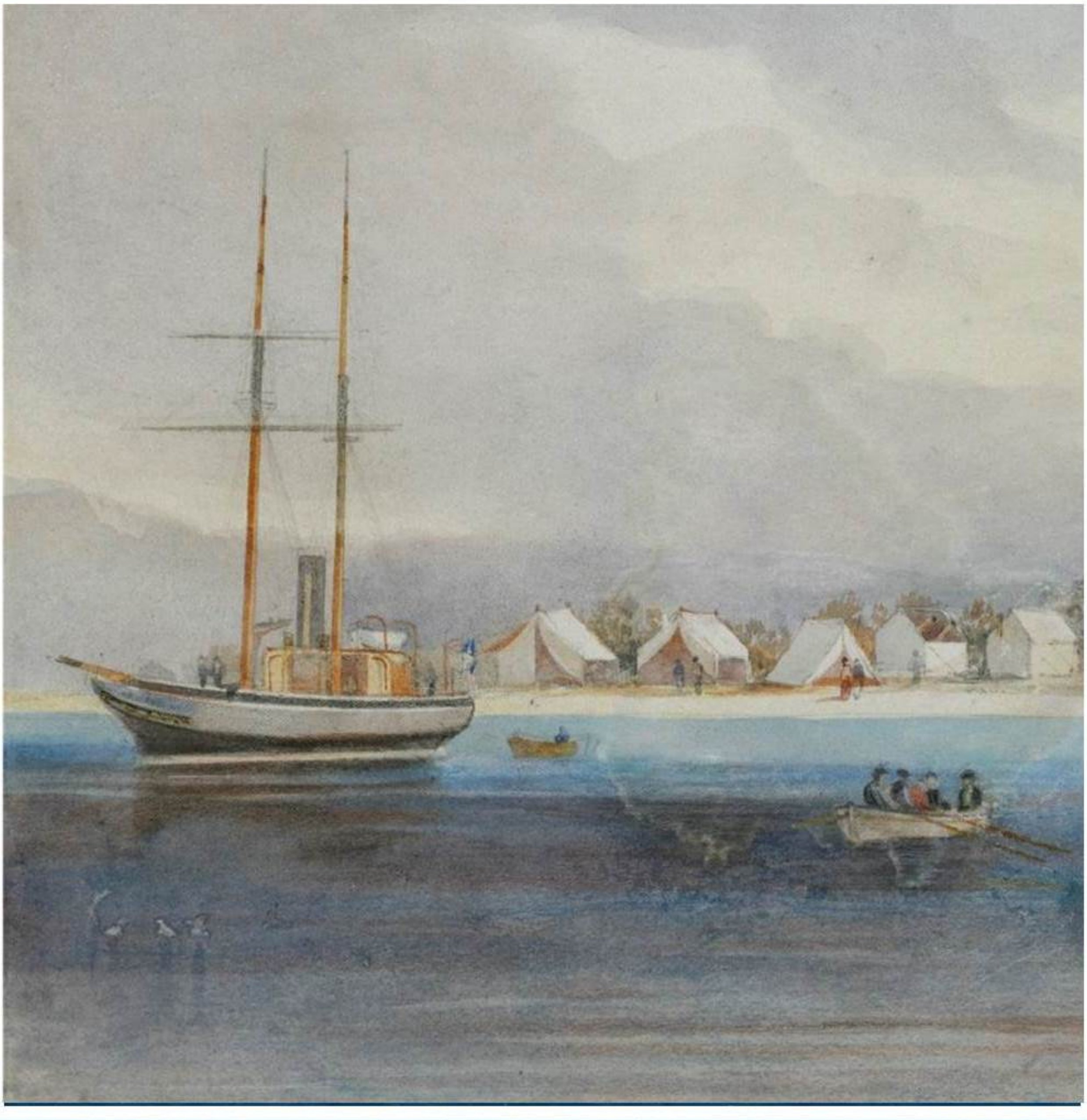
# JOURNAL OF ASTRONOMICAL HISTORY AND HERITAGE



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The *Journal of Astronomical History and Heritage* (*JAHH*) was founded in 1998, and since 2007 has been produced three times yearly, now in March/April, July/August and November/December. It features review papers, research papers, short communications, correspondence, IAU reports and book reviews.

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

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The JAHH is now an electronic journal. All content back to Vol. 1 may be downloaded free of charge from either the Journal's web site at http://www.narit.or.th/en/index.php/jahh or the SAO/NASA Astrophysics Data System site (http://bit.ly/1bMwxBr) and its 11 mirror sites around the world. The electronic version of the journal will continue to be produced three times a year (nominally in March, July and November) and posted on both sites. Those who wish a hard copy may print it out or have it done by their local printers. For this reason a single pdf of each entire issue is available on the site at NARIT.

## COVER IMAGE

The path of totality of a solar eclipse skirted the northern fringes of the Australian continent late in 1871. The Royal Society of Victoria initiated an expedition to the east coast of Cape York to observe the event, as described by Nick Lomb in a paper beginning on page 79. Astronomers and their instruments travelled on a chartered vessel, the *Governor Blackall*, shown here off Eclipse Island in a water colour painting. Although clouded out, the expedition was a milestone in the development of Australian science.

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# EDITORIAL

As foreshadowed in the Editorial that appeared in the Nov-Dec 2016 *JAHH*, this issue marks the start of a new era, with a new Editorial team, and a new Editorial Board. Richard Strom, Duane Hamacher and I welcome two new Associate Editors who have just joined the team, Cliff Cunningham and Peter Robertson. Here is a little about them:

> Clifford J. Cunningham earned his Ph.D. in history of astronomy at the University of Southern Queensland in Australia, and he is a Research Associate of the National Astronomical Research Institute of Thailand. His undergraduate degrees in physics and classical studies were earned at the University of Waterloo in Canada. Cliff has written or edited 14 books on the history of astronomy, and his papers have appeared in many journals, including *Annals of Science, Journal for the History of Astronomy, Culture & Cosmos, Studia Etymologica Cracoviensia, The Asian Journal of Physics*, *Renaissance and Reformation,* and this journal (where several of his asteroid research papers have been published). He is also a contributor to *Encyclopedia Britannica*, and since 2001 has been the history of astronomy columnist for *Mercury* magazine. Asteroid (4276) was named Clifford in his honour by the International Astronomical Union.
>
> Peter Robertson studied science at the University of Melbourne and completed a Masters degree in physics in 1972. He was an assistant editor of a physics journal in Copenhagen during 1975–1979, and upon returning to Melbourne was appointed Managing Editor of the *Australian Journal of Physics*. Peter has a long-standing interest in the history of Australian science and his publications include a history of the Parkes Radio Telescope (Cambridge University Press, 1992). He is currently completing a full-length biography of the Australian radio astronomer John Bolton, the inaugural Director of the Parkes Radio Telescope. Peter recently was awarded a Ph.D. by the University of Southern Queensland (Australia) for his study of Bolton's early career (1946–1953). Peter retired in 2009 after spending most of his career in science publishing, and is now an Honorary Research Fellow in the Astrophysics Group, School of Physics, University of Melbourne.

We also are in the process of revising the Editorial Board, and a full listing of the new Board will appear on the inside front cover of the Jul-Aug 2016 issue of *JAHH*. However, at this early stage we would like to welcome new members Dr Ian Glass (South Africa), Dr James Lequeux (France), Professor Nick Lomb (Australia), Professor Ray Norris (Australia), Dr Yukio Ohashi (Japan), Professor Xiaochun Sun (China), Professor Joe Tenn (USA), Professor Virginia Trimble (USA), Professor Mayank Vahia (India) and Professor Gudrun Wolfschmidt (Germany). Meanwhile, we are happy that the following existing Board members have agreed to remain with us: Dr Alan Batten (Canada), Dr Suzanne Débarbat (France), Dr Steven Dick (USA), Professor Bambang Hidayat (Indonesia), Dr Tsuko Nakamura (Japan), Professor Nha Il-Seong (Korea), Professor Richard Stephenson (England) and Professor Brian Warner (South Africa).

Readers will notice that *JAHH* has undergone a 'make-over' and now has a new colour scheme. We hope you find this attractive, and that it adds to your enjoyment of reading papers and book reviews in *JAHH*.

We now receive enough copy to fill—or more than fill—each issue of *JAHH*, but we always are happy to receive further unsolicited papers, especially about the astronomical history of nations that rarely feature in this journal or in others that publish on the history of astronomy. Our charter is to provide a truly-international perspective on astronomical history (including ethnoastronomy and archaeoastronomy). When preparing your MSS, please refer to the 'Guide for Authors' on our web site (www. http://www.narit.or.th/en/files/GuideforAuthors.pdf) for editorial guidelines. Note that we do not expect you to prepare camera-ready copy—it is the job of the Editor and Associate Editors to edit and format your papers.

Now that we have a new Editorial Board we are keen to expand the number of book reviews that appear in each issue of *JAHH*. Towards this end, one of our new Associate Editors, Dr Cliff Cunningham (asteroid4276@comcast.net), will be responsible for this. If you are interested in preparing reviews of any recently-published books please discuss this with Cliff. We are particularly keen to provide English-language reviews of books written in other languages so that *JAHH* can provide a more comprehensive overview of international developments in history of astronomy.

Finally, on behalf of the Editorial team I would like to take this opportunity to thank those retiring members of the Editorial Board for their support over the years, and also to thank all those who kindly refereed research papers for us in 2015.

**Professor Wayne Orchiston**
*National Astronomical Research Institute of Thailand*
*Editor*

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# PICTOGRAPHS AT PAINT ROCK, TEXAS: EXPLORING THE HORIZON ASTRONOMY AND CULTURAL INTENT

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**Abstract:** The Paint Rock pictograph site on the Campbell Ranch near Paint Rock, Texas, contains over 1500 pictographs. A monument erected on the bluff by the State of Texas indicates it is the largest pictograph site in Texas. Twelve active solar markers have been identified at the site, and with additional observations, possibly more will be discovered. These solar interactions at the Paint Rock site make it one of the most interesting archaeoastronomical sites in Texas. An initial study of Paint Rock suggested that the native cultures did not use the horizon for calendrical purposes, as both the eastern and western horizon are flat and almost featureless. As a result, these characteristics led to our primary research question: How did the cultures so accurately place these rock art glyphs so that they could interact with light and shadow on important solar points of the year? We will detail our search for the place of observation, and the discovery of a significant horizon notch. Our observations support the discovery of the potential horizon calendar and show how it was tied to the material culture. These data answer the primary research question. Interpretation of rock art is one of the great challenges of cognitive archaeology. The existence of solar markers in rock art can provide the most rigorous interpretation and evidence of intentionality in rock art. We detail the accuracy and precision of two of the most significant solar markers. Finally, we propose a tool to evaluate rock art solar markers called the 'Solar Marker Matrix of Intentionality'. This Matrix can be used to help identify potential solar markers and evaluate the strength of identified solar markers. Use of this tool will lead to a database for future statistical analysis.

**Keywords:** Archaeoastronomy; solar markers; rock art; landscape archaeology; cognitive archaeology

## 1 PAINT ROCK PICTOGRAPHS AND TEXAS ROCK ART

Paint Rock on the Campbell Ranch is the most archaeoastronomical-impressive rock art site in Texas. Other pictograph sites reported to have solar interactions with rock art only involve one glyph, but at Paint Rock there are no less than twelve pictographs with potential solar interactions that would qualify as 'solar markers' (a proposed definition will be provided later in the narrative). The largest pictograph site in Texas, Paint Rock, is reported to have 1,500 pictographs. A monument erected by the State of Texas provides these facts. The site is a cliff running NNW-ESE for more than a kilometer, consisting of broken layers of limestone (Figure 1). The site is approximately 175 meters north of the Concho River, and lies at the southern end of the Great Plains, surrounded by elements of the Texas ecoregion called the Edwards Plateau. The pictographs run for 300 meters on the cliff's largest outcrop section, which has the most exposed layers for the rock art (see Figure 2, which shows a site map of the locality). There are several locations along this section of the cliff that provide protection from the weather, room for habitation, and a potential place from which to observe the Sun along the horizon. Based on these characteristics and the number of solar markers, it is plausible that Paint Rock was a major Sun-watching station.

The site has a primary archaeological trinomial site number of 41CC1.[1] The only formal archaeological survey of the site was published by Turpin et al. (2002), which states that there is evidence of cultural use extending to the Middle Archaic Period. The Middle Archaic is an archaeological period that runs from approximately

Figure 1: A panoramic view of the cliff at Paint Rock, Texas on the Campbell Ranch. This view was taken from the center of the 300-meter span of the cliff that contains the pictographs. The cliff extends for approximately 1,200 meters with an orientation of northwest to southeast. This panorama extends approximately from 260° west to 130° southeast (photograph: Gordon L. Houston).

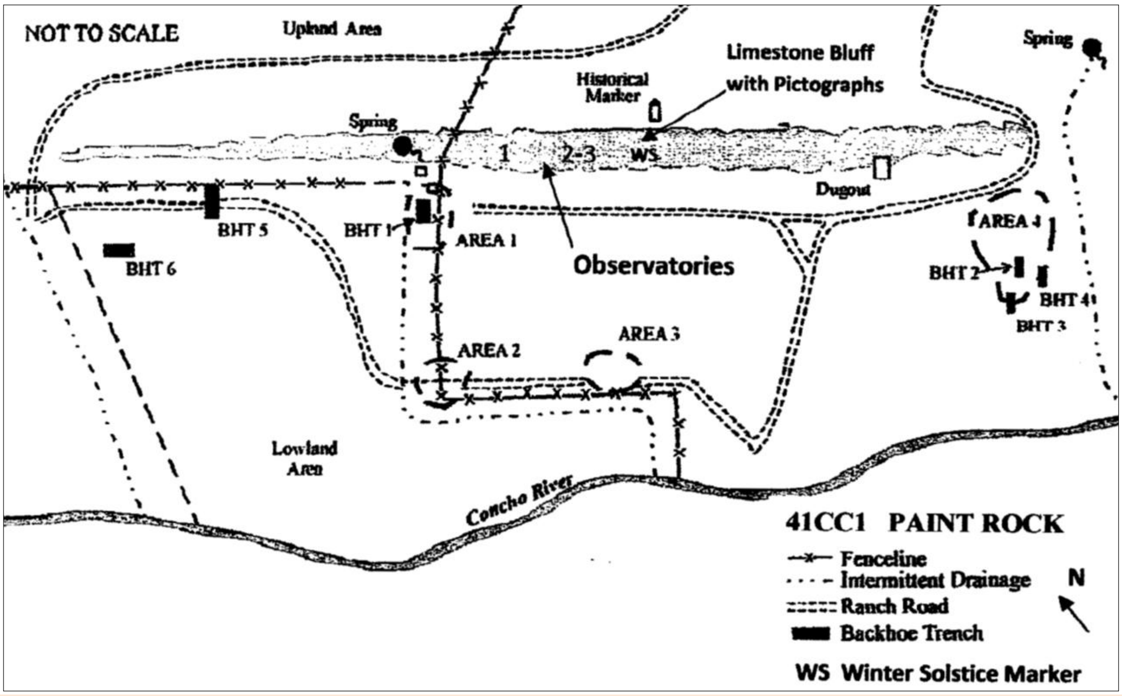


Figure 2: Site map of the Paint Rock Pictographs 41CC1. Numbers 1, 2, 3 in the shaded area of the bluff, indicate the approximate location of the three potential observation sites discussed in the narrative. WS is the location of the winter solstice solar marker (adapted from Turpin et al. (2002), map: Gordon L. Houston).

4000 to 2000 BCE (Pertulla, 2004). Turpin et. al. (2002) state that the pictographs have been known for 125 years, and to archeologists for at least 70 years. Texas artist, Forrest Kirkland, and his wife visited Paint Rock in 1934, which ignited his passion for rock art, and he spent the rest of his life painting rock art sites in Texas. These paintings became the basis of the book written by Kirkland and Newcomb (1967), with pages 146–158 dedicated to the Paint Rock site. This site also is mentioned prominently in the book by A.T. Jackson (1938).

The topography of Paint Rock lends itself to many advantages for cultural adaptation. The cliff runs NNW to ESE, and there are several areas that provide protection from the weather, especially the harsh winter winds and cold fronts. In the summer, the breeze is predominately from the SE, and the terrace provides protection from the heat. The site has multiple sources of natural water, one being the Concho River, and the other being springs that are located at each end of the most prominent portion of the cliff. The archaeological survey by Turpin et al. (2002) indicated that the largest habitation sites were near these springs. The bend in the river and the topography of this location have allowed a deep alluvial plain to develop along the cliff and across the river, making it a fertile agricultural location. At this location there is exposed bedrock that provides a natural ford across the Concho River. As a result, many paths, trails, and roadways in the landscape have converged on this location since Middle Archaic times. Hence, the site has been considered mainly as a nomadic site, and these characteristics made it a cultural cross-roads, enabling cultural diffusion.

General Robert E. Lee, the commander of the Confederate Army in the American Civil War, camped near the western spring on 16–17 July 1856 (Ashmore, 2010). The historical military road between US Army western forts, Ft. Mason and Ft. Chadbourne crosses the river at this site, as illustrated in a map by Rister (1946). The pictographs have been partially destroyed by what is now considered historic graffiti. The oldest graffiti relates to Lee's encampment, but much of it dates to the second half of the nineteenth century.

The Paint Rock pictographs were most likely produced during the Toyah Phase, a Texas archaeological period dating from CE 1300 to 1750 (Black, 1986). Evidence of this is Toyah Phase pottery found in association with hematite (iron oxide), the primary pigment of the monochrome pictographs (Turpin et al., 2002). There are many methods of painting pictographs, and these contrast with rock art known as petroglyphs, which are pecked or incised into the rock surface (Grant, 1967). The pictographs at Paint Rock have no analogues in Texas (Kirkland and Newcomb, 1967). Paint Rock's limestone exposures limit the size of the rock art, with the thickest strata being approximately 1 meter high. Many of the rock art sites recorded by Kirkland and Newcomb (ibid.) and by Jackson (1938) are small rock shelter sites. These sites are limited in size and scope, with the rock shelter being the delimiting factor. An exception to the size analogy is the area known as the Pecos River, an extremely rich rock art region, with more than 200 documented rock art sites.

The Lower Pecos River rock art region lies 300 km southwest of Paint Rock. It is an area bordered on the south by the Rio Grande River, and intersected by two tributary rivers from the north. The western river is the Pecos River, and the eastern river is the Devils River (Boyd, 1996; 2004; Shafer, 1977). The rock art in the Lower Pecos River dates to as early as 4500 BCE and as recent as CE 1280 (ibid.). The latest date is approximately equal to that of the earliest reported Paint Rock pictographs. Existing in large rock shelters, the Pecos River rock art motifs were painted on large parietal walls, allowing anthropomorphic figures to be as much as 8 feet in height (Boyd, 2004). Kirkland and Newcomb (1967) describe the Pecos River rock art as having no other comparison. On the basis of the descriptions published in books and research papers there are no confirmed rock art solar markers in the Pecos River area.

Our primary research question deals with discovering how the prehistoric occupants of Paint Rock were able to identify specific solar points and scribe the various rock art panels with such accuracy. Hence our interest in the use of the horizon for calendrical purposes. A secondary consideration is to verify the interactions that are reported to have occurred at major solar points. In this paper, we will discuss our method that was used in searching for the horizon astronomy, and we will highlight the precise positioning of the two main pictographs. But first, we will start by discussing solar markers in rock art, and finally, we will provide a preliminary 'intentionality matrix' to help identify solar markers in rock art.

## 2 SOLAR MARKERS IN ROCK ART

Rock art solar markers are one of the more objective of all material remains of Sun-watching, since they are open to rigorous interpretation. A review of the literature does not provide a concise definition of a 'solar marker', so on the basis of our study of the Paint Rock pictographs and archival records of other sites we propose the following definition:

> A 'solar marker' is an intentional rock art glyph or panel which records a significant component of the astronomical knowledge of a culture, preserving the interactions of light and shadows on the rock art at specific solar points.

The term 'solar point' defines the point on the ecliptic and the celestial sphere of the Sun on significant calendrical days and is referenced by the coordinate systems of right acension and declination, or altitude and azimuth. The visible signs of the solar points are reflected in the travel of the Sun along the horizon. The solar marker acts as a mnemonic device, and this knowledge is passed from one generation to the next. According to McCluskey (1993), in the absence of writing, this transfer of knowledge is encoded in various mechanisms to preserve the knowledge. The use of solar markers in rock art is one such mechanism.

The number of interactive rock art sites that have been identified over the years builds a *prima facie* case for the recording of astronomical knowledge. Johnson (1992) states he has documented more than 300 panels in northeast Utah. Preston and Preston (2005) claim to have identified 109 examples at 46 sites in the 'four corners region', excluding Colorado, while Fountain (2005) reports 219 observations at 45 sites. These and many other examples led Schaefer (2006: 52) to state:

> With other identical examples, the probability of the null hypothesis ("random" coincidences of shadow and [light on] petroglyphs) become very small, and we are forced into the realization that the only way to make all those spirals work on the solstice is if the designers did this intentionally.

The recording of astronomical knowledge represents a widespread pattern of behavior by prehistoric cultures. The operations of the solar markers are so precise in many cases that this would rule out a coincidental or accidental interaction hypothesis. In virtually all cases, the shift of a glyph or panel by as little as a centimeter would negate the claimed astronomical inference by eliminating the interaction with the focal point of the glyph.

Rock art solar markers are a unique form of the archaeological record in that they represent an intentional act by tying the landscape to the celestial sphere. Rock art is considered to be a form of writing (Jackson, 1938; Kirkland and Newcomb,1967; Robinson, 2001), while rock art tally marks are thought to be a rudimentary form of arithmetic (Closs, 1986b; Jackson, 1938; Murray, 1986). Research on astronomical ties to rock art has two significant advantages over other archaeological investigations. Firstly, rock art remains *in situ*, and is essentially unchanged by site formation processes (Murray, 1998). Personal conversations with the Campbells about the geological conditions of the site confirm this statement. Geologists have stated the site is stable and has been so for longer than the oldest pictographs, and as the top layer

Figure 3: The equinox panel at Paint Rock. This photo was taken on the day of the autumnal equinox, 22 September 2012 at 15:39:04 pm CST/ 20:39:04 UTC. The sun line advances across the pictograph on the equinoxes, aligning with the feet of the funeral figure on the upper right, making it appear to be walking up the line. On the day before and after, the sun line does not touch both feet at the same time: see Figures 4 and 5 (photograph: Gordon L. Houston).

Figure 4: This equinox panel photo was taken 21 September 2012 at 15:38:16 CST, 20:38:16 UTC, the day before the equinox. The sun line has reached the rear foot but is clearly away from the upper heal of the figure; see Figure 5, taken the day after the equinox for comparison (photograph: Gordon L. Houston).

Figure 5: The equinox panel solar interaction taken the day after the equinox on 23 September 2013, at 15:34:33 CST, 20:34:33 UTC. Although taken about 2 minutes prior to the time of the photograph taken on the day of the equinox, the sun line is already up on the ankle of the lower foot (photograph: Gordon L. Houston).

Figure 6: The winter solstice marker at Paint Rock, Texas. This sequence is just over 20 minutes of the interaction. Solar noon is at 12:38 CDT obtained by U.S Naval Observatory Almanac program MICA (2005). The time sequence from left to right in Central Standard Time is 12:27:40; 12:38:04; 12:48:00 (photograph: Gordon L. Houston).

monochrome pictographs are only 400–600 years old, weathering along the shadow-casting edges in that time frame would not significantly alter the interaction, if any. Secondly, we can observe the celestial sphere and the rising and setting of the Sun almost exactly as prehistoric cultures observed it. The rock art glyph and the solar interactions displayed are the whole archaeological record for a particular glyph or panel. It is a record of part of the astronomical knowledge of a culture. Hence, the recording of astronomical knowledge in rock art by prehistoric cultures provides the most rigorous interpretation and evidence of the artisan’s intentions. The study of solar markers has evolved from the necessity of an *a posteriori* requirement to *a priori* in status. In the next section, two of the most significant solar markers at Paint Rock, the Winter Solstice Marker and the Equinox marker, will be examined.

## 3 EQUINOX AND WINTER SOLSTICE SOLAR MARKERS AT PAINT ROCK

The first solar marker was noticed by Kay Campbell in 1996 while giving a tour of the pictographs during the spring. She noticed that a Sun line happened to line up with the feet of a funeral figure interpreted to be walking up the Sun line to heaven. This interaction is shown in Figure 3 and has become known as the ‘Equinox panel’. Later that same year, she noticed a dagger of sunlight interacting with a shield-shaped glyph on the winter solstice. This interaction is shown in Figure 6, and has come to be known as the ‘Winter Solstice marker’ (see Yeates and Campbell, 2002).

These were the first two solar markers discovered at Paint Rock. The Winter Solstice Marker was observed by Dr R. Robert Robbins, and he found the interaction to culminate within minutes of solar noon, adjusting for the equation of time. He gave an oral report of his observations of the site at the 1999 American Astronomical Society Meeting (Robbins 1998). This report also was the basis for the first two research questions.

The photograph of the Equinox panel shown in Figure 3 was taken on the day of the autumnal equinox, 22 September 2012, at 15:39:04 pm CST or 20:39:04 UTC, and shows the precise alignment of the Sun line relative to the bottom of the feet of the funeral figure. At first glance, one could say that this is purely coincidental and that the alignment occurs at a random time in the afternoon. However, close empirical observation of the interaction on the day before and the day after, at the same time of day, provides the evidence that this was an intentional act. Photographs taken the day before and the day after the equinox (Figures 4 and 5) show the Sun line interaction.

These photographs show how the rapid movement of the Sun along the horizon changes the angle of the Sun line, so there is no precise alignment on these days. On the day before the equinox, the Sun line reaches the lower rear foot before touching the upper leading foot shown in Figure 4. On the day after the equinox, Figure 5, the Sun line is across the ankle of the lower foot and just touching the heel of the upper foot. Hence, the exact alignment of the Sun line touching the bottom of both feet simultaneously only occurs on the day of the equinox. The precision of this alignment marks the day of the equinox and is a result of the geometric alignment of the shadow casting gnomon and the panel. The precision strongly argues the intentionality of the recording of astronomical knowledge.

Next, the winter solstice marker sequence is shown in Figure 6. The photographs of the ‘Sun dagger’ sweeping across the face of the glyph on the winter solstice shown in the three photographs is an approximate 20-minute sequence. The winter solstice marker is unique in that it operates at solar noon, meaning the ‘Sun dagger’ points directly at the focal point of the glyph at that time. The focal point is the center or primary feature of a glyph or panel, which will be discussed in the following sections (see Section 5.2, below). Long-term observation of this panel would indicate that it has calendrical characteristics as well. Once the Sun proceeds through the vernal equinox, most of the pictographs remain in shadowed areas until the autumnal equinox.

The operation of a solar marker at solar noon is more common than one might expect. Solar noon is when the Sun crosses the local meridian. Determination of solar noon adds an additional step of intentionality on the part of the culture that scribed this glyph and a strong indicator of their astronomical knowledge. The following are but three examples of solar markers whose main interaction occurs at solar noon. Preston and Preston (1983) detail a number of solar markers that operate at solar noon and glyphs that exhibit calendrical interactions. The primary interaction of the Three Slab site on Fajada Butte occurs at solar noon, and it has been shown that there are additional calendrical interactions (Sofaer and Sinclair, 1983). Bostwick (2005) details a star-shaped light pattern that occurs at solar noon in the Shaw Butte Rockshelter.

## 4 EXPLORING HORIZON ASTRONOMY

Sun-watching gave cultures the ability to define temporal cycles within their spatial environment. Watching and measuring the travel of the Sun along the horizon was the primary method of most Sun-watching cultures. Zeilik (1989: 149) indicates that horizon calendars “… have the most and best ethnographic information about them.” Identifying the Sun-watcher’s observing location is the first step in discovering a culture’s horizon astronomy. Young (2005) states that some Sun-watching stations were marked by iconographic elements of an astronomical nature. In discussing the Pueblos of the American Southwest, Zeilik (1989: 146) indicates that the observing sites were rarely marked, and he asks: “What would be the material evidence for a sun watching station?” The challenge is to connect the place of observation to the material record. The evidence worldwide is manifested in architecture, megalithic structures, megaliths, early wood construction, and rock art (Aveni, 1978; 1997; 2001; Burl, 1995; Ruggles, 1999; Simonia et al., 2009; Krupp, 1978a; Zeilik, 1984; 1985; 1989; Zoll, 2010).

The first paradigm of archaeoastronomy is to measure the horizon in order to establish solar declinations for interesting points on the horizon The potential horizon astronomy for any site purported to have archaeoastronomical implications must be established. The place of observation becomes critical and inversely proportional to the distance of the horizon. Horizons that are ≥10 km away allow a wider variance of a specific location to observe the same phenomena (Ruggles, 1999; Zeilik, 1989).

On the initial site inspection of Paint Rock to examine its astronomical potential, the first azimuth taken was a magnetic compass reading of the orientation of the cliff. The reading was 112°/114°–292/294°, without compensation for magnetic declination, which is 5.38° east. Hence, the cliff ran approximately from WNW to ESE. The first reaction was that the ESE direction was of interest for potential winter solstice interaction. However, at that time, a horizon ‘notch’ was not noticeable, yet it was right there, even when viewed from ground level. Once the observing position was determined and the notch of the horizon became apparent (to be discussed in later sections), the exact azimuth of the eastern notch was determined to be 110.04°. The calibration of the horizon notch will be discussed later and is shown in Figure 17. That first trip was spent observing the pictographs, including the equinox markers and, more importantly, observing the horizons, both to the east and the west.

When one stands on top of the bluff, the horizon is devoid of any significant topographical features. It is virtually a straight line, with only a few dips or rises within the ‘solar arc’, which is the path of the Sun along the horizon for a given location. The solar arc at Paint Rock, defined by the sunrises at the Summer and Winter solstices, is 62° to 117° as determined by MICA software program for the US Naval Observatory (2005). This is confirmed in Figure 7 (the east-

Figure 7: From the upper bluff area, the east horizon is virtually featureless (photograph: Gordon L. Houston).

Figure 8: The west horizon from the upper bluff area. The horizon is virtually featureless (photograph: Gordon L. Houston).

ern horizon) and Figure 8 (the western horizon), where both horizons are straight and almost featureless. A field survey of these two horizons from the upper bluff area confirmed that it was impossible to measure the movement of the Sun along the horizon, using horizon features, due to the lack of any topographical relief.

Figure 9: A photograph taken from the western end of the upper bluff area, looking east. Where the cliff meets the far eastern horizon, a 'horizon notch' occurs (photograph: Gordon L. Houston).

Figure 10: The 'horizon notch'. It was not until the photographs were reviewed following the first survey trip that this photograph produced one of those 'ah ha' moments with the realization that the cliff intersected the far horizon, created a significant horizon feature or 'notch' that could be used to measure the travel of the Sun along the horizon (photograph: Gordon L. Houston).

Figure 9 shows the first indication of a horizon feature that could be used to measure the Sun's travel. This dip is created by the bluff visually meeting the distant horizon. Figure 9 was taken from the western end of the main cliff area above the portion containing the pictographs. The entire length of the bluff was surveyed for possible observing positions and/or material evidence of observations. No evidence was found of an observing position along the top of the bluff, which provides no protection from the weather or the Sun. One of us (G.H.) experienced the winter weather during several survey trips, and the Arctic north winds were so cold that even with modern thermal clothing it was difficult to withstand the conditions without taking advantage of the shelter provided by the cliff. Hence, this lack of weather protection was one reason that we eliminated any position on top of the bluff as a place of observation. Ultimately, there were no signs along the bluff above the cliff face to suggest a position where solar observations were carried out. The few horizon features noted were not in positions that provided any type of anticipation or confirmation of a calendrical solar point.

Figure 11: Observation Site 1 has a limited viewshield, with the horizon notch blocked from view. Other negative features include a limited living area, a low ceiling, and the roof and weather protection was poor (photograph: Gordon L. Houston).

The next area to be surveyed was the terrace at the base of the pictographs. The terrace is at the top of the debris fall, along the broken slabs of limestone containing the pictographs. This terrace was not continuous, and there were only three potential areas that could have provided space for human activity. For the purposes of this discussion, these are referred to as Observation Sites 1, 2 and 3. The survey along the base of the cliff continued for two more fieldtrips. A photograph was taken from Observation Site 3, east of the other two sites, on the first survey trip, but it was only after reviewing the photographs taken on this fieldtrip that a 'horizon notch' became apparent (see Figure 10). Indeed, 'horizon notches' were noted to the east *and* the west where the cliff intersected the horizon. The initial compass bearing of the orientation of the cliff suggested that these notches may have been significant for horizon astronomy.

When Observation Site 1 (Figure 11) was examined it was found to possess one major flaw: the horizon and the notch were not visible. An obstructed view also was true for Observation Site 2 (Figure 12). Both of these locations had additional negative qualities. Observation Site 1 had limited living space, a low ceiling, and the roof slabs did not provide protection in wet weather. Observation Site 2 had a larger potential living area, but the overhead rock layers were broken and would not provide good weather protection. Observation Site 3 (Figure 13) had all the right qualities: a good view of the horizon and the 'horizon notch', a large living area, and a large rock for seating purposes. It also had a solid roof, which provided excellent protection from Sun, wind and rain (see Figure 14).

Figure 12: Observation Site 2. This was the first area selected. It has an extended living area, but the viewshield did not include the 'horizon notch' or that portion of the horizon traversed by the Sun (photograph: Gordon L. Houston).

The other distinctive feature of Observation Site 3 was the presence of 47 tally marks (Figure 15) on a layer of rock just above the large rock that would have been used to sit on. In fact, there are a number of other sets of tally marks only in this area of the cliff, with some being in black and underneath portions of other tally marks. No one has suggested why these are here, as they are limited to this area and do not have any design similarities to the pictographs. This material evidence is surely the key to the horizon astronomy. Marshack (1985) discusses record keeping, and Murray (1986) describes tally marks at Northern Mexico rock art sites. If you count 47 days from 6 November (the midway point between the autumnal equinox and the winter solstice), the date when the Sun is at the 'horizon notch', you arrive at the day of the winter solstice. If you counted backwards from this date, identification of the equinox would also be possible. This indicates that Observation Site 3 was a primary Sun-watching location.

Figure 13: Observation Site 3. This was the final site considered as a Sun-watching location. It had all the qualities that neither of the other potential sites possessed, including a clear view of the horizon and the 'horizon notch' (photograph: Gordon L. Houston).

Figure 14: Observation Site 3 has a continuous, unbroken rock slab layer, providing excellent weather and rain protection (photograph: Gordon L. Houston).

A horizon survey of Observation Site 3 was then carried out. Figure 16 is a sketch of the horizon, with significant points of interest marked, and calibrated with calculated declination points. The 'notch' created by the intersection of the cliff and the horizon has a calculated declination of –16° 03′ 47.9″, which closely matches the Sun's declination on 6 November. The calculated declination tallies with that provided by the MICA program (see U.S. Naval …, 2005) of –16° 16′ 12.0″, Aveni's (2001) Solar Declination

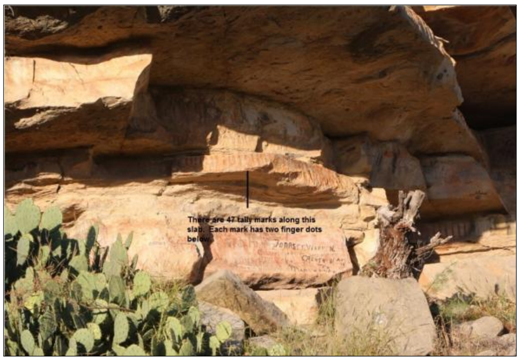
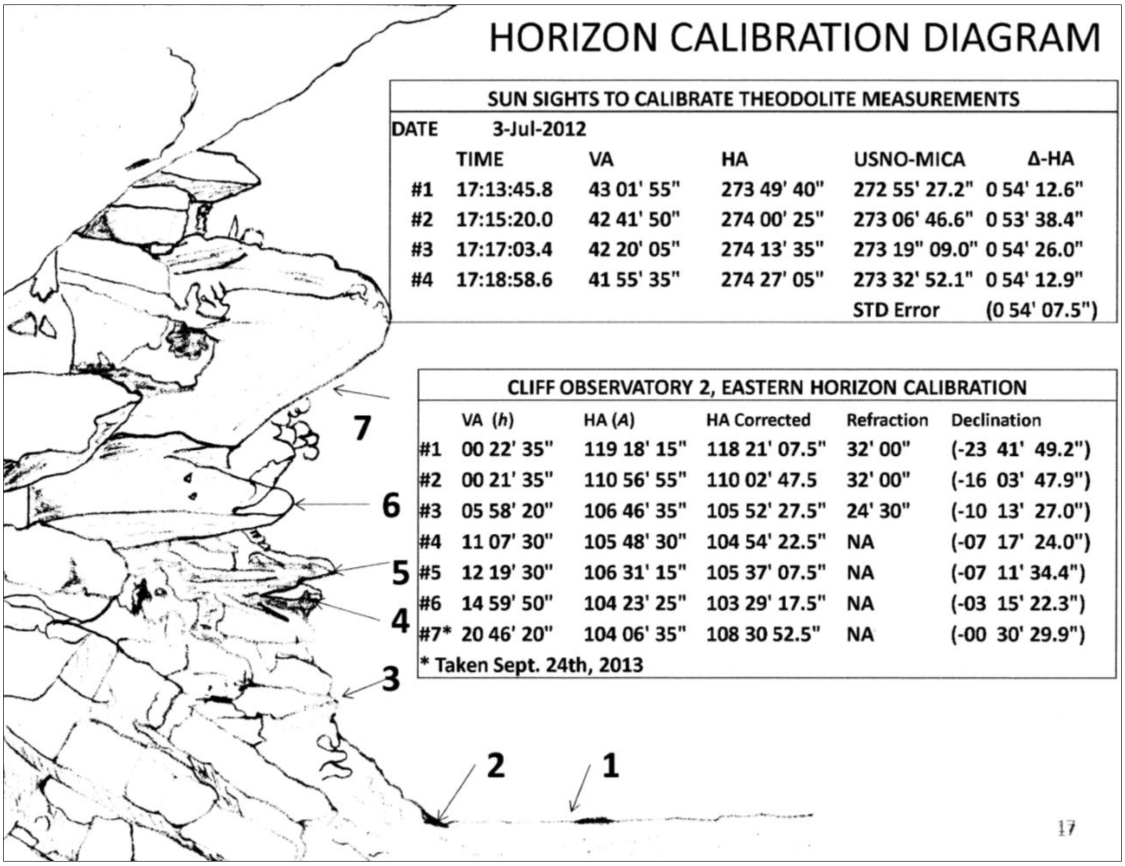


Figure 15: Observation Site 3 has a slab with 47 tally marks. Each tally mark has two small marks below, suggesting their use in multiple counting sequences. No marks of this nature exist at the other two sites (photograph: Gordon L. Houston).



HORIZON CALIBRATION DIAGRAM

SUN SIGHTS TO CALIBRATE THEODOLITE MEASUREMENTS

DATE 3-Jul-2012

|  | TIME | VA | HA | USNO-MICA | Δ-HA |
|---|---|---|---|---|---|
| #1 | 17:13:45.8 | 43 01' 55" | 273 49' 40" | 272 55' 27.2" | 0 54' 12.6" |
| #2 | 17:15:20.0 | 42 41' 50" | 274 00' 25" | 273 06' 46.6" | 0 53' 38.4" |
| #3 | 17:17:03.4 | 42 20' 05" | 274 13' 35" | 273 19" 09.0" | 0 54' 26.0" |
| #4 | 17:18:58.6 | 41 55' 35" | 274 27' 05" | 273 32' 52.1" | 0 54' 12.9" |
|  |  |  |  | STD Error | (0 54' 07.5") |

CLIFF OBSERVATORY 2, EASTERN HORIZON CALIBRATION

|  | VA (*h*) | HA (*A*) | HA Corrected | Refraction | Declination |
|---|---|---|---|---|---|
| #1 | 00 22' 35" | 119 18' 15" | 118 21' 07.5" | 32' 00" | (-23 41' 49.2") |
| #2 | 00 21' 35" | 110 56' 55" | 110 02' 47.5 | 32' 00" | (-16 03' 47.9") |
| #3 | 05 58' 20" | 106 46' 35" | 105 52' 27.5" | 24' 30" | (-10 13' 27.0") |
| #4 | 11 07' 30" | 105 48' 30" | 104 54' 22.5" | NA | (-07 17' 24.0") |
| #5 | 12 19' 30" | 106 31' 15" | 105 37' 07.5" | NA | (-07 11' 34.4") |
| #6 | 14 59' 50" | 104 23' 25" | 103 29' 17.5" | NA | (-03 15' 22.3") |
| #7* | 20 46' 20" | 104 06' 35" | 108 30 52.5" | NA | (-00 30' 29.9") |

* Taken Sept. 24th, 2013

Figure 16: Horizon calibration. This sketch shows the cliff intersecting the horizon at notch number 2. Solar sights were taken to calibrate the theodolite to true north. Points along the cliff profile were recorded and, using spherical trigonometry and adjusting for atmospheric refraction, the declinations of each point were determined (diagram: Gordon L. Houston).

Table 11, of –15° 48′, and Starry Night Pro (2009) of –16° 11′ 31.9″. Figure 16 details the Sun sights taken to calibrate the theodolite, and the determination of solar declinations using spherical trigonometry of significant horizon points. A review of the survey shows that the Sun-watcher could have used the whole outline of the cliff for calendrical purposes.

## 5 THE MATRIX OF INTENTIONALITY

The best interpretation of rock art involves a holistic approach. As a result of observations made during the 20 planned field surveys and a review of the literature, it became evident that there needed to be a way to quantify rock art solar markers in a uniform manner. The Matrix will allow individual observers to evaluate a potential solar marker objectively by using standardized parameters. Fountain (2005) attempted to create a database using a pool of observers, and he concluded that the available data con-firmed the intentional placement of glyphs for calendrical solar interactions. However, the data were insufficient to evaluate the interactions statistically. We believe that some of the variables chosen could not be used for statistical analysis, and that not a broad enough range of variables was provided. We therefore propose the Solar Marker Matrix of Intentionality, shown in Table 1, which expands the number of variables to be measured and resolves the issues encountered by Fountain.

The idea of the matrix was conceptualized from two other matrices used in archaeology: Harris' (1997) matrix for stratigraphy and Parker's Borderland Matrix, which deals with inter-cultural exchanges along boundaries. Initially, the introduction of these matrices was met with skepticism (Harris, 1997: xi–xii), but now they are accepted as part of every-day archaeological practice. As Parker (2006: 77) states in his abstract, his matrix is applicable to "… proposed terminology, models or conceptual frameworks …" for borderland processes. We propose our Solar Marker Matrix of Intentionality with these same intentions. Following is a brief overview of the Matrix and its functions, while the following sections provide further details. The Matrix is preliminary and will be revised as new observations and information come to hand.

In the Matrix (Table 1) the astronomical analysis is in four categories, namely

Table 1: The Solar Marker Matrix of Intentionality (credit: Gordon L. Houston).

| Points | 1. Solar Points | A | Points | 3. Interactive Characteristics | B |
|---|---|---|---|---|---|
| 5 | 1.1 Winter/Summer Solstice (WS, SS) | | 5 | 3.1 Focal Point(s)—Geometric Alignments | |
| 4 | 1.2 Cross-quarter Days (V, S, A, W)* | | 4 | 3.2 Register Mark Alignment | |
| 3 | 1.3 Confirmed Anticipatory Points | | 3 | 3.3 Rapid Interactions | |
| 2 | 1.4 Equinox (VE, AE) | | 2 | 3.4 Tangent Alignment | |
| 1 | 1.5 Random Days | | 1 | 3.5 Random | |
| | | | | | |
| Points | 2. Time of Day | | Points | 4. Supporting Evidence | |
| 5 | 2.1 Solar Noon | | 5 | 4.1 Horizon Astronomy** | |
| 4 | 2.2 Sunrise | | 4 | 4.2 Geometric Conditions | |
| 3 | 2.3 Sunset | | 3 | 4.3 Informed Sources | |
| 2 | 2.4 Random Morning | | 2 | 4.4 Formal Examination | |
| 1 | 2.5 Random Afternoon | | 1 | 4.5 Analogy/Symbolism | |
| | | | | | |
| | Total Point: Column A | | | Total Point: Column B | |
| | Intentionality Factor | | | Column A & B Totals | |
| | Very High 19–≥20 | | | | |
| | High 14–18 | | | | |
| | Medium 8–13 | | | | |
| | Low 4–7 | | | | |

* Key: V = vernal; S = summer; A = autumnal; W = winter.

** The Horizon Astronomy category may include confirmation of any form of astronomical knowledge.

1. Solar Points
2. Time of Day
3. Interactive Characteristics
4. Supporting Evidence

There are five entries below each of these categories, listed in descending order of importance, and each entry attracts points, which range from 5 to 1. Thus, the highest characteristics in each of the four categories are interactions that occur during the winter solstice (1.1), at solar noon (2.1), where the interactions intersect the focal point of the glyph (3.1) and where horizon astronomy has been established for that location (4.1). A 'solar marker' with all four of these characteristics would have an 'Intentionality Factor' of 20 points. However, it is possible to have a score >20, as more than one category can be scored in Category 4 (Supporting Evidence). Sections 4.2 (Geometric Conditions) and 4.3 (Informed Sources) may also be scored, in addition to 4.1 (Horizon Astronomy), making the highest possible score 27 points.

The scores for each of the four categories are totalled, and the final score gives the 'Intentionality Factor'. An interactive panel with a score of >20 would have the highest intentionality. The Matrix can be used as a guide to evaluate encountered light and shadow interactions or as a tool to search for solar markers. Scores using the matrix will help rule out coincidental or accidental light and shadow interactions, which are the most common arguments against these interactions.

As an example, the winter solstice marker at Paint Rock would be scored as follows:

Category 1, Solar Points
  1.1 Winter Solstice (WS) = 5
Category 2, Time of Day
  2.1 Solar Noon = 5
Category 3, Interactive Characteristics
  3.1 Focal Point—Geometric Alignments = 5
Category 4, Supporting Evidence
  4.1 Horizon Astronomy = 5
Total: 20

Hence, the objective interpretation based on the Matrix is that the 'sun dagger' and winter solstice marker was an intentional act of the culture and the artisan who scribed the pictograph.

In the following Sections, we will discuss each of the four Categories.

## 5.1 Astronomical Analysis: Categories 1 and 2

The first category of astronomical analysis, Solar Points, relates to the apparent travel of the Sun along the ecliptic. There are four major solar points along the ecliptic: the Vernal Equinox (1.4), Summer Solstice (1.1), Autumnal Equinox (1.4) and the Winter Solstice (1.1). There are also four minor solar points: the mid-points between sets of the four major points, referred to as 'cross-quarter days' (1.2) and designated by the time of the year. Each of the solar points may have significant meaning to various cultures. The winter solstice is one of the most significant points, as rituals are performed to entice the Sun to return. Light and shadow operations that occur on specific solar points have the highest significance or level of intentionality.

Use of the term 'cross-quarter days' has been met with some resistance, and seen as 'Eurocentric', mainly due to lack of ethnographic evidence of their importance. We offer the following evidence in support of this term. Preston and Preston (1983) report that 11% of their recorded interactions were "… about 45 days before and after winter solstice." and Fountain (2005) reports fully 20% of the interactions to occur on cross-quarter days. McCluskey (1977) indicates the Hopi's most important celebrations were known as Wuwuchim, and the dates were fixed by horizon observation "… some 45 days before the winter solstice …", which corresponded to the autumn cross-quarter day. As we have shown above, the horizon astronomy at the Paint Rock pictograph site marks a notch on the horizon where the Sun rises 47 days before the winter solstice. In fact, this is the approximate period from any solstice or equinox to a cross-quarter day. Thus, with further study, evidence may point to cross-quarter day significance. It is important to note that the Solar Marker Matrix of Intentionality is proposed for all rock art worldwide and is not limited to solar markers in the USA.

The second category of astronomical analysis is the time of day. Light and shadow operations occur throughout the day at many rock art sites. The categories used in our analysis, in order of relevance of intentionality by the artisan, are 'solar noon' (2.1), 'sunrise' (2.2), 'sunset' (2.3), 'random morning' (2.4) and 'random afternoon' (2.5). The interaction of light and shadow that has the highest intentional rating occurs at or within ten minutes of solar noon. Young (2005) discussed solar noon as one of the three daily stations of the Isleta Puebloans, and their ceremonies occurred around noon. Sofaer and Sinclair (1983) detail the primary interactions of the three slab site on Fajada Butte occur at solar noon. A glyph or panel that operates at solar noon requires an additional step of intentionality. Solar noon has to be determined and is site specific, i.e. the transit of the Sun across the local meridian. Determination of solar noon is the reason that solar noon has the highest point value of all time of day categories.

Malville (2008) indicates that many Sunwatchers observed both at sunrise and sunset, and he also states that sunrise was a 'crucial' time for horizon astronomy. Young (1986) also details the importance of sunrise, sunset and solar noon. Some American Southwest tribes divided the year by which horizon they watched, east or sunrise from Winter Solstice to Summer Solstice, and then the western horizon. He indicates that eastern Puebloans watched the sunrise and the Zuni both sunrise and sunset. Rock art that interacts with light and shadow within a one-hour window of sunrise or sunset is governed by the geometrical alignment of the geologic structure and the Sun. Hence, interactions occurring within one hour of sunrise and sunset have the next level of significance, with sunrise being more important than sunset operations.

The term 'random' in 1.5, 2.4, 2.5 and 3.5 refers to random days in the Solar Points, Time of Day and Interactive Characteristics categories. In most cases, these are coincidental interactions with glyphs and panels of rock art that have no astronomically-significant meaning. These have the lowest level of intentionality. However, it should be noted that a solar marker for anticipatory observations in preparation for rituals on major solar points may occur on a random day and at a random time. The only way to verify an anticipatory marker is through sources of informed or formal analysis; since these may never be known, the interactions should simply be classified as coincidental.

## 5.2 Interactions With Rock Art: Category 3

The appearance of the 'sun dagger' at Fajada Butte is the most recognizable example of a solar interaction with rock art. Preston and Preston 1983) state that the interactions they observed occurred with the leading or trailing tip. A literature review of other sites indicates a point (i.e. like the tip of a capital 'A') or corner shape (i.e. an 'L' shape) or Sun lines (i.e. straight lines) are the predominant operations (Hudson et al. 1979; Lehrburger, 2005; Preston and Preston, 1983). The Sun or shadow lines have no points but still interact with significant design elements of rock art. These Sun and shadow lines are not always straight and can have crooked shapes. The crooked shapes can then line up with or match the designs of a rock art glyph, an example being the equinox marker at the Pathfinder petroglyphs site in south-eastern Colorado (Lehrburger, 2005). This is illustrated in Figure 17. Observations of the pictographs at Paint Rock reveal that the solstice markers are involved with the 'point' of the sunlight shaft, pointer, or dagger, and a moving Sun line (e.g. see Figure 6). Whatever the shape, these types of interactions align with shapes on the rock art or can create a framing of the pictograph. Space limits a full discussion here on the shapes of light and shadow forms. The position of the light and shadow on the rock art is more important than the shape.

Interaction of light and shadow with rock art is dependent upon the solar altitude, which changes with solar declination. There is an inverse relationship between the solar altitude and the position on the panel or glyph of the solar interaction: the lower the Sun's altitude, the higher the interaction is on the panel. For example, at the winter solstice, the Sun is at its lowest altitude, so the solar interaction is at the highest point on a glyph, and *vice versa* for the summer solstice interaction. The solar declination also has a seasonal impact, as it changes; some panels are in the shadow for a significant portion of the year.

The concept of a 'Focal Point' (3.1) was introduced by Preston and Preston (1983) in desribing the position on the rock art intersected by the light and shadow mechanics. The Focal Point is the central feature, especially when dealing with spirals or concentric circles. There may also be multiple Focal Points that are a function of both the glyph or panel design and features. Interactions with the Focal Point are the primary recording of the astronomical intentions of the artist. Any additional calendrical activity may be purely coincidental.

A 'Register Mark' (3.2), introduced by Zoll (2010), is an intentionally-placed mark on a glyph that acts as a specific day identifier other than on one of the primary solar points. Zoll describes the importance of the agave harvest in the Sinagua Culture, which occurs in late April. The register mark on the equinox marker aligns with the Sun line 30 days after the vernal equinox, and therefore occurs at the end of April. As Zeilik (1989: 144) states, it is a burden of proof for archaeoastronomy that "… the site must 'work' culturally …", and this is an excellent example. The placement of a Register Marker is intentional and may also be found to be an anticipatory maker. For these reasons, a Register Mark is assigned the second highest score in this category.

Reports of 'Tangent Alignment' interactions (3.4) have been associated with the markings at Fajada Butte. The tangentially-aligned Sun daggers occur at the winter solstice, and the rock formation creates two daggers, one on either side of the spiral. The question is: did the hand that created the spiral know how big to make the spiral so that these winter solstice daggers would strike on either side, just barely touching the spiral? There are no reports of the spiral being created in stages, say a smaller one for the original summer solstice interaction and then expanded to be framed by the dual winter Sun daggers. These interactions are a form of Tangent Alignment interactions as many times they align with the outer edges of the design.

As the Sun moves along the ecliptic, its altitude changes throughout the year. Thus, the Sun's rays hit the Earth's surface at different angles virtually every day of the year. These geometric configurations, the angle of the Sun's rays and the angular position of rock surfaces and gnomons, are unique to each rock art site. Thus, these geometric conditions create unique 'Geometric Alignments' (3.1) with the rock art. There are two types of Geometric Alignments. One is formed by a Sun or shadow line, usually straight in nature, which moves across a panel

Figure 17: The sketch and picture shows a geometric alignment (3.1) on the equinox morning sunrise. The right edge of the shadow mimics the outline of the glyphs. The alignment is precise, except at the upper and lower portions, which is possibly explained by changes in the edge of the shadow casting rock (adapted from Lehrburger, 2005: 13–14. Photograph and sketch by Carl Lehrburger).

or glyph. The other is a Sun or shadow line that mimics the design in the rock art, so the usually-irregular Sun or shadow line matches the design (see Figure 17). At Paint Rock, this geometry is responsible for the equinox panel interaction (see Figure 3).

The overall length of time that the interactions operate on a solar marker is another important aspect to consider. The observed solar markers at Paint Rock have two basic properties, 'Rapid' (3.3) and 'protracted'. The winter solstice primary solar marker, shown in Figure 6, has a rapid interaction, with a timeframe of twenty minutes. Another winter solstice solar marker, described by Yeates and Campbell (2002), is a large circular shield, whose mid-morning random interaction starts with a light point. This point of light then stretches across the shield and expands to frame the shield tangentially before moving off to the right. From the time the first point of light appears to the time of the tangent alignment is more than an hour, so this would be defined as a 'protracted interaction'. Rapid Interactions (3.3) required the hand that inscribed the rock art to be more aware of the location of the interaction in order to align the rock art, and thus a greater degree of intentionality can be considered than for protracted interactions. Thus, Rapid Interactions are another defining characteristic of solar markers and intentionality.

## 5.3 Supporting Evidence: Category 4

Supporting evidence is the last section of the Matrix, which includes both astronomical and archaeological considerations.

### 5.3.1 Horizon Astronomy: Sub-Category 4.1

The top entry in this category, with 5 points, is documentation of the horizon astronomy for a site. Discovering and documenting the horizon astronomy, a key component of any sun-watching culture's astronomical knowledge, is a big step towards confirming a culture's ability to accurately place glyphs and panels in order to record specific solar points. Hence, the highest point given in category 4. Discussion of an example of this was the primary focus of this paper.

### 5.3.2 Geometric Conditions: Sub-Category 4.2

The geometric conditions of a glyph or a panel involve an examination of the operation of a solar marker. This examination details the accuracy and precision of the interactions. As illustrated in the discussion of the operation of the equinox marker, the precision shown on the day of the equinox, compared to the day before and the day after, reflects the astronomical knowledge. Two facets define the precision of the interactions. Firstly, the precise knowledge of the day of the equinox had to be known to the culture scribing the pictograph. Secondly, the geometric conditions casting the Sun line need to be examined. In some instances, there is evidence of manipulation of the shadow-casting gnomon (e.g. see Fountain, 2005; Zoll, 2008) or even a suggestion that artificial gnomons were used (Hudson et al., 1979).

### 5.3.3 Informed Sources, Formal Examination and Analogy Symbolism: Sub-Categories 4.3, 4.4 and 4.5

In their paper, "An archaeology of rock-art through informed methods and formal methods", Chippendale and Tacon (2004b) provide a methodological framework for the study and interpretation of rock art. The three primary focal points are: 1. Informed methods, 2. Formal methods and 3. Analogy. These three methods set the standards followed by the rock art community. Examples include Tacon and Chippindale (2004) and Whitley (2011), who discuss the informed and formal methods, and Boyd (2004), who discusses the interpretation of rock art using several examples of analogy.

'Informed Sources' is a method based upon knowledge provided by people and cultures connected with the rock art, through ethnography or ethno-historical documentation. In an archaeological context, this is also known as the 'Direct Historical Approach'. 'Formal Methods' are the opposite of Informed Sources, as there is no access to ethnographic data for the rock art being studied. 'Analogy Symbolism' is indirectly related to the Formal Method in that it, too, has no access to ethnographic data and is further isolated from the original rock art site by inferring interpretation from other sites in the primary study area. This final method becomes very subjective.

These methods hope to ensure that rock art studies are made within a scientific framework and methodology. They come under the cognitive-processual approach in archaeology, which is the interpretation of a culture's ideology, including their ritual practices connected with astronomical observations, and their worldview (Fagan and DeCorse, 2005). A holistic approach incorporates all facets of evidence to draw the best conclusions, which applies to rock art as it relates to the recording of astronomical knowledge. The rock art itself is a significant part of the archaeological record, and a cultural process (Judge, 2008), or technology, that has many archaeological implications about a culture's world view.

## 6 CONCLUSIONS

We have introduced the largest pictograph site in the state of Texas, Paint Rock. It is the most important archaeoastronomical site known in

Texas. Over the course of 20 survey trips, we have observed the interactions of twelve solar markers and believe that there are more to be discovered. We have shown their accuracy and precision by detailing the first two solar markers discovered at Paint Rock. The challenge was to determine how the cultures responsible for them were able to place the glyphs so accurately in order to accommodate the solar interactions. The search for the place of observation, which involved four field trips, was detailed. We have shown how the place of observation is tied to the material record and the horizon astronomy. Confirmation of the place of observation came through linking the material record—in this case the pictograph tally marks—to the location. Identifying the place of observation then led to the discovery of the horizon astronomy. This allowed us to answer our primary research question, which was: "How did the cultures so accurately place these rock art glyphs to interact with light and shadow on important solar points of the year?"

The enigma that is rock art has led to a sequence of hypotheses that have attempted to interpret their meaning, and these have evolved over time. This changing of hypotheses supports the positivistic ideology that any attempt to interpret rock art is purely speculative. Many would postulate that the solar interactions are nothing more than fortuitous events, but we have argued to the contrary. Murray (1998: S4) states that the intentionality of rock art "… solves the *a posteriori* test of replication required of other archaeoastronomical evidence." In the American Southwest and Great Basin alone, the number of analogous sites with interactive rock art solar markers is extensive, with Paint Rock being within the broad region defined by these areas. Schaefer (2006) concludes that the large number of operating solar markers defines the intent. Hence, the astronomical knowledge recorded by rock art solar markers is one of the more rigorous interpretations of rock art.

We have provided a working definition of a 'solar marker'. Our preliminary Solar Marker Matrix of Intentionality has been explained in detail. The hope is that it will assist those whose knowledge of solar interactions is limited. The Matrix will be a guide for observed solar interactions, and a tool that can be used to search for unknown solar markers. The numbers of solar markers reported in Section 1 by various researchers will populate the data sample rapidly. The hope is that through time, with enough observations and scoring of solar markers, a database of solar markers may lead to better statistical analysis and support of our hypothesis.

## 7 NOTES

1. The Smithsonian Trinomial Site Designation system was designed for archaeological sites in the United States. The first number is the assigned State number, the second set of letters the county or parish, and the third number is the site number for that county.

## 8 ACKNOWLEDGEMENTS

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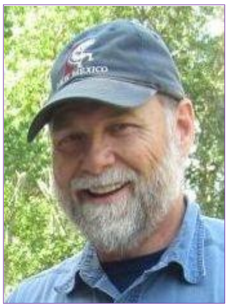

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[This paper has been retracted]

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# EXPLORING THE FIRST SCIENTIFIC OBSERVATIONS OF LUNAR ECLIPSES MADE IN SIAM

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**Abstract:** The first great ruler to encourage the adoption of Western culture and technology throughout Siam (present-day Thailand) was King Narai, who also had a passion for astronomy. He showed this by encouraging French and other Jesuit missionaries, some with astronomical interests and training, to settle in Siam from the early 1660s. One of these was Father Antoine Thomas, and he was the first European known to have carried out scientific astronomical observations from Siam when he determined the latitude of Ayutthaya in 1681 and the following year observed the total lunar eclipse of 22 February. A later lunar eclipse also has an important place in the history of Thai astronomy. In 1685 a delegation of French missionary-astronomers settled in Ayutthaya, and on 10−11 December 1685 they joined King Narai and his court astrologers and observed a lunar eclipse from the King's 'country retreat' near Lop Buri. This event so impressed the King that he approved the erection of a large modern well-equipped astronomical observatory at Lop Buri. Construction of Wat San Paulo Observatory—as it was known—began in 1686 and was completed in 1687. In this paper we examine these two lunar eclipses and their association with the development of scientific astronomy in Siam.

**Keywords:** Siam, King Narai, lunar eclipses, Ayutthaya, Jesuit astronomy, Lop Buri, Wat San Paulo Observatory

## 1 INTRODUCTION

The Jesuits are an order of the Roman Catholic religion with a long tradition in science, and especially astronomy (Udias, 2003). While the astronomical activities of European Jesuits in Beijing during the seventeenth century are well known (e.g. see Needham, 1959; Pigatto, 2004; Udias, 1994), few astronomers are aware that French Jesuits triggered the emergence of scientific astronomy in Siam (present-day Thailand) *and* India (see Kochhar, 1991; Rao et al., 1984) during this same century.

Jesuit astronomers were responsible for the first scientific astronomical observations made in Siam, in 1681–1682 and 1685, and in each instance a total lunar eclipse was involved. This paper examines these two events, and forms part of a larger research project that is described in Orchiston et al. (2016b).

But before we examine these eclipses we should meet King Narai who was largely responsible for the introduction of scientific astronomy in Siam.

## 2 KING NARAI: A BIOGRAPHICAL SKETCH

One of the most revered of Thailand's historic rulers, 'King Narai the Great' (Figure 1) was born in 1633 and died prematurely on 11 July 1688. He was the fourth king to rule during the Prasat Dynasty, which was the fourth of the five Dynasties of the Ayutthaya Kingdom (see Table 1). Narai became the King of Ayutthaya in 1656, when just 23 years of age, and remained on the

Figure 1: A contemporary French sketch of King Narai dressed in Persian attire (en.wikipedia.org).

Table 1: Thai kingdoms and dynasties. King Narai ruled during the Prasat Dynasty.

| Kingdom | Duration (years AD) | Dynasty |
|---|---|---|
| Sukhothai | 1238–1438 | |
| Ayutthaya | 1350–1767 | Uthong |
| | | Suphannaphum |
| | | Sukhothai |
| | | **Prasat** |
| | | Ban Phlu Luang |
| Thonburi | 1767–1782 | |
| Rattanakosin/ Thailand | 1782– | |

throne until his death. Upon his succession King Narai

> ... inherited a large and powerful kingdom in the centre of mainland South-East Asia. His realm reached south to the kingdoms of Pattani, Ligor, Phattalung and Songkhla; in the east Cambodia had acknowledged Ayutthaya's suzerainty, and in the west the port of Tenasserim on the Bay of Bengal was under Thai control. (Hodges, 1999: 36; for Thai localities mentioned in this paper see Figure 2).

Despite his comparative youth, from the start King Narai was an astute politician and a skilled military strategist. To stabilize the political environment in northern Siam he occupied Chiang Mai in 1662 and later that year and in 1663 he occupied parts of present-day Myanmar in order to pre-empt a Burmese invasion of Siam. However, his troops subsequently abandoned both regions and concentrated on consolidating their military presence in the Ayutthaya-Lop Buri-Bangkok area. Towards this end, forts designed by French engineers were erected in these cities and other cities in Siam.

Figure 2: A map showing Thailand localities mentioned in the text (map: Wayne Orchiston).

King Narai also was very active in international affairs, and he saw exposure to Eastern and Western civilizations as a way of developing Siam. Thus, he signed treaties with England, France, Holland and Persia and expanded trade between Siam and India, Indonesia, China and Japan. These initiatives led to a proliferation of international trade, and cemented "… Ayutthaya's reputation as an 'emporium of the East' ..." at this time, which rested largely "... upon her role as a focus for the trans-shipment of goods between Europe/India and China/Japan ..." (Sternstein, 1965: 108). Because of his enlightened policies we could regard King Narai as

> ... a strange but also positive anachronism—or precursor—for the Siam of the time. Not only [because of] his wide spirit of religious tolerance but also his positive interest in faraway lands, their customs, religions and peoples ... (Sioris, 1992: 60).

In 1675 a Greek adventurer named Constantine Phaulkon (1647–1688; Figure 3; Sioris, 1988) came to Siam. He quickly learnt Thai, and being fluent already in English, French, Portuguese and Malay joined King Narai's court as a translator. Thanks to his prior experience with England's East India Company he quickly emerged as one of the King's favourites and gained increasing power until he became the King's principal advisor. As Sioris (1992: 60) remarks,

> The adventurer, the old seaman, the man of profit, changed into the mature and experienced courtier and politician, the intriguer—and the trusted Counselor. Mere survival in the exotic land had been secured. Now, the investment in work and effort had to bring in dividends of influence and power. At this juncture there emerges the new Phaulkon, who projects himself onto the great diplomatic chessboard of the times, corresponding with popes, monarchs, bishops, generals, politicians, intriguing with Jesuits, missionaries and diplomats, planning or destroying great alliances, undercutting or supporting old and new religions. The small shipboy of remote Cephallonia was now wearing exotic golden uniforms and receiving ambassadors and envoys ...

Through Phaulkon's influence, Siam forged close diplomatic relations with the court of Louis XIV of France (1638–1715) as part of a carefully-planned strategy to use the French as a counter to the growing economic dominance of the Dutch in Siam (see Cruysse, 2002; Hutchinson, 1933). King Narai also had heard of King Louis XIV's military success over the Dutch during the war of 1672–1679 (Love, 1994a). Meanwhile, for their part, the French

> ... had been seeking ways to establish France as a great commercial, political and military

> power in the Far East, in direct challenge to Dutch hegemony. (Love, 1994b: 156).

Consequently, they were eager to establish a major trading centre in Siam, and also to convert the local population to Catholicism, so increasing numbers of French missionaries and lay persons made their way to Siam, and particularly Ayutthaya, Lop Buri and Bangkok. Among their number were architects, engineers and craftsmen who became involved in the construction of forts, and when King Narai decided to develop Lop Buri as an alternative capital (Thavornthanasan, 1986) they helped design and build a new palace, drains, fountains and a water reservoir.

In January 1684 two Thai ambassadors, Pichai Warit and Pichit Maitri, accompanied by a French missionary, Father Bénigne Vachet (1641–1720) from la Société des Missions Étrangères de Paris who had been in Siam since 1671, went to France and had an audience with King Louis. They presented the King with a letter from King Narai inviting him to send astronomers to Siam. The following year the French obliged, and on 3 March 1685 a mission led by Chevalier de Chaumont (1640–1710) sailed from Brest on the *l'Oiseau* and *la Maligne* bound for Siam. Accompanying de Chaumont were Father Vachet, François-Timoléone Choisy (1644–1724) and a number of Jesuit astronomers. They arrived in Siam on 24 September 1685 and were greeted by two mandarins and an impressive retinue of forty men, sent by King Narai. Meanwhile, the King's astrologers had been assembled to determine "... the luckiest day of the Year to be pitched upon for his [de Chaumont's official] Reception ..." at court (Love, 1994a: 60). This turned out to be 18 October, when the French delegation had an audience with King Narai (Figure 4) in Ayutthaya.

According to de Chaumont (1686), at this time

> His Majesty the King Narai is about 55 years old, handsome, lovely, dark, has good behavior, and is brave. He is also intelligent, a good ruler … [and is] kindhearted …

Regrettably, there are no other descriptions of King Narai, so we cannot ascertain whether the likeness shown in Figure 1 is realistic or not. What we do know, however, is that King Narai's clothing shown in this representation is distinctly non-Siamese: apparently, prior to meeting the French he had entertained a Persian delegation, and he liked their attire so much that he decided to adopt it for his own court appearances (Smithies and Bressen, 2001).

Soon afterwards the delegation proceeded to Lop Buri (or Louvo as it was usually referred to by the French).[1] The city they encountered upon their arrival was impressive, and was described by Gervaise (1689) as "… a town which is, so to speak, in the Kingdom of Siam what Versailles is in France." Because King Narai favoured Lop

Figure 3: A contemporary drawing of Constantine Phaulkon (en.wikipedia.org).

Figure 4: A painting showing Chevalier de Chaumont presenting a letter from King Louis XIV to King Narai in 1685. He is accompanied by the Jesuit missionaries, Fathers Tachard and Vachet. Constantine Phaulkon is crouching on the left, with his hand raised (en.wikipedia.com).

Buri over the official capital, Ayutthaya, he "... had caused to be carried out many works in his desire to improve and embellish the town." (Giblin, 1904: 9). Thus, he repaired the ruined Bhuddhist temples, built a new palace and other buildings, and surrounded them with attractive gardens, ornamental fountains and water features (e.g. see Chaumont, 1686; Gervaise, 1689; Smith, 1880). Is it any surprise, then, that King Narai liked to spend up to nine months of each year in Lop Buri, enjoying the more relaxed lifestyle, and

> ... pleasure trips to the forests abounding with every variety of trees and to the wild mountain scenery abounding in birds and beasts, and [he] was enchanted with the romantic scenery of the region. (Smith, 1880).

It was within this idyllic environment that the French attended to affairs of state, ceremonies and conferences (Giblin, 1904). Then on 10 December de Chaumont and Phaulkon signed an agreement that gave French missionaries special privileges in Siam, and as we shall see, through the Jesuits this would soon benefit Siamese astronomy. It is interesting that one of the five conditions in the agreement specifically reflected King Narai's personal interest in science, and especially in astronomy:

> The King of Siam permits the Apostolic Missionaries to instruct any of his natural-born subjects in any of the sciences, and to receive them into any of their monasteries, schools, and dwellings with similar privileges to those enjoyed in the other monasteries of Siam, and without constraint from anyone. The said missionaries are allowed to teach *science*, *law*, *and any other subjects that are compatible with the Government and Laws of the realm*. (Hutchinson, 1935: 221; our italics).

To understand King Narai's interest in astronomy and the reason for the inclusion of astronomers in the 1685 mission we need to examine his education. In keeping with his royal pedigree, as a prince Narai received a sound Buddhist temple education from the monks, but he also was taught non-religious subjects such as astrology, astronomy, mathematics and medicine by lay teachers. The young prince showed a special interest in astronomy and astrology, and it is noteworthy that his lay teacher in these subjects later was appointed Siam's Chief Royal Astrologer. Hodges (1999: 36) also reminds us that

> Narai's contact with foreigners also contributed to his education. His reign coincided with European advances in the sciences associated with navigation, astronomy and horology. He lived in an age when humans were first beginning to grasp the nature and extent of the cosmos ...

Once he was King, Narai was in an ideal position to indulge his astronomical interests, and he learnt about telescopes and other scientific instruments, the newly-constructed Paris Observatory and Jesuit astronomical activities in Peking from Jesuits and others who were on their way to Peking or returning home to Europe and stopped off in Siam along the way. Moreover, he sometimes was able to influence the types of gifts he received from visiting dignitaries, which went far beyond the typical "... cloth, spices and jewellery of his predecessors ..." and —at his specific request—included telescopes, clocks and military equipment (ibid.). Thus, among the gifts brought out to Siam by the 1685 delegation were a celestial globe, a terrestrial globe, telescopes and other scientific instruments (Tachard, 1686).

## 3 SIAM'S FIRST EUROPEAN ASTRONOMERS

### 3.1 Father Antoine Thomas

Following King Narai's enlightened policy of promoting increasing contact with Eastern and Western nations, both Lop Buri and Ayutthaya quickly acquired a cosmopolitan flavour with Armenian, Chinese, Dutch, English, French, Indian, Japanese, Javanese, Malay, Persian, Portuguese and Turkish communities. Many of these people worked for the state or had their own businesses, but there was always a transient population of visiting Europeans, Arabs, Indians and Asians. Because of this, there is a wealth of published material on seventeenth century Siam, as book after book appeared describing—and often singing the praises of—Ayutthaya and Lop Buri. It must be remembered that by international standards both were large cosmopolitan cities.

Among the Europeans who settled in Ayutthaya at this time were French missionaries from the Société des Mission Étrangères de Paris. The Société was formed to

> ... bypass the old privileges of the Portuguese and Spanish missions that depended entirely on the kings of Portugal and Spain, and to launch a new missionary instrument at the Pope's beck and call. (Cruysse, 1992: 64).

Their missionaries first arrived in Siam in 1662 (see Love, 1999), but they found that other Catholic missionaries were already living in the city, and thus began an intriguing and complicated power-play involving different factions of Catholics and different nationalities. To explain this situation we need to understand that there were different orders of the Roman Catholic faith (e.g. Jesuits, Dominicans, Franciscans, etc.) and at the time there was competition between the Pope (the international leader of the Catholic Church, and based in the Vatican) and the Kings of Spain and Portugal (working collectively) for control of Catholic missionaries world-wide. Until the second half of the seventeenth century

> All the Catholic missions in the East [i.e. in Asia] were under Portuguese protection and the *personnel* were composed mainly of Portuguese and Spaniards. (Hutchinson, 1933: 6; his italics).

Then, from the 1660s,

> ... two rival Catholic missionary circuits shared the Asian scene ... They engaged in a fierce struggle where all kinds of dirty tricks were allowed. It will surprise nobody that the Siamese were sick and tired of the neverending quarrels, and that very few among them felt the urge to join the Church which preached peace and brotherly love, but whose representatives were at each other's throats. (Cruysse, 1992: 64–65).

Of all the Catholic faiths, the Jesuits had a special passion for science, and especially mathematics and astronomy, and during the sixteenth century the Spaniard Jesuit, Francis Xavier, founded missions in Asia. Then during the early years of the seventeenth century

> ... his followers spread over the Indo-Chinese Peninsula, and, when P'ra Narai came to the throne of Siam [in 1656] there were Jesuits as well as Dominicans [already] established in the Portuguese colony at Ayŭt'ĭa. (Hutchinson, 1933: 6).

It was against this politico-religious backdrop that Father Antoine Thomas (1644–1709), a Belgian Jesuit missionary, arrived in Ayutthaya in 1681, and as far as we have been able to determine he was the first European to carry out *serious* astronomical observations and therefore expose Siam to Western astronomy.

So who was this pioneer of scientific astronomy in Thailand? Antoine Thomas was born on 25 January 1644 in Namur, in what is now Belgium. He joined the Jesuit Order in 1660, and by 1678 had been ordained a priest. While training for the priesthood he led a peripatetic existence, between 1662 and 1675 studying in Namur, Douai, Lille, Namur (again), Huy and once again in Douai (in that order—see Collani, n.d.). He taught at schools in Armentières, Huy and Tournai,[2] and served as a Professor of Philosophy at the College de Marchiennes in Douai.

In the course of his training, Father Thomas developed a passion for mathematics and astronomy, and between March 1678 and January 1680 he studied mathematics in Coimbra, Portugal. Whilst there he observed a lunar eclipse, and he published a short account of this in the *Journal des Sçavans* (Thomas, 1679), the earliest European academic journal, which included obituaries of notable people, church history, legal notes and, of course, astronomy.

Thomas' goal was to carry out missionary work in Japan, which ultimately would prove to be impossible, but while trying to arrange this he was forced to spend nearly a year in Siam, arriving in Ayutthaya on 30 August 1681 (Collani, n.d.). He was living there when the February 1682 eclipse occurred.[3]

After finally realising that his dream of carrying out missionary work in Japan was not to be, Father Thomas determined to go to China instead, and on 4 July 1682 he arrived in Macau. He would spend the rest of his life living in China, where he enjoyed a distinguished career in astronomy and mathematics (Han, 2003; Jami, 2007; Witek, 2003). He died in Peking on 28 July 1709 at the age of 65 (Collani, n.d.).

Soon after arriving in Ayutthaya Father Thomas carried out solar observations in order to determine the latitude of the city. This occurred on 14 October 1681 and he conducted further observations on 30 December 1681. When various corrections were applied, these gave values of 14° 18′ 21″ and 14° 20′ 18″ N respectively (Thomas, 1692).[4] Father Thomas indicates that his observations were made from "… the House of the Society of Jesus in the suburbs, to the south of Juthia [i.e. Ayutthaya]." (ibid.; our English translation). This residence must have been close to the Jesuit church in the Portuguese residential sector of Ayutthaya, which in Figure 5 is marked by the 'I' at the centre bottom of the map, beside the western bank of the river. This location is confirmed by a second—albeit somewhat cruder—map of Ayutthaya, which was published in 1686, and is reproduced here in Figure 6. The datum point for these latitude observations was a wooden board that was mounted high on one of the walls of the church, and contained an indented metal plate that was aligned parallel to the horizon (ibid.).

There is no record of the *precise* location of the Jesuit residence near the church (where Father Thomas was based), but from Loubère's (1693) account we can anticipate that it was built of brick and was only one storey high:

> The Europeans ... build with brick, every one according to his Genius ... At the side of their Houses, to keep off the Sun and not hinder the Air, some do add Penthouses, which are sometimes supported by Pillars ... The Chambers [in the main house] are large and full of windows, to be the more fresh and airy ... (cited in Sternstein, 1965: 100).

While he was Belgian by birth, it is natural that Father Thomas ended up living in the Portuguese sector of Ayutthaya given that there was no suburb reserved for Belgians. During his religious training he spent some time in Portugal; he came to Siam via Goa, the Portuguese colony on the west coast of India; and when trying to arrange to conduct missionary work in Japan it was Portuguese supporters who lobbied (unsuccessfully in the end) on his behalf (see Collani, n.d.). All of his associations were with the Portuguese, and it is noteworthy that

> ... Portuguese was the *lingua franca* for communication with Europeans in Ayutthaya in the seventeenth century ... (Smithies, 1989: 60).

### 3.2 The First Contingent of Astronomers

With Father Thomas' departure for China in July 1682, Siam lost its sole active European astronomer, but he was soon to be replaced, for the 1685 French delegation included

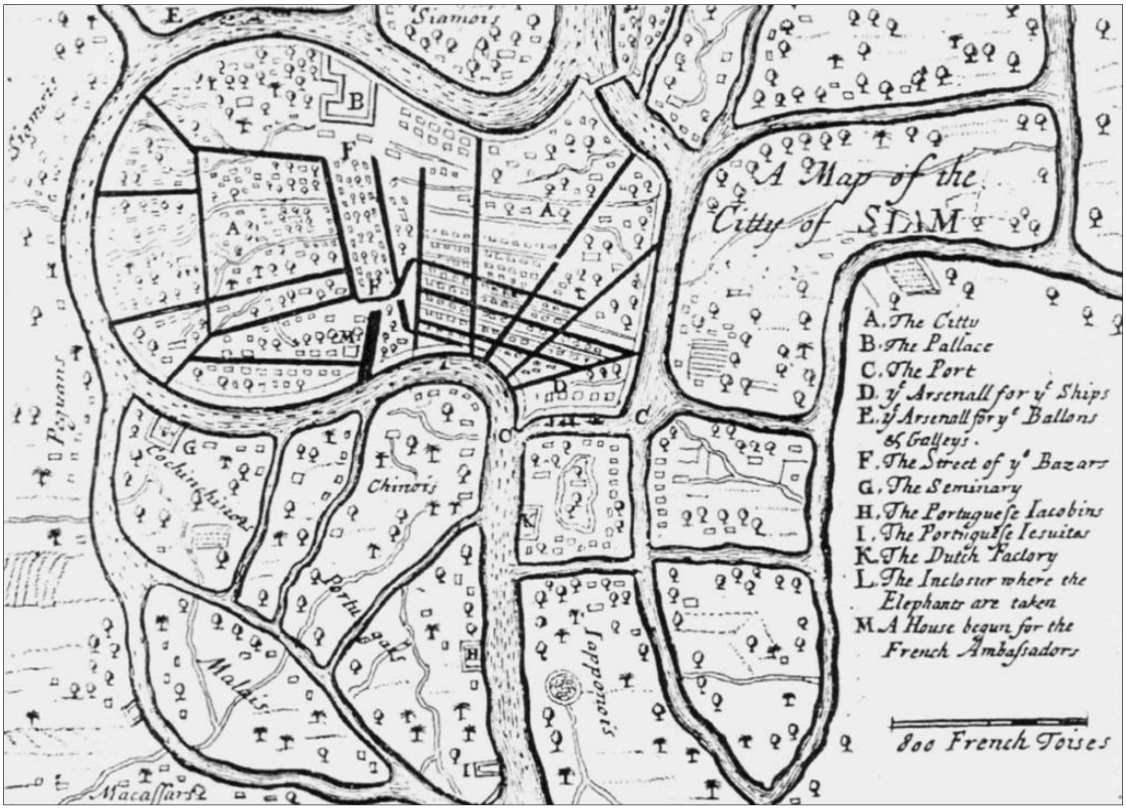

Figure 5: A map of Ayutthaya in the 1680s showing the location of the Portuguese residential precinct (marked 'Portugals' to the south of the river on the left, and above the Malayan precinct (after Loubère, 1693).

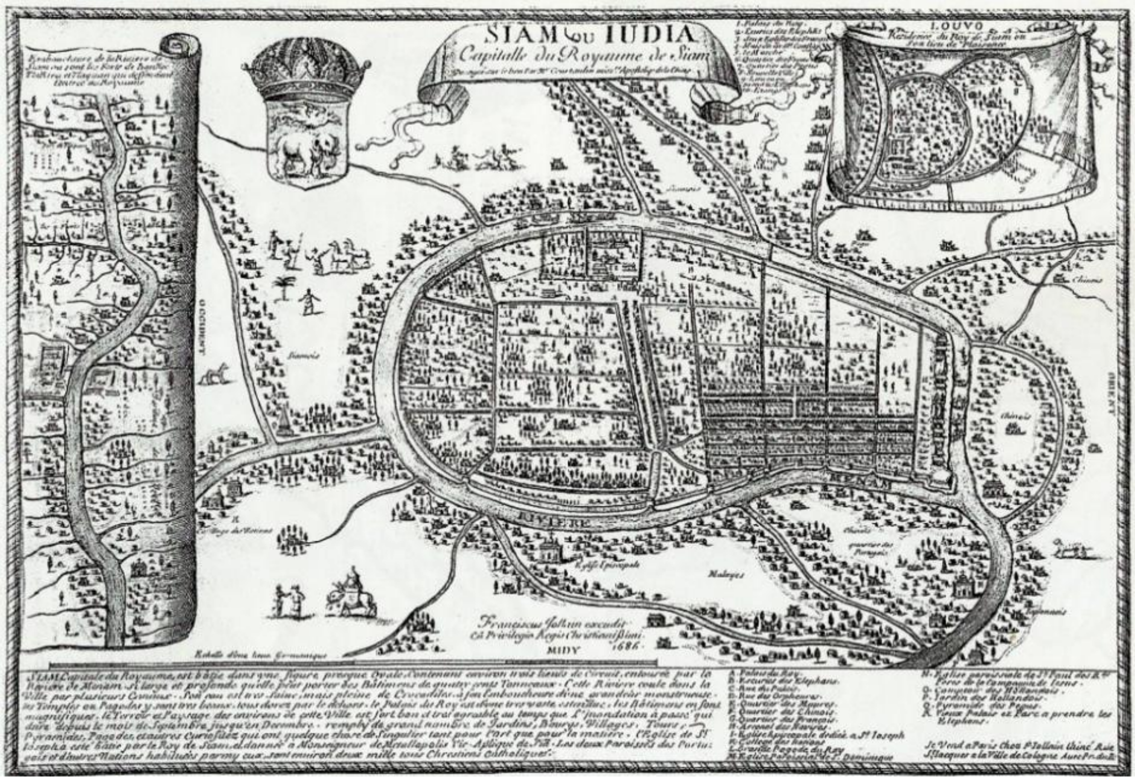

Figure 6: A map of Ayutthaya by Jean de Courtaulin de Maguellon (1686) confirms the location of the Jesuit church in the Portuguese residential precinct. The inset map at top right shows Lop Buri (http://www.esnips.com/web/NDMI-Oldmap).

Table 2: Jesuit missionary-astronomers who came to Siam in 1685 with the French delegation.[5]

| Name | Birth/Death Dates | Immediate Destination after Siam |
|---|---|---|
| Jean de Fontenay | 1643–1710 | China (1688–1702) |
| Joachim Bouvet | 1656–1730 | China (1688–1697; 1699–1730) |
| Louis le Comte | 1655–1728 | China (1688–691) |
| Jean-François Gerbillon | 1654–1707 | China (1688–1707) |
| Guy Tachard | 1648–1712 | Remained in Siam |
| Claude de Visdelou | 1656–1737 | China (1688–1709); India (1709–1737) |

> ... six Jesuit mathematicians [*cum* astronomers] sent out by Louis XIV., under a royal patent, to carry out scientific work in the Indies and in China, in order, as the patent puts it, "to establish Security in Navigation and to improve Sciences and Arts." (Giblin, 1909: 1).

They were led by Father Jean de Fontenay (see Table 2), and although they were supposed to continue on to China, all but one of their number would remain in Siam until the end of 1687 and then move to Peking. The exception was Guy Tachard (1651–1712; Figure 7), who would stay behind and play a key political role in the development of scientific astronomy in Siam (see Orchiston et al., 2016b).

Before they left France, Tachard and the other five Jesuit astronomers were admitted to the Académie Royale des Sciences, and supplied with astronomical instruments on the understanding that these would be used—among other things—to determine the latitude and longitude of different geographical features and population centres. Such data would later prove invaluable when creating maps of the Asian region. As well as scientific instruments, the astronomers were supplied with tables of Jovian satellite phenomena, courtesy of Paris Observatory, and various reference books and charts. And in addition to astronomy, they also were required to collect information on natural history, geography, culture, etc.

Once in Siam the French Jesuit astronomers unwittingly became involved in a power struggle with non-Jesuit Catholic missionaries from the Société des Mission Étrangères de Paris (Cruysse, 2002, Hutchinson, 1933). When the Jesuit astronomers arrived, missionaries from the Société were already well established in Siam, and their goal was simply to capture the minds, hearts and souls of the Siamese by gathering as many Catholic converts as possible. Whilst this was an aim of the Jesuits, they also had scientific objectives in mind. To access King Narai both parties had to use Constantine Phaulkon as an intermediary, and most of those from the Société despised him, whereas the Jesuits found him helpful and supportive, partly because he was a Jesuit convert himself and partly because of the King's personal interest in astronomy. The Jesuits openly exploited this situation, and upon arriving in Ayutthaya Tachard

> ... set himself to cultivate an intimacy with Phaulkon acting as his secretary and confidant ... [and soon] was working on behalf of the Jesuits to supplant Bishop Laneau [from the Société des Mission Étrangères de Paris] as intermediary between the French and Siamese Courts. (Hutchinson, 1933: 25).

This tactic worked admirably, and Father Tachard soon became King Narai's personal astronomical consultant and eventually his scientific ambassador, first to Paris and later to the Vatican (Smithies and Bressen, 2001).

While Tachard could be viewed as an astro-politician *par excellence*, others have painted a less than charitable picture of him in a non-astronomical context. For example, when back in France with Chaumont and Choisy in 1686, he usurped the rightful role of the three official Siamese ambassadors and carried out secret negotiations with the French court, and

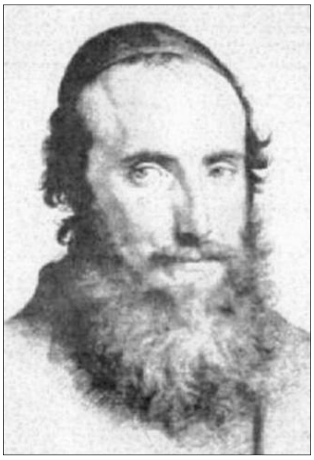
Figure 7: A drawing of Father Guy Tachard by Carlo Maratta (en.wikipedia.org).

> During the second French embassy in 1687 of La Loubere and Ceberet, Tachard behaved outrageously towards the accredited French envoys ... Power had simply gone to his head. He was as arrogant towards them as he was subservient to Phaulkon. (Smithies, 1994: 176).

Smithies (ibid.) also states that Tachard "... was universally loathed by all who came into contact with ..." (ibid.) him except for François Martin, and he then assembles first-hand or second-hand opinions of Capuchin Fathers from the Coramandel Coast, the Cardinale de Tournon, Chaille, Choisy, employees of the French East India Company, Forbin, the Papal Legate in the Indies, the Patriarch of Antioch and Vachet, to the effect that Tachard was "... imbued with foolhardiness

Table 3: Details of the 22 February 1682 lunar eclipse.

| Totality | Local Time | Moon Altitude | Moon Azimuth | Sun Altitude | Sun Azimuth |
|---|---|---|---|---|---|
| Start | 05h 25m | +17° | 267° | –19° | 96° |
| Middle | 06h 13m | +06° | 279° | –07° | 99° |
| End | 07h 01m | –05° | 282° | +05° | 102° |

to a degree beyond which it would not be possible to proceed ..."; was "... a swindler and an impostor ..."; and was "... the most despicable and pernicious of all men." (Smithies, 1994: 177). Fellow professor, Dirk van der Cruysse (1992: 67), also has little time for Tachard:

> [He] ... was about to play a pernicious part in Siamese-French relations, [and] is the leading "bad character" in our story.

But are all of these criticisms justified? As we have seen, there was no love lost between the Jesuits and other factions within the Roman Catholic Church or between the French Jesuits in Siam and their confrères from the Société des Mission Étrangères de Paris, and it is noteworthy that all—or almost all—of Tachard's critics were non-Jesuits. Undoubtedly Tachard had some faults, but he was not all bad. Yet Vongsuravatana (1992) goes too far in trying to rehabilitate Tachard, and claim that he was "... an extraordinary diplomat who deserves a place of choice in French maritime history ... [and] also deserves to be considered a great diplomat by the Siamese ..." (Vongsuravatana, 1994: 98).

## 4 LUNAR ECLIPSE OBSERVATIONS

Although there was interest during the seventeenth century in explaining the visibility of the Moon prior to totality, astronomers mainly wanted to time lunar eclipses in order to determine the longitudes of their observing sities. Link (1959: 10) notes that

> In the 17th and partly also in the 18th century Hipparchos's old method for the determination of longitudes was renovated using the transits of craters on the edge of the shadow ... Though the accuracy of this method could not exceed more than some tenth of a minute of time, its utility was great in those times. For instance the eclipse of 1634 observed in Cairo, Aleppo and the western part of Europe, enabled the astronomers to shorten the Mediterranean Sea by 1000 km in respect to its assumed length before that time ...

In seventeenth Siam, lunar eclipses therefore held special appeal. In the years immediately following Father Thomas' arrival in Ayutthaya, lunar eclipses were successfully observed on 22 February 1682, 11 December 1685, 30 November 1686 and 15–16 April 1688 (Bhumadhon, 2000). The first two eclipses were associated with the birth and early development of scientific astronomy in Siam, and are discussed below.

Table 4: Details of the 11 December 1685 lunar eclipse.

| Totality | Local Time | Moon Altitude | Moon Azimuth | Sun Altitude | Sun Azimuth |
|---|---|---|---|---|---|
| Start | 04h 37m | +26° | 288° | –27° | 109° |
| Middle | 05h 29m | +15° | 290° | –15° | 110° |
| End | 06h 21m | +03° | 293° | –04° | 113° |

### 4.1 The Eclipse of 22 February 1682

There is embarrassingly little information available, other than that Father Thomas (1692) successfully observed this eclipse from Ayutthaya,[6] and derived a longitude of 121° E of El Hierro for the city (Tachard, 1686). The currently-accepted value is 100° 33′ 54″ east of Greenwich, but note that at this time the French measured longitude from the island of El Hierro, which was 20° 23′ 09″ west of Paris, and Paris is 2° 20′ 14″ east of Greenwich.

Father Thomas probably observed the eclipse from the Jesuit church, in the Portuguese district, or just possibly from the veranda or courtyard of the Jesuit residence near the church. From our knowledge of the Moon's position at the time we can ascertain that the eclipse would have been visible from throughout this residential area of Ayutthaya, as adjacent buildings would not have impeded visual access to the western sky.

Listed in Table 3 are start, middle and end times of the total phase of the lunar eclipse in local time,[7] along with the positions of the Moon and Sun, as observed from Ayutthaya. We can see that this eclipse was visible in the morning shortly before the beginning of astronomical twilight, with the Moon located low in the western sky. The Sun rose at 06h 39m local time, before the completion of the eclipse, so only the very early parts of totality would have been viewed in a completely dark sky. Mid-totality took place just before the beginning of civil twilight, so by this time the sky would have had an obvious blue hue, and only the brighter stars would still have been visible.

The eclipse was readily visible to the naked eye, and there is no mention that Father Thomas used a telescope to record it, but in order to record the times of the contacts and derive a longitude for Ayutthaya from the observations he used a pendulum clock (Thomas, 1692).

### 4.2 The Eclipse of 11 December 1685

After arriving in Ayutthaya with Chevalier de Chaumont's diplomatic mission, Father Fontenoy and his fellow Jesuits discovered that they could not immediately continue on to China and would have to remain in Siam for some time. At first they were frustrated because they could not use their astronomical instruments:

> ... because all the time we were at Ayutia the City and the Camping places were so inundated that we had no place to set them up. The very house where we were lodged, being of wood, the least movement shook it so much

> that our Clocks and our Quadrants were disturbed. (Tachard, 1686).[8]

This situation changed when they moved to Lop Buri in order to prepare for a total lunar eclipse that conveniently would occur on the night of 10–11 December 1685, during their stay in Siam. Table 4 lists the start, middle and end times of the total phase of this lunar eclipse in local time based upon modern calculations, along with the positions of the Moon and Sun, as observed from Lop Buri. This eclipse was visible in the morning on 11 December 1685, with the start of totality occurring well before the beginning of astronomical twilight. At this time, the Moon was low in the sky about 20° north of due west. At mid-totality, astronomical twilight had just begun, and in the east there would have been a minor twilight glow on the horizon 20° south of east.

On 22 November 1985 the French astronomers had a meeting with King Narai in Lop Buri, and he honoured them by inviting them to join him in observing the eclipse from his 'country retreat', "... a very roomy Palace ... surrounded by brick walls fairly high." (Giblin, 1904: 11), located at the water reservoir called 'Tale Chupsawn' about 4 km east of Lop Buri (Giblin, 1904: 22). This small artificial lake is described by Father Tachard in his 1686 book:

> There is a large stretch of water which makes of it a peninsula [where King Narai's 'country retreat' was located], and on this water the King of Siam has built two frigates with six small pieces of cannon, on which this Prince takes pleasure in going about. Beyond this canal [lake] is a forest, 15–20 leagues in extent and full of Elephants, Rhinoceros, Tigers, Deer and Gazelles. (Giblin, 1904: 12).

The reservoir had been completed not long before in order to provide a continuing supply of fresh water to the palace in Lop Buri. Armed with three Galilean telescopes (these included a 12-ft and a 5-ft) and a clock, Phaulkon and the astronomers visited the observing site on 9 December, and the French were suitably impressed:

> A more convenient spot could not be selected. We saw the Heavens on all sides and we had all the space necessary for setting up our instruments. Having settled everything we returned to Louvo. (Tachard, 1686).

Subsequently,

> … we had cause to be transported to the Tale-Poussonne our telescopes and a spring clock very trustworthy and regulated by the Sun … [so that we could] observe there the Eclipse, according to the orders of the King. (ibid.).

Upon arrival, they immediately set up their instruments on the waterside terrace adjacent to the reservoir, then they rested for 3–4 hours before rising and heading for the observing site. By this time "It was then nearly three hours after mid-night." (ibid.).

Fortunately the night of 10–11 December was clear (it was the dry season), and

> We prepared for the King a very long telescope of 5 feet [length] in a window of a saloon which opened on the corridor [terrace] in which we were.[9] The Penumbra being well advanced the King was informed and came at once to the window. We were seated on Persian mats, some with telescopes, others with the clock, others ready to write the time of the observation. We saluted His Majesty with a profound bow, after which the observations were begun. (ibid.).

It is interesting that during the eclipse King Narai

> … wished to look through a telescope 12 feet long, which Father de Fontenay was using, and we immediately carried it to him. He allowed us to rise and stand up in his presence, and he was quite willing to look through the Telescope after we had done so, for it was necessary to put it in position to show it to him.
>
> Those who know the respectful attitude which Siamese Kings expect from those who may be in their presence have spoken to us of this favour as of something very unique. (ibid.).

Figure 8 shows the Jesuit astronomers and King Narai observing the eclipse, in the presence of the prostrated court astrologers.[10] From all accounts, the King thoroughly enjoyed the experience, and

> … expressed a special satisfaction seeing all the spots [craters, etc.] of the Moon in the Telescope, and in seeing that the plan [map] which had been drawn of it at the Paris Observatory agreed with it so well. He put several questions to us during the Eclipse. For example: Why the Moon appeared upside down in the Telescope? Why one could still see the part of the Moon which was eclipsed? What time was it at Paris? What could be the utility of such observations made at the same time at two places at such a distance apart? &c. (ibid.).

The map of the Moon referred to in this quotation was one that Jean Dominique Cassini, the Director of Paris Observatory, first presented to the Academy of Sciences in Paris on 18 February 1679 (see Launay, 2003). It is reproduced here as Figure 9,[11] and clearly shows the maria, highland regions and various distinctive craters that would have attracted King Narai's attention.

It is interesting that Tachard (ibid.) also includes the times of the start and end of totality that were recorded by the Jesuit astronomers. These were 04h 23m and 06h 10m, both of which are earlier than the times listed in Table 4 by 14 minutes and 11 minutes respectively. Using their recorded times of totality the French computed the longitude of Lop Buri to be 121° 02′ E of the island of El Hierro. Meanwhile, the latitude of Lop Buri later was reported to be 14° 48′ 17″ N (Tachard, 1689). The currently-accepted value is 14° 48′ 00″ N, while Lop Buri is now known to be 118° 42′ E of the island of El Hierro.

The various quotations reproduced above demonstrate that Father Tachard provided a detailed account of this eclipse in his 1686 book

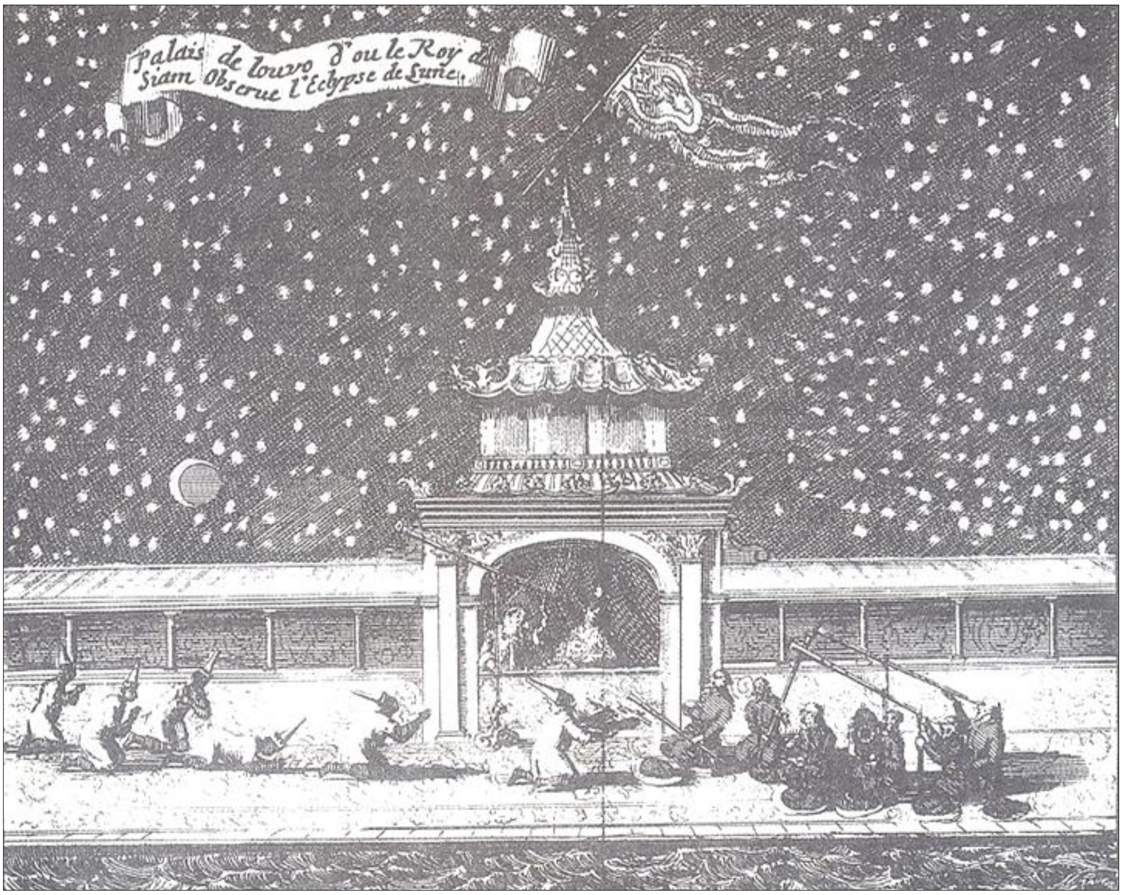

Figure 8: A drawing showing King Narai and the Jesuit astronomers observing the 11 December 1685 total lunar eclipse from the King's country retreat which was on an island in the water reservoir that was located to the northeast of his palace in Lop Buri (en.wikipedia.com).

*Voyage de Siam des Pères Jésuites Envoyés par Roi aux Indes & à la Chine.* Choisy (1687) also mentions the eclipse in his book, but he supplies no details, and does not even identify the water reservoir—as opposed to King Narai's palace in Lop Buri—as the site where the observations took place.

As we have seen, in addition to Tachard's detailed description of the eclipse observations there is the drawing shown here in Figure 8, which was included in Tachard's 1686 book. But how reliable is this drawing as a realistic depiction of the country retreat, King Narai and the astronomers and their instruments, and their observations of the eclipse?

All six Jesuit astronomers are shown in the drawing, along with King Narai, his advisor, Constantine Phaulkon (in the pavilion with the King), and six court astrologers (who, incidentally, are never mentioned in the contemporary European accounts of this eclipse). Three different telescopes are shown in the drawing if we assume that the Jesuit astronomer closest to the King's pavilion is holding a telescope support and not a fourth telescope, and this tallies with the account that during the eclipse some of the astronomers used telescopes, others attended the clock and yet others recorded the observations. Two of the telescopes were stated to be 5-ft and 12-ft in length and the size of the third telescope is not mentioned, yet in Figure 8 the telescope used by King Narai is only ~20% longer than the lengths of the two telescopes used by the Jesuit astronomers—which are similar in length—not ~240% longer (and this takes no account of perspective). From this observation alone we can conclude that the drawing contains an element of artistic licence.

Nor does the drawing in Figure 8 realistically depict the lunar eclipse itself. Knowing the altitude and azimuth of the Moon at the time of totality and the fact that King Narai observed through a window in his country retreat, we can establish that the King and the Jesuit astronomers had to be located on the western side of the country retreat. The azimuth of the Moon (~22°) is realistically depicted in the drawing (cf. Table 4), but the Moon should not have been included in the diagram at all for at the time it was located in the northwestern sky whereas only part of the sky extending from the northeast to the southeast is shown. The Moon therefore

Figure 9: A copy of the 1679 map of the Moon produced at Paris Observatory that was consulted by King Narai and the French astronomers during the 11 December 1685 eclipse (© Observatoire de Paris).

would have been located in the sky *behind* the 'artist's position', as depicted in the drawing. So, allowing for perspective, we can see that King Narai has his telescope pointing in approximately the correct direction, but the two telescopes of the Jesuit astronomers are pointing in quite the wrong direction.

The afore-mentioned comments reinforce the view that the Figure 8 drawing cannot be accepted as a realistic depiction of the eclipse observations. Is this confirmed by architectural and other details that are shown in this drawing? Fortunately, some of the walls of the water reservoir country retreat have survived, and these show clearly that the design of most of the windows there mirrored those found in King Narai's palace in Lop Buri and in stately houses that were constructed in Lop Buri at the time. As illustrated in Figure 10, most of the windows were rectangular and with 'portrait' orientations (as opposed to the 'landscape' orientation depicted in Figure 8). Moreover, most of the windows at the water reservoir country retreat had lintels immediately above and below them, and therefore lacked the arched top shown in Figure 8. Yet there are some exceptions (for example, the building shown in Figure 11), but we can see that although the general shape of each window is identical, their proportions differ markedly from King Narai's 'viewing window' depicted in Figure 8.

In Figure 8, the rather pagoda-like form of the roof above the pavilion in which King Narai is located also is an artistic aberration. Contempor-

Figure 10: A view, looking north, of the ruins of King Narai's country retreat at the water reservoir site in Lop Buri. This photograph was taken in October 2014 (photograph: Wayne Orchiston).

Figure 11: A close-up view of the building in the left foreground in Figure 10, which has windows with vaulted tops (photograph: Wayne Orchiston).

orary accounts of the palaces and other royal buildings erected during King Narai's reign indicate that they contained one or a succession of gable roofs, none of which stylistically reflected seventeenth century Siamese Buddhist temple architecture (e.g. see Sternstein, 1965).

Finally, we should note that the pennant shown at top left in Figure 8 erroneously suggests that the eclipse observations took place at King Narai's palace in Lop Buri, and not at his water reservoir country retreat near Lop Buri.

All of this additional evidence confirms that we cannot accept the drawing in Figure 8 as a realistic 'photographic' depiction of the eclipse observations, and this tallies with Michel Jacq-Hergoualc'h's evaluation. In 1986 he prepared an

Figure 12: The edge of the waterwide terrace along the western margin of the country retreat is indicated by the extended foundations on the left side of this image (photograph: Wayne Orchiston).

exhibition at the Musée de l'Orangerie in Paris which included this drawing. In his exhibition catalogue Jacq-Hergoualc'h (1986) noted that this figure and others in Tachard's 1686 tome were drawn by Pierre-Paul Sevin and engraved in Paris by Cornelius-Martin Vermeulen, even though neither was a member of the 1685 delegation to Ayutthaya and Lop Buri, or had ever visited Siam! Smithies (2003: 191–192) concludes that

> The drawings and engravings were probably made in great haste after a few casual descriptions gleaned from the manuscript [of Tachard's 1686 book] or possibly Tachard in person, and perhaps sketches which he may or may not have seen.

Notwithstanding these comments, and despite the somewhat dilapidated state of the western side of the country retreat (when compared to the southern walls), we were able to correlate existing foundations with the covered walkway shown in Figure 8, and these are shown in Figure 10 starting at the main building and leading diagonally across the photograph towards the bottom right margin. This marks one wall of the walkway and the other runs near the right-hand wall of the ruined room on the left foreground in this photograph. This covered walkway led from the main building, and would have provided safe and ready access to those rooms along the western side of the country retreat both day and night, and in all kinds of weather.

We also were able to identify foundations that marked the margin of the terrace that fringed the western side of the country retreat and directly abutted the water reservoir (as illustrated in Figure 8). These foundations are shown in Figure 12, and run continuously along the full length of the country retreat.

In Figure 8 it is apparent that there is no indication of the country retreat main building *behind* the small single-storey room where King Narai is conducting his observations, and if this was intentional it would suggest that this room was located either to the north or the south of the main building and access to it was afforded via the covered walkway.

If this is a valid interpretation and our identification of the foundations of the covered walkway and margin of the waterside terrace are correct, then we can tentatively identify King Narai's location when he observed the 11 December 1685 lunar eclipse. He was in the room, now in ruins, shown in the left foreground in Figure 10, in close-up in Figure 11 and on the extreme right (and partly obscured) in Figure 12. Figure 13 is a scale drawing showing the location of this 'pavilion' relative to the main buildings of the country retreat, the covered walkway and the edge of the terrace beside the water reservoir.

More than one hundred years ago, the Australian-born Director of the Thai Royal Survey

Department, Ronald Worthy Giblin, examined sites associated with King Narai and had no trouble finding the water reservoir:

> Making now a short excursion into the country, less than a league [from King Narai's palace in Lop Buri] will take us to the Tale Chupsawn, the reservoir built by King Narai. Reference to a map made up by sheets of the cadastral survey will show just how this small artificial lake is situated with regard to the town. It must be remembered that to the east the ground slopes upwards to form a low range of hills running north and south. These hills, with the somewhat striking and jagged peaks of the hills near Prabat, may be seen from the northern railway line. *The reservoir is enclosed by a heavy earth embankment, nearly 4½ miles long. This bank is about 12 to 13 feet high,* and the area available for the storage of water is roughly one square mile. Mr. Irwin[12] ... is of opinion that the probable depth of water, when the tank was full, came to not less than nine feet and a half, deeper in some places and less in others ...
>
> Within the reservoir and near the western embankment on a small elevated piece of ground stand the ruins of the King's country residence. *It was here he took part in the observation of an eclipse of the moon, recorded by Father Tachard.* (Giblin, 1904: 22; our italics).

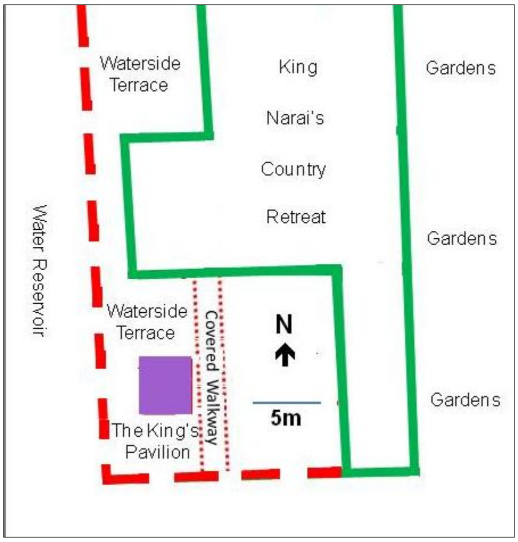

Figure 13: A plan showing the location of the pavilion from which King Narai observed the eclipse (purple rectangle), the edge of the waterside terrace (red dashed line), the covered walkway (red dotted lines) and the main and other adjacent country retreat buildings (green outline) (plan: Wayne Orchiston).

This would have written not long before Giblin's paper was published in 1904 in the *Journal of the Siam Society*, and at that time the water reservoir and King Narai's country retreat were easily recognisable.

The cadastral maps that Giblin refers to in the above quotation were prepared sometime between 1895 and 1903, but enquiries in Bangkok revealed that unfortunately they are no longer extant (Visanu Euarchukiati, pers. comm, November 2015), and moreover, copies of them could not be located in Bangkok (ibid.) or in Lop Buri. So they can no longer be used to identify the water reservoir and artificial island where the country retreat was located "... with regard to the town [of Lop Buri]." However, aerial photographs of the region (e.g. see Goggle maps) clearly show the country retreat and the artificial island. The latter is elliptical in shape, and measures ~55m N-S by ~45m E-W. A field reconnaisance in November 2015 by the first two authors of this paper revealed that despite the passage of time, the boundaries of this island were obvious, with the land sloping down steeply, especially to the north, east and south. Aerial photographs also revealed that the country retreat was not centrally-located on the island, but was close to its western edge. To the east of the main building there is now an area of lawn, which back in 1685 would have contained attractive gardens, and perhaps fountains, if the beautification of King Narai's palace in Lop Buri is any indication.

Despite the absence of Mr Irwins' cadastral maps, aerial photographs and a field reconnaisance (also made in November 2015) easily allowed us to identify the almost 4.5-mile long 12–13 foot high heavy earth and stone embankment that was built in the early 1680s to create the reservoir. As Figure 14 indicates, modern roads now run along the top of embankment, and where recent construction work is absent it is easy to see the land sloping down steeply from these two roads to what originally was the floor of the water reservoir. Meanwhile, it also is telling that although this historic water reservoir no longer exists *per se*, there are still extensive expanses of emponded water in this area (see Figure 14), indicating the low-lying nature of the land where the water reservoir once was and the continuing effectiveness of the southern embankment.

## 5 DISCUSSION

### 5.1 The 1682 and 1685 Eclipses: The Nature of the Evidence

It is regrettable that so little information has been published about the Jesuit observations that were made in Siam of the February 1682 and December 1685 total lunar eclipses, and it remains to be seen whether relevant archival records have survived. However, in the paper where he provides English translations of selected contents of Tachard's *Voyage de Siam des Pères Jésuites Envoyés par le Roi aux Indes & à la Chine* (1686), Giblin (1909: 14) has these sobering comments:

> The foregoing pages contain all that is to be extracted from the two volumes of travels published by Father Tachard. It must be admitted that the results in quantity do not amount to

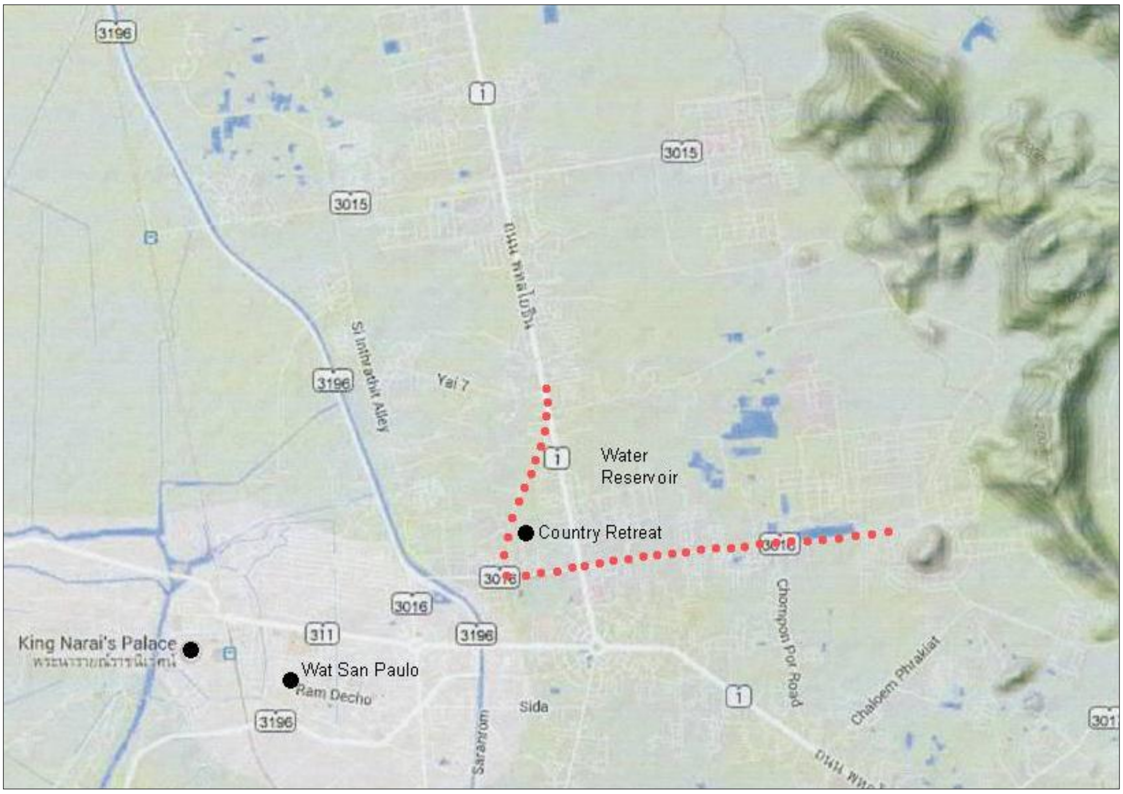

Figure 14: A map of part of Lop Buri showing the location of King Narai's water reservoir and 'country retreat' in relation to his palace. The red dots mark the position of the embankment that was erected to stop run-off from the mountains to the east and form the water reservoir. Terracotta pipes carried the water from the southwestern corner of the embankment to King Narai's palace (map modifications: Wayne Orchiston).

> very much, but this would hardly be the right way in which to weigh them. At the time when the observations were made they furnished values which were, no doubt, acceptable and accepted as the best available for use for the construction of charts and for navigation purposes. From an historical point of view the fact that the observations were taken at all, and the circumstances surrounding them must always remain of interest, especially to those connected with Siam and concerned in any way in its past, whilst allied to this aspect of the case lies the possibility or power, which has its utility to a surveyor, to institute comparisons between the results obtained then and those of a later date.

## 5.2 Subsequent Seventeenth Century Astronomical Developments in Siam

The successful observations of the lunar eclipse of 11 December 1685 encouraged Phaulkon to propose the establishment of a major observatory at Lop Buri, and King Narai agreed to this. The result was Wat San Paulo, an impressive two-storey rectangular structure with a large internal courtyard, and a four-storey tower Observatory at one end (see Figure 15). The Observatory section of this large building, inspired in part by the Paris Observatory, was completed in 1687 and its design and inspiration are discussed in Orchiston et al. (2016b), along with an account of the surviving remains of this historic observatory building.

King Narai was so impressed by the achievements of the first contingent of French astronomers that he invited King Louis XIV to send more astronomers to Siam, and at the end of September 1687 a second contingent, totalling fourteen Jesuit astronomers, arrived in Ayutthaya.[13] For further details see Orchiston et al. (2016b).

Between 1686 and 1688 (inclusive) the French astronomers used state-of-the-art telescopes and other astronomical instruments to carry out observations of a comet; two further total lunar eclipses; Jovian satellite phenomena; conjunctions of Mars; an occultation of Jupiter by the Moon; and a new double star. The last serious astronomical observations they carried out at Lop Buri were of the partial solar eclipse of 30 April 1688 (see Orchiston et al., 2016a).

## 5.3 The Demise of Scientific Astronomy at Lop Buri

The success of the French Jesuit astronomers was in large part due to the patronage of King Narai and the role that Constantine Phaulkon played in fostering Siamese-French relations, but this combination ultimately would lead to their downfall (see Cruysse, 2002; Le Blanc, 1692; Smithies, 2002). Not unexpectedly, Phaulkon's

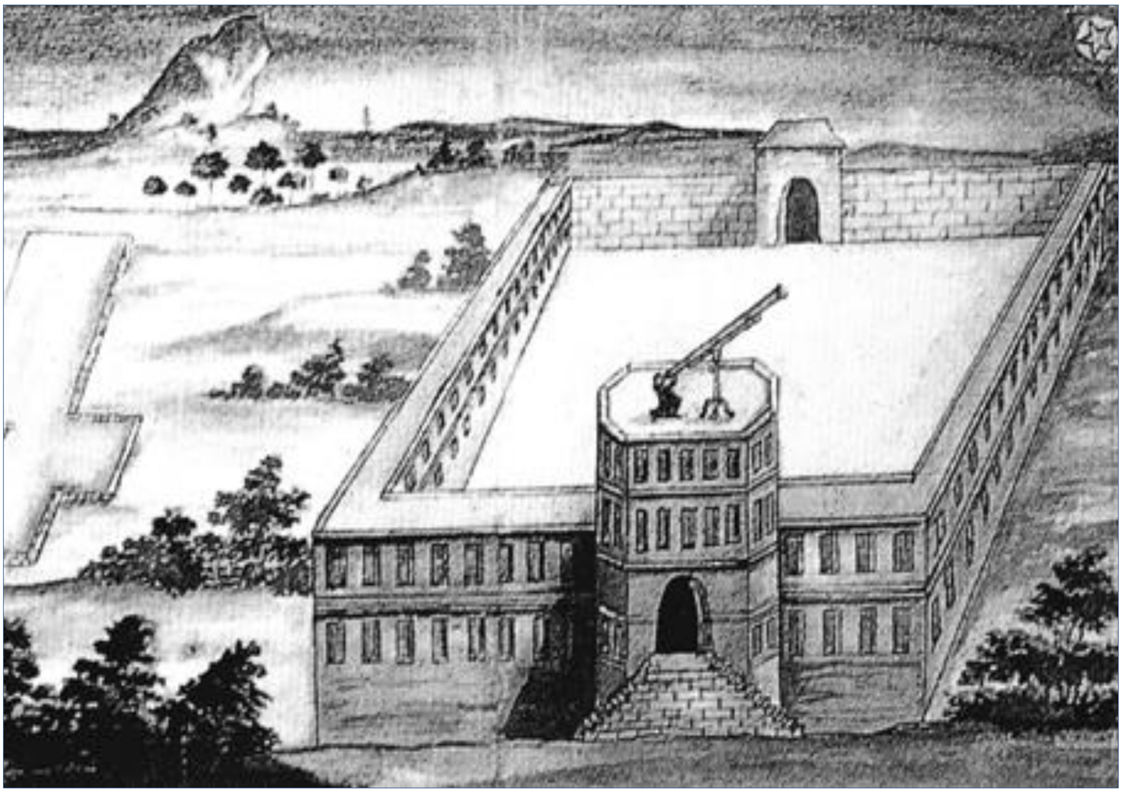

Figure 15: A contemporary drawing of Wat San Paulo, with its distinctive 4-storey observatory (en.wikipedia.org).

rise to power in Siam generated envy among some members of the Royal Family, including Pra Phetracha, King Narai's foster brother. By 1688 King Narai was terminally ill (it is thought by some that he was poisoned), and a malicious rumour spread that Phaulkon wished to become the next King of Siam and planned to install the designated heir, Phra Pui, as a puppet ruler. Pra Phetracha used this as an excuse to stage a *coup d'etat*, and Phaulkon, Phra Pui and their supporters were arrested and on 5 June 1688 they were executed.[14] King Narai was mortified when he learnt of this, but he was too weak to organize a counter-offensive and died soon afterwards, on 11 July 1688.

Pra Phetracha then went and installed himself as the new King of Ayutthaya, and reversed King Narai's previous enlightened policies by closing Siam's 'doors' to the West and expelling most of the foreigners who were living there (Smithies, 2002).[15] This led to the immediate close-down of Wat San Paulo. All but one of the Jesuit astronomers there quickly moved to the protection of the French fort in Bangkok and from there sailed for India, thus bringing to an abrupt end an all-too-short, yet extremely productive, period of scientific astronomical activity in Siam. However, adopting a very different viewpoint, Professor Dirk van der Cruysse (1992: 64) concludes that

> Whether one likes it or not, the story of the commercial, religious and diplomatic contacts between Louis XIV and Phra Narai is the story of a failure.

Meanwhile, in his encyclopaedic *A History of Southeast Asia*, the distinguished British historian, Professor D.G.E. Hall (1981: 397), points out that

> ... the reaction against the policy of King Narai and Constant Phaulkon had caused such a powerful upsurge of anti-foreign sentiment that, until the days of [King] Mongkut ... Siam was to be very chary of granting privileges to Europeans.

Thus, nearly two centuries passed before Western astronomers were able to re-instate—albeit temporarily—scientific astronomy in Siam, first in 1868 when French astronomers would observe a total solar eclipse from Wa Ko (see Figure 2) under the patronage of King Rama IV (Orchiston and Soonthornthum, 2016), and then in 1875 when British astronomers would observe another total solar eclipse, this time from near Phetchaburi (see Figure 2) and with the support of King Rama V (Hutawarakorn-Kramer and Kramer, 2006). This Royal patronage of scientific astronomy initiated by King Narai and demonstrated by Kings Rama IV and V has continued through to the present day, with strong support from His Majesty King Bhumibol Adulyadej (Rama IX) and Her Royal Highness Princess Maha Chakri Sirindhorn (see Soonthornthum, 2011), culminating in the establishment of the National Astronomical Research Institute of Thai-

พระที่นั่งไกรสรสีหราช (พระที่นั่งเย็นหรือตำหนักทะเลชุบศร)

พระที่นั่งเย็นมีความสำคัญทางดาราศาสตร์ในฐานะที่สมเด็จพระนารายณ์ฯ ใช้เป็นสถานที่สังเกตปรากฏการณ์จันทรุปราคา เมื่อวันที่ 11 ธันวาคม พ.ศ. 2228 และทอดพระเนตรสุริยุปราคาแบบบางส่วน เมื่อ วันที่ 30 เมษายน 2231 ร่วมกับบาทหลวงเยซูอิตและบุคคลในคณะทูตชุดแรกที่พระเจ้าหลุยส์ที่ 14 แห่งประเทศฝรั่งเศสส่งมาเจริญสัมพันธไมตรี เหตุที่ได้ใช้พระที่นั่งเย็นเป็นที่สำรวจจันทรุปราคามีบันทึกของชาวฝรั่งเศสกล่าวว่าเป็นที่เหมาะสมสามารถมองท้องฟ้าได้ทุกด้าน และมีพื้นที่กว้างมากพอสำหรับที่จะติดตั้งเครื่องมือ จึงกล่าวได้ว่า การศึกษาวิชาดาราศาสตร์สมัยใหม่เกิดขึ้นครั้งแรกในประเทศไทย ณ พระที่นั่งเย็น เมืองลพบุรีนี้เอง

Kraisorn Siharaj Hall (Phra Thinang Yen or Tale Chub Sorn Hall)

Kraisorn Siharaj Hall was astronomically significant as it marked the first era of modern astronomy in Thailand where King Narai the Great with the Jesuit priests and the first assembly of envoys representing King Louis XIV of France observed the Lunar Eclipse on 11 December 1685 and the Partial Solar Eclipse on 30 April 1688.

According to one of the French chronicles, the hall was selected as one of the best observing sites due to its superb observing condition where panoramic sky could be seen. Moreover, it provided abundant space for the installment of astronomical instrument.

Figure 16: The plaque at the water reservoir site; note the erroneous inclusion of the 1688 solar eclipse on the second and third lines in the English-language text (photograph: Wayne Orchiston).

land in Chiang Mai in 2009 and the opening of the Thai National Observatory and its 2.4-m Ritchey-Chrétien telescope on Doi Inthanon (see Figure 2) in 2013.

### 5.4 Promoting the Early History of Scientific Astronomy in Siam

Since we do not know *precisely* where Father Thomas was located within the Portuguese residential sector when he observed the 1682 lunar eclipse, it is understandable that no attempt has been made to commemorate the site with a plaque, and even attempts to pinpoint the exact location of the Jesuit church have been unsuccessful (see Vandenberg, 2010).

Fortunately, this is not so at Wat San Paulo[16] or at the water reservoir, where commemorative plaques and interpretive display panels have been erected that alert visitors to the astronomical significance of both sites. However, it is to be regretted that both the plaque (Figure 16) and the panel at the water reservoir include a serious error: in addition to mentioning the 11 December 1685 total lunar eclipse, they state that the 30 April 1688 partial solar eclipse also was observed from this site. In fact, it was observed from King Narai's palace in Lop Buri, as documented elsewhere (see Orchiston et al., 2016a).

Finally, we should note that King Narai's liaison with the West in order to develop Siam has not been neglected by those responsible for promoting Thailand's history. Thus, within one of the two large round-abouts on the highway that leads into the centre of Lop Buri from the east there is an imposing statue of this famous king who facilitated the birth of scientific astronomy in Siam (Figure 17).

## 6 CONCLUDING REMARKS

Largely because of King Narai's personal interest in astronomy, and the influence of his main councillor, Constantine Phaulkon, Siam (present-day Thailand) experienced the first blossoming of Western scientific astronomy in the seventeenth century. On 14 October 1681 the Belgian Jesuit mathematician and astronomer Father Antoine Thomas observed the Sun in order to determine the latitude of Ayutthaya, and this is the first scientific astronomical observation that is known to have been made from Siam. Then, on 22 February 1682, he observed a total lunar eclipse and determined the longitude of the city. Later, on 11 December 1685, a contingent of six French Jesuit astronomers joined King Narai and observed a total lunar eclipse from the King's country retreat near Lop Buri, using three Galilean telescopes and a pendulum clock. For reference purposes, they had access to the latest Moon map from Paris Observatory.

The success of the latter observations inspired the construction of a large well-equipped astronomical observatory at Lop Buri, and further astronomical observations were made, both there and at Ayutthaya, until 1688 when the European astronomers were obliged to leave Siam following King Narai's untimely death.

Nonetheless, for seven short years—between 1681 and 1688 (inclusive)—scientific astronomy flourished in Siam, and the 1682 and 1685 lunar eclipses played a very important role in these developments.

## 7 NOTES

1. In the 1680s Lop Buri was variously referred to as Louvo (Tachard, 1686), Louveau (Gervaise, 1689), Luvo (see Giblin, 1904) and Lawo (ibid.) by the French.

Figure 17: The King Narai monument at the roundabout in Lop Buri (photograph: Wayne Orchiston).

2. In the mid- to late-seventeenth century the political geography of Europe was quite different to that found there today (e.g. see Wiesner, 2006). As already stated, Namur is in present-day Belgium, as are Lille and Tournai, while Armentières, Douai and Huy are in France.
3. Constantine Phaulkon played a key role in facilitating the development of scientific astronomy in Siam, and it may be that initially he acquired this sympathy for astronomy from Father Thomas, who on 2 May 1682 (Smithies, 1994: 176)—not long after the 22 February lunar eclipse—converted him from the Church of England faith to Roman Catholicism (Hutchinson, 1933).
4. The currently-accepted value for the latitude of Ayutthaya is 14° 21′ 12″ N.
5. Professor Michael Smithies (2003: 189) is a highly-respected authority on Siam of the 1680s, but he errs in stating that those listed in Table 2 "… as well as being mathematicians were also astrologers …" Today the distinction between astrology and astronomy is very obvious to everyone, so perhaps he was misled by the English translation of Tachard's 1686 volume, which reads: *Relation of the Voyage to Siam Performed by Six Jesuits sent by the French King, to the Indies and China, in the Year 1685, with their Astrological Observations, and their Remarks on Natural Philosophy, Geography, Hydrography, and History* (Tachard, 1688). This is a clear mistranslation, as the original volume refers specifically to '*Astronomical Observations*' and does not mention astrology.
6. Bhumadhon (2000) gives the impression that this eclipse was observed by Father Thomas *and* Father Gouye from Ayutthaya, but the original French account (Gouye, 1692: 693) clearly identifies Thomas as the sole observer. The confusion appears to have arisen because even though Gouye was tasked with publishing the astronomical observations of the Jesuit missionary-astronomers who were based in Siam, he also liked to add his own comments and corrections. However, Gouye's biography (see Thomas Gouye, n.d.) clearly indicates that he spent his whole life in France and never visited Siam.
7. All of the times listed in Tables 3 and 4 were calculated using Herald's OCCULT v3.6 and the NASA Catalog, which agreed to within one minute in all instances.
8. This quotation and subsequent ones listed as 'Tachard (1686)' are actually taken directly from Giblin (1909) and are Giblin's English translations of the astronomical excerpts contained in Tachard's 2-volume work *Voyage de Siam des Pères Jésuites Envoyés par le Roi aux Indes & à la Chine* (1686).
9. Even though the presents that King Louis XIV gave King Narai included telescopes, it is interesting that the Siamese king did not use one of these to observe the lunar eclipse, relying instead on a telescope supplied on the night by the Jesuit astronomers.
10. Soonthornthum (2011) erroneously states that this eclipse was observed from the yet-to-be constructed Jesuit observatory at Wat San Paulo, in Lop Buri itself, and not from King Narai's country retreat.
11. The original map is in the Paris Observatory Library and Archives and measures 550 × 563 mm. The diameter of the Moon is 530 mm (Launay, 2003). Subsequently, this map was engraved by Jean Patigny, and distributed to interested parties—including the Jesuit astronomers who went to Siam.

12. Giblin (1904: 23) identifies Mr A.J. Irwin as the individual who conducted the cadastral survey of the district and mapped the water reservoir. The Royal Thai Survey Department was founded by King Rama V in 1886, and the cadastral survey commenced ten years later (Giblin, 2008).
13. Smithies (2003: 192) also refers to these astronomers as astrologers.
14. This is sometimes referred to as the '1688 Siamese Revolution', even though it was not a popular uprising, or a 'revolution', in the strict sense of the word.
15. Thus ended France's brief but economically-successful escapade in Siam. The only concession Pra Phetracha made to foreigners was to allow the Dutch to maintain a single factory in Siam (Love, 1994a).
16. However, there is confusion over the correct spelling of Wat San Paulo, with both this (correct) version and 'Wat San Paolo' featuring at different times on different interpretive panels at the site itself! Soonthornthum (2011: 181) also uses Wat San Paolo.

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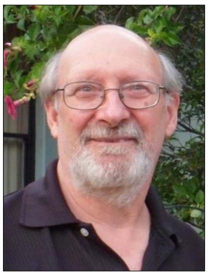

on historic transits of Venus and solar eclipses; historic telescopes and observatories; the history of cometary and asteroidal astronomy; the history of meteoritics; and the history of radio astronomy. Since he joined NARIT, his research interests increasingly have focussed on Asia, and especially Indian, Indonesian, Japanese, Philippines and Thai astronomy, and astronomical links between SE Asia and India and SE Asia and Australia. Wayne has been a member of the IAU since 1985, and has been very active in commissions dealing with history of

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# PHILIPPE DE LA HIRE'S EIGHTEENTH CENTURY ECLIPSE PREDICTOR

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**Abstract:** We investigate the workings of an early eighteenth century instrument for predicting eclipses described by the French astronomer de la Hire in his book *Tabulae Astronomicae*.

**Keywords:** history of astronomy, astronomical instruments, eclipses, volvelles

## 1 INTRODUCTION

In the beginning of the eighteenth century there was a great interest in trying to find methods to determine the geographical longitude. One of the then current methods was to use timings of the immersions and emersions of the satellites of Jupiter; another one was to use timings of lunar eclipses. These longitude methods became obsolete with the invention and construction of precise mechanical chronometers, notably by John Harrison in the middle of the eighteenth century (see Sobel, 1995).

Figure 1 shows a picture of an instrument for predicting eclipses that can be found at the last pages of *Tabulæ Astronomicæ*, by Philippe de La Hire (1702). De la Hire (Figure 2; 1640–1718) was a French mathematician and astronomer (see Sturdy, 2014). On pages 89–94 in his 1702 book there is also a description of the instrument and an explanation of its use (written in Latin). De la Hire's instrument was intended as a tool for finding dates of lunar eclipses that could be used to determine longitude. It also predicted solar eclipses.

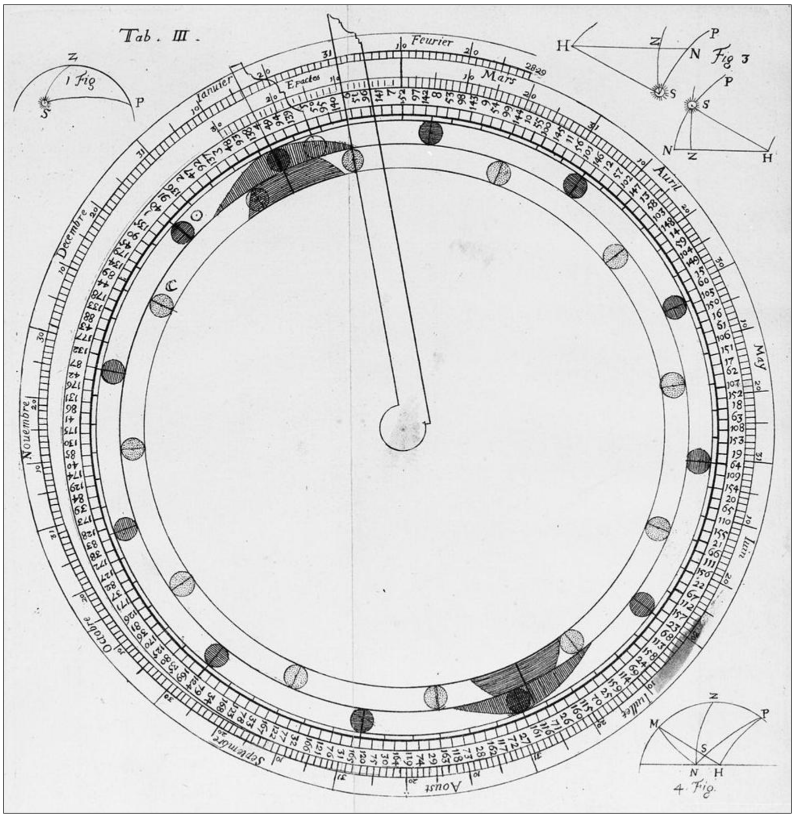


Figure 1: de la Hire's eclipse predictor (source: gallica.bnf.fr).

The use of volvelles as computing devices had a long tradition before de la Hire. A well-known and magnificent example is in *Astronomicum Caesareum* by Petrus Apianus (Apianus; 1495–1552). Based on the Ptolemaic system, it contains more than thirty ingenious and intricate volvelles for computing astronomical events, among them several for predicting eclipses in great detail. In comparison, de la Hire's instrument is less precise, but it had the advantage that it could very easily and quickly be set up.

## 2 THE INSTRUMENT

The instrument, or volvelle, consists of three disks on top of one another, with the two top disks being able to rotate around a common centre. There is also a ruler that can be used to transfer data between the disks.

The bottom disk has one turn of 346 days starting with 1 March and ending with 10 February. The extra 18/19 days in February ends the outer spiral. The reason for this is twofold: the leap day of the year will come at the end of the period and, secondly, the remaining 18/19 days at the end of February give a handy way of accounting for the difference between the Gregorian and the eclipse years (see below). There is a scale of 30 days before 1 March that can be used for finding the epacts.

The middle disk has a pair of diametrically-located shadowed regions that are centred on the lunar nodes. The shadows mark the regions in which there can be a solar or lunar eclipse. The text in de la Hire's book states that the outer shadowed region, to be used for solar eclipses, is black and the inner one, for lunar eclipses, is red. For solar eclipses the limit for an eclipse is ±16° around the nodes, and for a lunar eclipse it is ±11°; these limits correspond well with modern accepted ones. Around the edge of this disk are 179 numbered slots.

The top disk has two sets of circular holes, the outer one with thirteen consecutive new moons for solar eclipses, and the inner one with twelve full moons for lunar eclipses. The distance between the holes is a lunation or 29.53 days. The sets are marked by Sun and Moon symbols respectively. When any of these holes is above the shadowed regions, the amount of shadow shown through the hole is an indicator of the size and kind of the eclipse. The top disk also has a tab for setting the lunar year on the middle disk and the date on the bottom disk.

## 3 THEORY

The instrument uses mean quantities of the Sun and the Moon, thus the indicated eclipse dates may deviate by a day from the true ones. Times are civil, i.e. reckoned from midnight to midnight, and refer to the meridian of Paris.

Fundamental parameters:

The Gregorian year: $GY = 365.2425$ days
The synodic month $SM = 29.53059$ days
The draconic month $DM = 27.21222$ days, lunar period from ascending node to ascending node.
The lunar year $LY = 12 \cdot SM = 354.36700$ days
The eclipse year $EY = (SM \cdot DM)/(SM - DM) = 346.61979$ days, the period of return of the Sun to the lunar node.

De la Hire uses values for some of these parameters that are slightly different from modern values, something that will not seriously affect the arguments presented below.

The difference between the lunar year and the eclipse year:

$LY - EY = 354.36700 - 346.61979 = 7.74721$ days

Figure 2: An engraving of de la Hire made during his lifetime (en.wikipedia.org).

The circle with 179 numbered slots on the middle disk is arranged as follows:

1 46 91 136, 2 47 92 137, … , $n$ $n+45$ $n+90$ $n+135$, … , 45 90 135 1, i.e. with every fourth slot the number increases by 1 and after four rounds we are back at the origin.

The 179 slots on the middle disk correspond to one eclipse year on the bottom disk. Thus we have that 7.7472 days correspond to

$(7.7472/346.61979) \cdot 179 = 4.0008 \approx 4$ slots very nearly.

Thus, these slots can be used to correct for the yearly movement of the lunar nodes relative to the Moon. Another way of expressing the relation above is to say that 179 lunar years are almost exactly equal to 183 eclipse years:

$179\ LY = 63431.69$ days, and
$183\ EY = 63431.42$ days

The difference between the Gregorian year and the eclipse year is 18.6227 days (*GY* – *EY* = 365.2425 – 346.61979 = 18.6227). This number allows us to move from one eclipse year to another.

De la Hire has placed the descending node of the Moon at the lunar year 4 that started on 17 January 1684 at 1:38 hours. A modern calclation shows that indeed the mean new moon at that time actually was very close to the descending node and that there consequently was a solar (annular) eclipse. It was not visible in France; the Sun being below the horizon at the time.

## 4 MANIPULATION OF THE DISKS

1) Set the tab of the top disk to the lunar year number of the middle disk.
2) Move the two top disks *together* until the top disk tab points to the start date of the lunar year taken from de la Hire´s table below.
3) If the date of the lunar year falls in November, December, January, or February, it may be necessary to move the two top disks together *back* (anti-clockwise) by 18 or 19 days in order to see the eclipses from 1 March and on. This will move the settings to the next eclipse year.
4) In order to see eclipses *before* the start date of a given lunar year, set up the disks for the *previous* lunar year.

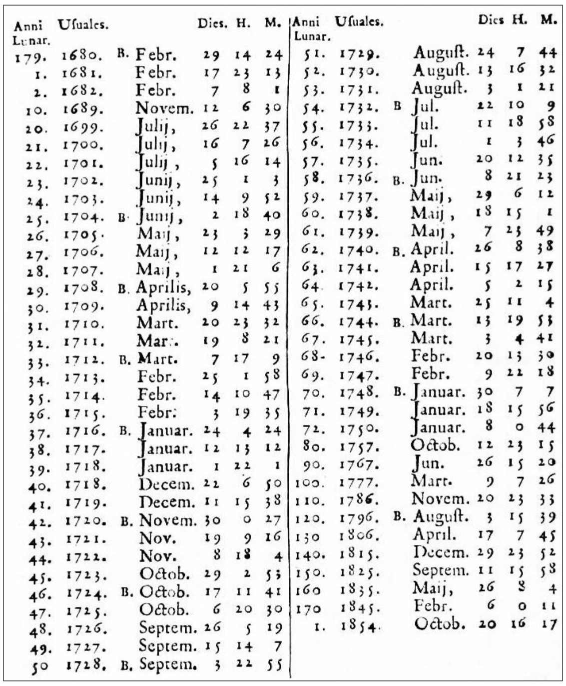
Here are four examples.

1) AD 1703. The lunar year is 24 in the sequence with start of the lunar year on 14 June. Setting up the disks according to 1) and 2) above results in a partial solar eclipse on 14 July, a partial solar eclipse on 8 December, a total lunar eclipse on 29 June and another one on 23 December. Note that there seems to be a partial solar eclipse on 22 June but this Moon belongs to the end of the current lunar year and is false. In order to examine the part of the solar year that comes before the start of lunar year 24, we use rule 4) above. Set up the disks for lunar year 23, start of the lunar year 25 June. There will now be a partial solar eclipse on 17 January 1703 and a partial lunar eclipse on 3 January 1703.
2) AD 1680. This is lunar year 179 with start 29 February. We set up the disks accordingly and to see possible eclipses after 29 February we move to the next eclipse year by moving the two top disks together back 19 days (1680 is a leap year) until the tab points to 1 March /10 February. There will be a total solar eclipse on 30 March and another one on 22 September.
3) AD 1681. This is lunar year 1 with start 18 February. We set up the disks and move them together back 18 days. The tab will point to 30 January. There is now a partial solar eclipse on 20 March and another one on 12 September and a partial lunar eclipse on 4 March and one on 29 August.
4) AD 1748. This is eclipse year 70 with start 30 January. We set up the disks. Before we move them we note that there is a partial solar eclipse on 30 January and a partial/total lunar eclipse on 14 February. We then move the disks back 19 days (1748 is a leap year). The tab now points to 11 January and we then see a total solar eclipse on 25 July and a partial lunar eclipse on 9 August.

## 5 LUNAR YEAR TABLE

The table that de la Hire gives for the lunar years and their starting dates and times is shown below in Table 1.

Table 1: De la Hire's lunar year table.



| Anni Lunar. | Uſuales. | | | Dies. | H. | M. | Anni Lunar. | Uſuales. | | | Dies | H. | M. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 179. | 1680. | B. | Febr. | 29 | 14 | 24 | 51. | 1729. | | Auguſt. | 24 | 7 | 44 |
| 1. | 1681. | | Febr. | 17 | 23 | 13 | 52. | 1730. | | Auguſt. | 13 | 16 | 32 |
| 2. | 1682. | | Febr. | 7 | 8 | 1 | 53. | 1731. | | Auguſt. | 3 | 1 | 21 |
| 10. | 1689. | | Novem. | 12 | 6 | 30 | 54. | 1732. | B | Jul. | 22 | 10 | 9 |
| 20. | 1699. | | Julij, | 26 | 22 | 37 | 55. | 1733. | | Jul. | 11 | 18 | 58 |
| 21. | 1700. | | Julij, | 16 | 7 | 26 | 56. | 1734. | | Jul. | 1 | 3 | 46 |
| 22. | 1701. | | Julij , | 5 | 16 | 14 | 57. | 1735. | | Jun. | 20 | 12 | 35 |
| 23. | 1702. | | Junij , | 25 | 1 | 3 | 58. | 1736. | B. | Jun. | 8 | 21 | 23 |
| 24. | 1703. | | Junij , | 14 | 9 | 52 | 59. | 1737. | | Maij , | 29 | 6 | 12 |
| 25. | 1704. | B. | Junij , | 2 | 18 | 40 | 60. | 1738. | | Maij , | 18 | 15 | 1 |
| 26. | 1705. | | Maij , | 23 | 3 | 29 | 61. | 1739. | | Maij , | 7 | 23 | 49 |
| 27. | 1706. | | Maij , | 12 | 12 | 17 | 62. | 1740. | B. | April. | 26 | 8 | 38 |
| 28. | 1707. | | Maij , | 1 | 21 | 6 | 63. | 1741. | | April. | 15 | 17 | 27 |
| 29. | 1708. | B. | Aprilis, | 20 | 5 | 55 | 64. | 1742. | | April. | 5 | 2 | 15 |
| 30. | 1709. | | Aprilis, | 9 | 14 | 43 | 65. | 1743. | | Mart. | 25 | 11 | 4 |
| 31. | 1710. | | Mart. | 20 | 23 | 32 | 66. | 1744. | B. | Mart. | 13 | 19 | 53 |
| 32. | 1711. | | Mart. | 19 | 8 | 21 | 67. | 1745. | | Mart. | 3 | 4 | 41 |
| 33. | 1712. | B. | Mart. | 7 | 17 | 9 | 68. | 1746. | | Febr. | 20 | 13 | 30 |
| 34. | 1713. | | Febr. | 25 | 1 | 58 | 69. | 1747. | | Febr. | 9 | 22 | 18 |
| 35. | 1714. | | Febr. | 14 | 10 | 47 | 70. | 1748. | B. | Januar. | 30 | 7 | 7 |
| 36. | 1715. | | Febr: | 3 | 19 | 35 | 71. | 1749. | | Januar. | 18 | 15 | 56 |
| 37. | 1716. | B. | Januar. | 24 | 4 | 24 | 72. | 1750. | | Januar. | 8 | 0 | 44 |
| 38. | 1717. | | Januar. | 12 | 13 | 12 | 80. | 1757. | | Octob. | 12 | 23 | 15 |
| 39. | 1718. | | Januar. | 1 | 22 | 1 | 90. | 1767. | | Jun. | 26 | 15 | 20 |
| 40. | 1718. | | Decem. | 22 | 6 | 50 | 100. | 1777. | | Mart. | 9 | 7 | 26 |
| 41. | 1719. | | Decem. | 11 | 15 | 38 | 110. | 1786. | | Novem. | 20 | 23 | 33 |
| 42. | 1720. | B. | Novem. | 30 | 0 | 27 | 120. | 1796. | B. | Auguſt. | 3 | 15 | 39 |
| 43. | 1721. | | Nov. | 19 | 9 | 16 | 130 | 1806. | | April. | 17 | 7 | 45 |
| 44. | 1722. | | Nov. | 8 | 18 | 4 | 140. | 1815. | | Decem. | 29 | 23 | 52 |
| 45. | 1723. | | Octob. | 29 | 2 | 53 | 150. | 1825. | | Septem. | 11 | 15 | 58 |
| 46. | 1724. | B. | Octob. | 17 | 11 | 41 | 160 | 1835. | | Maij, | 26 | 8 | 4 |
| 47. | 1725. | | Octob. | 6 | 20 | 30 | 170 | 1845. | | Febr. | 6 | 0 | 11 |
| 48. | 1726. | | Septem. | 26 | 5 | 19 | 1. | 1854. | | Octob. | 20 | 16 | 17 |
| 49. | 1727. | | Septem. | 15 | 14 | 7 | | | | | | | |
| 50 | 1728. | B. | Septem. | 3 | 22 | 55 | | | | | | | |

The letter 'B.' stands for bissextile (leap year). Note that the dates from years 1806 and later should be one day later as de la Hire has neglected that 1800 was not a leap year.

## 6 A NOTE ON EPACTS

In the ecclesiastical calendar, the epact is the age of the Moon on a specific date, calculated by cyclical reckoning. In the Julian calendar, this date is 22 March and in the Gregorian calendar it is the start of the year. De la Hire uses mean astronomical reckoning and, for the instrument, the Moon's age on 1 March. The distance between 1 January and 1 March is 59 or 60 days, very close to two lunar months of 29.5 days. Thus de la Hire's epact on 1 March is very nearly the epact in 1 January and also nearly the same as the Gregorian epact.

De la Hire has tables (de la Hire: Tabulae, 38) for calculating his epact for any date but they are quite difficult to work with as he uses expired years, expired days and astronomical time, from noon to noon and leap years have to be treated specially.

In order to find the epact on 1 March using the instrument, you set it up for the *previous* year, move to the next eclipse year, and then read off the epact for the new moon that falls within the range of the epact scale on the bottom disk.

Here is an example.

What is the epact on 1 March 1703? Set up the instrument for 1702, lunar year 23, with start date 25 June. Then move the middle and top disks together back 18 days (1703 is not a leap year) and finally read off the epact as 11. The Gregorian epact is 12 (Catholic Encyclopedia).

## 8 REPLICA

Those who would like to build and use a replica of the eclipse predictor can download a PDF document with complete printable drawings of the instrument and an assembly instruction. It also includes de la Hire's table above (corrected) and a continuation of that table for the years 1800–2067. The volvelle works quite well also for these more modern years. You will find the material on the link http://www.thep.lu.se/~larsg/EclipsePredictor.pdf

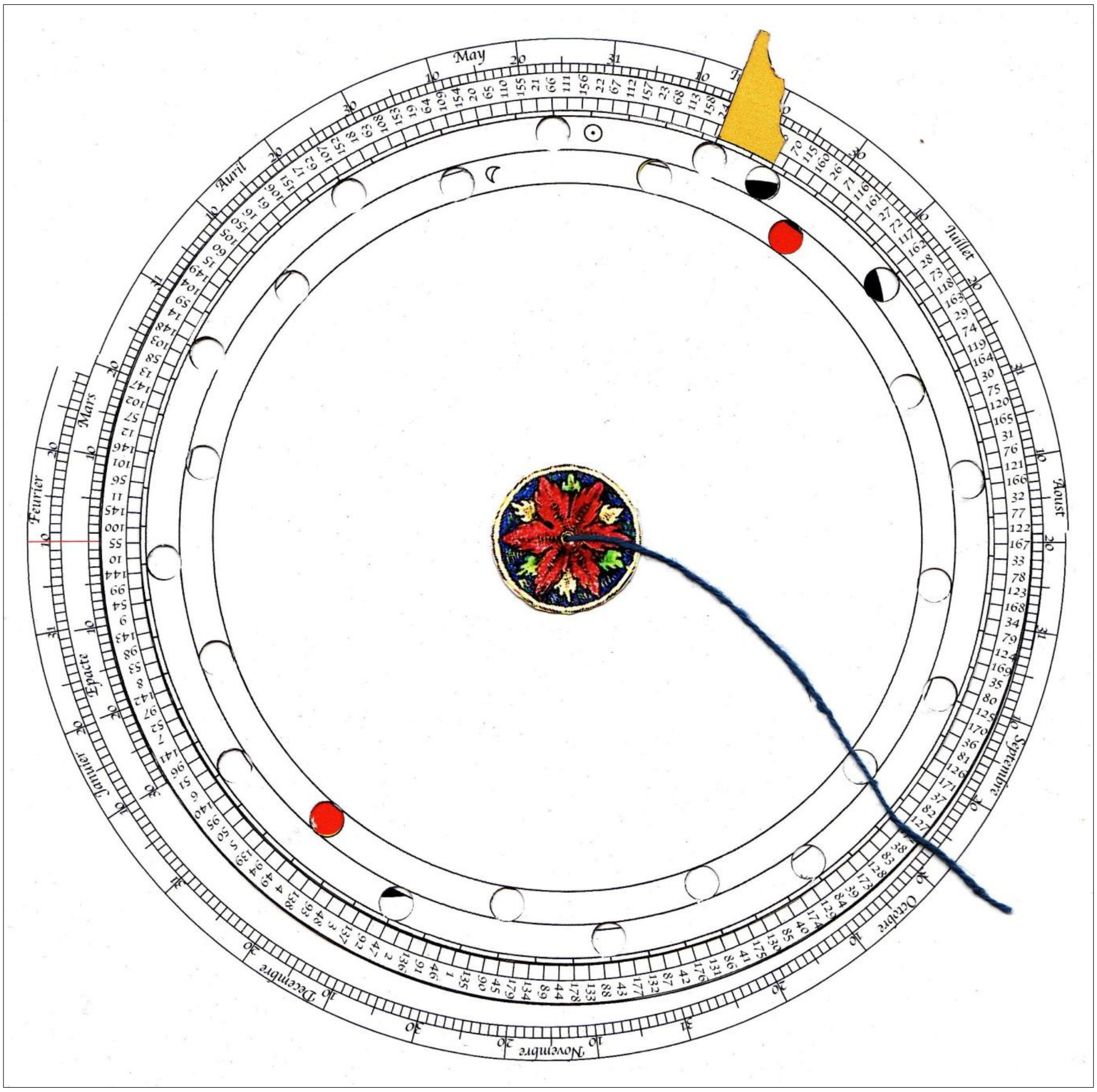


Figure 3: The replica of the de la Hire eclipse predictor set up for the year AD 1703 (photograph: Lars Gislén).

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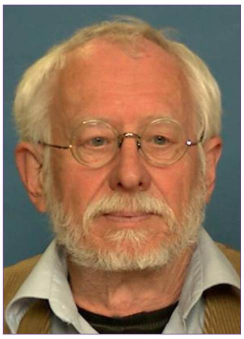

Dr Lars Gislén is a former lector in the Department of Theoretical Physics at the University of Lund, Sweden, and retired in 2003. In 1970 and 1971 he studied for a Ph.D. in the Faculté des Sciences, at Orsay, France. He has been doing research in elementary particle physics, complex system with applications of physics in biology and with atmospheric optics. During the last fifteen years he has developed several computer programs and Excel sheets implementing calendars and medieval astronomical models from Europe, India and South-East Asia (see http://home.thep.lu.se/~larsg/).

Dr Chris Eade has an M.A. from St Andrews and a Ph.D. from the Australian National University. In 1968 he retired from the Australian National University, where he had been a Research Officer in the Humanities Research Centre before moving to an affiliation with the Asian Studies Faculty, in order to pursue his interest in South-East Asian calendrical systems. In particular, research that he continued after retirement concerned dating in the Thai inscriptional record, in the horoscope record of the temples of Pagan and in the published record of Cambodia and Campa.

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# COMTE, MACH, PLANCK, AND EDDINGTON: A STUDY OF INFLUENCE ACROSS GENERATIONS

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**Abstract:** Auguste Comte is frequently ridiculed by astronomers for saying that human beings would never be able to know the physical nature and constitution of the stars. His philosophy, however, influenced scientists throughout his lifetime and for over a century after his death. That influence is traced here in the work of three outstanding scientists who spanned, roughly speaking, three successive generations after his own, namely, Ernst Mach, Max Planck and Arthur Stanley Eddington.

**Keywords:** Auguste Comte, philosophy, positivism, Ernst Mach, Max Planck, Arthur Stanley Eddington,

## 1 AUGUSTE COMTE

Although there are exceptions, astronomers in general are not noted either for their knowledge of, or interest in, philosophy. It is, therefore, somewhat ironical that so many of them should remember Auguste Comte (1798–1857; Figure 1) who, although he was influential in his lifetime and, indirectly so, well into the twentieth century, was scarcely in the first rank of philosophers. He ventured to state, however, that human beings would never be able to know the physical nature and chemical composition of the stars and many astronomers have recalled this statement to ridicule not only Comte himself, but sometimes philosophy in general.

Only a few years after Comte's death, Gustav Kirchhoff (1824–1887) and Robert Bunsen (1811–1899) laid the foundations of spectroscopic analysis, which would eventually enable astronomers to do just what Comte supposed they could never do. I sometimes imagine that, in whatever portion of the Elysian Fields that is reserved for philosophers, the shade of Comte permits himself a wry smile every time a living astronomer quotes him on that subject: at least he is being remembered! We are too ready to make fun of him and to forget that he wrote his *Cours de Philosophie Positive* before astronomers had reliably determined the distance to a single fixed star.

Moreover, leading astronomers of the day would have agreed with him and, perhaps, would have argued that the study of the composition of the stars was not part of astronomy. For example, Friedrich Wilhelm Bessel (1784–1846) an older contemporary of Comte, wrote to Alexander von Humboldt (1769–1859) emphasizing that astronomy was restricted to what could be observed from the Earth and was a matter of precise measurements of the positions and orbits of celestial bodies, adding that

> Everything else that one may learn about the objects, for example their appearance and the constitution of their surfaces, is not unworthy of attention, but is not the proper concern of astronomy. (Kragh, 2004: 18).

Similarly, George Biddell Airy (1801–1892), who was born only three years after Comte, wrote of the importance of a national observatory having some distinctly useful task (such as the time service in Greenwich or the meridian survey in Pulkovo) to prevent "… astronomers from wasting their time in the mere fanciful abstractions of science." (Airy, 1848: 355). It is not entirely clear what Airy meant by that phrase but we may be fairly sure that he held much the same view of the proper concerns of astronomers as Bessel did.

Figure 1: Auguste Comte (en.wikipedia.org).

Comte was echoing quite accurately the opinions of leading scientists of his day, and he had a high opinion of astronomy as he knew it. He maintained that there were three stages in the development of a science, the theological, the metaphysical, and the positive, and he considered the science of astronomy to have been the first—except for pure mathematics—to reach the final stage (Martineau, 1853: 32, 56). Unlike terrestrial sciences, astronomy was limited by what could be deduced by the use of the sense of Sight (capitalization in the English version of his philosophy) and it is hardly surprising that he should, in the 1830s, have supposed that the internal constitution of the stars must be forever beyond our powers of discovery. Astronomers themselves have not always been very prescient about what can or cannot be known: Kragh (2004: 20) also reminds us that, as late as 1906, even Simon Newcomb thought that the human race would never be able to know whether or not there were other galaxies besides our own Milky Way

The best source in English for what Comte actually said is Harriet Martineau (1853). Her freely translated and condensed version of Comte's original work appeared in his lifetime and had his approval. She wrote:

> Whatever knowledge is obtainable by means of the sense of Sight, we may hope to attain with regard to the stars, whether we at present see the method or not; and whatever knowledge requires the aid of other senses, we must at once exclude from our expectation, in spite of any appearances to the contrary. As to questions about which we are uncertain whether they finally depend on Sight or not, -- we must patiently wait for an ascertainment of their character, before we can settle whether they are applicable to the stars or not. The only case in which this rule will be pronounced too severe is that of questions of temperatures. The mathematical thermology created by Fourier may tempt us to hope that, as he has estimated the temperature of the space in which we move, we may in time ascertain the mean temperature of the heavenly bodies: but I regard this order of facts as for ever excluded from our recognition. We can never learn their internal constitution, nor, in regard to some of them, how heat is absorbed by their atmosphere. Newton's attempt to estimate the temperature of the comet of 1680 at its perihelion could accomplish nothing more, even with the science of our day, than show what would be the temperature of our globe in the circumstances of that comet. We may therefore define Astronomy as the science by which we discover the laws of geometrical and mechanical phenomena presented by the heavenly bodies.
>
> It is desirable to add a limitation which is important, though not of primary necessity. The part of the science which we command from what we might call the Solar point of view is distinct, and evidently capable of being made complete and satisfactory; while that which is regarded from the Universal point of view is in its infancy to us now, and must ever be illimitable to our successors of the remotest generations. Men will never compass in their conceptions the whole of the stars. The difference is very striking now to us who find a perfect knowledge of the solar system at our command, while we have not obtained the first and most simple element in sidereal astronomy – the determination of the stellar intervals.[1] Whatever may be the ultimate progress of our knowledge in certain portions of the larger field, it will leave us always at an immeasurable distance from understanding the universe. (Martineau, 1853: 148–149).

However wrong Comte may have been about our inability to probe the internal constitution of the stars, that final sentence still rings true, despite all our advances in cosmology! Experience shows that solving today's problems in cosmology only brings to light new problems for us to tackle. Comte's later thinking developed his system almost into a substitute religion, causing T.H. Huxley (1889: 70) to remark that he desired "… to leave to the Comtists the entire monopoly of the manufacture of imitation ecclesiasticism." The underlying principles of Comte's positivism remained influential, however, even after his death and were very similar to many found in the philosophy of Ernst Mach. Through the latter, they were transmitted to the Vienna Circle and, as *logical positivism*, continued to influence both philosophers and scientists well into the twentieth century.

## 2 ERNST MACH

If it is ironic that Comte is remembered by scientists mainly for his false limitation on our knowledge of the stars, it is even more so that Ernst Mach (1838–1916; Figure 2) is remembered by non-scientists only because his work on shock waves led to the use of his name as the unit of speed in supersonic aeronautics, and by scientists primarily for 'Mach's Principle' (which he never enunciated) and his apparently-stubborn refusal to acknowledge the reality of atoms, even though he lived to see the work of Rutherford on the atomic nucleus and Bohr's model of the hydrogen atom with its explanation of the emission spectrum of hydrogen.

In fact, Mach made many contributions not only to physics, but also to the newly-emerging science of psychology, and to the history and philosophy of science—he may almost be said to have invented that latter discipline. A thorough biography and account of his work and philosophy has been published by Blackmore (1972).

Mach is often described as a positivist; he did not use that term of himself, but neither did he reject it when others used it of him. There are certainly similarities between Mach's ideas and Comte's, particularly their joint insistence on the priority of sense-data. Mach (1905: 72) also quoted with approval Comte's notion of the three stages of science, and seems to have agreed with him that astronomy and mathematics were the sciences that had advanced closest to the final stage.

For Mach, sensations, or 'elements' as he preferred to call them, *were* reality, and the business of science was to relate sensations to each other as economically as possible, and preferably by mathematical equations. From this point of view, atoms *could not* be real, although Mach was prepared to grant that it might be helpful to think in terms of atoms until the true relationship between various sensations could be found. This attitude to atomism may be the reason that Mach has been largely neglected. In his lifetime he was much respected and extremely influential, especially through his many books.

As a young man, in his twenties, he did, for a short time, accept the reality of atoms, as he admits in his book *Erkenntnis und Irrtum* (Mach, 1905: 329). As he developed his philosophy (although he was reluctant to call it that) he came to believe that he had been mistaken. Individual atoms could not be observed—at least in his lifetime—and therefore, he argued, could not be regarded as real. Already, when he wrote that book, Joseph John Thomson (1856–1940) had discovered the electron a decade previously, and Ernest Rutherford (1871–1937) had moved to Manchester, where, with his associates, he began his most important work on the atomic nucleus.

Mach's progress was against the trend set by most nineteenth-century scientists. Although John Dalton (1766–1844) had published a version of atomic theory in 1808, it was by no means immediately generally accepted. By the time of Thomson's discovery of the electron, however, the reality of atoms was increasingly being accepted by physicists and Einstein's (1905a) paper on Brownian motion convinced all but the most resolute sceptics that molecules, at least, were real. After Rutherford's results and Niels Bohr (1886–1962) developed his model of the atomic nucleus, Mach was almost alone in maintaining that, at best, atoms could be regarded as useful models until a better explanation of the phenomena was found. Yet he continued to exert an influence, as indicated by the following excerpt from a letter to him from Albert Einstein (1879–1955):

> You have had such an influence on the epistemological conceptions of the younger physical generation, that even your current opponents, such as Herr Planck for example, would be considered "Machists" by physicists holding the views of most physicists of some decades ago. (cited in Blackmore, 1972: 223).

During the nineteenth century, James Clerk Maxwell (1831–1879), Lord Kelvin (1824–1907), Hermann von Helmholtz (1821–1894) and Ludwig Boltzmann (1844–1906) were developing the kinetic theory of heat, which identified heat with the kinetic energy of atoms or molecules. Mach, who made contributions of his own to thermodynamics, continued to maintain that atoms were at best explanatory models that ultimately would be found unnecessary. It is understandable that Mach, with his belief that sensations were reality, should be sceptical of a theory that explained the sensation of heat as the result of the motions of a vast number of hypothetical particles, for which there was very little observational evidence at the time and which then certainly could not be observed directly.

We belong to a generation that was taught the kinetic theory of heat as established fact and, probably, few if any of us doubt it. Nevertheless, I suspect that if we were called upon to explain to a non-scientific friend how the vibrations of atoms in a solid body could convey to our own bodies the sensation of warmth, let alone in extreme cases, the burning of our flesh, most of us would be hard put to do so convincingly. All the same, it is harder to understand why Mach continued to resist the reality of atoms after the experiments of Rutherford, and Bohr's (1913) theoretical explanation of the hydrogen spectrum.

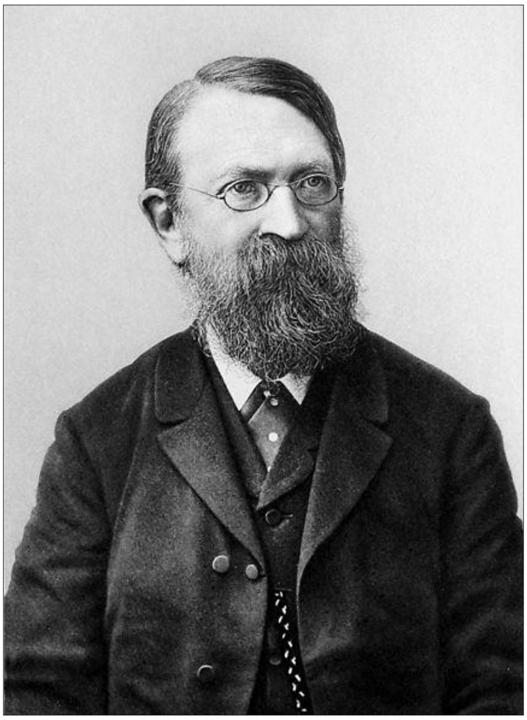

Figure 2: An photograph of Ernst Mach made prior to 1902 (after *Zeitschrift für Physikalische Chemie*, 1902).

There has been some speculation that Mach did indeed change his mind towards the end of his life, and this is discussed by Blackmore in an Appendix (pp. 319–323) to the work already cited. Apparently, Mach was shown scintillations caused by individual alpha particles (helium nuclei) and was reported to have said that he now believed in atoms. Blackmore concludes, however, that there was no conversion, and offers several quotations from Mach's later years to support his conclusion. The latest, written in 1915 a year before Mach's death, and two years after the publication of Bohr's paper, seems to me conclusive:

> I do not consider the Newtonian principles as completed and perfect; yet in my old age, I can accept the theory of relativity just as little as I can accept the existence of atoms and other such dogma.

Interestingly, Mach appears to have had no trouble accepting Clerk Maxwell's theory of electromagnetism, which also was controversial when first published until Hertz discovered radio waves. Mach (1905) was convinced of the wave theory of light, and in *Erkenntnis und Irrtum* presents it as the final word on the nature of light. He does not so much as mention Planck's quantum of action (discovered in 1900) or (even in the 1906 edition) Einstein's (1905b) famous paper on light quanta. Mach's openness to the wave theory of light leaves one wondering if, had he lived to see Schrödinger's development of wave mechanics, he might have hailed that as a step towards a more realistic description of what we now regard as sub-atomic phenomena. Had he been granted another thirty years of life, Mach would have witnessed the explosions over Hiroshima and Nagasaki; in a sense, they exploded his philosophy of science too.

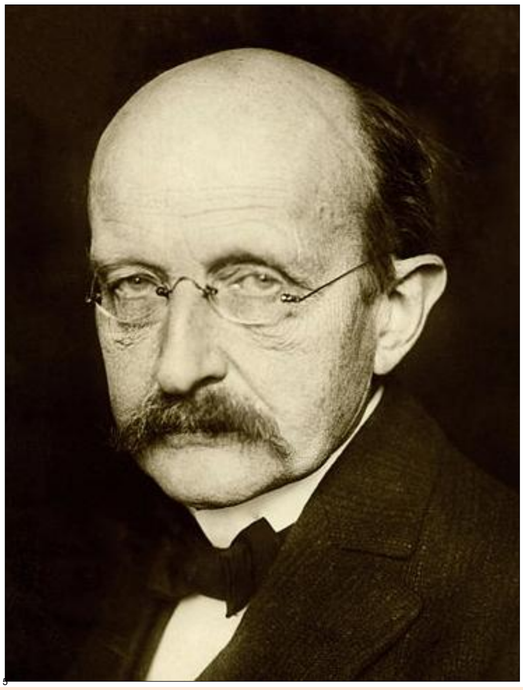

Figure 3: Max Planck in 1933 (en.wikipedia.org).

It would be a mistake, however, to discount that philosophy altogether. One does not have to share it to admire the thought and the erudition that went into its construction, and it was influential well beyond Mach's lifetime. The 'Vienna Circle', that flourished between the two world wars, originally called itself the *Ernst Mach Verein* and developed his ideas into logical positivism, introducing the notion that statements that could not be verified empirically were meaningless, and influencing the thinking of many scientists until well into the twentieth century. It was in reaction to this that Karl Popper (1959) placed emphasis on *falsifiability* as a criterion of a scientific theory, rather than *verifiability*, and this idea, too, is still influential today with many scientists.

## 3 MAX PLANCK

As a young man, Max Planck (1858–1947; Figure 3) was strongly influenced by Ernst Mach and, like him, was sceptical about the reality of atoms but came round to accepting their reality before his own discovery of what he later called 'the elementary quantum of action'. (Planck, 1949: 98). His early work was in thermodynamics and especially was concerned with the nature of entropy. It was at this stage of his life that he was most strongly influenced by Mach, and earned the disapproval of Boltzmann because of his disbelief in the reality of atoms—something that he regretted in later life, although he became reconciled with Boltzmann after his discovery.

B.R. Brown (2015: 115–124) gives the clearest account that I have read of Planck's reasoning and his own estimate of what he had achieved. The assumption that energy was quantized was 'purely formal', and he did not use the word "quantum" in 1900. Five years later, Einstein (1905b) developed Planck's thinking and postulated the light quantum, or photon. The well-known historian of science, Erwin Hiebert, as quoted by Blackmore (1972: 220), and Abraham Païs (1986: 193), however, point out that Planck was reluctant to accept that light could behave like a particle and only some years later fully accepted the physical reality of light quanta.

As Planck matured, however, and developed his own philosophy of science, he departed more and more from Mach's point of view, and became a realist, in the sense that he believed that scientists were investigating a real world that existed independently of human consciousness, but which we could never hope to understand completely. A referee has kindly drawn my attention to a quotation from a 1930 essay by Planck, reprinted in a book unavailable to me (Greenberg, 1990: 64), which makes this last point very clear:

> The physicist's ideal goal is knowledge of the real outside world; but his only research tool, his measurements, never tell him anything directly about the real world, but are always only a more or less uncertain message … a sign that the real world transmits to him and from which he then tries to draw conclusions, similar to a linguist who must decode a document

> which comes from a culture completely unknown to him.

Planck (1932: 82−83) returned to the theme in a collection of essays published in English under the title *Where is Science Going?* where he wrote:

> Now there are two theorems that form together the cardinal hinge on which the whole structure of physical science turns. These theorems are: (1) *There is a real outer world which exists independently of our act of knowing*, and, (2) *The real outer world is not directly knowable*. (Planck, 1932: 82−83; his italics).

This is followed at the bottom of page 83 by:

> But if physical science is never to come to an exhaustive knowledge of its object, then does not this seem like reducing all science to a meaningless activity? Not at all. For it is just this striving forward that brings us to the fruits that are always falling into our hands and which are the unfailing sign that we are on the right road and ever and ever drawing nearer to our journey's end. But that journey's end will never be reached, because it is always the still far thing that glimmers in the distance and is unattainable. It is not the possession of truth, but the success which attends the seeking after it, that enriches the seeker and brings happiness to him.

Planck, therefore, departed from positivism and from Mach, whom he regarded as the leading exponent of that philosophy in late nineteenth-century Germany and Austria. In 1908, he gave a lecture that ended with a personal attack on Mach, who soon replied. Planck returned to the fray in 1910 with a still more personal attack. Planck's strident tone, for which he has been criticized, may partly be explained by the fact that this was just the time when, according to Hiebert and Païs, Planck was wrestling with his own views on the reality of photons and, as Brown (2015) points out, it was also close to the death of his first wife. A fuller account of this episode, including some of the criticisms levelled against Planck and references to the original sources, is given by Blackmore (1972: 223–226). Planck's real target was positivism, of which Mach happened to be the representative. Einstein's letter about Mach's lasting influence on physicists, quoted above, was written in the context of this debate between Planck and Mach. Later, Einstein's own philosophical position moved much closer to Planck's than to Mach's, although he still retained his respect for the latter.

Brown (2015) makes the point that the development of the Copenhagen interpretation of the quantum theory seemed to Planck to be a return to Mach's positivism, as does Planck's other biographer, J.L. Heilbron (1986). Mach, at least as Planck understood him, denied the existence of a real external world, while Planck, for his part, developed the ideas in the first quotation above to distinguish three worlds, or perhaps better, a threefold division of the world into the world of the senses, the real world, and the world of the physicist. We shall encounter a theme very like that in the next section.

Planck was also much interested in the fundamental constants of nature. In a paper published in his *Scientific Autobiography* (Planck, 1949: 168*ff.*) Planck discusses the masses and charges of elementary particles, and, earlier in the book (on page 98) the velocity of light and his 'elementary quantum of action', which all the rest of us know as 'Planck's constant'. Positivists, he argues, do not like these universal constants since they are evidence for the real outer world which exists independently of our act of knowing. Indeed, one of Mach's objections to the theory of relativity was the postulate that the velocity of light is the same for all observers, whatever their relative motions may be. For Planck, the existence of fundamental constants of nature shows that the philosophy of positivism is false. His concern with these fundamental constants is one of many ideas that, as we shall see, he shared with A.S. Eddington.

It is, however, surely something of an oversimplification to say that Mach denied the existence of an external world. While, as mentioned above, 'Mach's principle' was not enunciated by Mach himself, he did discuss the possibility of relating motions to the fixed stars, which presumably confers some sort of reality behind the optical sensations that most of us interpret as arising from the external Universe

## 4 ARTHUR STANLEY EDDINGTON

Eddington (1882–1944; Figure 4) was a generation younger than Planck, as Planck was than Mach. There were many points of similarity between Eddington's thinking and Mach's, possibly indicating that the latter had considerable influence on Eddington, just as he had had on Planck. Kragh (2004) discusses the influence of positivism on the thinking of both Jeans and Eddington, although, somewhat surprisingly, Stanley (2007), in his important study of Eddington's life and work, does not refer either to positivism or to Mach, and his sole reference to Comte is to the dictum with which I opened this discussion.

Eddington's insistence that all we know directly are our sense impressions and internal thoughts could have been taken straight from Mach's *Erkenntnis und Irrtum*, although that work was not available in English during Eddington's lifetime. Several of Mach's works were available in translation, however, even during Eddington's student years, and he was certainly familiar with some aspects of Mach's thought. In one of his books, *Space, Time and Gravitation: An Outline* *of General Relativity Theory* (Eddington, 1920: Chapter 10), Mach is discussed in the context of what we now call 'Mach's Principle' but, apart from that, the names of Mach and Comte, or the term 'positivism', do not appear in the indices of any of Eddington's semi-philosophical works.

Eddington's (1928: 252) statement that all our knowledge of the physical world reduces to pointer readings was anticipated by Mach, who recognized that instruments both give our sensations more precise quantitative values and extend the range of sensation to, for example, infrared or ultraviolet radiations, that we cannot see directly. Nowadays, of course, we would substitute digital read-outs for pointer readings, but that implies no change of principle. Mach, who understood the necessary interaction between theory and observation, might even have agreed with Eddington's (1935: 211) statement that, while most physicists distrusted a theory that was not supported by observation, one should also be wary of accepting observations that were not supported by theory. There are even germs of Eddington's (1939: 16–27) 'selective subjectivism' in the final chapter of *Erkenntnis und Irrtum.* Finally, Eddington's (1928: 291) famous definition of the electron as "... something unknown is doing we don't know what ..." might well have been hailed by the older man, had he lived to read it, as justification for his scepticism about the physical reality of atoms.

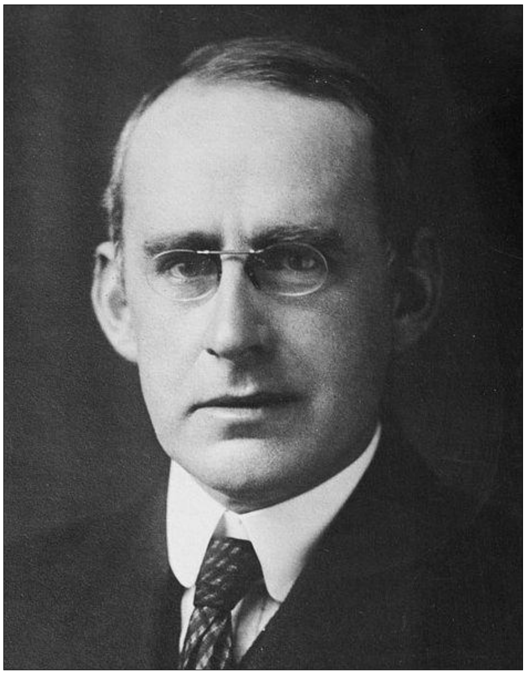
Figure 4: A.S. Eddington (en.wikipedia.org).

Undoubtedly positivism, the most popular philosophy of science in Eddington's lifetime, had its effects on his thinking, yet he was *not* a positivist; his Quaker mysticism did not accord well with the atheism of both Comte and Mach. Moreover, like Planck, Eddington was a realist in that he believed that the physical world was part of an objective reality, even though he thought there were very definite limitations to what we could know about it. Eddington held Planck in high regard, although it is unclear if they ever met, and there are also parallels between the thinking of those two, which perhaps are more important than those between Eddington and Mach.

For example, as just mentioned, like Planck, Eddington believed that scientists were investigating a real external world, but, also like Planck, he was aware of the difficulty of defining just what 'reality' is. This, it seems to me, is the real point of the introduction to *The Nature of the Physical World* (Eddington, 1928: xi) in which Eddington describes his two tables: the ordinary everyday table, with which we are all familiar, that provided a firm surface for his writing paper, and the 'scientific table' composed of atoms whose vibrations supported the paper rather as a swarm of bees might do. This illustration invited the criticism of the philosopher Susan Stebbing (1937: 54–60) who thought it quite misleading. Her criticism was based on the assumption that Eddington really believed that there were *two* tables. I do not read him so: rather, I think he was challenging his readers to question which one of these two descriptions of the table were closer to reality or, to use a Kantian phrase with which Mach dispensed, to the *ding an sich*. Planck (1932: 69) also adopted the imagery of a swarm of atoms supporting the paper on his desk and on pages 92 and 97 of the same book there are passages on the mutual dependence of theory and observation that are reminiscent of Eddington's statement cited above about not trusting an observation unless it is supported by theory.

Eddington fully agreed with Planck that we could not hope to know the external world completely, and he wrote:

> We seek the truth; but if some voice told us that a few years more would see the end of our journey, that the clouds of uncertainty would be dispersed, and that we should perceive the whole truth about the physical universe, the tidings would be by no means joyful. In science as in religion the truth shines ahead as a beacon showing us the path; we do not ask to attain it; it is better far that we be permitted to seek. (Eddington, 1929: 16).

The parallel between Eddington's "... beacon showing us the path ..." and Planck's "... still far thing that glimmers in the distance and is unattainable ..." is striking. Did these two men hit on similar metaphors, or did one copy the other? Since Eddington's book was published first it would have been Planck who copied, if copying there was; but it does not matter whether there was copying or independent choice of the metaphor. Either way, the two men, each of profound physical insight, were thinking in a similar fashion. Both men saw science as an endless quest: neither would have agreed with Horgan (1996) that all the best and most fundamental scientific discoveries have now been made. Planck (1932: 82), a mountaineer, used the metaphor of reaching a hilltop only to find still more hills ahead of us.

In addition, Planck, almost certainly, and Eddington, quite possibly, were influenced by the eighteenth-century German writer, Gotthold Ephraim Lessing (1729–1781), in their insistence that seeking the truth is more rewarding than possessing it. Lessing (1778) wrote:

> It is not in the possession of truth, which a person holds, or claims to hold, that the value of human beings lie, but rather in the sincere effort which they have applied to get behind it. It is not possession of the Truth, but rather the pursuit of Truth by which they extend their powers and in which their ever-growing perfection consists.

In an Eddington Memorial Lecture, the British physicist and philosopher Herbert Dingle (1890–1978) discussed Eddington's realism, which he regarded as a relic of Victorian thinking (Dingle, 1954). Eddington, he believed, could not break free from this 'Victorian' conception that scientists, and in particular physicists, were investigating a real external world. Dingle believed that the theory of relativity had made it impossible to believe that physicists were in fact investigating the external world. He wrote:

> In other words, the scientific problem, as seen by the Victorians, is reversed. Instead of starting with a given, unknown world and finding out its nature and character by observation, we start with observations and construct (or infer, if you prefer the word) a world to satisfy them. (Dingle, 1954: 12–13).

Dingle is in fact advocating here a point of view very similar to Mach's who, after all at least in point of time, was a 'Victorian', but his argument that the theory of relativity had made it impossible to believe that physicists were investigating a world that existed independently of human consciousness is questionable. Even Einstein himself believed he was investigating a real world and Planck (1932: 198), whom Dingle does not mention in his lecture, explicitly denied that the theory of relativity had got "... rid of the absolute." On pp. 17*f*, Dingle went on to summarize Eddington's position, reasonably fairly, as one in a belief in three worlds, or at least, as with Planck, a threefold division of the world. There is the real, or as Dingle termed it, the *external* world, which we wish to study, parts of which we can study by metric methods, and the results of these methods give us the world of the physicist which in some way symbolizes the *structure* of the external world. Meanwhile, non-metrical studies, such as art and religious experience, showed us a *spiritual* world comprising other aspects of the external world. Here again it seems that Planck and Eddington were thinking quite independently and yet reaching very similar conclusions (see the previous Section).

Dingle, however, saw Eddington's three-fold division as a rather tortured attempt to reconcile the developments in physics of the early twentieth century with the notion (which, as we have seen, Dingle believed to be untenable) that physicists were investigating a real external world. As already mentioned, Dingle's own philosophy of science appears to have been Machist: his statement (Dingle 1954: 12) that post-relativistic physics is "... a description of the relations existing between the results of certain operations ..." would have won Mach's full approval, as would the phrase on pages 37–38 defining science as "… the rational correlation of experience." Perhaps Dingle's own tendencies to Machism were a factor in his strenuous attacks, only a few years after this lecture, on the theory of relativity, which Mach had not accepted. If so, it is an inconsistency in his own thinking that he should turn on the very theory that seemed to him to lead directly to Mach's brand of positivism. It is also curious that Dingle sees the belief that physics is a description of a real external world as 'Victorian'. Perhaps it was in Britain, but in Germany Mach's positivism prevailed for much of the nineteenth century and Planck came to what Dingle called the 'Victorian' belief by rebelling against Mach.

Perhaps the most important agreement between Planck and Eddington, however, and where they each diverge from Mach, is in their interest in the fundamental constants of nature. Eddington is famous (or notorious—depending on your own views) for his belief that the values of these constants could be deduced by pure reasoning, without empirical input. Such a notion, of course, would have been anathema to Mach and would probably not have been accepted by Planck. In recent decades the study of these constants has become of great interest in the discussion of the so-called 'fine-tuning' of the Universe, to which I shall return in the next Section, even to those who do not subscribe to Eddington's beliefs.

There is another important matter, however, in which Planck and Eddington found themselves on opposite sides, and that is the question of whether or not the Universe is deterministic at the level of sub-atomic particles. Planck, like Einstein, believed that there must be deterministic laws underlying the apparent indeterminacy of quantum physics. As we have seen, Planck was troubled by Heisenberg's (1927) uncertainty principle. Eddington believed that the behaviour of sub-atomic particles was truly unpredictable. He even ventured to speculate that that indeterminacy provided an opening for human free-will. Planck (1932) devoted two whole chapters to the question of physical causation and free-will and came to the qualified conclusion that, if we knew all the influences acting on us, we could predict the behaviour of others, but that we do not yet have sufficient knowledge to do so. Moreover, since we could not analyze our own behaviour without interfering with it, we felt ourselves to have free will even though we do not. Here, he was closer to Mach (1905: 45), who believed that our will, as a "... special mental power ..." does not exist, and

> The will consists in subordinating less important or only temporarily important reflex actions to the processes that have a leading role in the functioning of life …

Eddington and Planck also shared an interest in the relations of science and religion and both wrote and lectured on the topic. Planck was active in the Lutheran Church throughout his life, although his beliefs were hardly orthodox. Like Einstein, he denied a belief in a personal God and yet he certainly believed in a creator of some kind. Eddington was an observant Quaker and explicitly endorsed the concept of a personal God (Eddington, 1929: 49–50) but, in practice, there may not have been all that much difference between Planck's deism and Eddington's mysticism.

## 5 THE COLLAPSE OF POSITIVISM?

The title of this section is inspired by a book by Michael Heller (1996), an English translation of a book originally published in Polish four years earlier. The biologist Peter Medawar (1984: 66) also referred to positivism as "dated". Heller seemed confident that positivism had begun to collapse early in the 1970s, although he conceded that its attitudes would linger on in the minds of many scientists. Also, commenting on the search for a so-called "... theory of everything ..." he showed considerable prescience with the following remark:

> I wish … to draw attention to the fact that, in my opinion, in the not too distant future this will be an attractive theme for various anti-religious ideologies. (Heller, 1996: 71–72).

It is of interest that Heller considers that the first signs of the collapse of positivism appeared in the early 1970s. This was when interest in the fundamental constants of nature was revived in the astronomical community and Brandon Carter's (1972) paper appeared, which promoted the 'anthropic principle'. As we have seen, positivists tended to resist the idea of universal constants, at least so Planck argued. Carter's contribution was to point out that the relationships these constants bear to one another created the conditions in which our kind of life could appear and flourish. Moreover, those ratios are very tightly constrained indeed if carbon-based intelligent life is to appear in the Universe.

There seem to be two possible explanations: either the Universe was deliberately created by some omnipotent power in order that intelligent and morally self-aware life should appear, or there is a vast number of Universes (composing a so-called 'Multiverse') so that by chance there would inevitably be at least one in which such life would appear. Neither solution would have been very palatable to Mach. His atheism would not have commended the first to him, and someone who throughout almost his whole life had opposed the idea that atoms had a real existence, despite the slowly-accumulating evidence for them that he witnessed, would hardly believe in the existence of many 'Universes' that were certainly unobservable in his lifetime and for which we still have no clear observational evidence. Nevertheless, had he come to accept the significance of universal constants, he would have had a way out of the dilemma: another aspect of his philosophy was monism. He believed that the Universe is One (Bradley 1971: 158). Since we are a part of the One, the Universe must necessarily have the properties that enable us to exist. As to *why* the One has those properties and includes us, that probably is a matter on which Mach would have declined to speculate.

There is an interesting strand running through the thought of all four of the men discussed in this paper: the limitations on human knowledge. Comte may have been wrong about what he thought we could never know, which included not only the physical nature of the stars but the whole of modern cosmology; at least he was modest enough to suppose that there *were* limits on what we could know. Mach did not express that idea quite so explicitly, but he limited reality and, therefore, what we could hope to know to our bodily sensations and the relations between them. Ideas like the Multiverse, and possibly even 'dark matter' and 'dark energy', he would have dismissed as hopelessly unscientific. Planck and Eddington, although they believed that they were investigating a real physical Universe, agreed that we would never be able fully to understand it.

Peter Medawar (1915–1987), a generation younger than Eddington and a generation older than my own contemporaries, also shared a belief in the limits of science, but he did not think that this any way derogated from science. Science, he argued (Medawar, 1984), was designed to answer questions of a certain sort and there are no limits to the number of questions of that sort or to the ability of science to answer them; Planck's metaphor of the hilltops would have won his full approval. On the other hand, Medawar believed that there were questions, the ultimate questions about the meaning of life and the Universe and the beginning of the Universe, which science *could not* answer.

There is a different spirit abroad amongst at least some scientists of our time. Krauss (2012), for example, believes that it is the business of science to find a naturalistic explanation for everything, including the origin of the Universe itself. Historically that belief was not shared by most of the people we look on as the founders of modern science, and there are still many scientists who would not subscribe to it, but Krauss is representative of a considerable number of modern scientists. He tackles the Big Question: why is there something rather than nothing? He favours the Multiverse solution to the dilemma outlined above, and argues that this ensures that there will be at least one Universe in which the laws of quantum physics will be such as to permit the emergence of beings like us. I, personally, do not find his argument convincing, but the main point I wish to make here is that those who argue like him are creating a new view of the nature and scope of science. That may not be wrong in itself; after all, Comte, Mach, and their successors the logical positivists created a new view of science that was certainly different from the views of Galileo, Newton and Boyle, to name a few. Heller may or may not be correct that positivism has collapsed in our own time; he was certainly prescient to see how the search for a "theory of everything" would affect the science-religion debate, for it is precisely that search that leads to the claims of those who think like Krauss.

Einstein, too, was correct when he wrote to Mach that his influence had been so pervasive, that even those who attacked him were in some sense 'Machists', but we seem to have reached a time in which even that influence has begun to wane. Of course Comte and Mach were right to insist on the importance of sense-data as both the starting point and the test of scientific theories: in that limited sense all scientists must be positivists. The positivist view of the nature of science may well have been incorrect, but it avoided Airy's "... mere fanciful abstractions of science ..." and acknowledged the limitations on our human ability to understand this Universe of which we are a very small part. Planck was perhaps thinking of a distinction similar to that made by Medawar when he argued, during a conversation with Einstein that

> Science cannot solve the ultimate mystery of nature. And that is because, in the last analysis, we ourselves are part of nature and therefore part of the mystery that we are trying to solve. (cited by Planck, 1932: 217).

That remark remains a useful warning against the *hubris* of supposing that the methods of science can lead to a final understanding of life, the Universe, and everything.

## 6 NOTES

1. I assume that what is meant here is *stellar distances*, which were indeed unknown when Comte first wrote.

## 7 ACKNOWLEDGMENTS

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# ABORIGINAL ASTRONOMICAL TRADITIONS FROM OOLDEA, SOUTH AUSTRALIA, PART 2: ANIMALS IN THE OOLDEAN SKY

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**Abstract:** Australian Indigenous astronomical traditions demonstrate a relationship between animals in the skyworld and the behaviour patterns of their terrestrial counterparts. In our continued study of Aboriginal astronomical traditions from the Great Victoria Desert, South Australia, we investigate the relationship between animal behaviour and stellar positions when these relationships are not explicitly described in the written records. We develop a methodology to test the hypothesis that the behaviour of these animals is predicted by the positions of their celestial counterparts at particular times of the day. Of the twelve animals identified in the Ooldean sky, the nine stellar (i.e. non-planet or non-galactic) associations were analysed and each demonstrated a close connection between animal behaviour and stellar positions. We suggest that this may be a recurring theme in Aboriginal astronomical traditions, requiring further development of the methodology.

**Keywords:** Ethnoastronomy, cultural astronomy, ethnoecology, Aboriginal Australians, Indigenous knowledge, animal behaviour

> *"Most of the totemic ancestral beings are represented in the sky by stars and planets. Although they leave their material bodies on earth metamorphosed into stone, their spirits are the stars."*
> – Ronald and Catherine Berndt (1943).

## 1 INTRODUCTION

The study of the astronomical knowledge and traditions of Indigenous Australians has revealed a wealth of traditional knowledge regarding the night sky. Calendars and food economics are closely integrated with astronomical traditions (Fredrick, 2008; Johnson, 1998; Sharp, 1993) often involving animals and their behavioural habits. Oral traditions describing animals in the skyworld are common across Australia (Stanbridge, 1861) and the world (e.g. Kelley and Milone, 2011: 499; Urton, 1981). These animals may be represented by constellations, asterisms, individual stars, star clusters, planets, nebulae, or other celestial objects. In Australia, celestial animals are commonly linked to behavioural patterns of their terrestrial counterparts, such as mating, birthing or brooding their young (Cairns and Harney, 2003; Johnson, 1998; Stanbridge, 1861). These traditions serve, in part, as a guide for noting the time of year to access particular food sources.

This paper is a continuation of the study of Aboriginal astronomical knowledge in the Great Victoria Desert near Ooldea, South Australia (for Part 1, see Leaman and Hamacher, 2014). Most of this information comes from the work of amateur anthropologist Daisy Bates (Bates, 1904–1935; 1921a; 1921b; 1924a; 1924b; 1933; 1938) and professional anthropologists Ronald and Catherine Berndt (Berndt, 1941; Berndt and Berndt, 1943; 1945; 1974; 1977). The primary information used in this paper comes from Daisy Bates in a story she recorded about the constellation and star cluster known by Western astronomers as Orion and the Pleiades (Bates, 1921b; 1933). Through her work, Bates described many animals in the Ooldean sky, but gave no details about a relationship between the animals and their celestial counterparts. In most cases, the stories simply stated the type of animal that each celestial object represented and their major or minor role in the narrative.

In this paper, we test the hypothesis that each animal in the Ooldean sky is associated with a celestial object that is used to predict the breeding habits of these animals, such as mating, birthing, incubating eggs, brooding and fledging young.[1] Thus, we investigate whether these breeding habits are predicted by the heliacal or acronychal rising or setting, or meridional transit, of their respective celestial counterparts.

## 2 ANIMALS IN THE ABORIGINAL SKYWORLD

According to the cosmogony and cosmography of Aboriginal Australians, the realm of the skyworld has topography similar to and every bit as real as the terrestrial landscape below (Clarke, 2007/2008; 2015b). This realm is inhabited by plants, animals and ancestral beings, each represented by celestial bodies (Clarke, 2014; 2015a; 2015b; Leaman and Hamacher, 2014), or other prominent features of the night sky, such as the prominent dark bands of the Milky Way (e.g. see Fuller et al., 2014a; 2014b).

In his foundational work on Aboriginal astronomy in western Victoria, William E. Stanbridge (1820–1894; 1861) recorded some of the astronomical traditions handed to him by the Boorong, a clan of the Wergaia language group living near Lake Tyrell. His papers include several animals that relate to stars. For instance, the star Vega ($\alpha$ Lyrae), called *Neilloan* in the Wergaia language, was linked to the Mallee fowl (*Leipoa ocellata*), a chicken-sized ground-dwelling megapode that builds its nest-mounds when Vega rises at dusk (acronychal rising). When Vega is high in the sky at dusk (dusk meridian crossing), the birds are laying their clutches of eggs, and when Vega sets at dusk (heliacal setting), the chicks begin hatching. Similarly, the star Arcturus ($\alpha$ Boötis), called *Marpeankurrk* in the Wergaia language, is related to the larvae of the wood-ant, which are plentiful for only a couple of months of the year—August and September—the same time Arcturus is visible in the evening sky. In his M.A. thesis and subsequent research the late John Morieson (1938–2015) built upon these associations to construct a detailed picture of the Boorong night sky, noting the complex calendars that are related to seasonal animal behaviour (Morieson, 1996; 1999).

Recent studies of Aboriginal astronomical knowledge (e.g. Cairns and Harney, 2003; Fredrick, 2008; Fuller et al., 2014b; Hamacher, 2012) show a definitive link between animal behaviour and the positions of their celestial counterparts in the sky, particularly at dusk and dawn. The appearance of the celestial emu in the evening sky, traced out by the dark spaces in the Milky Way from Crux to Sagittarius, informs Aboriginal people of when emus are laying their eggs, which is an important food source (Fuller et al., 2014a; Norris and Hamacher, 2009).

Examples like these are commonplace in Aboriginal traditions, yet it seems most of the traditions collected by early anthropologists do not provide much information of this sort. This paper explores animals in the Ooldean sky for connections to their terrestrial counterparts in terms of annual breeding behaviour patterns to better understand the nature of Aboriginal astronomical knowledge.

## 3 ANIMALS IN THE OOLDEAN SKY

Ooldea is on the traditional lands of the Kokatha peoples (Gara, 1989). The presence of a permanent water source at Ooldea Soak made it an important drought refuge and meeting place for trade and ceremony for these people and many surrounding Aboriginal language groups (Bates, 1938; Gara, 1989; Tindale, 1974). At the time of Daisy Bates' visit to Ooldea, activities associateed with the Trans-Australian Railway (Bates, 1938; Brockwell et al., 1989; Colley et al., 1989) were causing major disruption to traditional lifestyles of these peoples, an important one being the establishment of more permanent camps, with diverse peoples of the region living in close proximity to each other. This may explain the blending of vocabularies from different language groups in the word lists of Daisy Bates (e.g. see Bates, 1918), and in the skylore she recorded in the Ooldea region (Bates, 1921a; 1921b; 1924a; 1924b; 1933).[2] Rather than attempting to disentangle Bates' records, in this paper we have adopted the term 'Ooldean sky' to describe the linguistically-blended skylore of the region at the time of its recording by Bates.

The records provided by Bates (1904–1935) note several animals in the Ooldean sky (Table 1): the Australian Bustard, Black Cockatoo, Dingo, Emu, Grey Kangaroo, Owlet Nightjar, Crow, Redback Spider, Red Kangaroo, Thorny-devil Lizard and the Wedge-tailed Eagle. Most animals are related to stars, star clusters and asterisms, or to the dark band of the Milky Way (see also Leaman and Hamacher, 2014). Exceptions are the Red and Grey Kangaroos, which are related to the 'morning' and 'evening' stars, respectively. Bates identifies these as the planets Jupiter and Venus, respectively, but it is not clear if she is misrepresenting Jupiter as the morning star (as Venus is typically called both the morning and evening star) or if Jupiter was prominent in the morning when Bates recorded the relevant astronomical traditions. There is no time stamp for the dates when she recorded these traditions, but they are in her notes from Ooldea, where she lived and worked from 1919 to 1935. During that 16-yr period, both Venus and Jupiter would have been bright in the early morning sky on numerous occasions. The Black Cockatoo is related to both Antares and Mars. Planets are not suitable for denoting *annual* seasonal change on Earth, but may be used in referencing longer climatic cycles (e.g. droughts, floods, El Niño Southern Oscillation-driven events, etc.), so Venus, Mars, and Jupiter will have no regular connection with the annual seasonal behavioural cycles of any animal.

A list of the celestial objects, their location in the sky, their spectral type (which indicates colour), and their brightness (visual magnitude, $m_v$) are given in Table 2. All of the individual stars listed are first magnitude (among the brightest 22 stars in the night sky). We exclude *Babba*, the dingo father, as we do not know the exact star that represents *Babba* in the sky. Bates (1933) describes it as being the 'horn of the bull'. Leaman and Hamacher (2014) argue that it could be either the stars β or ζ Tauri, but this is uncertain, and Aldebaran (α Tauri) is already ascribed to a major character in the narrative.

## 4 TERRESTRIAL BEHAVIOUR OF OOLDEAN SKY ANIMALS

The behaviour patterns and lifecycles of the animals represented in the Ooldean sky are discussed in the following sections. These will set the foundation on which we test the connections between animal behaviour and stellar positions.

Table 1: A list of animals in the Ooldean sky and their celestial counterpart in alphabetical order by Aboriginal name, taken from "The Orion Story" recorded by Daisy Bates (Leaman and Hamacher, 2014).

| Aboriginal Name | Animal | Species | Type | Object |
|---|---|---|---|---|
| *Gibbera* | Australian Bustard | *Ardeotis australis* | Bird | Vega |
| *Joorr-Joorr* | Owlet Nightjar | *Aegotheles cristatus* | Bird | Canopus |
| *Kalia* | Emu | *Dromaius novaehollandiae* | Bird | Coalsack |
| *Kangga Ngoonji* | Crow Mother | *Corvus spp.* | Bird | Altair |
| *Kara* | Redback Spider | *Latrodectus hasseltii* | Arachnid | Arcturus |
| *Kogolongo* | Black Cockatoo | *Calyptorhynchus banksii* | Bird | Mars |
| *Kulbir* | Grey Kangaroo | *Macropus fuliginosus* | Mammal | Venus |
| *Maalu* | Red Kangaroo | *Macropus rufus* | Mammal | Jupiter |
| *Ngurunya (?)* | Dingo | *Canis lupus dingo* | Mammal | Achernar |
| *Nyumbu* | Crow (chicks) | *Corvus spp.* | Bird | Delphinus |
| *Waljajinna* | Wedge-tailed Eagle | *Aquila audax* | Bird | Crux |
| *Warrooboordina* | Black Cockatoo | *Calyptorhynchus banksii* | Bird | Antares |
| *Yugarilya* | Thorny-devil Lizard | *Moloch horridus* | Reptile | Pleiades |

Table 2: Data for each of the celestial objects mentioned in Table 1. Data include common name, Bayer designation, coordinates (right ascension and declination in J2000). Spectral types, and visual magnitudes ($m_v$) are taken from the SIMBAD star database (simbad.u-strasbg.fr). For planets the range of $m_v$ are the minimum to maximum values. The value given for the coordinates of Crux is 35 Crucis, which lies near the centre of the constellation. The $m_v$ quoted are for α Crucis and δ Crucis, the brightest and faintest of the four major stars in Crux. Planet colours are approximate.

| Name | Designation/Type | RA | DEC | SpecType | Colour | $m_V$ |
|---|---|---|---|---|---|---|
| Achernar | α Eridani | 01h 37m 43s | −57° 14' 12" | B6V | Blue-White | 0.46 |
| Altair | α Aquilae | 19h 50m 47s | +08° 52' 06" | A7V | White | 0.76 |
| Antares | α Scorpii | 16h 29m 24s | −26° 25' 55" | M0.5Iab | Orange | 0.91 |
| Arcturus | α Bootis | 14h 15m 40s | +19° 10' 57" | K0III | Orange | −0.05 |
| Canopus | α Carinae | 06h 23m 57s | −52° 41' 44" | A9II | Yellow-White | −0.74 |
| Coalsack | Dark Nebula | 12h 31m 19s | −63° 44' 36" | – | - | – |
| Crux | (Constellation) | 12h 31m 40s | −59° 25' 26" | – | - | 0.81(α), 2.78(δ) |
| Delphinus | (Constellation) | 20h 39m 38s | +15° 54' 43" | – | - | > 3.00 |
| Jupiter | (Planet) | – | – | – | Red-White | −1.61 to −2.94 |
| Mars | (Planet) | – | – | – | Red | 1.84 to −2.91 |
| Pleiades | (Open Star Cluster) | 03h 47m 00s | +24° 07' 00" | A0, B6, B7 | Blue-White | 1.60 |
| Vega | α Lyrae | 18h 36m 56s | +38° 47' 01" | A0V | White | 0.03 |
| Venus | (Planet) | – | – | – | White-Yellow | −3.8 to −4.9 |

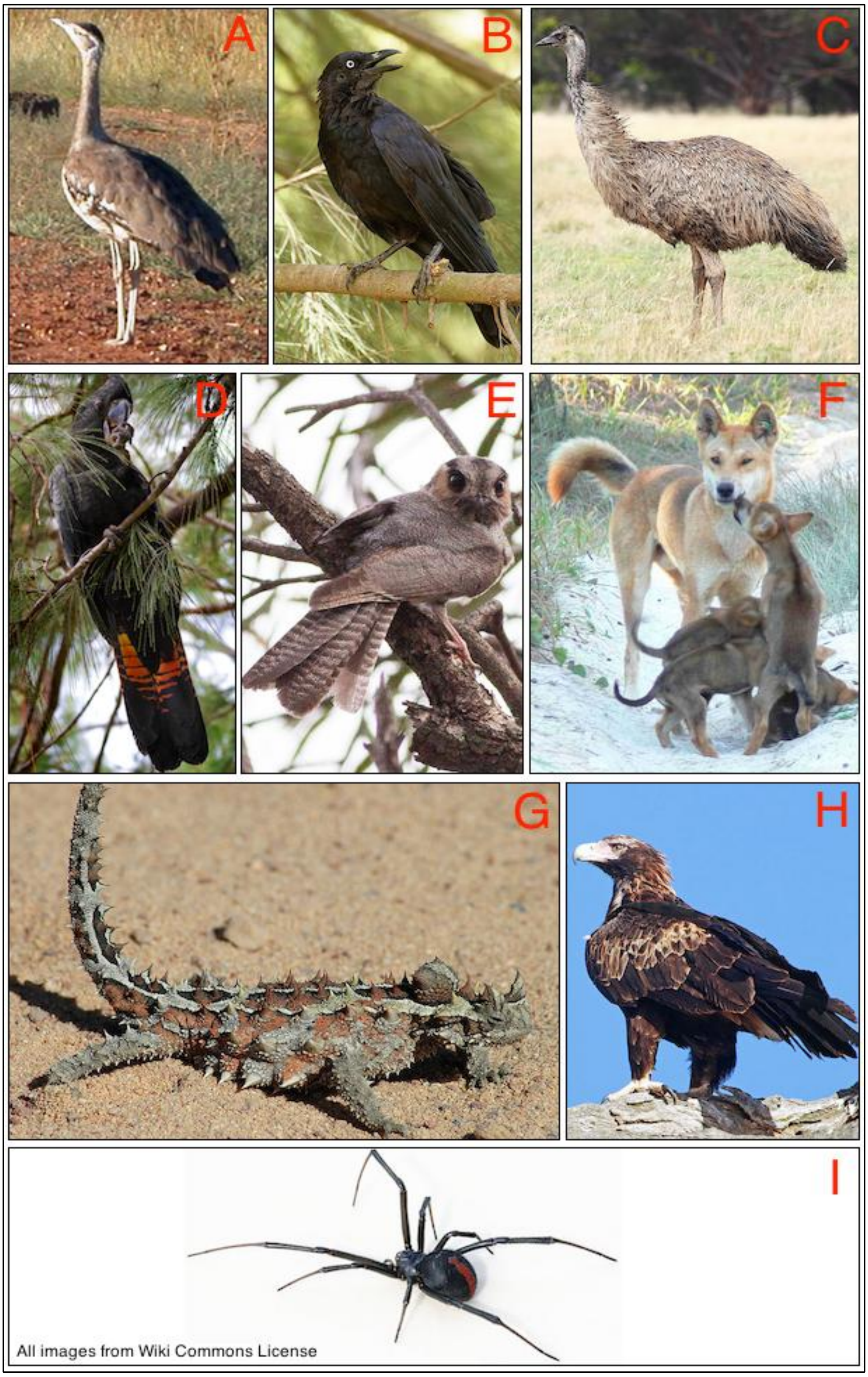

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Figure 1: Animals in the Ooldean sky (images reproduced from Wikimedia Commons license): (A) Australian Bustard (Glen Fergus); (B) Australian Raven (J.J. Harrison); (C) Emu (Benjamint444); (D) Red-tailed Black Cockatoo; (E) Owlet Nightjar (Ron Knight); (F) Dingo male with pups (Partner Hund); (G) Thorny-devil Lizard (Thorny Dragon) (KeresH.); (H) Wedge-tailed Eagle (J.J. Harrison); and (I) Redback Spider (Toby Hudson).

### 4.1 The Australian Bustard (Vega)

The star Vega ($\alpha$ Lyrae) is *Gibbera*, the bush turkey (Figure 1A). In the deserts of Central Australia, the term 'bush turkey', or 'brush turkey', is colloquially used by Aboriginal people to refer to the Australian Bustard (*Ardeotis australis*). This is not to be confused with the Australian brush (bush) turkey (*Alectura lathami*), which inhabits more temperate and wet tropical areas. The Bustard is an important food source for Aboriginal people (Ziembicki, 2009).

The breeding cycle of the Australian Bustard varies across Australia and appears to be closely linked to weather and seasonal patterns, especially rainfall frequency (Ziembicki, 2009; 2010; Ziembicki and Woinarski, 2007: Figure 2). In arid areas, such as at Ooldea, populations are transient and migratory, with numbers fluctuating in response to habitat and food availability in wet/dry years (Ziembicki, 2009). In good years, breeding at Ooldea generally occurs between May and August, with a slight peak in June (Ziembicki, 2009). Chicks emerge after an incubation period of 23 days (Beruldsen, 2003).

### 4.2 The Crow Mother (Altair) and her Chicks (Delphinus)

The star Altair ($\alpha$ Aquilae) is *Kangga Ngoonji*, the mother crow, and the stars of the constellation Delphinus are *Nyumbu,* her chicks. In the Pitjantjatjara language, *Kangaa* (or *Kaanka*) is the name for the Torresian Crow (*Corvus orru*) (Reid et al., 1993). However, since this species is not normally found south of the Birksgate Ranges, to the northeast of the Great Victoria Desert, it is unlikely that this is the species referred to in Bates' story. A similar-looking species, the Little Crow (*Corvus bennetti*) does inhabit the area around Ooldea, and is easily mistaken for the Torresian Crow. Although the Pitjantjatjara name *Wangarangara* is normally specific to this species, there is a chance that the name *Kangaa Ngoonji* was used for it around the time Bates was recording her story, especially if her informants were less particular about distinguishing between the two. To add more confusion, another similar-looking species, the Australian Raven (*Corvus coronoides*) (Figure 1B) can also be found at Ooldea. It inhabits a thin stretch of land across the Nullarbor and in the desert regions of South Australia (Beruldsen, 2003).

Regardless of which species is referred to in Bates' account, the breeding season is similar for all three, being from July to September, and the incubation period for the clutch is roughly 20 days. The chicks are fledged within 45 days, but the mother continues to feed them for up to

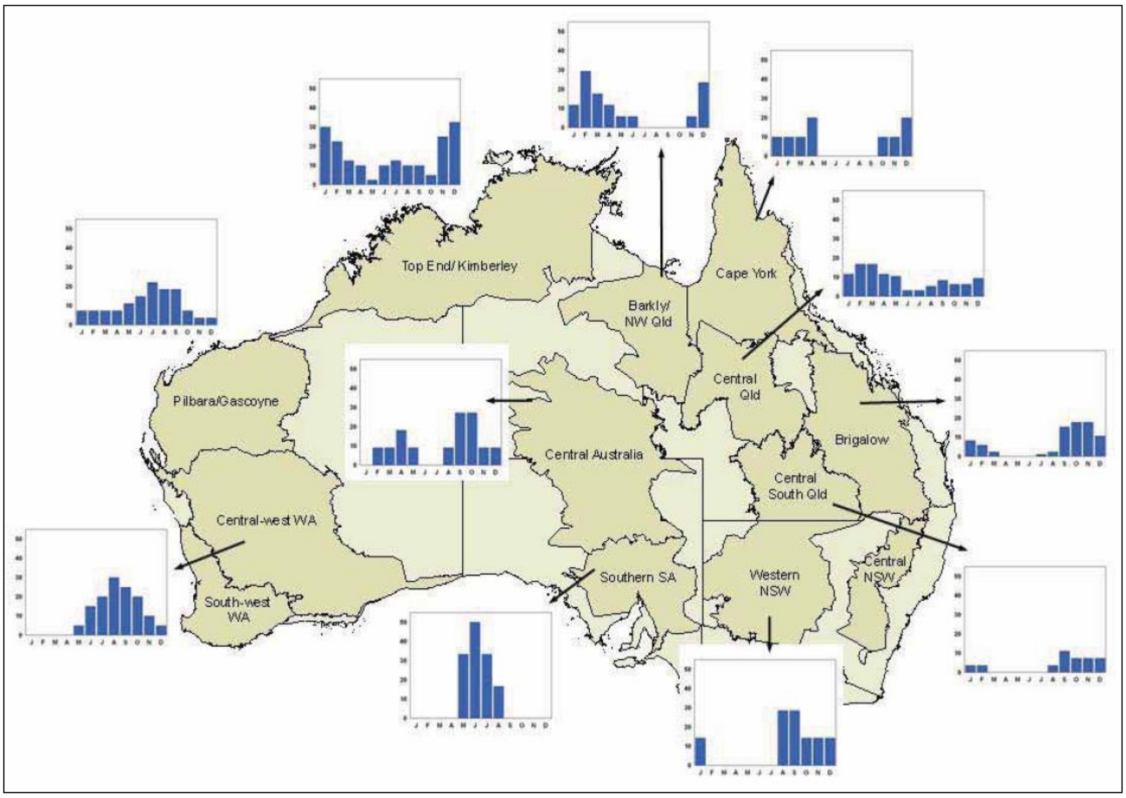

Figure 2: Regional variation in breeding cycle peaks in the Australian Bustard in response to seasonal variations in rainfall patterns over a year, in terms of mm precipitation (y-axis) by month (x-axis) (from Ziembicki, 2009: 49). Ooldea lies at the extreme western edge of the area labeled 'Southern SA'.

four months (Beruldsen, 2003).

## 4.3 The Emu (Coalsack Nebula)

The Coalsack Nebula is the head of *Kalia* the emu (*Dromaius novaehollandiae*) (Figure 1C). The Coalsack is a dark absorption nebula that borders Crux, Centaurus, and Musca, and resembles the profile of an emu's head, replete with beak. Emus form into breeding pairs in December and January and begin mating in late April to early May and continue through to June (Eastman, 1969). Emus lay one egg every day or two and incubation does not commence until all eggs are laid. As clutch sizes vary between five to 20 eggs, it can take up to three weeks for the whole clutch to be laid. Incubation of the eggs lasts for 56 days (Eastman, 1969; Reid et al., 1993). Male emus rear the chicks for up to seven months. Interestingly, wedge-tailed eagles are the prime predators of emu chicks (Reid et al., 1993), which may be another reason that the constellation of the Wedge-tailed Eagle has been placed in Crux, adjacent to the celestial Emu, its natural prey in both celestial and terrestrial worlds.

The association of the Coalsack with the head of the emu is found across Australia (e.g. Cairns and Harney, 2003; Fuller et al., 2014a; Stanbridge, 1861; Wellard, 1983). Although only the Coalsack is specified as 'the emu', in many Aboriginal traditions it is the head of the emu, with the eye represented by the star BZ Crucis ($m_v = 5.3$) (Hamacher, 2012). A profile view of the emu is traced out along the Milky Way, from the Coalsack to the centre of our Galaxy in Scorpius, Ophiuchus and Sagittarius, where the Galactic bulge outlines the body of the emu. Similarly, Bates (1904–1935: No. 25/308, p. 13) claims that the "… long dark patch in the Milky Way … [is the] emu father …" in the traditions of another desert community. Since the emu is traced out by a large part of the sky, the criterion used for single celestial objects is not applicable, hence the Coalsack's absence in Tables 3 and 4. Similarly, we exclude it from further analysis here. However, we reiterate that across Australia, the rising of the celestial emu at dusk coincides with the breeding and egg-laying season of the emu (e.g. see Fuller et al., 2014a).

## 4.4 The Black Cockatoo (Antares)

The red-giant star Antares (α Scorpii) is *Warrooboordina*, the Red-tailed Black Cockatoo (*Calyptorhynchus banksii*) (Figure 1D). The Red-tailed Black Cockatoo is the only species of the genus *Calyptorhynchus* found in the Central Desert. Although its distribution does not extend to the Ooldea region, probably due to the lack of mature River Red Gums along major watercourses (that the species requires for breeding), they do occur through the Musgrave Ranges, near the northern extent of the Anangu-Pitjantjatjara-Yankunytjatjara (APY) lands ~480 km to the north of Ooldea. The red colour of the Cockatoo's tail feathers provides a clue as to why it is connected to the bright red star Antares. These birds breed from March to September (Forshaw, 2002) and incubate their clutch for around 30 days (Kurucz, 2000). Breeding for the inland subspecies *Calyptorhynchus banksii samueli* also begins in March but has a peak in July (Higgins, 1999; Storr, 1977). Fledging takes a median of 87 days after hatching, and chicks are fed by both parents for a further three to four months after leaving the nest (Higgins, 1999).

## 4.5 The Owlet Nightjar (Canopus)

The star Canopus (α Carinae) is *Joorr-Joorr*, the Australian Owlet Nightjar (*Aegotheles cristatus*) (Figure 1E), which is found throughout the Australian Outback wherever tree hollows or rock crevices are present in which the birds can breed. The bird's name is onomatopoeic, mimicking the sound of one of its repertoire of nocturnal calls. This and other calls commonly used by this species have been described as sounding like human 'laughs' or 'chuckles' (Higgins, 1999).

This bird breeds mainly from October to January, with an incubation period of 18 to 29 days, depending on temperature (Brigham and Geiser, 1997). The chicks from the first clutch of eggs hatch by late October and are fledged about a month afterwards. The birds also go through a short period of hibernation (torpor) from May to September (Bringham, et al., 2000).

## 4.6 The Dingo (Achernar)

The star Achernar (α Eridani) is *Ngurunya*, the mother Dingo (*Canis lupus dingo*) (Figure 1F). Across most parts of Australia, the Dingo breeding season generally begins in March with gestation lasting between 61 and 69 days (Corbett, 1995), with the first litters being whelped from May to July (Catling et al., 1992). Although there is a distinct breeding peak in the Central Desert in March, Dingoes have been observed with pups all year round (Purcell, 2010: 43), suggesting that breeding cycles are also likely influenced by seasonal availability of food resources due to weather and climate cycles.

## 4.7 The Thorny-devil Lizard (Pleiades)

The Pleiades (M45 open star cluster) are *Yugarilya*, the seven Mingari sisters. As Nyeeruna (Orion) attempts to seduce the sisters (Leaman and Hamacher, 2014), they become frightened and transform into the Thorny-devil Lizard (*Moloch horridus*) (Figure 1G). This lizard is their totem animal and plays a central role in the narrative.

The lizard, also called the 'Thorny Dragon', is small (20 cm in length) with conical spines and camouflaged skin (Browne-Cooper et al., 2007). Females lay a clutch of ten eggs in a burrow some 30 cm deep between the months of September and December (Pianka, 1997). The eggs incubate for three to four months (ibid.), after which the lizards crawl out of their subterranean burrows.

### 4.8 The Wedge-tailed Eagle (Crux)

The stars of the Southern Cross constellation (Crux) are seen as the footprint of *Waljajinna*, the Eagle-hawk, or Wedge-tailed Eagle (*Aquila audax*) (Figure 1H). The four brightest stars of Crux resemble the footprint of the Wedge-tailed Eagle—an association found in the astronomical traditions of Arrernte and Luritja communities in the Central Desert (e.g. Maegraith, 1932; Mountford, 1976).

The Wedge-tailed Eagle is one of the largest birds of prey in the world and is commonly found across the Ooldea region. The breeding season begins in March and April and runs to September, but a majority of the eagles lay their eggs in July (Olsen, 1995; 2005). Eggs are incubated for 45 days.

Normally two eggs are laid, but it is very common for only one of these to survive to fledge the nest. The weaker chick is usually outcompeted for food and sometimes killed by the stronger sibling, a phenomenon known as 'Cainism' (after the biblical Old Testament siblicide story of Cain and Abel). This is a common action among eagles in the *Aquila* genus worldwide (Olsen, 1995; Simmons, 1998). The weaker chick is thought to usually be dead within 20 days of hatching. Fledging rates are variable, between 75 to 95 days, dependent on factors such as food availability and nest disturbance (Marchant and Higgins, 1993).

### 4.9 The Redback Spider (Arcturus)

The red-orange star Arcturus ($\alpha$ Boötis) is *Kara*, the Redback Spider (*Latrodectus hasseltii*) (Figure 1I). Although identified in some of Bates' records as the blue star Rigel ($\beta$ Orionis), this was probably a transcription error in her notes (for justification of this conclusion see Leaman and Hamacher, 2014).

Redback Spiders, which are less common in desert regions, mate all year round. However, the breeding rate increases when the temperature is warmer, peaking in summer (Forster, 1995). Studies near Perth (Western Australia) showed that Redback Spider sexual activity begins to peak in late November (Andrade, 2003). The spiderlings may emerge from the sacs as early as 11 days after being laid, but their emergence is also temperature-dependent, and cooler temperatures may prolong the time before they emerge.

## 5 METHODOLOGY

How can we test for connections between a particular star or asterism given animal associations and the behaviour of its terrestrial counterpart when these connections are not explicitly stated by Aboriginal people or included in the written record? Here we develop a methodology that considers two primary variables: the time and duration of each particular animal's behaviour and the time and position of the associated star's appearance in the sky. Animal behaviour, particularly breeding, may be dependent on weather, temperature, and other variables. As a consequence, the timing of a particular animal's behaviour can range over a period of weeks. Conversely, the rising or setting of specific stars at particular times as viewed from a given location in any given year can be calculated to the exact day.

The development of an appropriate methodology should make best use of the information available in the most rigorous manner possible. A similar study relating stellar positions to seasonal changes was published by Hamacher (2015). Building upon this methodology, we attempt to predict the reasons why each animal is linked to its celestial counterpart.

Traditionally, archaeoastronomers use precise definitions for heliacal and acronychal rising and setting (e.g. see Aveni, 1980; 2001; Bruin, 1979; Robinson, 2009; Schaefer, 1987; 1997). According to these definitions, *heliacal rise* (HR) occurs when an object is first visible above the eastern horizon just before the Sun rises. *Heliacal set* (HS) occurs when an object is last visible above the western horizon after sunset. Similarly, *acronychal rise* (AR) occurs when an object is first visible above the eastern horizon just after sunset, and *acronychal set* (AS) occurs when an object is last visible above the western horizon just before sunrise. A star's highest point in the sky occurs when it crosses (transits) the meridian. For this study, we define meridional transit at sunrise (Mdawn) or sunset (Mdusk) as the point when the star crosses the meridian at its last and first visibility, respecttively. All six aspects are illustrated for clarity in Figure 3.

The heliacal, acronychal, or meridional visibility of a celestial object depends on several factors, including its brightness relative to the background glow of the Sun (Aveni, 2001: 112); refraction of the starlight and sunlight through the Earth's atmosphere; atmospheric conditions; extinction; visual acuity of the observer; visibility of the horizon (e.g. vegetation and local topography); and the elevation and altitude of the hor-

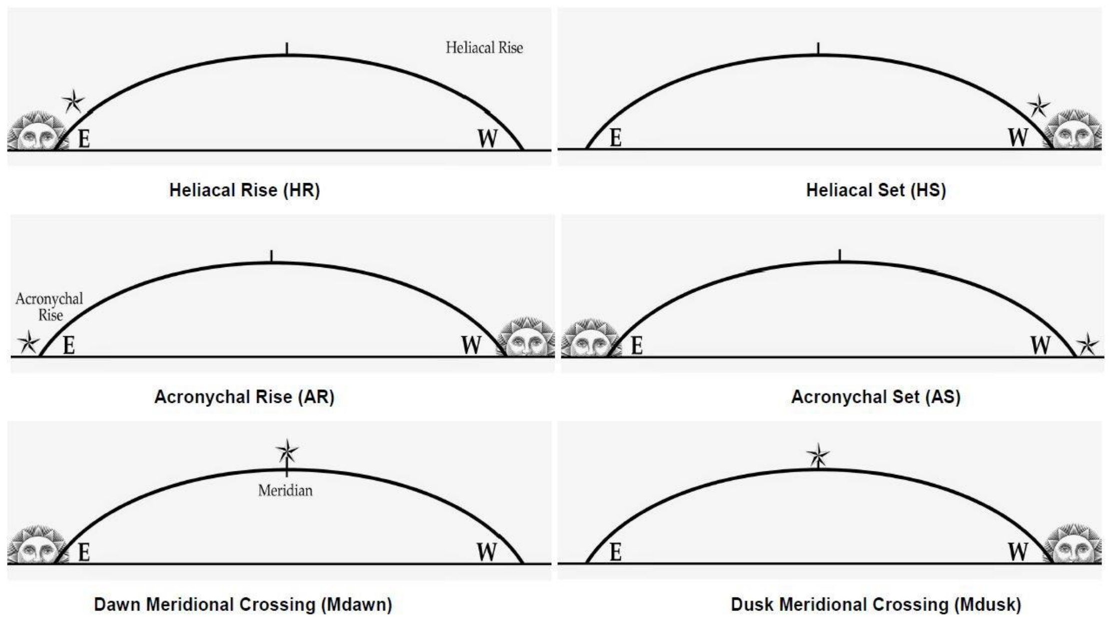

Figure 3: A diagrammatical representation of the six aspects described in the text (courtesy: Freedom Cole. URL: svatantranatha.blogspot.com.au/2014/09/heliacal-cycle.html).

horizon from the observer (see Hamacher, 2012; 2015). The interested reader is directed to Aveni (1980; 2001), Schaefer (1986; 1987; 1997; 2000) and Robinson (2009) for a more detailed account of observing conditions and visibility as applied to cultural astronomy research.

For a best-case scenario, which assumes no Moon glow, ideal observing conditions (dry, no cloud cover, still air, etc.), and an acute observer (20/10 Snellen vision ratio), 1st magnitude stars become visible at heliacal rise/set at a minimum altitude of 5° (the extinction angle, see Schaefer, 2000), when the Sun has an altitude of −10°. For 2nd magnitude stars, the Sun's altitude needs to be a minimum of −14°; and −16° for 3rd magnitude stars (Aveni, 1980: 110). For example, to an observer at Lake Tyrrell in western Victoria in the year 2000, the heliacal rising of the Pleiades occurred on 18 June. On this day, the Pleiades rose at 05:36 am (altitude at 0°), emerged from Earth's obscuring atmosphere to become visible at 06:07 am (Pleiades at +5° altitude, Sun at −16° altitude), and were visible for a further 50 minutes (Pleiades at +13°, Sun at – 7°) before the Sun drowned out the light of this star cluster.

Here, we test for connections between the rising/setting or meridian transit times of stars having animal associations (as recorded by Bates and the Berndts), and the behaviours and lifecycles of their terrestrial animal counterparts. We utilise the Stellarium positional astronomy software package[3] for calculations of stellar positions throughout the year using the coordinates of Ooldea, South Australia (30° 27′ 0″ S and 131° 50′ 0″ E, and an elevation of 80 m; see Tables 3 and 4). As we have no time stamp of the dates Bates recorded these stories, azimuths and altitudes are calculated for the year 1919, being the first year of Bates' arrival at Ooldea and the earliest possible date she could have collected these traditions.

The effects of precession, nutation and stellar proper motion, or the range of observing locations across the Ooldea region, are negligible for this study and will not greatly affect the values listed here. The rise and set times are based on *apparent* azimuths and altitude, not *geometric* azimuths and altitudes (where the former values take into account atmospheric refraction).

The heliacal/acronychal rise and set times can be calculated to the day, as would be necessary for an archaeoastronomical study on the precise alignments of ancient monuments. But that is not necessary for the purpose of this study. There is a significant window of time between the exact rising/setting times of these stars and the breeding behaviour of the animals (which can range from days to months). Studies (as cited above) show that Aboriginal astronomical knowledge relating stars to animals was not intended to be precise 'to-the-day', but rather to simply inform the people of the seasonal habits of these animals. The values cited in this paper are meant to provide an approximate measurement of the time, date, and location in the sky these objects rise and set, and their connection to animal breeding cycles.

Table 3: Acronychal rising (AR) and setting (AS) azimuths (in degrees), dates, and times for celestial objects representing Ooldean animals. The altitude (in degrees), date, and time of when each object crosses the meridian after sunset (Mdusk) is also provided. η Tauri and α Delphinus are used to calculate times and positions for the Pleiades and Delphinus, respectively, and γ Crucis is used for Crux (as α Crucis is circumpolar). The times are calculated for when the object has an altitude of at least 5°. Values calculated using Stellarium.

| Object | Acronychal Rise (AR) | | | Dusk Meridian Crossing (Mdusk) | | | Acronychal Set (AS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Az | Date | Time | Alt | Date | Time | Az | Date | Time |
| Achernar | 159° | 23-Aug | 19:35 | 62.9° | 18-Dec | 21:03 | 201° | 31-Dec | 5:22 |
| Altair | 76° | 28-Jul | 19:22 | 51.0° | 07-Oct | 20:01 | 283° | 06-Jul | 7:23 |
| Antares | 118° | 19-May | 19:11 | 85.8° | 23-Aug | 19:35 | 243° | 08-Jun | 7:18 |
| Arcturus | 63° | 14-May | 19:13 | 40.0° | 24-Jul | 19:20 | 296° | 14-Apr | 6:47 |
| Canopus | 151° | 02-Nov | 20:22 | 67.8° | 12-Mar | 20:19 | 209° | 20-Feb | 6:10 |
| Crux | 157° | 07-Jan | 21:33 | 63.7° | 25-Jun | 19:27 | 203° | 21-May | 6:49 |
| Delphinus | 68° | 6-Aug | 19:55 | 43.9° | 11-Oct | 20:32 | 291° | 22-Jul | 6:51 |
| Pleiades | 58° | 12-Nov | 21:02 | 35.6° | 09-Jan | 21:43 | 302° | 05-Dec | 4:39 |
| Vega | 49° | 04-Aug | 19:26 | 20.7° | 21-Sep | 19:50 | 321° | 26-May | 7:10 |

Table 4: Heliacal rising (HR) and setting (HS) azimuths (in degrees), dates, and times for celestial objects representing Ooldean animals. The altitude (in degrees), date, and time of when each object crosses the meridian before sunrise (Mdawn) is also provided. η Tauri and α Delphinus are used to calculate times and positions for the Pleiades and Delphinus, respectively, and γ Crucis is used for Crux (as α Crucis is circumpolar). The times are calculated for when the object has an altitude of at least 5°.

| Object | Heliacal Rise (HR) | | | Dawn Meridian Crossing (Mdawn) | | | Heliacal Set (HS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Az | Date | Time | Alt | Date | Time | Az | Date | Time |
| Achernar | 159° | 11-Mar | 6:26 | 62.9° | 15-Jul | 7:22 | 201° | 06-Jun | 19:05 |
| Altair | 76° | 16-Feb | 6:06 | 51.0° | 25-Apr | 6:42 | 283° | 11-Dec | 20:59 |
| Antares | 118° | 18-Dec | 5:15 | 85.8° | 11-Mar | 6:26 | 243° | 17-Nov | 20:36 |
| Arcturus | 63° | 14-Dec | 5:14 | 40.0° | 12-Feb | 6:01 | 296° | 26-Sep | 19:55 |
| Canopus | 151° | 23-May | 7:09 | 67.8° | 20-Oct | 5:46 | 209° | 02-Aug | 19:24 |
| Crux | 157° | 23-Aug | 6:38 | 63.7° | 26-Jan | 5:22 | 203° | 24-Oct | 20:33 |
| Delphinus | 68° | 08-Mar | 5:53 | 43.9° | 12-May | 6:35 | 291° | 10-Dec | 21:34 |
| Pleiades | 58° | 16-Jun | 6:50 | 35.6° | 01-Sep | 6:19 | 302° | 19-Apr | 20:04 |
| Vega | 38° | 22-Feb | 6:11 | 20.7° | 8-Apr | 6:44 | 321° | 05-Nov | 20:26 |

Taking all factors into consideration, the criteria used here for estimating the date of each respective astronomical event is given as follows:

- For the 1st magnitude stars Achernar, Altair, Antares, Arcturus, Canopus, and Vega:
    - o Heliacal or acronychal rise/set occurs when each star has a minimum altitude of 5° and the Sun has a maximum altitude of −10°.
    - o Meridional transit occurs when each star crosses the meridian when the Sun has a maximum altitude of −10°.
- The constellation Crux, which comprises stars ranging from 1st to 3rd magnitude, will be treated as a 2nd magnitude star focused on γ Crucis (as α Crucis is circumpolar).

  Therefore:
    - o Heliacal or acronychal rise/set occurs when α Crucis has a minimum altitude of 5° and the Sun has a maximum altitude of −14°.
    - o Meridional transit occurs when γ Crucis crosses the meridian when the Sun has a maximum altitude of −14°.
- Delphinus, which contains stars ranging from 3rd to 5th magnitude, and the Pleiades, will be treated as a 3rd magnitude star located at α

Delphinus and η Tauri (Alcyone) respectively.

Therefore:

- Heliacal or acronychal rise/set occurs when α Delphinus or η Tauri has a minimum altitude of 5° and the sun has a maximum altitude of −16°.
- Meridional transit occurs when α Delphinus or η Tauri crosses the meridian when the sun has a maximum altitude of −16°.

## 6 RESULTS AND ANALYSIS

The stellar aspect data presented in Tables 3 and 4 were combined with the annual lifecycle information outlined in Section 4 to form a metadata table, with the year broken down into twelve months of four weeks each (see Table A1, Appendix). From this table, the connection between the stellar aspect and the start of a particular lifecycle stage (e.g. mating/laying; birthing/hatching; whelping/fledging, etc.) was graded according to 'closeness of fit', and given a colour code accordingly (see Table 5):

- Green = stellar aspect occurs within two weeks of the start of a lifecycle stage;
- Yellow = between three and four weeks;
- Red = between five and six weeks;
- Grey = more than six weeks.

Where there is an extended breeding cycle (such as in the case of the Black Cockatoo and Wedge-tail Eagle), or the cycle is continuous throughout the year (such as in the case of the Dingo), the connection was determined from the beginning of the peak in these cycles. The following sections discuss the observed connections between stellar aspect and lifecycle stage for each of the terrestrial animals represented in the Ooldean sky.

### 6.1 The Australian Bustard (Vega)

The acronychal rising (AR) of Vega occurs in early August and sets at sunset (HS) by mid-November, crossing the meridian (reaching its maximum altitude) in the northern sky at dusk in late September. Therefore, the star is prominent in the evening skies during the entire Bustard mating season for most regions of Australia (Figure 2), with peaks occurring close to the dusk meridian transit (Mdusk). A similar relationship is given regarding the Mallee Fowl and the star Vega in Wergaia traditions of western Victoria (Stanbridge, 1861).

According to the population survey conducted in 2007–2009, the breeding cycle in the region surrounding Ooldea can occur earlier, from May to July (Ziembicki, 2009). In this case, mating/laying/hatching corresponds to the acronychal setting (AS) of Vega, and fledging occurs during the star's acronychal rise (AR). As the Bustard population is transient and highly dependent on rainfall, it is likely that the actual breeding patterns surrounding Ooldea are highly variable, and wetter years may be more typical of other regions. In the absence of other reliable data, we rely on that supplied by Ziembicki (2009) for this study.

### 6.2 The Crow Mother (Altair) and her Chicks (Delphinus)

The acronychal rising (AR) of Altair occurs in late July, when the Crows begin laying clutches of eggs. By early August the eggs are hatching and the brighter group of stars in Delphinus (the chicks) rise at sunset (AR). By October, when most chicks are fledged, Altair crosses the meridian in the sky after sunset (Mdusk). In December, as the last of the chicks start leaving the nest, both Altair (mother Crow) and Delphinus (celestial chicks) set at dusk (HS). It is also worth noting that Altair and Delphinus first set in the western sky at dawn (AS) during the very start of the breeding season in July, before reappearing in the eastern sky at dusk (AR). This gives two possible (and sequential) connections to signify the start of the breeding season.

### 6.3 The Black Cockatoo (Antares)

The dawn meridian crossing (Mdawn) of Antares coincides with the start of the breeding cycle, and the acronychal rising (AR) in early May coincides with the first clutches of eggs hatching. The peak in the breeding cycle occurs soon after the acronychal setting (AS) in mid-June. By mid-August, towards the end of the breeding season and the start of fledging, Antares crosses the meridian and is nearly at the zenith after sunset (Mdusk).

In the traditions recorded by Bates, the Red-tailed Black Cockatoo was also called *Kogolongo*, represented by the planet Mars. The connection of both objects to this bird is almost certainly due to the red feathers in the bird's tail. Their relationship to each other is most likely due to the fact that the ecliptic passes through Scorpius, and Mars sometimes comes to within a few degrees of Antares.[4] Between 1919 and 1935, this occurred ten times in the evening sky, on September 1920 (angular separation 2.7°); March 1922 (5.4°), July 1922 (2.4°), February 1924 (4.9°), January 1926 (4.7°), December 1927 (4.4°), December 1929 (4.2°), November 1931 (3.9°), October 1933 (3.8°) and September 1935 (3.1°).

There is no clear time-stamp of when Bates recorded the story, but we can reasonably assume that the red colour of Mars and Antares and their occasional close approach are the reasons for both objects being associated with the

Table 5: Connection of Stellar aspect (AR = acronychal rise; AS = acronychal set; HR = heliacal rise; HS = heliacal set; Mdawn = dawn meridian crossing; Mdusk = dusk meridian crossing) with the annual lifecycles of terrestrial Ooldean animals. Colours denote degree of connection (see legend). *Aspect order in each row follows the sequence through the year from 1st Jan to 31st Dec.

| Star | Animal | Lifecycle | Connection between Stellar Aspect and Lifecycle* | | | | | |
|---|---|---|---|---|---|---|---|---|
| Achernar | Dingo Mother | Mating | 🟩 HR | HS | Mdawn | AR | Mdusk | AS |
| | | Birthing | HR | 🟨 HS | Mdawn | AR | Mdusk | AS |
| | | Whelping | HR | 🟥 HS | 🟨 Mdawn | AR | Mdusk | AS |
| Altair | Crow Mother | Mating/Laying | HR | Mdawn | 🟩 AS | 🟨 AR | Mdusk | HS |
| | | Hatching | HR | Mdawn | 🟨 AS | 🟩 AR | Mdusk | HS |
| | | Fledging | HR | Mdawn | AS | AR | 🟨 Mdusk | HS |
| Antares | Black Cockatoo | Mating/Laying | Mdawn | AR | 🟨 AS | Mdusk | HS | HR |
| | | Hatching | Mdawn | AR | AS | 🟨 Mdusk | HS | HR |
| | | Fledging | Mdawn | AR | AS | 🟩 Mdusk | HS | HR |
| Arcturus | Redback Spider | Mating/Laying | Mdawn | AS | AR | Mdusk | HS | 🟨 HR |
| | | Hatching | Mdawn | AS | AR | Mdusk | HS | 🟩 HR |
| Canopus | Owlet Nightjar | Mating/Laying | AS | Mdusk | HR | HS | 🟨 Mdawn | 🟥 AR |
| | | Hatching | AS | Mdusk | HR | HS | 🟩 Mdawn | 🟨 AR |
| | | Fledging | AS | Mdusk | HR | HS | Mdawn | 🟥 AR |
| | | Torpor | AS | Mdusk | 🟩 HR | HS | Mdawn | AR |
| Crux | Wedge-tailed Eagle | Mating/Laying | AR | Mdawn | AS | 🟨 Mdusk | HR | HS |
| | | Hatching | AR | Mdawn | AS | Mdusk | 🟩 HR | HS |
| | | Fledging | AR | Mdawn | AS | Mdusk | HR | 🟨 HS |
| Delphinus | Crow Chicks | Laying | HR | Mdawn | 🟨 AS | AR | Mdusk | HS |
| | | Hatching | HR | Mdawn | 🟩 AS | 🟩 AR | Mdusk | HS |
| | | Fledging | HR | Mdawn | AS | 🟨 AR | 🟥 Mdusk | HS |
| Pleiades | Thorny-devil Lizard | Mating/Laying | Mdusk | HS | HR | 🟩 Mdawn | AR | AS |
| | | Hatching | Mdusk | HS | HR | Mdawn | 🟥 AR | 🟩 AS |
| Vega | Australian Bustard | Mating/Laying | HR | Mdawn | 🟩 AS | AR | Mdusk | HS |
| | | Hatching | HR | Mdawn | 🟥 AS | AR | Mdusk | HS |
| | | Fledging | HR | Mdawn | AS | 🟩 AR | Mdusk | HS |

*Colour coding: connection occurring within 1–2 weeks (green), 3–4 weeks (yellow), 5–6 weeks (red), >6 weeks (grey).

Red-tailed Black Cockatoo.

### 6.4 The Owlet Nightjar (Canopus)

The dawn meridian crossing (Mdawn) and acronychal rising (AR) of Canopus occurs in mid and late October, respectively, and Canopus is high in the southern sky at dawn, coinciding with the start of the breeding season. In the "Orion Story" (Leaman and Hamacher, 2014) *Joorr-Joorr* observes Nyeeruna's attempts to seduce and impress the seven Mingari sisters, represented by the Pleiades, and laughs at Nyeeruna's humiliation at the hands of the eldest sister Kambugudha, represented by the Hyades. By early December, when most chicks are fledging and begin using the 'churring' adult call (Higgins, 1999), Orion is rising at dusk. A combination of fledglings calling and a seasonal spike in the bird's vocal activity during the warmer nights of summer (Schodde and Mason, 1980) lead to increased vocalization overall. This may explain why *Joorr-Joorr* laughs at Nyeeruna in the "Orion Story" (Leaman and Hamacher, 2014).

Another interesting celestial correspondence is the heliacal rise (HR) of Canopus just as the Owlet Nightjar begins a period of winter torpor. This lifecycle concludes during the onset of spring, which coincides with the heliacal setting (HS) of Canopus.

### 6.5 The Dingo (Achernar and the Pleiades)

The peak of the breeding season in March corresponds to the heliacal rising (HR) of Achernar to the southeast. By June, when the Dingoes begin whelping pups, Achernar sets at dusk (HS) and the Pleiades rise at dawn (HR). Dingoes are related to the Mingari women of the Pleiades who kept a 'tribe of dingoes' with them to keep the men away (Bates, 1933). In Aboriginal cultures of the Central Desert, the heliacal rising of the Pleiades signalled the start of winter and the time to start harvesting Dingo puppies (e.g. Clarke, 2007/2008; Mountford, 1956; 1958).

### 6.6 The Thorny-devil Lizard (Pleiades)

The start of egg-laying coincides with the dawn meridian crossing (Mdawn) of the Pleiades. The emergence of the first clutch of lizards from their nests in early December is heralded by the acronychal rising (AR) of the Pleiades just two weeks prior to this, followed by the acronychal setting (AS) closer to the actual hatching time, with the last hatchings occurring just prior to the heliacal setting (HS) in April.

Their most important predator is the Bustard (Pianka and Pianka, 1970). Interestingly, this predator-prey relationship may be seen in the interaction between their celestial counterparts: as Vega (the Bustard) disappears from view in the northwest sky, the Pleiades (the Thorny-devil) 'safely' emerges soon afterwards in the northeast. This scenario is similar to the eternal pursuit of Orion and Scorpius in Greek mythology.

### 6.7 The Wedge-tailed Eagle (Crux)

Crux is at its highest altitude in the sky at dusk (Mdusk), with $\alpha$ and $\gamma$ Crucis crossing the meridian at close to the same time in late June, coinciding with the start of the peak in breeding and laying. This also coincides with the hatchings of the first clutches of eggs laid in late March, with the siblicide process usually completed and the remaining chick well on the way to fledging. The peak in breeding then carries over to a peak in hatching in mid- to late-August, coinciding with the heliacal rise (HR), and a peak in fledgings in mid- to late-November, just after the heliacal setting of Crux (HS).

### 6.8 The Redback Spider (Arcturus)

The peak in the breeding cycle of Redback Spiders in late November results in the majority of spiderlings emerging from the egg sacs in early to mid-December, which closely corresponds to the heliacal rising (HR) of Arcturus.

## 7 DISCUSSION AND CONCLUDING REMARKS

In this paper we focus on the associations between the celestial animals of the Ooldea night sky and the lifecycle of their terrestrial counterparts. Excluding planetary (e.g. Venus, Mars, Jupiter) and galactic (e.g. 'celestial emu') associations, we demonstrate that each of the remaining nine celestial animals represented appears to inform Aboriginal people about the lifecycle (e.g. mating/breeding, laying/birthing, fledging/whelping, etc.) of their terrestrial counterparts. More specifically, we found that the 26 lifecycles studied correlated with stellar aspects in the following proportions (Figure 4):

- acronychal rising (9),
- acronychal setting (8),
- dusk meridian crossing (4),
- heliacal rising (5),
- heliacal setting (3) and
- dawn meridian crossing (5)

This is illustrated graphically in Figure 4.

Of these 34 correlations, 14 (41%) occur within two weeks of one of these six stellar aspects, and 28 (82%) occur within four weeks. Similarly, there appears to be a stronger bias towards lifecycles occurring within four weeks of an acronychal aspect (AR, AS: 46%), rather than meridional (Mdawn, Mdusk: 29%) or heliacal (HR, HS:25%) aspects.

This study suggests that Aboriginal people from Ooldea deliberately selected certain prom-

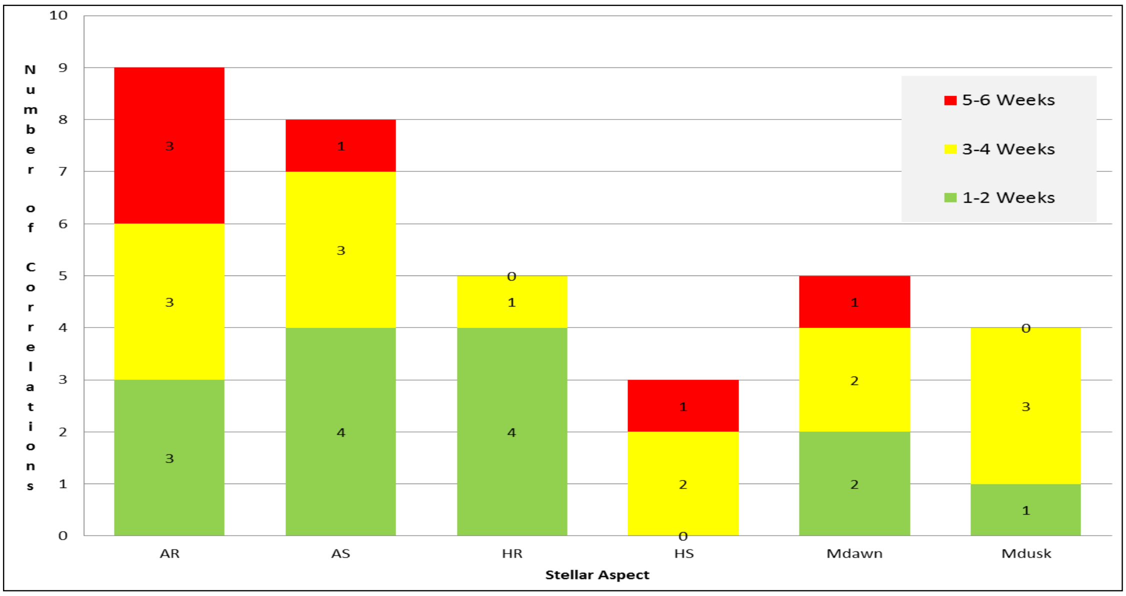

Figure 4: Summary table of total numbers of connections between stellar aspect of the Ooldean animals and the lifecycles of their terrestrial counterparts (AR = acronychal rise; AS = acronychal set; HR = heliacal rise; HS = heliacal set; Mdawn = dawn meridional crossing; Mdusk = dusk meridional crossing).

inent stars and asterisms to match the breeding cycles of the terrestrial animals they represent. Further studies will determine whether this is (a) a unique feature of Ooldean astronomy, (b) restricted to a few language groups, or (c) a more common thread that runs through Aboriginal astronomical traditions right across Australia. A larger study is planned to address these questions.

Implicit in this study is a method of determining the antiquity of these stellar-terrestrial connections. Firstly, as lifecycles of some animals are dependent on temperature (e.g. the Redback Spider, the Thorny-devil Lizard) and/or rainfall (e.g. the Australian Bustard, the Dingo) (see Section 4), then Australian climatic variability constrains these connections to the post-glacial period of the last ~9,000 years, during which Australia started to experience temperature and rainfall patterns similar to current trends (e.g. see Reeves et al., 2013). Secondly, the effects of precession further constrain this to the last ~2,000 years. Prior to this, precession would cause mismatches between stellar aspects and terrestrial lifecycles such that the selected stars would be unreliable calendrical indicators, and other stars or asterisms would have been assigned (Hamacher, 2012).

The results of this study are not definitive, as the meaning of the star-animal relationship is known to the original Ooldean Aboriginal custodians of the traditions and not the authors of this paper. The effects of colonisation on Indigenous traditions and knowledge systems have been severely negative, and some traditions have been damaged, fragmented or lost altogether. The development of methodologies used to reconstruct astronomical traditions is simply a step forward in helping Indigenous communities reclaim their traditions.

## 8 NOTES

1. Bates' Ooldean taxonomy is consistent with information in Reid et al. (1993). Vertebrate species names are drawn from Census of South Australian Vertebrates, 4th (current) Edition (https://data.environment.sa.gov.au/Content/Publications/Census-of-SAVertebrates-2009.pdf). Invertebrate taxonomy (the Redback Spider) was drawn from Gray, M., *Laterodectus hastletti*. *Species Bank*. Australian Biological Resources Study, Canberra (www.environment.gov.au/biodiversity/abrs/online-resources/species-bank/index.html). It should be noted that while ethnotaxonomies and zoological Linnaean taxonomies do not always agree, in the case of the species discussed in this paper, Ooldean and scientific taxonomies do overlap, with the possible exception of the Corvids (Crows/Ravens). An enlightening exploration of the complexities in reconciling Anangu and zoological taxonomy can be found in Reid et al. (1993: 86–88).
2. For instance, Bates' word for Emu, *Kalia*, is specific to the Central and Western Desert regions (Pitjantjatjara language), whereas the word for the Wedge-tailed Eagle, *Waldja-(jinna)*, is from the Eyre Peninsula (Wirangu language). Many of the bird names listed in Bates' Ooldean Sky can be found in Condon (1955a; 1955b) and Sullivan (1928), along with their language group origins.

3. Stellarium: www.stellarium.org
4. In Greek mythology, Ares was the god of war—the counterpart of the Roman god of war, Mars. Antares means 'anti-Ares', or 'rival of Ares', as Antares and Mars are bright red and sometimes appear close together in the sky, fighting for dominance.

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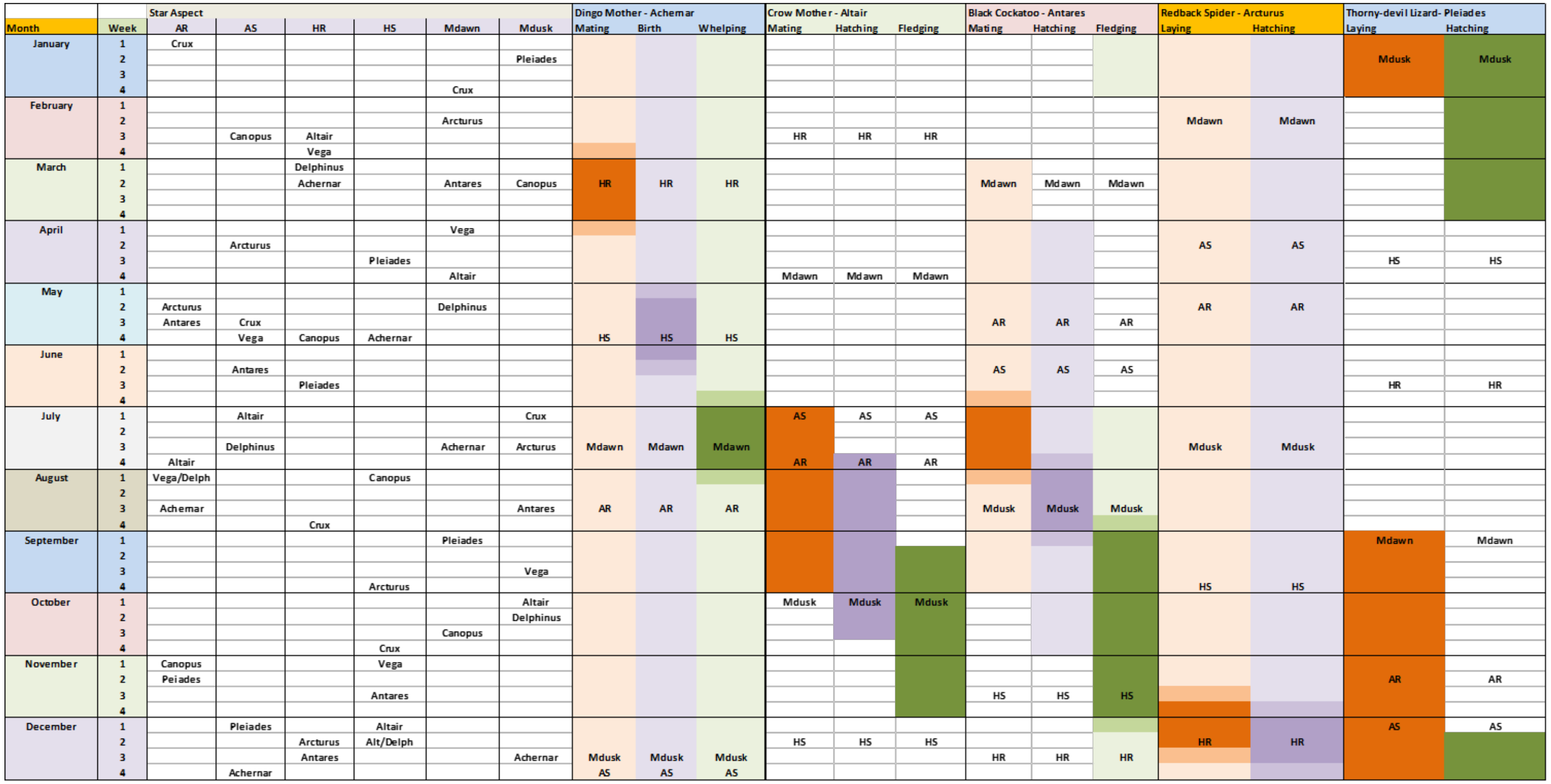
## 11 APPENDIX

**Table A1:** Stellar aspects (AR = acronychal rise; AS = acronychal set; HR = heliacal rise; HS = heliacal set; Mdawn = dawn meridional transit; Mdusk = dusk meridional transit) versus annual lifecycle stage (Mating/breeding; Birthing/hatching; whelping/fledging) for Dingo Mother (Achernar), Crow Mother (Altair), Black Cockatoo (Antares), Redback Spider (Arcturus) and Thorny-devil Lizard. (Bold colours denote peaks in lifecycle stages).



| | | Star Aspect | | | | | | Dingo Mother - Achemar | | | Crow Mother - Altair | | | Black Cockatoo - Antares | | | Redback Spider - Arcturus | | Thorny-devil Lizard- Pleiades | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Week | AR | AS | HR | HS | Mdawn | Mdusk | Mating | Birth | Whelping | Mating | Hatching | Fledging | Mating | Hatching | Fledging | Laying | Hatching | Laying | Hatching |
| January | 1 | Crux | | | | | | | | | | | | | | | | | | |
| | 2 | | | | | | Pleiades | | | | | | | | | | | | Mdusk | Mdusk |
| | 3 | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | Crux | | | | | | | | | | | | | | |
| February | 1 | | | | | | | | | | | | | | | | | | | |
| | 2 | | | | | Arcturus | | | | | | | | | | | Mdawn | Mdawn | | |
| | 3 | | Canopus | Altair | | | | | | | HR | HR | HR | | | | | | | |
| | 4 | | | Vega | | | | | | | | | | | | | | | | |
| March | 1 | | | Delphinus | | | | | | | | | | | | | | | | |
| | 2 | | | Achernar | | Antares | Canopus | HR | HR | HR | | | | Mdawn | Mdawn | Mdawn | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | |
| April | 1 | | | | | Vega | | | | | | | | | | | | | | |
| | 2 | | Arcturus | | | | | | | | | | | | | | AS | AS | | |
| | 3 | | | | Pleiades | | | | | | | | | | | | | | HS | HS |
| | 4 | | | | | Altair | | | | | Mdawn | Mdawn | Mdawn | | | | | | | |
| May | 1 | | | | | | | | | | | | | | | | | | | |
| | 2 | Arcturus | | | | Delphinus | | | | | | | | | | | AR | AR | | |
| | 3 | Antares | Crux | | | | | | | | | | | AR | AR | AR | | | | |
| | 4 | | Vega | Canopus | Achernar | | | HS | HS | HS | | | | | | | | | | |
| June | 1 | | | | | | | | | | | | | | | | | | | |
| | 2 | | Antares | | | | | | | | | | | AS | AS | AS | | | | |
| | 3 | | | Pleiades | | | | | | | | | | | | | | | HR | HR |
| | 4 | | | | | | | | | | | | | | | | | | | |
| July | 1 | | Altair | | | | Crux | | | | AS | AS | AS | | | | | | | |
| | 2 | | | | | | | | | | | | | | | | | | | |
| | 3 | | Delphinus | | | Achernar | Arcturus | Mdawn | Mdawn | Mdawn | | | | | | | Mdusk | Mdusk | | |
| | 4 | Altair | | | | | | | | | AR | AR | AR | | | | | | | |
| August | 1 | Vega/Delph | | | Canopus | | | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | | | | | | | |
| | 3 | Achemar | | | | | Antares | AR | AR | AR | | | | Mdusk | Mdusk | Mdusk | | | | |
| | 4 | | | Crux | | | | | | | | | | | | | | | | |
| September | 1 | | | | | Pleiades | | | | | | | | | | | | | Mdawn | Mdawn |
| | 2 | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | Vega | | | | | | | | | | | | | |
| | 4 | | | | Arcturus | | | | | | | | | | | | HS | HS | | |
| October | 1 | | | | | | Altair | | | | Mdusk | Mdusk | Mdusk | | | | | | | |
| | 2 | | | | | | Delphinus | | | | | | | | | | | | | |
| | 3 | | | | | Canopus | | | | | | | | | | | | | | |
| | 4 | | | | Crux | | | | | | | | | | | | | | | |
| November | 1 | Canopus | | | Vega | | | | | | | | | | | | | | | |
| | 2 | Peiades | | | | | | | | | | | | | | | | | AR | AR |
| | 3 | | | | Antares | | | | | | | | | HS | HS | HS | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | |
| December | 1 | | Pleiades | | Altair | | | | | | | | | | | | | | AS | AS |
| | 2 | | | Arcturus | Alt/Delph | | | | | | HS | HS | HS | | | | HR | HR | | |
| | 3 | | | Antares | | | Achernar | Mdusk | Mdusk | Mdusk | | | | HR | HR | HR | | | | |
| | 4 | | Achernar | | | | | AS | AS | AS | | | | | | | | | | |

**Table A1 (cont.)**: Stellar aspects (AR = acronychal rise; AS = acronychal set; HR = heliacal rise; HS = heliacal set; Mdawn = dawn meridional transit; Mdusk = dusk meridional transit) versus annual lifecycle stage (Mating/breeding; Birthing/hatching; whelping/fledging) for Owlet Nightjar (Canopus), Wedge-tailed Eagle (Crux), Crow Chicks (Delphinus) and Australian Bustard (Vega). (Bold colours denote peaks in lifecycle stages).

| | | Star Aspect | | | | | | Owlet Nightjar - Canopus | | | | Wedge-tailed Eagle - Crux | | | Crow Chicks - Delphinus | | | Australian Bustard - Vega | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Week | AR | AS | HR | HS | Mdawn | Mdusk | Mating | Hatching | Fledging | Torpor | Mating | Hatching | Fledging | Mating | Hatching | Fledging | Mating | Hatching | Fledging |
| January | 1 | Crux | | | | | | | | | | AR | AR | AR | | | | | | |
| | 2 | | | | | | Pleiades | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | Crux | | | | | | Mdawn | Mdawn | Mdawn | | | | | | |
| February | 1 | | | | | | | | | | | | | | | | | | | |
| | 2 | | | | | Arcturus | | | | | | | | | | | | | | |
| | 3 | | Canopus | Altair | | | | AS | AS | AS | AS | | | | | | | | | |
| | 4 | | | Vega | | | | | | | | | | | | | | HR | HR | HR |
| March | 1 | | | Delphinus | | | | | | | | | | | HR | HR | HR | | | |
| | 2 | | | Achernar | | Antares | Canopus | Mdusk | Mdusk | Mdusk | Mdusk | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | |
| April | 1 | | | | | Vega | | | | | | | | | | | | Mdawn | Mdawn | Mdawn |
| | 2 | | Arcturus | | | | | | | | | | | | | | | | | |
| | 3 | | | | Pleiades | | | | | | | | | | | | | | | |
| | 4 | | | | | Altair | | | | | | | | | | | | | | |
| May | 1 | | | | | | | | | | | | | | | | | | | |
| | 2 | Arcturus | | | | Delphinus | | | | | | | | | Mdawn | Mdawn | Mdawn | | | |
| | 3 | Antares | Crux | | | | | | | | | AS | AS | AS | | | | | | |
| | 4 | | Vega | Canopus | Achernar | | | HR | HR | HR | HR | | | | | | | AS | AS | AS |
| June | 1 | | | | | | | | | | | | | | | | | | | |
| | 2 | | Antares | | | | | | | | | | | | | | | | | |
| | 3 | | | Pleiades | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | Mdusk | Mdusk | Mdusk | | | | | | |
| July | 1 | | Altair | | | | Crux | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | | | | | | | |
| | 3 | | Delphinus | | | Achernar | Arcturus | | | | | | | | AS | AS | AS | | | |
| | 4 | Altair | | | | | | | | | | | | | | | | | | |
| August | 1 | Vega/Delph | | | Canopus | | | HS | HS | HS | HS | | | | AR | AR | AR | AR | AR | AR |
| | 2 | | | | | | | | | | | | | | | | | | | |
| | 3 | Achernar | | | | | Antares | | | | | | | | | | | | | |
| | 4 | | | Crux | | | | | | | | HR | HR | HR | | | | | | |
| September | 1 | | | | | Pleiades | | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | Vega | | | | | | | | | | | Mdusk | Mdusk | Mdusk |
| | 4 | | | | Arcturus | | | | | | | | | | | | | | | |
| October | 1 | | | | | | Altair | | | | | | | | | | | | | |
| | 2 | | | | | | Delphinus | | | | | | | | Mdusk | Mdusk | Mdusk | | | |
| | 3 | | | | | Canopus | | Mdawn | Mdawn | Mdawn | Mdawn | | | | | | | | | |
| | 4 | | | | Crux | | | | | | | HS | HS | HS | | | | | | |
| November | 1 | Canopus | | | Vega | | | AR | AR | AR | AR | | | | | | | HS | HS | HS |
| | 2 | Peiades | | | | | | | | | | | | | | | | | | |
| | 3 | | | | Antares | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | |
| December | 1 | | Pleiades | | Altair | | | | | | | | | | | | | | | |
| | 2 | | | Arcturus | Alt/Delph | | | | | | | | | | HS | HS | HS | | | |
| | 3 | | | Antares | | | Achernar | | | | | | | | | | | | | |
| | 4 | | Achernar | | | | | | | | | | | | | | | | | |

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# AUSTRALIAN SOLAR ECLIPSE EXPEDITIONS: THE VOYAGE TO CAPE YORK IN 1871

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**Abstract:** Techniques such as photography and spectroscopy only became available to study solar eclipses in the 1860s. The first subsequent total eclipse of the Sun to be visible from Australia was one in December 1871 that was visible from far north Queensland. Initiated by the Royal Society of Victoria, astronomers in Melbourne and Sydney cooperated to organise the Australian Eclipse Expedition aboard the steamship *Governor Blackall* to a suitable observing location. Though on the day of the eclipse clouds prevented viewing, this was an important expedition that was complex to organise and involved dealings with colonial Governments and with relatively large sums of money that Australian scientists had not previously experienced. With a newspaper reporter as part of the expedition along with two photographers the expedition was well recorded and provides a clear insight into the activities of late ninteenth century astronomers and other scientists.

**Keywords:** nineteenth century eclipse expeditions, 1871 total solar eclipse, Eclipse Island, Royal Society of Victoria, *Governor Blackall*, Melbourne Observatory, Sydney Observatory

## 1 INTRODUCTION

Total eclipses of the Sun are one of the most spectacular sights provided by Nature (Figure 1), and always are watched with great interest. When one occurs, the sky becomes dark, the visible disc of the Sun is covered for a period of a few minutes by the Moon, and the faint corona surrounding the Sun becomes visible. Those with keen eyesight or with optical aid can sometimes make out red prominences surrounding the darkened disc. The Australian Aboriginal people, amongst many others, were keen watchers of eclipses and developed their own theories to explain them (Hamacher and Norris, 2011).

To astronomers, total eclipses provide rare opportunities to study solar features such as the prominences and the corona that are otherwise not observable, or at least, not until relatively recently. Unfortunately, total eclipses at a particular location are fairly rare; in the southern hemisphere on average one is likely to occur only once in 540 years (Steel, 1999: 351). That means that interested astronomers must be willing to travel if they want to observe an eclipse. During a total eclipse the Moon casts a shadow on the Earth and totality occurs for those inside the shadow. This shadow moves across the surface of the Earth from west to east and forms an eclipse track. Such eclipse tracks can be calculated in advance, and keen observers can station themselves along the track. Of course, the actual observing locations are carefully selected and depend on such criteria as accessibility and weather prospects, if known.

Up until about 1860 astronomers lacked suitable observing instruments to record and to try to understand what they were seeing during an eclipse. For instance, when the Reverend William Scott (1825–1917), the Government Astronomer of New South Wales, set out to observe the total eclipse of 26 March 1857 from South Head, near the entrance of Sydney Harbour, all he had was a small refractor with an unstable mounting, micrometers and a thermometer (Scott, 1857). In any case, cloud prevented much observation. However, by 1860 photography had advanced sufficiently for the eclipsed Sun to be permanently recorded and in the same year Kirchhoff and Bunsen (1860) showed the link between chemical elements and their spectra. Spectroscopy was soon applied to the sky and the science of astrophysics was established (Meadows, 1984). With new tools available eclipse expeditions assumed much greater importance than previously.

Figure 1: Clouds parted for the total eclipse of 14 November 2012 as seen from Palm Cove, Queensland (photograph: Nick Lomb).

Figure 2: A map of Australia showing locations mentioned in the text as well as the path of totality for the December 1871 eclipse (map: Nick Lomb).

The first total eclipse of the Sun from Australia after the one Scott had attempted to view in 1857 was on 12 December 1871, with an eclipse track crossing the north of the continent. The Royal Society of Victoria in co-operation with the colonial Governments of Victoria, South Australia, New South Wales and Queensland organised an expedition to view the eclipse from its most accessible point, an island almost at the furthest extremity of Cape York (Figure 2 shows the track of the 1871 eclipse, as well as the places visited on the expedition and other Australian locations mentioned in this paper). As Hoare (1976: 9) states, "This enterprise was the first real attempt at formal inter-colonial scientific co-operation [in Australia] on any scale." The cooperation and friendships formed would have eased the way to the formation of the Australasian Association for the Advancement of Science in 1888 (MacLeod, 1988) with two of the participants on the eclipse trip, Henry Chamberlain Russell (1836–1907) and Robert Lewis John Ellery (1827–1908), taking leading roles in the new association. Furthermore, the instruments acquired for the voyage to far north Queensland would have introduced Australian astronomers to the brand new science of astrophysics. This paper examines the background to the 1871 Australian Eclipse Expedition, the organisational details and the voyage itself.

Of course, the track of the 1871 eclipse did not only pass through Australia but also through India, Ceylon (present day Sri Lanka) and the Dutch East Indies (Indonesia). The eclipse was carefully observed in all three places, especially from India where there were both locally-based observers such as Lieutenant-Colonel James Francis Tennant (1829–1915) and expeditions organised from Britain such as that of Norman Lockyer (1836–1920) and from France such as that of Jules Janssen (1824–1907). As observationally these expeditions were more successful than the Australian one they have been described both by participants (Lockyer, 1872) and by modern astronomical historians (Launay, 2012; Orchiston and Pearson, 2011). Mumpuni et al. (2016) discuss the observations of Jean Abraham Chrétien Oudemans (1827–1906) in the Dutch East Indies.

## 2 ECLIPSE EXPEDITIONS 1860–1870

An expedition to observe the 1871 eclipse obviously had to take into account the discoveries that had been made during solar eclipses overseas in the previous decade. Nineteenth century Australian astronomers were especially interested in developments associated with eclipse expeditions organised from London as they took their lead from Britain, which at that time was still referred to as 'Home'.

The British expedition to observe the total eclipse of 1860 from Spain was organised by the Astronomer Royal George Biddell Airy (1801–1892) and two well-known gentleman amateur astronomers, Warren de La Rue (1815–1889) and William Huggins (1824–1910) (Pang, 2002: 14). De La Rue succeeded in taking the first photographs of the eclipsed Sun, as did the Director of the Roman College Observatory the Reverend Pietro Angelo (see Lankford, 1984). By comparing the two series of photographs taken from different locations and allowing for parallax it was established that the prominences did belong to the Sun (Todd, 1894). Examination of drawings of the corona made at the same eclipse indicated that the corona surrounded the Sun and was not, as some had suggested, part of the Earth's atmosphere.

For the eclipse of 1868, which was visible from India, more new instruments became available, namely the spectroscope and the polariscope. By viewing through the latter instrument an observer could detect if the light from the corona was polarised due to scattering by dust or by something else (Pang, 2002). The eclipse was notable for its long, five and a half minute, duration, as well as for a striking prominence that was named 'The Great Horn' (Todd, 1894). Among the major discoveries made during this eclipse, Norman Pogson (1829–1891), the Director of Madras Observatory, found the first indication of a spectral line from an unknown element that was later to be called helium (Nath, 2013), while Jules Janssen and others saw bright lines in The Great Horn indicating the presence of hydrogen gas (Cottam and Orchiston, 2015).

The first important result about the corona obtained with the spectroscope was when two American astronomers on 7 August 1869 noted a bright green light in the spectrum at 1474 in the Kirchoff scale (Todd, 1894). As there was no known terrestrial equivalent, this line was thought to be due to some unknown substance that was later dubbed 'coronium'.[1]

The final solar eclipse before the 1871 eclipse was that of 22 December 1870. At that eclipse observations by a British team that had travelled to Sicily only confused what had been discovered during the two previous eclipses. A drawing made by an observer with a 'powerful telescope' indicated a boundary to the corona much closer to the edge of the dark Moon than previously claimed. This led to renewed speculation about the connection with the Sun of the much more extensive regions stretching away from it recorded on photographic plates at the same eclipse (Lockyer, 1872). Although much had been discovered about the Sun during the brief periods of these earlier total eclipses, there was much more to investigate during the 1871 eclipse and those that would follow it.

## 3 INITIATING THE PLAN

The suggestion for the eclipse trip came at an ordinary meeting of the Royal Society of Victoria on the evening of Monday 12 March 1871. Near the end of the meeting William Parkinson Wilson (1826–1874), Professor of Mathematics at the University of Melbourne and Chairman of the Board of Visitors to Melbourne Observatory, informed the 28 members present that in December 1871 a total eclipse of the Sun would be visible from northern Australia. Proposing that the Society organise a voyage to Cape York by hiring a steamer for that purpose, he stressed that there would not be another opportunity to view a total eclipse from Australia for the remainder of the century. As well, he noted that no one present was likely to have seen a total eclipse previously (RSV Ordinary Meeting minutes, 1854–1893).

The President of the Society, Robert Ellery, Government Astronomer at Melbourne Observatory, warmly supported the proposal and it was decided to discuss the idea further at the next meeting (Royal Society of Victoria, 1871). At that meeting, held on 17 April 1871, an Eclipse Committee comprising Wilson, Ellery, a Dr Parker and an engineer named Smith was set up to consider the proposed trip. The need for urgency was emphasised as,

> Some instruments would have to be procured from England and that therefore no time should be lost. (RSV Ordinary Meeting minutes, 1854–1893).

The Eclipse Committee estimated the cost of hiring a steamer for an all-inclusive voyage of 25 days from Melbourne to Cape Sidmouth on Cape York at £2,000 (~$400,000 in 2015 dollars).[2] They proposed raising the funds by opening participation in the voyage to suitable gentlemen: if there were 100 participants the cost to each would be £20 ($4,000) and if only 80 then £25 ($5,000). The following advertisement was then placed in the local newspaper:

> Gentlemen desirous of JOINING the EXPEDITION must apply forthwith, enclosing £25 as their share of the expense, to Mr Ellery, at the Observatory.

Despite the use of the word 'Gentlemen' at the special meeting of the Eclipse Committee on 18 October 1871 (RSV Council Meeting minutes, 1854–1888), it was clarified that the eclipse voyage also was open to ladies.

The advertisement was not a great success as by 11 September there were only 15 or 16 applicants for the voyage. This meant that the scale of the proposed expedition had to be cut back and Government support was essential if the voyage was to eventuate. The Eclipse Committee drafted a strongly-worded letter appealing for funds, which was sent by the Secretary of the Royal Society to the "The Honourable the Chief Secretary" of Victoria. This letter asked for the direct payment of the fares of Observatory staff going on the expedition, as well as a guarantee to cover any unmet expenses of the voyage. To reinforce the importance of the proposed expedition, the letter stated that:

> ... it appears by the last paper from Europe that entire dependence seemed to be placed upon Victoria and New South Wales to observe the approaching Eclipse in Australia.

As mentioned in Section 1, this same eclipse also was visible from India and a British eclipse expedition was sent there (Lockyer, 1872). Clearly, Australia was too far away to send people, but the Eclipse Committee of the British Association for the Advancement of Science did send the following up-to-date instruments for use by the Australian astronomers:

> An integrating spectroscope on small equatorial stand by Grubb; [to observe the spectrum of the entire eclipsed Sun]
> An analysing spectroscope by Browning; [to observe selected sections of the eclipsed Sun]
> A hand spectroscope, by Browning;
> Two Savart's polariscopes;
> One large long focus rectilinear photographic lens and camera, by Dallmeyer;
> And several useful photographic appliances. (Ellery, 1874b: 9).

There was little knowledge of the weather to be expected near Cape Sidmouth at the date of the eclipse in December, even though this was the 'wet season' in tropical northern Australia. The Dutch ship SS *Curaçoa* was heading north, and while it was still in port in Melbourne the Captain was asked to provide weather reports during the journey. At the October Ordinary Meeting of the Royal Society of Victoria a letter was read from Mr Ploos van Austel, written on board the ship while it was docked in Bowen, Queensland. This warned that

> ... the weather is often thick and heavy about the middle of December, with a dense atmosphere, skies overcast and clouds gathering in great masses.

After a fairly positive reply from the Chief Secretary's Office tenders were called for a steam ship to travel to Cape York via Sydney on the basis of 40 first-class passengers. Two ships were offered: the *Alhabra* at £2,100 and the Coorong at £1,700. At a special Council Meeting of the Royal Society of Victoria on 25 October the *Alhabra* was under active consideration, despite its high cost. The fee for paying passengers was raised from £25 to £30 ($6,000), the Chief Secretary was to be informed of the cost, and a telegraph message was to be sent to the Government of South Australia asking for a financial contribution.

The situation changed on 28 October 1871 when a telegram was received from Henry Russell, the Government Astronomer in New South Wales and Director of Sydney Observatory (The Queensland Government and the Eclipse Expedition, 1872b). In the telegram Russell informed Ellery that the Queensland Government was likely to lend the steam ship *Governor Blackall* (Figure 3) at a cost of under £1,300 ($260,000). Russell stated that the "Steamer is just what is wanted." He clarified the situation regarding the steamer in a letter sent a few days later, on 2 November 1871. After the use of the ship was suggested to Russell by Captain Francis Hixson (1833–1909), the Superintendent of Light Houses, Harbours and Pilots, enquiry was made of the ship's agents and the Queensland Government (which owned the vessel). The indication was that provided the estimated cost of about £1,200 was met, the ship would be available. One of the reasons why the agents were willing to proceed with the enterprise was that Lieutenant Jack Gowlland (1838–1874), an experienced Royal Navy officer engaged in mapping the coast of NSW, and who just happened to be Captain Hixson's brother-in-law (Vink, 2013), had volunteered to captain the ship.

With just two weeks left before the Melbourne party had to depart there was still considerable doubt about whether the expedition would go ahead, because of lack of funds. In spite of grants of £100 each from the South Australian and Queensland Governments plus £300 from the New South Wales Government (which also would cover the cost of their observing party), Ellery telegraphed Russell on 7 November 1871 indicating that a further £150 had to be found in order to cover the cost of the ship (The Queensland Government and the Eclipse Expedition, 1872b). At that afternoon's Committee meeting of the Royal Society of Victoria it was resolved to write to the Chief Secretary threatening to abandon the expedition if the funding shortfall could not be resolved.

This threat worked, and the Victorian Government promised an additional £250 for the expedition, in order "... to carry it into execution." Ellery then telegraphed Russell on 11 November

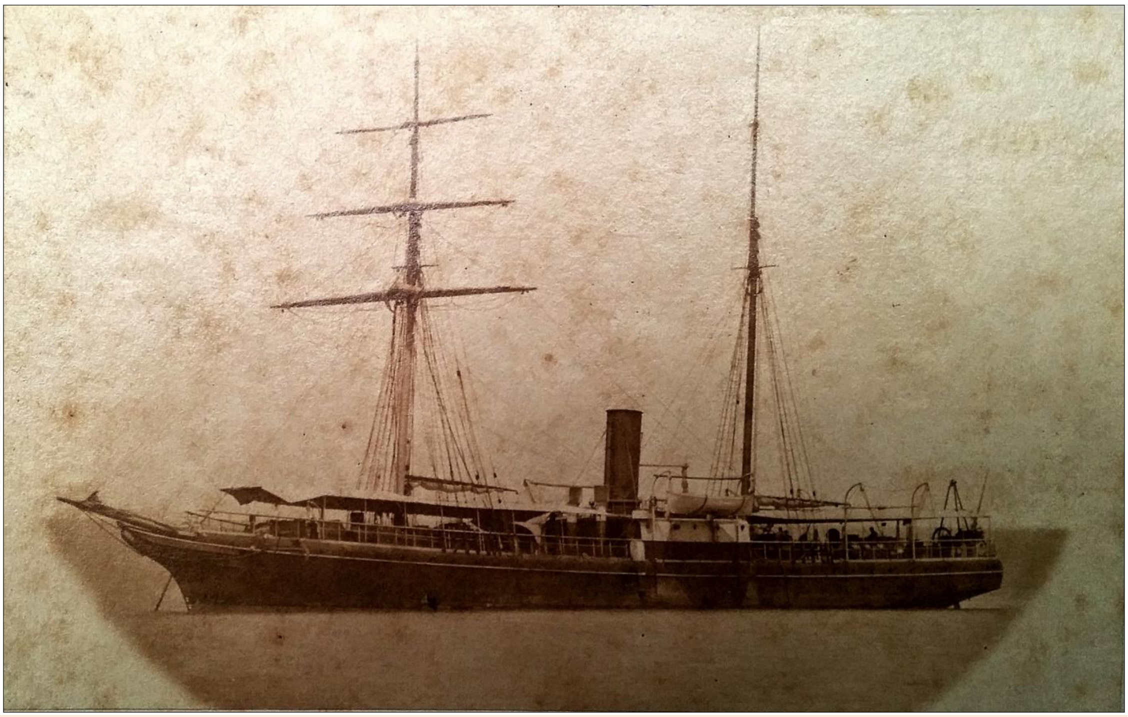

Figure 3: The photograph taken by Beaufoy Merlin of the *Governor Blackall* (courtesy: State Library of NSW, Australian Eclipse Expedition 1871, SPF).

1871: "You can finally accept Blackall offer." At that afternoon's meeting of the Council of the Royal Society of Victoria final arrangements were discussed, including the passage to Sydney, and an important decision was reached "... not to take 2nd class passengers besides those attached to the observing staff." In the meantime, on 16 November Russell went ahead (on behalf of Ellery) and signed the contract with the agents, Eldred and Spence. When a copy of the contract reached Melbourne it was found that the Queensland Government had withdrawn their promised £100, stating that

> ... the use of the steamer (valued at £300) be regarded as the contribution of the Queensland Government towards the expense of the expedition.

Ellery received the contract just three days before departing for Sydney, so it was too late for him to request any alteration to the conditions.

## 4 TRAVELLING TO SYDNEY

The Victorian party left from Port Melbourne (then called Sandridge) at 2 pm on Thursday 23 November 1871 on board the Australian Steam Navigation Company's iron steamship the *Wonga Wonga* (White, 1869–1876). The observing party was mainly from Melbourne Observatory and consisted of Ellery, the Assistant Astronomer Edward John White (1831–1913), Assistants Charles Moerlin and Ebezener Farie MacGeorge (1836–?) plus Alexander Black (1827–1897) of the Geodetic Survey, the photographer Charles Walter (1831–1907), Professor Wilson and an assayer from the Melbourne Mint, George Foord (ca. 1823–1898). The dozen or so other members of the Victorian party included the journalist Henry Britton (1843–1938), who wrote a useful and detailed series of articles about the voyage, and Henry Keylock Rusden (1826–1910), who was the Secretary of the Royal Society of Victoria.

Apart from initial sea sickness for some of the passengers the voyage went smoothly, and the *Wonga Wonga* berthed in Sydney at around 1 am on Sunday 26 November. Lodgings for the whole party were at the Royal Hotel (Britton, 1871a), which was centrally located in George St between King and Market Streets. During the day there was an excursion by steamboat to Parramatta, which included a visit to the site of the old Parramatta Observatory near Government House (White, 1869–1876). The next day, departure day, Edward White transferred the chronometers from the *Wonga Wonga* to the *Governor Blackall*, and then called at Sydney Observatory in order to obtain accurate time for his pocket chronometer.

Another expedition member who came to Sydney was Silvester Diggles (1817–1880), a naturalist, artist and musician from Brisbane. As one of the conditions for supporting the Australian Eclipse Expedition the Queensland Government reserved the right to send someone on the voyage and Diggles was chosen, partly because he was "... accustomed to the use of the telescope ..." (Diggles, 1872). In order to save the expedition the trouble of stopping in Brisbane on the way north he travelled to Sydney to join the rest of the party, arriving on Saturday 25 November. While in Sydney he visited the Botanical Gardens and renewed an acquaintance with the Director, Charles Moore (1820–1905), who also would join the expedition. However, Diggles spent most of his time at the Museum (now the Australian Museum), with its Curator, Gerard Krefft (1830–1881).

## 5 THE *GOVERNOR BLACKALL*

When the members of the eclipse expedition embarked on the *Governor Blackall* on Monday 27 November 1871 they were on an almost brand new ship, the largest that had been built in the Colony of NSW up to that time. However, the ship already had a curious history as it was implicated in the bringing down of a Queensland Premier and Government.

An historical article in *The Brisbane Courier* newspaper (Famous ship, 1931), written on the occasion of the scuttling of the *Governor Blackall* off Sydney Heads relates the circumstances surrounding the ordering of this ship and its consequences. In 1869 the Australian Steam Navigation Company supposedly misused its monopoly power in Queensland by asking for large subsidies, not bringing the English mail from New South Wales, and providing an irregular service. In December 1869, while visiting Sydney, the Queensland Premier, Charles Lilley (1827–1897) and the Queensland Governor, Colonel Blackall (1809–1871), decided to confront the monopoly by ordering a fleet of ships to be operated by the Government.

Lilley then negotiated for the construction of three ships by Mort and Co., each of 480 tons, at a cost of £16,500 ($3.3 million) for the first and £16,000 ($3.2 million) for the other two. Not surprisingly, his cabinet colleagues were strongly opposed, with the Treasurer cabling back, "We think had better not buy steamers. Cannot tell what annual cost may be". Despite this opposition Lilley managed to have one ship built that became the *Governor Blackall*. However, the political cost was high as it was a significant contribution to the disintegration of his government a few months later and the opposition assuming government.

The *Governor Blackall* was designed by Captain William Henry Eldred (1819–1897) who, with his partner Edward Jones Spence, became the agents for the ship. The steel-hulled ship had two steam engines and an auxiliary brigantine rigging (i.e. two masts with sails). There was saloon accommodation for "... twenty-seven gentlemen and nine ladies ....", as well as steerage berths for "... twenty-eight males and eight females." (Trial trip of the steamer Governor Blackall, 1871).

## 6 THE VOYAGE NORTH TO ECLIPSE ISLAND

By 4 pm on the afternoon of Monday 27 November 1871 the expedition party was on board the *Governor Blackall*, which was berthed at Campbell's Wharf close to Sydney Observatory (Britton, 1871b). The freshly-cleaned and painted ship, equipped with new pistons, departed soon afterwards for the Heads at the entrance to Sydney Harbour. The New South Wales observers had only one representative from Sydney Observatory, Henry Russell, but he was to have a number of helpers: the Reverend William Scott (1825–1917) who had been the first astronomer at Sydney Observatory and had employed Russell there as a 'computer' (Orchiston, 1998), William John Macdonnell (1842–1910) a bank manager and active amateur astronomer (Orchiston, 2001), and the photographer Beaufoy Merlin (1830–1873) (Bradshaw, 2005). Others from New South Wales, extracted from the list of expedition members that Merlin (1872) provides at the start of his "Rough Notes" on the expedition, were Charles Moore, from the Botanical Gardens in Sydney (King, 1974); the conchologist John William Brazier (1842–1930) (McMichael, 1969); Henry James Bolding, the police magistrate at Raymond Terrace; and a Mr C. Whitehead of the Clarence River.

There were 33 members of the eclipse party housed in the saloon. On sitting down to dinner they were pleased to find menus on the tables headed "S.S. Governor Blackall" and "Eclipse Expedition" with an illustration of champagne bottles and glasses resting on grapes and vine leaves (Britton, 1871b) suggesting to the participants that their voyage would not be Spartan. For the first few days, the Victorians having become acclimatised to sea travel on the *Wonga Wonga* could watch the others fall to sea sickness with "... a sense of calm superiority."

By the end of the week the *Governor Blackall* had reached the Great Barrier Reef. Britton (1871b) was unimpressed stating that "There is nothing picturesque about these reefs ..." and stressing how dangerous and difficult they were for navigation. On the afternoon of Friday 1 December the ship reached No 2 Percy Island (now Middle Percy Island), and the passengers were able to disembark, though with some difficulty and some trepidation. The difficulty was that the waves were pushing the boats sideways so that there was a risk of capsizing and some deft manoeuvring was needed with the oars (Diggles, 1872) before the passengers could reach the sandy beach. The fear also was due to the remembrance that 17 years earlier local Aboriginal people on the island had speared and killed a young naturalist and collector Frederick Strange (1826–1854), along with three members of his party (Murder of Mr. Strange and three others, 1854). Fortunately for all concerned, there appeared to be no inhabitants on the island when the eclipse party landed. Diggles found a plant of interest with its leaves being eaten by "... a very pretty species of Cassida or Tortoise Beetle." Others found some small but sweet oysters and someone else discovered a turtle nest from which many of the eggs were removed for later cooking and eating; the white portions of the eggs turned out to be "... rather slimy and tasteless ..." (Merlin, 1872). A number of cockatoos were shot and, to the later disgust of the steward, the naturalists collected a host of specimens of snails, shells, coral and green ants.

On Sunday 3 December 1871 as the ship was passing the Palm Islands that are about 60 km north of Townsville Reverend Scott performed a church service with a sermon that according to Merlin (1872) was "... truly devotional and impressive". The next day the ship anchored in a sheltered bay at Fitzroy Island near present-day Cairns in order to fill up its water tanks. Some of the passengers explored the island; Edward White with five others including some of the ship's crew climbed the island's peak and determined its height as 653 feet (199 m). Diggles was pleased with the island, for he considered that, "The insect tribes were holding high holiday on our arrival ..." so that he could catch many specimens, especially Lepidoptera (moths and butterflies). Later, when back on board the *Governor Blackall*, Diggles was called upon by some of his fellow passengers to identify birds that they had shot and collected.

On the late afternoon of Tuesday the ship anchored at yet another tropical island, Lizard Island, which lies to the north of present-day Cooktown. Those who left the ship found footprints in the sand, indicating the presence of local Aboriginal people. As well, the island had a ruined stone house, one wall of which was still standing, and on which was painted a large black cross. Although Robert Louis Stevenson's *Treasure Island* was not to be published for another decade, the cross was taken as an invitation to dig, which they did, but without finding any treasure. The house was believed to have been used by collectors of sea cucumber, also known as *bêche-de-mer* and *trepang*, which was exported to China where it is considered as a delicacy (Diggles, 1872).

Being now close to the right latitude for the eclipse, which was calculated to occur just one week later, it was time to make a decision about the observing location. Merlin (1872) relates that a discussion was held on Tuesday evening to decide between two candidate sites. One was Cape Sidmouth on the mainland and the other was Number 6 Island of the Claremont Group. Although the Cape had been the planned destination, it was surrounded by shallow water for 5 km or so making the landing of instruments difficult and, in addition, there was considerable fear of the Aboriginal people who were believed to live in the locality. Hence, No 6 Claremont Group was selected as the observing site.

## 7 ECLIPSE ISLAND

The *Governor Blackall* reached No 6 Claremont Group at 6:30 pm on the evening of Wednesday 6 December 1871 (White, 1869–1876), just six days before the eclipse, and Ellery (1874a: lxi) was far from impressed:

> ... it was a most uninviting place—a mere sandbank, over which an 8 ft. [2.4 m] tide would have swept, clothed only with a few miserable bushes, and infested with myriads of rats."

When the tide was low a reef 10-km long and 3-km wide was exposed, while at high tide only the sandbank, with a length of about 800 m and a width of 200 m, was above the water level. Nonetheless, the island met the main criteria for an observing site in that the instruments could be easily and safely landed, and there was sufficient room for them to be set up.

Figure 4 shows a reproduction of a watercolour, almost certainly painted by Silvester Diggles, of the *Governor Blackall* at the island, which the expeditioners dubbed 'Eclipse Island'.[3] Unfortunately, the name does not seem to have stuck. Comparison with a nineteenth century map of the area by the British Hydrographic Office (Coral Sea and Great Barrier Reefs, 1886) shows that Number 6 Island of the Claremont Group is the same as the northernmost of the two Morris Islands marked on modern maps. The Queensland place names website set up by the Queensland Government provides no information about the origin of that name, which does not appear to be known.[4] The earliest reference to the name that could be found is from 1894, in the form "Morris Island, No. 6 Claremont" (Wrecked cutter, 1894), when it was in the news in connection with a rather grisly discovery by Frank Lee, the owner of a bêche-de-mer station on the island.

Edward White's observations provide a position for the island of 13° 29′ 36.1″ S latitude and 143° 46′ 30″ longitude (Ellery, 1874a). The latitude is 'spot on' according to modern coordinates from the above website, but the longitude is too far to the east by a distance of about 5 km or 3′. That is equivalent to an error of only 12 seconds

Figure 4: A watercolour painting by Silvester Diggles of the *Governor Blackall* at Eclipse Island (courtesy: State Library of NSW, Australian Eclipse Expedition 1871, SV*/Ecl/1).

of time, which is quite reasonable for the period, especially as poor weather prevented White from taking many observations for time.

On the Thursday, the first full day after arrival at the island, the first task was to build the piers for the instruments. Henry Caselli, an architect from Ballarat in Victoria, built these from bricks brought for the purpose and set in cement. As these piers were to remain after the departure of the eclipse party they were built as time capsules enclosing newspapers from different colonies, a list of the passengers and a few coins (Diggles, 1872). Edward White quickly installed a transit instrument on one of the piers and that evening began making prime vertical transit observations, that is, timing stars crossing the east-west plane at right angles to the meridian; these observations provided the latitude of the observing site.

For the observers the first three days on the island were spent unloading the instruments and setting them up, along with the tents that were to shelter them from the elements. For the New South Wales observers the main instrument was the 7¼-inch (18-cm) aperture and 124-inch (3.15-m) focal length Merz and Sons refracting telescope[5] that Scott had ordered, and first used in 1861, when he was the founding Director of Sydney Observatory. Once he became Director, Henry Russell, devised an ingenious regulator for controlling the speed of the telescope's clock drive. Silvester Diggles (1872) explained the system as

> ... being merely the immersion of a wooden wheel in a trough of mercury, under which is a regulating screw, which causes the wheel to dip more or less deeply into the fluid.

Although this was an effective method of keeping a star or another astronomical object steady in a telescope, it is to be hoped that precautions were taken to avoid inhaling the mercury vapour.

The Merz telescope was to be used for photography: its eyepiece had been replaced by a camera for focal plane photography, and another camera, with its own 3-inch (7.5-cm) lens, was attached to the telescope tube. During the eclipse Russell was to operate the former, while the photographer Beaufoy Merlin was to use the attached camera. There were two small telescopes with clockwork for visual observing; one was to be used by Lieutenant Gowlland and the other by Silvester Diggles. Reverend Scott was to observe with a slightly larger aperture Troughton and Sims telescope that was equatorially mounted but had to be moved by hand (Russell, 1872). Figure 5 shows the New South Wales party posing in front of their instruments.

Figure 5: NSW eclipse party clustered around the 7¼-inch (18-cm) Merz telescope at the entrance of the Sydney tent. Pictured from left to right are William Macdonnell, Rev. William Scott, Lieutenant Jack Gowlland, Silvester Diggles, Henry Chamberlain Russell, Russell's assistant J. Thrustell (identified in Stevenson, 2012) and Beaufoy Merlin (photograph: Beaufoy Merlin, courtesy: State Library of NSW, Australian Eclipse Expedition 1871, SPF).

These instruments were all housed in a large 'Sydney tent' that also enclosed a photographic dark room with 20 baths and apparatus so that 20 plates could be taken during totality. At that time wet-plate photography was in use so that photographic plates had to be coated before exposure and then developed immediately afterwards. By experimenting, Russell worked out that at the ambient summer temperature on Eclipse Island he could wait ten minutes after coating before exposure and then wait another ten minutes before developing without damaging the plate. Working in that way, and with only two people, 20 exposures could be made during the brief period of totality.

Russell's plans for the eclipse did not include spectroscopy, but only because the instruments sent out from Britain were being used by the Victorian party and he had been unable to source a spectroscope locally. Instead of using a large tent like the Sydney observers, the Melbourne party housed their greater number of instruments in a number of smaller tents. Robert Ellery was to use one of the Browning spectroscopes that was attached to a telescope by the same maker with a then new-style silver on glass mirror made by the English expert George Henry With (Diggles, 1872). His aim was to examine "... the nature of the light of the chromosphere and the corona." (Britton, 1872a). George Foord from the Mint was in charge of the second Browning spectroscope and had the same aim. Ebezener MacGeorge was looking after the integrating spectroscope, while Professor Wilson had the two Savart's polariscopes to see if the light from the corona was polarised in order to "... ascertain whether the light of the corona is that of a self-luminous body or a reflected light." (Britton, 1872a). Figure 6 shows Ellery and Wilson with other members of the Victorian party in front of two of their instruments.

Charles Moerlin from Melbourne Observatory and the photographer Charles Walter were to take photographs with a 4-inch (10-cm) rapid rectilinear lens, a four element lens with low distortion, by Dallmeyer. With a focal length of 30-inch (76-cm) it provided a 0.3-inch (0.8-cm) image of the Sun. Edward White who, as mentioned above, was making observations for time and position with an altazimuth instrument and a

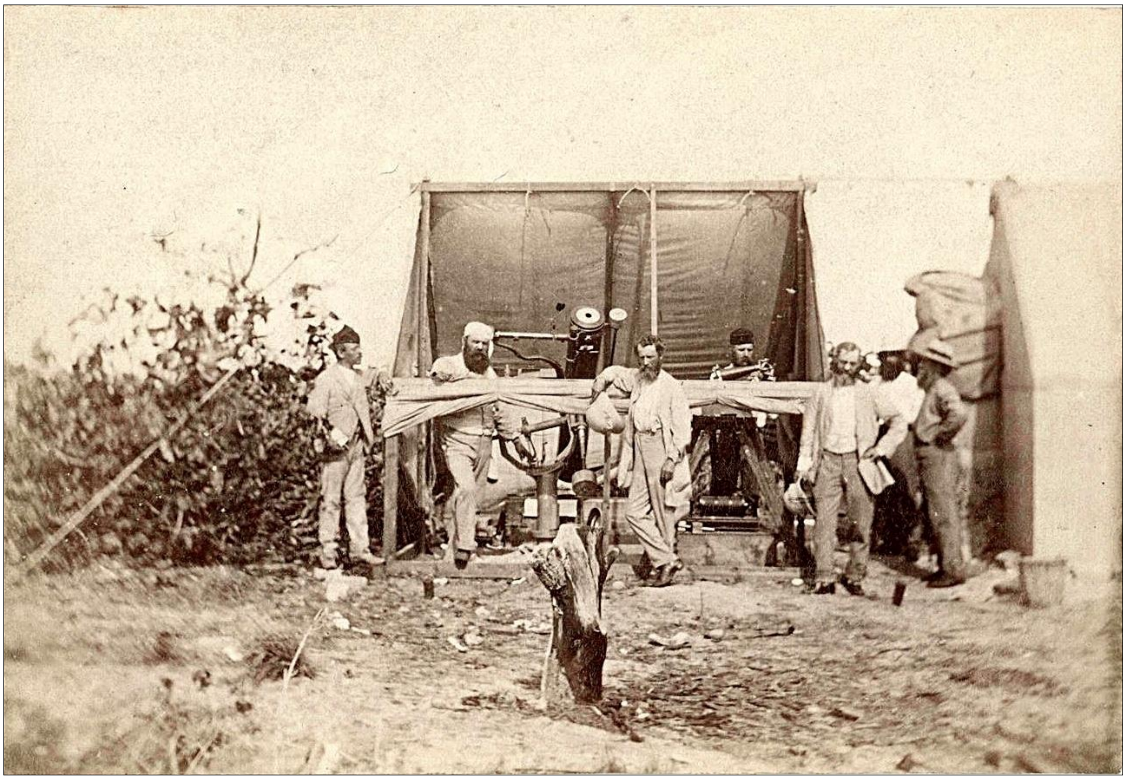

Figure 6: Part of the Victorian party in front of one of their tents. The surveyor Alexander Black is second from left, Robert Ellery is third from left and Professor William Parkinson Wilson is fifth from left (photograph: Charles Walter, courtesy: Museum Victoria Collections http://collections.museumvictoria.com.au/items/1465827, accessed 14 December 2015).

transit telescope (see Figure 7), completed the Melbourne observers.

As the observers were setting up the instruments and rehearsing for the totality, the rest of the passengers spent their time exploring, and collecting corals, shells and botanical specimens. Some wandered on the island's exposed reef at low tide, while Charles Moore went by boat to Cape Sidmouth on the mainland with four passengers, two servants and three of the crew.

There they saw evidence of the presence of the local Aboriginal people, but actually only saw three of them. Fear of attack, however, almost led to disaster one night when Charles Moore, who was wearing dark clothes, was challenged and almost shot by two of the party on guard duty after being mistaken for an Aboriginal. Among the variety of interesting plants that Moore and his party found was a species of Eugenia that "... bears a fruit about the size and colour of a cherry, having a pleasant sub-acid flavour." (Britton, 1872a). The party happily availed themselves of this fruit, which is likely to have been *Eugenia reinwardtiana* or Cedar Bay cherry.

A number of the eclipse party would bathe in the sea each morning, and Edward White, for example, records bathing on Friday, Saturday and Sunday at Eclipse Island. On the Sunday, however, the sportsmen managed to catch a number of sharks. After each unfortunate shark took the bait, its head was drawn above the water and then shot three or four times. In just an hour and a half six sharks were placed on the deck to be drawn and quartered, and two more were killed and allowed to sink in the water. Britton (1872a) notes that "After this experience, the morning ablutions of the company were limited to splashing about the decks under the hose."

## 8 THE ECLIPSE

For the first few days on Eclipse Island the party experienced fine weather. It was so fine that little, if any consideration was given to splitting the party as a precaution against bad weather. When he was in Tahiti in 1769 to observe the transit of Venus, James Cook sent two observing teams to different islands, just in case it was cloudy at his observing site of Point Venus at the critical time (Orchiston, 2005), but this was not done at Eclipse Island in 1871, even though on the days just before the eclipse the weather turned bad. For Sunday 10 December, White (1869–1876) recorded in his diary: "Weather cloudy with heavy rain at night." The next day was no better: "Weather cloudy with heavy storm of rain and terrific thunderstorm at night." Merlin (1872) gives a vivid description of the heavy even-

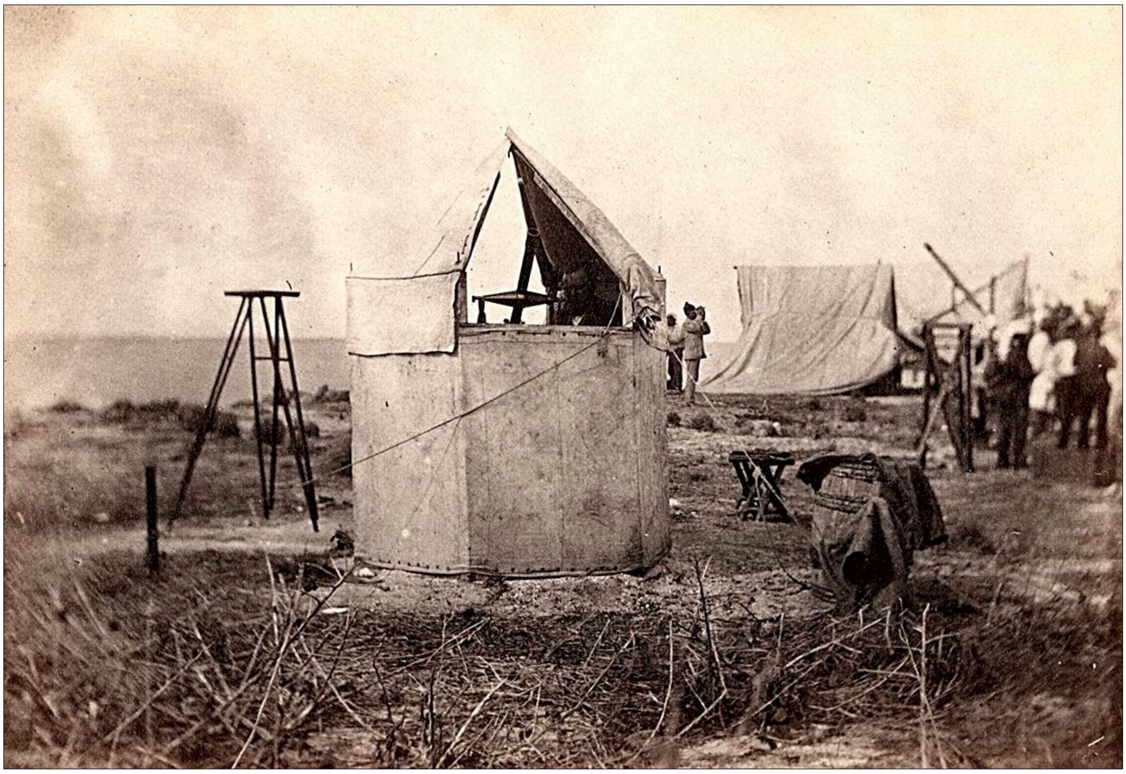

Figure 7: A photograph by Charles Walter of Edward White with the transit telescope (courtesy: Museum Victoria Collections http://collections.museumvictoria.com.au/items/1465839, accessed 14 December 2015).

ing tropical storm:

> At last the thunder broke out—peal after peal, then volley after volley, like the rattle of artillery close at hand. The steamer shook and quivered in every part. Rain followed—such rain!

On Tuesday 12 December, the morning of the eclipse, White (1869–1876) reported that the weather had not improved and there were still clouds, rain and thunder. The observers were rather concerned, as shown in Figure 8 where they have "… an appropriately desponding appearance." (*The Argus*, 1872a). Still some clear patches offered hope, and White made some time observations with the altazimuth. Clouds covered the sky at the start of the eclipse, at 1:15 pm local mean time, but three minutes later White managed a glimpse of the slightly-covered Sun. Just two minutes before totality there was another glimpse, this time of a thin crescent. White (1869–1876) says that

> During totality a ring of light surrounding the Sun was just visible through the clouds, the birds went to roost, but the darkness was not very great, but peculiar.

From the Sydney tent Russell (1872) also had two brief glimpses of the Sun during the eclipse, although at different times to White. Just in case the clouds were to clear suddenly, Russell and Moerlin prepared nine plates for use, and they even exposed two plates for 40 seconds, but without success.

After totality, the disappointed astronomers quickly packed up their equipment and everything was on board the *Governor Blackall* by 5:30 pm. To cheer themselves up that evening, over dessert numerous toasts were drunk, to "Success to the Other Eclipse Expeditions", "Professor Wilson, the original proposer of the expedition", "The Australian Governments", "The Leaders of the Observing Parties", "Captain Gowlland, the successful navigator of the ship" and "The Passengers" (Britton, 1872a).

Later that evening the eclipse party had a surprise visit from a sailing ship, the schooner *Matilda*, on its way from the Torres Straight to Sydney with a cargo of pearl shell. The crew of the *Matilda* were more fortunate than those at Eclipse Island for as they were sailing near Night Island, 38 km to the north, they had a good view of the eclipse. The officers of the vessel were not anticipating the eclipse, and initially they assumed that it was bad weather that was causing the darkness. Professor Wilson closely cross-examined Mr Walton, the master of the *Matilda*, on his observations of the eclipse. Using a diagram Walton correctly indicated where the Sun's disc was seen to disappear at the start of totality and where it reappeared at the end. He described the appearance of the corona, as did the

Figure 8: A photograph by Charles Walter of the Victorian party during a rain shower just before the time of the eclipse (courtesy Museum Victoria Collections http://collections.museumvictoria.com.au/items/1465822, accessed 14 December 2015).

*Matilda's* first officer, who used a vivid analogy for the colour that he saw in the corona, "... like the glow of fire when the fire is concealed." (Britton, 1872a). According to the first officer, only one small cloud passed across the Sun during the eclipse.

The news of the successful observations of the eclipse relatively close to Eclipse Island must have led to some soul-searching among the leaders of the expedition about whether not splitting the observing party had been a lost opportunity. Britton mentions the disincentives to doing so included difficulties in transporting the instruments and the fear of the local Aboriginal people. In any case, most likely if another party had been sent elsewhere it would have been to the mainland at Cape Sidmouth, where the weather would have been the same as at Eclipse Island. Furthermore, from the description of the *Matilda's* officers, it seemed that the sky was not sufficiently clear at their location to make spectroscopic observations. Certainly, Russell (1872) did not think so as he stated that "It was quite evident from their evidence that there were light clouds over the Sun during totality."

The *Governor Blackall* began its voyage home the next morning, leaving behind on the island the photographers' darkrooms and the brick piers for the instruments, one of which was inscribed on the top: "Sacred to the memory of the Australian Eclipse Expedition." (Britton, 1872a). On Saturday 16 December the ship reached Cardwell, approximately halfway between present-day Cairns and Townsville. As the nearest settlement to Eclipse Island with a telegraph station, it was an important stop for those on board. According to Britton (1872b), immediately upon landing the expeditioners "... marched in a compact phalanx to the telegraph-office." There, he says, the telegraph master

> ... will not forget our visit readily. He had, probably, not sent a message for weeks before, and we left him floundering through a pile of 20 or 30 separate telegrams in a distracted condition.

Four days after Cardwell the ship berthed at Brisbane. There the party was well treated with free accommodation at the Queensland Club and a visit by the Governor on the day after arrival. As well, the members of the expedition were invited on an excursion by coach [horse-drawn] and train to the Darling Downs. The invitation was accepted and they saw "... some fine portions of Queensland scenery." (Merlin, 1872). As the leader of the expedition Robert Ellery (1872: lxii) was most appreciative of

> ... the great hospitality and kindness which was shown to every member of the Australian Eclipse Expedition by the Government and people of Brisbane.

After three days there the ship left for Sydney, which it reached on Christmas Day, 25 December 1872. Before the end of the voyage the passengers showed their appreciation to Lieutenant Gowlland in the form of a testimonial:

> ... as some slight recognition of his high and varied qualities as a commander, his urbanity as a gentleman, and his uniform kindness to every individual connected with the Eclipse Expedition of 1871. (Merlin, 1872).

The Melbourne members of the party arrived home just before New Year's Day 1872.

## 9 THE RESULTS OF THE ECLIPSE EXPEDITION

The naturalists and other collectors were much more successful on the voyage than the astronomers. Silvester Diggles (1872) for example obtained a variety of moths and butterflies such as *Acröe Andromache*, *Danais Archippus*, *Junonia*, *Orythia*, *Velleda* and "... the beautiful Diameda Alimena ..." of which he collected examples of both sexes. He regretted though losing a brilliant green Cetonia moth that was caught in his net but still managed to escape. He also grabbed some parasites from the bodies of the sharks that had been killed at Eclipse Island. These he sent to Gerard Krefft at the Sydney (Australian) Museum, who published at least one paper—complete with illustrations—on his researches into these creatures.

The conchologist John Brazier (1874) was also successful and, in a paper read before the Royal Society of New South Wales on 23 September 1874, he reported on the discovery of 11 new species of shells during the voyage. The leading astronomers on the trip also benefited, as some of the new species were named after them. Henry Russell had two species named after him: *Helix (Conulus) Russelli* from Fitzroy Island and *Columbella (Mitrella) Russelli* from Eclipse Island. There also were shells named after Robert Ellery, William Macdonnell, the Reverend Scott and Edward White. Professor Wilson is notably absent from the list of astronomers immortalised by having species named after them. Brazier also named a shell after the Queensland naturalist Silvester Diggles. The greatest number of species names, three, were reserved for the Captain of the voyage, who sadly was no longer alive by the time Brazier came to present his paper. As he explained in regard to one species:

> I have named it after my late lamented friend John Thomas Ewing Gowlland, Staff Commander, R.N., who was unfortunately drowned while employed surveying Port Jackson, August, 1874.

The photographers also did well. The Melbourne-based photographer Charles Walter took a series of images that provide an evocative view of the activities of the voyage, including at Eclipse Island. According to a paragraph in *The Argus* (1872a), soon after the return of the party he had available—presumably for sale—a set of ten pictures, either printed so as to be suitable for placing in an album or as stereoscopic slides. This brief newspaper article highlights the picture taken in rain just before the eclipse that is reproduced here as Figure 8. A month later another brief article in *The Argus* (1872c) announced the availability of a set of 12 photographs from Beaufoy Merlin, who was part of the Sydney party. In addition to views of the astronomers with their equipment, views at Fitzroy Island and a picture of the *Governor Blackall*, there was a large 'carte' with oval-shaped photographs of all the participants on the voyage. The article comments that "The likenesses are generally excellent."

The poor weather on the day of the eclipse meant that the astronomers could make no useful observations. However, there were major intangible benefits to the voyage that will be discussed below in Section 11, as well as tangible benefits with regard to the modern instruments sent to Ellery by the Eclipse Committee of the British Association. In his Annual Report to the Observatory's Board of Visitors, Ellery (1872: 9) reported that all the instruments taken on the voyage were undamaged on their return to Melbourne, and those from England were "... packed up ready for sending back ...", though he did enquire about purchasing the most useful ones. In his next report to the Board (Ellery, 1874b: 9) would happily state that Norman Lockyer had written on behalf of the Eclipse Committee presenting the three spectroscopes, two polarimeters, a Dallmeyer lens and camera, as well as other photographic equipment, to Melbourne Observatory. A few years later, while on leave in England, Ellery (1876: 415) met Lockyer at a Royal Society reception and heard that there had been some unpleasantness over this donation: the items had been lent to the Eclipse Committee by the Royal Astronomical Society, so the Committee had no authority to dispose of them. In any case, none of the items seems to have survived at Melbourne Observatory to the present day, as they all appear in the 'Unlocated Items section' of the Melbourne Observatory inventory (Clark, 2007).

## 10 THE AFTERMATH

Ellery gave an account of the eclipse expedition at an ordinary meeting of the Royal Society of Victoria on 22 January 1872, the first such meeting after their return. He explained that the lack of observations of the eclipse was unavoidable due to the cloudy weather. Then he moved on to the financial aspects of the expedition and mentioned "... the difficulty of closing the a/cs. [accounts] unexpected bills having been sent in by the agents." (RSV Ordinary Meeting minutes, 1854–1893). Not only had the Queensland Government withdrawn its promised £100 contribution, but it also insisted that the expedition was responsible for bringing the *Governor Blackall* up to operating condition, including painting the ship before and after the voyage and replacing its cracked pistons. However, while the ship was in Brisbane on the return voyage, the Queensland Government agreed to pay for the £115 cost of replacing the cracked pistons (*The Argus*, 1872b).

Even though Ellery merely provided a factual report on the situation, *The Argus'* report of the meeting raised the ire of the Queenslanders. Three weeks after the report *The Brisbane Courier* began a war of words by reprinting some of Ellery's comments, and then "... to show how far this statement is borne out by the actual facts ..." they reprinted some of the official correspondence regarding the loan of the ship (The Queensland Government and the Eclipse Expedition, 1872a). This correspondence was mainly between the Colonial Secretary in Brisbane and the ship's agents, Eldred and Spence. A few days later, *The Brisbane Courier* again addressed Ellery's remarks, this time in a column titled 'Odd Notes' that was written by 'A Bohemian' (1872). According to the Bohemian, the

> ... publication of the correspondence shows that there is [*sic*] two sides to it, and that the savans [*sic*] of the Royal Society of Victoria took the wrong one.

Of course, the publication of the correspondence and comments upon it did not go down well in Melbourne. At a special meeting of the Council of the Royal Society of Victoria on 26 February 1872 (RSV Council Meeting minutes, 1854–1888) Ellery told his colleagues that the published correspondence was "... entirely one-sided ..." as only one letter from Melbourne was included, and the missing correspondence would show that "... he had not been duly acquainted with conditions desired to be observed or imposed until the last moment." In a battle of published letters the meeting decided to ask *The Argus* to publish Ellery's correspondence in chronological order. This publication occurred on 8 March 1872 (The Queensland Government and the Eclipse Expedition, 1872b).

Although at our remove this minor dispute between the Queensland Government and the Royal Society of Victoria may seem petty and the conduct of both sides slightly childish, the publication of the letters is a boon for understanding the organisation of the Australian Eclipse Expedition. From the letters published in *The Argus* we learn in one from the ship's agents addressed to Ellery that after the members of the expedition disembarked at Campbell's Wharf the *Governor Blackall* was towed to another wharf, and on the way "... the L. T. [lower top] gallant stay of the Governor Blackall caught the jibboom of the ship Parramatta, and carried away the topmast." The repairs to the other ship were yet another expense for the Royal Society of Victoria. The last letter published in *The Argus* was from Eldred and Spence (the ship's agents) to Ellery, indicating the difficult position in which they found themselves in this dispute: "We regret that anything should have arisen to interfere with the amicable feeling that has subsisted throughout." (The Queensland Government and the Eclipse Expedition, 1872b).

There was still further correspondence between Ellery and Eldred and Spence after the publication of the letters, as there were monetary issues still to be finalised. At the Council meeting of 4 April 1872 (RSV Council Meeting minutes, 1854–1888) an offer from Eldred and Spence to accept the bedding and linen that was used on the expedition as part payment equivalent to £50 of their commission was discussed. The Council instead requested that the items be sold and pointed out that the commission was only to be paid after all other payments have been made. The imminent receipt of the £100 voted by the South Australian Parliament promised that the Society could soon clear all the debts associated with the voyage of the *Governor Blackall*.

## 11 DISCUSSION

The botanists and other collectors were successful on this voyage as they were not tied to a specific time nor were they constrained by the weather. Astronomers, however, always take a risk when travelling to see a solar eclipse or a similar event such as a transit of Mercury or Venus; sometimes they are fortunate and there are no clouds or the clouds clear at the appropriate moment, but at other times clouds totally block the view. In the case of the voyage to Cape York to see the 1871 total solar eclipse the astronomers were not favoured by the weather and could not make any useful observations. Still the voyage was important and exceptionally useful, with implications for the future development of astronomy and science in Australia.

Possibly the most important aspect was the cooperation between the colonies in organising this scientific expedition. As was quoted from Hoare (1976) in the Introduction, this was the first time that such cooperation had happened, especially on such a large scale. This cooperation occurred at Government level and also at a personal level. The two Government Astronomers, Ellery from Melbourne and Russell from

Sydney, became well acquainted when organising the voyage and during it. The lasting friendship between them is reflected in the tone of numerous letter sent by Russell to "My Dear Ellery" preserved in the Sydney Observatory archives, such as one dated 15 January 1891 (Russell, 1891). Three years prior to that letter the scientific cooperation between the colonies, specifically between the Royal Societies in the colonies, led to the formation of the Australasian Society for the Advancement of Science (see MacLeod, 1988), with Russell as President and Ellery in charge of Section A, that included Astronomy (Lomb, 2015).

The eclipse expedition for the first time led astronomers to seek support from Governments on a large scale, initiating 'big science' in Australia. Handling the large amounts of money involved in mounting the expedition also was an important learning exercise. Similarly, negotiating with the shipping agents about a contract worth the equivalent of a quarter of a million dollars in today's money would have been instructive, especially for Russell who had been in his position only since the previous year. For both Government Astronomers, being involved in the rapid organisation of such a complex logistical exercise would have helped them in making arrangements for the next major astronomical event in Australia, the 1874 transit of Venus (see Lomb, 2011). These arrangements were complex, with Melbourne and Sydney Observatories both sending well-equipped teams consisting of mixtures of professionals and scientific volunteers to a variety of suitable locations (Orchiston, 2004). There was to be no repeat of the 1871 situation of being clouded out at only one observing location!

The expertise and friendship built up on the eclipse voyage was not only needed at astronomical events. In 1887, Sydney and Melbourne Observatories, under Russell and Ellery, respectively, joined the international Astrographic Catalogue project. To operate this project the two Observatories needed access to funds, the ability to organise staff, and to cooperate between each other as well as with other observatories in Australia (Stevenson 2014).

There was also a gain in scientific expertise due to the eclipse trip. Russell and the staff from Melbourne Observatory gained familiarity with the complex process of using wet-plate photography for astronomical observing, a skill that was to be important again during the 1874 transit of Venus. The loan and subsequent donation of the latest astronomical instruments from London—spectroscopes and polarimeters—also boosted interest in astrophysics. There had already been some spectroscopic observing with the Great Melbourne Telescope over the previous two years (Le Sueur, 1870), but that did not directly involve Ellery, and certainly not Russell.[6] Russell was so enthused by the possibilities that during his first trip to England, in 1875, he made sure to purchase a three-prism spectroscope for his Observatory from the eminent London maker Hilger (Russell, 1875: 144).[7]

To the Royal Society of Victoria in a way the eclipse expedition represented redemption after the disastrous Burke and Wills expedition that its Exploration Committee had organised a decade or so earlier. In that large-scale expedition seven lives were lost, including that of the two leaders (Fitzpatrick, 1969). In contrast, all of the eclipse expedition participants returned safely and expeditiously to their homes.

The 1871 Australian Eclipse Expedition may not have succeeded in its primary objective of researching a rare total eclipse of the Sun, but it had positive ramifications for Australian science, and especially astronomy, for the remainder of the century and beyond.

## 12 NOTES

1. Today that line is identified with highly ionized iron (Fe-XIV) at a wavelength of 530.3 nm.
2. Estimating the value of money in the nineteenth century is difficult due to lack of official statistics at the time and the different structure of society. A rough conversion factor of 200 was estimated by a) comparing the fare charged passengers for the 1871 voyage with the cost of a modern cruise around Australia of comparable length, and b) comparing the cost of building the *Governor Blackall* with the advertised sale price of a comparably-sized ship.
3. Confusingly, there is an Eclipse Island off the coast of Queensland, but it is over 600 km to the south of the 1871 observing site and has no connection with it. Only a few hundred meters long and part of the Palm Island group, the island has the Aboriginal name of *Garoogubbee*. The Queensland place names search website suggests that it was "Probably named by [the] Admiralty Hydrographer, date unknown, after HMS Eclipse, on Australia Station of the Royal Navy 1862–66."
4. An attempt will be made to persuade the relevant authorities to revert to the name Eclipse Island.
5. The tube of the telescope is missing but the lens is part of the collection (H10187) of the Museum of Applied Arts and Sciences in Sydney and as of 2015 was on display at Sydney Observatory.
6. Although both astronomers would remain committed to positional astronomy, in 1881 Russell would carry out spectroscopic obser-

vations of the Great Comet of 1881 (see Orchiston, 1999), and later in the 1880s Ellery and his Melbourne Observatory colleague, Pietro Baracchi, would conduct spectroscopic surveys of southern stars (Andropoulos and Orchiston, 2006).

7. H9974 in the collection of the Museum of Applied Arts and Sciences, Sydney.

## 13 ACKNOWLEDGMENTS

The author would like to thank William Kitson who provided the reference to Joanna Vink's book on Staff Commander J.T.E. Gowlland and other useful information. Malcolm Carkeek indicated the present location of the extant records of the Royal Society of Victoria and Dr Barry Clark gave the helpful reference to Ellery's 1876 article in *The Melbourne Review*. The referees provided helpful suggestions, especially pointing out the existence of the 'Eclipse Island' in the Palm Island group.

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Dr Nick Lomb obtained a Ph.D. from Sydney University for work on short-period variable stars. One of the outcomes of his thesis was a technique of frequency analysis that today is widely used in many areas such as finding exoplanets. In 1979 he joined Sydney Observatory, where he became the co-author of the Sydney Southern Star Catalogue that was published just after the Observatory came under the auspices of the Museum of Applied Arts and Sciences. Afterwards as Curator of Astronomy he organised numerous exhibitions at the Observatory and at the Museum with the last being *From Earth to the Universe* in 2009. He is the author of a number of books on astronomy including the annual *Australasian Sky Guide* (that is now in its 26th edition) and *Transit of Venus: 1631 to the Present*. Retiring from full-time work in December 2009, he is currently an Adjunct Professor at the University of Southern Queensland. With regard to the topic of this article, he has been to see three total eclipses of the Sun and has been fortunate with the weather at all three: South Australia 2002, Siberia 2008 and Palm Cove, Queensland 2012.

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# BOOK REVIEWS

***Masters of the Universe: Conversations with Cosmologists of the Past,* by Helge Kragh. (Oxford: Oxford University Press, 2015), pp. [viii] + 285. ISBN 978-0-19-872289-2 (hardback), 133 × 215 mm, US$49.95.**

This rather unconventional book presents a fascinating picture of the progress of cosmology and the attitudes of cosmologists over the first two-thirds of the twentieth century. Why unconventional? It takes the form of interviews conducted by an imaginary relative of the author with fourteen scientists, mostly theoretical physicists, who did research in cosmology. Although the conversations are invented, they are accurate portrayals of what could have occurred. The scholarly notes, which, with brief biographies, comprise 40% of the book, show that in many cases the interviewee uses words he actually wrote or said.

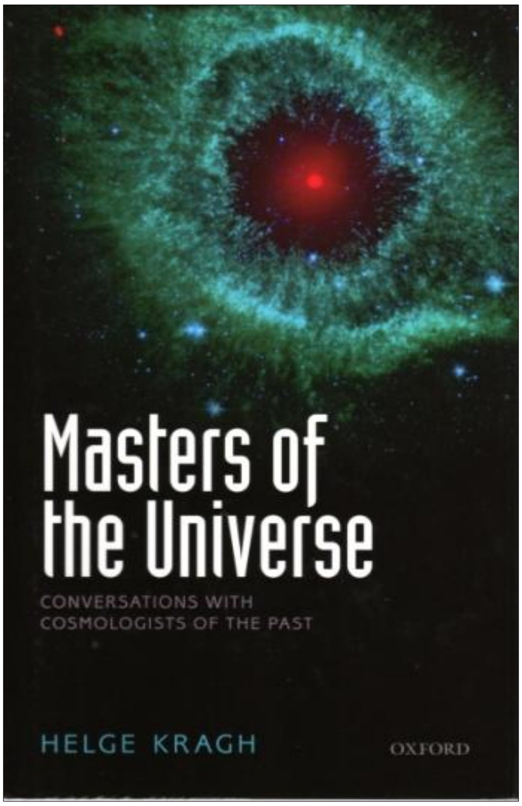
As Professor Kragh points out in the foreword, “My granduncle CCN could have existed.” This man was, like Kragh, a Dane. An engineer who read and thought a lot about cosmology, he ‘lived’ in Denmark, Germany and the United States at different times and conducted interviews in several languages. The one great mystery in the book is the identity of the person shown in a photograph with an equally unidentified woman and labeled as the interviewer.

The first two interviewees are a bit of a surprise. Kristian Birkeland (1867–1917) was a Norwegian physicist who investigated the aurora and geomagnetism. In his 1913 interview he advocates a Universe in which interstellar space is filled with a tenuous plasma and electromagnetic forces are as important as gravitational ones.

Svante Arrhenius (1859–1927), the Nobel Prize-winning physical chemist now best-known for his prediction of global warming due to the greenhouse effect (which he thought a good thing, as it would make Sweden more comfortable), is interviewed in 1916. The Director of the Nobel Institute for Physical Chemistry considers himself a physicist now, working in many branches of science, even immunology. He advocates a Universe that is infinite in space and eternal in time, an early type of ‘steady state’ Universe. Light pressure plays a major role in his Universe, but the relatively new quantum ideas of Planck and Bohr are rejected as irrelevant.

Our protagonist conducts the remaining interviews with scientists familiar to those with an interest in physics and astronomy, although several are best known for their work in fields other than cosmology.

CCN’s second 1916 interview is with Karl Schwarzschild (1873–1916). It is held at his Potsdam home just two months before the great astrophysicist died of an illness contracted while serving on the Russian front. Schwarzschild discusses his work on the possible curvature of space and, briefly, his papers of that year on general relativity and quantum mechanics. The chapter contains a wonderful quotation from a 1913 lecture by Schwarzschild that was published in Eddington’s (1917: 319) obituary:



> Mathematics, physics, chemistry, astronomy, march in one front. Whichever lags behind is drawn after. Whichever hastens ahead helps the others. The closest solidarity exists between astronomy and the whole circle of exact science.

CCN interviews German statistical astronomer Hugo von Seeliger (1849–1924) after the Great War is over, in 1920. Seeliger has recently published the result of his life work: an investigation of the distribution of the stars in space. He has developed much of the theory of statistics of stellar distributions. He and his friendly rival, Jacobus C. Kapteyn (not interviewed), have been counting stars for decades. Seeliger’s conclusion is quite similar to Kapteyn's: that the stellar system is ellipsoidal and ~10 kpc in diameter, and that the Solar System happens to be located quite near the center. Asked about the recent proposal of Harlow Shapley, that the system of globular clusters outlines a much larger galaxy centered many kiloparsecs away in the direction of Sagittarius, Seeliger states that he considers it 'plain wrong'. He says, "I suspect it's just another example of American sensationalism and tendency to megalomania." In common with Kapteyn and Shapley, he says that he has considered interstellar absorption of starlight and concluded that it is negligible. The septuagenarian Seeliger is quite conservative regarding such radical ideas as an infinite Universe or one that changes with time. He also rejects General Relativity.

The next interview, in 1928, is with Albert Einstein (1879–1955) himself. By this time CCN declares that

> … it had become clear to me, somewhat belatedly, that cosmology had entered a new phase that differed significantly from the subject as studied by classical astronomers such as Kapteyn and Seeliger. The new cosmology was essentially rooted in the general theory of relativity … (page 67).

The creator of General Relativity spends some time talking about beauty "... or perhaps sublimity is a more appropriate term ..." of the equations. He says that he has not spent much time on cosmology in recent years and that he still believes in his original model, a closed, finite, eternal Universe. He recalls informing Georges Lemaître the previous year of Alexander Friedmann's priority in finding additional, time-varying solutions to the equations of General Relativity when applied to the Universe, but stresses that he does not accept these models. This interview is timed to be just before Edwin Hubble changed cosmology forever.

The year 1933 finds CCN in Leiden, interviewing Willem de Sitter (1872–1934). By this time much has changed. Hubble's velocity-distance relation has provided evidence for an expanding Universe, and Lemaître's evolving Universe models, first published in 1927, have finally reached the influential cosmologists. The interview is far-ranging and quite interesting. It even includes a mention of Einstein's unpublished attempt at a steady state Universe with continuous creation, a model discarded by its author in 1931 and made known to the public only recently when it was discovered, translated, and published by Cormac O'Raifeartaigh and his colleagues (2014).

In 1934 CCN wisely moves from Germany to the United States. Four years later he interviews Lemaître (1894–1966) during a cosmology conference at the University of Notre Dame. The interview provides insights into the Belgian priest's views on the differences between his independent solutions to Einstein's equations and the earlier ones of Friedmann, the importance of quantum mechanics and radioactive decay to his work, and his emphatic rejection of the suggestion that his religious views affect his scientific research. There is even a mention of Lemaître's translation of his own 1927 paper into English for publication in the *Monthly Notices of the Royal Astronomical Society* in 1931, a fact only discovered after much controversy in 2011 (see Livio, 2011).

The interview with Arthur Stanley Eddington (1882–1944) was the most disappointing to me, not that it is in any way inaccurate, but because it takes place so late in Eddington's life. Had he been interviewed in the 1920s Eddington would have come across as the dominant figure in astrophysics and the most important promoter of General Relativity to scientists and the public in the English-speaking world. By 1938 he is lost in his mystical approach to the Universe, convinced that he has calculated the fine structure constant (exactly 137) and the total number of electrons in the Universe. He even spouts such nonsense as "According to my theory [the Universe] must be finite. Observations cannot give us an answer, but theory can." (page 133).

The only purely observational cosmologist interviewed is, of course, Edwin Hubble (1889–1953). The interview takes place in 1951, very near the end of Hubble's life. Hubble states that in the 1920s he kept up with developments in cosmology mostly through conversations with Caltech theoretical physicists Richard Chace Tolman and Howard Percy Robertson (who left Caltech in 1929). Hubble says

> My work of 1929 was important because it demonstrated for the first time the law of redshifts, but I did not actually conclude that the universe is expanding, and for that matter, I still feel it is premature to see in the redshift law a proof that the universe is in a state of expansion. (page 148).

and also:

> It's the privilege of the observational astronomer that he can afford the luxury of staying neutral in theoretical controversies, and it's a privilege I value. (page 149).

Our intrepid interviewer visits theoretical nuclear physicist George Gamow (1904–1968) in 1956. By this time Gamow is renowned for the theory of alpha decay, for many popular books about physics and astronomy, and especially for his strong advocacy of what Fred Hoyle has dubbed the 'Big Bang' model of the Universe. Gamow's student, Ralph Alpher, has written a famous doctoral dissertation, *On the Origins and Relative Abundance of the Ele-*

*ments*, in 1948, and the two, together with Robert Herman, have published several papers on the early Universe and nucleosynthesis.

In the interview Gamow refers to the early Universe as "... nature's own nuclear laboratory ..." and describes himself as a 'nuclear archaeologist' trying to reconstruct the early Universe from the current abundances of the atomic nuclei. Gamow makes it clear that his work has nothing in common with Lemaître's and that he considers only his model to be quantitative and based on nuclear reactions. He cites evidence that the Universe is infinite and hyperbolic in geometry. He is open to the possibility of a Universe that contracted before it expanded (only once) and says that we may never know. Gamow mentions the prediction of the cosmic radiation that may still be around, conveniently forgetting that he did not believe it when it was first proposed by Alpher and Herman in 1948. He takes pride in the calculations of the abundances of hydrogen, deuterium and helium, which are in reasonable agreement with observations, and concedes that it may be necessary to conclude that the heavier elements are made in stars. (Hoyle and his colleagues had just suggested this and the monumental paper by E.M. Burbidge, G.R. Burbidge, W.A. Fowler, and F. Hoyle (1957) was in preparation, although Gamow may not have been aware of it.) In common with most non-British scientists, Gamow finds it difficult to take the steady state cosmological model seriously.

The only joint interview is with Fred Hoyle (1915–2001) and Hermann Bondi (1919–2005) in 1958. There is discussion of the differences between the Bondi-Gold version and the Hoyle version of steady state cosmology. The former retains General Relativity, while the latter modifies it. The two agree on many questions, and both Hoyle and Bondi believe they have made cosmology more scientific. They disparage evolutionary cosmologies and call Lemaître and Gamow 'creationists'. Hoyle refers to the big bang as "… an irrational process outside science." Bondi is more inclined to consider philosophy and takes pride in the falsifiability of the steady state theory. They also discuss Martin Ryle's claims that radio source counts are inconsistent with a steady state Universe and Hoyle's ongoing work on nucleosynthesis in stars. The uncertainty in the ages of the oldest objects and their possible inconsistency with the Hubble time are also topics of discussion.

Historians of astronomy seldom think of Paul A.M. Dirac (1902–1984) as a cosmologist, but Kragh, who has written a major biography of Dirac, includes him among the interviewees, concentrating on Dirac's 'large number hypothesis'. In 1963 CCN travels to Cambridge to interview the founder of relativistic quantum mechanics on his cosmological research. Dirac believes that since the ratio of the electrical force to the gravitational force between a proton and an electron is of the same order of magnitude ($10^{39}$) as the ratio of the age of the Universe to the atomic unit of time ($e^2/mc^3$), that this must be a permanent law of physics, implying that the strength of the gravitational force decreases as the age of the Universe increases. He calls his assumptions "... reasonable and natural ...", although few have agreed. Dirac also says that to him $10^{-39}$ and $10^{-44}$ are of the same order of magnitude. There are definite echoes of the numerical claims made by Eddington in his last years. And the Dirac of the interview lives up to his reputation of often giving one-word answers to lengthy questions.

Our interviewer conducts his last interview at age 78 when he visits Robert Dicke (1916–1997) in 1965. Dicke is fascinated that CCN started his interviews before Dicke was born and talked with Einstein before the expansion of the Universe was known. Famous for his work on microwave radar during WWII, Dicke has achieved success in both experimental and theoretical physics at Princeton University. He heads a research group on gravity, and he and his student, Carl Brans, have developed a scalar-tensor theory that generalizes General Relativity. Dicke has explored consequences ranging from plate tectonics to a slightly different shape of the Sun.

CCN wants to know more about the microwave radiation just discovered by Arno Penzias and Robert Wilson and interpreted by Dicke, P. James E. Peebles, Peter G. Roll, and David T. Wilkinson (1965), as the cosmic background they had just 'predicted' and were preparing to search for. They seemed totally unaware that Alpher and Herman had predicted it in 1948. The Princeton physicists, or at least Dicke, considered a cyclic Universe that expanded and contracted forever, thus avoiding the creation of something out of nothing. The interview includes discussion of the history leading up to the famous back-to-back papers by the Bell Labs team (Penzias and Wilson, 1965) and the Princeton team (Dicke, et al., op. cit.) and the neglect of Alpher and Herman's earlier prediction.

I highly recommend this book. The author uses the fictitious interviews to present much factual information, revealing the personalities and attitudes of some of the principal players in twentieth century cosmology. Kragh is clearly an expert on the subject. The references include no fewer than six books and twenty-one scientific articles and book chapters by the author (three of them with coauthors), as well as two papers he posted on arXiv.

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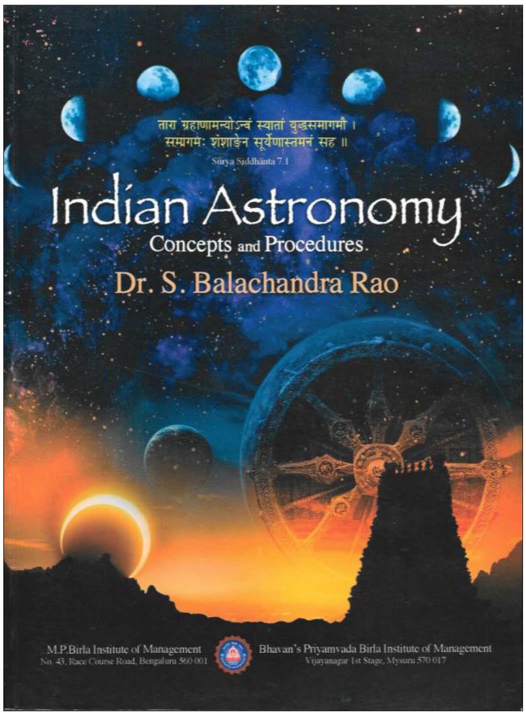
***Indian Astronomy: Concepts and Procedures*, by S. Balachandra Rao (M.P. Birla Institute of Management, and Bhavan's Gandhi Centre of Science and Human Values, Bengaluru, 2014), pp. [xiv] + 332. No ISBN (paperback), 180 × 240 mm, US$45.**

Indian astronomy stands apart from astronomy of other cultures due to its emphasis on precise calculations of motions of transient objects in the sky rather than discussions of stories and myths of constellations and zodiacs. Like most other cultures, it originally began with the realisation that twelve full moons brought the Sun close to its original zodiacal sign and hence twelve months make (nearly) a year—with a shortfall of 11 days. It therefore developed a concept of two intercalary months to be added to the lunar calendar every 5 years to synchronise the luni-solar calendar. This period was called a *Yuga* which was expanded significantly in later literature.

Since the exact time of the year and day was important for several ancient rituals, this initial arithmetic went on to take a complex root and the *Panchanga* or Indian almanac was born. *Panchānga* literally means 'having five limbs'. The five elements are:

(a) The *Tithi*, which is the time taken by the Moon in increasing its distance from the Sun by 12°. Since the motions of the Sun and Moon are always varying in speed the length of a *tithi* constantly alters;
(b) The *Nakshatra*, which marks the path of movement of the Moon. In one synodic revolution, the Moon travels through 27 stars fields that were said to form the 27 *Nakshatras* (lunar mansions);
(c) The *Vara*, or day of the week;
(d) The *Yoga*, the period of time during which the distance between the Sun and Moon is increased by 13° 20′ (~1 day); and
(e) The *Karana*, is half the *tithi*¸ during which the difference of the longitudes of the Sun and Moon is increased by 6°.



While the first three units are still in use, *Karanas* and *Yogas* are hardly used in day-to-day life.

Different aspects of these early concepts are found in some of the early astronomy, and *Tithi* and *Nakshatras* can be found in the earliest text of the *Vedanga Jyotisha* (the component of astronomy to the Vedas), which dates to about 1,000 BC. This text includes details of how to calculate solstices and other parameters that were needed for various rituals.

Since then works like the *Surya Siddhanta* (which dates to around 600 BC) significantly advanced our understanding of the skies. The *Surya Siddhanta* gives the method that should be used to determine the true motions of the planets, the Sun and the Moon. It gives the locations of several stars other than the *Nakshatras*, and it explains how to calculate the occurrence of solar eclipses as well as the solstices. The Earth's diameter and circumference also are given. Lunar eclipses, and the colour of the eclipsed portion of the Moon, are mentioned.

Building on this, Indian astronomers went on to define a complete coordinate system, and make precise calculations of the true motions of the Sun, the Moon and the planets, including occultation of stars. The mathematics they evolved for this was based on algebraic equations that needed sine and cosine functions for which reference tables were created. These calculations also needed accurate synchronisation with observations. The complete methodology and procedure was formulated around AD 500 by Aryabhata.

The methods of calculation are unique and interesting and give very accurate results for the period during which they were computed. They are of great significance to historians of Indian and world astronomy. Unfortunately there are very few well-written and concise books giving details of the methods of computation in English which can be easily accessed by a student who is new to this field. Dr Balachandra Rao has tried to fill this gap.

Rao is a very distinguished researcher in the mathematical subtleties of Indian astronomical calculations, and he has written several books on various aspects of astronomical calculations in ancient Indian texts. The present tome is designed as a text book for students of Indian astronomy, and it explains several aspects of these calculations in a systematic manner with examples and explicit solutions to several problems to help a student understand the complete intricacies of the working of the mathematical aspects of Indian astronomy.

The only problem with this book is that it gives a complete coverage of Indian mathematical astronomy without providing finer historical markings. The history of the subject is only covered in the first few pages, and the book then gets down to explaining various subtle terms used in these calculations and their context. This emphasis is made clear by the subtitle of the book: *Concepts and Procedures*. The book takes great care to refer most of the terms used in Indian astronomy to modern or English terms, and therefore is an excellent introduction for a student desirous of understanding how to calculate various astronomical terms. It will prove invaluable for this purpose alone. While discussing the calculations, Rao continues to use Indian terms, so a glossary of Sanskrit terms and (where possible) English translations would have been very useful.

This book is even more significant for scholars in its attempt to exhaustively cover all aspects of calculations that can be undertaken. The book has discussions on calculations of transits of Venus and Mercury, and occultations of stars and planets by Moon. It also discusses the evolution of the methods of calculation to improve the process of calculation over time. All this makes the book one of the finest for students who wish to learn astronomical calculations in ancient India.

In conclusion, Rao has produced an excellent and a very readable treatise on the concept and procedures used in Indian astronomical calculations and this will provide a very useful guide to all students wishing to learn about the subject.

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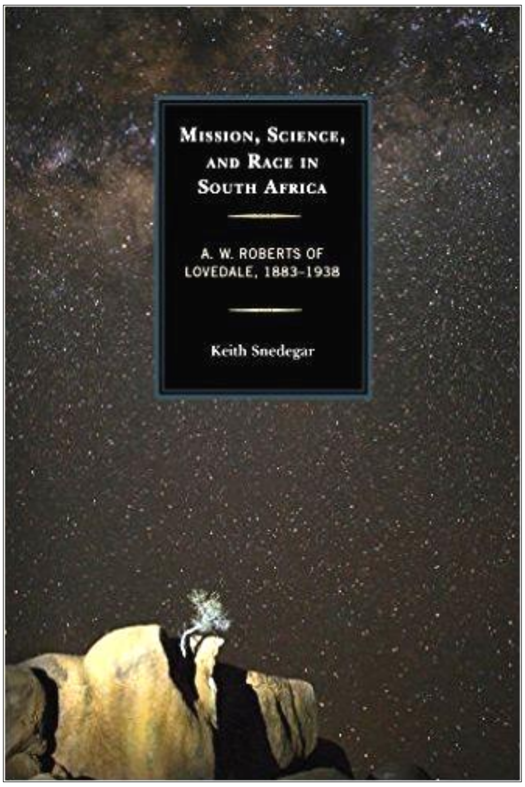
***Lost in the Stars: A.W. Roberts at the Crossroads of Mission, Science, and Race in South Africa 1883–1938*, by Keith Snedegar. (Lanham, Lexington Books, 2015), pp. xii + 189. ISBN 978-0-7391-9624-3 (hard cover) 978-0-7391-9625-0 (electronic), 160 × 234mm, US$80.00.**

This is the biography of a remarkable person who, though well-known to South African historians for his political work, deserves to be remembered worldwide for his astronomy. By day a lay teacher at the Lovedale missionary school in the rural Eastern Cape, by night he was a pioneering observer of variable stars. Late in life he came to play an important political role at the time when black Africans were beginning to claim their rights in the face of a complacent and generally-uninterested white minority government.

Alexander William Roberts came from a relatively poor Scottish family but was fortunately bright enough to receive a good education. He grew up a liberal Presbyterian and was to spend most of his life as an educator, Europeanizing and championing the rights of 'native' South Africans.

As a pioneer of serious amateur astronomy in South Africa he carved out an enviable reputation in the field of variable star studies, earning the respect of specialists in Europe and the United States of America. He eventually published nearly a hundred papers in scientific journals. This book conveys how difficult it was to do work of this kind from the isolated and austere institution of Lovedale. On top of it all, as a scientist, he was distrusted by his missionary colleagues. However, he soon began to receive encouragement from David Gill, W.H. Finlay and J.K.E. Halm, all professional astronomers at the Royal Observatory, Cape of Good Hope.

Arriving in South Africa in 1883, at first Roberts was limited to a pair of binoculars but later he could use a borrowed theodolite. Of particular interest to him were Algol-type variables such as R Arae that show eclipses. At that time, many pulsating stars were thought to be eclipsing also. Roberts appears to have been stimulated to undertake variable star observations by E.C. Pickering of Harvard. From the measured light curves he was able to derive a number of parameters of the variable systems, such as period, relative sizes of binary components, departure from sphericity, etc. It is curious how excited the small astronomical community was in those days over the discovery of even one new variable star!



Inevitably, visual observations were subject to personal quirks. Roberts' method was to bracket the variable between two other stars that were respectively fainter and brighter. To obtain the best results it was necessary to worry about which part of the field of the telescope was being used. Roberts sought to eliminate systematic effects by multiple observations of the rotated field. Through Gill's influence, around 1900 he was presented with a small properly-mounted telescope and a prefabricated dome, as well as a chronometer. The telescope had a special prism in front that allowed rotation of the field.

Recognition for his work came slowly but surely. He was one of the founder members of the (amateur) British Astronomical Association in 1890. He was elected to the Royal Astronomical Society in 1894, proposed by Gill. In 1896, he became a Fellow of the Royal Society of Edinburgh. In 1897 he visited a number of well-known astronomers and delivered a paper at the Royal Astronomical Society. On that occasion he was invited for dinner at the Royal Astronomical Society Club, a kind of 'Inner Party' of British astronomy. He was recognized in South Africa by the award in 1899 of an honorary doctorate by the University of the Cape of Good Hope.

In a 1901 paper on "Southern Variable Stars" he could list 93 variables.

His scientific influence grew greatly in the early twentieth century and he was a founder member of S2A3—the South African Association for the Advancement of Science. The Cape Astronomical Association was formed in (1912) also with Roberts as one of the founder members. This later developed into the Astronomical Society of Southern Africa.

By 1920 or so, Roberts's observing became very sporadic and he ceased to work up his light curves for publication. Snedegar suggests that this was partly due to shyness on account of his lack of theoretical competence. The book lists the stars that Roberts observed in detail, comprising Miras, semi-regulars, Algol-type and classical cepheid variables, with a smattering of rarer types and stars found to be constant.

As a quasi-politician in the twenties and thirties of the last century, Roberts was openly in favor of the franchise for blacks on the same basis as for whites, a very radical position for the time. He had become well-known in political circles both through his membership of educational committees and his activity in the South African Association for the Advancement of Science.

In 1920 he was appointed a member of the Native Affairs Commission, intended as an official channel of communication between the then government and the 'native' population. He often found himself at odds with the other members, who tended to be much more conservative than he was. Unfortunately, as time went on and governments changed, communication tended to flow in only one direction and he found himself having to justify the government's unpalatable policies, particularly in landownership matters. He was appointed a senator by the statesman J.C. Smuts, an amateur scientist himself, to be one of four who were intended to represent the interests of the non-white races. He was regarded as having their interests at heart in a sober and level-headed (i.e. politically-acceptable) way. Not unexpectedly, he tended to become more conservative as he aged although even then he sometimes stood on the toes of those who had championed his appointment.

Snedegar's study is a *tour de force* of research into the political and scientific background of the South Africa in which Roberts lived and made his mark. Snedegar tells us that his interest in Roberts started in the late 1980s. He has made exhaustive use of material from archives and other sources scattered worldwide. His understanding of the convolutions of South African racial politics is by itself impressive. For my own part I found it hard to put the book down, opening as it did for me so many aspects of the scientific and political life that prevailed a century ago.

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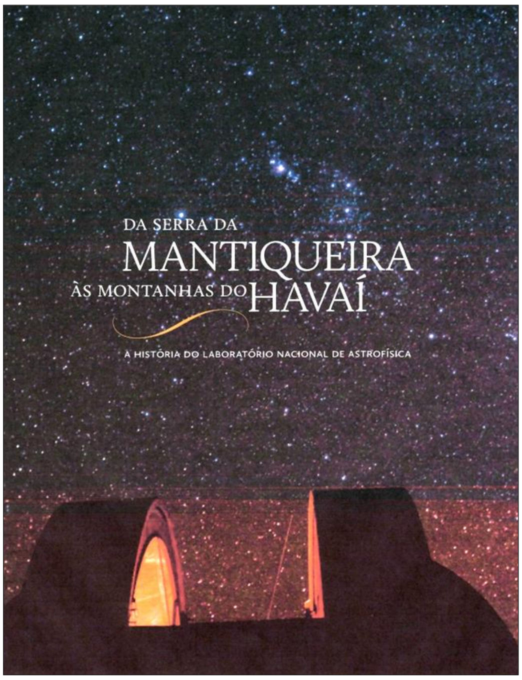
***Da Serra da Mantiqueira às Montanhas do Havaí – A História do Laboratório Nacional de*** **Astrofísica, by Christina Helena da Motta Barboza, Sérgio Tadeu de Niemeyer Lamarão, and Cristina de Amorim Machado. (Itajubá, LNA/MCTI, 2015), pp. 212. ISBN 978-85-98138-08-4 (paperback), 203 × 280mm. No set price.**

The plans to write this book about the history of the Laboratório Nacional de Astrofísica (National Astrophysics Laboratory, LNA) in Brazil began casually at a lunch in Brasilia during the 4th National Science and Technology Conference in 2010, when the then Director of the LNA, Albert Burth, asked me whether I knew anyone who could take on the task of researching and retelling the institution's history. The name of Cristina de Amorim Machado came to mind. Meanwhile, I myself would be a kind of project supervisor, since the budget did not stretch to paying more than one person. For bureaucratic reasons, an agreement had to be set up between the LNA and the Museu de Astronomia e Ciências Afins (Museum of Astronomy and Related Sciences, MAST) for Cristina to receive a research grant and have access to the MAST archives. Even before this was cemented, she started perusing the literature I had put her way. Still in 2010, we began having periodic meetings to discuss this pioneering project to recount the history of the LNA and the primary and secondary literature on astronomy in Brazil. I remained the official coordinator until the agreement was signed and the MAST took over the research and the writing of the book, designed to mark the 30th anniversary of the LNA.

The involvement of the MAST cast the project in a new light, changing substantially the nature of the resulting publication. After all, two institutions, both run by the Ministry of Science, Technology & Innovation, were now supposed to work together to produce a coherent version of the trajectory of the LNA from its beginnings until the present day. The end result, it must be said, is consistent with the new direction adopted when I stepped down as project supervisor. Cristina Machado carried on the work for some time, but she was not involved in writing the final draft of the book, since she had taken up a post as a Professor of Philosophy of Science and Research Methodology at the State University of Maringá.



As explained earlier, this book should be read as one version of the history of the LNA. As is common in the domain of history, other different versions could also be told. The story told here counted on the active participation of at least two of the institution's researchers: its former Director, Albert Bruch, and its current Director, Bruno Castilho. Both were involved in researching photographs, as credited on the title page. It is also important to stress that even before the MAST was involved, the project received wholehearted acceptance and support not only from the LNA's Directors, but especially from its employees, some of whom were interviewed and provided access to their personal archives. Without their involvement, this book could not have been written; indeed, nor could any other, since the LNA is still quite a young institution.

Something else that confirms the nature of this book is its Foreword by the former Minister of Science, Technology & Innovation, Aldo Rebelo. Similar projects have been pursued by other institutions from the same ministry. For instance, the Observatório Nacional (the National Observatory) and the Centro Brasileiro de Pesquisas Físicas (a Physics Research Institute) have both engaged in activities that resulted in the production of books, booklets and exhibitions. A major objective of many historical enterprises of this ilk is the opportunity to showcase past achievements in order to garner continued Government support for science in the future.

The book under discussion here is richly illustrated. There are five chapters, plus an Introduction and a Conclusion. The trajectory it describes is long, reaching as far back as the mid-1800s, when the Imperial Observatory of Rio de Janeiro began looking for a suitable site to install equipment for astrophysical research. The story then shifts to the 1930s, when a similar, also abortive, effort was made to equip the country with an astrophysical observatory. It was only in the 1960s, with the joint efforts of Luiz Muniz Barreto and Abrahão de Moraes, that things started to change. This phase, essentially the pre-history of the LNA, lasted some 20 years. Finally, in 1980, the first telescope for modern astrophysical research was installed on Brazilian soil. After these two initial chapters, the rest of the book presents a more strictly institutional perspective. The scientists themselves take supporting roles as the LNA is put center stage, and thus it continues to the end of the book.

In a bid to appeal to a wider audience, the book provides a glossary of technical and scientific terms, which helps readers understand many of the LNA's scientific projects and goals. The text itself makes pleasant reading, even if the tone becomes more official from the middle onwards, reflecting the work's institutional nature. The spotlight turns more to the LNA's achievements than those of its researchers, and the facts are more narrated than discussed. Some delicate periods from the institution's history are described, but some of the details are missing, even though many, if not most, of the people who lived through those times of tension—such as when the Brazilian Astrophysics Observatory (the original name of the LNA) split from the National Observatory—are still alive and active in their respective fields. In other words, this is not a book that will stir up any controversy. Rather, its aim is to show how much Brazilian astronomy has grown and matured through the work of the LNA.

Written by Barboza, Lamarão, and Machado, this book constitutes an important contribution to the history of astronomy in Brazil, but not just this. At least since the 1990s, the LNA has taken part in international projects like ESO and SOAR, in line with its institutional mission to coordinate the international work of Brazilian astronomers. The LNA effectively oversees Brazilian astronomy in other observatories in Chile, the United States and other sites where conditions for observing the sky are more favorable.

I do not know how this book can be acquired. I have only seen it in pdf format, even though it has already been printed. As it is institutional in nature, it will likely be distributed free of charge, but it can be accessed online on the LNA website (see http://lnapadrao.lna.br/acesso-a-informacao/institucional/livro_lna.pdf). The fact that it is written in Portuguese may prevent this important contribution to the history of Brazilian astronomy gaining wider attention. Until such a time as it is translated into English—which I hope will happen soon—readers may be interested in a research paper that was published in English in this very journal last year (Amorim Machado and Videira, 2015), which recounts some of the key events culminating in the creation of the LNA.

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