatory library. Hagen surely knew all the facts, but he ignored that they were incompatible—except the description: 'hole' vs. 'black hole'. Was Hagen's argument only based on this literary match?

It seems likely that he wanted to feature the Jesuit, Father Secchi. To achieve this it was helpful, to establish a significant relation between Secchi and Herschel, the distinguished master of visual astronomy. This was done by the claim that Secchi was the second discoverer of Herschel's hole and, moreover, the first person presenting a plausible explanation about its nature: 'dark matter'. This was Hagen's favourite subject. He was the initiator and strongest advocate of the theory claiming the existence of extensive 'obscure nebulae' in space (Hagen, 1921). However, such 'Hagen clouds' were never detected. Facing this, it was natural for him to leave aside Herschel's paper—it could weaken his arguments.

In 1929 Hagen published a second paper on the issue (Hagen, 1929). He first summarised his earlier result:

> It was ascertained with great probability that Herschel's well-known exclamation about a 'hole in the sky' relates to a dark spot, which was entered as No. 86 in the 'Catalogue of Dark Markings in the Sky' by its third discoverer Barnard.

He again criticises Clerke for not giving the source of Caroline's report. But now Hagen has found it in "… the very rare book …" *Memoir and Correspondence of Caroline Herschel* (Herschel, Mrs J., 1876). To leave no doubt, the Vatican astronomer consulted John's daughter Francisca Herschel (1846–1932) at Slough and got a copy of the relevant letter to Lady Herschel, sent on 1 August 1833, including the "P.S.S.".

Table 1: Comparison of the facts concerning the two candidates for Herschel's 'hole in the sky'.

Parameter	Herschel	Hagen
Description	hole	black hole
Constellation	Scorpius	Sagittarius
Size	4°	2′–16′
Cluster	M 80	h 3721 (NGC 6520)
Cluster appearance	very rich and compressed	small, loose
Distance to cluster	2°	6′
Direction to cluster	west	east

3 THE DEBATE IN THE *JOURNAL OF THE BRITISH ASTRONOMICAL ASSOCIATION*

Hagen's paper of 1928 initiated a debate, mainly in the *Journal of the British Astronomical Association*, under the heading 'Hole in the Sky'. It lasted until 1944. The origin was not the paper itself but a translation, done by Hagen's helpful friend William Parr, Librarian of the British Astronomical Association (BAA). It appeared in Volume 39 of the BAA *Journal* (Parr, 1928). For him the Vatican astronomer treats a "… classic episode in 'English' Astronomy." Six years passed until a reply appeared, written by Peter Doig (1882–1952) from the BAA's Historical Section (Doig, 1934). He states:

> Father Hagen gives good reason to believe that Barnard 86 is the object in question, although it does not seem absolutely certain from any written account that this is so.

Doig also points to Caroline's opinion that her brother's object

> … was something more than a total absence of stars. [For him] …it appears quite probable, therefore, that Sir William Herschel saw something in the nature of a faint nebulous appearance.

Against it, the South African amateur Hendon Edgerton Houghton (1892–1947) believed that

Hagen's identification was correct, once again quoting parts of the Herschel correspondence (Houghton, 1942).

The issue was also treated by a female member of the Herschel family, Emma Dorothea Herschel (1867–1954), one of John's many grandchildren. However, concerning the nature of the hole, she and her younger brother John Charles (1869–1950) "… have come to the unexpected conclusion that W.H. really intended to convey a diametrically opposite idea!" (Herschel, E.D., 1944). That is:

> … it seems to us much more probable that it was the 'beautiful globular clusters', as observed by Sir John, that had absorbed the repeated and wrapt attention of his Father, rather than merely a dark empty hole. It would be interesting if some kind astronomers could tell us whether there is any remarkable 'coal sack' in the neighbourhood at all.

This argument is based on Herschel's standard handbook, bought already in 1773: *Astronomy Explained upon Sir Isaac Newton's Principles*, written by James Ferguson (1710–1776; see Davenhall, 2010). There we read (Ferguson, 1756: 385):

> But the most remarkable of all cloudy stars is that in the middle of Orion's sword [M 42]. It looks like a gap in the sky, through which one may see (as it were) part of a much brighter region.

Emma Dorothea focuses on the characters and education of William and Caroline:

> I feel also that the parenthesis '(as it were)' in Ferguson, coupled with the constructional emphasis on the word 'wahrhaftig' [truly] by Herschel, both rather subtly suggest a playful allusion to some pre-supposition familiar to everyone at the time. Lady Lubbock appears to sense this innuendo, as she goes on to say [Lubbock, 1933: 62]: 'This ides of light shining through rifts in a dark envelope is a survival of the mediaeval conception of the universe as a series of concentric spheres, the outer and highest of all being the pure Empyrean of heavenly light … That Caroline appears to have been quite unaware of any such popular belief is perhaps not surprising. Astronomy formed no part of her early interests (music and needlework filled her thoughts), and it is quite likely that she switched on to astronomy under her brother's enlightened influence with a virgin mind devoid of any preconvinced ideas. One rather wonders whether the puzzle that had struck in her mind for so many years was ever solved to her satisfaction!

Doig immediately replied that he knows a "… very remarkable 'coal sack' in the neighbourhood of the lowest part of Scorpio, which may be the cause of Sir William Herschel's famous remark." (Doig, 1944). Citing Hagen's paper, he wrote that "Barnard's Nebula 86 … is the object in question …"—though in lower Sagittarius. Strange too is Doig's claim that

> … the explanation of Herschel's repeated scrutiny seem to be that he *suspected* something of the kind [obscuring nebulosity], but did not become sufficiently certain to commit himself to an opinion or to publish anything about the object. (his italics).

Here he ignores Herschel's paper.

Just following Doig's note in the *JBAA*, we find an independent reply to Emma Dorothea Herschel's query by the English astronomer Philiibert Jacques Melotte (1880–1961). He presents some areas devoid of stars in the southern part of Scorpius, found on the *Franklin-Adams Charts*. Published in 1914 by the English amateur astronomer John Franklin-Adams (1843–1912) they are one of the earliest photographic atlases showing the complete sky. Two areas are near the globular clusters M 80 and M 4. Melotte (1944) writes:

> It seems likely that Herschel may have noticed some peculiarity when examining these fields, as the falling off in star density in the obscured areas is very pronounced, and that Caroline Herschel sought further information in confirmation of this, particularly in the case of the most southern area.

Undoubtedly, the case now demanded a more detailed review of Herschel's 1785 paper. This was carried out in 1944 by the British engineer Charles Frederick Nelson Powell (1905–1994). Herschel mainly describes the results of his 'star gages'.[1] This term designates star counts made in the field of view (measuring 15′ in diameter) during a sweep—his basic method to determine the distribution of stars on the sphere. Moreover, the star numbers allowed him—by a few assumptions—to figure the spatial structure of the stellar system, i.e. the Milky Way (Steinicke, n.d.). Normally several fields were counted along the sweep path of about 2° length, when the tube of his 18.7-in reflector moves up or down in the meridian. Caroline calculated the mean star number for the fields (usually 10), giving decimal values. The posi-tion of a gage is equal to the mean right ascension (RA) and north polar distance (PA) of the fields.

Herschel's paper presents a "Table of star gages", listing the 683 gages made until the beginning of 1785. He wrote:

> When five, ten, or more fields are gaged, the polar distance in the second column of the table is that of the middle of the sweep, which was generally from 2 to 2½ degrees in breath; and, in gaging, a regular distribution of the fields, from the bottom of the sweep to the top, was always strictly attended to.

During this task, Herschel had found many 'vacant places', i.e. fields showing very low star numbers. An extraordinary case is treated in the section "An opening in the heavens" (Herschel, W., 1785: 256–257). Powell (1944) quotes the whole content:

> Some parts of our system [Milky Way] indeed seem already to have sustained greater ravages of time than others, if this way of expressing myself may be allowed; for instance, in the body of the Scorpion is an opening, or hole, which is probably owing to this cause, I found it while I was gaging in the parallel from 112 to 114 degrees of north polar distance. As I approached the milky way, the gages had been gradually running up from 9.7 to 17.1; when, all of a sudden, they fell down to nothing, a very few pretty large stars excepted, which made them shew 0.5, 0.7, 1.1, 1.4, 1.8; after which they again rose to 4.7, 13.5, 20.3, and soon after to 41.1. This opening is at least 4 degrees broad, but its height I have not yet ascertained. It is remarkable, that the 80th *Nebuleuse sans étoiles* of the *Connoissance des Temps* [M 80], which is one of the richest and most compressed clusters of small stars I remember to have seen, is situated just on the western border of it, and would almost authorise a suspicion that the stars, of which it is composed, were collected from that place, and had left the vacancy. What adds not a little to this surmise is, that the same phenomenon is once more repeated with the fourth cluster of stars of the *Connoissance des Temps* [M 4]; which is also on the western border of another vacancy, and has moreover a small, miniature cluster, or easily resolvable nebula of about 2½ minutes in diameter, north following it, at no very great distance.

Powell consulted Herschel's gage table to get the positions of the vacant fields in question; Table 2 collects the relevant data. Right Ascension (RA) and North Polar Distance (PD) are given for 1690, i.e. the epoch of the *British Catalogue*, compiled by John Flamsteed (1646–1719); Herschel used this important star catalogue for his reference stars (Steinicke, 2014). The star "g Serpentarii" is now called ρ Ophiuchi and "19 Scorpii" is o Scorpii. Though the term 'hole in the sky' does not appear in Herschel's paper, it was obvious to Powell that the table describes this 'opening'. He added: "Allowing for the effect of precession, the above 'opening' evidently corresponds to the first of the obscureed areas referred to in P.J. Melotte's letter". The second hole, near M 4, also was identified by Melotte.

No doubt, Powell's paper brought the breakthrough. But was this the death of Hagen's claim? Of course, the paper was less influential than that written by a recognized authority like the Director of the Vatican Observatory. So Hagen's wrong identification of the 'hole in the sky' would remain for some time.

Fortunately, serious authors have questioned Hagen's result. An outstanding example is the American astronomer and historian Joseph Ashbrook (1918–1980; Figure 11). His important *Astronomical Scrapbook* of 1984 contains a chapter "A hole in the sky" (Ashbrook, 1984: 392–406). It starts with the known Herschel correspondence but Ashbrook rightly adds: "Actually, Sir William's own writings tell a good deal more." Here the 1785 paper is referred to. Concerning Herschel's sweeps and gages, he correctly summarises:

Table 2: Extract from William Herschel's "Table of star gages", relating to the vacancy near M 80 (see text).

RA h m s	PD ° ′	Stars	Fields	Memoranda
16 04 19	113 06	0.5	10	Perfectly clear
16 06 28	113 04	0.7	10	Perfectly clear
16 09 28	113 04	1.1	10	Perfectly clear
16 11 28	113 04	1.4	10	The same
16 13 28	113 04	1.8	10	g Serpentarii and 19 Scorpii visible to the naked eye

> During the course of these sweeps, made with a 157× eyepiece, he frequently stopped to count the number of stars per unit area, as seen in a particular direction, brighter than the limiting magnitude of the telescope. (A rough comparison with modern star counts suggests that this limit was about magnitude 15.) For greater accuracy, Herschel often averaged the counts for as many as 10 neighbouring fields.

From the coordinates given in Herschel's gage table, Ashbrook correctly concludes about the position of the hole:

> This is the vicinity of Rho Ophiuchi, and Herschel's 'Loch im Himmel' is unquestionable the Rho Ophiuchi dark nebula, familiar in Milky Way photographs ever since E.E. Barnard's time.

The discovery story of dark nebulae, and especially Herschel's contribution, is discussed by the American historian of astronomy Steven J. Dick (1949–) in his interesting book *Discovery and Classification in Astronomy*. He writes:

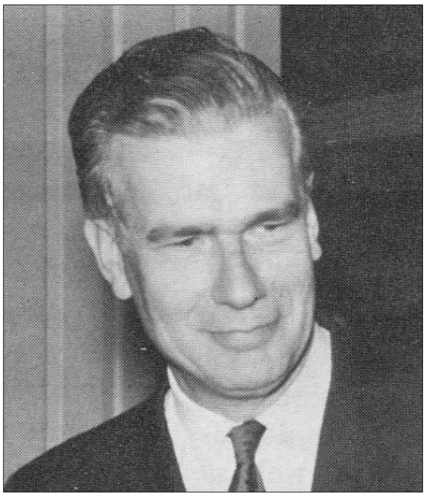


Figure 11: The American astronomer and historian Joseph Ashbrook (Steinicke Collection).

> According to his sister and assistant Caroline, coming upon one such spot in Sagittarius (now known as the Ink Spot) she heard him "after a long, awful silence exclaim 'hier ist wahrhaftig ein Loch im Himmel'" … Was Herschel or Barnard the discoverer of what we now know as dark nebulae? (Dick, 2013: 80).

Dick presents a figure showing the dark nebula B 86 and the nearby open cluster NGC 6520. However, the answer to the question "Herschel or Barnard?"—which should better read "Herschel or Secchi?"—is left to the reader.

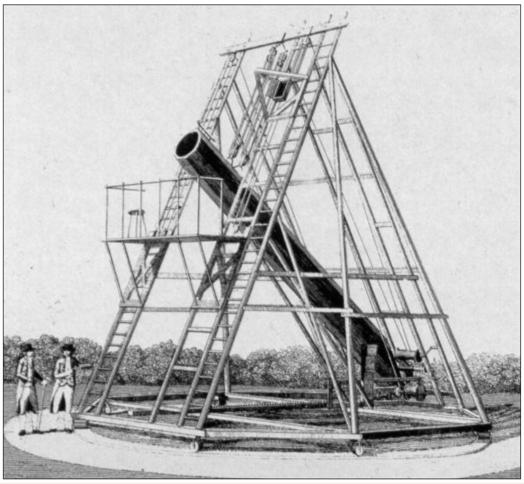


Figure 12: William Herschel's 18.7-in reflector of 20-ft focal length, used for the sweeps. It moved up and down in the meridian. The standard eye-piece had a magnification of 157× and gave a 15′ field of view (Steinicke Collection).

4 HERSCHEL'S DISCOVERY OF THE 'HOLE IN THE SKY'

After having cleared up the identification of Herschel's hole, we may ask: "What is the very source?" Of course, it is not the paper in the *Philosophical Transactions* of 1785, which only summarises the observational results. Concerning the discovery date we often read 1785—a simple claim. But what is the true date?

To answer these questions one has to consult the (unpublished) sweep records, carefully compiled by Caroline in different versions. There are additional tables, listing the dates and limits, or even charts, showing the sweep areas and object positions. However, because the sweeps are ordered by date and not by right ascension (like modern catalogues), it is difficult to find out when William searched a certain region, i.e. that of M 80 in Scorpius.

I responded to these queries by referring to a large digital database, although it was not specially designed for this case. It contains all information about Herschel's observations, starting in the early times of his star reviews (1776–1783), followed by his epochal sweep campaign (1783–1802)[2] and ending with observations of special objects in about 1810. Herschel used various methods and telescopes from 6.2 inches to 48 inches aperture. However, his standard instrument was the 18.7-in reflector (i.e. 'the large 20ft'; see Figure 12).

The original sources are stored in numerous manuscripts, lists, compilations and charts—mainly the work of Caroline. They are accessible in the Herschel Archives of the Royal Society and the Royal Astronomical Society (RAS) in London. For instance, there are four different versions of the sweep records (alas, the original notes made at her desk during the observation were not kept). The final one contains positions of all objects for the epoch 1800 and additional comments. The digital database is split into many single files, containing different information (e.g. objects, sweeps, dates, instruments).

This database was used to find observations covering the regions around M 80 (Herschel's hole) and M 4 (second hole). The search yields 11 hits. In two observations, made before the sweep campaign, the target was M 4 in Scorpius. On 5 May 1783 the 8.3-in ('10ft') reflector was used and on the following night the 12-in ('small 20ft'). No hole was noted. Seven observations appeared in the sweeps, which mutually overlap (Table 3 gives the data). No doubt, May was the favourite month. The two remaining observations were made in the course of Herschel's later star reviews, using the '7ft', a 6.2-in reflector (Herschel, W., 1792–1800: 3; Herschel, W., 1802–1810: 14). The dates are 9 June 1793 and 10 June 1804. On both nights the double star ρ Ophiuchi (here called g Ophiuchi) was visited (see below). Vacant places were not reported.

The sweep areas are visualised in Caroline's "Register of nebulae" (Figure 13). Note that sweeps 215 and 222 are marked by single lines instead of the usual crosses, which means 'half swept'. This explains her sentence in the letter of 1 August 1833: "But you will have seen by the register, that those parts could only be marked *half swept*." The term means that the sweep (or a part) was influenced by twilight, moonlight, haze or anything similar. However, this qualification is often not used very strictly. For instance, sweep 222 started with "strong daylight" but at 10:00 pm it was "pretty dark" and about 0:20 am the sky became "perfectly clear"; at 1:00 am "twilight very strong" is noted. Thus, Caroline's attribute 'half swept' is justified for only 1.5 hours of the 4.5-hour sweep.

Concerning the sweep records we start with Caroline's first copy (Herschel, C., 1784–1785). In sweep 212 Herschel performed two gages in Scorpius. M 80 was the last observed object, and was "… very bright … must be visible with an achromatic".[3] In sweep 215 the globular cluster

Table 3: Sweeps covering the regions about the globular clusters M 80 and M 4. The positions for start and end of a sweep are for 2000; B is the vertical breadth; a sweep marked by a * was 'half swept'. Herschel's 'hole in the sky' near M 80 was discovered in sweep 222, a second one (near M 4 and NGC 6144) in sweep 223.

Sweep	Date	UT	Place	Start	End	B	Objects
212	11 May 1784	00:30 am–01:05 am	Datchet	15 46–21 30	16 21–23 21	2.0	M 80
215*	14 May 1784	00:20 am–01:00 am	Datchet	15 53–23 42	16 32–25 28	2.0	ρ Oph
222*	21 May 1784	09:15 pm–01:45 am	Datchet	13 17–23 21	17 47–24 32	2.0	M 80, hole in Scorpius
223*	22 May 1784	09:55 pm–02:10 am	Datchet	14 03–24 56	18 15–26 10	2.1	M 4 & NGC 6144, 2nd hole
224*	24 May 1784	10:35 pm–02:00 am	Datchet	14 54–27 00	18 16–28 18	2.2	M 4, 2nd hole
566	26 May 1786	10:50 pm–02:00 am	Slough	15 11–21 55	18 18–23 44	2.6	M 80, hole
741	19 May 1787	10:30 pm–00:50 am	Slough	14 24–17 47	16 40–19 59	2.2	north of M 80

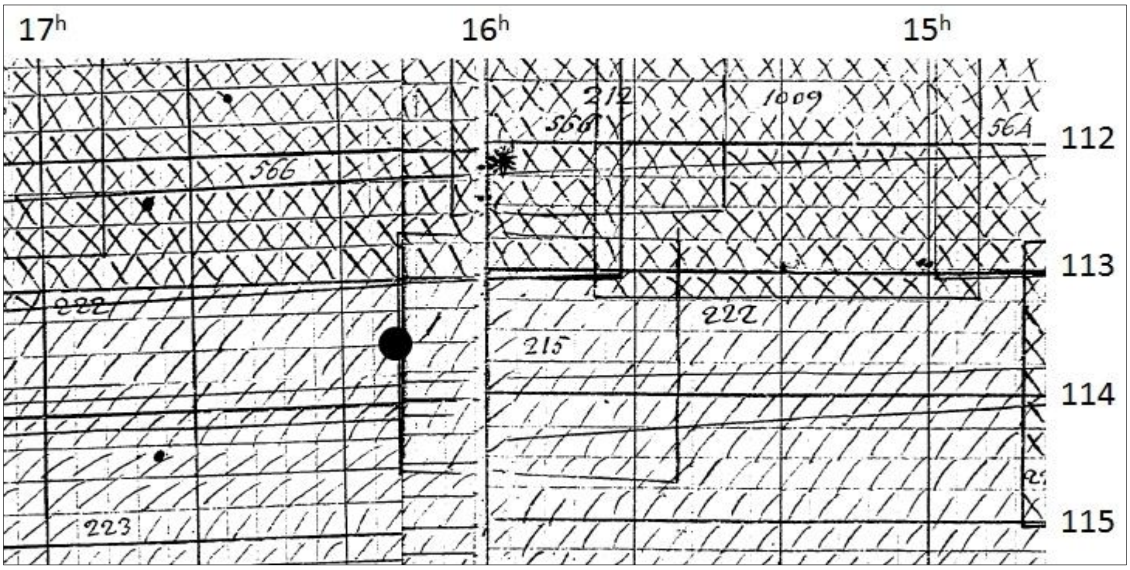


Figure 13: Part of Caroline's "Register of sweeps" (Herschel, W., 1783–1785), which shows the areas of sweep 212, 215, 222 and 566 including Herschel's 'hole' (marked as black spot). The number at right marks the north pole distance (PD = 90°-declination). Note that the sweeps mutually overlap.

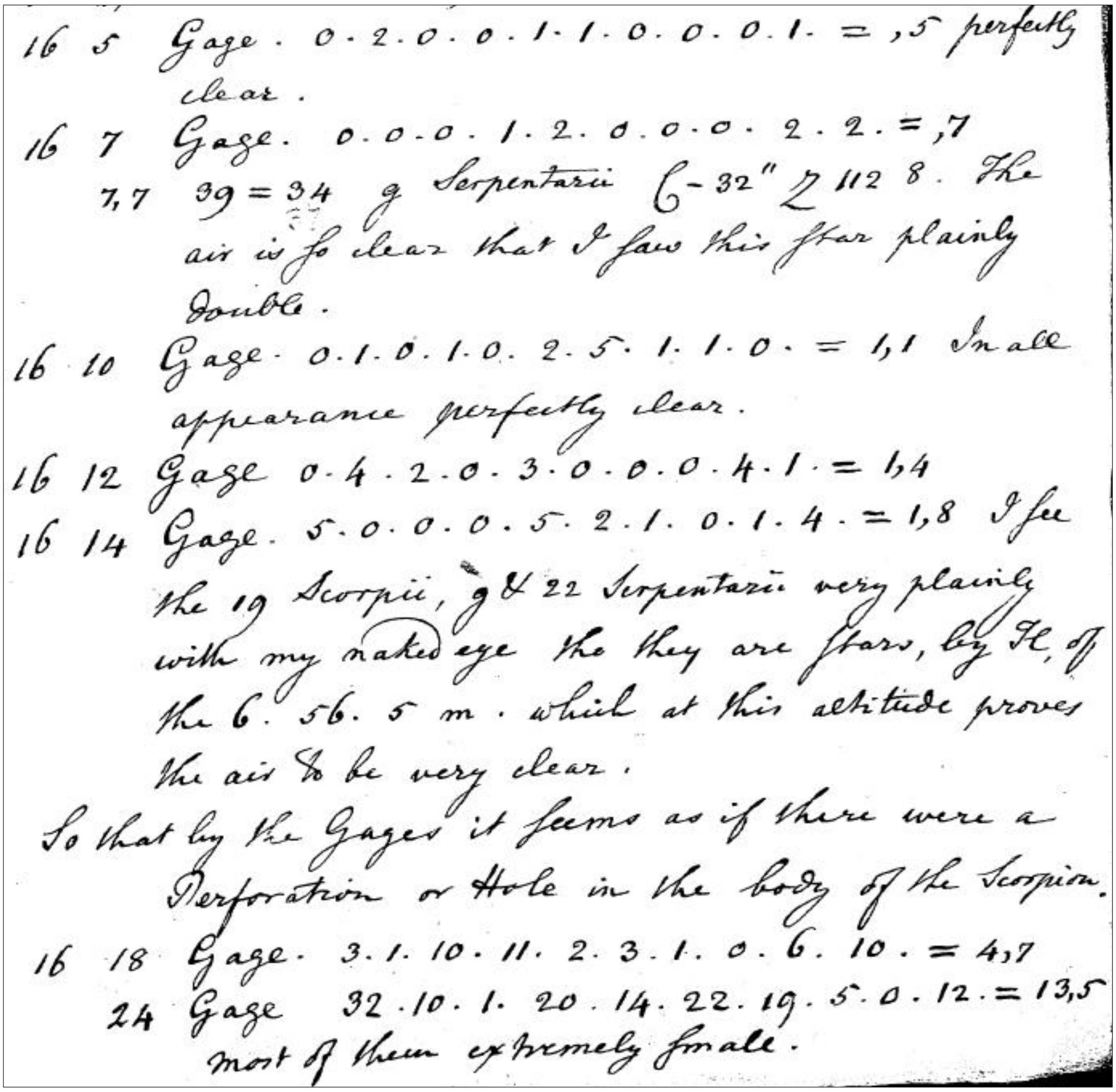
was not observed. After a gage over two fields (yielding 32.5) three bright stars were seen. The first was not identified in Flamsteed's catalogue ("star not in Fl"), but it is o (19) Scorpii (correctly listed in the final version of the sweep records); the second is called g Serpentarii (ρ Ophiuchi) and the third is 22 Scorpii. The short sweeps contain no hint for a 'hole in the sky'.

In the long sweep 222 Herschel made 14 gages. Four minutes after he met M 80 (at 0:15 am on 22 May), the star 19 Scorpii was seen. It was taken as a reference star to determine the coordinates of unknown objects. The following gage, taken at 0:20 am, brought a mean star number of only 0.5. It was calculated from 10 fields along the sweep path: 0 . 2 . 0 . 0 . 1 . 1 . 0 . 0 . 0 . 1 = 5/10 = 0.5; the mean position for 1690 was later calculated by Caroline to be RA 16h 4m 19s, PD 113° 6′ (see Table 2). The next gage brought a value of 0.7. Then g Serpentarii (ρ Ophiuchi) entered the field ("I saw this star plainly double"[4]). The next three gages yielded 1.1, 1.4 and 1.8 ("… in all appearances perfectly clear."). The following note reads: "I see the 19 Scorpii & g Serpen[tarii] & 22 Scor[pii] very plainly with my naked eye." The relevant five gages were performed in about 10 minutes; at that time this area of sky was only 13° above the horizon.

The data leave no doubt that this is the region mentioned by Herschel in his section "An opening in the heavens". However, the term 'hole' is missing in the first record version. But the second, included in Herschel's *Journal no. 9* (Herschel, W., 1784a), includes more data (see Figure 14). Obviously, Caroline had worked out the original information (exclaimed by William, and written down during the observation by her) in more detail—especially concerning the identification of conspicuous objects. Now the globular cluster in Ophiuchus is correctly identified as "Messier 80 Neb." More important is the enhanced note on 19 Scorpii which now reads:

> I see the 19 Scorpii & g Serpentarii & 22 Scor[pii] very plainly with my naked eye they are of the 5, 5-6 & 6 magnitudes, which at this altitude shews the air to be very clear. So that by the Gages it seems as if there were [sic] *a hole in the Scorpion.* (my italics).

In the next two record versions we read of "… a Perforation or Hole" (Herschel, W., 1784b; Herschel, W., 1784c) and in the final one, Caroline gives the positions of the five gages for 1800 (precessed from 1690). However, the RA of the first is 4^m too large (16h 14m 50s instead of 16h



16 5 Gage. 0·2·0·0·1·1·0·0·0·1· = ,5 perfectly
clear.
16 7 Gage. 0·0·0·1·2·0·0·0·2·2· = ,7
7,7 39 = 34 g Serpentarii 6 − 32" Z 112 8. The
air is ſo clear that I ſaw this ſtar plainly
double.
16 10 Gage· 0·1·0·1·0· 2·5·1·1·0· = 1,1 In all
appearance perfectly clear.
16 12 Gage 0·4·2·0·3·0·0·0·4·1· = 1,4
16 14 Gage. 5·0·0·0·5·2·1·0·1·4· = 1,8 I ſee
the 19 Scorpii, g & 22 Serpentarii very plainly
with my naked eye tho' they are ſtars, by Fl. of
the 6. 56. 5 m. which at this altitude proves
the air to be very clear.
So that by the Gages it ſeems as if there were a
Perforation or Hole in the body of the Scorpion.
16 18 Gage. 3·1·10·11·2·3·1·0·6·10· = 4,7
24 Gage 32·10·1·20·14·22·19·5·0·12· = 13,5
most of them extremely ſmall.

Figure 14: The relevant part of sweep 222 (22 May 1784, 0:20 am – 0:39 am) recording Herschel's discovery of "a hole in the Scorpion". The naked-eye star g Serpentarii is now called ρ Ophiuchi.

10m 50s) and the PDs of the first two are too large by 4′ and 6′ (113° 27′ for both instead of 113° 23′ and 113° 21′, respectively). These might be 'typos', but if so a rare event, as Caroline's calculations are usually correct.

For the hole Herschel gives a diameter of "… at least 4 degrees …" but by the star chart it is about 2° (see Figure 15). Due to the sweeping method, he could not survey greater areas (the breadth of sweep 222 was 2°). So the size value is a mere extrapolation.

In the long sweep 223, performed the next night, Herschel found a second hole in Scorpius, about 4° south of the first and near to the globular cluster M 4, located 1.3′ west of Antares. North of it the mean star numbers dropped down to 1.6, 2.0 and 3.8; soon after he discovered the globular cluster NGC 6144, 18′ away. Herschel does not use the term 'hole' here but it appears when the vacant place was seen again in sweep 224: "The two next fields above the gage going up the second time were again 0. 0. So that the border of the hole is thereby pointed out." (Herschel, W., 1784c: 630).

Sweep 224 also brought the discovery of VII 7 = NGC 6520, the small open cluster 6′ east of B 86. The striking dark nebula is not mentioned, though it certainly was in the field of view. The reason why Herschel missed it is simple: "… daylight very strong." (the sweep is marked 'half swept'). Normally he would have seen the object, which needs a perfect dark sky to get the right contrast.

In sweep 566 no gages were taken. However, Herschel detected some vacant places ("… the night very fine."). They appeared a few

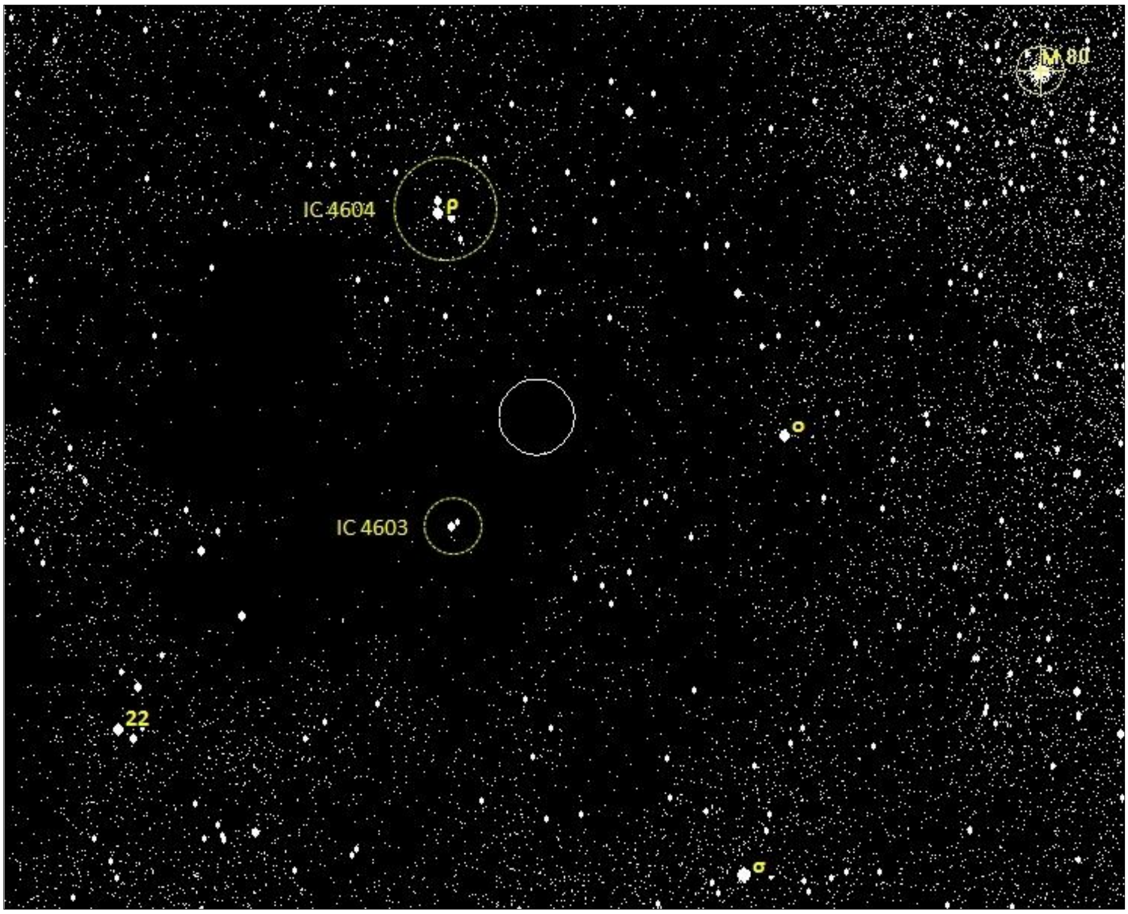


Figure 15: Herschel's hole in Scorpius (at the border to Ophiuchus), located about 1.7° southeast of the compact globular cluster M 80. The circle shows the central field (of 10) on the sweep path. The four bright stars around are σ (20) Scorpii, o (19) Scorpii, ρ Ophiuchi and 22 Ophiuchi. Herschel missed the reflection nebulae IC 4603 and IC 4604 (ρ Ophiuchi Nebula); their sizes are given by the dotted circles.

minutes after M 80 was observed (at about 23:50 pm). Caroline calculated positions matching those of sweep 222. However, sweep 566 was about 1° further north, so that only the northern part of the hole was seen. The notes do not give a hint to the former sweep. Finally, in sweep 741, a region 5° northeast of M 80 brought 20 new vacant places.

An interesting point concerns the reflection nebulae IC 4604, surrounding ρ Ophiuchi, and IC 4603, around a fainter star 1° south. Barnard wrote (1927: text to Plate 13):

> One very striking thing about all the nebulosity in this region is the fact that it is so faint that it cannot be seen with the eye even in a powerful telescope.

This is irritating because both were discovered visually by him in 1882 with the 5-in Byrne refractor at his hometown of Nashville. They were again looked at in 1892 at the Lick Ob-servatory with refractors of 6.5 and 12 inches aperture. Three years later Barnard photographed the region with a 6-in portrait lens, writing: "The Willard Lens had shown that the nebula [IC 4604] occupied a singularly blank region from which large vacant channels diverged towards the east." (Barnard, 1895). Herschel had not perceived the two nebulae, whereas in other places he was very sensitive to 'extended diffuse nebulosity'. First, according to the sweep data, IC 4603 was not on his path. But what about IC 4604? Its size exceeded his field of view (diameter 15′) thus there was little contrast, influenced, moreover, by the bright star (ρ Ophiuchi). This object is a much easier target for a small telescope, like Barnard's, with low magnification and large field of view (a 'comet seeker'). Another factor is the latitude difference between the observing sites of Herschel (Datchet) and Barnard (Nashville); at the latter IC 4604 stands 30° above the horizon (which is 16° higher).

According to Caroline, there should have been more visits to the hole. In her letter of 1 August 1833 to John she writes: "I remember your father returned several nights and years to the same spot." However, there is no evidence, either in the sweep records or in other manuscripts (journals, reviews).

5 IDENTIFICATION OF HERSCHEL'S 'HOLE' BY LATER OBSERVERS

The next to observe the region around M 80 was John Herschel in his sweep 474 of 29 July 1834, made at Feldhausen, using an 18.25-in reflector. He informed Caroline about the results in his letter of 22 February 1835. From the given positions it is evident that he saw the hole southeast of M 80 and the neighbouring vacant regions near M 4. His campaign is reviewed in Section 7.

In April 1837 William Henry Smyth (1788–1865) observed both globular clusters with a 5.9-in Tully refractor at Bedford. The results are included in his popular book *A Cycle of Celestial Objects* (Smyth, 1844: 356 and 360). The author explicitly mentions Herschel's vacant regions. The Rev. Thomas William Webb (1807–1885) also saw the vacant region near M 4 with his 3.7-in Tully refractor at Hardwicke (probably in about 1857). The observation is given in his popular book *Celestial Objects for Common Telescopes* (1859), which was inspired by the work of Smyth. Webb writes that M 4 is "… followed by a vacant space without stars distinguishable in my telescope." (Webb, 1859: 233). He also observed M 80, but the hole is not mentioned.

On 11 May 1882 Ormond Stone (1847–1933), Director of Cincinnati Observatory, independently discovered the hole in Scorpius with the 16-in Clark refractor. He communicated this find in the new journal, the *Sidereal Messenger* (Stone, 1882):

> In [visually] observing one of our D.M. zones (–23° dec.) a remarkable vacuity was found in the region between 16^h 17^m and 16^h 25^m right ascension. In this region [at the border of Scorpius and Ophiuchus] there is no star brighter than 9.5 mag., and only one of that magnitude.

Stone's observation was discussed a year later in the June issue of the *Sidereal Messenger* by the German astronomer Christian Heinrich Friedrich Peters (1813–1890), Director of Hamilton College Observatory in Clinton, N.Y. He wrote:

> There is nothing new in this; in fact, the absence of larger stars in that region was known about hundred years ago to the elder Herschel. As it seems to have struck Sir William not less than Professor Stone. (Peters, 1883).

Being an expert in the history of astronomy too, Peters knew the relevant sources, particularly Lady Herschel's *Memoir and Correspondence of Caroline Herschel* of 1876. He comprehensively reviewed the case (letters of Caroline and John, especially that of 22 Feb. 1835 presenting the positions), outlining that the 'vacuity' was discovered by William Herschel. Thus Peters is the person who first states the identity of Herschel's hole with the vacant places seen by John Herschel on the Ophiuchus/Scorpius border, communicated to Caroline.

Another person who was acquainted with the literature, was the French astronomer and publisher Camille Flammarion (1842–1925). In 1882–1883 three important reports landed on his desk in Paris. The first concerns the discovery of a 'dark space' in Sagittarius by his French colleague Étienne Trouvelot, mentioned in the book *Astronomical Drawings.* Through a private communication he received Trouvelot's drawing (Figure 16). The second was Barnard's note in the *Sidereal Messenger*, announcing the discovery of a 'black hole' in Sagittarius (B 86). For Flammarion the identity was obvious. Then he read Stone's short note in the same journal about a 'vacuity' at the border of Scorpius and Ophiuchus. In 1884 Flammarion wrote a paper titled "Les vides dans le ciel" ("The voids in the sky") for his new journal *L'Astronomie* (Flammarion, 1884). He not only presented the three observations, but also reviewed the historical background, based on the Herschel correspondence. Flammarion concluded: "These are the gaps that had struck Herschel and his sister just a century ago." Was this the result of an independent research? Certainly not, because Flammarion's text strongly looks like a mere translation of Peters' recent account in the *Sidereal Messenger*. However, this paper is not cited—even though it must have been known to him!

Six years later the English amateur George Frederick Chambers (1841–1915) presented a better rendition of Trouvelot's drawing in his book *Descriptive Astronomy* (Chambers, 1890: 111–112). The text is mainly a translation of Flammarion's article, which is cited. Concerning the observations of William Herschel and his son he writes that "Sir John Herschel seems to have returned to the subject [hole]."

More comprehensive is the chapter "Holes in the heavens" in the book *Astronomical Essays*, written by the English amateur John Ellard Gore (1845–1910), who discusses the known facts about the "… absolutely black spot about 4° in width … east of the globular cluster 80 Messier." (Gore, 1907: 250). Barnard also is mentioned: that he saw "… great nebulous [*sic*] surrounding the stars ρ Ophiuchi and 22 Scorpii." (ibid.).

To summarise the case: Peters, Flammarion, Chambers and Gore were convinced that Herschel's hole and B 86 were different objects. This was long before Hagen entered the scene with his disastrous paper. The Vatican astronomer does not mention these authors; also Trouvelot's observation is missing. It is interesting that the contributions of Peters, Trouvelot and Flammarion were not mentioned in the *JBAA* debate; perhaps because the subject—according

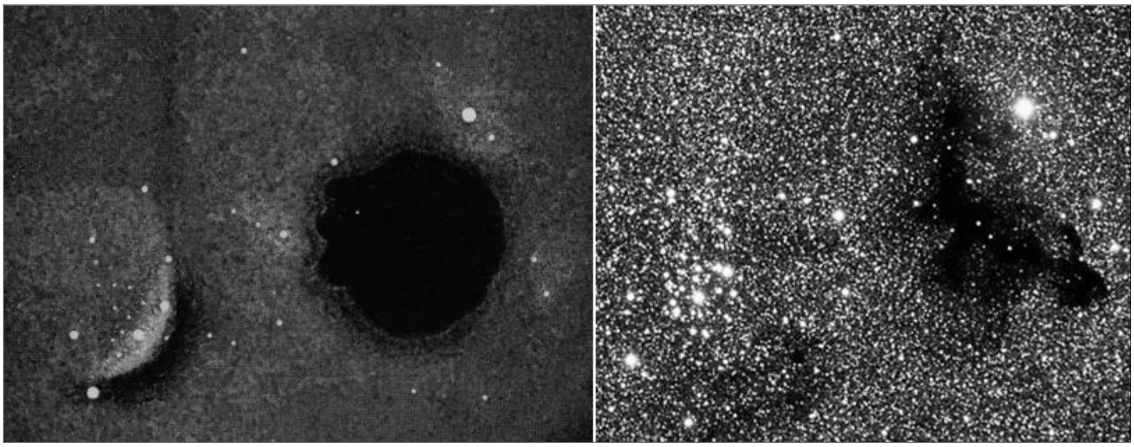


Figure 16: Left: Trouvelot's drawing of the dark nebula B 86 near the open cluster NGC 6520 in Sagittarius; right: modern image (measuring 10' east-west). Note that Trouvelot's "another narrow opening near a small, loose cluster" is real.

to one of the contributors (William Parr)—exclusively concerns "… a classic episode in 'English' Astronomy."

6 HERSCHEL'S 'VACANT PLACES'

The matter starts with Herschel's sweep 54 on 19 December 1783 (on that night the first gage was taken). He noticed "… many vacant places …" in southern Taurus. In sweep 78 (17 January 1784), covering the northern part of the constellation, he even found "… the longest vacant space I ever have seen." The same appeared 11 days later in Virgo (sweep 131). In sweep 189 on 12 April 1784 a gage was taken in Bootes, showing "… about 5 or 6 stars generally in the field." Then seven sweep paths, spread over about one hour of time, showed "… many fields without stars." Caroline determined the average position of this void in Bootes. Some more places were found, and then Herschel encountered the famous fields in Scorpius near M 80 and M 4 on 21 and 22 May 1784 (sweeps 222 and 223). Many more vacant places were detected in later sweeps.

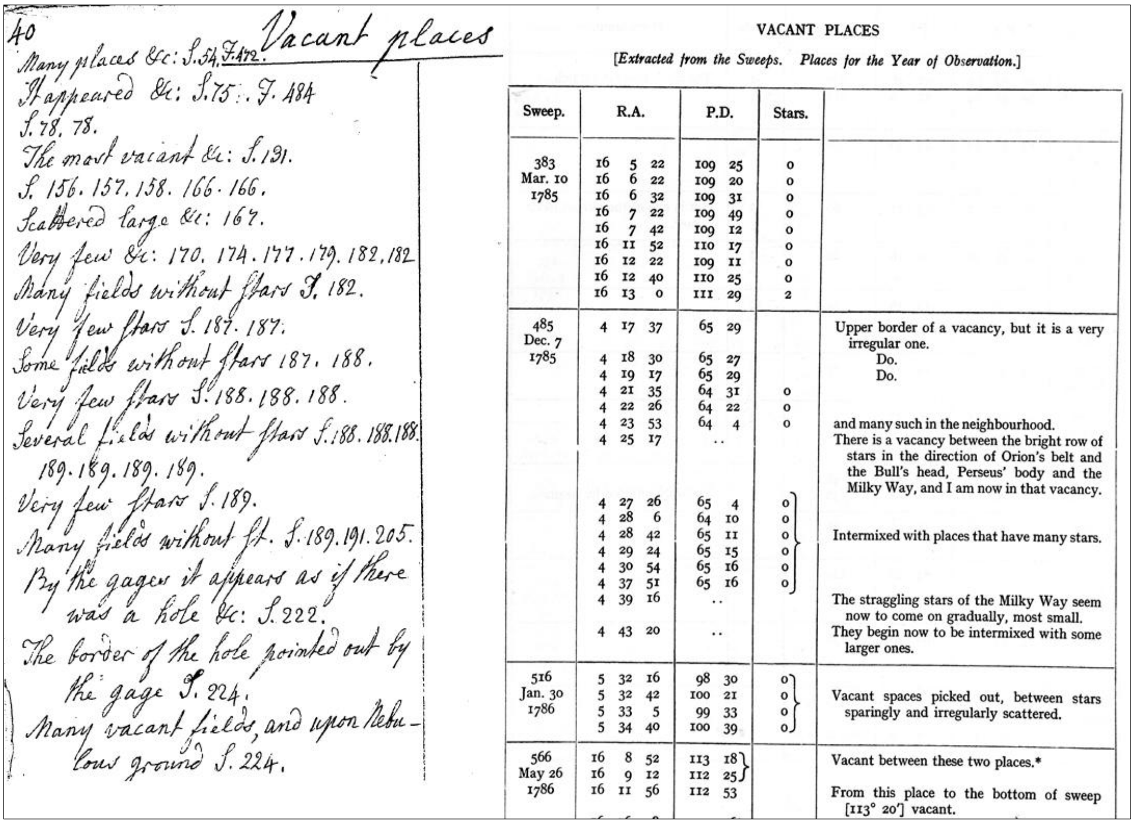
Caroline's register of important subjects and events—her "Temporary Index"—contains a table of 53 'vacant places' (Herschel, C., 1802: 40). For sweep 222 it is noted: "By the gages it appears as if there was a hole …"; and for sweep 224 we read: "The border of the hole pointed out by this gage." However, this is misleading, for two different 'holes' are meant: near M 80 and M 4, respectively. Later Dreyer, when preparing the *Scientific Papers*, carefully checked the sweep records, stored at the Royal Astronomical Society. Starting at sweep 383 and ending with 741, he lists 77 'vacant places' (Dreyer, 1912: 712–713). Sweep 383 was the first taken after Herschel's paper of 1785 and containing a vacant place. It is astonishing that there is little overlap between Caroline Herschel's and Dreyer's collections (see Figure 17).

A recent investigation of the sweep records yielded no less than 198 vacant places, found in 67 different sweeps. Following Caroline's policy, this includes gages with a mean star number below 5 or non-gaged regions, only recorded as vacant or anything similar. The following plot shows the distribution of all places on the celestial sphere (see Figure 18). They were found between 19 December 1783 (sweep 55) and 2 November 1790 (sweep 976). In 40 sweeps only one place was detected; but we have 15 in sweep 484 (all in Taurus), 20 in sweep 741 (Ophiuchus) and even 22 in sweep 627 (Taurus); often the vacant places are connected.

About half the places (102) lie in or near the Milky Way; they are spread over seven constellations: Cygnus (2), Ophiuchus (30), Orion (7), Sagittarius (1), Scorpius (19), Serpens (3) and Taurus (40). The high number found in Taurus corresponds with observations made by Friedrich Wilhelm Argelander (1799–1875) in the course of the *Bonner Durchmusterung* during the 1850s: "… the region near the horns of Taurus, although close to the Milky Way, is absolutely the poorest in the northern hemisphere." (Clerke, 1890: 361).

Is it possible to identify the Milky Way 'objects' with known dark nebulae? The main catalogues were published by Edward Emerson Barnard (B) in 1927 and Beverly Turner Lynds (1929–) in 1962; the latter objects are designated LBN (Lynds Dark Nebula). In 17 cases (from 10 different sweeps) identification is possible; seven objects bear a B-number. Most successful were the sweeps 222–224 in May 1784, yielding seven known dark nebula. Table 4 may be called a 'Herschel Catalogue of Dark Nebulae'.

What about vacant places outside the Milky Way? Some are real in the following sense: there are directions (e.g. towards the North Galactic Pole in Coma Berenices) showing very few stars



40 Vacant places

Many places &c: S.54. F.472.
It appeared &c: S.75.. F. 484
S.78. 78.
The moſt vacant &c: S.191.
S. 156. 157. 158. 166. 166.
Scattered large &c: 167.
Very few &c: 170. 174. 177. 179. 182. 182
Many fields without ſtars S. 182.
Very few ſtars S. 187. 187.
Some fields without ſtars 187. 188.
Very few ſtars S. 188. 188. 188.
Several fields without ſtars S. 188. 188. 188.
189. 189. 189. 189.
Very few ſtars S. 189.
Many fields without ſt. S. 189. 191. 205.
By the gages it appears as if there was a hole &c: S. 222.
The border of the hole pointed out by the gage S. 224.
Many vacant fields, and upon Nebulous ground S. 224.

VACANT PLACES

[*Extracted from the Sweeps. Places for the Year of Observation.*]

Sweep.	R.A.	P.D.	Stars.	
383 Mar. 10 1785	16 5 22	109 25	0	
	16 6 22	109 20	0	
	16 6 32	109 31	0	
	16 7 22	109 49	0	
	16 7 42	109 12	0	
	16 11 52	110 17	0	
	16 12 22	109 11	0	
	16 12 40	110 25	0	
	16 13 0	111 29	2	
485 Dec. 7 1785	4 17 37	65 29		Upper border of a vacancy, but it is a very irregular one.
	4 18 30	65 27		Do.
	4 19 17	65 29		Do.
	4 21 35	64 31	0	
	4 22 26	64 22	0	
	4 23 53	64 4	0	and many such in the neighbourhood.
	4 25 17	..		There is a vacancy between the bright row of stars in the direction of Orion's belt and the Bull's head, Perseus' body and the Milky Way, and I am now in that vacancy.
	4 27 26	65 4	0	Intermixed with places that have many stars.
	4 28 6	64 10	0	
	4 28 42	65 11	0	
	4 29 24	65 15	0	
	4 30 54	65 16	0	
	4 37 51	65 16	0	
	4 39 16	..		The straggling stars of the Milky Way seem now to come on gradually, most small.
	4 43 20	..		They begin now to be intermixed with some larger ones.
516 Jan. 30 1786	5 32 16	98 30	0	Vacant spaces picked out, between stars sparingly and irregularly scattered.
	5 32 42	100 21	0	
	5 33 5	99 33	0	
	5 34 40	100 39	0	
566 May 26 1786	16 8 52	113 18		Vacant between these two places.*
	16 9 12	112 25		
	16 11 56	112 53		From this place to the bottom of sweep [113° 20′] vacant.

Figure 17: Parts of the registers of 'vacant places', compiled by Caroline Herschel (1802) and John Louis Emil Dreyer (1912).

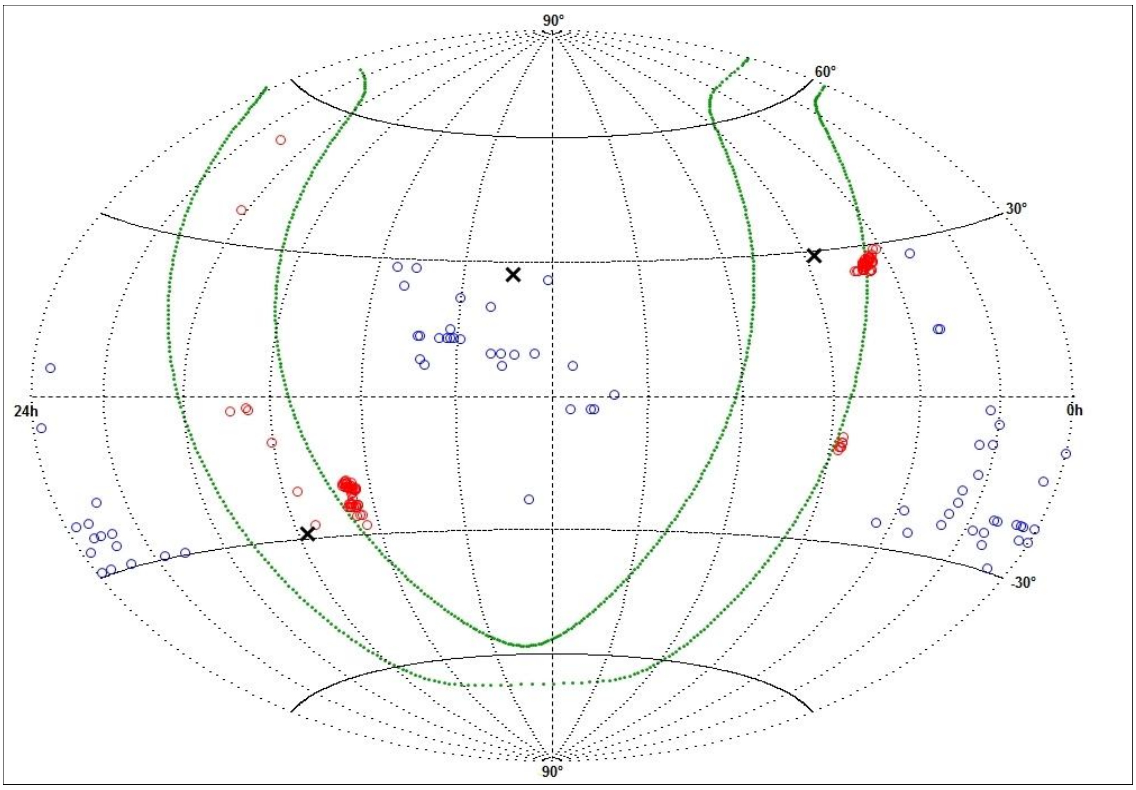


Figure 18: Distribution of Herschel's 198 vacant places on the celestial sphere (red circles = in/near the Milky Way; blue circles = outside the Milky Way). The green curves represent the border of the Milky Way; the crosses mark the Galactic Centre in Sagittarius (left), the North Galactic Pole in Coma Berenices (middle) and the Galactic Anti-Centre in Auriga (right).

Table 4: A 'Herschel Catalogue of Dark Nebulae', listing all 'vacant places' located in or near the Milky Way, which can be identified in the main catalogues of dark nebulae. The (approximate) position is for 2000.0. The most prominent case is the hole in Scorpius near M 80 and ρ Ophiuchi, identified with B 42. In the last column a * indicates that the data are based on a star gage; otherwise Herschel only notes a 'vacant place'.

Sweep	Date	Position		Const.	Dark Nebula	Remarks
		RA	Dec			
78	17 Jan. 1784	04 08	+29 00	Tau	B 7	*, seen again in sweep 360
222	21 May 1784	16 25	–23 48	Sco	B 42	*, hole in Sco near M 80, seen again in sweep 556
222	21 May 1784	16 30	–23 46	Sco	LBN 457	*
222	21 May 1784	16 32	–23 46	Sco	LBN 462	*
222	21 May 1784	16 36	–23 46	Sco	B 44	*
223	22 May 1784	16 19	–25 44	Sco	B 229	*, near M 4, seen again in sweep 224
223	22 May 1784	16 22	–25 43	Sco	LDN 441	*, near M 4
223	22 May 1784	16 27	–25 44	Sco	LDN 453	*, near M 4 and NGC 6144
224	24 May 1784	17 33	–25 42	Sco	B 78	*
228	16 Jun. 1784	18 01	–09 42	Sgr	LDN 400	near NGC 6517
242	21 Jul. 1784	18 54	–03 08	Ser	LDN 535	*
356	10 Oct. 1785	05 44	–09 30	Ori	LDN 337	*, seen again in sweeps 362 & 516
383	10 Mar. 1785	16 22	–20 23	Sco	B 41	
627	26 Oct. 1786	04 24	+27 00	Tau	LDN 187	*
627	26 Oct. 1786	04 33	+26 00	Tau	LDN 214/229	
627	26 Oct. 1786	04 33	+26 15	Tau	B 19	
862	26 Sep. 1788	21 00	+51 11	Cyg	LDN 989	

other than the brighter ones. Thus, with a telescope like Herschel's (showing stars down to about magnitude 15 under good conditions), one can easily get the impression of a void, i.e. a lack of stars. Of course, modern deep images mostly do not confirm this appearance.

7 EARLY SPECULATIONS ABOUT THE NATURE OF 'VACANT PLACES'

How were 'vacant places' interpreted by William Herschel and his followers? Generally, there is no doubt that Herschel favoured the idea of the existence of true voids in the stellar distribution. But it is interesting that in 1782 he thought about the possibility of obscuring matter in space reddening the light (Herschel, W., 1782: 105, first footnote):

> An allowance ought also perhaps to be made for some loss that may happen to the light of very remote stars in its passage through immense tracts of space, most probably not quite destitute of some very subtle medium. The conjecture is suggested to us by the colour of the very small telescopic stars, for I have generally found the red, or inclined to red; which seems to indicate, that the more feeble and infrangible rays of the other colours are either stopped by the way, or are least diverted from their course by accidental deflections.

However, this idea was not progressed later. Against it, the existence of true voids supported his theory of the formation of star clusters. This was developed in the paper of 1785. In the section "Formation of Nebulae", five forms of stellar aggregations are defined, and Form V refers to 'Vacant Regions'. Herschel wrote:

> … there will be formed great cavities or vacancies by the retreat of the stars towards the various centers which attract them; so that upon the whole there is evidently a field of the greatest variety for the mutual and combined attractions of heavenly bodies to exert themselves in.

His prime example is the hole in Scorpius. Herschel believed that the gravitational forces of the massive cluster [M 80] would have attracted the stars in its neighbourhood, i.e. "… the stars, of which it is composed, were collected from the place, and had left the vacancy." Beside the pair of the hole in Scorpius and the globular cluster M 80, there are more examples. The second hole (in Scorpius) even has two neighbouring globulars, M 4 and NGC 6144. A third case is the vacant place in Ophiuchus, 45′ distant from the globular cluster NGC 6517; both discovered in sweep 228 (all pairs are listed in Table 4).

About 30 years later Herschel wrote that, due to the universal attractive force, the Milky Way is already breaking up into groups, leaving openings or gaps in space (Herschel, W., 1814: 282–283):

> … observations … authorise us to anticipate the breaking up of the milky way, in all its minute parts, as the unavoidable consequence of the clustering power arising out of the preponderating attractions which have been shewn to be every where existing in its compass … Now, since the stars of the milky way are permanently exposed to the action of a power whereby they are irresistibly drawn into groups … it is evident that the milky way must be finally broken up, and cease to be a stratum of scattered stars.

The existence of 'vacant places' was an argument against the uniform scattering of stars. However, in 1785, based on the gage data, Herschel had used the assumption of a constant star density to determine the spatial structure of the Milky Way. But later he rejected it due to observational evidence (Steinicke, n.d.). His idea of a flattened stratum of stars remained.

Table 5: An extract of John Herschel's list of 49 vacant regions, showing all cases in the Milky Way which can be identified with dark nebulae in the catalogues of Barnard and Lynds. The (rough) position is for 2000. Three objects were already seen by his father (see Table 4). For B 42 (Herschel's hole) John remarks "not the smallest star".

Sweep	Date	Position RA Dec	Con	Dark Nebula	Remarks
453	13 May 1834	16 19 –25 55	Sco	LDN 440	
453	13 May 1834	17 32 –26 16	Oph	B 264	
453	13 May 1834	17 34 –26 05	Oph	B 78	WH, seen again in sweep 474
474	29 Jul. 1834	16 41 –24 08	Sco	B 44	WH
588	24 May 1835	16 20 –22 55	Sco	LDN 443	
588	24 May 1835	16 24 –24 01	Sco	B 42	WH, seen again in sweep 793
588	24 May 1835	16 47 –21 17	Sco	LDN 481	seen again in sweeps 588 & 793
608	15 Jul. 1835	18 02 –04 47	Oph	LDN 809	
609	16 Jul. 1835	18 23 –07 05	Ser	LDN 944	
699	7 May 1836	16 53 –15 35	Oph	LDN 504	
722	14 Jul. 1836	16 23 –19 32	Sco	LDN 439	
723	15 Jul. 1836	17 22 –26 53	Oph	LDN 630	
723	15 Jul. 1836	17 28 –26 55	Oph	LDN 649	

John Herschel shared his father's view that vacant regions were due to the absence of stars. He also agreed about the structure of the Milky Way as a flat stratum, at least in principle. For him it seems likely to encounter an empty region in directions where the stellar system has a small extent (Herschel, J., 1902: 712–713). During his southern sky survey (1834–1838) he found many vacant places, and a special paragraph in his bulky publication *Astronomical Results* is dedicated to this subject (Herschel, J., 1847: 381–382); it treats "… fields of view totally devoid of any perceptible star." John Herschel writes:

> When such a field has occurred in sweeping, it has usually been noticed as a thing worthy of special remark, and its place taken and registered *as an object*.

He presents a list of 49 cases, found between May 1834 and June 1837. Of these, 35 are located in or near the Milky Way. Table 5 shows identifications of these in the catalogues of Barnard and Lynds. The objects B 42, 44 and 78 were already seen by his father.

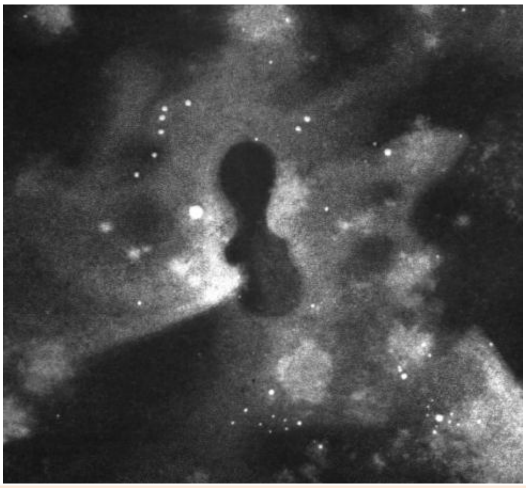


Figure 19: John Herschel's drawing of the 'keyhole' dark nebula in the centre of the η Carinae Nebula (the original is black on white). The object is about 2' long; the star η Carinae is left of it.

Curiously the first two vacant fields, mentioned in the letter to Caroline of 22 February 1835 and found in sweep 474 at 16^h 15^m 113° 56′ and 16^h 19^m 116° 3′ (1690), are not among the 49 published cases. Further, it is interesting that John has not included the striking dark marking in the centre of the conspicuous nebula around η Carinae (called η Argus at that time). The reason is simple: the great nebula is treated in a special section of the *Astronomical Observations*, headed "η Argus and the Great Nebula Surrounding It." Herschel describes the dark marking as a "… singular lemniscate-oval vacuity …" (see Figure 19). The phenomenon was interpreted (Herschel, J., 1849: 572–573):

> The conclusion can hardly be avoided that in looking at it we see through, and beyond the Milky Way, far out into space, through a starless region, disconnecting it altogether from our system.

Later the apt name 'keyhole' was created (Converse, 1873).

We now know that the low star numbers in 'vacant places' of the Milky Way are due to absorbing interstellar matter (dust). Already Secchi, the discoverer of the dark nebula B 86 near NGC 6520 in Sagittarius, had formulated this idea (Secchi, 1877: 32–33). He wrote that such 'black holes' ('fori neri') are

> … quite improbable, especially after the discovery of the gaseous nature of the nebular areas and it is instead more probable that this blackness results from a dark nebulosity projected on a lucid background and intercepting its rays ... This very likely applies to the curious hole in the nebula η Argus, which appears in the form of a lemniscate.

However, 20 years earlier the Vatican astronomer had written about B 86:

> This spot, by its contrast, shows that the galaxy [Milky Way] in that region is quite strewed with stars, which give a white aspect to the firmament. (Secchi, 1857).

No doubt, spectroscopy had triggered this idea.

Barnard, too, had changed his view about the issue (Dick, 2013: 80–82). During the photographic studies of the Milky Way he found many dark nebulae. In 1906 he was still convinced that Herschel was right in believing that these objects are "… real vacancies among the stars." (Barnard, 1906). However, first doubts appeared in 1910 and he wondered whether "… the dark spaces of the sky are due to absorbing matter between us and the stars." (Barnard, 1910). Three years later he wrote

> The so-called 'black holes' in the Milky Way are of very great interest. Some of them are so definite that, possibly, they suggest not vacancies but rather some kind of obscuring body lying in the Milky Way, or between us and it, which cuts the light of the stars. (Barnard, 1913).

Observational evidence came from the imaged shapes of dark nebulae, being quite similar to those of bright nebulae (Barnard, 1916).

Soon after, the English astronomer William Sadler Franks (1851–1935) started an observing campaign. He visually inspected 42 Barnard objects with a 6-in Cooke refractor, offering a 36′ field of view (Franks, 1930). Among them were four objects found by William Herschel: B 41, 42, 44 and 78. Franks was aware of their discovery and of Secchi's idea of an 'obscure nebulosity'.

Finally, it is interesting that in more recent times the concept of true holes has been resurrected—and examples presented. This is mainly due to observations by Walter Baade (1893–1960), made in Cygnus (1943) and Sagittarius (1946). In 1944 the Dutch astronomer Jan Oort (1900–1992) concluded that

> The region of the great Cygnus cloud investigated by Baade appears to be one of abnormally high transparency. It does not seem unlikely that the brilliance of the cloud is due in larger measure to the absence of absorption. (Oort and Oosterhoff, 1942).

It is interesting that this paper was mentioned by the British amateur Percy Mayow Ryves (1876–1956) in the *JBAA* debate (Ryves, 1944).

Baade's second hole is the famous 'Baade Window', discovered by the German astronomer in 1946. It is about 1° wide and located in the direction of the globular cluster NGC 6522 in Sagittarius[5]—a nice new example of cluster and hole (moreover, the cluster is only 2° south of B 86). Due to low amounts of interstellar dust it offers a view of the Galactic Centre (which is otherwise heavily obscured). This area corresponds to one of the brightest patches of the Milky Way. Thus, we learn that a true 'hole in the sky' can either be dark or bright—depending on the remote background. On the other hand, we are now again faced with false 'Herschel holes', though in another sense: dark nebulae detected by the *Herschel Space Observatory*, which has imaged the infrared sky from 2009 to 2013 in high resolution.

8 CONCLUSION AND TIMELINE

From the discovery of William Herschel's hole in May 1784 up to the late 1920's there was no conflict about its location (near the globular cluster M 80 in Scorpius) and identification as the 'vacant place' southwest of the bright star ρ Ophiuchi (see the Table 6 timeline). But the situation became confusing when the Vatican astronomer Johann Georg Hagen entered the scene, bringing his former Jesuit colleague Father Angelo Secchi into the fray. The latter had discovered a striking dark nebula near the open cluster NGC 6520 in Sagittarius, later catalogued as B 86 by Edward E. Barnard. Against all the evidence, Hagen identified Herschel's 'hole' with Secchi's object, even though Herschel was very clear about its position and extent in his paper of 1785. Hagen simply ignored the information presented by Herschel in the section titled "An opening or hole". So Hagen's claim was not based on facts—it appears to have been more literal, simply relating Herschel's 'hole' with the 'black hole' of Secchi and Barnard. Probably Hagen wanted to promote his former Jesuit colleague as the first to present the idea of 'dark matter' as the cause for 'vacant places' in space.

Fortunately, the strange intermezzo was terminated by the work of Charles Powell—and later Joseph Ashbrook. However, neither of them consulted the original sources, which contain the details of Herschel's observations made in the sweeps. This has been carried out in the present paper. Perhaps this can help clear up misunderstandings about this subject that are still in the literature—and, of course, on the internet (e.g. see Slootegraaf, 2016). There, for instance, we are faced with ridiculous discovery dates like 1781 (mix-up with Uranus?) or even 1774 and 1884 (Cain, 2016; Starke et al., 2010).

9 NOTES

1. Herschel always used the incorrect word 'gage' instead of 'gauge'. Anyway, his term is used in this text.
2. The sweeps are numbered 1 to 1112, dating from 29 October 1783 to 30 September 1802 (but there was an additional sweep, 1113, on 31 May 1813).
3. Although William possessed Messier's final catalogue from about April 1784, M 80 was not identified by Caroline. This was used in the next version of the sweep records. With "achromatic", this refers to Herschel's Dolland refractor of 39 inches focal length.
4. The star is listed as II 19 in Herschel's catalogue of double stars.

Table 6: Chronology of Herschel's hole, starting with the discovery and ending with the conclusive paper by Powell about its identity. An asterisk in the 'ρ Oph' and 'B 86' columns marks the favoured identification, i.e. the dark nebula near ρ Ophiuchi/M 80 or Barnard 86 in Sagittarius.

Date	Person	Subject	ρ Oph	B 86
22 May 1784	W. Herschel	discovery (sweep 222, Datchet)	*	
1785	W. Herschel	paper in *Philosophical Transactions* 1785	*	
1 Aug. 1833	C. Herschel	letter to John		
6 Jun. 1834	J. Herschel	letter to Caroline		
29 Jul. 1834	J. Herschel	observation (sweep 474, Feldhausen)	*	
11 Sep. 1834	C. Herschel	letter to John		
22 Feb. 1835	J. Herschel	letter to Caroline (positions)	*	
Apr. 1837	W. H. Smyth	*Cycle*, observation (M 80, M 4)	*	
1847	J. Herschel	*Astronomical Results* (49 vacant places)	*	
Summer 1857	A. Secchi	discovery of B 86 (Rome)		
1859	T. W. Webb	*Celestial Objects*, observation (M 4)		
12 Aug. 1876	E. Trouvelot	2nd discovery of B 86 (Washington)		
1877	A. Secchi	*Memoria*, dark matter		
11 May 1883	O. Stone	2nd discovery of hole (Cincinnati)		
July 1883	E.E. Barnard	3rd discovery of B 86 (Nashville)		
1883	C.H.F. Peters	identification	*	
1884	C. Flammarion	Trouvelot drawing (copy of Peters)	*	
1890	G. Chambers	*Descriptive Astronomy* (copy of Flammarion)	*	
1895	A.M. Clerke	*The Herschels* (letters)	*	
1907	J.E. Gore	*Astronomical Essays*, identification	*	
1907	E.E. Barnard	dark nebulae		
1912	J.L.E. Dreyer	*Scientific Papers* (paper of 1785)	*	
1913	E.E. Barnard	dark matter		
1919	E.E. Barnard	first Barnard catalogue		
1927	E.E. Barnard	*Atlas*, final Barnard catalogue		
1928/1929	J.G. Hagen	letters, identification		*
1928	W.A. Parr	*JBAA* debate, Hagen paper (translated)		
1930	W.S. Franks	visual observations of Barnard nebulae	*	
1934	P. Doig	*JBAA* debate, identification		*
1942	H.E. Houghton	*JBAA* debate, identification		*
1944	P.M. Ryves	*JBAA* debate, true holes (Baade, Oort)		
1944	E.D. Herschel	*JBAA* debate		
1944	P. Doig	*JBAA* debate, identification		*
1944	P.J. Melotte	*JBAA* debate, identification	*	
1944	C.F.N. Powell	*JBAA* debate, identification	*	

5. NGC 6522 was found by Herschel on 24 June 1784 in sweep 232. He mentions extremely rich fields here.

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RECONSTRUCTING THE STAR KNOWLEDGE OF ABORIGINAL TASMANIANS

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Abstract: The canopy of stars is a central presence in the daily and spiritual lives of Aboriginal Tasmanians. With the arrival of European colonists, Tasmanian astronomical knowledge and traditions were interrupted and dispersed. Fragments can be found scattered in the ethnographic and historical record throughout the nineteenth century. We draw from these ethnohistorical documents to analyse and reconstruct Aboriginal astronomical knowledge in Tasmania. This analysis demonstrates that stars, the Milky Way, constellations, dark nebula, the Sun, Moon, meteors and aurorae held cultural, spiritual and subsistence significance for the Aboriginal cultures of Tasmania. We move beyond a monolithic view of Aboriginal astronomical knowledge in Tasmania, commonly portrayed in previous research, to lay the groundwork for future ethnographic and archaeological fieldwork with Aboriginal elders and communities.

Keywords: Cultural Astronomy; ethnoastronomy; Indigenous Knowledge Systems, Aboriginal Australians, Tasmania

Warning to Australian Aboriginal Readers: This paper contains the images of Aboriginal people who have died.

“Aboriginal Tasmanians spoke of the subject of stars with great zest.” (George Augustus Robinson, 13 March 1834).

1 INTRODUCTION

The study of Indigenous Knowledge Systems can reveal a wealth of information about how scientific information is encoded into oral tradition and material culture (Agrawal, 1995), particularly with respect to astronomical knowledge (Cairns and Harney, 2003; Fuller et al., 2014; Hamacher, 2012; Norris, 2016). The continued study of Aboriginal and Torres Strait Islander astronomical knowledge, and the traditions though which this knowledge is passed to successive generations, has led to a more detailed understanding of how the Sun, Moon and stars aided navigation, seasonal calendars, food economics, animal behaviour, social structure, sacred law, and relationships between the land and the sky (Johnson, 1998). This is done through the various methodologies and theoretical frameworks of cultural astronomy, an interdisciplinary academic field that seeks to understand the role and use of the stars in culture (Ruggles, 2015).

Ethnohistorical literature is one of the primary sources for studying and reconstructing Indigenous astronomical knowledge (Hamacher, 2012). Aboriginal Australians are considered to be among the oldest continuous cultures, and *the* most researched Indigenous people on the Earth (Smith, 1999: 3), with records of language, customs, and traditions going back to before European colonisation in 1788. However, these records are highly biased, as Aboriginal people were considered to be among the lowest rung of human cultures by the colonists. This false position, and the rapid decimation of Aboriginal people and culture after British colonisation, lead to the practice of ‘salvage anthropology’, where ethnographers sought to record Aboriginal traditions before the people and cultures ‘disappeared’, sometimes with minimal regard for the secrecy or sacredness of that knowledge. This led to a rather large body of published information about Aboriginal cultures. Unfortunately, much of the astronomical knowledge from these records is highly fragmented and incomplete. A lack of formal training or understanding of astronomy by these ethnographers means much of the recorded information is filled with conflated terminology, misidentifications, incorrect assumptions, and transcription errors.

Aboriginal Tasmania has long been a place of contrasts, contention and devastation (Ryan, 1996). Colonialism, dispossession, genocide, and disease nearly wiped out Tasmania Aboriginal people (who call themselves ‘Palawa’, the name of the first man created from a kangaroo by a creator spirit). Before the arrival of Europeans, it is believed Aboriginal people arrived in Tasmania over 40,000 years ago (Pope and Terrell, 2007) when the island was connected to mainland Australia by a land bridge (see Orchiston, 1979a, 1979b; Murray-Wallace, 2002).

Approximately 8,000 years ago, rising sea levels created the island of Tasmania, separating the Palawa from mainland Aboriginal people. It is believed that the Palawa remained relatively isolated until European contact and subsequent colonisation (Johnson et al., 2015: 16). Groups were spread across about nine territories (Johnson et al., 2015: 36): Northeast, Ben Lomond, North Midlands, Oyster Bay, Southeast, Big River, North, Northwest, and Southwest (Figure 1). Within each of these territories existed smaller groups tied through marriage, kinship, and language, led by a respected male elder (ibid).

Relatively little is known about Palawa cultures prior to colonisation. Ethnographic studies were limited and the focus of colonial presence in Tasmania became one of complete Aboriginal removal from the island. Following a series of conflicts between colonists and Aboriginal Tasmanians in the early nineteenth century—a period known as the Black War—a builder and evangelist named George Augustus Robinson was hired from 1829 to 1834 to find the remaining Palawa living in Tasmania, facilitate their ‘peaceful surrender’, then relocate them to Flinders Island. This ‘Friendly Mission’ was accomplished by 1835 and many of the 200 relocated Palawa died from poor health and the prison-like conditions in which they were held. This had a devastating impact, resulting in the near decimation of Palawa culture, traditions and languages. In the time since, a cultural revival has taken hold and a resurgence of Palawa language, archaeology, history and culture is rapidly growing.

Because of colonisation, disease, dispossession, and genocide, we know relatively little about Palawa astronomical knowledge. Most of the archival information is ethnohistorical in nature, having been recorded by colonists and missionaries from their Aboriginal contacts. And much of that is fragmented, incomplete, sometimes ambiguous, and always recorded through the lens of the coloniser. Some traditional knowledge has survived with the Aboriginal people, who continue to pass their traditions on to successive generations.

This paper attempts to sort through the fragments of astronomical knowledge from Aboriginal Tasmanians scattered throughout the ethnohistorical literature and archives, reanalyze them using established and emerging methodologies from cultural astronomy, and attempt to reconstruct this knowledge to the best of our ability (although we acknowledge our limitations in this endeavor). This will serve as a base for further ethnographic and archaeological studies in the future, with application to education and cultural revival.

2 METHODOLOGY

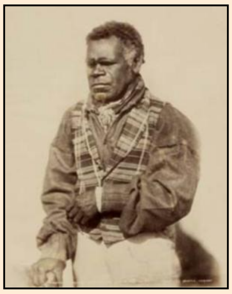
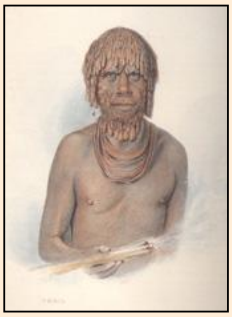
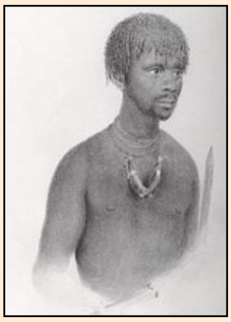
This research draws upon ethnohistorical documents and published material in the literature, including newspapers, library and museum archives, and any associated media that makes any mention of astronomical objects or phenomena with respect to Palawa traditions. No ethnographic fieldwork was conducted for this project.

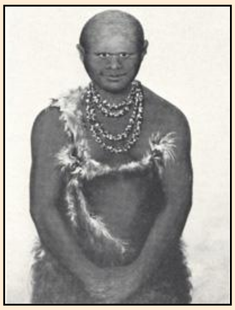
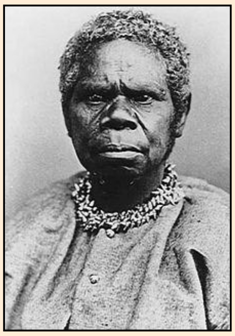
Figure 1: Map of major Tasmanian regions at the time of first European contact (Wikimedia Commons).

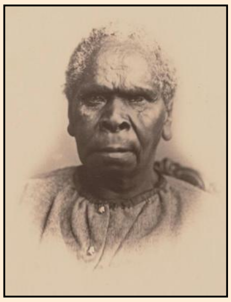
We identify the original Aboriginal sources of information, and link the accounts, narratives or descriptions whenever possible. Two key sources of information were *Mannalargenna*, a leader of the northeast Palawa, and *Woorrady*, a Nuenonne man from Bruny (Brune) Island/ Lunawanna-Alonnah. They guided Robinson through Tasmania in the 1830s. As they spoke of their people’s culture, Robinson recorded it in his journals. Much of the cultural knowledge was recorded during a period of rapid growth of the colony. As such, many of Robinson’s (and others’) records do not name the Aboriginal sources of these oral traditions. Sometimes only the region from which the tradition was recorded is provided.

The people in Table 1 are potential sources of astronomical knowledge despite not being

Table 1: Palawa who accompanied Robinson on his mission and expedition who are likely sources of the recorded information in Robinson's journals. Timler was not part of Robinson's expedition, but is cited as a source of oral traditions by Cotton (1979).

Name	Image	Details
Bullrer *Other Names:* Drummernerlooner Rumanaloo Jumbo Louisa		**Life**: ca 1812- ??? (> 1845) **Bio**: Pairrebeenne woman from Tebrikunna in the far northeast of Tasmania. She was regarded as a highly-intelligent woman who spoke English well. Bullrer joined Robinson's expedition in 1830 when she was 18 as one of eight guides, and she also assisted the military with Line operations. She was the daughter of Bullrub/Poolrerrener, a Pairrebeenne clanswoman. She later married Calamarowenye. **Further Reading**: http://www.utas.edu.au/telling-places-in-country/historical-context/historical-biographies/bullrer
Calamarowenye *Other Names:* Kalamaruwinya Tippo King Tippo		**Life**: ca 1812-1860 **Bio**: Man from the Big River region and husband of Bullrer. He participated in guerrilla attacks against the colonists during the Black War. He kept the jawbone of his murdered brother as a protective amulet, but it was taken by Robinson. **Further Reading**: http://tacinc.com.au/wp-content/uploads/2015/11/Mumirimina-People-of-the-Lower-Jordan-Valley-12.9.10.-29.4.12.pdf
Kickerterpoller *Other Names:* Kikatapula Black Tom Tom Birch	No picture available	**Life**: ca 1803-1832 **Bio**: Paredarererme man kidnapped by colonists at age 9. He broke free in 1822 and joined the Aboriginal resistance against the colonists. He joined the Robinson expedition because of his multi-lingual abilities. **Further Reading**: http://www.utas.edu.au/telling-places-in-country/historical-context/historical-biographies/kickerterpoller
Mannalargenna *Other Names:* Unknown		**Life**: ca 1775-1835 **Bio**: Leader of the Pairrebeenne clan (Cape Portland) in northeast Tasmania. He led guerrilla attacks against the colonists during the Black War and was part of Robinson's team. He was considered a 'clever man' and it is believed that his secret intentions were to lead Robinson away from the people Robinson was trying to find and relocate. **Further Reading**: http://www.utas.edu.au/telling-places-in-country/historical-context/historical-biographies/mannalargenna
Marlapowaynererner *Other Names:* Maulboyheenner Timmy Timme		**Life**: ca 1825–1842 **Bio**: Son of clan leader Raleleeper from Georges Rocks who joined the Robinson expedition in 1830, serving until 1835. He joined Tunnerminnerwait in Victoria and was charged with killing two whalers. He was hanged in Melbourne Gaol on 20 January 1842, along with Tunnerminnerwait. **Further Reading**: http://www.utas.edu.au/telling-places-in-country/historical-context/historical-biographies/timme

Tanleboneyer *Other Names:* Sall Maria		**Life**: ca 1807–1835 **Bio**: A Loontiteermairreloinner clanswoman from Oyster Bay. She became Mannalargenna's second wife in 1830 at age 23. She and Mannalargenna joined Robinson's group in late 1831 and remained until 1835. In August 1835 she fell ill and died at age 28. **Further Reading**: http://www.utas.edu.au/telling-places-in-country/historical-context/historical-biographies/tanleboneyer-sall
Timler *Other Names:* Unknown	No picture available	**Life**: Unknown. Alive in 1830s **Bio**: Timler was an elder of the Big River people who recounted some of his stories to Joseph and Isobel Cotton in the 1830s. He was regarded as one of the most powerful clansmen in Tasmania, but was not a member of Robinson's expedition. **Further Reading**: Cotton (1979)
Truganini *Other Names:* Lalla Rookh Lydgudggee Trugernanner Trukanini Trucanini		**Life**: ca 1812–1876 **Bio**: A Nuenonne woman from Bruny Island, Trugannini was well versed in English and joined Robinson's party in 1829. She was Woorrady's wife and daughter of Mangana, the Bruny Island leader. Truganini suffered a life of abuse, rape and violence. In 1838, she formed a small band of guerilla fighters against the colonists. She narrowly avoided execution, but was imprisoned for 20 years on Flinders Island and a further 17 at Oyster Cove camp. **Further Reading**: http://australianmuseum.net.au/truganini-1812-1876
Tuererningher *Other Names:* Pagerly	No picture available	**Life**: Unknown –1837 **Bio**: Bruny Island woman and sister to a female Nuenonne clan leader known as Nelson. She was on Robinson's expedition from 1829 until 1835, before dying in 1837. Kickerterpoller was her second husband (her first was Mangana, who died in 1829). **Further Reading**: http://www.utas.edu.au/telling-places-in-country/historical-context/historical-biographies/pagerly
Tunnerminnerwait *Other Names:* Peevay Jack of Cape Grim Napoleon		**Life**: ca 1812–1842 **Bio**: Pairelehoinner man from Cape Grim, also known as Peevay. Joined Robinson's expedition in 1830 and served until 1835. Later he was charged with killing two whalers in Victoria, and was hanged on 20 January 1842. **Further Reading**: http://www.utas.edu.au/telling-places-in-country/historical-context/historical-biographies/peevay

Wapperty *Other Names:* Wobberrertee Wonoteah		**Life**: ca 1797–1867 **Bio**: A Pairrebeenne woman and daughter of Manalargenna (one of four). In the 1820s, she was abducted by John Thomas, a sealer, and taken to the Hunter Islands. She lived on Flinders Island for many years and had a child with a Maori sealer named Myetye. Many Palawa today are descendants of Wapperty. **Further Reading**: Lydon (2014: 37)
Woorrady *Other Names:* Mutteellee The Doctor Count Alpha		**Life**: ca 1784–1842 **Bio**: Nuenonne man from Bruny Island who joined Robinson's party as a guide in 1829, along with this wife, Truganini. He joined the team when he was about 45 years old, and showed concern about approaching other clansmen, whom he feared would spear him. He apparently died of 'senility' at age 58. **Further Reading**: http://www.utas.edu.au/telling-places-in-country/historical-context/historical-biographies/woorrady
Woretermoteteyer *Other Names:* Wattermoteer Bung Pung Margaret	No picture available	**Life**: ca 1797–1847 **Bio**: Woman of the Coastal Plains Nation of the northeast coast. She was abducted by George Briggs and accompanied Straitsmen across the Indian Ocean to Africa. She spent time as a guide in Robinson's expedition in the early 1830s. Woretermoteteyer gave birth to a daughter named Dalrymple (Dolly) Johnson, and she passed away at Latrobe in 1847. **Further Reading**: http://www.utas.edu.au/telling-places-in-country/historical-context/historical-biographies/woretermoteteyer-woretemoeteyenner

specifically identified in the written record. They were members of Robinson's expedition team, guides or close relations to those guides. In addition to Robinson, Palawa information was recorded by Henry Roth (1899), James Walker, Joseph Milligan (1890) and James Bonwick (1870; 1884). These men recorded features of Palawa astronomy, usually within a broader discussion of Western ideas of religion and spirituality. Robinson's journals are frequently regarded as the most detailed written account of Palawa life available. During Robinson's mission from 1829 to 1834, he documented his interactions with Aboriginal people in his journals, which were later published as *The Friendly Mission* (Robinson and Plomley, 2008). It is within these journals that we find a majority of the references to Palawa astronomical knowledge.

One of the problems with examining colonial records is that they are translated into Western terminology by non-Aboriginal recorders, who often had a very limited understanding of the Aboriginal traditions. This was further complicated if the recorder did not have a detailed knowledge of astronomy. Misidentifications, conflated terminology and transcription errors plague colonial records of Aboriginal astronomical knowledge (e.g. Hamacher, 2012; Leaman and Hamacher, 2014). Limited information is provided about the identities of the stars in Palawa traditions, and some seem inconsistent or unlikely. In this paper, we examine the identifications proposed by other researchers, and then offer those we think best fit the information provided. This is aimed at obtaining the best picture of Palawa astronomical traditions in the most rigorous way possible. This will form the basis of future work with Palawa elders.

3 RESULTS AND ANALYSIS

Our survey revealed 42 accounts of Aboriginal astronomy tied to a physical location in Tasmania. The astronomical traditions include stars, constellations, and celestial objects (14), the Moon (5), the Sun (1), planets (2) and ancestral spirits connected to the stars (8). These are divided between Bruny Island (13), the Northwest (8), Cape Portland and Swan Island (7), Oyster Bay (5), the Northeast (5), Port Sorell (1), the Big River (1) and Ben Lomond (1).

Figure 2: “The Creation of Trowenna” (left) and "The Creation of *Parnuen* the Sun and *Vena* the Moon" (right). Paintings byTrawlwoolway artist Lisa Kennedy (http://lisakennedy.me), a descendent of Woretermoteteyer. Used with permission.

We present results on the following themes.

(a) Cosmogony: Palawa traditions that describe the formation of the land and the creation of the first people;
(b) Stingray in the Sky: a Palawa constellation, attempting to identify the celestial objects involved in the tradition, as their Western counterparts are not explicitly named;
(c) Time and Astronomy: different concepts of time and the ways astronomical objects were used to denote time reckoning and seasonal change;
(d) Lunar Traditions: Palawa views of the Moon; and
(e) Transient Phenomena: Palawa traditions of aurorae, meteors and eclipses.

3.1 Cosmogony

In Palawa cultures, the sky, land and people are intricately linked, and the stars form the basis of Palawa cosmogony (the formation of the world). The journals of Robinson indicate that Palawa spirituality was based on ‘star gods’, with a good spirit ruling over the day (*Noiheener*) and an evil spirit ruling over the night (*Wrageowraper*) (Ryan, 1996: 10). The creation of the world occurred when ancestral spirits formed the landscape, animals, vegetation and sea, which are represented in material culture (see Figure 2). Traditions from across the island differed slightly, including the pronunciation of the names and details of the story (Cotton, 1979; Cotton, 2013; McKay, 2001; Robinson and Plomley, 2008: 406−410), but in general they were similar.

Leigh Maynard retold a Neunone story from Bruny Island about the creation of Tasmania (Thompson and Tasmanian Aboriginal Community, 2011). It is unclear if this knowledge was passed to Maynard or if he was drawing from earlier written sources. Maynard described the tradition as a circular story, like the cycles of the Moon and the Sun. Long ago, Tasmania (*Trowenna*) was a small sandbank in southern seas. Ice came and went and as the sea rose, the Sun flashed fire. *Punywin*, the Sun man, and his wife *Vena*, the Moon, moved from horizon to horizon together, creating life and sinking into the seas each evening. But *Venna* could not travel as fast as *Punywin*, and she fell behind. He reflected light on her to encourage her to move across the sky and catch up with him. As *Venna* struggled to keep up with *Punywin* and fell behind, he allowed her to rest on icebergs.

One day the Moon seemed to be permanently on the horizon. The day after, their first son, *Moinee*, was born. He was placed high in the sky, above *Trowenna*, as the Great South Star. The next day came their second son, gentle *Droemerdeene*. *Punywin* and *Venna* placed him in the sky between Moinee and themselves as the star Canopus.

The day after *Droemerdeene* was born, the Sun and Moon rose together again above the sandbank that was Tasmania. They dropped seeds for the trees and plants. The next day shellfish appeared in the waters and were plentiful. *Trowenna* gradually rose from the seas and icebergs rubbed against *Trowenna*, pushing it from the great south land (mainland Australia) to the island we see today as Tasmania.

The Palawa guides on the Robinson expedition provided the first records of the creation traditions (Robinson and Plomley, 2008: 406). As in the Maynard account, the Sun and Moon were regarded as a man and woman, respectively. They gave birth to two sons: *Moinee* (the elder) and *Droemerdeenne* (the younger). They came together to create the first man, named *Palawa* or *Parlevar* (now the name given to Aboriginal Tasmanians). *Moinee* first created *Palawa* with a tail like a kangaroo and no knee joints, making it impossible for him to sit or lay down. Seeing *Palawa* struggle, *Droemerdeenne* cut off his tail, then used animal fat to rub over the wound and gave him knee joints (ibid). *Droemerdeene* and *Moinee* later got into a fight in the sky. *Moinee* was cast down and lived on the Earth, followed by his wife, who went into the sea, and his children who came down as rain and fell into his wife's womb (Robinson and Plomley, 2008: 409). When *Moinee* died, he was turned into a stone found at Cox Bight. A Toogee elder, Timler, recounts a similar tradition (Cotton, 1979).

Moinee is said to have made the first man, the rivers and the islands—attributes also given to *Laller*, a small ant. The interchangeability of the two creator spirits may indicate they are one and the same: a totemic relationship similar to some practiced in mainland traditions (Robinson and Plomley, 2008: 406; Witzel, 2013: 11). It may also simply reflect variations in the story across the island. The stellar identity of *Moinee* is not known. He was called the "… Great South Star … [who] comes out of the sea …" (Robinson and Plomley, 2008: 406). Plomley identifies *Droemerdeenne* as Canopus, the second-brightest star in the night sky. Canopus is circumpolar as seen from Tasmania and can appear to "… come out of the sea …" as it reaches its lowest altitude (~5.5° from southern Tasmania, which is close to the extinction angle) and begins climbing back up into the sky. *Droemerdeenne* was placed between *Moinee* and their parents, the Sun and Moon. This suggests that *Droemerdeene* is between *Moinee* and the ecliptic.

The identity of *Moinee* is unclear, as the star's Western counterpart is not named and the definition of "southern" is not explicit. *Moinee* is a bright star 'in the south', presumably meaning southerly declination, and *Droemerdeene* is a bright star positioned between *Moinee* and the Sun and Moon, presumably referring to the ecliptic. This leaves a number of options open. If we assume that the brothers are represented by the brightest stars in the night sky, then the best fit is *Moinee* as Canopus and *Droemerdeene* as Sirius. These two stars have similar right ascensions. If we connect a straight line between Canopus, Sirius, and the ecliptic, then Sirius lies almost halfway between Canopus and the ecliptic: $\Delta\alpha$ (Canopus-Sirius) = 36°, $\Delta\alpha$ (Sirius-Ecliptic) = 39°. Other combinations are possible, such as Achernar and Fomalhaut, but these stars are not as bright.

Another clue comes from Robinson and Plomley (2008: 425). On 1 August 1831, Robinson wrote that *Droemerdeene's* brothers were two stars sitting south and east of Orion's Belt:

> Tonight the Brune [Bruny Island] natives pointed out two stars to the southward, laying eastward of Orion's belt, which they said was Dromerdeenne and his brother, i.e. Beegerer and Pimerner. They were brilliant stars and appear to move towards the observer, rising as it were in the southern horizon and setting in the north.

Plomley identifies these two stars as Betelgeuse and Sirius. He suggests the text may be in error and should read "… Dromerdeene's *brothers*, i.e. Beegerer and Pimerner …", instead of "… Dromerdeenne and his brother …" (Robinson and Plomley, 2008: 500). The recorded traditions do not mention additional brothers of *Moinee* and *Dromerdeenne*. Robinson's journal indicates a single brother with two variations in name: *Beegerer* and *Pimerner*. The passage is confusing. Did he mean "… *Beegerer* or *Pimerner* ..."? Neglecting small long-term changes due to stellar proper motion, the declination of stars is constant, meaning a star rising in the southeast will set in the southwest, never the northwest. What did he mean? Were the names *Beegerer* and *Pimerner* some variation of *Moinee*?

If we assume Robinson was recording different names of a single brother of *Dromerdeenne*, (whom we identify as *Moinee*) then his description of the two stars "… laying eastward of Orion's belt …" and rising in southward (southeast), best fits Canopus and Sirius. Orion was not visible until the early morning on the day Robinson wrote in his journal (1 August). When it did rise, Sirius and Canopus were clearly visible in the southeastern sky (the former rising at nearly the same time as Orion's Belt and the latter already 16° above the horizon). Both stars moved in a northerly direction until the Sun rose and the stars disappeared. By this time, Sirius was in the northeastern sky while Canopus remained in the southeast.

We suggest the evidence best supports the identities of the star-brothers as Canopus (*Moi-*

nee) and Sirius (*Dromerdeenne*). We feel it is a better fit than *Droemerdeene* as Canopus and *Moinee* as an unidentified star, but this remains uncertain. The idea that a bright star appeared in the sky but is no longer visible may hint at a possible nova or supernova, but there is currently no supporting evidence for this interpretation (Hamacher, 2014).

On a final note, Cotton (1979) recorded a story from Timler explaining that the son of Moinee was a little star named *Palana*. *Palana* mixed ashes and blood and rubbed it along the back of a thylacine pup, causing the animal's distinctive stripped feature. The Western counterpart of *Palana* is not given.

3.2 The Gemini Twins and the Origin of Fire

Traditions that describe how fire was brought to the Palawa tend to focus on the actions of two ancestor spirits who can be seen today as two stars near the Milky Way. A tradition from Oyster Bay tells how the two men stood on a mountaintop and "… threw fire, like a star … [that] fell among the blackmen." (Milligan, 1859: 274). The two men lived in the clouds and could be seen in the night sky as the stars Castor and Pollux (the Gemini twins in Greek traditions). On 14 August 1831, Robinson discussed religion with Mannalargenna. Mannalargenna said that two men created fire and now lived in the skyworld. Mars was his foot and the Milky Way his road. According to Mannalargenna, the Cape Portland people believed fire was first made by *Pormpenner*. This name will be mentioned twice more in relation to fire but was spelt differently each time it was recorded: *Pardedar* (Robinson and Plomley, 2008: 872) and *Parpedder* (Robinson and Plomley, 2008: 577). On 15 August 1831, Robinson wrote that Palawa from Bruny Island said two stars in the Milky Way represented two men (Robinson and Plomley, 2008: 433). Woorrady described *Parpedder* as being the one who gave fire to the people of Bruny Island. Why two men were identified, but then referred to in the singular is unclear.

On 16 August 1831, Mannalargenna called the two stars *Pumpermehowlle* and *Pineterrinner*. He described them as the two spiritual ancestors who created people and fire, but the stars' Western counterparts were not named. Later, Milligan (1859: 274) recorded a story called *The Legend of the Origin of Fire* from an unknown Oyster Bay person, who identified Castor and Pollux (the Gemini twins) as the two men who created fire.[1]

There is a problem with setting a planet as the body-part of a celestial ancestor. Planets constantly move relative to the stars. Was the foot of the man (men?) actually Mars, or a red star of similar brightness? During 14–16 August 1831, Castor and Pollux rose heliacally. They set before dusk, so were not visible in the evening sky. Mars was in near conjunction with Saturn (and <2° distant) at very low altitudes at dawn, with Venus and Mercury above them in the western sky. Since the stars were not in the sky when Robinson was told about them, how did he identify the foot of the man as Mars?

Castor and Pollux are northerly stars, only reaching a maximum altitude of ~16° and ~20°, respectively, as seen from Tasmania. There are no bright (first magnitude) red stars between the Gemini twins and the Milky Way. Orion is on the other side of the Milky Way and the ecliptic passes between them. Mars could appear at the "foot" of the hunters walking on the Milky Way, but this would be (relatively) sporadic. Earlier in May 1831, Mars was visible between the Gemini twins and the Milky Way. Perhaps this is the reason Mars was recorded in this way? The stellar counterparts remain unclear, but this is the only written record of the hunters' identity.

If the recorded information is from Mannalargenna, then from whom did Milligan get his information? Milligan was a doctor on Flinders Island after the Robinson expedition and would have formed relationships with the same Aboriginal people who accompanied Robinson. Mannalargenna died in 1835, nine years before. Sometime between 1843 and 1855, Milligan recorded the *Legend of the Origin of Fire.* Milligan did not specify the gender of the narrator. Still, a census was performed by Robinson in 1836 renaming Aboriginal people with English names (Plomley and Robinson, 1987: 878). It is probable this list contains the name of the person who gave Milligan this story. It is important to note that among this role-call were Wapperty, Calamarowenye, Truganini and Bullrer—all of whom were on the Robinson expedition and originated from the Oyster Bay region (Gough, 2014: 33). Any of the aforementioned people could have been Milligan's source.

3.3 The Coalsack and the Celestial Stingray

Robinson recorded a tradition of a stingray in the sky on 13 March 1834 at 23:00 (Robinson and Plomley, 2008: 895). The stingray was described as a black spot in the Milky Way (or Orion's Belt) that people were spearing. It was called *Larder* in the south (Table 2) and *Larner* on the east coast. Robinson used *Larder* in 1831 to identify the 'dark area' in the Milky Way (ibid: 497). *Larner* was also used in relation to Mars and *Lawway Larner* translates to "Milky Way/road – Stingaree" (Robinson and Plomley, 2008: 895). *Larner* may have been incorrectly linked with Mars, or this word may take on other meanings. Another version of the word for fish is '*Lerunna*', which was recorded by Milligan (1890: 28) as "Flat Fish or Flounder".

Table 2: Notes regarding star names found at the end of Robinson's journals, April–July 1831.

Object	Oyster Bay	Brune/Bruny Island	Cape Portland
Mars		LAW.WAY LAR.NER	LAW.WAY DEVER.ER
Star (1)	PUCK.AR.NE.PEN.NER	PY.LE.BAY	PUM.PER.ME.HOWL.LE
Star (2)	LORE.NE.PEN.NER (wife)	LAW.WAY	PINE.TER.RIN.ER
Black Milky Way		LAR.DER	PY.ER.DREEM.ME TONE.NER.MUCK.KEL.LEN.NER
White Milky Way		LAW.WAY.TEEN.NE	PUL.LEN.NER

Figure 3: The Coalsack, bordering the Southern Cross (Crux) (Image: Wikipedia Commons).

Robinson identified the 'black spot' as being in the Milky Way or Orion's Belt. This was probably the Coalsack (Figure 3), a dark absorption nebula that could be seen clearly with the naked eye and appeared as a dark hole against the backdrop of the otherwise-bright Milky Way.

The Coalsack borders the Western constellations of Centaurus, Musca and Crux, not Orion (which is 90° away on the other side of the sky). On 13 March 1834, Orion was sitting prominently above the western horizon at 23:00 and it did not contain any large or obvious dark nebula visible to the naked eye.

Robinson's entry states that the stingray was being speared by the men. We suggest the spears may have been the Pointer Stars, α and β Centauri.[2]

Cotton (2013) provides a retelling of the story of *The Legend of the Origin of Fire*, in which the men and their wives were identified as the stars of Crux (the Southern Cross). The original account of the story was recorded by Joseph and Isobel Cotton from Timler, an East Coast Palawa storyteller, in the 1830s, but the records were lost in a house fire in 1959 (Stephens, 2013). Years later, descendent William Jackson Cotton (1909–1981) rewrote the stories from memory and published them as *Touch the Morning* (Cotton, 1979). More recently, William Cotton's daughter, Jane Cooper, published William's recollected stories in Cotton (2013), but without consultation with the local Aboriginal community (Johnson et al., 2015: 14). The republished version of the story, called *Cross of Fire*, evokes substantial Christian imagery.

It identifies the mountain in the story, *Meledna Lopatin* (Mountain of Fire), as Mount Amos in eastern Tasmania (Cotton, 2013: 62). It also names the two men who bring fire as *Una* and *Bura*. Translations of the men's names are found in Roth's (1890) consolidated vocabulary. *Una* or *Une* translates to *fire*. The two words joined —*Une Bura*—is translated to 'lightning' and *Bura* alone is translated as 'thunder' (Roth, (1890: xiv). *Una* and *Bura* differ from the names given to these two stars in Robinson's recordings, and give a literal and direct translation to their intended meaning: fire, lightning and thunder. Similar to *The Legend of the Origin of Fire*, this story ends with the two men and the two women returning to the sky. However, *Cross of Fire* identifies the four stars as the brightest four stars in Crux (the Southern Cross), called *Urapane Lopatin* ('Cross of Fire') in the eastern Palawa language (Roth, 1890: xxiii, xi, respectively). In this account, the stingray joins them in the sky. This is the first account that mentions this. Conversely, the *Cross of Fire* story does not identify the Coalsack or any dark patches in the sky (see Cotton, 2013: 71). It is difficult to ascertain the accuracy of these records, given that they were retold from memory long after they were recorded, and they contain heavy Christian imagery.

Going back to Robinson's journals between April and July 1831, he identified a particular star, *Lorenepenner,* as being female (Table 1). The Oyster Bay word *Lorenepenner* is translated as 'wife' (Robinson and Plomley, 2008: 497). Milligan (1890: 51) identified the women as *Lowanna*, which was a common word for women in Milligan's own collected vocabulary. The presence of a female-star in Robinson's notes supports the idea that a version of *The Legend of the Origin of Fire* could have been relayed to Robinson during his mission, with the names of the stars representing the names of the ancestral protagonists featured in the story.

On 27 June 1831, Robinson wrote:

> In conversation with the natives respecting the stars. These people, like the ancients, have described constellations in the heavens as resembling men and women, men fighting, animals, and limbs of men; together with names for the stars. The Aborigines pointed them out. (Robinson and Plomley, 2008: 497).

Unfortunately, like many of Robinson's entries, it is condensed and short on detail. The excerpt provides a summary of features of Aboriginal interpretations of the stars, many identifiable within Milligan (1890).

This tradition, shared by a member of the Oyster Bay group, can be unpacked beyond that of labels and language. Oral traditions are passed down for (potentially) thousands of years. These traditions are encoded with information significant to the survival and navigation of the physical and social landscape. Reading the canopy of stars above as a form of traditional text informs practice on land, which is evident in *The Legend of the Origin of Fire.* On the surface, this tradition explains how fire came to the people of Tasmania. But this story contains information about seasonal indicators, fishing customs, burial and healing practices, as well as fire attainment.

Palawa women living on coastal environments, like Oyster Bay, spent many hours in the water. Acting as the main hunters of shellfish and being trained from a young age, they could dive considerable depths on a single breath (Robinson and Plomley, 2008: 66−88; Johnson et al., 2015: 39). Due to the significant time people spent in the sea, the oral tradition and the night sky were important for informing cultural practices regarding how to navigate their environment safely.

According to the oral tradition, two women diving for crayfish were 'sulky' due to the actions of their unfaithful husbands. Consequently, the women were speared by the stingray and died. The same wording was used in an earlier recording of a separate incident in Robinson's journals. On 4 November 1830, Robinson described the women returning from diving for crayfish off Swan Island, where they were chased by a shark (Robinson and Plomley, 2008: 302). The women were described as sulky, which made the sharks come.

The Legend of the Origin of Fire also described the women as being 'sulky' when they were speared and killed by the stingray. Afterwards, the two star men arrived and killed the stingray with their spears (Milligan, 1890: 13). This reflects culture practiced on the ground. Lloyd (1862: 52) recorded a personal observation from an Aboriginal hunting trip the morning after a significant corroboree was held during a Full Moon. He describes how up to 300 people surrounded stingrays in a semi-circle, and then the men speared them.

The final section of this tradition (Milligan, 1890: 13) explains the revival of the two women who were speared by the stingray. The dead women were placed on either side of a fire and the men placed 'blue ants' on the breasts of the women. After being bitten severely, the women came back to life. The importance of fire within Aboriginal cultures and its relationship with rejuvenation and healing is described in oral tradition. On the Wellesley Islands in the Gulf of Carpentaria, meteors signal the end of a healing process (Cawte 1974: 110). A disease called *malgri* is treated by lighting a fire next to the patient, encouraging them to heal by sweating.

Similarly, Bonwick (1870) described a Palawa patient drinking lots of cold water then lying by the fire to encourage perspiration.

The blue ant (*Diamma bicolor*) is actually a parasitic wasp found throughout southeast Australia. The female has an ant-like appearance and if disturbed, her stinger can cause burning pain and swelling. Early recordings ascribe large ants or *Diamma bicolor's* eggs as being a delicacy among the Palawa (Noetling, 1910: 281). Blue ants are active in mid to late summer, playing an important role in pollinating native plants, a possible timing component within the tradition that indicates seasonal change (ibid.).

3.4 Time, Navigation and Astronomy

Time-keeping is important for food economics, calendar development and ceremony. Consolidated vocabularies of the language groups of Tasmania (Table 3) reflect words used to indicate time of the day (e.g. sunrise, midday, sunset, twilight), astronomical presence (e.g. starlight, moonlight) and seasons (Milligan, 1890; Plomley, 1976). There are no words for the concept of time itself, a point made by Stanner (2011).

Roth (1890: 146) made a fleeting comment on the understanding of time and astronomy of Aboriginal people. He noted that they pointed out the diurnal motion of the Sun with their hands and held up two fingers to denote two days. He then claimed that "This is the only reference to any knowledge of the movement of the heavenly bodies." Conversely, Robinson wrote on 13 March 1834 that the Palawa were quite familiar with the stars and had names for them all and were aware of their movements (Robinson and Plomley, 2008: 302). This demonstrates knowledge of the movement of heavenly bodies.

On 25 December 1830, Robinson praised the "… considerable knowledge …" of Palawa on meteorology so much so that they had "… attained to such celebrity." As a result, Robinson and other white men would consult them on the subject and be pleased at the information they received as it was seldom wrong (Robinson and Plomley, 2008: 334). The Palawa used the stars and clouds to predict weather and determine when to fish, build huts and travel.

Astronomical knowledge is embedded in Aboriginal traditions, but is not always as obvious as a direct statement. Robinson's manuscripts describe a song from the northwest, north coast, and interior Palawa groups that was possibly used for navigation and travel. The Palawa

> … repeat the words *tonener* (Sun) and point the way the Sun is travelling in her course, and point to where they are stopping for the Sun to be there. (Plomley, 1976: 51).

Tonner also referred to the 'West' (Plomley, 1976: 205) and was part of the word for the Black Milky Way, *tonnermuckkellenner* (Plomley, 1976: 408). The description of the actions that accompanied the repetition of *tonner,* indicated that this song was sung to help with timing and navigation on their journey, serving as an insight into a Tasmanian songline. We suggest that the songline describing "… the way the Sun is travelling … [and indicating] where they are stopping …" in relation to the Sun demonstrates a form of celestial navigation.

Table 3: Vocabulary table of Aboriginal words indicating time of day (after Plomley, 1976).

Term	Bruny Island /Southern TAS	Oyster Bay	Northern TAS	Western TAS
Twilight	nunto neenah	teggrymony keetana narra long - boorack		
Early morning twilight	nunawenapoyla	tuggamarannye		
Sunrise	panubre roeelapoerack	muenattemelar	warkala wetinneger	
Sunrise		puggalena parrack boorack		
Midday	toina wunna	tooggy malangta		
Midday	wer			
Sunset	punubra tongoieerah	wietytongmena		
Sunset		partopelar		
Moonlight	weetapoona	wiggetapoona		weenapooleah
Starlight	oarattih	teahbertyacrackna		

Table 4: Names given to the three stars shown to Robinson on 30 June 1834

Origin	Aboriginal Word	Possible meaning
Bruny Island	PUR	White Edible Berry
Oyster Bay	PARNG.GER.LIN.NER	Wife (Eastern)
Northern	NOE.GO	West Point (place)
Western	LONE.ER.TEN	Wife

3.5 Seasonal Change and Astronomy

A group of three unidentified stars marking seasonal change are mentioned three times in the literature: twice in Robinson's journals (on 20 June 1832 and 30 June 1834) and again in interviews conducted by Ernest Westlake between 1908 and 1910. In all instances, the three stars were used to track time seasonally. In the 1832 account, the dark phases of the Moon were used in conjunction with stars to indicate specific shorter intervals of time. The Western names of these stars remain unknown.

Robinson's 30 June 1834 entry (Robinson and Plomley, 2008: 111) provides the positions and magnitudes of the mystery stars and their use as a seasonal indicator (the names are listed in Table 4):

> AM, calm and clear, fine weather, Sun hot. The natives showed me the three stars which they say is a sign that the fine weather is coming and when those stars are vertical the fine weather is come. They appeared in the heavens to the eastward. No. 1 was large and is called the mother, No. 2 the husband is of lesser magnitude and No. 3 the offspring is hardly visible. They are called by the Brune natives PUR, by the western natives LONE. ER.TEN, by the northern natives NOE.GO, and by the natives of Oyster Bay PARNG.ER. LIN.NER.

The Bruny Island word *Pur* is similar to *Purrar*, a Bruny word given to white edible berries (Plomley, 1976: 340). This association suggests that the star is white, ruling out red stars. The Western group's word *Loneerten* has connections with *Looner*, or 'wife' across many Palawa-language groups (Plomley, 1976: 471). The Northern word *Noego* is quite close to *Nongor*, the Palawa name for West Point in northern Tasmania. *Parnggerlinner*, from Oyster Bay, may be related to the word *Parnuneninger* for 'wife' used by some eastern groups (Plomley, 1976: 321).

Key information provided from this journal which aids in identifying the stars is as follows:

(1) The date visible was 30 June 1834 at dawn (see Figure 4);
(2) The stars appeared eastward (azimuth between 0° and 180°); and
(3) The stars were of different magnitudes: a large (bright) star (presumably first magnitude), a lesser bright star (presumably a second or third magnitude star), and a hardly visible star (presumably of the fifth or fainter magnitude).

The orientation of the three stars in his drawing is an illegible number. Plomley interpreted this number to be 30, presumably from looking at the sketch drawn by Robinson in Figure 5. Robinson wrote that the stars indicated fine weather was coming. When they were vertical, fine weather had come. Identifying a period of

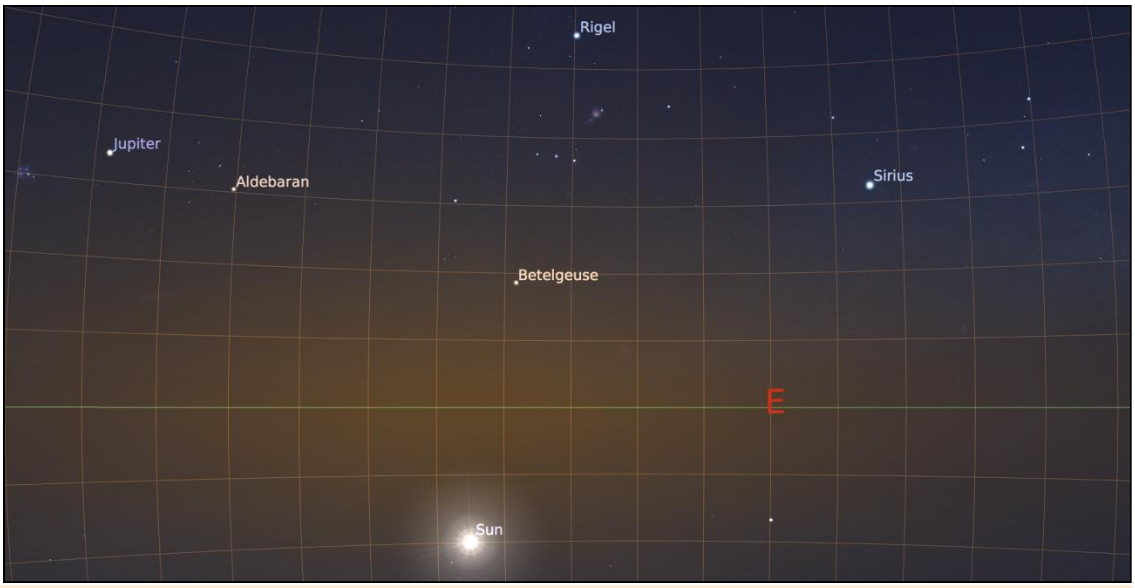


Figure 4: Stars in the eastern sky at dawn (when the Sun is at an altitude of –10°) on 30 June 1834. Notable first magnitude stars are Sirius (right), Rigel (top), Betelgeuse (centre), and Aldebaran (left). The grid is shown in 5° increments in both declination and right ascension, where the green horizontal line is the horizon (Image: Stellarium).

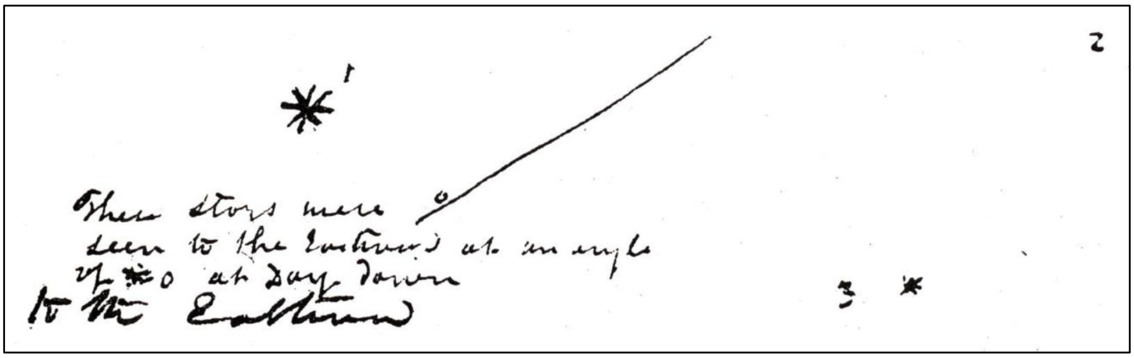


Figure 5: The sketch Robinson made showing the orientation of the three stars described on 30 June 1834.

‘fine weather’ in the calendar year will approximate a date to then test for stars that are vertical at this time. The clan territories that name the stars are from the North, East, West, and South of the island, indicating that ‘fine weather’ would (on average) be experienced across the whole of Tasmania. Meteorological data show that Tasmania experiences constant rainfall through the year, with winter having the most, and can experience multiple seasons in one day. Based on these data, ‘fine weather’ could be considered the ‘summer months’, most likely January. Since the time when climate records were first kept, January has the least rainfall.[3]

With these variables in mind, Plomley’s identification can be tested. Plomley classified the three stars as the Pointer stars, α and β Centauri (Plomley, 1997; Robinson and Plomley, 2008: 953). On the morning of 30 June 1834 (when the Sun was 10° below the horizon; see Hamacher, 2015), the Pointers appeared in the southwest (Az = 185°–190°), not the east. The Pointers were both of similar brightness (V_{mag} = +1.33 and +0.61 for α and β, respectively) and a third barely visible star in a line with these was difficult to identify.

The Pointers are circumpolar as seen from Tasmania, so they can appear to be horizontal on some occasions in the morning and vertical in others: they are vertical (having the same azimuth) in the morning sky in mid-January and are horizontal (having the same altitude) high in the sky a month later in mid-February, or horizontal low in the sky in late July/early August.

Plomley's identification is inconsistent with the information drawn from the journal entry. Despite lining up vertically at certain times of the year, α and β Centauri encircle the South Celestial Pole. Robinson stated that the three stars lay to the east. In subsequent publications, researchers have mis-transcribed Plomley’s hypothesis by claiming the stars in question are α and β Crucis (the two brightest stars in the Southern Cross), causing some confusion (e.g., see Coon, 1972: 288).

While it is difficult to accurately label the stars from the description given, there were a number of stars sitting on the eastern horizon on that morning. Many moved to a vertical position on the western horizon, on a mid-January morning. The following stars/star groups appeared prominently in the east at dawn on 30 June 1834: Pleiades (Messier 45), Sirius (α Canis Majoris), Aldebaran (α Taurii), Betelgeuse (α Orionis), Bellatrix (γ Orionis) and Orion’s Belt (Mintaka, Alnilam, Alnitak).

This list identifies *the most prominent* stars visible at that time. Canopus is not included in this list as it sat closer to the southeast, never set below the horizon (it was circumpolar), and previously was identified as the creator ancestor *Droemerdeene* (although we question this identification). We attempt to identify the stars recorded by Robinson by examining a suitable list of candidates and comparing them with the information provided in the record, utilising the stars’ magnitudes, relative positions, and colours (Tables 5 and 6).

Robinson’s sketch does not show the stars in a linear pattern. The third star is described as being “… barely visible”. Due to the faint magnitude of the third star there are multiple candidates. When grouping the three stars we take into consideration the orientation of the third star as well as the magnitude; only picking stars that were fifth magnitude or brighter.

Groups 3 and 7 are the only ones that meet all of the criteria. The Group 3 stars (Figure 6) fit the description reasonably well. Of the three stars, Sirius the brightest star in the sky, sat eastward at dawn. Its orientation with Adhara and Wezen was similar to the sketch drawn by Robinson (Figure 5). Sirius, the most northerly of these stars, exceeded an altitude of 5° (the extinction angle) when the Sun was at −10° altitude on 15 June 1832. This is considered the first day the three stars of Group 3 were unambiguously visible in the east at dawn. The relative brightnesses are roughly consistent, although Wezen, with a V_{mag} of 1.2, is not “hardly visible”. But when the stellar trio were very low on

Table 5: Seven possible groupings of three stars as recorded by Robinson. The groupings of three stars noting their visual magnitudes (V$_{mag}$), general spectral type (colour), and the star's coordinates (right ascension and declination in J2000).

Common Name	**Bayer Designation**	**V_{mag}**	**ST (Colour)**	**RA (J2000)**	**DEC (J2000)**
Rigil Kent	α Centauri	0.01	G (Yellow/White)	14^{h} 39^{m} 36.5^{s}	–60° 50′ 02.4″
Hadar	β Centauri	0.61	B (Blue)	14^{h} 03^{m} 49.4^{s}	–60° 22′ 22.9″
Hip 70264 A	n/a	4.90	K (Orange)	14^{h} 22^{m} 38.02^{s}	–58° 27′ 36.7″
Mintaka	δ Orionis	2.23	O/B (Blue)	05^{h} 32^{m} 00.4^{s}	−00° 17′ 56.7″
Alnitak	ζ Orionis	1.77	O/B (Blue)	05^{h} 40^{m} 45.5^{s}	−01° 56′ 33.3″
Alnilam	ε Orionis	1.69	B (Blue)	05^{h} 36^{m} 12.8^{s}	−01° 12′ 06.9″
Sirius	α Canis Majoris	−1.46	A (Blue/White)	06^{h} 45^{m} 08.9^{s}	−16° 42′ 58.0″
Adhara	ε Canis Majoris	1.50	B (Blue)	06^{h} 58^{m} 37.6^{s}	–28° 58′ 19.0″
Wezen	δ Canis Majoris	1.82	F (White)	07^{h} 08^{m} 23.5^{s}	−26° 23′ 35.5″
Aldebaran	α Tauri	0.87	K (Orange)	04^{h} 35^{m} 55.2^{s}	+16° 30′ 33.5″
Bellatrix	γ Orionis	1.64	B (Blue)	05^{h} 25^{m} 07.9^{s}	+06° 20′ 58.9″
Meissa	λ Orionis	3.50	B (Blue)	05^{h} 35^{m} 08.29^{s}	+09° 56′ 03.0‴
Betelgeuse	α Orionis	0.42	M (Red)	05^{h} 55^{m} 10.3^{s}	+07° 24′ 25.4″
Mirzane	β Canis Majoris	1.99	B (Blue)	06^{h} 22^{m} 42.0^{s}	−17° 57′ 21.3‴
Beta Monocerotis	β Monocerotis	4.60	B (Blue)	06^{h} 28^{m} 49.16^{s}	−7° 01′ 58.2‴
Rigel	β Orionis	0.12	B (Blue)	05^{h} 14^{m} 32.26^{s}	−8° 12′ 06.0″
Mirzam	β Canis Majoris	1.99	B (Blue)	06^{h} 22^{m} 42.0^{s}	−17° 57′ 21.3″
Saiph	κ Orionis	2.09	B (Blue)	05^{h} 47^{m} 45.4^{s}	−09° 40′ 10.6″
Bellatrix	γ Orionis	1.64	B (Blue)	05^{h} 25^{m} 07.9^{s}	+06° 20′ 58.9″
Saiph	κ Orionis	2.09	B (Blue)	05^{h} 47^{m} 45.4^{s}	−09° 40′ 10.6″
Gamma Monocerotis	γ Monocerotis	3.95	A (White)	06^{h} 14^{m} 51.10^{s}	−06° 16′ 26.0″

Table 6: Possible groupings of three stars using the description recorded by Robinson. The groupings are tested to see if they match the criteria using Robinson's recorded descriptions.

Star Groupings	**Non-Red Stars**	**Eastward**	**Dawn**	**Sketch and Magnitude**	**Vertical in mid-January**
Group 1	✔		✔		✔
Group 2	✔	✔	✔		✔
Group 3	✔	✔	✔	✔	✔
Group 4		✔	✔		✔
Group 5		✔	✔	✔	✔
Group 6	✔	✔	✔		✔
Group 7	✔	✔	✔	✔	✔

the horizon at dawn, the background light was enough to sufficiently obscure it and make it appear much fainter.

Group 7, while meeting all of the criteria, seems less likely as they straddled Orion's Belt. Orion's Belt was mentioned by Robinson in earlier entries, indicating that he knew the asterism and was likely to have labeled or located them when describing the three stars. There is one problem: if Plomley is correct in identifying Betelgeuse and Sirius as *Dromerdeene's* brothers, would he not recognise Sirius—the brightest star

Figure 6: A trio of bright stars in Canis Major—Sirius, Adhara, and Wezen (Group 3)—are the best fit for the three stars described and illustrated in Robinson's journals. Sirius has an azimuth of 107.5° at an altitude of 5° at dawn (when all three stars are first visible together above the horizon) on 15 June 1832 (shown) (Image: Stellarium).

in the sky—and realise that it was already identified in Palawa traditions?

An altercation between the Tarkiner group of Northwest Tasmania and the Robinson party occurred, and a fight was scheduled to take place at Nongor (West Point). The two entries below were made by Robinson regarding the timing of this fight (Robinson and Plomley, 2008: 652):

> 19 June 1832: I learnt that the TARKINER natives were to come and fight them when the rest came back from Robbins Island – the TARKINER would come two dark nights after the Moon was gone (it was now moonlight).
>
> 20 June 1832: Learnt that the greater part of the natives had gone to Robbins Island and were engaged in getting spears, that they would return again when two darks or when the three stars come.

The New Moon (denoting the days where less than 3% of the Moon facing the Earth is illuminated) occurred from 26 to 28 June 1832. The fight with the Tarkiner was scheduled for 29 June 1832—two nights after the 'disappearance' of the Moon. This allowed the combatants nine days to prepare. Additionally, the appearance of the stars may have signified the time of day, not the day of the month. This may have been indicated by two dark nights (date) and "… when the three stars come" (time), translating to Friday 29 June 1832 at approximately 05:45.

The reference to "… when the three stars come …" seems to refer to the three stars we are trying to identify in this section. Coincidently, Robinson was shown the three stars that indicated seasonal change exactly two years later, on 30 June 1834, suggesting the same three stars were described in both accounts. The earlier mention of the three stars in 1832 indicates that they had yet to appear in the sky.

In an interview with Ernest Westlake, noted under the heading 'Springtime', Augustus Smith (Fanny Cochrane Smith's grandson) spoke of three stars (Plomley et al., 1991: 63):

> Three little stars in the east on a level only once in a year. Thought a lot of them, justto see them blinking. FS thought it a terrible thing if didn't welcome these three little stars. Would sprinkle the ashes from the hearth very early in the morning before the Sun had risen, when the stars are bright.

Like the two previous entries in Robinson's journals, Smith described the three stars to the east in the early morning 'on a level', and associated them with seasonal change (springtime). The three stars of Orion's Belt (Alnitak, Alnilam, and Mintaka) are seen in the early morning sky rising 'on a level' during the winter months of June, July, and August (Figure 7). The stars of Orion's Belt rise heliacally (at dawn) around 8 June each year, and heliacally set (at dusk) around 19 July. The heliacal rise appears to be premature for a welcoming of Spring, yet the Orion asterism is visible in the sky, just as described in the three literature entries.

The earliest recording of three stars in June 1832 gives timing components (dates, two dark nights, indication of moonlight) to cross check. The emergence of the three stars of Orion's Belt is in line with the description. Orion's Belt ap-

Figure 7: The stars of Orion's Belt rising in the East (right) and setting in the West (left) as seen from Tasmania in the 1830s. The belt stars are 'level' as the rise, and perpendicular to the horizon as they set (Image: Stellarium, but 'without atmosphere' for clearer visibility for the reader).

peared above the horizon early in the morning from 05:30, before setting with the Sun at 07:00. Two years later, nearly to the day, Robinson wrote about three stars again. Accompanying the entry is the sketch placing the stars as 'eastward' at 'day dawn'. The three stars of Orion's Belt were clearly visible on the horizon in the east at that time. The repetition of the position of the three stars at the similar time of year supports the idea that the three stars of Orion's Belt could be the stars recorded in the journal. The constellation of Orion is visible above the horizon during summer nights, supporting the idea that the first appearance of these stars would have been welcomed after a cold Tasmanian winter. This is uncertain, but will be the topic of future ethnographic work.

3.6 Lunar Traditions

As noted in Cotton's (1979; 2013) recording of Toogee elder Timler's tradition, the Sun and Moon are parents of the creation ancestors that became the first stars. Similar traditions exist across Tasmania. The Palawa of Bruny Island told Robinson how the Moon-woman, *Vetea*, got her dark patches (the maria on the Moon):

> The Brune natives affirm that the Moon (VETEA) came from England and that she stopped at the RORE.DAIR.RE.ME.LOW, that is, the country at Oyster Bay, that the kangaroo and mutton fish asked the Moon to stop there, that the Moon was LOONER, woman, that she was roasting mutton-fish when the Sun (PARNUEN) came and swept her away, and she tumbling into the fire was hurt on her side and then rolled into the sea, and afterwards went up into the sky (WARRANGERLY) and stopped there with her husband the Sun. They say the rainbow is the Sun's children. [Woorady] Told me if I looked I would see it black where she had been burnt. (Robinson, 1831: 412).

The Adnyamatana of the Flinders Ranges in South Australia have a tradition in a similar vein. *Vira*, the Moon-man falls off his stick ladder while trying to punish his nephew for stealing his food (Tunbridge, 1988: 68–69). On impact he bursts open, leaving marks on his belly.

The Moon was used by Palawa to tell the time (Robinson and Plomley, 2008: 652) and count (Robinson and Plomley, 2008: 267). The appearance of the Moon could also signal a change in the weather (Robinson and Plomley, 2008: 334):

> … if a circle [halo] is round the Moon it's a sure sign of bad weather. Indeed, they have numerous signs by which they judge and I have seldom found them to err. Thus they are enabled to know when to build their huts, to go to the coast for fish, travel etc. They also judge by the stars and have names by which they distinguish them.

In the weather folklore of cultures around the world, lunar haloes have long been used to predict bad weather (e.g. Guiley, 1991: 22). The halo itself is caused by moonlight being refracted by ice crystals in the atmosphere. These crystals form in cirrus clouds, which often come before a low pressure system, of which rain is a frequent result.

These traditions emulate a constant theme of disruption and restoration that is common in lunar traditions. We argue that the Moon was a symbolic cycle of pain and healing that was reflected on the bodies of Palawa. Scarring was first thought to be unique to each group, as a distinguishing feature between nations. Yet often when there was mention of cicatrices, Robinson offered an astronomical motif in partnership, indicating meaning beyond the cosmetic (Johnson et al., 2015: 35). Sightings of Moon- or crescent-shaped markings on Palawa bodies appeared, but were not limited to the east coast of Tasmania. When they landed on the east coast of Tasmania, Lieutenant Le Paz, a member of French explorer Marc-Joseph Marion Dufresne's expedition in 1772, noticed "… several little scars or black marks in a crescent shape …" on the chest of a young man (Duyker, 1955: 33).

On 1 November 1830, Robinson observed

most of the people from the eastern groups "… had the form of the Moon cut on their flesh." (Robinson and Plomley, 2008: 297). In a note written on the end pages of his journal, Robinson carried on this thought and wrote (ibid.: 613):

> … the Aboriginal females on the islands have round circles cut in their flesh in imitation of the Sun or the Moon. I have seen a woman with four of them on her body; others I have seen with two or three. They are very fond of them, are generally placed on each side of the backbone and about the hips ... The cicatrices of the Sun and Moon is intended to remove inflammation and having the power of those luminaries they imagine it will have the same influence on the part infected.

Similar circular images were reproduced in rock engravings, drawings, huts, stone arrangements (Bonwick, 1870: 192), and on bodies, often involving more than one meaning. Robinson wrote of a surveyor, Mr Hellyer, seeing a circular charcoal drawing and believing it was a representation of the Sun. Robinson corrected him in his journal stating: "Those circles are emblematical devises of men and women …" (ibid.: 575). In regard to this entry, Plomley addresses the conflicting meanings without mentioning the possibility of the circle being a polysemous symbol. The Moon was previously identified as a woman named *Vetea*, indicating a circle can mean both woman and Moon. The multi-layered meanings of man, woman, Moon, and Sun are interchangeable and complex. The power of each is not confined to a singularity, but rather an Indigenous view of well-being, traversing body, environment, and spirit in an ebb and flow of meaning and balance.

Robinson identified women specifically in the above passage, noting their cicatrices were localised around the hips and on either side of the spine. These areas on a woman's body are affected by strain during childbirth and menstruation. The waxing and waning Moon is often linked to the cyclic flow of menstruation (Berndt and Berndt, 1993). The Moon is recorded as both male and female across Aboriginal communities in Australia (usually male), and is often related to fertility, no matter the gender. The Moon man in some traditions, if looked at directly, can impregnate young women (Haynes, 1997: 107) or oppositely render the onlooker barren (Bates, 1972).

In Tasmania, the placement of these cicatrices could have been used as a healing agent in response to back pain and curing issues around fertility. Women were assigned much of the labour, including hunting crayfish and seals, climbing trees for possum, mining ochre, and on Robinson's journeys carrying the bulk of the load while travelling. The men hunted larger game and act as guards for the group (Johnson et al., 2015; Robinson and Plomley, 2008).

Finally, the origin story recounted by Leigh Maynard (Thompson and Tasmanian Aboriginal Community, 2011) in Section 3.1 described the phases of the Moon. In the beginning, the Sun and Moon rose together (New Moon). As each day passed, the Moon woman fell behind the Sun man in their journey across the sky. He encouraged her by lighting more of her up each day, which explained the waxing Moon. Eventually she was on the opposite side of the sky to the Sun (Full Moon). This is one of the rare accounts that explicitly acknowledges that the light of the Moon is a reflection of the Sun's light (a point noted by R.S. Fuller, pers. comm., 2016).

3.7 Transient Phenomena

Transient phenomena, such as meteors, comets, eclipses and aurorae, are featured prominently in Aboriginal traditions across Australia (Hamacher, 2012). Palawa from across Tasmania also have traditions of these phenomena, which are discussed in this section.

3.7.1 Meteors

There are few records of how Palawa perceived or understood meteors in their traditions. In southern Tasmania, a meteor was called *Pachareah* (Milligan, 1866: 426) and Coon (1972: 288) mentions that a falling meteorite one night startled some Palawa, who shrieked and hid their heads.

In Plangermairrener traditions (Noonuccal, 1990: 115–119), a cheeky woman named *Puggareetya* tormented and fought a snake. Their wrestling upheaved the ground, forming the hills and mountains of the landscape. The snake cast the woman into the sky and is held there by the sky spirit *Mienteina*. *Puggareetya* continues to play tricks on the sky deities, who occasionally grow frustrated with her antics and throw her across the sky. She is then seen as a meteor (Hamacher and Norris, 2010).

As discussed in Section 3.1, the star-spirits, *Moinee* and *Droemerdeenne*, battled and *Moinee* fell to Earth at Cox Bight, where he can be seen today as a large standing stone (Coon 1972: 288). It is assumed *Moinee* took the symbolic form of a meteor ('falling star'), but this is inferred, never stated.

3.7.2 Aurorae

Cultural traditions of the *Aurora Borealis* (northern lights), which are commonly visible to cultures at high latitudes, tend to be associated with positive omens (Hamacher, 2013). Where aurorae are less common, such as those in the Southern Hemisphere, traditions err towards caution and act as warning. The positioning of Australia on the northern edge of the southern auroral zone means that the *Aurora Australis* was rarely seen, compared to areas within the peak of the auroral zones. Aurorae in Aboriginal traditions are often associated with blood, fire and death because of its sometimes reddish appearance (ibid.).

The *Aurora Australis* is well known to the Palawa, as Tasmania lies at the northern edge of the southern auroral zone. There are a few different Palawa names of aurorae, as noted in Robinson's journals. On 19 October 1837, Robinson recorded two names from Rolepa, a leader of the Ben Lomond group, as *Nohoiner* and *Purnenyer*, and two names from the Western Palawa: *Genner* and *Nummergen*.

Nohoiner is nearly identical to the Cape Portland name *Noiheener*, attributed to an 'electric spark' recorded in an entry by Robinson six years earlier. The Ben Lomond Palawa were thought to be linked in trade agreements with the Cape Portland Palawa. It is possible that they shared language and it is possible that the two words meant the same thing with respect to random light phenomena (Ryan, 2012: 32).

The earlier use of the Cape Portland word *Noiheener* was recorded by Robinson on 12 August 1832 and parallels the sentiments of mainland Aboriginal Australia's feelings of apprehension when an aurora was visible (Robinson and Plomley, 2008: 430):

> The natives last night saw an electric spark in the atmosphere, at which they appeared frightened, and one of them told them not to mention it as they would all be sick if they did – the native of Cape Portland call in NOI.HEE.NER and the Port Sorell natives call it NAR.NO.BUN.NER.

It is unclear if the 'electric spark' was referring to an aurora. Similar words with slightly different spelling variations are applied to various forms of light phenomena, including aurorae, lightning and thunder. *Nowhummer* was a word used by Aboriginal people from West Point and Cape Grim in Tasmania's Northwest for an evil spirit (Plomley, 2008: 650). People from Bruny Island are also recorded as believing thunder and lightning is an evil spirit (Plomley, 2008: 321). In Plomley's consolidated word list, *Noiheenner* is a name given by various language groups to represent 'God', good spirit, Sun, Moon, thunder, and lightning. These words may first appear to be different yet they all share attributes of ancestral beings. Robinson, being a religious man, may have translated meanings of thunder and lightning as God or spirits, all of which were taught to be respected and feared.

Records of auroral traditions in Tasmanian languages provide insight into how Palawa paid close attention to properties of natural phenomena. According to Anonymous (1877):

> There was a splendid Aurora in 1847, grand in its-effects at Hobart Town; and an interim one September 4, 1851, at the same place where the vividly shooting streamers of violet, red and other colors, where somewhat marred by the bright moonlight. The Aborigines of Tasmania compared the crackling noise of the curruscation to the snapping of their fingers.

Despite reports of sound associated with aurora, it was not believed an aurora could produce these sounds, as it was too far away. In 2012 researchers from Finland found a direct link between noise and aurorae, and that the auroral sounds actually were generated close to the ground (Laine, 2012).

3.7.3 Eclipses

There are no confirmed accounts of solar eclipses in recorded Palawa traditions, but there is a record of a lunar eclipse. During the Robinson expedition from 1829 to 1834, 11 lunar eclipses were visible from Tasmania, including two total eclipses (both in 1830).[2] But only one was mentioned in any of Robinson's journals and none was identified from the remaining literary sources.

On 24 August 1831, Robinson wrote that two days earlier, Manalargenna, Kickerterpoller, and three women left to make contact with other people in the area. They were away from Robinson's party for five days, and during their absence the guides with Robinson noticed the Moon move into the Earth's shadow. They took this as an ominous sign that harm had come to Kickerterpoller and he had ascended to the Moon. Truganini and Woorrady saw the lunar eclipse from Waterhouse point and read it as a bad sign that Robinson had been speared (Cameron, 2015). We identify this as a reference to a partial lunar eclipse visible on 23 August 1831 that reached mid-eclipse at 22:00. The perception of the eclipse by Truganini, Woorrady, and Robinson's guides is more or less consistent with other Aboriginal views of eclipses from across Australia (Hamacher and Norris, 2011).

4 SUMMARY AND CONCLUSION

This paper explores the fragments of Palawa astronomy recorded in the literature dating back to the early nineteenth century, from which we attempt a partial reconstruction. While variations of knowledge in some cases are evident, there is continuity with many of the traditions, including those relating to the Sun, Moon, the creation brothers, the stingray in the sky, calendars, time keeping, and views of transient phenomena. This suggests that Palawa used the Sun for navigation and developing songlines.

Mainland Aboriginal traditions share fundamental similarities with those of Aboriginal Tasmanians. Locality affects individual groups' astronomical traditions across Australia, as the adaptive nature of the traditions reflects the natural world in which the community lives. Astronomical objects commonly associated with Aboriginal traditions on the mainland of Australia are the Milky Way, Orion, the Pleiades, the Magellanic Clouds, dark nebula (e.g. the Coalsack), the Sun, and the Moon. All are represented in recorded Tasmanian traditions except for the Pleiades and the Magellanic Clouds. The absence of these objects is peculiar. They are incorporated into traditions of nearly all Aboriginal groups across Australia. Johnson (2011: 295) believes it is unlikely there were no Tasmanian traditions about the Pleiades, but for some reason they simply were never recorded.

This paper is a preliminary study into how Palawa constructed and utilised the connection between the landscape and skyscape. This included the diurnal motion of the Sun and its application to navigation, how the movements of the stars were used to denote seasonal change and timekeeping, and how transient astronomical phenomena were associated with death or bad omens. The Moon's importance as a symbol of restoration and healing may have had symbolic representation on cicatrising marks found on people's bodies and explained through oral traditions.

This research shows how the night sky is a blackboard on which traditions are drawn with stars, and retold to educate generations about moral code and law. But it is also only a rudimentary starting point for future research.

5 NOTES

1. In Boorong traditions of western Victoria (Stanbridge, 1858: 140), Castor (*Yuree*) and Pollux (*Wanjel*) represented two young male hunters who pursued a kangaroo and killed him at the commencement of the 'great heat' (summer).
2. In this context it is interesting that in northwestern Victoria the Coalsack was an emu named *Tchingal* in the Wergaia language. The eastern stars of the Southern Cross (α and β Crucis) were the pointy ends of the spears of two warriors who speared the emu through the neck and rump (Stanbridge, 1858: 139).
3. https://en.wikipedia.org/wiki/Climate_of_Tasmania
4. Javascript Lunar Eclipse Explorer, NASA. Eclipse predictions by Fred Espenak and Chris O'Byrne. http://eclipse.gsfc.nasa.gov/JLEX/JLEX-index.html

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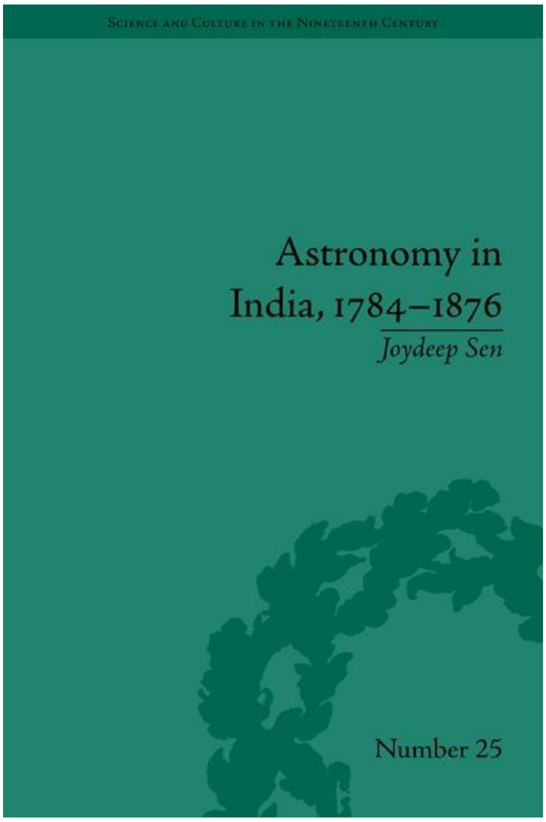
BOOK REVIEWS

***Astronomy in India 1784–1876*, by Joydeep Sen. (Pickering and Chatto, London, 2014; Science and Culture in the Nineteenth Century Number 25). Pp. xiii + 268. ISBN 9781781440780, 16 × 24 cm, UK 60 pounds.**

Indian science experienced a major renaissance with the arrival of the British in the late eighteenth century. Till then, astronomy in India was largely restricted to either computational astronomy of Solar System bodies or stars and corrections in the computational tables based on direct observations. The biggest advancement till then had been to build large observatories called Jantar Mantar to measure the locations of stars. Maharaja Jai Singh II of Jaipur constructed five Jantar Mantars in total, in New Delhi, Jaipur, Ujjain, Mathura and Varanasi; they were completed between 1724 and 1735. However, before they could be fruitfully used, telescopes arrived and these made the Jantar Mantars superfluous.



Although the first known astronomical use of the telescope in India occurred in 1618 (see Kapoor, 2016), telescopic astronomy only flourished with the 1761 and 1769 transits of Venus (Kapoor, 2013). At that time the value of the Astronomical Unit and the relative distances between the Earth, Venus and the Sun were not known with great accuracy. High precision measurements of the exact start and end times of the transits would provide valuable measurements of these parameters. Hence observing the transits was of great scientific importance. Neither of the transits would have been visible in Europe but they would have been easily visible from southern India. During that period the British and the French had colonies in India and both were in competition. Hence the transit observations were driven both by the needs of science and by political competition.

The 1761 transit was widely observed from India, but in 1769 the monsoon restricted observations to just a few centres. However, these transits proved a boon for Indian astronomy with the arrival of new modern observational instruments and techniques.

Soon after that, the British decided to undertake the Great Triangulation Survey of the Indian subcontinent and for that they needed accurate determination of longitudes of various places. This heralded the establishment of astronomical observatories, starting with one in Chennai. The roles of these observatories were later expanded to include solar observations and the creation of sky charts. The Madras Observatory was eventually shifted to Kodaikanal and is still operational today, but with new and improved instrumentation. These observatories have been credited with several insightful observations. For example, the British astronomer John Evershed first observed the radial motions in sunspots known today as the Evershed Effect from the Kodaikanal Solar Observatory. These activities also resulted in the spread of observational, and in particular telescopic, astronomy to colleges in India and played an important role in the evolution of a scientific approach to nature in the subcontinent.

Joydeep Sen's book on *Astronomy in India, 1784–1876* meticulously records the British contribution to this development as understood from British archives. The book is detailed and provides numerous quotes and references from documents of this period.

However, this book evolved out of Dr Sen's Ph.D. thesis, and this limitation shows up in the book. The treatment of the pre-1784 period in India is sketchy and taken from a handful of European and American scholars. Many of these references are incomplete and do not do justice to the quality of the observational astronomy that was being carried out in India at that time. For example, while the author seems to be aware of the *Indian Journal of History of Science*, no attempt has been made to summarise papers published in that journal from time to time about astronomy of the period. Similarly the research of Indian scholars such as

Rajesh Kochhar who have extensively documented the period in a systematic, objective and scholarly manner (e.g. see Kochhar, 1985a; 1985b; 1989; 1991a; 1991b; 1991c; 1993; 2002) finds no mention in the book. Similarly, the seminal research of British astronomers who worked to document Indian astronomical practices of the period (e.g. Kaye, 1998) also does not find an important place in the book.

In summary, the book would have been far more potent if it had discussed in detail issues such as the dramatic impact of the arrival of European astronomers in India, and the cultural conflict that followed the arrival of telescopes (a point that is mentioned more in passing). The language and content of the book are more focused on bringing out the contents of individual communications rather than the exciting impact of these developments on Indian science. The book therefore provides valuable insights into the exact dynamics of the evolution of telescopic astronomy in the subcontinent, but it does not document its impact in India, which was very significant. However, within the limited focus of documenting the debates and discussions in Britain about supporting astronomy in India the book does provide valuable research material.

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***Wolf Telescopes: A Collection of Historical Telescopes*, by Edward D. Wolf. (Trumansburg NY, printed for the author, 2016). Pp. 365. ISBN 978-0-9980037-1-9 (hard-back), 222 × 287 mm, US$125 (plus shippping). Place orders through www. wolftelescopes.com. An earlier soft-cover edition also is available, at US$85 (plus postage & packing).**

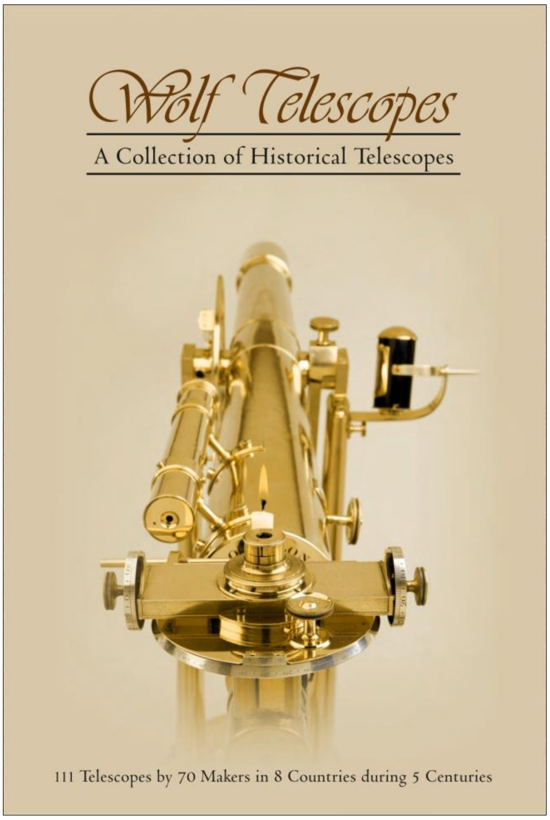
Historic astronomical telescopes can be found in long-established observatories, because that is where they were used, and in public museums. An example is the National Museum of Scotland in Edinburgh, which holds dozens of instruments with Scottish connections and earlier this year held an exhibition “Reflecting Telescopes” highlighting the work of James Gregory and James Short. But private individuals also collect telescopes, often in conjunction with other scientific instruments, or books. Charles Frank and his son Arthur in Glasgow come to mind, as do Robert B. Ariail in the United States and Peter Louwman in The Netherlands.

To this list must be added the name of Edward D. Wolf, Emeritus Professor at Cornell, who after a doctorate in physical chemistry followed a career in industry and academia. Since the beginning of the millennium, he has amassed a collection of 111 telescopes, or an average of a new one every six weeks. Most of them are astronomical, though some are terrestrial or marine, and there is a handful of binoculars and surveying instruments.

The principal feature of the collection is its rich variety. It boasts telescopes from many of the famous French, American, English and German makers, such as Adams, Bardou, Alvan Clark, Dollond, Grubb Parsons, Lemaire, Lerebours & Secretan and successors, Mailhat, Merz, Nairne, Negretti & Zambra, Passemant, Plössl, Ramsden, Short, Steinheil, Troughton & Simms, Utzschneider & Fraunhofer, and Zeiss. In total, some seventy makers from eight countries are represented, including instruments from five different centuries if you accept that one beautiful Japanese spyglass might just date from as early as 1690. Most, however, date from the eighteenth and nineteenth centuries.

In choosing telescopes, Wolf favoured those that retained their associated accessories, such as multiple eyepieces, filters, micrometers, dust caps, storage boxes, tripods, etc. This is valuable, because over time accessories have often been lost, or in the case of boxes, discarded. Many instruments are rare. As an example, I would cite Foucault-Secretan silvered-glass reflecting telescopes. Only a few hundred would appear to have been made, yet the Wolf collection includes three, and they were of great service in my recent study of these instruments (Tobin, 2016). As a practical matter, the collection is limited to portable instruments—there are no pedestal-mounted telescopes. Nor are there specialist instruments, such as transit telescopes.

The question of what to do with one's collection must haunt every collector. Is the collection permanent, or just a temporary grouping? The dice were rolled for the Frank Collection, which was dispersed at auction in 1986, thereby feeding, amongst others, the National Museum of Scotland, the Science Museum in London and, via intermediaries, the Wolf Collection. Ariail gave his collection to the South Carolina State Museum. Louwman's Collection is exhibited as part of his family's motor-car museum in a suburb of The Hague. The good news for the Wolf Collection is that it will not be dispersed. It has just been sold to the Beijing Planetarium with the expectation that it will be exhibited at the fifteenth-century Beijing Ancient Observatory, which is now run as an affiliate museum of the Planetarium.



Wolf Telescopes

A Collection of Historical Telescopes

111 Telescopes by 70 Makers in 8 Countries during 5 Centuries

Dispersed or not, every collection is treasure for those interested in telescope history and heritage, and a catalogue is an essential adjunct. For the Frank Collection, the sale catalogue and an earlier exhibition catalogue are the primary resources (Nuttall, 1973; Sotheby's, 1986). The Ariail Collection can be accessed on-line (Ariail, 2016). Louwman has published a magnificently-illustrated compendium of some of his telescopes (Louwman and Zuidervaart, 2013). And now Wolf follows suit with *Wolf Telescopes*, the even-more-magnificent catalogue of his 111 instruments.

Wolf Telescopes is a joint work between Wolf, his wife, daughter, a granddaughter, and a photographer, Gary L. Hodges. The catalogue does not claim to be a scholarly work. Indeed, no information is given as to how dates were ascribed to individual telescopes (privately, Wolf indicates he used Clifton (1995) extensively for telescopes of British origin). Provenance information is sparse, and there are a few confusions, such as 'Wentworth' with 'Whitworth' and 'Marc Secretan' with 'Auguste Secretan'. But these are minor. The great and unparalleled strength of the catalogue is its 1,500 crystal-clear photographs, which, as Wolf notes, were often technically challenging, requiring a large depth of field for objects composed of parts with very different reflectivities. The multiplicity of images means each instrument is thoroughly documented, and many are seen disassembled. This is invaluable for researchers who want to make detailed comparisons without travelling to China! For example, in *Wolf Telescopes* we can study the great variety of spring designs that different eighteenth-century makers used to support the speculum-metal primary mirrors of their Gregorian telescopes, and the different focus-adjustment mechanisms for the secondaries. The Collection contains two Secretan telescopes numbered 236, one a reflector and the other a refractor, which confirms the suspicion that the two types were numbered separately. And rather subtle differences, well-presented in the photographs, may permit the assignment of unsigned instruments to one maker or another, as I have shown with prism supports in Secretan and Bardou reflectors (Tobin, 2016).

The catalogue begins with a Foreword by Robert B. Ariail and other introductory and summary text. This is interspersed with full- or half-page photographs of some of the choicest items in the Wolf Collection, such as a very pretty shagreen-covered 1-inch reflector *c.*1750, a Dollond 12-foot (long) refractor *c.*1762 with rope-and-pole mount, the aforementioned 19th-century silvered-glass reflectors, a 92-mm Secretan refractor *c.*1915–1920, and an Alvan Clark 106-mm refractor dated 1867, which prior to sale to the Beijing Planetarium was believed to be the earliest Clark telescope in a private collection. There then follows a series of 'galleries' presenting the whole collection. Six galleries permute refractors and reflectors with different mountings—hand-held, table or tripod. Final galleries present binocular telescopes, surveying instruments and some historical telescope books. After that, sections present the evolution of makers' signatures, mounts and tripods, ocular focusers, and comparisons with related instruments in other collections. As necessary, Wolf cleaned, repaired and restored his telescopes. This is described and photo-documented in the final hundred pages of the catalogue, along with a page of restoration 'Do's and Don'ts'. ("In general, don't restore!" is Wolf's wise advice.) Since information on any given instrument is often spread throughout the catalogue, it is to be regretted that there is no comprehensive index to hasten finding. It should be noted that for the next year or two, much of the material in *Wolf Telescopes* will remain available via the website www.wolftelescopes.com .

To summarize: The Wolf Collection is important and extensive. Because of its numerous excellent photographs *Wolf Telescopes* sets a new and exacting standard. It is a comprehensive record of the Collection and an unparalleled tool for the study of both the Collection itself and historic telescopes elsewhere. Dealers, all museums with telescope collections, and everyone passionate about telescope heritage should acquire a copy.

A final comment. The investigation of the optics of the Wolf Collection and other Secretan reflectors that Ed Wolf and I undertook in Tobin (2016) was very simple. China has an extensive optics industry and in metropolitan Beijing (population 22 million) numerous students will be studying practical optics. I hope that their professors ally with the Beijing Planetarium to devise student projects that study the Wolf telescopes. Accurate evaluation of the form of the optical surfaces and the performance of the instruments can but yield valuable insights into the development of the optician's art across the centuries.

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***Chintamani Ragoonatha Charry and Contemporary Indian Astronomy,* by B.S. Shylaja. (Bangalore, Bangalore Association for Science Education and Navakarnataka Publications Private Limited, 2012). Pp. 96. ISBN 978-81-8467-283-1, 142 × 215 mm, Rs 75.**

The transits of Venus in 2004 and 2012 evoked great public interest all over the world, spurring educators, historians, scientists and numerous others to write papers and books and produce other material for the occasion. The book under review is one such. Published in 2012, it is about transits, the life of Ragoonatha Charry (1828–1880), the First Assistant to Norman Pogson, Astronomer at Madras Observatory, and a 38-page pamphlet that he brought out about the 8 December 1874 transit while preparations were under way for its observation by astronomers spread across India (and elsewhere).

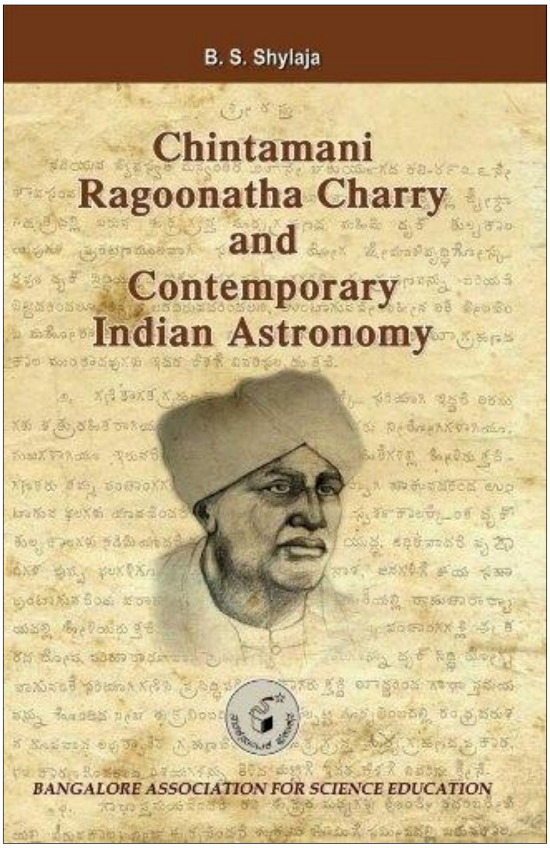
Ragoonatha Charry came from a family of almanac makers and when around eighteen years of age joined Madras Observatory in 1847 during T.G. Taylor's time as Director (Rao et al., 2009). Although steeped in traditional astronomy, once there he learnt about modern European astronomy. He was so devoted to astronomy that he even maintained a private observatory at his home, and he contributed many observations. A science enthusiast, he took a keen interest in communicating information on forthcoming astronomical events to the general public in their own languages. Pogson (1861) has spoken highly of him. About the life and works of Ragoonatha Charry, one should look up his obituary in the *Monthly Notices of the Royal Astronomical Society* (Obituary, 1881), and refer to the papers by Rao et al. (2009) and Shylaja (2009).

Ragoonatha Charry's pamphlet, titled 'Transit of Venus', was brought out early in 1874 in English and a few Indian languages. Charry states in the Preface:

> Having been accustomed for many years to discuss astronomical facts and methods verbally with Hindu professors of the art, my present sketch has naturally, as it were, taken the form of a dialogue; but in the Sanscrit, Canavese, Malayalum, and Maharathi versions I have found it convenient to vary the arrangement. The sketch was first drafted in Tamil, and then translated into English and the other languages …

Through several figures, the pamphlet, as Charry called it, beautifully explains the transit to the lay public. The English version was presented in the form of dialogue between a Pandit and a Sidhanti, an expert familiar with modern European astronomy wherein the former, a traditionalist requests the latter to explain the forthcoming transit of Venus, a subject not treated in

Hindu astronomy texts. In each version of the pamphlet, the style and the contents differ somewhat. The pamphlet was printed but was not published as such. It also included Charry's passionate address at the Pacheappa's Hall in Madras on 13 April 1874 (one day after Tamil New Year) to a large gathering of 'Native Gentlemen'. Here, he urges them to support a modern *Siddhānta* that he wishes to bring out; the establishment of an observatory for which he offers a few crucial instruments of his own; and the formation of a local society, along the lines of the Royal Astronomical Society. Notably, a favourable review of the pamphlet later appeared in *The Astronomical Register* (see Reviews …, 1875).



As the transit of Venus of 2012 drew close, the Indian Institute of Astrophysics (IIA) took copies of the pamphlet out of its Archives and reprinted the English version (Ragoonatha Chary, 2012). Around the same time, B.S. Shylaja from the Jawaharlal Nehru Planetarium in Bangalore wrote the book *Chintamani Ragoonatha Charry and Contemporary Indian Astronomy*, which is the subject of this review.

What is this book about? Shylaja examined the English, Kannada and Urdu versions of the pamphlet and noted certain differences in their contents. This motivated her to present Ragoonatha Charry's contribution in a complete form by providing a translation of the Kannada version back into English. As she says (page 33), "... the last three sections of the book are exclusive to the Kannada version …." Shylaja gives a brief account of Charry's life and the necessary background to the original pamphlets and informs us in what ways the contents differed among themselves. She begins with a description of the transits in general and talks about some of the observations of the transit of 1874 that were made from India. The key parts of the original pamphlets are presented in the form of Appendices 1 and 2. Appendix 1 reproduces the Kannada text of Charry's pamphlet, and the facing pages carry the English translation. The Kannada narration is not in the form of dialogue as it was in the other pamphlets. Appendix 2 deals with the method of estimating the parallax of the Sun as devised by Charry; it uses simple geometry and is elegant. At the end, there is a list of specific technical terms in Kannada that Charry used or coined, along with the English equivalents.

Shylaja's book was brought out with good intent, and just in time for the 2012 transit, but unfortunately it was written in haste. Consequently, at times the narrative is haphazard; there are incorrect statements in places; and key references are missing (Bigg-Wither, 1883; Biswas, 2003; Hennessey, 1874–1875; 1879; Nursing Row, 1875; Pigatto and Zanini, 2001; Pringle, 1875; Strange, 1874; Tennant, 1875a, 1875b, 1877, 1882; The transit of Venus, 1875). Chapter 1 ('Introduction') begins with a grave misprint by referring to the transit of 1881 (instead of 1882), while Chapter 3 refers to the transit of 1768 (it occurred in 1769). Chapter 2 presents a sketch of the life of Ragoonatha Charry. Here, Shylaja quotes from Charry's Urdu pamphlet where reference is made to a 5′ long equatorial telescope. For some reason she thinks that this may be a typographical error and the reference should be to a 5″ equatorial telescope. Elsewhere in this chapter she states that Charry was the first-ever Indian science communicator, but this is simply not true. Several astronomical works and even encyclopaedias were written in Persian and Urdu in the eighteenth century and the early part of the nineteenth century that dealt with modern aspects of astronomy, including telescopes (e.g. see Ansari, 2000; Ghulām Ḥusain Jaunpūrī, 1835; Habib and Raina, 1989), and several works of a similar kind came out in Bangla around the same time. While it is not possible to comment on the accuracy of the translation, there are obvious grammatical mistakes and 'typos' (for example, on page 73 the elongation of Venus is given as 40°, not 35°, as in Ragoonatha Chary, 2012: 27). Furthermore, the referencing leaves much to be desired, with far too great an emphasis on web sites instead of published books and papers, and there is no Index at the end of the book. However, on the brighter side, we both found Appendix 2 useful.

A book like this that incorporates astronomical and biographical material should be treasured by those interested in the history of Indian astronomy and provide them with enjoyable and, more importantly, reliable, reading. Sadly, this is not such a book, and the fact that the author is no expert on historic transits of Venus and therefore was unfamiliar with much of the relevant literature really stands out. But the publishers also are to blame, and have done a shabby job. At very least, the Kannada text and the corresponding English translation should have been placed on facing pages so as to facilitate a one-to-one match.

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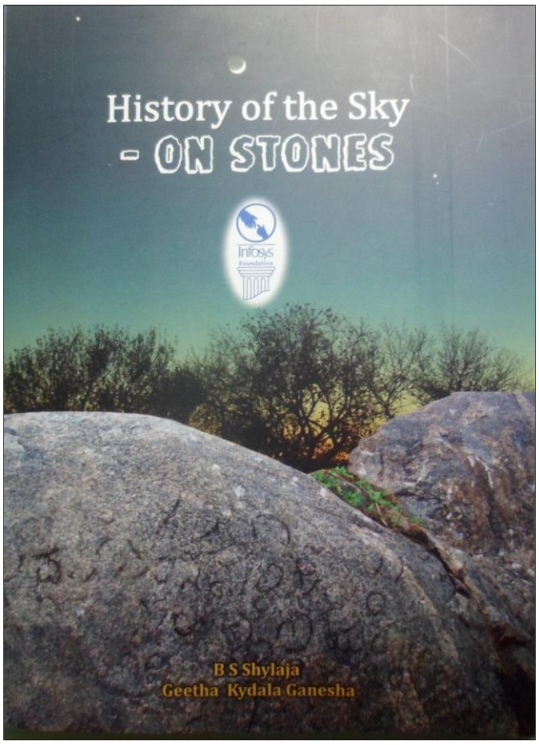
***History of the Sky – On Stones*, by B.S. Shylaja and Geetha Kydala Ganesha. (Bangalore, Infosys Foundation, 2016). Pp. 152. No ISBN listed (paperback), 180 × 240 mm, Rs 200.**

One of the distinct benefits enjoyed by those of us who attended the recent 9th International Conference on Oriental Astronomy in Pune was the concurrent appearance of new books about the history of Indian astronomy.

One of these was an attractive paperback about the invaluable information that inscriptions on stone provide about historic astronomical objects and events. As the authors point out in their Preface:

> Every village has a history; and every village has it recorded on one or several stone [sic.]. These stone inscriptions are of great importance to historians, sociologists and traditional scholars, though very little attention was paid on the study as sources of astronomical records.
>
> When we ventured to explore this new avenue to fetch unknown records of astronomical observations we did not know the volume of the task that lay ahead. (page 3).

I suspect that had the authors realised the magnitude of the task at hand they would quickly have diverted their attention to other projects, for soon they were 'drowning' in inscribed stones, where ~ 38,000 inscriptions had been recorded over the past century or more. These inscriptions date back to the third century BC, and they contain a "… wealth of information on various aspects of evolution of culture, trade, history and region …" (page 12). Most of these have no relevance to astronomy, but those that do and are discussed by Shylaja and Ganesha in their book exceed 1,500. The stunning thing is that their study was restricted to the central part of southern India, and even there new inscriptions continue to be discovered. Imagine the plethora of data available if and when the whole Indian Subcontinent is surveyed in this way!



So what sorts of information have Shylaja and Ganesha uncovered in the course of their research? Since inscriptions normally were only engraved on special occasions, there are abundant records of solar and lunar eclipses, planetary conjunctions, and lunar occultations, and occasional references to comets. Fortunately, the dates of all of these are accurately recorded in the inscriptions, but since various dating systems were used in different parts of India during the past two millenia the inscription dates must be converted to our current 'Western' calendrical system. This challenge is outlined in Chapters 2, 3 and 4.

Solar eclipses and lunar eclipes are discussed in Chapters 5 and 6 respectively. Solar eclipses (total, annular and partial) date from AD 21 May 616 to 24 March 1849 and they are listed individually on pages 107–115. Several of these eclipses are mentioned in more than one inscription. Not all of these eclipses were in fact observed, as some of the paths of totality bypassed India. However, the authors conclude that

> In general we find that the large number of eclipse records provide a homogeneous data for verifying long term variation of parameters involved in the prediction of eclipses. (page 38).

The earliest lunar eclipse recorded on an inscription dates to AD 30 April 660, and the latest to 8 May 1876. Individual eclipses are listed on pages 116–126. A particularly interesting record dates to 14 February 1710 when the eclipsed Moon occulted Regulus (*Magha*) just before moonset at dawn.

Many planetary conjunctions are recorded on stone inscriptions, and these, and lunar occultations of stars and planets, are discussed in Chapter 8 and listed individually on pages 127–148. Some of these must have been visually-aluring events. For example: on 2 October 1117 and 22 August 1467 Saturn was in conjunction with Aldebaran (*Rohini*) and the Hyades; on 2 March 1169 the Moon, Jupiter and Mercury were in conjunction; on 10 February 1671 the Moon, Mercury and Saturn were in conjunction; and occultations of Mars by the Moon occurred on 12 December 1112 and 14 December 1132. In addition to these and other conjunctions and occultations, there also are many records of solstices and equinoxes, the earliest of which dates to AD 687.

Chapter 9 is titled "Revelations of Celestial Phenomena", and the authors claim that "Our studies of stone inscriptions have revealed quite a few new results which have escaped the attention of epigraphists", but some of their conclusions are open to debate. Thus, drawing on references to *Ketu,* they suggest that two new stars reportedly observed by Chinese astronomers on 9 and 18 December 1297 between Pisces and Andromeda can be associated with the planetary NGC 7662, on the basis that its two distinct ellipsoidal shells document eruptions 700 and 1050 years ago. Yet neither of these dates aligns precisely with the Chinese observations, and planetary nebulae are not known for nova-like eruptions.

In Chapter 9, Shylaja and Ganesha also point out that inscriptions hold promise of identifying transits of Mercury and Venus, but although they suggest one possible transit of Mercury (21 April 1056), they were not able to assemble any convincing evidence of transits of Venus (cf. Kapoor, 2013). However, they live in hope:

> These examples offer an optimistic view: the current survey on stone inscriptions has covered only 10% of the available 30,000 (and more being added now) records centered in and around Karnataka. Hence a systematic search of such inscriptions from all over India is likely to yield more results. (page 84).

Arguably one of the most important parts of the whole book is Section 9.3, which is titled "The period of rotation of the earth". Here Shylaja and Ganesha discuss the role that accurately-dated solar eclipses have played in documenting variations in the rotation rate of the Earth, a field of study pioneered by the noted British astronomer, Professor Richard Stephenson of Durham University. Stephenson has plotted these variations (referred to as ΔT) against time (e.g. see Stephenson, 2006; 2007; 2011; Stephenson and Morrison, 1995), and in Figure 9.3 on page 87 Shylaja and Ganesha include one of his plots (erroneously referred to as a 'Soma Diagram', and published by Morrison), where eight new data points, based on dated Indian eclipses, are included. It is heartening to see India finally making a valued contribution to this important area of history of astronomy research, which is known as Applied Historical Astronomy.

While most of this book is devoted to astronomical stone inscriptions, the authors devote nearly four pages to the lifespan of Sri Rāmanujācārya, "… the great saint of the Srivaishnavaite sect, [who] has left a remarkable imprint in the whole of South India." (page 97). His birth and death dates are generally given as AD 1017 and AD 1137, and this long lifespan has generated much debate. Using data contained in inscriptions, Shylaja and Ganesha come up with a revised birth date of AD 1077, and a more realisitic lifespan of 68 years.

The final chapter in this book is titled "Expectations and realities", where the authors stress that astronomical inscriptions were not recorded because of the importance of the celestial events *per se*, but rather because their occurrence led to offerings being made. Thus

> … emphasis lay on the act of donation … and recording the donor and donee. The actual celestial event was perhaps only an excuse to perform this action ... [and get] its name immortalized on the stone inscription. (page 102).

Most of the inscriptions used in this study were already recorded earlier by others, and the challenge Shylaja and Ganesha faced was to work their way through these extensive published lists and sift out the astronomical inscriptions. In the process they encountered many unfamiliar words that had to be deciphered; some of these words were unique to the inscriptions and were not found in the general historical literature. Sometimes the inscriptions offered conflicting interpretations, but by using off-the-shelf astronomical software (e.g. Occult, or NASA eclipse web sites) they were able to resolve many of these issues. Nonetheless, many areas of India were not covered in their study, and Shylaja and Ganesha now "… are eagerly awaiting the new and revised compiled volumes [of inscriptions] to be published." (page 106).

This is an attractive-looking reasonably-priced paperback book, liberally decorated with figures, maps and tables (many in colour). I noticed very few 'typos', although in my copy of the book the last four lines of text on page 80 were duplicated at the top of page 81, and earlier on page 80 in two places Greek symbols were replaced by pairs of boxes. Apart from these anomalies, the Infosys Foundation did a good job as the publisher.

Finally, I should mention that unlike the book by Shylaja about Charry and the 1874 transit of Venus that is reviewed above by Ramesh Kapoor and me, *History of the Sky – On Stones* reveals Shylaja's true talents when she focusses on a topic she is familiar with. It is to be hoped that she and Ganesha will continue this study, and expand their analysis of astronomical inscriptions beyond central southern India. Obviously, this is a long-term project, but an important one, as it can throw valuable new light on Indian astronomy and at the same time contribute to Applied Historical Astronomy.

I feel that this interesting book marks a new era in the study of Indian astronomy, and that it deserves a place on the bookshelf of anyone with an interest in the history of Indian astronomy.

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***History of Indian Astronomy. A Handboook*, edited by K. Ramasubramanian, Aniket Sule and Mayank Vahia. (Science and Heritage Initiative Indian Institute of Technology, and Tata Institute of Fundamental Research, Mumbai, 2016). Pp. x + 662. ISBN 978-81-923111-9-7 (hard cover), 170 × 247 mm (for the price, email mnvahia@gmail.com).**

The other book received by those who attended ICOA-9 in Pune, India, in November 2016 was a handsome 672-page volume, edited by three luminaries of Indian astronomical history, Professor K. Ramasubramanian (Indian Institute of Technology), Dr Aniket Sule and Professor Mayank Vahia (both from the Tata Institute of Fundamental Research).

As the 'blurb' on the back cover indicates,

> This volume is a compilation of twenty-one thematic articles that provide a glimpse of the origin and development of astronomy in India from the Vedic period till the beginning of 20th century. These articles have been contributed by a galaxy of renowned scholars.

After an introductory chapter titled "Roots of Indian astronomy" by Mayank Vahia, Nisha Yadav and Srikumar Menon where they review astronomical basics before discussing "Astronomy and civilisation" in an Indian context, the archaeologist, Riza Abbas, writes about "Rock art and astronomy in India". Those familiar with international developments in rock art studies will be aware of the challenges involved in assigning astronomical meaning to different motifs, so I was very surprised to read that Joglekar et al. (2006) have found evidence of a prehistoric supernova explosion depicted on an engraved stone slab at Burzahom, and that "In this study they have scientifically proved that this would be first record of a sky map drawn to record a particular event." (page 48). Even though I allowed the publication of a paper about this same engraving in this journal (see Iqbal et al., 2009) in order to encourage lateral thinking and discussion, in fact this engraving is controversial, and other equally-compelling interpretations can be proposed for it that have nothing whatsoever to do with a supernova.

In Chapter 3 Srikumar Menon discusses "Megalithic astronomy in India", where he stresses their relative abundance in southern India (see the distribution map on page 65). Menon concludes:

> Despite nearly two centuries of academic attention being focussed on them, the Indian megaliths still have a lot of unanswered questions centred on them ...
>
> Stone alignments in different parts of southern India and Vidarbha seem to hold some promise of astronomical sightlines incorporated as part of their design and layout. (page 81).

We then move from archaeastronomy to ethnoastronomy (Chapter 4), where Mayank Vahia and Ganesh Halkare talk about "Astronomy of tribals of central India". Although regretting the use of the term 'tribals' in lieu of 'tribes', I found this chapter interesting, although most of it was familiar to me thanks to a series of research papers that the authors had already published (and several of them in this journal). As Vahia and Halkare point out, "... several Indian tribes that have been isolated from the mainstream have their own understanding of the sky and constellations." (page 85). Over the next 11 pages or so they discuss indigenous constellations in different areas of the sky and their terrestrial associations (ecological activities, the monsoon, etc.), along with the Milky Way, Solar System objects, eclipses and creation myths. The authors hope that this chapter "... will encourage researchers in other parts of the country to undertake similar studies of the astronomy of the tribes of India before modernity completely overwhelms them." (page 104).

Then follow two chapters about Vedic astronomy, and I found the first of these, by R.N. Iyengar (Jain University, Bangalore), captivating, where he discovers references to eclipses, comets, meteorite impacts, and the shifting of the 'pole star' in Vedic texts. However, these references are not always obvious since

> ... Vedic culture personified celestial objects and their actions. Hence the texts carry a background that has to be deciphered for extracting the archaic models of the visible sky." (page 108).

As with those who wrote earlier chapters in this book, Iyengar draws on his own earlier publications, but then brings his long 63-page chapter up-to-date by including considerable new material.

Kak's much shorter chapter follows, and this presents a useful overview of the relationship between Vedic astronomy, ritual and temple design.

Those with an interest in calendars will value Chapter 7, where two retired Indian astronomers, S.K. Chatterjee and A.K. Chakravarty discuss the "Indian calendar from post-Vedic period to 1900 CE". Their long and detailed account (49 pages) is a partly-revised version of a paper that they first published in 2000.

An old Japanese friend of mine, Dr Yukio Ohashi, is the author of the next chapter, which is titled "The mathematical and observational astronomy in traditional India". This long chapter is a reprinted version of a paper that was originally published in 2009 so was in little need of up-dating. Those with an interest in Vedic astronomy and Indian calendars also will find much of interest in this 77-page chapter, which in fact ranges beyond India to also discuss—albeit briefly—Greek, Islamic, Tibetan, Chinese and even Thailand and Burmese astronomy. Immediately prior to presenting an invaluable 9.5-page list of references, Yukio winds up his informative chapter in a charming way: "I hope some readers of my paper will become future researchers, and they will make my paper outdated by their own research works!"

In Chapter 9, M.S. Sriram, M.D. Srinivas and K. Ramasubramanian review "The traditional Indian planetary model and its revision by Nīlakaṇṭha Somayājī", while M.S. Sriram discusses "Bhāskarācārya's astronomy" in Chapter 10.

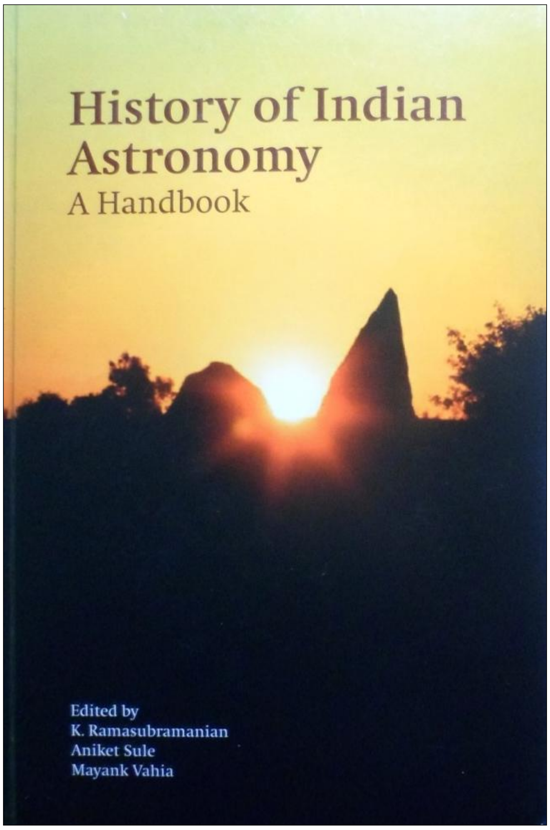
"Lunar and solar eclipse procedures in Indian astronomy" by P. Venugopal, K. Rupa and S. Balachangra Rao comprises Chapter 11 while the same authors but in revised order (Balachangra Rao, Venugopal and Rupa) discuss "Transits and occultations in Indian astronomy in the following chapter. From ca. 505 CE Indian astronomers knew the causes of solar and lunar eclipses and in Chapter 11 the circumstances of the eclipses were computed "... according to Bhāskara II's *Karaṇakutūhala*, *Grahalāghava* and Improved *Siddhāntic* procedures ISP." (page 408). Meanwhile, similar procedures were used to compute transits and occultations, but although planetary conjunctions are discussed in most traditional textbooks on Indian astronomy transits of Mercury and Venus are not explicitly mentioned. The authors therefore proceed to outline a procedure developed by Professor T.S. Kuppanna within the framework of Siddhāantic astronomy, using the 2004 and 2012 transits as examples.

The next chapter is titled "An overview of the *vākya* method of computing the longitudes of the sun and moon" and was written by Venketeswara Pai, K. Ramasubramanian, S. Srimam and M.D. Srinivas, and aims "... to highlight the ingenuity and beauty of the *vākya* method of planetary computations." (page 430).

Continuing the computational astronomy theme, Chapter 14 by Clemency Montelle (from New Zealand) and K. Ramasubramanian discuss "The numerical tables related to eclipse computation in the *Parvadvayasādhana* of Mallāri". They point out that the *Parvadvayasādhana*

> ... is somewhat unusual in the sense that it presents more complex tables having multiple rows and columns in the form of beautiful verses in *śardūlavikrīḍita* metre (19 syllables per quarter). (page 475).

The theme of the book changes notably with Chapter 15, which is about "Indian astronomical instruments: A descriptive catalogue of extant specimens", penned by S.R. Sarma. In researching this theme, Sarma says that he



> ... decided to make a survey of museums and identify pre-modern astronomical and timekeeping instruments. Such a survey, I hoped, would be useful because the actual specimens might help in understanding the brief descriptions of the texts. Conversely, textual knowledge would help in identifying an instrument and in dating its original design. Finally, this combined approach of studying the texts together with instruments would throw better light on trans-cultural exchanges, especially between the Sanskrit and Islamic traditions of instrumentation in the medieval period. (page 478).

In the following 21 pages Sarma presents an assortment of astrolabes, celestial globes, armillary spheres, various types of quadrants, sundials, gnomons, water clocks and other rarer types of instruments of Indian design and construction. On a plaintive note Sarma describes how he made an inventory of the portable astronomical instruments at the Sawai Jai Singh Astronomical Observatory in Jaipur in 1991 and later sent his catalogue to the Observatory's Superintendent, but by the time a new building for the display of these instruments was opened the original Superintendent had retired and the instruments were displayed without proper identification. "It is like a museum displaying a painting by Picasso without any label! It is a great pity." (page 498). I totally agree with him.

The next two chapters in the book were written by B.S. Shylaja, whose name should now be well known to all, thanks to the two preceding book reviews that appear in this issue of this Journal. Chapter 16 is about "Navigation and astronomy". I presume that Shylaja's primary focus is meant to be Indian maritime navigation, but unfortunately she ranges far and wide geographically, discussing the Kerkennah fishermen of Tunisia; Gilbert and Caroline Islanders in the Pacific; Portuguese navigators; Lieutenant James Cook's use of eclipses, Jovian satellite phenomena and the 3 November 1769 transit of Mercury to determine longitude; the Bugis voyagers of Indonesia; and even the Vikings. I have to say that I found this hotchpotch of examples confusing, as much better case studies could have been employed if Shylaja's aim was simply to document the range of techniques used internationally in order to determine latitude and longitude. Then, when we finally put aside these various examples and look just at Indian navigation the pickings are lean and we end up with a rather simplistic account of how certain coastal people from the Subcontinent used astronomy to successfully sail from one place to another. However, variations in the navigational techniques and instruments used at any one time in different coastal regions of the Subcontinent are not discussed, and there is no attempt to trace changes in the techniques and technology that occurred with the passage of time. Various indigenous names for different stars listed on page 508 and 511 are not referenced, while some key references that Shylaja does mention in the text are not listed in the References section (e.g. Grimble, 1931; Leybourn, 1861 and the various papers by Vardarajan). A map of the Subcontinent and adjacent regions of the Indian Ocean would have been helpful for those readers wishing to pin down localties that Shylaja does mention. However, Shylaja seems aware of the limitations of her study when she mentions that the navigational techniques of some coastal groups have still to be studied. Furthermore, "The study hints at a vast treasure house of astronomical knowledge which is slowly being lost." (page 512), and "... satellite communication systems have now revolutionized the lifestyle in these tiny islands and are slowly wiping out the traditional techniques." Despite these caveats, and although I am vitally interested in this topic and have written on it myself (e.g. see Orchiston, 1998; 2016: Chapters 4–6), I found this to be one of the least rewarding chapters of the book.

Happily, Shylaja has made a better fist of Chapter 17, "Astronomical aspects associated with temples". Temples in India date back more than 2,000 years, and apart from their religious and educational functions some of them also were associated with time-keeping and calendar-making. After reviewing Indian calendars and festivals Shylaja transports us to South Africa, where ceremonies of reputed south Indian origin are still performed by the local inhabitants at specially-constructed places of worship. These reported south Indian-South African cultural links are fascinating and warrant critical examination. The book then returns us to India and the mathematical and astronomical knowledge exhibited by temple-builders across the subcontinent and across the sands of time. Two structures with clear astronomical associations that she reviews in considerable detail are the Vidyāśaṅkara Temple at Śṛṅgerī and the Gavi Gaṅgāhareśvara Temple at Bengalaru, although she seems unfamiliar with the paper by Kameswara Rao and Thakur (2011) about the former temple. Shylaja then discusses a number of other temples that exhibit solstice alignments, and then explores the concept of a basic scale that was used in temple construction in southern India. Leading from this is the fascinating idea that the sun temples in some cities—such as ancient Varanasi (see Rana, 2009)—were based on astronomical alignments. Shylaja stresses that her study is still in its infancy, and

> A mammoth task lies ahead — we have to decode how the blueprint of the temples were [*sic*] prepared and what were the astronomical aspects that were incorporated. (page 545).

In Chapter 18 we return to astronomical instrumentation—albeit on a gigantic scale—when N. Rathnasree (from the Nehru Planetarium) discusses "The Jantar Mantar observatories of India teaching laboratories of positional astronomy". I found it interesting that one of Jai Singh's objectives when he set up these giant masonary observatories 300 years ago was that "... common citizens could ... make observations on their own ..." (page 552) and this is precisely what Rathnasree has done as part of the outreach program of the Nehru Planetarium.

So, for the first time in 300 years, the Jantar Mantar were used successfully as a teaching laboratory, as illustrated by various photographs and graphs that accompany this chapter. After reading this interesting chapter, I now see the Jai Singh observatories in a totally new light.

The third-last and penultimate chapters in this long but invaluable book were written by Professor Raza Ansari, a long-time colleague through our mutual IAU and ICOA associations. Chapter 19 is titled “Tradition of astronomical sciences in medieval India” and was developed from a paper that Ansari published in 2014 so is totally up-to-date. After some introductory comments, Ansari discusses in sequence the major astronomical features associated with the Sultanate Period (AD 1191–1526) and the Mughul Period (1526–1748), including the contributions made by Babur, Naṣīruddīn Muḥammad Humāyūn, Abul Fatḥ Jalāluddīn Akbar, Nūruddīn Jahāngīr, Abul Muẓaffar Shahābuddīn Muḥammad Shāhjahān and Roshan Aktar Muḥammad Shāh. As Ansari points out,

> During the Mughal period, the constant stream of scholars, crafts men, and artists particularly from Central Asia continued vigorously, and those migrants brought with them knowledge of all natural sciences into India. (page 583).

In an astronomical context, this is well portrayed in this excellent, well-researched and well-referenced chapter, but one key reference that has been published since Ansari wrote this chapter is Kapoor (2015).

Nor does this high standard change in Ansari’s next chapter, “Reception of modern western astronomy in the 18th–19th centuries”, where

> ... we confine ourselves mainly to Persian-speaking Indian scholars, who came into direct contact with the British scientists, engineers, and doctors. These ideas resulted in an academic interaction and exchange of scientific ideas. Consequently, we present here a brief survey of selected Indo-Persian writings dealing with Modern European Astronomy ... (page 607).

Those selected for this analysis are: Sawā’i Jai Singh, Mīr Muḥammad Ḥusain, Mirzā Abū Ṭālib Khān Iṣfahānī, Ghulām Ḥusain Jaunpūrī, Raja Ratan Singh, Ḥadā’iq al-Nujūm and Tafaḍḍul Ḥusain Khān bin Ikramullāh Khān. But much of this impetus was stiffled when the British Colonial Government introduced English as the official language during the nineteenth century.

And so we arrive at the final chapter in this impressive tome, Professor Rajesh Kochhar’s contribtuion on “The growth of modern astronomy in India, 1651-1960”. I have known Rajesh for several decades, and have been impressed with his writings on the history of Indian astronomy, so I was rather disappointed to discover that all he chose to do was reprint a paper that originally was published in *Vistas in Astronomy* back in 1991 (and is listed in the references assembled on page 349 in these book reviews). The problem is that while the basic narrative of Indian astronomical history has not changed during this 300-yr period, much additional research has been published. So we certainly can accept Rajesh’s accounts of “Use of the telescope in the 17th century”, “Advent of modern astronomy in the 18th century”, “Madras observatory (1786–1899)”, “The great trigonometrical survey of India ...”, “Lucknow observatory (1831–49)”, “Trivandrum observatory (1837–52)”, “Poona non-observatory”, “19th century positional astronomy – a critique”, “Advent of physical astronomy (1874)”, “Takhtasinghji’s observatory in Poona (1888–1912)”, “Kodaikanal observatory (1899)”, “Nizamiah observatory (1901)” and “Uttar Pradesh state observatory, Nainital (1954)”, but to bring readers up-to-date the books by Launay (2012), Nath (2013) and Sen (2014) need to be consulted, while all of the following research papers contain material that supplements that presented in Kochhar’s chapter: Biswas (1994; 2003); Kameswara Rao et al. (2009; 2011); Kapoor (2011; 2013; 2014); Kochhar (2002); Orchiston et al. (2006); Orchiston and Pearson (2011); Pigatto and Zanini (2001); Rathansree et al., (2012); and Reddy et al. (2007).

After Kochhar’s chapter, the book ends with a 10-page glossary of astronomical terms, but there is no Index.

Notwithstanding my comments about the final chapter, and the absence of an Index, overall this is a wonderful book, with lots of interesting reading. Most of the chapters are well illustrated, and many chapters have long lists of references for those wishing to follow up specific areas of interest. I have no hesitation in recommending this book, and believe that it will long remain a primary reference work for those interested in the history of Indian astronomy.

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