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

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COVER PHOTOGRAPH

This photograph shows the Vidyasankara Temple in Sringeri, India, which was constructed entirely of granite. This temple is architecturally unique, and was built on the banks of the Tunga River by Sri Bharati Tirtha and Sri Vidyanarya about A.D. 1350 as a memorial to their teacher, Sri Vidyasankara Tirtha. The interior of one half of the temple contains twelve elaborately-carved zodiacal stone pillars arranged in a square. In the course of the year sunlight at sunrise enters the temple through selected doorways and successively illuminates the different columns. However, the columns in question do not tally with the zodiacal constellations in which the Sun is located at the present time, but rather relate to the position the Sun occupied in the sky about 4,000 years ago. For information about this unusual temple and its remarkable astronomical associations see the paper by N. Kameswara Rao and Priya Thakur on pages 136-144 in this issue of the journal.

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WE'RE GOING GREEN—AND FREE

The November 2011 issue of this journal will be the last one published on paper. Starting with the March 2012 issue, the *JAHH* will be published online, and it will be available to readers everywhere at no charge.

We expect many benefits from the new policy. Most important, it should increase our readership substantially. The hard work put in by our authors and editors in writing and publishing articles will be repaid by having an increased number of readers. This should also expand the awareness of the journal among the history of astronomy community.

Additional benefits include savings in paper, printing, and postage, and the reduction of carbon emissions. In fact, the journal will be produced using only recycled electrons!

Articles will be available as pdf files, available for download from the SAO/NASA Astrophysics Data Service at <http://www.adsabs.harvard.edu/> (with twelve mirror sites around the world). Just go to http://adsabs.harvard.edu/toc_service.html and enter jahh for Journal Name/code and the volume or year you wish to download. All papers published in the *JAHH* in past years will also be posted on ADS, as time allows.

From 2012, our plan is to continue producing three issues per year, in March, July and November, each with between 85 and 100 pages. If you would like to be know when each new issue is posted on ADS please send an email now to jahh@sonic.net so that your name and email address can be entered on our master list. As each issue is completed we will send out a circular email message to all those on this list.

We realize that there will be some individuals and libraries who will still wish to read and store a paper version of the journal. For this reason, at the end of each year we plan to print out a complete volume (up to 300 pages, with a limited number of colour pages), including title page, table of contents and author and subject index, as a single issue. This version will be produced only for those who have prepaid. Late requests for printed copies cannot be fulfilled.

We anticipate that the cost of this annual hard copy volume in 2012 will be €50 (about US\$75 currently), including postage and shipping (with exactly the same price for private individuals and for institutions). Those interested in receiving this paper version should inform Associate Editor Hilmar Duerbeck either by e-mail (hilmar@uni-muenster.de), or by letter (Postfach 1268, 54543 Daun, Germany), no later than 1 July 2012. An invoice will subsequently be sent out, and the annual copies will be mailed out soon after the final issue of the 2012 volume is completed.

If you have any queries do not hesitate to email the Editor (Wayne.Orchiston@jcu.edu.au), or either of the Associate Editors (hilmar@uni-muenster.de or joe.tenn@sonoma.edu).

Wayne Orchiston, Editor
Hilmar Duerbeck, Associate Editor
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HIGHLIGHTING THE HISTORY OF FRENCH RADIO ASTRONOMY. 7: THE GENESIS OF THE INSTITUTE OF RADIOASTRONOMY AT MILLIMETER WAVELENGTHS (IRAM)

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Abstract: Radio astronomy in France and in Germany started around 1950. France was then building interferometers and Germany large single dishes, so it was not unexpected that their first projects involving millimetre radio astronomy were respectively with an interferometer and a single dish. In this paper, we explain in detail how these two projects finally merged in 1979 with the formation of the Institute of Radio Astronomy at Millimetre wavelengths (IRAM), after a long process with many ups and downs. We also describe how Spain started radio astronomy by joining IRAM. Presently, IRAM is the most powerful facility worldwide for millimetre radio astronomy.

Keywords: radio telescope, radio interferometer, IRAM, radio astronomy, millimetre waves

Dedication: We wish to dedicate our paper to the memory of Émile-Jacques Blum (1923–2009), who played a major role in the construction of IRAM but died before he could participate in the writing of this paper. An interview made one month before his death was very useful in the preparation of this paper.

1 INTRODUCTION

In France, radio astronomy started in 1947 at the Physics Laboratory of the École Normale Supérieure in Paris, soon after WWII (see Orchiston and Steinberg, 2007). There was soon an interest in solar interferometry, when fringes were obtained at 3 cm wavelength by Jacques Arzac and Jean-Louis Steinberg in May 1952 (Lequeux et al., 2010). In 1954, the radio astronomy group moved to the Paris Observatory (Meudon), with an observing station at Nançay on grounds purchased by the École Normale Supérieure (see Orchiston et al., 2007). There, Émile-Jacques Blum (Figure 1) built a large E-W solar interferometer operating at 169 MHz. This was completed in 1956, and was followed in 1961 by a N-S solar interferometer (Pick et al., 2011). Between 1959 and 1963 James Lequeux used another interferometer at 1420 MHz which was made from two German 7.5-m diameter Würzburg antennas and was movable on rails (Orchiston et al., 2007). As early as 1953, Jean-François Denisse and Jean-Louis Steinberg proposed a larger interferometer consisting of two movable 25-m antennas, for observation of the 21-cm hydrogen line and in the continuum. However, this project was abandoned the following year, only to be replaced by Le Grand Radiotelescope, the construction of which began in 1956 and was completed in 1967 (Lequeux et al., 2010). This caused some frustration for several

members of the staff who saw more future in interferometry, which at the time was rapidly being developed in Australia, in Great Britain at Cambridge and Jodrell Bank, and at the California Institute of Technology (Caltech) in the U.S.A.



Figure 1: Émile-Jacques Blum (1923–2009) around 1970 (courtesy: Observatoire de Paris, Station de Radio-astronomie de Nançay).



Figure 2: The 8-mm two-element interferometer at the Bordeaux Observatory in 1973 (courtesy: *Observatoire Aquitain des Sciences de l'Univers*).

In Germany, radio astronomy started thanks to the efforts of Leo Brandt (1908–1974), an electronic engineer and radar pioneer who became in 1949 the Secretary of State of Nordrhein-Westfalen. He initiated the creation in Stockert, near Bad-Münstereifel-Eschweiler, of a radio observatory equipped initially with a Würzburg antenna, and later with a 25-m diameter radio telescope, completed in 1956 (Menten, 2008; Wielebinksi, 2007). The ownership of this Stockert radio telescope was shared by the University of Bonn and a research institute for high frequency physics.¹ It was one of the best steerable dishes at this time. After this success, the Volkswagen Foundation promised money in 1964 to build a larger radio telescope, and this stimulated the creation in 1966 of the Max-Planck-Institut für Radioastronomie (MPIfR) in Bonn. Otto Hachenberg (1911–2001), who had been teaching radio astronomy at the University since 1962, became the first Director of this Institute, and the Stockert radio telescope became his responsibility. The new instrument financed by the Volkswagen Foundation was the 100-m Effelsberg radio telescope, which was completed in 1972 (Hachenberg et al., 1973; Wielebinksi et al., 2011). Thanks to these radio telescopes, Germany acquired expertise in the design and construction of large steerable dishes, while France



Figure 3: The 2.5-m diameter POM 1 antenna on top of its building at the Bordeaux Observatory; this antenna was previously one of the two elements of the interferometer shown in Figure 2 (courtesy: *Observatoire Aquitain des Sciences de l'Univers*).

gained expertise in interferometers. Thus it was natural that future projects in each country were oriented in these respective directions. It was also clear that the future lay in the millimetre wavelength range, which was almost unexplored in the 1950s and 1960s.

2 THE INITIAL IDEAS

In France, the first ideas about a millimetre interferometer arose in 1964, when Blum replaced Denisse as the Head of the Paris Observatory's Radio Astronomy Department and of the Nançay field station. At that time, Blum was building the first three receivers for Le Grand Radiotelescope in collaboration with Jean Delannoy, Émile Le Roux and Léonid Welichew (1936–1986), but his main interests were already in interferometry and in the millimetre wavelength range.

By a fortunate coincidence, Bordeaux Observatory and the University of Bordeaux wanted to enter radio astronomy at this time, so Blum and Delannoy had little difficulty convincing Pierre Sémirot (1907–1972), the Director of the Observatory, and Roger Servant (1909–1987) and André Charru (1931–2003)—both of whom were professors at the University and members of its ultra-hertzian optics laboratory—to build a millimetre interferometer at the Observatory. Starting in 1966, this resulted in the financing of a prototype interferometer with two fixed 2.5-m diameter antennas on altazimuth mounts, working at 8 mm (Delannoy et al., 1973) which was designed to observe the Sun (see Figure 2). Delannoy then moved to the Bordeaux Observatory to build this interferometer. Construction began in 1967, and the instrument was finished in 1973. It was used successfully over a number of years for solar observations, then it was dismantled. One of the antennas, christened the 'Petite Opération Millimétrique 1' (POM 1; see Figure 3) remained in Bordeaux (Baudry et al., 1980), while the other (POM 2) was given to the newly-created observatory in Grenoble and installed on Plateau de Bure near Gap (Hautes-Alpes) in 1986 (Castets et al., 1988).

The few scientists who took an active part in the construction of Le Grand Radiotelescope at Nançay in rather difficult conditions were exhausted by the time of its completion in 1967, and partially lost interest in this instrument. Steinberg left to work full-time in the Space Radio Astronomy Laboratory that he had created in Meudon, while Blum spent six months at Charlottesville (Virginia) at the National Radio Astronomy Observatory (NRAO) in order to become familiar with millimetre techniques. This was when construction of the Very Large Array (VLA) was beginning so Blum could see what a major radio astronomy project was really about, and he was conscious of the importance of the receivers in such a project. He also realized that financing a large instrument would probably be easier than financing a small one, at least in a European context. He also met Peter Mezger, who was then at the NRAO and later was to be his main interlocutor at the MPIfR. For his part, Lequeux, with a few enthusiastic young scientists, founded the first Infrared Laboratory at the Meudon Observatory. They used a balloon to obtain the first submillimetre spectrum of the Sun, and installed a small submillimetre observatory at the Gornergrat in Switzerland at an altitude of 3,200 m, where they measured atmospheric transmission. They also calculated this trans-

mission as a function of precipitable water (Lequeux, 2009: 135-136). In the summer of 1968, Lequeux left for a year to Caltech where he observed with the 2×25 -m interferometer at the Owens Valley Radio Observatory (OVRO). Clearly, the time was ripe in France for a millimetre interferometer.

3 THE FIRST REQUESTS FOR FINANCING

At the end of 1967 a group of French radio astronomers, including Blum and Lequeux, met several times with Ronald J. Allen, a Canadian scientist who was a Post-doctoral Fellow at Meudon, in order to elaborate a plan for the future. They proposed a medium-size project costing 10 million francs (10 MF)—equivalent to 11 million in 2008 Euros (11 M€),²—and involving an interferometer between the Le Grand Radiotelescope at Nançay and one or two 40-m dishes movable on N-S rails. They also proposed a larger project: a national instrument or participation in a European project in the centimetre-millimetre domain, which could be either a large single dish or an interferometer. The requested sum for this more ambitious project was 20 MF (≈ 22 M€), as a part of a large instrument estimated at about 150 MF (≈ 170 M€).

The scientific motivations for going to millimetre wavelengths were rather vague at this time. One of the arguments was that the synchrotron radiation from quasars was expected to become optically thin at millimetre wavelengths, allowing scientists to penetrate deeper into the cores of these objects. This was also the case for the thermal radiation of very compact HII regions and planetary nebulae. One also hoped to study the thermal radiation from the planets and to detect that of their satellites, because it was stronger at shorter wavelengths. The best argument, although not easily accepted by financing authorities, was that one could hope for unexpected discoveries in this almost unexplored wavelength range. The report of the French radio astronomers, dated February 1968, summarized the arguments:

The centimetre and millimetre domain (from 1 mm to 21 cm) is certainly the richest in possibilities because it is there that radio sources exhibit anomalies in their continuum spectrum and time variations, and also that the line spectrum is by far the richest and the most interesting.

The cosmological problems that will certainly be central to investigations in the coming years will be approached with the highest chances of success by large instruments at centimetre wavelengths.

Finally, the relation with the almost unknown infrared and submillimetre domains gives to millimetre instruments a particular interest. (Préparation ..., 1968: 2; our translation).

The mention in 1968 of a rich line spectrum in the millimetre range is of interest. Clearly the proponents were thinking of recombination lines of hydrogen and other elements, and also of rotation lines of interstellar molecules, of which only a few were known at this time. The discovery in 1970 by Penzias and Wilson of many interstellar molecules through their millimetre lines was to give a new impetus to the field and better arguments for the project.

As for interferometry, it was claimed in the report that this would allow better angular resolution than a single dish, and good positions allowing identification

of radio sources with optical objects: this was indeed one of the main objectives of the OVRO interferometer, which was then meeting with much success (see Cohen, 2007). It was also thought that an interferometer would be better suited than a single dish to observe very faint sources since these would produce a coherent signal on the different antennas while the atmospheric thermal noise would be uncorrelated. In more practical terms, construction of an interferometer looked easier, at least in France, than that of a large single dish, and the French radio astronomers had strong expertise in the relevant techniques. In addition, one could begin small and progressively enlarge the instrument by extending the baselines and adding more antennas.

A further plea for the new facility was written by Blum in January 1970. There were now budgetary restrictions for research and it was clear that an interferometer between Le Grand Radiotelescope at Nançay and movable antennas had to be abandoned. Meanwhile, the chance of obtaining the requested 20 MF for the other project was small, because the total amount foreseen for allocation to astronomy during the 6th Plan, starting in 1971 (at this time research was planned in periods of five years), was only 27 MF (≈ 27 M€). However, Blum (1970: 3; our translation) insisted that

A large new instrument is necessary to replace the large [Nançay] radio telescope ... This radio telescope is presently in full productivity. In a year, [the Effelsberg 100-m radio telescope] will begin to be a competitor, and it is probable that within 5 to 6 years there will be a risk that the originality of the scientific programs will decrease.

Another competitor not mentioned in this submission, but one that was even more powerful than the 100-m radiotelescope, was the Westerbork array, which had only just been inaugurated (see Raimond, 1996), as it was more sensitive than Le Grand Radiotelescope at Nançay, especially at 21-cm, and could obtain images of radio sources. The idea of a single dish was then abandoned by the proponents of the French project (at that time Blum, Delannoy, Encrenaz and Lequeux), who were all in favour of an interferometer. Eventually, their proposal was accepted for the 6th Plan, but with a reduced scope and without a financial commitment. Nevertheless, this acceptance could be considered as official approval, a necessary but not sufficient condition for financing. This was to be the beginning of an eight-year struggle.

During these eight years, the main interlocutors of the proponents on the French side were Bernard Grégory (1919–1977; Figure 4) and then Robert Chabbal, General Directors of the Centre National de la Recherche Scientifique (CNRS); Pierre Creyssel (1933–2007; Figure 5), Administrative and Financial Director of the CNRS; Jean Delhaye (1921–2001), Director of the Institut National d’Astronomie et de Géophysique (INAG) of the CNRS; and Pierre Charvin (1931–1991), Scientific Secretary of INAG for astronomy. On the German side, they were Reimar Lüst (Figure 6) and Friedrich Schneider, who were President and General Secretary respectively of the Max-Planck-Gesellschaft zur Förderung der Wissenschaften (MPG).



Figure 4 (left): Bernard Grégory (courtesy: *Archives du CNRS*).
Figure 5 (right): Pierre Creyssel (courtesy: *Archives du CNRS*).

4 REVIVAL OF RADIO ASTRONOMY AT THE ÉCOLE NORMALE SUPÉRIEURE

For a start, Blum was told by the INAG that there would be no funding for the project before 1975. Nonetheless, a project team, led by Patrick Dierich, was organized by the radio astronomers, and a technical team of six people under Gérard Beaudin started studies in Meudon in January 1972. Then, unexpectedly, a fresh opportunity soon arose through the creation of a new laboratory for millimetre radio astronomy in France.

In 1973, Yves Rocard (1903–1992), the Director of the Physics Laboratory at the École Normale Supérieure (ENS, where French radio astronomy had started), retired. At this time there were three main research foci of this Laboratory: quantum optics, solid state physics and theoretical physics. Rocard's successor, Jean Brossel (1918–2003), was very interested in radio astronomy, presumably due in part to the influence of Charles Townes, who had spent lengthy periods at the laboratory and in the 1970s had made vibrant pleas for the possible detection of interstellar molecules via their millimetre lines. Aided by his collaborator, Michel Glass, Brossel decided to set up a new Laboratory for Millimetre Radioastronomy, and this was created in 1975 under the leadership of Pierre Encrenaz, but with close ties to the radio astronomy group at Meudon. Françoise Combes, Denis Créte, Édith Falgarone and Robert Lucas soon joined the scientific staff, then Alain Omont and others in following years, along with a number of graduate students. For their observations they used three American millimetre radio telescopes, located at Kitt Peak National Observatory in Arizona, McDonald Observatory in Texas and the Aerospace Corporation in El Segundo, California, which were the only ones available at that time. Several distinguished colleagues visited the Laboratory for more than three months, including Harm Habing, Arno Penzias, Paul Richards, Ken



Tucker, Robert Wilson and Gerard T. Wrixon.

Two engineers from the Physics Laboratory formed the technical staff, along with two other people. Working in close collaboration with those at

Figure 6 (left): Reimar Lüst (courtesy: *Max-Planck-Gesellschaft*).

Meudon, they constructed millimetre detectors and closed-circuit helium cryogenerators in order to cool the receiver front-ends. A state-of-the-art prototype millimetre receiver using these new techniques was built for the CO line at 115 GHz by the Meudon and ENS groups and technicians from the Bordeaux Observatory, under the leadership of Gérard Beaudin. In 1976 this was completed, and it was installed for testing on the POM 1 radio telescope.

The crucial element of radio astronomy receivers, which are all heterodyne, is the detector junction, a non-linear element where the signal from the antenna combines with that of the local oscillator. In the 1970s, the only ones working at millimetre waves were Schottky junctions in which a tiny wire (the so-called whisker) made a contact with a semiconductor, generally gallium arsenide. They were not available in Europe, so that the ENS group invited to Paris one of the key people from the Sperry Rand Corporation which produced these junctions in the USA. As a reward, he brought a few of these precious detectors (Figure 7), and they were used for the prototype receiver.

The ENS group also developed a closed-circuit helium cryogenic system giving a cooling power of 1 watt at 2 K, and another system using acoustic waves in a 'pulsed gas tube'. Unfortunately these developments did not generate interest within the French Air Liquide Company, which lost in this way an early opportunity to commercialize cryogenerators. These machines are currently in widespread use for the many millimetre receivers under construction and for medical applications like magnetic resonance imaging.

5 DEVELOPMENTS IN GERMANY AND PROBLEMS IN FRANCE

During those years, interest was also growing at the MPIfR in the millimetre wavelength domain, but the situation was considerably easier than in France. In 1971, the 100-m radiotelescope was already in the final stages of construction, and the MPIfR was dreaming of a large millimetre radio telescope and was looking for finance from the Volkswagen Foundation. This was subsequently obtained, and under the supervision of Peter Mezger—who was appointed as another Director of the Institute—work started on millimetre receivers and on bolometers for the millimetre-submillimetre range.

On the psychological side, the situation was different in the two countries. The Germans had a remarkable new large radio telescope which could be used down to 1 cm wavelength. It was mainly under the responsibility of Richard Wielebinski, who was one of the three Directors of the MPIfR. Meanwhile, millimetre radio astronomy was the domain of another Director, Peter Mezger, so that there were no strong grounds for internal competition. In France, Le Grand Radiotelescope at Nançay was much less versatile than the Effelsberg dish and in practice was only usable down to 10 cm or so (see Lequeux et al., 2010). As we have seen, these limitations were used as an argument in favour of their proposal by those promoting the millimetre interferometer. These people held the power in the radio astronomy group, Blum being the only Director, backed by several of the most active scientists of this group. However the millimetre pro-

ject was seen by the other members of the Laboratory, and especially by the technical personnel, as a competitor which was diverting means and people from their own activities. Long-standing uneasy feelings arose, resulting much later in a splitting of the Radio Astronomy Department into ‘millimetre’, ‘decimetre’ and ‘solar’ radio astronomers. The millimetre project found little support also amongst the financing authority, the INAG, which was dominated by ‘classical’ astronomers not much interested in radio astronomy. The INAG gave priority to the Canada-France-Hawaii 3.60-m telescope, which was to absorb most of the funding for several years. This was the main difficulty encountered by Blum and the other proponents of the new project. The problems described in this paragraph are the subject of a very interesting study (Darmon, 1981) which was quite useful in the preparation of this paper.

Another point of friction between Blum and the INAG was Blum’s idea of setting up a Visiting Committee for his Radio Astronomy Department. While this was common practice in foreign radio astronomy institutes (e.g. Blum was a member of the MPIfR *Fachberreit* and of the *Foreign Advisers Committee* of SRON, the Netherlands Foundation for Radio-astronomy), it was rejected by the French scientific authorities who were anxious to preserve their prerogatives. Blum never succeeded in getting an official Visiting Committee, but he gathered every few years an unofficial one consisting of several foreign experts. This turned out to be very useful for the development of the millimetre project, because Blum had no difficulty in convincing three foremost colleagues to give their advice on the project at a crucial time, as we will see later.

6 TOWARDS AN INTERNATIONAL PROJECT

Given the unlikely prospect of funding a national project in France in 1971, a possible solution was to propose a European one. Following the initiative of the Dutch astronomer Jan Oort (1900–1992), a member of Blum’s unofficial visiting committee, some contacts had already been made between the main European radio astronomy institutes, but with little success. Moreover, the French were not initially in favour of an international project, preferring to start small and to extend later their own project. They thought of beginning with two 25-m antennas that were good at 8 mm, an obvious adaptation of the 1953 interferometry project, and to add other 25-m dishes later. But the future became even bleaker when a new project competing for money was officially announced in January 1972: an ionospheric incoherent scattering sounder named the *European Incoherent SCATter facility* (EISCAT), which was also to be financed by the INAG. However, the millimetre project was not completely abandoned, as a modest sum of 0.7 MF (≈ 0.43 M€) was allocated in 1973 for technical developments and site studies. But the proponents were urged by the INAG to search for international co-operation.

The opportunity came from the Committee for scientific and technological policy of the *Organisation de Coopération et de Développement Économique* (OCDE), which discussed ‘mega-science’ projects starting with astronomy. At its meeting held in Paris on 27 and 28 February 1973, cooperation in millimetre radio

astronomy between France, Germany and Great Britain was recommended. The representatives for science of the three countries seized this opportunity and, after several meetings, decided on 2-3 August 1973 to finance a European laboratory to build diodes for millimetre mixers. We have seen that these diodes were then only produced in the USA. They were so crucial that the European countries wanted an independent source. The idea of a devoted European laboratory was strongly pushed by R.E. Jennings in UK, Mezger and Gispert Winnewisser in Germany, Blum and Encrenaz in France, and also by Erik Kollberg in Sweden, a country which was also developing millimetre astronomy. The laboratory was installed in Cork (Ireland) in 1974. It was directed by Gerard T. Wrixon, an Irish-born scientist who came from the Bell Laboratories.³ The first junctions were produced in 1977, with satisfactory results at 115 GHz (Figure 8).

At the same time, the IBM Watson Research Center at Yorktown Heights (New York) and the Bell Laboratories at Murray Hill (New Jersey) were beginning developments on superconductor-insulator-superconductor (SIS) junctions which were expected to be better than the Schottky ones. The Meudon and École Normale groups decided to enter the field, in spite of unfavourable advice from the Solid State Physics Laboratory at the École Normale Supérieure. They worked on niobium/magnesium oxyde/niobium SIS junctions which indeed proved later to be the way to go. In Garching near Munich in Germany, similar SIS junctions, first using lead, then niobium, were built successfully by Karl Heinz Gundlach and Hans Hartfuss in the Max-Planck-Institut für Plasmaphysik for diagnostics of plasma radiation in machines for fusion studies. Gundlach and Hartfuss moved to IRAM at its creation in 1980 in order to continue the development

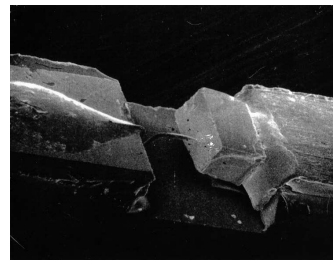
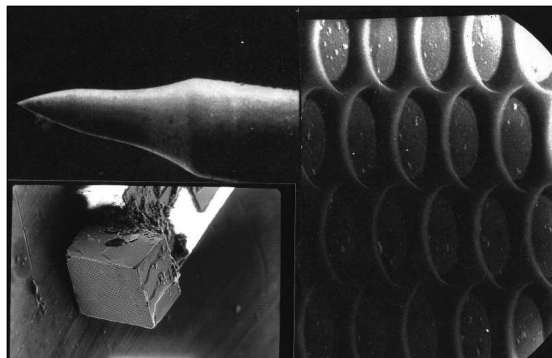


Figure 8: Electron micrographs of a Schottky junction built in the Cork laboratory in 1977. Bottom left: the substrate block with small pits where the whisker can make contacts, general view. Top left: the whisker point. Right: the network of pits. The two last images are taken with much larger magnification than the first one (courtesy: Laboratoire de Physique, École Normale Supérieure).



and fabrication of SIS junctions for the IRAM receivers.

Let us return to 1973. On 6 August the OCDE representatives also decided to create a *Scientific Advisory Group for Millimetre Astronomy* (SAGMA). On 8 October 1973 this group defined a European millimetre project, that they estimated at 36.6 million Deutschmarks (equivalent to 54 M€). It would consist of a 30-m radio telescope built by the Germans from 1976 on and financed mainly by the Volkswagen foundation outside this budget, and an interferometer built in two steps: first a 10-m antenna constructed by Great Britain, to be ready in 1975, followed by three additional 10-m antennas which would be operational by the end of 1978. The choice of 10-m for the diameter was dictated by the British. The two instruments would be placed at a common site, for which studies would start in 1974, shared between the three countries.

The Germans started immediately by establishing a contract with ARGE (the Krupp-MAN consortium) in order to study the 30-m radio telescope. They had their own ideas about a suitable site: they wanted to avoid France, because they were afraid of political instability and strikes and also because two German-French scientific institutes (the Max von Laue-Paul Langevin Institute in Grenoble and the Grenoble Laboratory for Intense Magnetic Fields) were already installed in France. So they looked at possibilities in the Sierra Nevada in southern Spain and on Mauna Kea in Hawaii. However the French were reluctant to go to Hawaii.

Unfortunately, by this time research in Great Britain was suffering from serious financing difficulties, and in January 1974 they withdrew from the EISCAT project and warned that they might also have to withdraw from the millimetre project. However, as a safeguard they decided to participate in the site testing which was to be conducted over four months during the summer of 1974. Possible sites, which had to be at high elevation where there was little precipitable water in the atmosphere, and sufficiently flat to accommodate an interferometer, were selected from detailed maps and meteorological archives. Mountains in France, the Atlas Mountains in Morocco, the Sierra Nevada and the Canary Islands were all considered, but Morocco was eliminated because of difficulties in the logistics, southern Spain because no sufficiently flat site was obvious at high elevations and the Canary Islands because the possible sites were protected areas. Three possible sites remained in France after Blum, Dierich and Lequeux had made a number of visits and taken some topographic measurements: the Pla de la Padrille near Font-Romeu in Pyrénées-Orientales, the Plateau de Bure in Hautes-Alpes and the Causse de Montbel in Lozère. British, German and French personnel then carried out studies at these three sites, which included the measurement of precipitable water with a specially-designed infrared hygrometer. The Plateau de Bure, at 2550 m elevation, turned out to be by far the best of these sites.

In 1975, 2 MDM (about 2.3 M€) were allocated to the project by the Max-Planck-Gesellschaft, which had already spent 3 MDM on it. The financial situation was much less favourable in France: only 1.03 MF (≈ 0.66 M€) were allocated in 1975, whereas the pro-

ponents of the interferometer were hoping for a financial allocation similar to the German one. Moreover, Great Britain withdrew completely from the project in April 1975, and decided instead to join with the Netherlands and construct its own millimetre facility. The result was the 15-m James Clerk Maxwell radio telescope in Hawaii, which became operational in 1987.

SAGMA then considered it necessary to find another partner. The NRAO was approached but declined, so any possibility of installing the instruments in Hawaii vanished. Spain was considered in the summer of 1975 (see later), but it was judged premature by Blum and others to start negotiations because of the uncertainties in the political situation before and after the death of Franco on 20 November 1975. However, the German collaborators insisted on siting the 30-m radio telescope in southern Spain, preferably at Calar Alto, where there was already a German-Spanish optical observatory. The official reason was that this location offered better access to the Galactic Centre than the French site, but in reality the MPG also wanted to smooth out political difficulties that had arisen from a previous near-colonialist attitude at the Calar Alto Observatory. As it happened, Calar Alto turned out to be a poor site for millimetre observations, and after a short site study Pico Veleta in the Sierra Nevada, which was at a much higher altitude, was favoured.⁴ Blum and Jesús Gómez-González carefully reconsidered the idea of installing an interferometer in this area (see later), but with no positive outcome.

As a consequence, the millimetre project faced two big difficulties: (1) a severe lack of money, due to competition from other projects in France and withdrawal of the British, and (2) the fact that no single site suited the needs of the two partners. In order to resolve this deadlock, Grégory and Creyssel for the CNRS, and Lüst and Schneider for the MPG—all of whom had supported the project from the beginning—with Blum's help decided to set up a panel of international experts to formulate recommendations. This panel consisted of three well-known radio astronomers: Bernard Burke (from the Massachusetts Institute of Technology), Ken Kellermann (from the NRAO) and Paul Wild (1923–2008), Chief of the CSIRO's Division of Radiophysics in Australia. They met in June 1976, visited sites and institutes and on 26 June provided the following conclusions

The Plateau de Bure is by far the better of the two sites to locate the interferometer, even though the latitude is higher than ideal.

The Pico Veleta is by far the better of the two sites to locate the 30 m telescope, even though it is remote from centres of relevant expertise and is a relatively inconvenient place to live.

We believe that to choose between the two sites would favour one instrument at the expense of the other.

The *modus operandum* described in the SAGMA report places the main emphasis for controlling and developing the project separately in the two parent institutes.

... We believe that the centre of the cooperative programme should be located in an observatory headquarters. ... We suggest that Grenoble would be a highly suitable city in which to locate the headquarters owing

to its concentration of scientific and technical activities and its proximity to one of the sites being proposed [Plateau de Bure, at 90 km] (cited in Darmon, 1981: 180-181).

Retrospectively, it is clear that the experts had little choice when drawing their conclusions. However, their support for the project in general, for utilising two different observing locations and for siting the headquarters in Grenoble was crucial for the success of the project. The suggestion of Grenoble as the headquarters came as a result of a proposal by the President of the University, Michel Soutif, to build the new institute on the University grounds, together with a new astrophysics laboratory (which was indeed created and later became an astronomical observatory).

In spite of some reservations from Mezger about the choice of Grenoble—which was not so easily accessible from Bonn—the conclusions of the experts were accepted by the MPG and the CNRS, and the *Conseil de Direction Provisoire Intérimaire* (Provisional directorate) was created. This was led by Wolfgang Hasenclever, a former Director of the von Laue-Langevin Institute in Grenoble. This Council started work immediately on the possible statutes of the new institute, which was named the Joint Institute for Millimetre Radioastronomy (JIMA).

7 THREE YEARS LOST BEFORE THE FINAL DECISION

Unfortunately the situation in France did not improve in spite of all this progress. Grégory left the Directorship of the CNRS in July 1976, only to be replaced by Chabbal who was much less in favour of the project. Fortunately, Creyssel was still there to support it. Grégory became *Délégué Général à la Recherche Scientifique et Technique*, an important position from which he could still exert some pressure in favour of the project, and he was soon to act. At the beginning of December 1976 he and Jacques Sourdille (1922–1996), State Secretary for Research, spent two hours at the École Normale Supérieure. They started by visiting the Physics Laboratory and discussed the radio astronomy project with the Director, Brossel. The latter was so supportive of this project that he said that the École Normale Supérieure had enough funds to buy the land at the Plateau de Bure if necessary—just as it did in 1953 to form the Nançay radio astronomy field station. Suitably impressed, Grégory then wrote an enthusiastic report in which he recommended that France finance the whole project, even if Germany failed to contribute. Clearly this went against the wishes of Chabbal, the new Director of the CNRS, yet Grégory continued to actively support the project until his sudden death a year later, on 24 December 1977.

The French budget for JIMA for 1977 and even 1978 was uncertain, to say the least. To worsen the situation, the MPG was short of money in 1977 and had to delay financing of the new institute until 1978, but it did give a firm commitment. In France, after difficult discussions, 2.5 MF (≈ 1.3 M€) were allocated on 28 June 1977 by Sourdille for 1977 and 1978, this sum being blocked for the time being! In view of the new delays implied by the lack of funding, the two main French proponents, Blum and Lequeux, on 4 July 1977 sent separate letters to the INAG by which they announced their resignation from the project team. Shocked, the MPG put pressure on the CNRS-INAG

to proceed with the project, so the INAG designated Encrenaz and Weliachew as substitutes for Blum and Lequeux. All this turmoil had some effect on the CNRS, with the consequence that at a meeting of the MPG in Düsseldorf on 29 November 1977 Chabbal presented a new funding plan for the French participation in the project: 83 MF (≈ 42 M€) to be spread over eight years, from 1978 to 1985. This looked very slow, but at least the whole project was saved. At this meeting, the two partners even appointed a Project Manager, K. Johnsen, who had previously been Project Manager at CERN in Geneva. For the time being, 0.5 MF (≈ 0.25 M€) were allocated to the French radio astronomers in order for them to test their millimetre receiver on the POM 1 antenna in Bordeaux. Blum and Lequeux rejoined the project on 8 February 1978, at the request of the INAG.

The way was now open to finalize the creation of the new institute, and the formal agreement creating IRAM was signed between CNRS and MPG on 2 April 1979. According to this document, both instruments should be able to operate down to a wavelength of 1.8 mm, and the interferometer should have a total area of 300 m².

8 SPAIN JOINS IRAM

Radio astronomy in Spain began in 1971 when Jesús Gómez-González, then a fresh graduate student, was sent by the Universidad Complutense de Madrid to the Paris Observatory (Meudon) to obtain a Ph.D. in this field. The University's idea was to create in its Department of Electromagnetism a small group of radio astronomers who would be able to use the new 64-m antenna that NASA was installing at its Robledo de Chavela tracking station (60 km N-W from Madrid) during its 'idle time'.

Gómez-González stayed at the Department of Radioastronomy in Paris from 1971 to 1974, at the time when the French and German projects on millimetre radio astronomy were converging into what would eventually become IRAM. Accordingly, Blum asked Gómez-González to take part in the site study by examining maps of the Sierra Nevada region for possible sites for the interferometer (as by this time it was already clear that the 30-m dish would be installed in southern Spain). This search continued in 1976 when Blum and Gómez-González took a trip by road from the Calar Alto Observatory (which had just been dedicated) to Granada and personally inspected various possible sites, but none was found to be convenient. In this way, radio astronomy in Spain and IRAM were connected from the very first moments of their respective developments.

By the end of 1974, when Gómez-González returned to Spain, interest in radio astronomy had shifted from the University to the Royal Observatory in Madrid, which was a Department of the Instituto Geográfico Nacional (IGN). At this time, the Observatory had ordered a 14-m millimetre radio telescope from the U.S. Company ESSCO. The IGN agreed that Gómez-González should move to the Observatory and take charge of the new radio telescope which was subsequently installed at the Yebes Observatory in 1976-1977. Direct contacts took place with three radio astronomers at the MPIfR, Jaap Baars, Albert Greve and Johann Schraml, who were sent by Mezger to help



Figure 9: Rodolfo Núñez de las Cuevas in about 1980.

with the commissioning and calibration of the 14-m dish. In 1975, it became clear that when the time was right the IGN should become the Spanish partner in the IRAM project, as its Director, Rodolfo Núñez de las Cuevas (Figure 9), warmly supported that idea. In 1977, Blum and Encrenaz had their first contact with the IGN in Madrid, and in 1979 Núñez de las Cuevas and Gómez-González held a meeting with Creyssel at the CNRS headquarters in Paris, to define the conditions of an IRAM-IGN association. It was agreed that the IGN would contribute by giving the land on Loma de Dilar (near Pico Veleta) where the 30-m dish was to be installed, and by also supplying a 600-m² building (which was later



Figure 10. The 30-m millimeter telescope of IRAM at Pico Veleta (courtesy: IRAM).

enlarged to 800 m²) for offices and laboratories which would served as the IRAM headquarters in downtown Granada. As compensation, the IGN would obtain up



Figure 11: A recent view of the IRAM interferometer on Plateau de Bure, with its 6×15-m antennas. The large shelter in the background is used for antenna construction and maintenance (courtesy: IRAM).

to 10% of the observing time with the two IRAM instruments, the 30-m dish and the interferometer. The IGN would also nominate the Co-director of the IRAM installations in Spain, who would attend IRAM Executive Council meetings as an observer. On 16 May 1980 the IRAM-IGN Association Agreements were signed in Granada.

In 1982 Michel Guélin was appointed as the Director of the IRAM-Granada Station and, in 1983, Gómez-González moved there as the Spanish Co-director. A very enthusiastic group of German, French and Spanish astronomers, engineers and technicians worked hard during the following years to put the 30-m radio telescope and the Granada Station into operation. In 1986 the radio telescope started astronomical observations, and on 14 September 1987 it was officially dedicated by the Ministerio de Fomento of Spain. While this Ministry covered mainly public works, town planning and transportation, it also included astronomy, geodesy and geophysics.

In the IRAM-IGN agreement of 1980 it was foreseen that the IGN could later negotiate its participation in IRAM as a full member. This materialized in 1990, when IGN joined IRAM as a full member with a financial contribution of 6% of the total budget. In 1996, a special contribution by the IGN of 33% of the construction cost of the fourth interferometer antenna of the Plateau de Bure opened the way for the interferometer to be developed to its present capacity with six antennas.

9 CONCLUDING REMARKS

The first Director of IRAM was Peter Marinus de Jong who, like Johnsen, came from CERN. Blum, Delannoy and Weliachew, plus Michel Guélin and Bernard Lazareff, left Meudon or Bordeaux to join IRAM in Grenoble. At the same time, the University of Grenoble created an astrophysics laboratory (now the Laboratoire d'Astrophysique de l'Observatoire de Grenoble = LAOG) directed by Alain Omont, and Robert Lucas moved from the École Normale Supérieure to this Laboratory, working for IRAM. Similarly, Jaap Baars, Dennis Downes, Hartfuss, Albert Greve and Gundlach moved to Grenoble from Bonn or Munich. Many graduate students came from Spain to Meudon, Bonn and Grenoble to become acquainted with millimetre radio astronomy.

The 30-m IRAM radio telescope was put into operation in 1985-1986 (Figure 10), and at the time was the largest antenna in the world working down to 1 mm wavelength. On the other hand, the delay in the financing of the IRAM interferometer was such that there were already three other millimetre interferometers in operation by the time it was completed: the Owens Valley Radio Observatory and Berkeley-Illinois-Maryland (BIMA) arrays in California and the Nobeyama array in Japan. Observations at the Plateau de Bure started in 1989, twenty-three years after the first plans were discussed. When observations began there were only three 15-m antennas with a total area of 530 m² instead of the foreseen 300 m², moving on relatively short baselines.⁵ Since then, the number of antennas has been increased to six, and the two baselines lengthened, the maximum separation now being 760 m (Figure 11). Just before this journal went to press the heartening news was received that funding

has now been approved for the installation of four more antennas. It is hoped that two more will be added in the future, bringing the total to twelve 15-m antennas, and that the baseline will be extended to 1,600 m. This will make the IRAM array by far the most powerful millimetre interferometer in the Northern Hemisphere, and almost equivalent to the ALMA array in Chile.

IRAM would never have come into existence without the commitment, tenacity and diplomatic skills of Peter Mezger and Émile-Jacques Blum.

10 NOTES⁶

1. This institute was part of a “Society for the Promotion of Astrophysical Research” which was later renamed the “Research Society for Applied Sciences” (FGAN). This institute carried out military research in radar technology, and in the late 1960s obtained a 34-m parabolic antenna inside a 49-m radome at Wachtberg near Bonn, making the Stockert antenna 100% available for radio astronomy. Today the Wachtberg antenna is used for the detection of near-Earth objects (pers. comm., Hilmar Duerbeck, June 2011).
2. We give for all the sums their equivalent in Euros in 2008, based on a comparison of the costs of living at their epoch and at present. This conversion was established by the Institut National de la Statistique et des Études Économiques (INSEE) and is available on: <http://www.insee.fr/fr/themes/indicateur.asp?id=29&page=achatfranc.htm>
3. In 1981 Wrixon became the Director of the National Microelectronics Research Center of Ireland, then in 1999 President of the University College in Cork.
4. The 30-m radio telescope is at an elevation of 2850 m. The summit of the Sierra Nevada, the Mulhacén, at 3482 m, was initially considered, but the meteorological conditions were so harsh there that it was soon abandoned.
5. The decision to increase to 15 m the diameter of the antennas of the Plateau de Bure interferometer was taken because of the competition with the OVRO millimetre interferometer which had 10-m antennas.
6. This paper brings to an end the series of research papers on early French radio astronomy. What started off as a small-scale project with just four French collaborators and a cut-off date of 1961, grew into a much more ambitious program with seven different papers, additional co-authors and a much-extended end-date. We hope that in the future this series of papers will serve to inspire other French astronomers to document and write up important aspects of their radio astronomical heritage and share it with international colleagues.

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Professor Pierre Encrenaz started working in radio astronomy in 1968, first with Arno Penzias at Princeton then with James Lequeux at Paris Observatory (Meudon). He obtained his Ph.D. in 1972, joined the Observatory the following year, and from 1975 to 1979 was the Sub-director of the Physics Laboratory at the École Normale Supérieure. In 1975 he founded a laboratory of millimetre radio astronomy at the École; this is still active today, and staff work in close collaboration with those at the Paris Observatory. In 1995, he became full Professor of Astronomy at the Université Pierre et Marie Curie in Paris. Pierre played a major role in developing millimetre radio astronomy in France and was much involved in the genesis of the IRAM project. He has been a member of the IRAM Executive and Scientific Councils. With Gérard Beaudin, he was responsible for the construction of one of the submillimetre receivers on the HERSCHEL satellite and had a participation in the microwave instrument for the ROSETTA orbiter. Pierre recently retired, and he is currently working on the results of observations made with HERSCHEL and CASSINI-HUYGENS. He has been a member of the Acad-

émie des Sciences since 2000.

Dr Jesús Gómez-González obtained his Ph.D. in physics at the Universidad Complutense of Madrid in 1974, then spent three years in the Department of Radio Astronomy at the Paris Observatory (Meudon) and nine months at the National Radio Astronomy Observatory in the USA. Between 1989 and 2002 he was the Director of the National Astronomical Observatory of the National Geographical Institute of Spain (IGN); since then he has been Deputy Director for Astronomy, Geodesy, and Geophysics at the IGN in the Ministerio de Fomento. He was the first Director of the Yebes Radioastronomy Observatory, where he was responsible for the development of the instrumentation and laboratories, and in particular for the construction of the 40-m millimetre radio telescope and its incorporation into the Astronomy and Geodesy networks for very long baseline interferometry (EVN and IVS). Later, he was also appointed as the first Co-director of the IRAM Granada Station, and was a member of the executive boards of IRAM, EVN and JIVE (founding member and President of the latter for the period 2009-2011). Jesús has been the first and the main promoter of radio astronomy in Spain.

Dr James Lequeux started radio astronomy in 1954 as a student. After a long military service, he observed the structure of continuum radio sources with an interferometer at Nançay and obtained a Ph.D. in 1962. Then he worked on the construction of Le Grand Radiotelescope at Nançay, and in 1966 founded the first infrared astronomy group at

Meudon. He was deeply involved in the genesis of the IRAM project. Later, he was also involved in the scientific programs associated with the Infrared Space Observatory (ISO) as an associate scientist. For 15 years James was one of the two Editors-in-Chief of the journal *Astronomy & Astrophysics*. After a career in various fields of astrophysics, involving mainly research on interstellar matter and the evolution of galaxies, his post-retirement interests turned to the history of astronomy. He has now published several books and a large number of papers in this field, including six papers in this Journal.

Dr Wayne Orchiston is an Associate Professor in the Centre for Astronomy at James Cook University in Townsville, Australia. After serving with the CSIRO's Division of Radiophysics from 1961 to 1968 he worked in other scientific fields before returning to astronomy during the 1980s. He has a particular interest in the history of radio astronomy in Australia, Britain, France, India, Japan and New Zealand, and is the founder and current Vice-Chairman of the IAU Working Group on Historic Radio Astronomy. Wayne has published extensively, and edited the books *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth* (Springer, 2005) and *Highlighting the History of Astronomy in the Asia-Pacific Region* (Springer, 2011) which contain substantial sections on the history of radio astronomy. In 2011 Springer will also publish a book by Wayne and co-authored by Woody Sullivan, on the history of Australian radio astronomy. Since its founding in 1998, Wayne has been Editor of the *Journal of Astronomical History and Heritage*.

MADRAS OBSERVATORY AND THE DISCOVERY OF C/1831 A1 (THE GREAT COMET OF 1831)

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Abstract: In this paper we present excerpts from the records at the Indian Institute of Astrophysics Archives that show that T.G. Taylor, an astronomer at the Madras Observatory, was an independent discoverer of the Great Comet of 1831 (C/1831 A1) on 7.00972 January 1831 UT, although John Herapath who first observed the comet from Hounslow Heath (England) on January 7.25 is generally credited with the discovery. Taylor continued to observe the comet until 20 February 1831, and his observations were duly published by the Madras Observatory in 1832.

Key words: The Great Comet of 1831; Madras Observatory; T.G. Taylor

1 INTRODUCTION

This paper documents the discovery of the Great Comet C/1831 A1 (1830 II, 1831 a) by the Madras Observatory astronomer T.G. Taylor on 7.00972 January UT, even though he has not been credited with this discovery (e.g. see Kronk, 2003; Vsekhsvyatskii, 1964).¹ Rather, as a prominent naked eye object this comet was noticed in many different places at about the same time, but the first *reported* observation was made by the English physicist, John Herapath, on 7.25 January UT, or at about 6 a.m., from Hounslow Heath in England. He noted that it had a head as bright as a star of the second magnitude and a white tail that was 1° - 2° in length, while the head "... was of the same colour as the tail, but, in proportion, far more splendid." (Herapath, 1831). Observing from Boston, R.T. Paine independently discovered the comet on 7.42 January UT, and it was subsequently reported by others (see Kronk, 2003; Vsekhsvyatskii, 1964). When G. Santini first saw the comet on 8 January from Padova it was visible to the unaided eye and it remained so for much of the month of January. N. Cacciatore saw the comet from Palermo on the morning of 23 January, when it had a bright nuclear condensation about 20"

across embedded in a 3' nebulosity, with a tail 3° long. The comet had passed perihelion on 28.1604 December 1830, and it was closest to the Earth on 9 December 1830 (at 0.6856 AU) and on 16 February 1831 (at 0.5335 AU) (JPL Small-Body Database Browser). According to Kronk (2003), the last-known observation of this comet was made on 19.8 March 1831.

In this paper, we provide background information about the Madras Observatory and biodata on T.G. Taylor before discussing his observations of the comet.

2 A SHORT HISTORY OF THE MADRAS OBSERVATORY

Although sporadic observations of certain astronomical events were recorded during the seventeenth and eighteenth centuries, the earliest scientific astronomical observatory in India was established in 1786.² This was a private facility erected at Egmore in Madras (now Chennai) by William Petrie (d. 1816), an officer with the East India Company (see Kochhar, 1985a). Petrie's intention, expressed years later in a memorandum of 4 September 1804 to the Governor of Madras

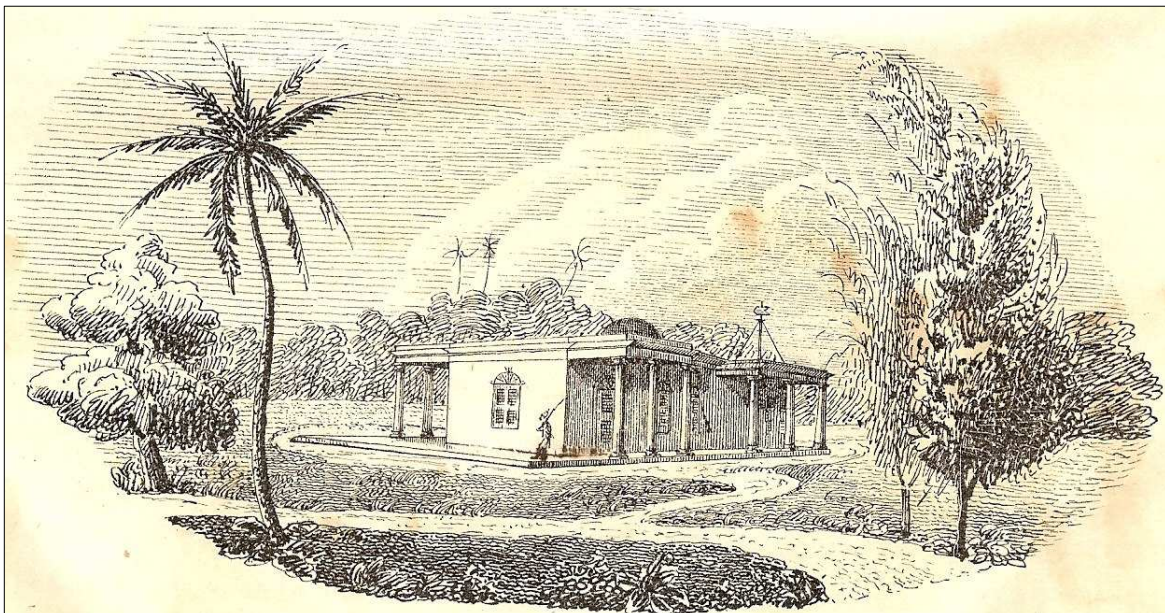


Figure 1: The Madras Observatory at Nungambakkam (from the cover of Taylor, 1838a; courtesy: IIA Archives).

was "... to provide navigational assistance to the company ships, and help determine the longitudes and latitudes of the company territories." (IIA Madras MS Records: 76). He possessed three 2¾-inch achromatic telescopes of 3½ feet focal length by John Dollond; an astronomical clock with compound pendulum by John Shelton (similar to the one used by James Cook during the 1769 transit of Venus), which was moved to the Kodaikanal Observatory in 1900 and is still functioning; a quadrant by John Bird; and a 20-inch transit instrument by Stancliffe (see Kochhar, 1985a; 1985b). The longitudes were determined from observations of Jovian satellite phenomena. The first observation on record, on page 164 in the MS Observations at the IIA Archives, dates to 5 December 1786 and pertains to the determination of the coordinates of Masulipatam Fort Flagstaff from such observations. In 1789, the East India Company took over Petrie's observatory, and it was moved in 1792 to new premises at Nungambakkam, designed by the Company's new astronomer and marine surveyor Michael Topping (1747–1796), and renamed Madras Observatory (Figure 1). In 1810, its ownership changed yet again when it became an official colonial government observatory, under the control of the Surveyor General of Madras (Kochhar, 1991b). Madras Observatory therefore has a long history (see Ananthasubramanian, 1991), but this was "... a chequered history for more than one hundred years ..." (Kochhar, 1985b: 288). The noted geographer Sir Clements Markham (1878: 340) later had this to say about the Observatory in his work *A Memoir on the Indian Surveys*:

The Madras Observatory is now the sole permanent point for astronomical work in India, and the only successor of the famous establishments founded by Jai Sing. It has been presided over by a succession of six able and accomplished astronomers, it has produced results which entitle it to take rank with the observatories of Europe, and its present Director is engaged in the prosecution of labours which are of great importance to astronomical science.

The Director referred to above was Norman R Pogson (1829–1891), who served in that capacity from 1861 until 1891. Madras Observatory eventually evolved into the present-day Indian Institute of Astrophysics.

As we have seen, in 1789 the Observatory passed from Petrie's private ownership to the East India Company and Michael Topping's Directorship; Topping also 'inherited' John Goldingham (1765/66–1849; Kochhar, 1985b), who initially was Petrie's assistant. Prior to his Madras Observatory appointment Topping had already undertaken a much-needed survey of the maritime-unfriendly Coromandal coast, and during 1786–1787 he determined the latitude and longitude of a number of different locations. In 1794 and 1795, Goldingham and Topping determined the longitude of Masulipatam, using observations of Jovian satellite eclipses (Taylor, 1832). The Madras Observatory then became the reference meridian for the trigonometrical survey of southern India which was initiated by the East India Company. From 1818 it was called the Great Trigonometrical Survey of India, and was intended to cover the entire Indian region (Kochhar, 1991a). A precise determination of the longitude of the Madras Observatory was thus essential, so that longitudes required during the survey could be measured. William Lambton began the survey at

Madras on 10 April 1802 when a baseline measurement relating to the longitude of Madras was made (Bappu, 1986).

In 1793 Goldingham commenced systematic meteorological measurements at the Observatory. He maintained a meteorological register for barometric pressure, which was measured at sunrise, 10 am, noon, 2 pm, sunset and 9 pm from 1796 until 1825, but with a gap through 1808–1812 during his years of absence (*Hundred Years ...*, 1976). Following Topping's untimely death in 1796 Goldingham served as Director for two discrete intervals, 1796–1805 and 1812–1830, and during the intervening period, while he was away to England, Captain John Warren (1769–1830) took charge. Goldingham was eventually succeeded by Thomas Glanville Taylor (1804–1848) in 1830. He, too, maintained the meteorological observations, and the tradition was duly followed by successive astronomers, with the series carrying entries for thermometer readings, rain gauge, wind and weather was published over the years. It was under Taylor's direction that high altitude meteorological observations were carried out at a bungalow built for the purpose atop Dodabetta at a height of 8640 feet (2633 m) in the Nilgiri hills. Observations began in February 1847, with an Osler anemometer, a barometer, thermometers and rain gauges. The measurements were taken at 9:40 am and 3:40 pm, the supposed hours of maxima and minima, and continued until 1858 (Markham, 1878: 280–281). More recently, this robust suite of historic Madras Observatory meteorological records has been utilized by climatologists to measure fluctuations in the El Niño southern oscillation phenomenon across the Indian Ocean basin and the Indian summer monsoon (e.g. see Allan et al., 2002).

In 1804 the Madras Observatory received a 12-inch Troughton circular altazimuth instrument, and in 1830 it acquired a 5-foot transit instrument, a 4 feet mural circle and a 5-foot equatorial telescope, all by Dollond. Once in office, Taylor lost no time installing these instruments (Kochhar, 1985b), and he provides information about this in the Observatory's publications (Taylor, 1832: Preface). For example, he says this about the transit telescope:

The five feet Achromatic is exceptionally well and steadily mounted on a mahogany frame armed with brass, and being supplied with two graduated circles and a long axis moving on a graduated arc, it has occasionally been employed as an equatorial in making rough observations out of the meridian in addition to its other uses in observing Occultations and Eclipses. (ibid.).

The introduction of these new instruments enabled work of greater astronomical relevance and precision to be carried out at the Observatory.

As was the norm for British colonial observatories at this time, research at the Madras Observatory focused on positional astronomy, and the transit telescope was used to accurately determine the positions of bright stars. The culmination of these early efforts was the preparation by Taylor of the famous catalogue of 11,015 stars in the southern sky, epoch 1 January 1835, entitled *A General Catalogue of the Principal Fixed Stars from Observations Made at The Honourable The East India Company's Observatory at Madras in the Years 1830-1843* (Taylor, 1844). Tay-

lor's catalogue was supplemented by further observations made between 1849 and 1853 of 1440 stars selected from the British Association Catalogue, and these were reduced to 1 January 1850 by his successor W.S. Jacob (1813–1862) and published in 1854 (see Worster and Jacob, 1854). The 'Madras Catalogue', as it came to be known, was acclaimed by the Astronomer Royal, George Biddell Airy, in his 1854 address to the Royal Astronomical Society:

I must characterise the Madras Catalogue of our late member, T.G. Taylor, as the greatest catalogue of modern times. In the number of observations and the number and distribution of stars, and the circumstance that the observations were made, reduced, combined, and printed, at the same place and under the same superintendence, it bears the palm from all others. But this was the fruit of an endowed observatory, the work of an astronomer and competent assistants, whose strength was not exhausted by any other employment. After this come such works as Groombridge's Catalogue ... (Airy, 1854: 145).

Taylor's zeal in this pursuit is reflected in the following comments that he included in the *Results of Astronomical Observations Vol. IV* ...:

At the outset of my Astronomical career at Madras, it occurred to me that one of the most useful purposes to which I could devote the Madras Instruments was that of determining the places of a large catalogue of Stars limiting the number of observations to an extent that might leave me sure to two or three tenth of a second of time for the Right Ascension, and, to two seconds of space for the Declination ... (Taylor, 1838a: 85).

The Madras Catalogue was subsequently revised by the Nautical Almanac in 1893 (see Kochhar, 1991b).

However, these stellar positional measurements were not the only astronomical observations conducted at the Madras Observatory. Solar system objects and events, and occultations of stars and planets by the Moon were also of interest. Goldingham's observational work was predominantly devoted to eclipses of the Jovian satellites, and these were published in five different volumes of the Observatory's publications, namely, *Astronomical Observations, Madras 1825-1827* ... (4 volumes) and *Madras Observatory Papers* (1827). These volumes also included observations of eclipses of the Sun (on 1 February 1813, 16 July 1814, 15 May 1817 and 3 March, 1825) and of the Moon (the total eclipse of 22 August 1812). Goldingham (1827) also communicated a paper to the Astronomical Society of London on the longitude of Madras determined from observations of eclipses of the first and second satellites of Jupiter made between 1817 and 1826.

Quite apart from its astronomical research, the Madras Observatory also provided a local time service (see Kochhar, 1991a). Since the local time (based on the transit of stars or the Sun) depends on the longitude of a place, for time-keeping purposes a standard longitude is chosen for a region, a state or a country. In 1802 Goldingham fixed the latitude and longitude of the Madras Observatory at $13^{\circ} 05' 24''$ N and $80^{\circ} 18' 30''$ E, respectively from eclipses of Jovian satellites and culminations of the Moon (although that was not the final word, for further longitude determinations were subsequently made). That started the first use of the current time zone, with the day beginning at midnight. The clock at the Observatory was linked to

a gun at Fort St. George that was fired at 8 p.m. every evening for the purposes of time-keeping and to serve as the standard time. A similar service was provided for ships in Bombay Harbour by the Colaba Observatory, which was founded in 1823 by the East India Company (see *Hundred Years ...*, 1976). For civil purposes, a standard time was assigned for India much later by rounding off to 5 hours 30 minutes ahead of Greenwich Mean Time. Pogson (1867) notes in his report on the Observatory's activities for the year 1 May 1865–30 April 1866 that

The Madras mean time of the flash of the 8 p.m. gun has been carefully noted, and published as formerly, to facilitate the rating of chronometers in the Roads. It is intended as early as possible to carry out the long contemplated telegraphic discharge of the Fort and Mount guns, and the erection of three sympathetic electrical clocks, for the convenience of the public in various parts of Madras.

Late in the nineteenth century an Indian Observatories Committee formed in England to assess the work of the Madras Observatory deliberated upon its future. In 1882 Pogson had proposed the acquisition of a 20-inch telescope for solar and stellar photography and spectroscopy, with this new facility preferably to be located at a southern hill station. Subsequently the emphasis veered towards observations of the Sun in the tropical Indian skies, and a quest began to find a suitable site. At a meeting held in 1893, the Committee decided to establish a solar physics facility at Kodaikanal in the Palani Hills, but deferred making a decision to establish a permanent astronomical observatory at a suitable location. By 1899, Charles Michie Smith had shifted the astronomical activities from Madras to Kodaikanal, and equipped with new instruments, clear skies and a favourable ambience at an altitude of 2343m the Kodaikanal Observatory began work, centered on solar astronomy (Bappu, 2000). Henceforth, the Madras Observatory focused on meteorological work, and the only astronomical work that continued there—up until 1931—was conducted in order to provide a time service. Today, Indian Standard Time (IST) is taken to be UT + 5.5 hrs, which is solar time at a longitude of 82.5° E, a location that is a little west of Mirzapur, near Allahabad.

We have seen above how in 1802 the Madras Observatory came to serve as the reference meridian for the trigonometrical survey of India (Markham, 1878). Of the other non-astronomical work, mention must be made of the Observatory's participation in the Göttinger Magnetischer Verein (Göttingen Magnetic Union), the world-wide network of 53 magnetic observatories (including 18 non-European ones) initiated by Alexander von Humboldt, Carl Gauss and Wilhelm Weber to record variations in the intensity and direction of the Earth's magnetic field. Simultaneous readings were taken off the magnetometers every five minutes on specific days during 1836–1841. In addition to the Madras Observatory, other Indian observatories that participated in this international collaboration were located at Shimla and Trivandrum (now Thiruvananthapuram). The results were collated and subsequently published by Gauss and Weber (see Gubbins and Herrero-Bervera, 2007: 729–733). Taylor (1837a) even published his observations in *The Journal of The Asiatic Society of Bengal*. He began by observing "Notwithstanding the value which has of late years

been attached to observations of the Magnetic dip and Intensity, I may, I believe, safely state, that the whole of British India has failed to put on record a single good act of experiments to this end ...”, and from his observations made on 26 April 1837 he provided a value of the Dip of $6^{\circ} 52' 30''$. He further noted that “During the present century, I cannot find that any observations for Dip have been made at *Madras*, but there is one result on record dated 1775, when Abercrombie found it to be $5^{\circ} 15' N$; if this result can be trusted, it would appear that the Dip is on the increase at the rate of $1' 34''$ in a year.” This was also the first publication on geomagnetism from India. Jointly with John Caldecott (1800–1849), Taylor also carried out geomagnetic observations at several other places in the region, but these were never published (see Sthanapati, 2010). Caldecott, a British Commercial Agent to the Travancore Government, was an amateur astronomer who became the Director of a modern astronomical observatory established in 1837 by Rama Vurma (Swathi Thirunal), the Raja of Travancore. The Raja was a great patron of science, and was deeply interested in astronomy. Magnetic observations at Madras were also continued in later years (e.g. see Pogson (1884) for further details).

Taylor’s Directorship ended in 1848, and it is only fair to say that the Madras Observatory flourished under subsequent Directors. His successor was W.S. Jacob (1813–1862) who, before moving to the Madras Observatory had set up a small private observatory housing a 5 feet Dollond equatorial at Poona (now Pune) in 1842. Jacob had observed eclipses of Jovian satellites and the rings of Saturn, and he had published two papers in the *Memoirs of the Royal Astronomical Society*. His main interest was in cataloguing binary stars, and investigating their orbits. At the Madras Observatory during the years 1848–1858 he added double stars to the research repertoire. Jacob followed Taylor’s lead and published papers in the prestigious *Monthly Notices of the Royal Astronomical Society*, thus bringing the Observatory’s work to a wide international audience (e.g. see Jacob, 1854; 1857). Norman Pogson (1829–1891), who was Director from 1861 to 1891, started his career as an astronomer at George Bishop’s South Villa Observatory in London, where he trained under J.R. Hind, and then enjoyed fruitful periods at the Radcliffe Observatory and at the Hartwell Observatory. Although his name is well known as the founder of the modern definition of the logarithmic magnitude scale, while at the Madras Observatory he also used the new eight-inch Cooke equatorial to discover five new asteroids and five variable stars (Bappu, 1986; also see Kapoor, 2010). In addition, in 1867 his Indian assistant, C. Ragoonatha Charry, discovered that R Reticuli was a variable star (Bappu, 1986; Markham 1878; see, also, Kameswara Rao et al., 2009).

3 THOMAS GLANVILLE TAYLOR: A BIOGRAPHICAL SKETCH

Information about T.G. Taylor in the IIA Archives is rather sparse at present, and the Institute does not even have a portrait of him. In his book, *Records of the Anglo-Norman House of Glanville from 1050 to 1880*, Glanville-Richards (1882: 121–145) states that Thomas Glanville Taylor was born in Ashburton (England) on 22 November 1804 to Thomas Taylor, Deputy Astron-

omer at the Royal Observatory, Greenwich,

... and after studying some time at the Royal Observatory under his father, during which period he gave every aid in his power to Colonel Sabine when he was engaged in his experiments “for determining the difference in the number of vibrations made by an invariable pendulum,” and also much aided the same gentleman in his still more difficult and delicate investigation respecting “the reduction to a vacuum of the vibrations of an invariable pendulum.”

Mr. T. Glanville Taylor also assisted Mr. Groombridge with the reduction of his “Catalogue of Stars within 50° of the North Pole.” His ability and zeal were so much approved of by the celebrated Astronomer Royal, John Pond, Esq., F.R.S., that at that gentleman’s recommendation Mr. T. Glanville Taylor was appointed in 1830 Astronomer at Madras; while in that position, he published his “Astronomical Observations” in five volumes, besides which he made a very extensive series of Meteorological and Magnetic Observations in different parts of India.

Taylor was elected a Fellow of the Royal Society on 10 February 1842. He was also a Fellow of the Royal Astronomical Society. Further details on T.G. Taylor are found in Markham (1878: 329–330) and in the write-up of Agnes Mary Clerke (1885–1900) in the *Dictionary of National Biography*, where it is stated that he died at Southampton on 4 May 1848.

4 TAYLOR’S OBSERVATIONS OF THE 1831 COMET

While at the Madras Observatory, Thomas Glanville Taylor was an independent discoverer of the Great Comet of 1831. He discovered this comet on the same day as John Herapath, but several hours earlier (in fact on 7.00972 January 1831 UT), and continued to observe it until 20 February. He subsequently published his observations in a volume titled *Results of Astronomical Observations Made at The Honourable The East India Company’s Observatory at Madras, Vol. I. for the Year 1831* (Taylor, 1832). His account of the astronomical observations is preceded by some comments on the state of his equipment:

In the foregoing statements I have endeavoured to represent as nearly the case would permit the degree of accuracy attained in each particular species of Observation, but in the present case, the Observations of an ill defined object, made with a Telescope supported upon a wooden stand, and that too in the open air; subject to flexure from its own weight, and to tremor from every breath of air which may happen to blow, render it desirable that the whole of the particulars of each observation should be stated, accordingly the following is copied from the book “Miscellaneous Observations” (Taylor, 1832: 95).

Taylor’s account of the cometary observations begins thus:

1831, 7th January at 4h 50m. A.M. Saw a Comet toward the East about 20 degrees high but approaching twilight prevented observation.

8th January, 5h. A.M. Adjusted the five feet Achromatic by Dollond as an Equatoreal, saw the Comet with a power of 60 but it was too faint to allow the field being illuminated, the following observations were made, at the time of its occupying the centre of the field of view.

Using Antares as a reference star, Taylor recorded the Sidereal Time, and the Horary Circle and Declination Circle measures at 5h A.M. local time, and remarked

that the comet was “Very faint, tail 4° long observations not to be depended upon to 5m.” For the given sidereal time of 12h 52m on 8 January, the UT is 00 24m, while Taylor’s observation on 7 January at 4h 50m would correspond to 00 14 UT. Meanwhile, back in England, Herapath’s (1831) longitude was 00° 21’ W, and since Hounslow Heath was located very close to the Prime Meridian his mean solar time is almost the same as UT.

Using η *Serpentis* as the comparison star on 9 January, Taylor observed the comet at ‘5h A.M.’ He provided a similar tabulation to that mentioned above, and remarked that “The Comet appeared very distinct notwithstanding its being situated within 30° of the Moon.”

The positions of the comet relative to various comparison stars on different dates are presented in tabular form from 8 January onwards. On 11 January Taylor remarked that “Clouds prevented any Observation.” then he tabulated the positions of the comet during the period 12-16 January, 19 and 20 January and 23 January, adding

The prevalence of haze and the presence of the Moon, added to the diminishing brightness of the Comet, prevented observation after the 23rd of January till the 19th of February, on the latter day as well as on the 20th I was fortunate enough to obtain meridional observations with the Transit instrument and Mural Circle, but these being made without illuminating the wires, in consequence of extreme faintness of the Comet, cannot be depended upon to 1 or 2 minutes of space.

On both 19 and 20 February, Taylor recorded the comet as “Very faint”.

Towards the end of this series of observations Taylor explained why the telescope support was so rickety:

It is necessary I should here remark that the instrument was removed every day after the observations were made, to the inside of the Observatory and brought out again early in the morning for adjustment previously to the above observations being made, in performing the adjustment, no pains was taken to adjust the Azimuth Circle, which will account for the changes which are found from day to day in the Index error. The Sidereal time set down is the *true* Sidereal time, found every morning by the Transit of Spica Virginis over the wires of the Mural Circle, the Transit Instrument not having been erected at this time. Employing the Sidereal time in conjunction with the Apparent Places of η and ζ Ophiuchi computed from the Astronomical Society’s Tables we obtain the *true* Altitude and Azimuth, which being compared with the *observed* (the Altitude being corrected for refraction) gives the Index Error in Altitude and Azimuth which we can now apply to the observed Altitude and Azimuth of the Comet as follows.

From the true altitudes and azimuths, Taylor provided a table listing the mean time, and the RA and NPD of the comet for the period 8 January–20 February 1831. It is notable that the positions Taylor reported were close to those we generated for the comet using JPL’s ‘Horizons On-Line Ephemeris System’. Taylor did not include the Comet’s orbital elements in his report, but for reference purposes they are provided here: the orbit was parabolic, with $q = 0.125887$ AU and $i = 135^\circ.2630$. The reader should also note that Full Moon occurred on 29 December, 28 January and 26 February.

In Figure 2, we reproduce a few pages from Taylor’s (1832) report extracted from the IIA Archives.

Taylor did not provide drawings to illustrate the appearance of the comet on different dates, and unfortunately the book that he refers to, *Miscellaneous Observations*, can no longer be traced.

5 DISCUSSION

The Great Comet of 1831 was not the first comet to attract the attention of the Madras Observatory astronomers, for the IIA Archives contain references to observations of the first two great comets of the nineteenth century, namely, those of 1807 (C/1807 R1) and 1811 (C/1811 F1). Both were observed by John Warren, who was Acting Astronomer at the Observatory during the years 1805-1812 while the astronomer, John Goldingham, was away on leave to England.³

The Great Comet of 1807 was discovered by Parisi, an Augustinian monk, on 9 September, and eight days later independently by J.L. Pons (Hind, 1852). Kronk (2003) credits Castro Giovanni of Sicily with having discovered it in the evening twilight near the horizon in the west-southwest direction on September 9.7. It was a bright comet, distinctively visible to the naked eye, and was well observed by William Herschel. It passed perihelion on September 19.2389; $q=0.646124$ AU. In October it showed up with two tails, a straight one $>6^\circ$ long and a relatively shorter curved one. It remained a naked-eye object throughout the months of October, November and even into December by which time it had dimmed. It was last observed on 27 March 1808 (Kronk, 2003). In a 218-page hand-written document in the IIA Archives titled ‘Madras M.S. Records’ spanning January 1794-October 1812 we find the Report of the Observatory dated February 1809, written by Captain John Warren (1769–1830), where the comet is briefly referred to on pages 78-79. The following passage in the Report describes the observations of the comet made at the Observatory:

In September, October and November 1807 the remarkable Comet appeared which had attracted so much of the attention of astronomers in Europe. Having no Instrument at the observatory of sufficient powers of observation of this nature, the acting astronomer was under the necessity to compensate by the number for the inaccuracy of his observations involving long and tedious calculations and approximations the power of which is well known to persons acquainted with those operations. The Paper on the movements and path of the Comet was submitted to Government early in 1808 the result of two months calculations.

The date of Warren’s first observation of the comet is not written down and so remains unknown. In those days, communication with overseas astronomers occurred through dispatches carried by ships, so it would have been many months before Warren learned about the independent discovery of this comet in Europe or elsewhere. Around the time of discovery, the comet was a low declination object (September 3: $-21^\circ 29'$; September 9: $-18^\circ 01'$; September 15: $-13^\circ 27'$; 12:00 UT; <http://ssd.jpl.nasa.gov/>) with a solar elongation of 34° - 35° , and therefore was easier to spot from a location like Madras. Note that Full Moon occurred on September 16, October 16, and so on. All through the months of September, October and November, the comet trailed the Sun. As Kronk (2003) says, this comet

RESULT

OF

ASTRONOMICAL OBSERVATIONS

MADE AT

THE HONORABLE

THE EAST INDIA COMPANY'S OBSERVATORY

AT MADRAS

BY

THOMAS GLANVILLE TAYLOR, Esq.

ASTRONOMER TO THE HONORABLE COMPANY.

VOL. I.

FOR THE YEAR 1831.

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Figure 2: The title page of *Results of Astronomical Observations Made at The Honourable The East India Company's Observatory at Madras. Vol. I. For the Year 1831* (Taylor, 1832), followed by the first page listing data from Taylor's account of his observations of the Great Comet of 1831 (courtesy: IIA Archives).

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RESULTS FROM OBSERVATIONS, 1831.

1831, 7th January at 4h. 50m. A. M. Saw a Comet towards the East about 20 degrees high but approaching twilight prevented observation.

8th January, 5h. A. M. Adjusted the five feet Achromatic by Dollond as an Equatoreal, saw the Comet with a power of 60 but it was too faint to allow the field being illuminated, the following observations were made, at the time of its occupying the centre of the field of view.

	Sidereal Time. h. m. s.	Horary Circle. h. m. s.	Declination Circle. ° ' "	REMARKS.
Comet.....	12 52 0	4 36 0	11 50 S.	Very faint, tail 4° long observations not to be dependent upon to 5m.
	13 2 0	4 25 30	11 43 —	
Antares.....	12 58 0	3 19 0	—————	
	13 5 40	3 12 0	25 15 S.	

9th January at 5h. A. M.

	Sidereal Time. h. m. s.	Horary Circle. h. m. s.	Declination Circle. ° ' "	REMARKS.
Comet.....	12 22 41	6 58 45	10 52 10 S.	The Comet appeared very distinct notwithstanding its being situated within 30' of the Moon.
	12 24 54	7 0 50	10 52 30 —	
	12 25 59	7 1 58		
	12 26 48	7 2 50		
γ Serpentis.....	12 31 53	7 32 0	14 33 30 S.	The wires did not require illumination.
	12 34 21	7 34 20		
	12 35 50	7 35 55	14 33 20 —	

1831, January 10.—In consequence of the difficulty attending the adjustment of the Instrument as an Equatoreal I have availed myself of a suspension spirit level which belongs to the Telescope, to adjust it as an Altitude and Azimuth Instrument; the error of adjustment of the vertical Axis cannot I imagine exceed 20 or 30 seconds.

	Sidereal Time. 1831 h. m. s.	Altitude. ° ' "	Azimuth from North Meridian. h. m. s.	Azimuth from South. ° ' "
10th January.....	12 11 14	9 25 30	6 44 10	78 57 30
	12 14 30	10 9 0	6 45 5	78 43 45
	12 17 27	10 53 0	6 45 50	78 30 00
Comet.....	12 19 44	11 24 30	6 46 35	78 21 15
	12 21 18	11 46 10	6 46 55	78 16 15
	12 23 52	12 24 0	6 47 45	78 3 45

should probably have been spotted from the southern hemisphere weeks before it was discovered from Europe. We are inclined to feel Warren might have been the first to spot this comet, or at least that he first observed it very soon after its initial discovery, although we cannot ignore the fact that this was also the period of the monsoons over Tamil Nadu. At the time he penned his reports—which now form part of the Madras MS Records—Warren knew that the comet had been keenly pursued in Europe. For some unknown reason Warren's paper, "An account of the Comet which appeared in the months of September, October and November 1807", was never published, and it is now part of the RAS Archives MS. It describes the Madras Observatory observations in detail (see Ananthasubramanian, 1991).

Similarly, in the Madras M.S. Records (1794-1812) on pages 143-144 we come across a letter dated 27 April 1811 written by Warren to the Acting Surveyor General informing him of the sighting of a nebulosity on the evening of the 25 April, before he came to know that this was in fact the Great Comet of 1811. This comet had been discovered on the evening of 25 March by Honoré Flaugergues at Viviers, and was in the constellation of Argo Navis (the Ship of the Argonauts).⁴ These observations are discussed more fully in the present author's ongoing work on comets observed from India.¹

During the early decades of the nineteenth century there were other Great Comets visible in 1819, 1823 and 1830, but the next one recorded at the Madras Observatory was the Great Comet of 1831.

It may be asked why Taylor did not send a report on his observations of the 1831 comet to Greenwich, and publish this in the *Philosophical Transactions of the Royal Society*, or the newly-formed *Monthly Notices of the Royal Astronomical Society*? For an astronomer adept at using telescopes and exploring the night sky, Taylor would know what astronomical discoveries meant. Coming from Greenwich, he would also know the importance of publishing his observations quickly and in an appropriate forum, but in the case of the 1831 comet it seems that he did not realize that he was the first to observe it, so there was no need—let alone urgency—to publicize this 'non-discovery' internationally. In this context, Jacob's Preface to the Madras Observatory publication, *Astronomical Observations made at the Honourable The East India Company's Observatory at Madras for the Years 1848-1852, Vol. 8* (Worster and Jacob, 1853) seems to be relevant when he says that he has "... followed his predecessor's plan in printing the results only, on account of the voluminousness of the original observations; but exact copies will be deposited at the India House, and will doubtlessly be there accessible to all parties wishing to examine them."

Taylor's first paper in the *Monthly Notices of the Royal Astronomical Society* only appeared in 1837 (on his observations of Halley's Comet; see Taylor, 1837), and prior to this date he only wrote up his astronomical observations for the Madras Observatory's in-house publication. Thus, the 5-page report on his observations of the Great Comet of 1831 lies hidden within the voluminous *Results of Astronomical Observations Made at The Honourable The East India Company's Observatory at Madras. Vol. I for the Year*

1831 (Taylor, 1832). In the Preface to this Volume, Taylor writes about his arrival at the Madras Observatory on 15 September 1830, before describing the transit telescope and the mural circle. Then with the aid of extensive tables he presents the various astronomical observations made with these instruments during the year 1831. Apart from his report on the 1831 comet, these observations included measurements of the Sun's diameter in passing the Meridian;⁵ the apparent Right Ascensions and North Polar Distances of the planets and of the Moon; an eclipse of the Moon on 26 February 1831; eclipses of the Jovian satellites in 1831; the latitude of the Madras Observatory; and a long table with 'Places of the Fixed Stars'. This table contains 2881 stars. One of these stars (no. 390) is η Argus, which was listed at magnitude 2 on the basis of six different observations made in 1831. It also appears in *Results of Astronomical Observations Made at The Honourable The East India Company's Observatory at Madras. Vol. II for the Years 1832 and 1833* (Taylor, 1833) as star no. 1281, and still at magnitude 2, judging from six observations made in 1833. Edmond Halley first recorded η Argus in 1677 from the island of St Helena as a star of the 4th magnitude, and he suspected it to be a variable. In the 1820s, η Argus began to brighten, but Taylor's initial observations are made some years before 'The Great Eruption' which extended from about 1837 to 1857 (Frew, 2004). In subsequent Madras Observatory publications, particularly those dating to 1837-1838 and April 1843 (when η Argus rivaled Sirius in brightness), Taylor catalogues fainter stars in Argo Navis but says nothing about the brightening of η Argus. In *Vol. VII* he merely includes η Argus in a list showing the mean places of 97 principal fixed stars (Taylor, 1848).

It is not clear if the individual volumes of astronomical observations made at the Madras Observatory were indeed sent to India House for safe-keeping soon after their publication. Even if they were, Taylor's discovery of the Great Comet of 1831 and his subsequent observations of it remained unknown to most overseas astronomers. Consequently, Taylor never received the credit he deserved as the discoverer of this comet, and up till now this honour has been awarded to John Herapath.

Back in the nineteenth century the accepted procedure if one wished to claim discovery priority for a new comet was to immediately submit a report that included the comet's precise position to a recognized professional observatory, located preferably in Europe, Britain or the USA, which was then responsible for publicizing the discovery. When such discoveries were made far from Europe or North America this sometimes disadvantaged those exposed to the so-called 'tyranny of distance'. Thus, several Australian astronomers who discovered comets in the days before the international telegraph were never formally credited with their discoveries (see Orchiston, 1997), just like T.G. Taylor and the Great Comet of 1831. In the case of this particular comet, Orchiston (personal communication, 2011) also offers the following comments:

Maybe amateur-professional astronomy differences during the nineteenth century also played a key role in Taylor's decision not to publish his 1831 comet observations in *Monthly Notices*. At this time, professional astronomers were expected to do positional astronomy, not to search for and track new comets—which was the

role of the amateur—despite public perceptions to the contrary. A good example was the vitriol heaped upon Sydney Observatory and its hard-working Director, William Scott, because it was the well-known local amateur astronomer, John Tebbutt, and not Scott who discovered the Great Comet of 1861, C/1861 K1. (e.g. see Orchiston, 1998).

6 CONCLUDING REMARKS

As we have documented in this paper, Madras Observatory Director Thomas Glanville Taylor deserves full credit for the independent discovery of Comet C/1831 A1, but international astronomers have long remained unaware of this because Taylor did not realize the significance of his observations and therefore chose to publish them in the Observatory's own relatively-obscure monograph series instead of in the high-profile pages of the prestigious *Monthly Notices of the Royal Astronomical Society* or the *Memoirs of the Royal Astronomical Society*.

Interestingly, Taylor observed the celebrated Halley's Comet and other comets in later years and published his results both in the Madras Observatory publications and in the two journals of the Royal Astronomical Society. Halley's Comet was first recovered in this greatly-awaited apparition by Father E. Dumouchel at the Collegio Romano in Rome on August 5.12 1835 (see Kronk, 2003), and was observed by Taylor (1836; 1837b; 1838b) at the Madras Observatory from 30 August 1835 until 5 February, 1836 and subsequently on 3 April 1836 with the Dollond 5-foot achromat mounted as an equatorial.

Another comet, designated C/1839 X1, was discovered in the constellation of Virgo on 2 December 1839 by J.G. Galle from Berlin (Vsekhsvyatskii, 1964),⁶ and was independently discovered by T.G. Taylor at the Madras Observatory on 6 January 1840, as noted by Vsekhvyatskii (*ibid.*). Meanwhile, R. Snow also independently discovered this comet on 29 December 1839, and made further observations from Ashurst on 30 December and from Dulwich on 6 and 7 January 1840. In the IIA Archives, we find a record of Taylor's (1848) observations of this comet:

1840, January 4th, at 5 A.M. saw a Nebulous appearance between α and β Ophiuchi but it became obscured by twilight before I could bring a telescope to bear upon it. January 5th, at 5 A.M. the same appearance as yesterday, but was again unsuccessful in observing its appearance with a telescope, to the unassisted eye it appeared to be a Comet with a tail about 3 deg long directed from the Sun. January 6th, having adjusted the 5 feet Achromatic to act as an Equatorial, several observations of the Comet were made ...'

In the various notes accompanying his table summarizing the observations made between 6 and 28 January, Taylor comments that on 6 January the comet was visible through the twilight. On 8 January it was visible through the twilight, with a better-defined nucleus. The appearance remained nearly the same until 17 January, and on then 18th he noted that the comet was "... necessarily very faint by reason of Moonlight." By 25 January the comet had faded, but on the 28th he commented that "The Morning beautifully clear, and the Comet rather brighter than on the 25th."

The great comet of 1844-5, C/1844 Y1, widely referred to as Wilmot's Comet, was observed in India

from three observatories, Bombay, Madras (by T.G. Taylor) and Trivandrum (by J. Caldecott). These and some other observations made in India will be subject of a later communication.

7 NOTES

1. This study is merely part of the author's ongoing research into cometary sightings and observations made from India from antiquity through to 1960, where available data—however minimal—permit the identification of each comet. Of special interest are those comets that have received little attention or no notice at all in the more recent cometary literature.
2. We specifically use the term 'scientific observatory' here because there were much earlier traditional Indian observatories (e.g. see Sharma 1985).
3. According to Kochhar (1991b), Goldingham returned from leave in October 1811, not in 1812.
4. Note that in 1752 the French astronomer Nicolas Louis de Lacaille had split this large constellation into the separate constellations of Carina, Puppis and Vela.
5. Assuming the Sun to be spherical, Taylor derived a value of $16' 0.15''$ for the solar semi-diameter, when viewed from the Earth's mean distance from the Sun.
6. According to Kronk (2003), the correct date is December 3.20, in the morning.

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ECLIPSES IN AUSTRALIAN ABORIGINAL ASTRONOMY

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Abstract: We explore about fifty different Australian Aboriginal accounts of lunar and solar eclipses to determine how Aboriginal groups understood this phenomenon. We summarize the literature on Aboriginal references to eclipses. We show that many Aboriginal groups viewed eclipses negatively, frequently associating them with bad omens, evil magic, disease, blood and death. In many communities, elders or medicine men claimed to be able to control or avert eclipses by magical means, solidifying their roles as providers and protectors within their communities. We also show that some Aboriginal groups seem to have understood the motions of the Sun-Earth-Moon system, the connection between the lunar phases and tides, and acknowledged that solar eclipses were caused by the Moon blocking the Sun.

Keywords: Australian Aboriginal astronomy; solar eclipses, lunar eclipses, ethnoastronomy, Australian place names

1 INTRODUCTION

Aboriginal Australians were careful observers of the night sky and possessed a complex understanding of the motions of celestial bodies and their correlation with terrestrial events, such as the passage of time, the changing of seasons, and the emergence of particular food sources (e.g. Fredrick, 2008; Haynes, 1992a; 1992b; Johnson, 1998; Norris and Norris, 2009). Aboriginal people used the sky for navigation, marriage and totem classes, and cultural mnemonics (Johnson, 1998). The celestial world was an important and integral aspect of the landscape, which was inseparable from the terrestrial world. Aboriginal knowledge was passed down to successive generations through oral tradition, dance, ceremony, and various artistic forms, including paintings, drawings and petroglyphs. Much of this knowledge was restricted to particular genders or totems, or was dependant on the initiation of an individual into the higher ranks of the community.

As part of our continuing research into Aboriginal Astronomy (Norris and Hamacher, 2011b; Norris and Norris, 2009), specifically regarding transient celestial phenomena (e.g. Hamacher and Frew, 2010; Hamacher and Norris, 2009; 2010; 2011), this paper explores Aboriginal knowledge of solar and lunar eclipses. We do this to gain a better understanding of Aboriginal sky knowledge and to determine the methods of scientific deduction from an Indigenous perspective.

Many Aboriginal cultures were heavily damaged by colonisation, and a significant amount of traditional (i.e. pre-colonisation) knowledge about celestial phenomena has been lost. Most of the records available in the literature are colonists' accounts—few of which come from professional ethnographers. Given that Aboriginal societies are extremely complex and exist in a framework that is foreign to most Westerners, we acknowledge our limitations in interpreting the available information, which is strongly influenced by the biases, interpretations and legitimacy of the sources. The sources from which we draw information include traditional Aboriginal custodians and elders, Western professional researchers, and amateurs with little or no training in the recording or interpretation of Indigenous knowledge.

In this paper, we examine five aspects of traditional Aboriginal knowledge regarding eclipses: 1) Aboriginal perceptions of and reactions to eclipses, 2) Aboriginal explanations regarding the causes of eclipses, 3) dating oral traditions using historic eclipses, 4) pre-

dicting eclipses, and 5) representations of eclipses in Aboriginal rock art. We begin by discussing the science of lunar phases, tides and eclipses. If the account describes or is attributed to a known historic eclipse, it is given an 'Event #', with the details of each event listed in Table 1 (solar and lunar eclipse data calculated using Espenak and O'Byrne, 2007a and 2007b, respectively). Meanwhile, in Table 2 we include those Australian place names that include the word 'eclipse', even if they have no direct link to Aboriginal culture.

2 THE SCIENCE OF THE EARTH-MOON-SUN SYSTEM¹

2.1 Lunar Phases

As the Moon orbits the earth, an Earth-bound observer will see a different percentage of the Moon illuminated by the Sun throughout a lunar month. These are referred to as lunar phases, and are divided into new, waxing crescent, first quarter, waxing gibbous, full, waning gibbous, last quarter, waning crescent, and back to new moon (see Figure 1). When the Moon is between the Earth and Sun, appearing near the Sun in the sky from an Earth-bound perspective, it is essentially invisible to us for about three days, which we call the new moon. As the Moon moves towards solar opposition, more of the surface is illuminated by the Sun. When less than half of the Moon is illuminated, it is called crescent, while more than half illuminated is called gibbous. When the illuminated portion of the Moon's surface is increasing, we deem it waxing. When the Moon is at solar opposition, the entire hemisphere of the Moon facing the Earth is illuminated, revealing a full moon. As the Moon fades, it is deemed waning. The Moon rises at dawn during new moon and dusk during full moon, with the first quarter moon rising at midday and the last quarter moon rising at midnight.

To understand the causes of eclipses, it is essential to understand the relative motions of the Sun and Moon, which cause lunar phases. By examining Aboriginal oral traditions, we can determine whether Aboriginal people in traditional times understood the relative motions of the Moon-Sun system and their correlation with events on the Earth, such as tides.

2.2 Eclipses

In the Earth-Moon-Sun system, there are two general types of eclipses: solar and lunar. When the Moon pass-

Table 1: Eclipses discussed in this paper are given in this Table, which includes the event number (#), the date of the eclipse (DD/MM/YEAR), coordinates of the location where it was seen, the eclipse type (T: S = solar, L = lunar) and subtype (ST: P = partial, T = total, A = annular), the percentage of the Sun's area eclipsed (Obs, only for solar eclipses), and the time of maximum eclipse (t, in local time). Events 2 and 8 are of the same eclipse seen from two different locations. Data are calculated using Espenak and O'Byrne (2007a; 2007b) with the following time zone conversions: WA = UTC +8:00; NT/SA = UTC +9:00; QLD/NSW/ VIC/TAS = UTC+10:00 (Eucla, WA = UTC +8:45).

#	Date	Location	T	ST	Obs	t
1	30/07/1916	27° 20' S, 126° 10' E	S	A	94.3	09:46:19
2	21/09/1922	25° 11' S, 133° 11' E	S	T	100	15:55:00
3	13/08/1859	34° 55' S, 138° 35' S	L	T		02:04
4	23/06/1899	16° 58' S, 122° 39' E	L	T		22:18
5	28/12/1917	30° 27' S, 131° 50' E	L	T		18:40
6	21/09/1922	32° 07' S, 133° 40' E	S	P	75.7	14:56:37
7	05/04/1856	19° 15' S, 146° 49' E	S	P	92.7	17:05:31
8	21/09/1922	28° 33' S, 150° 19' E	S	T	100	16:13:26
9 a	12/03/1793	31° 07' S, 138° 23' E	S	P	92.9	15:58:26
b	07/10/1782	31° 07' S, 138° 23' E	S	T	100	09:21:58
10	22/11/1900	16° 58' S, 122° 39' E	S	P	73.1	14:14:42
11	08/08/1831	33° 52' S, 151° 13' E	S	P	87.6	07:03:55
12	03/10/1819	13° 54' S, 126° 18' E	L	T		23:13
13	12/05/1873	22° 20' S, 131° 38' E	L	T		20:20
14	12/12/1871	18° 46' S, 146° 33' E	S	P	18.5	14:15:47
15	28/09/1791	35° 10' S, 117° 53' E	S	P	92.2	06:38:46

Table 2: The nomenclature behind place names in Australia that include the word 'eclipse'. We were unable to locate any references that explain the nomenclature behind two locations in Western Australia with the name 'Eclipse Hill', one near Buraminya (~750 km east of Perth) and the other near Lennard Brook (~70 km north of Perth).

Name	State	Coordinates	Event #	Reference
Eclipse Hill	WA	13° 54' S, 126° 18' E	12	Feeken & Feeken (1970: 230)
Eclipse Islands	WA	13° 54' S, 126° 18' E	12	Feeken & Feeken (1970: 230)
Mount Eclipse	NT	22° 20' S, 131° 38' E	13	Feeken & Feeken (1970: 164)
Eclipse Island*	QLD	18° 46' S, 146° 33' E	14	Reed (1973: 87)
Eclipse Island	WA	35° 10' S, 117° 53' E	15	Martin (1943); Reed (1973: 87)

*The local Aboriginal name of this island is *Garooqubbee* (Bindloss 2002: 330).

es between the Earth and Sun, an observer in the area on the Earth that falls into the Moon's shadow sees a solar eclipse. During a total solar eclipse, the Sun is completely blocked and day turns completely into night (called totality). During totality, the Sun's faint corona as well as prominences may be observed. The shape and intensity of the corona depend on the presence of sunspots, which relate to the 11-year solar cycle (c.f. Aschwanden, 2004). Total solar eclipses are rare, and can be seen on average from a given point on the Earth's surface only about once every 410 years in the Northern Hemisphere, while total solar eclipses in the Southern Hemisphere are even rarer, occurring only about once every 540 years (Steel, 1999: 351). If only part of the Sun is covered, we see a partial solar eclipse. While total eclipses are quite rare, partial eclipses are far more frequent, with more than 30 such events occurring every century. The Moon's orbit is eccentric, and if the Moon eclipses the Sun during apogee the Moon will completely fit within the disc of the Sun, leaving a ring of the solar disc visible, which is called an annulus. Thus, this is referred to as an annular eclipse.

There has been some debate regarding the visibility of partial eclipses. Even when 99% of the Sun is eclipsed, the remaining 1% is bright enough to cause damage to the eye (Chou, 1981; Marsh, 1982). There have been no studies that suggest what magnitude would be required for people to notice a partial eclipse, but Stephenson and Clark (1978: 39) claims that partial eclipses that cover 98% of the Sun's surface could go unnoticed, unless they were known in advance, the astronomer used an observing aide, or the eclipse was near the horizon and/or the light intensity was reduced by the presence of clouds (e.g. Newton, 1979: 101).

Mostert (1989) claims that no unambiguous hard evidence exists that a partial solar eclipse has been observed with the naked eye. If this were true, would we expect accounts of solar eclipses in Aboriginal oral traditions? We determine the frequency of total solar eclipses over a 1000-year period from AD 900-1900 for 11 locations across Australia (see Table 3). An average rate of 2.36 observed total eclipses from Australia over a 1000-year period is roughly consistent with the estimate of Steel (1999), or approximately one every 400-500 years. Assuming an average pre-European human lifespan of 35 years (Prokopec et al., 1994), a total solar eclipse would only be seen once in about every 14 lifetimes. Given this statistic, we would expect to find very few accounts of solar eclipses, either partial or total.

When the Moon passes through the shadow of the Earth, we witness a lunar eclipse. When the Moon is in the shadow it appears dark from half the Earth, so total lunar eclipses are visible from a much wider area of the Earth than solar eclipses, and they often occur more than once per year. During a total lunar eclipse, longer wavelengths of light from the Sun are refracted through the Earth's atmosphere and faintly illuminate the Moon, causing it to take on a ruddy appearance, although the colour may vary from red to orange, pink or copper, depending upon the aerosol composition of the Earth's atmosphere at the time. This phenomenon was noted by some Aboriginal groups.

3 ABORIGINAL ORAL TRADITIONS OF THE SUN AND MOON

In most Aboriginal cultures, the Sun is female and the Moon is male (Haynes, 1992a: 130; Johnson, 1998), although this is not universal (e.g. see Meyer, 1846: 11-

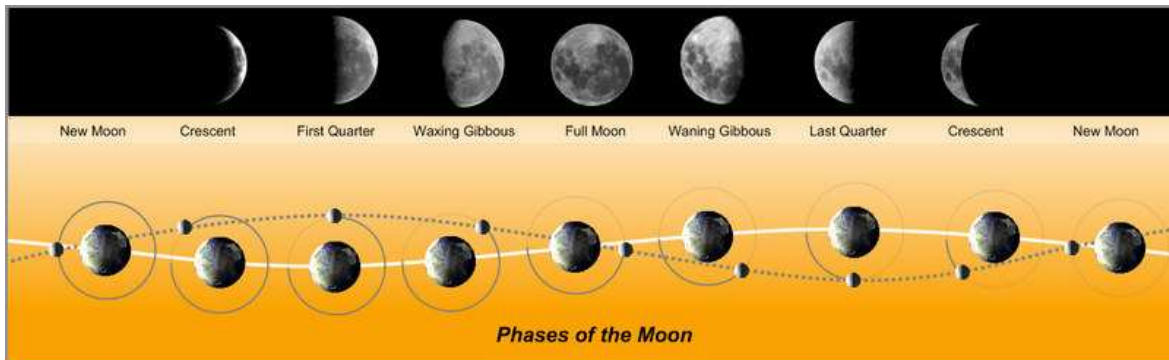


Figure 1: Lunar phases as seen from the Earth (top) and from above the Earth with the Sun to the left (bottom). This image, which is corrected for observers in the Southern Hemisphere, was reproduced under a Wikimedia commons licence agreement.

12). While the specific details vary between groups, many Aboriginal communities describe a dynamic between the Sun and Moon, typically involving one pursuing the other across the sky from day to day, occasionally meeting during an eclipse (Johnson, 1998: 129; Parker, 1905: 139-140; see next Section). Many stories explain why the Moon gets progressively ‘fatter’ as it waxes from new moon to full moon, then fades away to nothing as it wanes back to new moon. For example, the full moon is a fat, lazy man called *Ngalandi* to the Yolngu of Arnhem Land. His wives punish his laziness (or, in some versions, his breaking of taboos) by chopping off bits of him with their axes, causing the waning Moon. He manages to escape by climbing a tall tree to follow the Sun, but is mortally wounded, and dies (new moon). After remaining dead for three days, he rises again, growing fat and round (waxing Moon), until his wives attack him again in a cycle that repeats to this day (Hulley, 1996; Wells, 1964).

Because the lunar month is roughly the same length as the menstrual cycle, the Moon is sometimes associated with fertility, sexual intercourse, and child-bearing. In some communities, young women were warned about gazing at the Moon for fear of becoming pregnant (Haynes, 1992b: 107). The Ngarrindjeri of Encounter Bay, South Australia, saw the Moon as a promiscuous woman (Meyer, 1846: 11-12) who became thin and wasted away (waning Moon) as a result of her numerous sexual encounters. When she became very thin (crescent moon), the creator being Nurrunderi ordered her to be driven away. She was gone for a short while (new moon), but began to eat nourishing roots, causing her to fatten again (waxing moon). A similar account is given by the nearby Jaralde people, except the waxing Moon represents the Moon-woman coming to term in pregnancy (Berndt et al., 1993: 232-233). Several other Aboriginal groups associate the Moon with love, fertility and intercourse, including the Koko-Yalanyu of the Bloomfield River, Queensland (McConnell, 1931) and the Lardil people of Mornington Island in the Gulf of Carpentaria (Isaacs, 1980: 163-166; Roughsey, 1971: 82-84; also see Johnson, 1998 and Fredrick, 2008: 102-104 for more examples).

The Moon and the Sun have a gravitational influence on the ocean, causing tides. Higher tides than normal (spring tides) occur when the Sun and Moon are aligned or opposed, while lower tides than normal (neap tides) occur when the Sun and Moon are at 90° to each other as seen from the Earth, damping each other’s gravitational influence. Many coastal groups

understand the relationship between lunar phases and the ocean tides, including the correlation between the spring tide and full moon. According to the Yolngu of Arnhem Land and the Anindilyakwa of Groote Eylandt (Hulley, 1996), when the tides are high, the water fills the Moon as it rises at dawn and dusk (new and full moon, respectively). As the tides drop, the Moon empties (crescent) until the Moon is high in the sky during dusk or dawn, at which time the tides fall and the Moon runs out of water (first and last quarter). Warner (1937: 368) claims that “... the Murngin [another name for the Yolngu of Arnhem Land] have a most accurate knowledge of the locational, seasonal, and daily variation of the tides. Anyone who has taken a canoe trip with them along the seacoast quickly learns that this knowledge is immense in detail, well organised, and held by all the men.” Warner subsequently describes the important role of the tides, Moon, and Sun in the Yolngu ceremonies and rituals. Tidal data from Milner Bay (Groote Eylandt) and Gove Harbour (Arnhem Land) show that semi-diurnal ranges reach their maximum during the period of full and new moon in coastal areas of the Northern Territory (see Figure 2).

In addition to describing the lunar phases and their relationship to tides, some Aboriginal groups believed that the Earth was finite in expanse. The Yolngu tell how the Sun-woman, Walu, lights a small fire each morning, which we see as the dawn (Wells, 1964). She decorates herself with red ochre, some of which spills

Table 3: The frequency of total solar eclipses as seen from eleven different locations across Australia between AD 900-1900. Information includes the name of the observation location, the number of total eclipse events (N_e) and the years those eclipses were observed. Data are taken from Espenak & O’Byrne (2007a).

City/Town	State	N_e	Years of Total Eclipses (AD)
Alice Springs	Northern Territory	0	
Adelaide	South Australia	5	1033, 1339, 1517, 1728, 1802
Brisbane	Queensland	4	1134, 1308, 1554, 1831
Canberra	Australian Capital Territory	1	1247
Darwin	Northern Territory	3	1191, 1242, 1256
Hobart	Tasmania	3	909, 1064, 1728
Melbourne	Victoria	2	1008, 1782
Perth	Western Australia	1	1310
Cairns	Queensland	0	
Broome	Western Australia	2	1712, 1737
Cobar	New South Wales	4	1308, 1336, 1547, 1608

onto the clouds, creating the red sunrise. She then lights her torch, made from a stringy-bark tree, and carries it across the sky from east to west, creating daylight. Upon reaching the western horizon, she extinguishes her torch and starts the long journey underground back to the morning camp in the east. When asked about this journey, a Yolngu man told Warner (1937: 328) that "... the Sun goes clear around the world ...", who illustrated this by "... putting his hand over a box and under it and around again." Smith (1970: 93) notes that some Aboriginal astronomers (elders who studied the motions and positions of celestial objects) seemed to know that the Earth was round, as a particular reference to a 'day' meant "... the Earth has turned itself about ...", although the degree of cultural contamination by Westerners, if any, is uncertain.

These accounts reveal that some Aboriginal people were aware of the motions of the Sun and Moon, and some coastal groups were aware of their correlation with ocean tides. Understanding this relationship is a step towards determining the causes of eclipses.

4 ABORIGINAL REACTIONS TO ECLIPSES

4.1 Solar Eclipses

As with other transient celestial phenomena, such as comets and meteors (e.g. Hamacher and Norris, 2011;

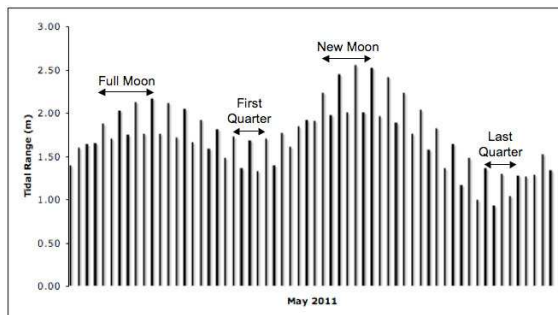


Figure 2: The tidal range (difference between high and low tide) over the course of May 2011 in Gove Harbour, eastern Arnhem Land, showing the data range that corresponds to particular lunar phases (the day of and two days preceding). Data taken from Northern Territory Transport Group (2011).

2010), many Aboriginal groups held a negative view of solar eclipses. They could be a warning of a terrible calamity, an omen of death and disease, or a sign that someone was working black magic (Mudrooroo, 1994: 59; Wood, 1870: 94). According to colonist accounts, solar eclipses caused reactions of fear and anxiety to many Aboriginal people, including those living near Ooldea, South Australia (Bates, 1944: 211; Clarke, 1990), the Euahlayi of New South Wales (Parker, 1905: 139-140), the Yircla Meening of Eucla, Western Australia (Curr, 1886: 400), the Bindel of Townsville, Queensland (Morrill, 1964: 61), the Wirangu of Ceduna, South Australia (Bates, 1944: 211), the Ngadjuri of the Flinders Ranges, South Australia (Tindale, 1937: 149-151), the Arrernte and Luritja of the Central Desert (Spencer and Gillen, 1899: 566; Strehlow, 1907: 19), the Kurnai of southeast Victoria (Massola, 1968: 162), the people of Roebuck Bay, Western Australia (Peggs, 1903: 358, 360) and Erldunda, Northern Territory (Hill, 2002: 88). One colonist noted seeing Aboriginal people run under the cover of bushes in a fearful panic upon a solar eclipse (Curr, 1886: 400). In 1934, Aboriginal informants of the Mandjindja language in the Western

Desert told Tindale (2005: 361-362) that they called a solar eclipse *Tindu korari*, an event they claim to have only seen once. They were struck with great fear at first, but were relieved when the eclipse passed with no harm having come to anyone. Tindale attributed this to an annular eclipse that occurred on 30 July 1916 (Event #1). The most recent annular eclipse visible from this region occurred 246 years earlier, while the most recent total solar eclipse occurred 1,082 years earlier, although four partial eclipses that covered more than 80% of the Sun's area were visible from this region between 1900 and 1934 (in 1900, 1905, 1915 and 1922). Although the specific eclipse the Mandjindja witnessed is uncertain, the annular eclipse of 1916 is the best candidate, as it covered 92.4% of the Sun's surface.

To some Aboriginal communities of southeast Australia, the sky world was suspended above the heads of the people by trees, ropes, spirits, or magical means. In Euahlayi oral traditions, the Sun is a woman named Yhi who falls in love with the Moon man, Bahloo. Bahloo has no interest in Yhi and constantly tries to avoid her. As the Sun and Moon move across the sky over the lunar cycle, Yhi chases Bahloo telling the spirits who hold the sky up that if they let him escape, she will cast down the spirit who sits in the sky holding the ends of the ropes and the sky-world will fall, hurling the world into everlasting darkness (Parker, 1905: 139-140).

To combat this omen of evil, some communities employed a brave and well-respected member of the community, such as a medicine man or elder, to use magical means to fight the evil of the eclipse. This typically included throwing sacred objects at the Sun whilst chanting a particular song or set of words. This practice was common to Aboriginal communities across Australia, including the Euahlayi, whose medicine men (*wirreenuns*) chanted a particular set of words (ibid.) and the Ngadjuri who threw boomerangs in each cardinal direction to avert the evil (Tindale, 1937: 149-151). Similarly, medicine men of Arrernte² and Pitjantjatjara communities would project sacred stones at the eclipsing Sun whilst chanting a particular song—always with success (Rose, 1957: 146-147; Spencer and Gillen, 1899: 566). The act of casting magical stones at the Sun strengthened the medicine man's status in the community since he was always successful in bringing the Sun back from the darkness, averting the evil and saving the people. A nearly identical practice was performed in the event of a comet, which yielded the same result (Hamacher and Norris, 2011). Among the Wardaman of the Northern Territory, the head of the Sun-clan is a man named *Djinboon*. He can prevent or rescue the Earth from an eclipse of the Sun by magical means, or allow it to occur and frighten the people if laws are broken or if he does not receive the gifts he desires (Harney and Elkin, 1968: 167).

Hill (2002: 88) explains that the Aboriginal people near Erldunda, Northern Territory, reacted with a combination of fear and joy to a solar eclipse that occurred on 21 September 1922 (Event #2), with some calling out "*jackia jackia*" while others sang, in a fearful tone, the song "*You want to know what is my prize*". However, not all Aboriginal communities viewed solar eclipses with fear, as the Aboriginal people of Beagle Bay, Western Australia, were apparently unafraid of solar eclipses (Peggs, 1903: 340-341).

4.2 Lunar Eclipses

Reactions to lunar eclipses are similar to those of solar eclipses. The Kurnai of Victoria saw a lunar eclipse as a signal that someone they knew on a journey had been killed (Massola, 1968: 163). Similarly, Mudrooroo (1994: 58) explains that a lunar eclipse was an omen that someone on a journey had a serious accident, although he does not cite a specific Aboriginal group. The Ngarrindjeri near the mouth of the Murray River were fearful of the lunar eclipse of 13 August 1859 (Event #3), believing it to have been created by powerful Aboriginal sorcerers living beyond the European colonial areas (Clarke, 1997: 139; Taplin, 1859: 2 Sept 1859). Aboriginal people in the Wellington District of Queensland believed a lunar eclipse to be an omen of calamity to a distant relative and reacted with fear and sorrow (Lang 1847: 460).

The perception that a lunar eclipse was an omen of death was shared by the Aboriginal people of Beagle Bay, Western Australia. During a lunar eclipse on 23 June 1899 (Event #4), an Aboriginal informant explained to Peggs (1903: 340-341) that the eclipse was an omen of death to a man—if the Moon is hungry and “... wants to eat someone (a man) ...”, it becomes dark—but it is not uninterested in eating a woman.³ On the same night, an Aboriginal man from a nearby community told Peggs that among his people, a lunar eclipse represented a man who had become sick.

A Wuradjeri account of a dying ‘Clever Man’ is associated with what is possibly a partial lunar eclipse. As the man lay dying, 30 km away a corroboree⁴ was being held. When some of the people in the corroboree looked up at the Moon, they saw the man’s *warangun* (spirit) strike the Moon, followed by two dark patches that began to cover the Moon, which was high in the sky. The people in a corroboree stopped singing and dancing, realising that a lunar eclipse was an omen that someone had died. The next morning, they received the message that the Clever Man had died during the night. He had been lying on his back looking at the Moon when he died—at the exact moment the people in the corroboree saw the Moon go dark (Berndt, 1947/48: 83).

In western Queensland, a colonist at Wymullah Station on the Widgeewoggera River recounted a firsthand story about how he exploited a lunar eclipse to reclaim horses stolen by a local Aboriginal group (McNeile, 1903). One day, his horses disappeared and he had reason to believe it was a local group of Aboriginal people. After failing to locate the horses, McNeile approached an Aboriginal man named Jimmy, who requested a ransom of rum, tobacco and clothes in exchange for the location of the horses. Later that day, McNeile read in the local newspaper that a lunar eclipse was predicted to occur that night (20 December, year not given). Using the event to his advantage, McNeile told Jimmy that if he didn’t reveal where the horses were, he would make the Moon disappear that night. And if they were not returned by the next morning, he would make the Sun disappear the next day—permanently. After being ignored by Jimmy, McNeile took a pair of bootjacks, went to the Aboriginal camp, and began dancing and chanting a song in Latin (which he improvised on the spot). As he did this, the people watched and laughed in amusement until the Moon began to go dark, which caused con-

fusion and anxiety. As it reached full eclipse, panic struck the people at the camp and they began screaming and running into their huts. The next morning, he found his horses in a nearby small pen. Jimmy informed him that the “Horses found themselves ... You no put out big feller Sun now, boss? You leave ‘m all right?” We attempted to identify a corresponding eclipse using Espenak and O’Byrne (2007b) from various vantage points across Queensland. We failed to identify any lunar eclipses on 20 December between 1800 and 1903 in any area of Queensland, suggesting the account was simply a fabricated story and not based on an actual event. The similarity of the eclipse story to Mark Twain’s novel *A Connecticut Yankee in King Arthur’s Court*, published a few years earlier, in 1889, suggests that McNeile’s story is simply fiction, which raises the critical issue of the veracity and accuracy of some literary sources. All need to be critically evaluated and assessed on their individual merits.

Although many groups viewed lunar eclipses as bad omens, the Aboriginal people near Ooldea, South Australia, held no negative views of lunar eclipses, which they called *pira korari*. They had witnessed one at Wynbring after colonists had built the Transcontinental Railway and paid little attention to it, according to Tindale (1934: 21-27). The Transcontinental (or Trans-Australian) Railway was completed in October 1917. In that year, there were three total lunar eclipses visible from this region, suggesting the men witnessed the eclipse on 28 December 1917, which was already eclipsing as it rose above the horizon (Event #5). The frequency of total lunar eclipses visible that year (on 8 January, 5 July, and 28 December) may explain why the event was downplayed by Tindale’s Aboriginal informants.

In hunter-gather societies, the sharing of food was essential for the survival of the community, and stealing or hoarding food was normally taboo. The Lardil of Mornington Island viewed the Moon as a greedy and selfish man who steals food and gorges, getting fatter (waxing Moon). As punishment for this action, he is cut into pieces, getting thinner (waning Moon) until he dies (new moon). The sudden and apparent ‘death’ of the Moon during a lunar eclipse (McKnight, 2005: xxii) served as a mnemonic and warning to younger generations about the Moon’s selfish nature, reinforcing the taboo of food theft and gluttony.

5 CAUSES OF ECLIPSES: AN ABORIGINAL PERSPECTIVE

5.1 Solar Eclipses

From the following accounts, it seems many Aboriginal groups had a firm understanding that during a solar eclipse, an object was covering the Sun, although many explanations were presented as to what that object was and why it covered the Sun. However, these explanations were dependent upon the person recording and translating these descriptions, which were nearly always non-Aboriginal people, typically recorded as a passing observation with little detail provided to the reader.

We first present cases where the people understood the Moon was the object covering the Sun. In Euahlayi culture, the Sun woman, Yhi, was constantly pursuing the Moon man Bahloo, who had rejected her advances. Sometimes Yhi caught up with Bahloo and tried to kill

him in a jealous rage (which was when an eclipse occurred). However, the spirits that held up the sky intervened and drove Yhi away from Bahloo (Parker, 1905: 139-140; Reed, 1965: 130). The Yolngu people of Elcho Island in Arnhem Land provided a similar, but less malevolent, explanation for a solar eclipse: it was an act of copulation between the Sun woman and Moon man (Warner, 1937: 538). The Wirangu of South Australia believed the solar eclipse on 21 September 1922 (Event #6) was caused by the hand of *maamu-waddi*, a spirit man that covered the Earth during the eclipse for the privacy of the Sun woman and Moon man while they were *guri-arra*, or "... husband and wife together." (Bates, 1944: 211). Near Eucla, South Australia, the Yircla Meening tribe believed solar eclipses were caused by "... the Meenings of the moon, who were sick, and in a bad frame of mind towards those of Yircla."⁵ (Curr, 1886: 400). This account implies a link between the Moon and Sun during an eclipse, although the cause is not specifically stated. In all of these cases, except for the last one, it is clear that the Aboriginal people understood that the Moon covered the Sun during the eclipse.

Such an understanding suggests that some Aboriginal groups were aware of the Moon's position in the sky through its various phases. Despite the fact that the Moon is essentially invisible for three days during the period of new moon, an observer who had been following the position of the Moon throughout the month would be able to predict its position during the new moon phase.

Among other communities, it is clear that the people understood *something* was covering the Sun during a solar eclipse, but attributed that 'something' to various objects or actions, including a large black bird called *tia* by the Arrernte (Strehlow, 1907: 19) or spun possum fur by the Luritja (ibid.). To some Aboriginal groups in the southwestern region of Western Australia, a solar eclipse is caused by *mulgarguttuk* (sorcerers) placing their *booka* (cloaks) over the Sun, while to some other groups they move hills and mountains to cover the Sun (Bates, 1985: 232). A similar view is held by Aboriginal people of the Central Desert who call a solar eclipse *bira waldurning* and claim it is made by a man (*waddingga*) covering the Sun with his hand or body (Bates, 1904-1912: Notebook 6a, 74). During an eclipse of the Sun on 5 April 1856 (Event #7), a Bindel man told Morrill (1864: 61) that his son covered the Sun and caused the eclipse in order to frighten another person in the community. An earlier Arrernte account attributes a solar eclipse (*Ipuma*) to periodic visits of the evil spirit *Arungquilha* who takes up residence in the Sun, causing it to turn dark (Spencer and Gillen, 1899: 566). The Pitjantjatjara of the Central Desert believed that bad spirits made the Sun 'dirty' during a solar eclipse (Rose, 1957: 146-147) while the Wardaman believed a solar eclipse was caused by an evil spirit swallowing the Sun (Harney and Elkin, 1968: 167). The Wheelman people of Bremer Bay, Western Australia, told Hassell and Davidson (1934: 234-236) a story about how one day the Sun and Moon fell to Earth, splitting it in half. The lazy people were separated from the rest of the community to the other side of the Sun. Sometimes they got bored and wanted to see what was happening in this world. As they tipped the Sun on its side to have a peek, several of them would gather, blocking the Sun's light, causing

a solar eclipse. They only do this for a short time—just long enough for each of them to have a look, which explains why the eclipse does not last long. Hassell's informant told her that "Yhi (the sun) hide him face and Nunghar look down ..." when storms come or the sky becomes dark in the daytime (solar eclipse). These accounts reveal an understanding that an object is covering the Sun during an eclipse, whether it is by natural or magical means, although the obscuration is not attributed to the Moon.

Not all causes of solar eclipses were attributed to an object covering the Sun. According to a community in Turner Point, Arnhem Land, a solar eclipse was caused when a sacred tree at a totemic site was damaged by fire or carelessness (Chaseling, 1957: 163). As such, sitting under the tree or even seeing it is reserved solely for initiated elders. One final account provides no insight to the cause of the eclipse, but provides an interesting example of how tangible and nearby some Aboriginal people thought the Sun to be. When astronomers in Goondiwindi, Queensland, were observing and recording the total solar eclipse of 21 September 1922 in order to test Einstein's General Theory of Relativity, some Aboriginal people present thought the astronomers were trying to catch the Sun in a net (Menzel, 1949: 275, Event #8). Unfortunately, Menzel gives no further information as to why the Aboriginal people thought this, or to their reactions during or after the eclipse.

5.2 Lunar Eclipses

We only find a few accounts describing the causes of lunar eclipses. The Arrernte believed a lunar eclipse was the result of the Moon man hiding his face behind the possum fur that he is constantly spinning, which is identical to the Luritja view of a solar eclipse (Strehlow, 1907). As with a solar eclipse, Aboriginal groups in the southwest region of Western Australia believe a lunar eclipse is caused by *mulgarguttuk* placing their cloaks or a hill/mountain over the Moon (Bates, 1985: 232). The Kayardild of Bentinck Island in the southern Gulf of Carpentaria believed the Moon was a man who used a net (halo of the Moon) to collect the souls of the recently-dead during a lunar eclipse (*jawaaja*). As the net filled, the Moon-man would disappear, as if he himself had died, which prompted the people to hide under fig trees, fearful that the Moon would kill them. If the people did not seek shelter, they would be struck with *jiljawatha*, a sickness that induced crusted sores (Evans, 1995: 590-596). Róheim (1971: 53) suggests a Eucla Dreaming that describes a man ascending to the Milky Way who can only be seen when he "... walks across the moon ..." may describe a lunar eclipse, showing an understanding that an 'object' (the earth's shadow) covers the Moon during lunar eclipses.

The generally reddish colour of the Moon observed during a total lunar eclipse, as discussed in Section 2, is noted by some Aboriginal groups, including the Aboriginal people of the Clarence River, New South Wales, who thought a lunar eclipse revealed the Moon-man's blood (Mathews, 1994: 60) and the Kurnai of Victoria who believed a red Moon signified that someone had been killed (Massola 1968: 162). The Lardil of Mornington Island believe the Moon man's blood is visible during a total lunar eclipse, prompting elder people to shout out "... don't kill him!" (McKnight, 1999: 105). Strehlow (1907) notes that the Luritja believed the Moon

sometimes goes into the graves of the recently dead and eats the entrails of the bodies. He then emerges into the sky, blood red in colour, so everyone can see what he has done. However, Strehlow claims this account has nothing to do with lunar eclipses but is instead referring to the new moon. The Moon can take on a reddish hue when it is low on the horizon, because the shorter wavelengths of light are reduced as they pass through the atmosphere at a low angle, allowing the longer wavelengths to dominate the colour.

In the Ungarinyin culture of Western Australia an unfriendly medicine man causes the face of the Moon to be covered with blood, which greatly frightens the people (the text is unclear how this is done, but is presumably by some magical means). A friendly medicine man then ascends into the sky during a dream. Upon his return, he informs the people that he made the Moon "... better." (Elkin, 1977: 126).⁶

6 DATING ORAL TRADITIONS FROM HISTORIC ECLIPSES

The age of a story that includes a description of a natural event may be estimated by identifying the date of that event. Tindale (1937: 149-151) believed that a Ngadjuri story from Parachilna, South Australia, described a solar eclipse, which he dates to 1793. In the story, an elderly female being came from the northwest accompanied by two dingoes who behaved as men—one with reddish fur and the other with black fur. Two brothers, *Wulkinara* and *Kudnu* of the lizard totem, succeeded in killing the dingoes and burning the old woman. As a result, the Sun disappeared, causing fear among the people. Members of the community tried diligently to bring the Sun back from the darkness, but eventually collapsing, exhausted and in tears, and fell asleep. *Kudnu* awakened during the darkness and cast magic boomerangs into the sky in each of the cardinal directions. The first three—to the north, south, and west—failed, but the fourth, cast towards the east, was successful and the Sun appeared again. Tindale attributes this event to a total solar eclipse that passed over Parachilna on 13 March 1793 (see Figure 3). Using Espenak and O'Byrne (2007a) and the Starry Night astronomical software package, we calculated that the solar eclipse that passed over Parachilna actually occurred a day earlier on 12 March 1793, and was a partial eclipse that covered ~93% of the Sun's area (Event #9a) with the path of totality more than 200 km to the north of Parachilna (although Tindale may have considered what was visible from Parachilna as 'total'). However, there was a total eclipse visible from Parachilna just eleven years earlier, on 7 October 1782 (Event #9b). Although there were no other total eclipses visible from Parachilna between 1701 and 1782, there were six other partial eclipses that covered 75% or more of the Sun during that time. The most recent total solar eclipses prior to 1793, aside from the 1782 event and a few annular eclipses, were in 1608 and 1610. A better candidate for Tindale's explanation would be the total solar eclipse in October 1782 that passed over Parachilna. Alternatively, perhaps some of those who witnessed the 1793 total eclipse later migrated to Parachilna, or else passed on details of the eclipse to those living there. Since we are unclear of Tindale's definition of a 'total eclipse', there will be some ambiguity with these interpretations. In areas where the 1793 total eclipse would have been

visible, such as at Lake Eyre, the planet Mercury would have been clearly visible just 1.5° above the Sun during totality, but there is no mention of this in the account. However, the story described the woman as coming from the north-west and the 1793 eclipse was visible in the west-northwest sky, while the 1782 eclipse was visible in the east-northeast sky.

A problem arises with Tindale's interpretation of this story as representing a solar eclipse: the story describes the people falling asleep while the Sun goes dark and waking sometime later with the Sun still dark. Under the best conditions, the Sun will remain in totality (completely covered) for no more than 7.5 minutes. The total duration of the 1782 eclipse was ~2.5 hours, with totality lasting only ~2.5 minutes. The people would have been in total darkness for only a couple of minutes—not long enough to exhaust oneself into sleep then wake sometime later with the world still in darkness. Another explanation would have been heavy cloud cover, although it seems unlikely people would react in such a fearful panic to mere clouds.

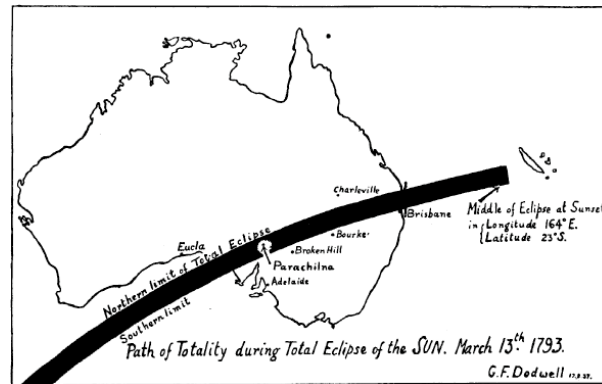


Figure 3: The path of the total solar eclipse that occurred on 12 March 1793 as calculated by South Australian Government Astronomer Mr G.F. Dodwell that Norman Tindale believed was the source of an Aboriginal story about the Sun becoming dark. Dodwell's calculation was out by one day, and the total eclipse was not visible from Parachilna (after Tindale, 1937: 152).

7 ABORIGINAL PREDICTION OF ECLIPSES

To understand the cause of eclipses is to understand the relationship between the motions of the Sun and Moon over time. If these motions are understood with sufficient accuracy, an eclipse can be predicted in advance. However, the required accuracy is very high, requiring carefully-constructed instruments to make the necessary measurements. We found only one account that mentioned such a prediction: A.J. Peggs (1903: 358, 360) presents letters that she wrote to C.J. Tabor whist living in Roebuck Bay, Western Australia, between 1898 and 1901. In a letter dated December 1899 Peggs (1903: 358) wrote: "We are to witness an eclipse of the sun next month. Strange! all the natives know about it; how, we can't imagine!" Peggs asked a local Aboriginal woman named Mary about the eclipse, who responded "Him go out all right." It is unclear from her account how she concluded that Mary had predicted the event—whether it was Mary's comment or by some means not described in the letter. The comment by Mary, however, may have been misleading, as she may have merely been acknowledging what happens during an eclipse. Peggs later wrote:

The eclipse came off, to the fear of many of the natives. It was a glorious afternoon; I used smoked glasses, but could see with the naked eye quite distinctly. There seemed such a rosy hue surrounding the sun, at times changing to yellow. After a good deal of persuasion Jack convinced Mary to look through glasses, but she was half afraid.

Given that the letter was dated December 1899, we searched for any solar eclipses during this period. Between 1891 and 1900, only one solar eclipse was visible from this region, a partial eclipse that covered 73% of the Sun's disk, which occurred on 22 November 1900 (Event #10).

Reasons for doubting the veracity of this story include (a) the inconsistency in the dates, (b) the lack of evidence that Aboriginal people made sub-arcminute precision measurements required for eclipse prediction, despite evidence elsewhere for Aboriginal astronomical alignments accurate to a few degrees (e.g. Wurdi Youang, see Norris and Hamacher, 2011b; stone rows, Hamacher and Norris, 2011); and (c) a reaction of fear to something they would have anticipated seems counterintuitive. Once again this example raises the issue of the credibility of some of the sources at our disposal.

8 REPRESENTATIONS OF ECLIPSES IN ABORIGINAL ROCK ART

Astronomical symbolism is found in Aboriginal rock art across Australia (see Norris and Hamacher, 2011a). Ku-ring-gai Chase National Park, north of Sydney, is home to a number of Aboriginal rock engravings, some of which depict crescent motifs (see Figure 4). Traditionally, archaeologists (e.g. McCarthy, 1983) refer to these motifs as boomerangs. However, we are currently conducting a detailed study to determine, statistically, if these shapes more likely represent crescent Moons, boomerangs, or an eclipsing Sun. An engraving at Basin Track in Ku-ring-gai Chase National Park depicts a man and woman, their arms and legs overlapping, with a crescent shape above their heads. While other engravings depicting a man and woman partially superimposed are found in the region, with only their arms and legs intersecting (see McCarthy, 1983) the crescent above their heads is found only at Basin Track. In other cases, the male figure is holding a crescent in one hand and a fish or shield in the other and some engravings show a single figure with a crescent above the head. The meaning of these motifs is unclear, as few ethnographic records regarding these engravings and ceremonial sites exist. In the case of the Basin Track engraving, Norris and Norris (2009) speculated that the motif might represent the Moonman obscuring the Sun-woman during a solar eclipse.⁷ Near the man-woman is an engraving of a hermaphrodite figure, which could represent the Sun and Moon in full eclipse (John Clegg, personal communication, 2009). If we speculate that this motif represents a solar eclipse as seen from that location in the direction of the engraving (i.e. a straight line from the feet of the figures through their heads and crescent, towards the horizon), the eclipse must occur near dawn, as the petroglyph faces $55 \pm 5^\circ$ east of north. We examined solar eclipse events visible from the region in the nineteenth century using the Starry Night software package. One eclipse candidate occurred at dawn on 8 August 1831 ($t_{\text{start}} = 06:45$, $t_{\text{max}} = 07:03$, $t_{\text{end}} = 08:13$), which covered $\sim 85\%$ of the Sun's disk (Event

#11). At mid-eclipse, the Sun closely resembled the crescent engraving, with the cusps of the crescent pointing downward (see Figure 5). The engraving aligns to the general direction of the eclipse as viewed from this location (i.e. between due east and 45° north-east), but unfortunately we have no supporting ethnographic evidence and dating a rock engraving is problematic (as engravings were typically re-grooved during ceremonies—see Stanbury and Clegg, 1996). Therefore, this interpretation remains speculative.

9 DISCUSSION AND CONCLUSION

Given the low probability of witnessing a total solar eclipse in Australia, we expected to find very few accounts of total solar eclipses. And since a partial eclipse can pass without notice because of the Sun's intense brightness, and because of the damage to the eye that can result from directly looking into the Sun, we did not expect to find many accounts of partial eclipses, either. Of the four accounts that we can attribute to a specific solar eclipse, three of them are partial eclipses, with some obscuring as little as 75.7% of the sun's disk. We also find a number of Aboriginal words and descriptions of solar eclipses, despite our initial predictions. This shows that Aboriginal people did observe some total and partial eclipses and the memory of these events remained strong in many areas. We cannot attribute any partial eclipses that covered less than 75% of the sun's disk to oral traditions and would use this as an estimated lower limit to what people could reasonably notice, although observing the Sun even when 75% is eclipsed would still cause retinal damage. However, we acknowledge that other factors can reveal partial eclipses, such as diffraction by tree leaves, sufficient cloud-cover, or low-horizon partial eclipses where the intensity of the Sun's light is reduced (Figure 6).

The available data reveal that some Aboriginal groups may have understood the mechanics of the Sun-Earth-Moon system and the relationship of lunar phases to events on the Earth. The Yolngu people of Arnhem Land provide the most complete ethnographic evidence, in that their oral accounts demonstrate that they understood that the Sun and Moon move in an east to west motion, the Moon goes through repeated phases that affect the ocean tides, the Earth is finite in space, and the Moon covers the Sun during a solar eclipse.

Particularly important are the accounts that Aboriginal people understood that lunar eclipses were associated with the Sun (Johnson, 1998; Reed, 1965). It is not surprising that someone familiar with the relative motion of the Sun and Moon might notice that a solar eclipse occurs when the Moon is close to the Sun, and deduce that a solar eclipse was caused by the Moon. But it would be an impressive intellectual feat for an individual to recognise that a lunar eclipse was connected with the position of the Sun. It is therefore important to get further independent evidence of knowledge of this association from historical accounts, in order to corroborate the account by Reed.

While conducting ethnographic fieldwork in 2006, one of us (R.P.N.) was with a Yolngu ceremonial leader during a lunar eclipse. The leader (name withheld) told me that his clan had no oral tradition about the eclipse. However, it is possible that the leader did not want to share this information, as it may have been considered sacred and secret.

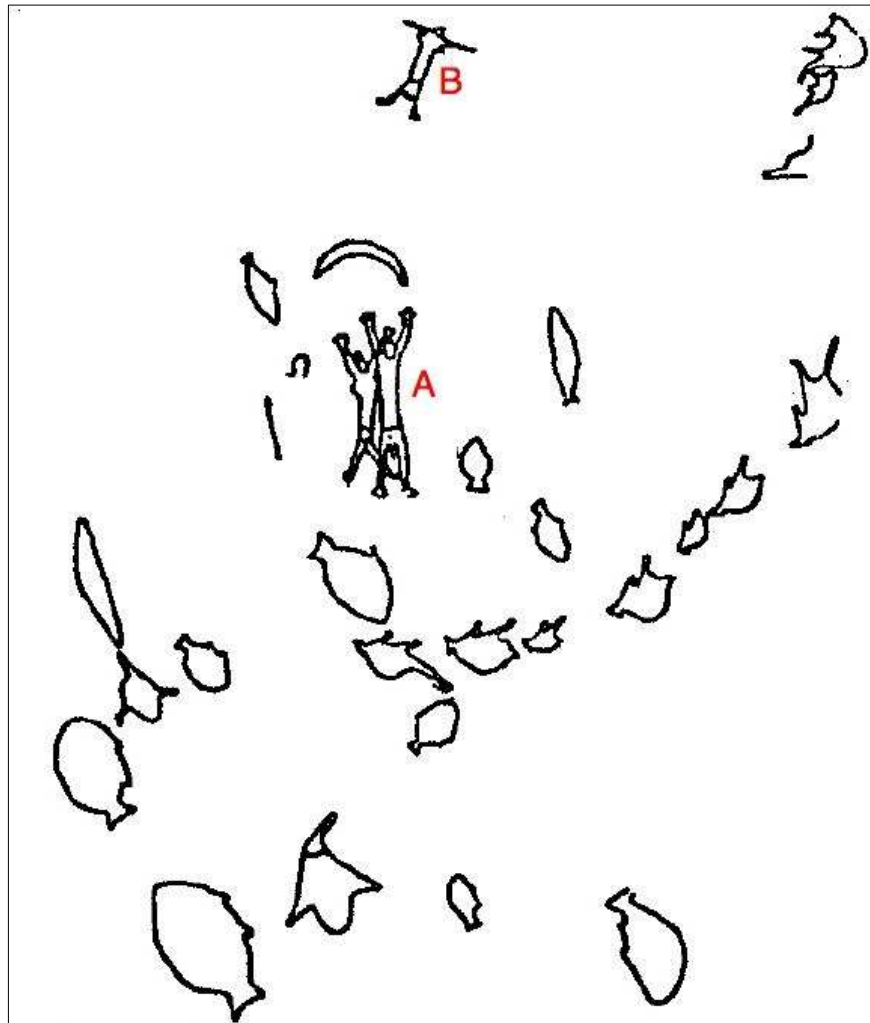


Figure 4: (Top) Aboriginal rock engravings at the Basin Head Track, Ku-ring-gai Chase National Park, taken from Stanbury and Clegg (1996), with photographs by D.W. Hamacher of the man and woman engraving (A) and the hermaphrodite figure (B).

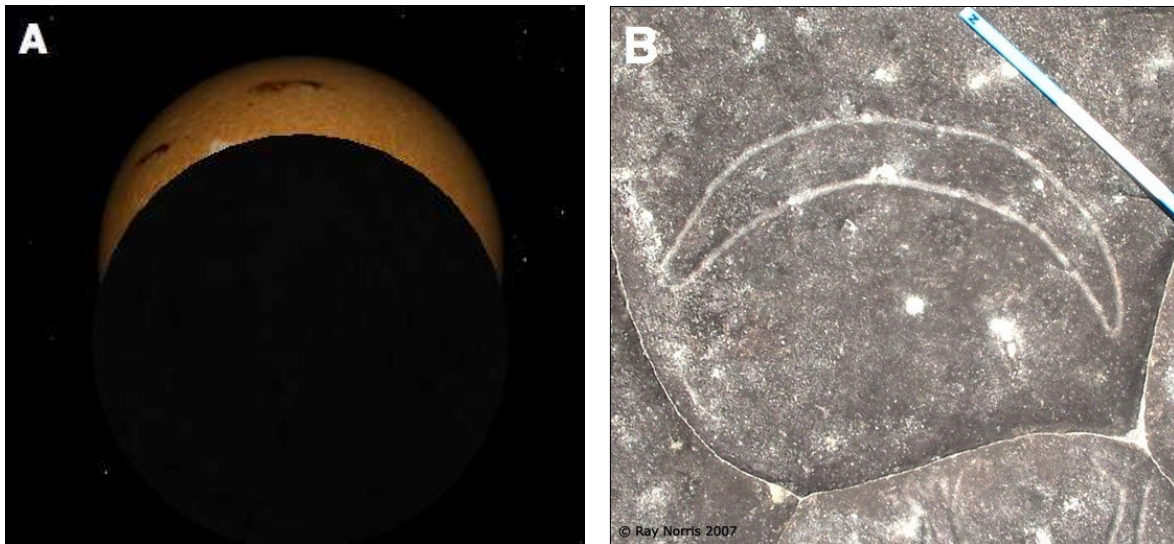


Figure 5: (A) A partial solar eclipse that occurred on 8 August 1831 as viewed from Ku-ring-gai Chase National Park just after 07:00 during mid-eclipse (Event # 10). Image taken from the Starry Night astronomical software package. (B) The Basin Head Track engraving of a crescent shape above the heads of a man and woman who are partially superimposed. The blue and white stick shows the orientation of magnetic north, which is 12.5° east of true north from this location (photograph by R.P. Norris).



Figure 6: Tree leaves acting as pinholes on 3 October 2005 in St. Juliens, Malta, allowing one to observe a partial eclipse without looking at the Sun (image reproduced under Wikipedia Commons license).

Overall, the cosmos is predictable, with most changes occurring gradually and slowly, such as the change in stellar positions over the night or throughout the year, the phases of the Moon, or the positions of the planets. The night sky served many important functions and roles within Aboriginal communities, including time-

keeping, food economics, navigation, social structure, marriage classes and as a mnemonic device. Surprising transient phenomena, such as eclipses, are relatively rare. This is probably the reason that eclipses are met with reactions of fear and anxiety and why they are generally associated with negative attributes, such as

death and disease—a reaction common to other surprising transient phenomena, such as meteorite impacts, fireballs and comets (see Hamacher and Norris, 2009; 2010; 2011, respectively). These perceptions are shared by many other cultures of the world.

Some interpretations presented in this paper are solid examples of ‘Aboriginal Astronomy’ in that they clearly display an understanding of the motions of the Sun and Moon and their relationship with eclipses, including those of the Yolngu, who had a clear understanding that the Moon covered the Sun during a solar eclipse. Other groups, such as the Wirangu and the Euahlayi, understood that *something* was obscuring the Sun during a solar eclipse, although it is not clear whether they defined that object as the Moon.

10 NOTES

1. While the material in this Section is well-known to astronomers it is included here because copies of this paper will be given to various non-astronomers.
2. Among the Arrernte (Anglicised as Aranda or Arunta), eclipses are caused by periodic visits of an evil spirit-magic called *Arungquilta* that takes up residence in the Sun. *Arungquilta* is also found in meteors and comets (Hamacher and Norris, 2010; 2011).
3. He also noted that if a child were born during a lunar eclipse, the child would be a boy.
4. A corroboree is a special ceremonial gathering of people from neighbouring communities, and often involves song and dance.
5. *Yircla* was the name of the community (Eucla) and also that of the Morning Star (Venus).
6. Although Elkin does not identify whether the heavenly object is the Sun or Moon, we interpret the account to refer to the Moon since the Moon turns red during a lunar eclipse.
7. While earlier illustrations of the engraving show the woman covering the man, the engraving itself is less clear. The engraving lines that comprise the arms and legs of the man and woman cross each other with no special reference to superposition.

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THE AFCRL LUNAR AND PLANETARY RESEARCH BRANCH

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Abstract: The Lunar and Planetary research program led by Dr John (Jack) Salisbury in the 1960s at the United States Air Force Cambridge Research Laboratories (AFCRL) investigated the surface characteristics of Solar System bodies. The Branch was one of the first groups to measure the infrared spectra of likely surface materials in the laboratory under appropriate vacuum and temperature conditions. The spectral atlases created from the results were then compared to photometric and spectral measurements obtained from ground- and balloon-based telescopes to infer the mineral compositions and physical conditions of the regoliths of the Moon, Mars and asteroids. Starting from scratch, the Branch initially sponsored observations of other groups while its in-house facilities were being constructed. The earliest contracted efforts include the spatially-resolved mapping of the Moon in the first half of the 1960s by Richard W. Shorthill and John W. Saari of the Boeing Scientific Research Laboratories in Seattle. This effort ultimately produced isophotal and isothermal contour maps of the Moon during a lunation and time-resolved thermal images of the eclipsed Moon. The Branch also sponsored probe rocket-based experiments flown by Riccardo Giacconi and his group at American Science and Engineering Inc. that produced the first observations of X-ray stars in 1962 and later the first interferometric measurement of the ozone and CO₂ emission in the upper atmosphere. The Branch also made early use of balloon-based measurements. This was a singular set of experiments, as these observations are among the very few mid-infrared astronomical measurements obtained from a balloon platform. Notable results of the AFCRL balloon flights were the mid-infrared spectra of the spatially-resolved Moon obtained with the University of Denver mid-infrared spectrometer on the Branch's balloon-borne 61-cm telescope during a 1968 flight. These observations remain among the best available. Salisbury also funded John Strong at the Johns Hopkins University for several near-infrared experiments which created a bit of a stir by detecting water vapor and ice high in the atmosphere of Venus. Once lunar geology transitioned from remote sensing to hands-on geology with the lunar landings, the Branch turned its attention to quantifying the thermal spectral emission from planets for their use as possible infrared calibration sources. The Branch and its research were phased out in 1976 when the program was terminated with the reorganization of AFCRL into the Air Force Geophysics Laboratory (AFGL).

Keywords: Moon, infrared, remote sensing, balloon experiments

1 INTRODUCTION

Quantitative thermal measurements of the Moon date to the 1860s with the studies of John Tyndall, Edward James Stone and William Huggins. However, Lord Rosse (1869; 1870; 1873) was the first to systematically quantify the radiant heat from the Moon by analyzing the disk-integrated lunar thermal properties. Rosse isolated the thermal emission from the Moon with measurements with and without a glass filter in the beam; all the lunar radiation gathered by his reflecting telescope impinged on the detector without the glass filter, while only the visible to near-infrared ($\lambda < \sim 2.5 \mu\text{m}$) sunlight reflected by the Moon got through the filter. Lord Rosse also presaged 'sky chopping' that was to become a standard infrared observing technique a century later (Sinton, 1986). He had found that the instabilities of his initial lunar measurements were related to the changing temperatures of the telescope and air. Consequently, he placed two identical thermopiles in the focal plane such that one viewed the Moon while the other looked at the sky next to the Moon, and the signals negatively combined to cancel the emission common to the beams.

Lord Rosse obtained fairly accurate disk integrated temperature profiles through a lunation and during an eclipse. Subsequently, lunar temperatures were occasionally updated during the next ninety years with observations obtained with gradually improving detectors. However, thermal measurements of the resolved disk of the eclipsing Moon were particularly interesting as the changes in the infrared fluxes could be continuously monitored over a relatively short time, hours instead of days for a lunation. Of the infrared pioneers in the first half of the twentieth century Edison Pettit

and Seth Nicholson became the most prolific, systematically measuring infrared radiation from stars, the Moon and the bright planets with a vacuum thermocouple on the Mt. Wilson Observatory telescopes. They published thermal profiles across the full Moon and cooling curves near the limb during the 14 June 1927 eclipse (Pettit and Nicholson, 1930), while Pettit (1940) confirmed these earlier results by measuring the thermal profile near the sub-solar point for the 27 October 1939 eclipse. The measurements revealed a rapid decrease in the lunar brightness temperature with the onset of eclipse, from $\sim 371\text{K}$ in full sunlight to $\sim 200\text{K}$ shortly after the beginning of full eclipse. The brightness temperature then declined much more gradually during totality, from $\sim 200\text{K}$ to $\sim 175\text{K}$ with temperatures at the limb about 10K cooler. Paul Epstein (1929), a Caltech theoretical physicist, used Pettit and Nicholson's 1927 observations to deduce that the lunar surface was covered by a thin insulating layer of dust rather than just bare rock; Doel (1996) noted that this was the first quantitative analysis of conditions on another planet. Subsequently, Ryadov, Furashov and Sharonov (1964) derived the thermal inertia of the lunar surface from $8\text{-}13 \mu\text{m}$ observations between full Moon and 150° phase angle. Murray and Wildey (1964) obtained the more difficult to measure night side $8\text{-}14 \mu\text{m}$ lunar brightness temperatures while Low (1965) obtained analogous measurements at $20 \mu\text{m}$.

As sparse as photometry/radiometry was during this time, spectral measurements were even more infrequent. Adel (1946) and Sinton and Strong (1960) had published $8\text{-}14 \mu\text{m}$ spectra of the sunlit Moon and of Mars, while Murcay (1965) obtained $8\text{-}14 \mu\text{m}$ spectra of the nearly full Moon on several nights in the fall of

1964 that were of sufficient quality to display subdued spectral structure.

This was the general state of lunar infrared measurements at the time that the Lunar-Planetary Research Branch of the Air Force Cambridge Research Center (AFCRC) initiated a multi-faceted research program to study conditions on Solar System bodies. The Branch built laboratory vacuum chambers to measure the spectra of candidate materials under simulated lunar temperature and vacuum conditions. The laboratory infrared spectra of the various materials thought likely to be found on the surfaces of the Moon, Mars and asteroids were assembled into a spectral library, which then could be compared with ground-based and balloon-borne infrared observations of these objects to infer their surface compositions. However, to provide the context as to why a military laboratory would be conducting basic research into the conditions of the Moon, brief descriptions of the origin of the Laboratories and how it operated within the larger arena of space exploration are given.

1.1 The Air Force Cambridge Research Laboratories (AFCRL)

To meet its research demands after WWII, the Department of Defense (DoD) turned to its few existing laboratories, such as the Naval Research Laboratory (NRL), and created new military laboratories.¹ In response, General H.H. (Hap) Arnold, the Commanding General of the Army Air Forces (AAF), tasked his Scientific Advisory Group led by Theodore von Kármán November 1944 to study and recommend how the AAF should best prepare for future research requirements. Von Kármán and the Advisory Group recommended that existing AAF developmental research facilities be expanded and new ones created (Gorn, 1994) under a budget of 5% of the wartime expenditure. Two AF basic research organizations were among the newly-created laboratories; the Cambridge Field Station and the Applied Research Section at the Wright-Patterson Air Force Base (AFB) (which was later renamed the Aerospace Research Laboratory).

In establishing the new Cambridge Field Station on 20 September 1945, the Army Air Force recruited among the electronics scientists and engineers who had worked on War-related radar and antenna research at the Massachusetts Institute of Technology (MIT) Radiation Laboratory, the largest such facility during the War, and the Harvard Radio Research Laboratory. The inducement to join this new organization was that about half the war-time military projects at these institutions were to be transferred into the Field Station. By the time the Air Force became a separate service in September 1947, the Field Station consisted of four electronics divisions. The subsequent transfer of the atmospheric sciences, meteorology and geophysics research at Watson Laboratory in Red Bank, New Jersey to Cambridge in June 1948 expanded the research mission for a newly-created Air Force Cambridge Research Center (AFCRC).

A decade later, AFCRC was slated for significant manpower and funding cuts under the Eisenhower administration's deficit reduction plans. Thus, the Secretary of Defense proposed a 10% cut in the fiscal year 1957 military research budget, which was to be

achieved by cancelling 600 Air Force and Navy research projects (Rigden, 2007). In light of this situation, the Air Force planned to shift emphasis within the AFCRC to operations, development and system support and to rely on contracts with university and private research organizations for the necessary basic and applied research. This all changed as the Air Force responded to the Sputnik launch in October 1957 and subsequent demands to improve the technical research base within the DoD laboratories. Astronomical programs within AFCRC that were conducted in the 1950s, such as solar physics, cosmic ray and meteoritics research, enjoyed a resurgence, while new programs in lunar and planetary research and the infrared celestial background were started in the early 1960s. John Salisbury (pers. comm., 23 October 2004) provides a personal anecdote highlighting this change. He visited AFCRC in 1956 early in his graduate work as he anticipated being assigned there upon graduation. When asked what he was interested in Salisbury replied 'space physics'—much to the amusement of his interviewers. Four years later he led his own Branch in this field.

1.2 Partitioning Space

McDougall (1985) described in depth the U.S. policy on space and the attendant politics during the 1950s through 1960s, a summary of which follows. The developers of the V-2, Werner von Braun and his most experienced staff, were brought to the United States after the War, to continue rocket development under the aegis of the U.S. Army at Huntsville, Alabama. The Redstone was the first substantial rocket produced by the group, and the first flight occurred on 20 August 1953. About this time, the Army began developing the much larger Jupiter rocket and a special test vehicle, consisting of a Redstone first stage upon which were stacked two additional stages of clusters of small solid propellant motors, was devised for high velocity re-entry testing in support of the Jupiter development. Von Braun's team specifically designed this vehicle, called the Jupiter C, to have orbital capability by having it able to accommodate a fourth stage motor.

In July 1955, President Eisenhower announced that the United States would launch a satellite as part of the International Geophysical Year; the experimental objectives of which would be guided by the upper Atmosphere Research Panel, which had previously overseen experiments on V-2 rockets after the War. An intense struggle ensued between von Braun's group and the Naval Research Laboratory for the launch vehicle. The Administration decided upon the Navy's project Vanguard in September 1955. The Vanguard launch vehicle consisted of a modified Viking first stage with Aerobee and Altair second and third stages, respectively. The Navy developed the Viking and Aerobee as research sounding rockets, which were used by academics and other experimenters, so the program had the decidedly desired 'civilian' flavor. However, as McDougall (1985) points out, the Army proposal, dubbed Project Orbiter, was recognized by the Government panel making the choice as having the better booster. Indeed, the Pentagon specifically ordered that a fourth stage motor was not to be included on the 16 November 1956 initial test flight to prevent an 'accidental' launch of a satellite into orbit.

The Administration's orderly approach to space was disrupted with the 4 October 1957 Sputnik launch. Sputnik caused a public furor that mixed national humiliation over having been beaten in the 'Space Race' with the specter of nuclear weapons in orbit. This was only compounded with the launch of Sputnik II a month later. The Vanguard program was accelerated in an attempt to launch a satellite on 6 December 1957 on the third of six test rounds originally scheduled; but it exploded seconds after launch. The next four attempts failed before the first success on 17 March 1958. In the interim, the Jupiter C was taken out of storage and von Braun's Army group successfully flew the first U.S. satellite, Explorer I, on 31 January 1958. A 'turf war' then ensued, as the services jockeyed to be the responsible agency for the U.S. space program. After extensive lobbying and numerous committee meetings, the Administration decided to elevate the civilian National Advisory Committee on Aeronautics (NACA) to agency status as the National Aeronautics and Space Administration (NASA) to lead the U.S. space effort. Thus, the U.S.'s open and peaceful program would be contrasted with Russia's secrecy. The roles of the Services were judged by their areas of responsibility and since the Navy emphasized sea power, it was eliminated early in the debate.² The Air Force was given the responsibility for the military use of space, due in part to its role in surveillance.

2 THE AFCRL LUNAR-PLANETARY EXPLORATION BRANCH

At the beginning of the 1960s, the roles of NASA and the Air Force in space were still being defined and preparatory research was essential to support the manned and unmanned missions contemplated. For example, manned exploration of the Moon was soon established as a goal, with the Air Force considering a manned lunar base (Brown, 1960). Many ambitious planners also had Mars penciled in as the next destination after the Moon. However, the exact nature of the lunar surface was a matter of conjecture at the time. Although most thought that the surface was covered by a thick layer of dust, some believed that the surface dust layer was loose enough to engulf any spacecraft that attempted to land (e.g. see Gold, 1959). The practical consequence of a deep loose dust layer that lacked appreciable bearing strength was that the foot pads on the Jet Propulsion Laboratory (JPL) Surveyor spacecraft would have to be so large to prevent the craft from sinking out of sight that there would be no room for experimental equipment (Salisbury, 2004).

Early on, Salisbury et al. (1963) resolved how far a landing craft would sink into the lunar dust by measuring a high vacuum adhesion for silicate particles and correctly predicting the bearing strength of the lunar surface, although not everyone was convinced at the time (Gold, 1965). The lunar surface properties also could be inferred by remote sensing with infrared spectral measurements. For example, the composition of the surface may be deduced from the infrared spectral signature indicative of its various mineral components while the relative strengths of these features are influenced by the size distribution of the soil in the lunar regolith (surface layer) and the packing of the particles. How hot the Moon gets during the daytime and how fast it cools with the onset of night or in

eclipse also tells us something about the lunar surface; a rocky surface cools more slowly than a dusty one.

To address such issues, AFCRC had established the Lunar-Planetary Exploration Branch within the Research Instrumentation Laboratory in 1960, with Charles Campens as Chief and Dr John Salisbury as the single person workforce, to investigate the surface properties of the Moon and planets. Campens had written an internal proposal to map the Moon, which was funded, and the two-person branch was created to do the research after John Salisbury arrived. Salisbury had joined AFCRC in July 1959 to fulfill his Reserve Officer Training Corps military obligation after obtaining a Geology degree from Yale University; his interest in space geology dovetailed nicely with the objectives of the new Branch. He subsequently became the Branch Chief in 1961 when Campens migrated to JPL. The Branch's charter to assess the Moon as a manned station is evidenced by the fact that the second published Technical report from the group was titled *Location of a Lunar Base* (Salisbury and Campens, 1961); the first Technical Report was a brief 1960 review of what was then known about the Moon. The Branch was reassigned to the Space Physics Laboratory in 1963 to reflect the basic research nature of the program.

As NASA began to ramp up planetary astronomy in the U.S., the Air Force also improved its in-house research capability to support space missions. On 1 April 1961 the status of basic research was elevated when all Air Force research was reconstituted into the Office of Aerospace Research (OAR), a separate operating agency that reported directly to Headquarters, U.S. Air Force. The Air Force Cambridge Research Laboratories (AFCRL—a recycling of the name as the facility was also so designated between 5 July 1949 and 28 June 1951) was the largest basic research component of OAR. Equally important, a number of civil service (pay scale) reforms designed to retain well-qualified Government researchers and to attract new talent were instituted in 1961-1962, and the manner in which the facilities and tools were funded were streamlined (see Berger, 1962).

The AFCRL lunar and planetary research benefited from these changes. Salisbury detailed the scope of the Branch's program to the Menzel (1962) panel in the winter of 1962. The Branch had inherited a number of research efforts funded by or through AFCRL such as lunar photography and mapping by the Pic du Midi Observatory (e.g. Kopal, 1960) and William Sinton's infrared radiometry and spectroscopy of the Moon (e.g. Geoffrion et al., 1960; Sinton 1962). Salisbury also planned to sponsor rocket-based X-ray and ultraviolet observations of the Moon and anticipated his own observatory facility. These observations were to be interpreted by measurements in the laboratory plus theoretical analysis. Salisbury emphasized that the program was tailored for the Air Force mission and that the research would complement that being done by NASA.

While in-house laboratory and observing facilities were being constructed at the beginning of the program, Salisbury and his team sponsored the efforts of others to obtain the observations in which they were interested. Salisbury and his Branch also periodically

compiled summaries of Solar System research papers published in the literature as a resource for their research. The first bibliography of published lunar and planetary research plus a synopsis of the papers that were collected by Salisbury, Van Tassel and Adler (1962) comprised a mere 28 pages. By the time Salisbury (1968), as editor, published the 3rd Supplement in 1968, the bibliography had grown to a book-sized 304 pages. These annotated compilations were deemed important enough by the planetary research community that Salisbury and his team subsequently published them quarterly in *Icarus*, beginning with Volume 12 in 1970 and continuing until Volume 22 in 1973, after which they were published in the *Moon* through 1976 with Zdeněk Kopal as primary author.

2.1 Probe Rockets Experiments and X-ray Astronomy

The Cambridge Field Station was involved in space-based research from sounding rockets almost from the time it was formed. The military strongly supported geophysical research after WWII as it required this information for operations. For example, knowledge of the density, temperature and composition of the upper atmosphere was needed in order to understand how these factors influenced ballistic missile performance. Conditions in the ionospheric regions of the upper atmosphere affected radio communications and a link between solar activity and ionospheric disturbances was strongly suspected before the War. Also, it was speculated that solar ultraviolet radiation maintained the ionosphere, but direct measurements of the solar ultraviolet flux were needed to quantify this connection. How the Sun affects the ionosphere and, in turn, how the disturbed ionosphere perturbs radio propagation was, and still is, of high military importance.

The post-WWII military emphasis on upper atmospheric research came with a new tool—rocket probes. A civilian V-2 panel was established in February 1946 to organize and direct the upper atmospheric experiments that were flown on captured German V-2 rockets; although the panel was ‘civilian-dominated’, the panel members had been engaged in war-time research either while serving in the military or allied with one of the military-sponsored laboratories. These experiments were ‘free rides’ on the Army tests, from which the military expected to gain experience in missile operations, tracking and guidance and control. The broad range of experiments included studies of radio propagation in the ionosphere, atmospheric composition, pressure, temperature and density, cosmic rays, meteoritics, atmospheric absorption in the ultraviolet and ultraviolet energy distribution of the Sun. The Naval Research Laboratory and Applied Physics Laboratory (APL) had a leadership role on the panel with support from General Electric Corp.; other organizations, including several universities, also participated. David DeVorkin (1992) superbly chronicles the history of the US rocket-based upper atmospheric research conducted under the aegis of the panel from the initial post-War V-2 flights to the International Geophysics Year in 1957. The panel disbanded in 1961, having undergone several name changes during its 15 years of existence.

Both the Naval Research Laboratory and the Applied Physics Laboratory existed at the end of the War and both organizations had research groups that were adapted to conduct upper atmosphere experiments. In contrast, the newly-formed Cambridge Field Station had to catch up. Marcus O’Day, Chief of the Field Station’s Navigation Laboratory, joined the V-2 panel a few months after it was formed and remained a member through the 1950s. He supervised the first successful Air Force V-2 (#15) launch from Holloman AFB, NM on 21 November 1946. Since O’Day’s core professional staff originally was composed almost entirely of Ph.D. physicists recruited from war-time radar groups at Harvard and MIT, the disciplines of these scientists reflected the Navigation Branch’s initial emphasis on electronics and radar research and, consequently, the first Air Force V-2 flights concentrated on ionospheric radio propagation. However, since O’Day coordinated the early Air Force work on the properties of the upper atmosphere, his branch was designated the Upper Air Laboratory in March of 1949 to reflect the importance of this research.

The V-2 experiments extended to higher altitudes and included *in situ* measurements of the density, temperature and constituents of the upper atmosphere, cosmic rays and solar ultraviolet radiation that were previously conducted from balloons. The ultraviolet transparency of the atmosphere is a direct measure of the ozone absorption profile as a function of altitude, which may be derived by measuring the ultraviolet spectrum of the Sun as it varies with altitude. On 10 October 1946, Richard Tousey’s Naval Research Laboratory group obtained the first ultraviolet spectra of the Sun (Baum et al., 1946) with a spectrometer mounted in the V-2 tailfin. However, the Physics Department at the University of Colorado achieved the ‘holy grail’ of the first far ultraviolet detection of Solar $L\alpha$ (Rense, 1953) on an 11 December 1952 Aerobee flight using a coronagraph and payload pointing control mechanism funded by O’Day. The key to their success was the significant improvement in attitude control.³

The 69th and last V-2 flew in September 1952. Of the various replacement options, the Aerobee⁴ emerged as the workhorse for upper atmospheric and astronomical research. The numerous exo-atmospheric solar flux measurements obtained from these rockets were important in establishing the link between the changes in the Earth’s climate and changes in the solar constant, and in showing that these changes drove the variations in density and height of the atmosphere that were being measured on rocket and balloon flights. At mid-century, an authoritative value for the variation in the solar constant was one percent or so (Doel, 1996). Thus, definitive measurements were needed to explore the Earth-Sun links to weather and, in this context, the first successful AFCRL Aerobee-based in-house experiment took place on 26 May 1950 to measure the solar constant.

AFCRL/AFCRL would fly rocket-based experiments at a frequency of about one per week; the majority of these flights were to probe the ionosphere. The Lunar and Planetary Research Branch sponsored a series of five probe rocket-based experiments, and the first two successful flights were historic as they were the first to detect X-ray stars.⁵

Salisbury funded a wide range of programs that provided the initial steps into several new fields of research. The X-ray results were, as Harwit (1981) noted, a specific example of how military research led to major astronomical discoveries. Giacconi (2009) recollects the events in some detail, so only a brief description is given here. In 1959 John Salisbury discussed the idea of a rocket-based X-ray lunar fluorescence experiment with Riccardo Giacconi, then at the American Science and Engineering Corp. (AS&E) in Cambridge, Massachusetts, although, as Giacconi (2009) noted, a calculation that he and his AS&E colleagues did at the time indicated that the expected fluorescence would be well below the detection limit of the proposed instrument. The first (unsuccessful) flight took place the following year. A second flight, on 18 June 1962, did not measure lunar fluorescence but did detect two objects, now design-nated Sco X-1 and Cyg X-1, outside the Solar System (Giacconi, et al., 1962). Two more AFCRL-sponsored experiments were flown in October 1962 and June 1963 that confirmed the discovery (Gursky, et al., 1963).

Giacconi (2005: 5-6) apparently is of the opinion that the discovery of the X-ray sources was due as much to preparation as to serendipity. He states:

We were successful in interesting Dr. John Lindsay of the Goddard Space Flight Center ... in funding a small program to develop grazing incidence telescopes but not in interesting NASA Headquarters in funding rocket instrumentation to search the sky for X-ray stars. We therefore turned to the Air Force Cambridge Research Laboratories that had funded previous work by ASE in the classified domain. The Air Force was receptive to providing support to place a small aperture (1 cm²) Geiger counter aboard a Nike-Asp rocket. The flight attempted in 1960 failed because of rocket misfiring. In January 1961 we received a new contract to fly four Aerobee 150 rockets for our experiments to search for X-ray stars, as well as lunar X-rays. The larger rocket permitted the design of a much more sensitive instrument ...

An important feature of the experiment was the use of a large field of view, which increased the probability of both observing a source anywhere in the sky and receiving a sufficient number of X-ray photons to make the detection statistically significant ...

After an-other rocket system failure in October 1961 we had a successful flight on June 18, 1962, when we discovered the first extrasolar X-ray source (Sco X-01) as well as the extragalactic X-ray background.

Note that Giacconi places the search for X-ray stars before measuring lunar X-ray fluorescence, the putative purpose of the experiments.

Salisbury funded AS&E for three more rocket-based experiments (Sodickson et al., 1968). The 26 May 1964 flight carried an X-ray package, but the pointing system failed. The 9 November 1965 Aerobee flight carried a Block Associates interferometer in an attempt to measure the 7-30 μm lunar spectrum at 40 cm^{-1} spectral resolution. The pointing system malfunctioned, and only two noisy unusable spectra of the Moon were extracted. However, as Baker, Steed and Stair (1981) pointed out, this experiment serendipitously obtained the first interferometric spectra of the Earth's limb in which the 15 μm CO₂ and 9.6 μm ozone bands were observed in absorption when the instrument looked at the Earth and in emission when viewed at a

tangent height of 55 km above the Earth's horizon. The third and final experiment on 26 November 1966 carried a telescope with an infrared circular variable filter to obtain spectra of the Moon. After considerable data processing, 4-13 μm spectra of the lunar maria and highlands were extracted that revealed little difference between the two.

2.2 Ground-based Observations of the Moon

An indication of the difficulty that the Air Force shared with NASA in conducting lunar and planetary research in the early 1960s is that not only was most of the research done under contract but that non-astronomers (physicists) and academics were pressed into service. Such was the case for the infrared observations of the Boeing team of John Saari and Richard Shorthill. The initial lunar observations and analysis sponsored by AFCRL and Air Force Office of Scientific Research concentrated on lunar eclipses as the infrared measurements could follow most of a complete thermal cycle in just one night's observing. Such eclipse cooling curves were measured for several lunar features by Shorthill, Borough and Conley (1960), who used a thermistor bolometer with a 5-40 μm response to scan across the Moon during the 13 March 1960 eclipse. A brightness temperature of <200K was measured for the eclipsed lunar disc but they also found that certain features, such as the crater Tycho, stood out with a 50K brightness temperature contrast over their immediate surroundings. The Aristarchus and Copernicus craters also displayed similar enhanced emission. Sinton (1962) and Saari and Shorthill (1963) confirmed the 50K difference between Tycho and its surroundings at the beginning of the 5 September 1960 eclipse and Saari and Shorthill (1963; 1966) derived temperature contour maps for several craters the day before, during and after this eclipse. They also determined eclipse cooling curves for the craters. These observations simply scanned across the Moon and, thus, were able to only sample a limited area of the lunar surface. Then, Saari, Shorthill and Deaton (1966) obtained the first global infrared maps of the eclipsed Moon by raster scanning the entire disk with a 10" beam using a Ge:Hg photoconductor with a 10-12 μm filter during the 19 December 1964 eclipse; a single image took 16 minutes to complete. These images revealed a large number of hot spots on the lunar surface, which were labeled as thermal anomalies; they were appreciably warmer than their surroundings. Ultimately, Shorthill and Saari (1966) tallied a total of about 1,000 hot spots, which Shorthill (1973) defined as discrete areas that are at least 5K above their surroundings. The preliminary classification of Saari and Shorthill (1967) associated about 85% of the hot spots with bright craters while another 9% corresponded to smaller isolated visible bright regions. Saari and Shorthill (1966) also converted the infrared images that covered areas selected as possible lunar landing sites into a set of isothermal (equal temperature) maps of the lunar equatorial regions, then synthesized isothermal and isophotal (equal brightness) visible and infrared atlases of the Moon throughout a lunation (Saari and Shorthill, 1967; Shorthill and Saari, 1965b).

Murray and Wildey (1964) found that the 8-14 μm thermal anomalies persisted for hours after sunset during a lunation and that, in concordance with eclipse

observations, Tycho and Copernicus were the most prominent hot spots. Hunt and Salisbury (1967) subsequently tracked Tycho as it cooled for four days after sunset and Dave Allen and Ed Ney (1969) monitored the elevated temperatures of Tycho, Copernicus and Aristarchus over their surroundings during the lunar night. Allen (1971a) was able to detect the thermal hot spots near the terminator for a couple of days after sunset at 10 and 20 μm . Allen and Ney found that the observed night-time brightness temperatures of a given area on the Moon decreased with wavelength, with a difference of ~ 30 K between the 4.9 μm and 12 μm values. Their low resolution spectra confirmed that the 8-13 μm color temperature was significantly higher (~ 50 K) than the brightness temperature.

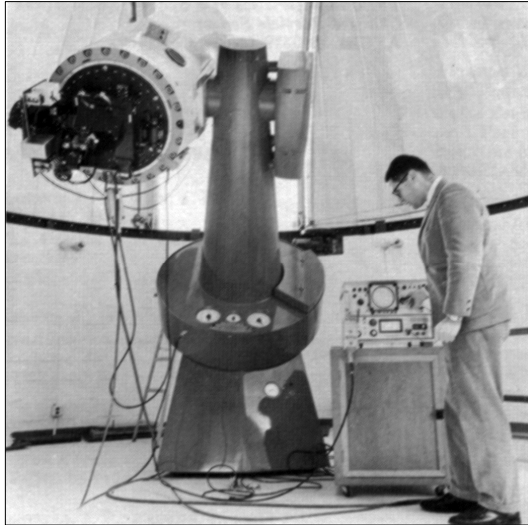


Figure 1: Dr John Salisbury at the controls of the Lunar and Planetary Research Branch's 60-cm telescope.

The Lunar and Planetary Branch planned their own observatory with which to obtain infrared observations. Smith and Salisbury (1962) detailed the results of a site survey conducted by New Mexico State University in the Cloudcroft area in the Sacramento Mountains of New Mexico as an initial step toward establish an AFCRL Lunar and Planetary observatory. Cloudcroft was chosen because the infrastructure (roads, electric power, etc.) were already in place, having been installed to support an AFCRC solar furnace that never materialized, plus the Air Force Avionics Laboratory had begun construction of a 1.22-m surveillance telescope at the site.⁶ Furthermore, Holloman AFB and the AFCRL Sacramento Peak Observatory were close by and could provide administrative support. Since the Smith and Salisbury site survey had been limited by both time and money, the Air Force asked Donald Menzel (1962) to convene a panel to evaluate both the site survey results and the suitability of the site. The panel concluded that the site survey was inadequate and that "... sufficient time and funds should be spent to get a thorough check of the seeing conditions at more than one possible site ..." (ibid.) with Sacramento Peak and Haleakala, Hawaii,⁷ specifically mentioned in addition to Cloudcroft. Salisbury's group did not have the resources to conduct such a survey.⁸ However, by the mid-1960s, the Lunar and Planetary Exploration Branch had constructed its own observing facilities, as shown in Figure 1. The telescope was one

of the first 60 cm Boller & Chivens telescopes built (serial number 2), which the Branch sited in Concord, MA. This was an interim infrared lunar observatory, which was operated from the end of 1966 until November 1968 when a comparable instrument was opened on a permanent site atop Mauna Kea in Hawaii. Built with AFCRL funds, the Mauna Kea facility was jointly operated with the University of Hawaii. Hunt, Salisbury and Vincent (1968) used the telescope in Concord to map about 70% of the Moon at 10 μm during the 13 April 1968 eclipse looking for subtle changes in the (fainter) thermal anomalies since the Saari, Shorthill and Deaton maps of the December 1964 eclipse. Lunar transient events and the emission of volatiles had been observed since the time of Lord Rosse, and if, as speculated, the source of the emission was volcanic, then such phenomena might have infrared signatures as internal heat sources that might have varied between the 1964 and 1968 eclipses. They did not detect any internal heat sources nor did they find definitive changes in the brightness of the fainter anomalies between the times of the two eclipses.

The anomalously warm regions of the Moon seen in eclipse are surface areas that retain heat from absorbed sunlight longer than their surroundings. Unfortunately, deriving the thermal inertia of the resolved surface of the Moon is complicated by the fact that the cooling curves observed during the lunar night appear to differ from those observed during an eclipse. Wildey, Murray and Westphal (1967) proposed that such a difference was expected as the thermal emission during an eclipse comes from the very top-most layer of dust while the night-time emission arises from several centimeters below the surface. The temperature contrasts of the anomalies could arise if the areas were rocky and the cooler surrounding areas were covered by a layer of dust. However, since the lunar surface exterior to the thermal anomalies has the same low thermal inertia found for the Moon in general, a small proportion of the area ($<10\%$) within the resolution element being used to observe the thermal anomalies and comprised of higher thermal inertia components such as boulders and large-scale surface roughness radiating at a higher temperature could explain the observations (Allen, 1971b; Allen and Ney, 1969). Although only a small proportion of the observed surface area, the higher temperature components dominate the thermal emission of the observations, especially at the shorter wavelengths.

While the infrared broadband photometry of the Moon provides information on the physical characteristics of the regolith, such as what terrain might be dusty or rocky and by how much, compositional information may be derived from the infrared emission spectra. Such spectra contain features indicative of the mineral composition, density, and particle size and packing. To explore these parameters, the Lunar and Planetary Exploration Branch created a spectral library from their laboratory measurements on likely lunar analog materials and used it to infer the mineral composition and surface properties of the Moon. These spectra were obtained in cooled vacuum chambers that simulated the temperatures and conditions on the Moon. Figure 2 shows an early laboratory vacuum chamber used to obtain the spectra of the candidate materials.

The most prominent spectral features between 8 and 25 μm are the fundamental stretching and bending modes of various types of silicate molecules, although grain size affects the exact wavelength of the peak and the shape and breadth of the features. The principle molecular vibration bands occur at what are classically labeled as the Christiansen frequencies of the minerals, where the maximum absorption or emission occurs at the wavelength at which particle scattering changes from being dominated by volume scattering to surface scattering. The vibrational and electronic bands combine linearly in a coarse mineral mixture (Thomson and Salisbury, 1993), which means the surface composition and the relative amount of the various constituents may be inferred by additively combining the spectra of individual minerals from the spectral atlas in various proportions until a match is found with observations. However, other factors influence the spectrum. Van Tassel and Simon (1964) concluded from early laboratory measurements that the strength of the infrared spectral signatures depended on particle size in the sense that the signatures were weaker in fine powder compared to coarser material, becoming barely discernable when the particles are the size of sand grains. Hunt and Logan (1972) extended and refined this analysis with detailed laboratory measurements on the effects that particle size has on the infrared spectrum for various silicate materials. Finally, the volume scattering of a small particle on a surface exhibits a 'transparency' or emission trough between the fundamental stretching and vibrational modes of silicates (Salisbury and Wald, 1992).

An observational database was needed with which to compare the laboratory spectra. To this end, Hunt and Salisbury (1964) obtained 16-24 μm spectra at four locations on the sunlit Moon using a Golay cell in a spectrometer mounted on the 1.07-m Lowell Observatory telescope. The spectra did, indeed, differ between locations: the 19-23.5 μm emission from Mare Serenitatis varied more steeply with wavelength than that from Copernicus. However, the atmospheric transmission impressed upon ground-based infrared spectroscopy dominated over the subtle mineral features in the lunar spectral energy distribution and one needed to get above the atmosphere to obtain uncontaminated measurements. Strong (1959) and de Vaucouleurs (1960) had posited early on that balloon-based astronomy could be a viable surrogate for satellites because, at altitude, a balloon platform is located above much of the atmosphere and the emission and absorption by atmospheric constituents are greatly reduced. Salisbury and Van Tassel (1962) also pointed out that much of the thermal emission from the atmosphere, which they believed had rendered ground-based determinations of brightness temperatures rather uncertain, would be eliminated at balloon altitudes.

2.3 The Balloon Program

AFCRC/AFCRL had been involved in balloon research since shortly after WWII and had actively advanced ballooning technology and applications. AFCRC/AFCRL and Holloman AFB combined have flown more than 2,500 balloon experiments over the years and have set the ballooning records for altitude, duration of flight and distance at one time or another. A bizarre side note is that Air Force operations from

Holloman AFB, New Mexico, have been a major source for UFO mythology. The Air Force's Watson Lab in Red Bank, NJ (soon to join the Cambridge Field Station) funded New York University's Project Mogul, a series of balloon flights that attempted to detect Soviet nuclear tests with acoustic sensors. The fourth flight in the series on 4 June 1947 and the first from Holloman AFB landed in a rancher's field near Roswell, New Mexico. The recovery of the debris by the rancher plus later civilian observations of the recovery of anthropomorphic dummies dropped from Holloman-based balloon-borne parachute tests under Project High Dive gave rise to the 'Roswell incident'. McAndrew (1995) has shown that this only became an

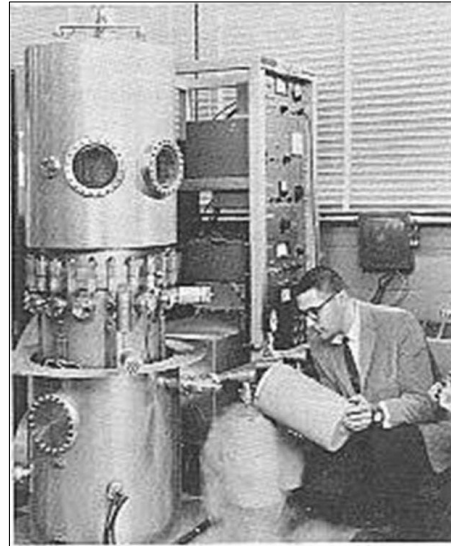


Figure 2: John Salisbury cooling the sample module for one of the environmental test chambers built and used by the Lunar-Planetary Exploration Branch to study the optical properties of candidate material that were thought likely to be found on the Moon, Mars and the asteroids.

incident in the 1970s with the publication of several lurid books about aliens, bodies and a crashed spaceship while McAndrew (1997) subsequently explained how the dummies and other incidents became the fodder for the Roswell UFO mythology. Ryan (1995), in his book: *The Pre-Astronauts: Manned Ballooning on the Threshold of Space*, tells the fascinating story of the manned balloon flights (Man High) in the early 1950s and the subsequent parachute tests with dummies (High Dive) and pilots (Excelsior) that culminated in Stargazer, a manned infrared astronomy flight.

While manned and unmanned balloons were used for cosmic ray research almost from the first ascent and optical observations were attempted in the mid-nineteenth century (e.g. Glaisher, 1863), quantitative optical astronomy from manned balloons began in earnest in the mid-1950s, principally due to the efforts of Audouin Dollfus at the Paris Observatory. In November 1956 and again in April 1957, Blackwell and Dollfus (Blackwell, Dewhirst and Dollfus, 1957; 1959) rode a balloon-borne gondola launched from the terrace of the Meudon Observatory to altitudes of between 5.5 km and 6 km to photograph solar granulation. Prior to that, on 30 May 1954, Dollfus became the first to obtain quantitative infrared observations

from a balloon. He was carried to 7 km altitude in an attempt to measure water vapor on Mars with a lead sulfide cell on a 50-cm telescope. His rather clever detection scheme was thwarted by saturation of the 1.4 μm water band in the atmosphere above the balloon. Dollfus later followed this experiment in 1959 with near-infrared observations of Venus from 14 km altitude from which he derived the stratospheric water content which he used to calculate planetary values from subsequent mountain top measurements (Dollfus, 1964). Although these flights demonstrated that astronomy could be done from balloons, they returned limited quantitative results.

DeVorkin (1986) provides an in-depth and lively description of the circumstances, politics and personalities involved in the manned balloon flights in the first half of the twentieth century in his book *Race to the Stratosphere: Manned Scientific Ballooning in America*. However, his post-WWII description concentrates on the role of the Office of Naval Research in ballooning, and only passing reference is made to the extensive Air Force balloon program that Ryan (1992) documented in his book *The Pre-Astronauts*.

Shortly after Dollfus' experiments, the DoD sponsored two manned astronomical balloon flights. On 28 November 1959, Charlie Moore and Malcolm Ross attempted to observe Mars and water vapor on Venus with a 40.6-cm Schmidt telescope that had an effective aperture of 30.5-cm and was carried on board the Navy-sponsored Strato-Lab IV balloon flight, but they obtained limited results (Ryan, 1995). John Strong, at Johns Hopkins University, planned the observations and was originally scheduled to fly on this experiment. According to Augason and Spinrad (1965), Strong had designed the experiment which had 14 slits centered on isolated lines in the 1.13 water vapor band of the spectrum seen in the Czerny-Turner spectrometer. The multiple slits increased the flux onto the PbS detector, thus increasing the sensitivity of the measurements. However, the results were limited because swaying of the gondola made observations difficult, and an independent measure of residual atmosphere using the Moon was not possible. Also, Strong did not have a good value for the pressure in Venus' atmosphere, which compromised interpretation of the observation. A flight the previous year to observe Mars with the same instrumentation was canceled when the balloon ruptured. The second program, Project Stargazer, was initially proposed at the January 1958 AFCRC Balloon Conference as a series of four flights in the spring and fall of 1961. This was a joint Air Force, Navy, Smithsonian Institution and MIT program for manned balloon astronomy experiments; the Navy contributed a navy civilian astronomer, William White, while the most experienced Air Force balloonist, Joseph Kittenger, was to pilot the gondola. The first Project Stargazer experiment flew on 13 December 1962 and obtained observations with a 32-cm telescope mounted on top of the gondola that was remotely controlled from within. A few months later, Stargazer II was in the final countdown on 20 April 1963 when a static discharge tripped the balloon release, ending the experiment. Thus, the single Stargazer experiment became the seventh and final Air Force manned balloon flight in the program and, although labeled a "... huge success ..." by the partici-

pating astronomers, Hynek and White (1963), stabilization problems and the expense of mounting such efforts resulted in the program being canceled before the Lunar and Planetary Research Branch's manned infrared lunar experiment could be flown.

As would later be the case for space-based astronomy, balloon researchers soon preferred remote operations without the weight and safety burden of manned gondolas, and both the Navy and the Air Force flew unmanned astronomical balloon experiments throughout the 1960s. The Office of Naval Research, the National Science Foundation, and NASA funded Princeton University for the Stratoscope II flights⁹ that carried a 0.9-m telescope. The first two Stratoscope II experiments were flown in 1963 and obtained near-infrared spectra of cool giant and supergiant stars (Woolf, Schwarzschild and Rose, 1964), Jupiter, and Mars (Woolf, 1965). Danielson (1966) describes the hardware, details the flight operations and summarizes the results from the flights. Six more Stratoscope II flights obtained high-resolution photographs of galaxies before the telescope was irreparably damaged by ground impact.

The Lunar and Planetary Research Branch teamed with the AFCRL Balloon Branch in a three-phased program to obtain infrared measurements from balloons, the most ambitious of which was Project Stargazer. About the same time as Stargazer, AFOSR funded John Strong, at the Johns Hopkins University, through AFCRL, to conduct Project BalAst to loft a modest-sized instrument to an altitude of 24 km on an AFCRL unmanned balloon to measure water vapor, CO₂ and other gases in the atmosphere of Venus. Unfortunately, the instrument failed on the initial April 1962 attempt, but a second successful flight in February 1963 looked for but did not unambiguously detect the 1.3 μm band of H₂O; an October 1963 experiment extended the wavelength coverage to 3 μm to search for water (Bottema, Plummer and Strong, 1964). This was followed by AFCRL's Project Sky Top, which carried a near-infrared spectrometer to an altitude of ~33 km in January and February of 1963 to obtain thermal emission spectra of the Moon in an unsuccessful attempt to refine the lunar night-time temperature to better than the 50K accuracy of contemporary measurements. The University of Denver also received funding through AFCRL to fly an infrared spectrometer on an AFCRL balloon to measure the solar emission between 4 and 5 μm (Murcay, Murcay and Williams, 1964) as part of the long-term AFCRL interest in determining the solar constant. At an altitude of 31 km, the observations were relatively free of atmospheric interference and the solar flux measured by this experiment was one of a limited number of high-quality infrared observations used by Labs and Neckel (1968) to derive an absolutely-calibrated spectrum of the Sun. AFCRC had supported research at the Lowell Observatory during the 1950s for ground-based monitoring of the reflected sunlight from the planets looking for variations in the solar constant and to study the global circulation patterns on Mars and Jupiter as analogs for the Earth (Jerzykiewicz and Serkowski, 1966; Sinton, Johnson and Iriarte, 1959).

Salisbury's group had contracted with Alvin Howell and his associates at Tufts University to construct a payload for their in-house balloon-borne instruments

to measure the infrared flux from the Moon and planets. Howell had an established relationship with the Hanscom balloon group, having built the instrument package for the first around the world balloon flight in 1957 (Long, 2004). The Lunar and Planetary gondola had a 61-cm telescope in a versatile payload capable of automatically acquiring and tracking any bright object in the sky; particularly, the Moon, Mars, and Venus. Van Tassel (1968) obtained 9-22 μm lunar spectra on the initial flight of this system in February 1966. He found no distinctive infrared spectral features that could be used for mineralogical identification. The 61-cm telescope and gondola package was flown 11 times between the first AFCRL launch in 1966 and five years later when the lunar measurements were terminated. Although only three of these experiments returned good data, Salisbury (2004) pointed out that the expense of a balloon flight was quite modest and the payload was recovered. Thus, the 'unsuccessful' flights could appropriately be considered as engineering development tests to perfect the hardware and flight procedures.

The most successful experiment mated the University of Denver spectrometer to the Tufts 61-cm telescope to obtain 7-13.5 μm spectra of six regions of the nearly full Moon on a 13 April 1968 flight (Murcay, Murcay and Williams, 1970). These results were a considerable improvement on Frank Murcay's ground-based measurements four years earlier (Murcay, 1965). The balloon-borne spectral energy distribution measured in each region was broader than could be accounted for by a single temperature blackbody, and the spectra were subtly different near the peak emission. In a companion paper, Salisbury et al. (1970) compared these results to the AFCRL spectral library but could not make any conclusive matches. Subsequently, Salisbury et al. (1995) found that additional simulation chamber measurements showed that the vacuum environment greatly enhanced the mid-infrared emission near the Christiansen frequency, broadening the spectral energy distribution and shifting the peak to shorter wavelengths. Thus, Salisbury and his colleagues were finally able to match the observed balloon-borne lunar spectra and infer that the lunar surface composition consisted of various combinations of silicate minerals.

2.4 A Slow Demise

With the manned landing on the Moon in July 1969, lunar studies went from remote sensing to hands-on geology, in which the Terrestrial Studies Branch duly participated (e.g. Logan et al., 1972). By this time, the primary military objective of the lunar research to characterize the environment that man and/or machines would encounter on the Moon had been achieved. The *1967-1970 AFCRL Report on Research* assessed the situation at the end of the decade:

... long before Surveyor 3 had sent back to earth the first lunar photos of a disturbed soil, or the Apollo 11 and 12 astronauts stepped upon the moon, AFCRL scientists had derived what proved to be a valid model of lunar surface material. They concluded that the surface would be covered by a very fine powder, that it would be relatively firm and that the lunar powder would tend to adhere to all surfaces with which it came in contact.

Reorganization within AFCRL was initiated in 1970 as a consequence of Section 203 of the FY70 Military Procurement Authorization Act, dubbed the 'Mansfield Amendment', that mandated that all DoD research must demonstrate relevance to military systems or operations. The immediate consequence of the reorganization was moderate since most of the programs were able to be justified, and most of the people associated with those programs that could not be continued either retired or were reassigned. The Space Physics Laboratory was the most affected by the reorganization: the micrometeor research that dated to the mid-1950s (Explorer I had an AFCRC acoustic detector aboard) was terminated at the end of the fiscal year (June), as was the astrophysics research.¹⁰ The infrared lunar observational program ended, and the Branch was reassigned to the Terrestrial Sciences Laboratory with a name change to the Spectroscopic Studies Branch to emphasize a new charter to determine the infrared spectral properties of the planets, particularly as to their suitability as infrared calibration sources.

AFCRL ceded ownership of a number of facilities at that time. Among them were astronomical facilities: in 1969 AFCRL gave up its interest in the Cerro Tololo 1.52-m telescope that was used for astrophysics. Similarly, Salisbury's recently-completed 61-cm planetary telescope on Mauna Kea was transferred to the University of Hawaii, becoming one of the worldwide network of instruments contributing to the NASA effort that Tatarewicz (1990) references. AFCRL also gave up its interest in the Arecibo telescope.

Salisbury's Branch survived by changing its research objective to establishing the planets as infrared calibrators for space-based sensors, thereby demonstrating their program utility. Planets had always been a Branch interest, as indicated by the fact that Van Tassel and Salisbury (1964) measured the laboratory infrared spectra of the materials likely to be found on the surface of Mars. Indeed, Logan, Balsamo and Hunt (1973) mapped the 10.5-12.5 μm Martian surface brightness on the final flight of the 61-cm balloon borne telescope on 4 April 1971. The system was absolutely calibrated in flight by on-board direct comparisons with a black body and several surfaces of various infrared emissivities at fixed, known temperatures. These measurements were supported by a detailed analysis of the surface conditions (Balsamo and Salisbury, 1973) and composition of Mars (Hunt, Logan and Salisbury, 1973). Modern infrared astronomy was still in its infancy in the early 1970s and mid-infrared to submillimeter calibration references were sorely needed. The planets, especially Mars, were frequently used. Wright (1976) developed an empirical model for the absolute infrared flux emitted by Mars based, in part, on the Logan, Balsamo and Hunt observations and analyses that was used to calibrate the absolute flux of infrared/submillimeter observations and that from standard stars.

In 1974 the Branch was assigned to the Optical Physics Laboratory. To support the calibration objectives of the Branch, a literature search and assessment by Cecil et al. (1973) indicated that Venus and Jupiter might be bright enough to serve as infrared calibrators. A new 1.27-m balloon-borne telescope built by Tufts University was flown in July 1974 to a 30-km altitude

to measure the absolute irradiances from these planets. Logan et al. (1974) obtained whole-disk 4.5-16 μm circular variable filter spectra and made raster scans across Venus and Jupiter at a set wavelength. The measurements were calibrated by reference to an on-board black body and various flat plates of known emissivity and temperature, as describe by Logan, Balsamo and Hunt (1973). However, the observed spectral content of the objects revealed by these measurements compromised their value for calibration purposes.

The geophysics research in AFCRL was reconstituted as a new organization, the Air Force Geophysics Laboratory (AFGL), with an attendant reduction in staff. As part of the reduction, the Spectroscopic Studies Branch was formally disbanded on 30 June 1976. The people in the group were laid off, and the Laboratory disposed of the residual equipment. The mothballed 61-cm Boller and Chivans telescope at Hanscom AFB was given to the Phillips Academy, a preparatory school in Andover, MA. The two balloon-borne telescopes and platforms were sent to Mike Mumma at NASA Goddard Space Flight Center. Goddard never used the instruments, and eventually they were discarded. The Sacramento Peak Solar Observatory was transferred to the National Science Foundation and the AFGL on-site staff reduced from 45 to 7.

After leaving AFCRL, John Salisbury continued his distinguished career in infrared spectroscopy as it relates to planetary surfaces, including the Earth. He initially went to the Department of Energy, then the US Geological Survey and, ultimately to the Johns Hopkins University. He is currently retired. Graham Hunt went to the US Geological Survey where, unfortunately, his research in remote sensing of minerals associated with ore deposits was cut short by cancer. Lloyd Logan had a successful career at Perkin-Elmer, retiring as a senior manager. Peter Dybwad started his own company that manufactures easily-transported Fourier Transform infrared spectrometers.¹¹

3 CONCLUSION

John Salisbury's assessment presented to the 1962 Menzel panel turned out to be quite correct: the AFCRL lunar and planetary research program was quite complementary to that developed by NASA. The research was unusual: it could be considered a complete investigation, as it combined telescopic infrared observations of the Moon and planets, laboratory observations under appropriate vacuum and temperature conditions of minerals likely to be found on this bodies, and theoretical analysis. However, emphasis was definitely on the laboratory experiments and interpretation, as the Branch scientists published about twice as many research papers on these results as on the observations during the nearly two decades of research at AFCRL. Part of this imbalance may be due to the fact that only four balloon experiments returned infrared observations worth publishing while none of the rocket-based data were adequate. The Branch did fund John Strong's balloon-based measurements of water vapor in the atmosphere of Venus; these were noteworthy at the time.

The best-known discovery with which the Branch is associated is the first detection of X-ray stars. Martin

Harwit and Riccardo Giacconi have well highlighted John Salisbury's role in providing AFCRL support. Less spectacular, the atlas of mineral spectra is perhaps the most useful legacy of the Lunar and Planetary Research Branch, especially if Salisbury's continuation of this research at Johns Hopkins University is included. However, the Branch's balloon-borne experiments were unique, as they are the only successful mid-infrared astronomical balloon-borne program in the literature except for the marginal quality spectra to 7 μm from the first Stratoscope II flight (Danielson et al., 1964). A testament to the difficulty of mid-infrared astronomical measurements from a balloon is that Ed Ney, at the University of Minnesota, an innovator and pioneer in both ballooning and infrared astronomy, published nothing in the field. Ney had conducted balloon flights to measure solar cosmic rays in the late 1950s and the solar corona and inner zodiacal light in the early 1960s and his pioneering infrared astronomy is highlighted by Low, Rieke and Gehrz (2010). However, according to Martin Cohen (pers. comm., 9 January 2009) and Bob Gehrz (pers. comm., 17 August 2010), Ney did attempt several balloon-borne mid-infrared surveys with a 30.5-cm telescope in the late 1960s and early 1970s, but only the Moon and the umbilical cord of the balloon were detected.

Mid-infrared astronomical measurements from balloons are difficult for two reasons. First, despite the large reduction in atmospheric molecular band absorption and in the emission from the residual atmosphere above the balloon, the mid-infrared thermal emission from the telescope is still substantial as the telescope equilibrates with the stratospheric temperature of 250-260 K. Thus, the observations are limited to the brightest sources—the planets. More subtle is that, at the time the measurements were made, lunar and planetary radiometry and spectroscopy did not excite much interest in the astronomical community. On the other hand, the limited atmospheric interference in the mid-infrared did allow Murcay, Murcay and Williams (1970) to obtain the best thermal spectra of the Moon to date (Lucey, 1991).

4 NOTES

1. NRL is the oldest US military laboratory, dating from 1923. It arose from a recommendation by the Navy scientific advisory board chaired by Thomas Edison toward the end of World War I to create a modern naval research facility for development and engineering.
2. However, the Navy continued to be pre-eminent in research rockets for experimenters. Aerobee 150s were flown from the twin towers at Launch Complex 32 at White Sands Missile Range, which are about 75 meters from the ship-board launcher that the Navy used to test its operational missiles—the desert ship. Although White Sands is an Army base, the Navy has launch capabilities there that are similar to the missile launchers on a ship, which are dubbed the desert ship, and the Navy occasionally test fires naval missile ordinance from these facilities. The Navy also hosts the research rocket experiments that fly Black Brant sounding rockets out of Launch Complex 36. NRL also sponsored Space Vector Corporation in the early 1970s to develop the ARIES rocket from the second stage of the

- Minute Man I. The first ARIES flew in 1973 and it was qualified at White Sands Missile Range in 1974. The ARIES is large enough to accommodate meter class optics in the payload and can loft ~700 kg (1500 lb) payloads to an altitude of approximately 360 km (225 miles), which permitted about 450 seconds of data acquisition.
3. Marcus O'Day's Upper Air Laboratory was disbanded in April 1953 and merged with other geophysics programs (Liebowitz, 2002). O'Day then became Superintendent of the newly created Advanced Research Laboratory, where he started a program in plasma physics. He retired several years later and died on 16 November 1961. A crater is named after him on the far side of the Moon to honor his pioneering space efforts and, in memoriam, AFRCRL established the Marcus O'Day award in 1962 for the best annual scientific publication.
 4. The Navy had sponsored James Van Allen, who was then at APL, to contract with the Aerojet Engineering Corporation in Pasadena, California, and the Douglas Aircraft Company to develop an inexpensive liquid-fueled rocket capable of lifting 100 lbs. to 100 miles altitude. Aerojet, a 1942 industrial spin-off of von Kármán and colleagues at the Caltech Guggenheim Aeronautical Laboratory, was renamed the Jet Propulsion Laboratory in 1944, and it supported the APL air-breathing ram-jet Project Bumblebee program and Aerobee, combining the names of the sponsoring project (Bumblebee) with that of its Aerojet developer. The first Aerobee was launched in September 1946 and 1,037 Aerobees of various types were flown by the time the rocket was retired in 1985. The Aerobee was eventually supplanted by less expensive or more capable vehicles in the late 1980s. The last Laboratory Aerobee was launched on 19 April 1983 and, aptly, carried a solar ultraviolet experiment.
 5. These X-ray observations opened this wavelength regime to astronomical exploration. The following three experiments attempted X-ray and infrared observations of the Moon and were less successful.
 6. The Air Force Avionics Laboratory at Wright-Patterson AFB began constructing a four-axis 1.22-m (48-in) telescope at Cloudcroft in 1962; but the instrument was unsuitable for planetary research. The facility became operational in 1964 and was used for optical measurements on satellites throughout the decade. Lambert and Kissell (2000; 2006) describe the facility and its use for surveillance for the next decade, after which AFGL astronomers monitored the variability of solar-type stars (e.g. see Worden, 1983). In 1994 NASA replaced the 1.22 m telescope with a liquid mirror instrument to monitor space debris.
 7. The Harvard astronomers were aware that the Advanced Research Projects Agency (ARPA) planned to install telescopes on Mt. Haleakala. The University of Michigan originally developed two 91.4-cm telescopes under ARPA sponsorship for visible and infrared observations. Construction began in 1963, with limited operations commencing in 1965 and full commissioning of the site in 1969. ARPA solicited interest from the astronomers who attended a 5 April 1962 meeting at Harvard University in using the infrared telescopes, but apparently the offer was not pursued.
 8. The Menzel panel did not appreciate the then-labyrinthine Air Force approval process for facility construction that prevented Salisbury from setting aside funds for another site survey and constructing the observatory. General B.G. Holzman (1962), AFCRL Commander from September 1960 to October 1964, describes these difficulties, using as his example the solar furnace that was supposed to be built at Cloudcroft. Both the Menzel panel and Tatarewicz were puzzled as to why this facility failed to materialize. The furnace was to provide the high temperatures needed for growing crystals and to conduct metallurgical experiments. The furnace was a multimillion dollar project first proposed in 1954 and dropped in 1960. Although the project was approved and funds allocated at various levels, the value of the project would be questioned by someone in the annual approval process. However, by 1960s the researchers who advocated the furnace found laboratory alternatives to the furnace with the felicitous outcome that the military budget cycle with its three to four year delay for facilities construction actually saved money and produced a better alternative (laboratory facilities) in this situation.
 9. Stratoscope I was a late 1950s solar experiment.
 10. The optical astrophysics program studied plasmas and how they interact with magnetic fields. This program provided the seed money in 1958 for the Cerro Tololo project (Doel, 1996) a collaborative effort with Yerkes Observatory for the site survey in the Chilean Andes for a 1.52-m telescope. The National Science Foundation funded site development and shared the cost of the telescope with AFCRL. The telescope was completed in 1966, and Space Physics Laboratory astronomers sporadically observed there. The branch also used shock tubes to derive radiative lifetimes of elemental lines important to astrophysics.
 11. John Salisbury (2004) kindly supplied the information regarding the fate of the people in the Lunar-Planetary Branch.
 12. The Air Force Technical Reports listed below may be accessed through the Defense Technical Information Service (<http://www.dtic.mil/dtic/>) using the identifier at the end of the reference. NASA and many AF publications are accessible through the National Technical Information Service (<http://www.ntis.gov/>).

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sky. He has had experiments on the recent infrared space observatories to map the Galactic Plane and obtain high-resolution spectra of a variety of objects. His other interests include Solar System studies (such as the zodiacal light), thermal modeling of asteroids, the threat posed by near-Earth objects, along with related issues with respect to Earth-orbiting objects. He continues an effort to establish infrared calibration resources for infrared sensors.

THE ATTRIBUTION OF CLASSICAL DEITIES IN THE ICONOGRAPHY OF GIUSEPPE PIAZZI

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Abstract: Giuseppe Piazzi's fame as an astronomer rests on two different but related accomplishments—the discovery of the asteroid Ceres and his star catalogue. The classical deities depicted in paintings and engravings to mark these accomplishments are sometimes misattributed in the scientific literature.

Key words: asteroids, planet, star catalogues, Piazzi, art

1 INTRODUCTION

Giuseppe Piazzi's discovery of the first dwarf planet, Ceres, in 1801 assured his fame in both popular and scientific circles (Cunningham, 2001). The discovery came as he was working on his star catalogue, a more mundane task that attracted no public acclaim. Contemporary paintings and engravings relating to both his discovery and the catalogue feature the goddess Ceres and the Muse of Astronomy, *Urania*. The scientific literature sometimes confuses one deity for the other.

2 CANONICAL REPRESENTATIONS OF URANIA AND CERES

To understand the ways in which *Ceres* and *Urania* were employed in the iconography surrounding Piazzi, it is necessary to consider how they were usually depicted in art.

The *Muses* originated in ancient Greek mythology as deities who were the source of knowledge. Over the centuries their numbers grew from three to nine, and by the Renaissance their depiction in art had become codified (Ripa, 1593). This was achieved through the consistent use of certain props or symbols associated with each *Muse*. The one associated with astronomy was given the name *Urania*, and her name is still used in modern times to denote this science (e.g. see Kinder, 1994; Rumstay, 2009; Trimble, 2000). *Urania* is from the Greek *Ourania*, the feminine version of *ouranios*, literally “heavenly”.

In the case of *Urania*, she is depicted with a globe and/or compass. Just as importantly, her head is adorned either by a single large sparkling star, or a circlet of smaller stars to symbolize astronomy. She is also often shown gesturing with one hand towards the heavens.

In many illustrations she appears with a mortal, clearly implying that she is a source of inspiration to yearn for higher things. This is exemplified by Henry Fuseli's drawing shown in Figure 1. The poet Aratus is seated beside a globe, while *Urania* (with a star on her head) stands beside him pointing to the sky.

The goddess *Ceres*, in the Roman pantheon, has always been associated with agriculture (Spaeth, 1995). Hence the sickle or scythe is an implement she often holds. Alternatively she is shown holding a cornucopia, symbolizing the bounties of agriculture. Sheafs of wheat are usually depicted with *Ceres*, and her hair is often adorned with stalks of corn.

But there was another very different depiction of *Ceres*, developed from one of the most famous events of Greek mythology, where *Ceres* was known as *Demeter*. Her daughter *Persephone* was much desired by *Pluto*, who abducted the youngster and took her to be his Queen in the Underworld. *Ceres* was distraught by the disappearance of her beloved daughter, and decided to search for her. Thus *Ceres* is often depicted in a chariot riding through the sky to see where *Persephone* was. *Ceres* was associated in Rome with the symbols of the Eleusinian Mysteries, notably snakes which are depicted pulling her chariot. As time went on the snakes were often replaced by dragons or lions (see Figure 2).

3 THE DEPICTION OF CERES IN PIAZZI'S 1802 MONOGRAPH

On 1 January 1801 Giuseppe Piazzi discovered an object in Taurus while observing from Palermo Observatory in Sicily. Being uncertain as to the nature of his discovery, it took him several months to accept the fact he had discovered a planet or planetary-like body and not merely a comet. By early May 1801 he had decided to give it the name ‘Ceres Ferdinandea’. Piazzi chose ‘Ceres’ as the patron goddess of Sicily in the ancient Roman pantheon, and ‘Ferdinandea’ in honour of his patron King Ferdinand III of Sicily (Cunningham et al., 2009).

The title page of Piazzi's monograph about Ceres (Piazzi, 1802) shows a cherub looking at the goddess *Ceres* through a telescope (see Figure 3). On the tube of the telescope is written “Ceres added to the sky.” The goddess herself is shown in a chariot. In her right hand she appears to hold a sickle, while her left appears to be holding a sheaf of wheat.

Her chariot is drawn by dragons, beasts that were said to have helped the goddess as she looked for her abducted daughter *Persephone* (Nalezty, 2009).

To the left of Ceres in the sky is the planet Jupiter with four satellites (two on either side). To the right of Ceres is the planet Mars, and directly above her head is another circle representing the celestial object that Piazzi discovered. The meaning of this is clear, as Ceres was found to orbit the Sun between Mars and Jupiter.

The view is across the harbour to Palermo, behind which rises Monte Pellegrino. Described by Goethe (1816) as “... the most beautiful of all the promontories in the world – a large rocky mass, broader than it is high ...”, Pellegrino rises to a height of 609 metres from the plain lying close to the sea north of Palermo.



Figure 1: Henry Fuseli's painting of the poet Aratus seated beside *Urania* (from the frontispiece of *Bonnycastle* (1816); engraved by John Keyse Sherwin).



Figure 2: A clock, made in Paris in 1799 by Pierre-Philippe Thomire. *Ceres* wears a castle-shaped crown and long flowing dress, and is seated in her cushioned chariot pulled by a pair of lions. *Ceres* is flanked behind by a seated *putto* holding corn sheaves and in front by a seated *putto* with a cornucopia (courtesy: Redding Antiques, Zurich).



Figure 3: Engraving by Baron Lo Guasto on the title page of Piazzi's 1802 monograph about *Ceres*.

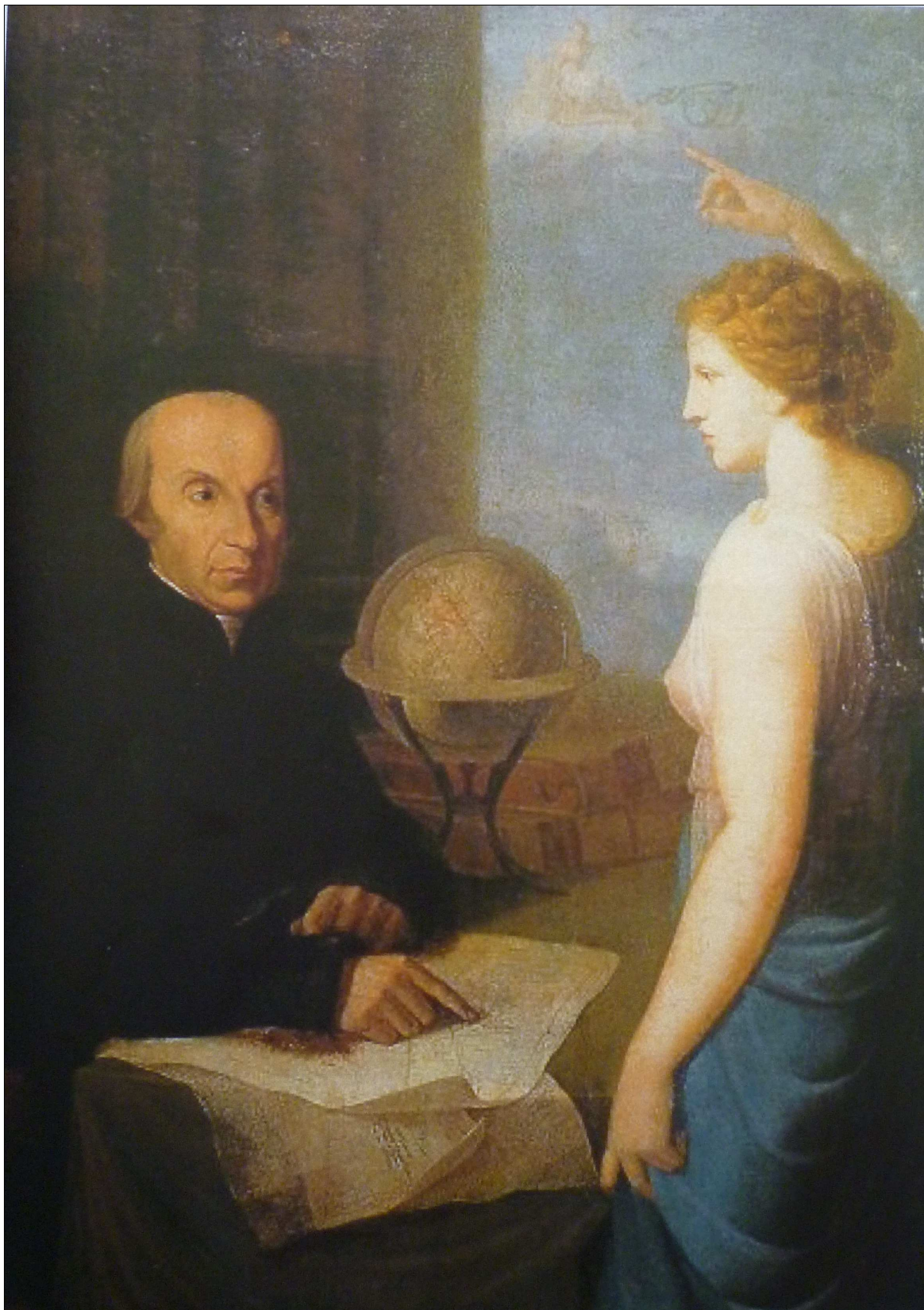


Figure 4: Painting by Francesco Farina showing Piazzi and *Urania* (courtesy: Palermo Observatory).

4 THE DEPICTION OF URANIA AND CERES IN A PAINTING OF PIAZZI

To commemorate Piazzi's discovery of Ceres, a beautiful painting was commissioned by friends of Piazzi. It was done by the portrait painter Francesco Farina (1778–1837), a pupil of the famous Joseph Velasco (1750–1827). The 1808 painting shows the Muse *Urania* looking directly into the eyes of Piazzi (Figure 4). He points to some sheets including a topographic map of the valley of Palermo, while *Urania* points upwards to *Ceres* who sits triumphant in a carriage or chariot. Between Piazzi and *Urania* rests a celestial globe in front of two large books representing his star catalogue. Even though the catalogue was published as a single volume, it appears artistic licence was taken to magnify its size. Alternatively, these may represent the original logbooks from which the final printed catalogue was published as a single book.

5 THE DEPICTION OF URANIA IN PIAZZI'S STAR CATALOGUE

Piazzi was the first Director of the Palermo Observatory, which was built in 1790 (Serio, 1993). His catalogue of 7,646 stars was a milestone in nineteenth century astronomy, deriving from a long series of observations made at the Observatory. The catalogue was first published in 1803, then it appeared in its definitive version in 1814 (Piazzi, 1814). The positional data in the catalogue were still being analysed into the twentieth century (e.g. see Proverbio, 1988).

Even though Ceres made him famous, the creation of the star catalogue was his *raison d'être*. William Henry Smyth (1844: 433), a personal friend of Piazzi, referring to this catalogue, says of Piazzi "I cannot forget his emphatic expression on putting a final correction to the last proof sheet in 1814. 'Now,' said he, 'my astronomical day is closed.'"

To illustrate the star catalogue, Piazzi engaged the services of Francesco Ognibene (1785–1837), a painter from the school of Vincenzo Riolo in Palermo. Ognibene painted both mythological frescoes and religious subjects, which can still be seen in Sicilian churches.

In Piazzi's catalogue the engraving shows a woman with a star on her head. She is floating in the air, pointing to Ramsden's circle (Figure 5). It was this great 5-foot instrument that Piazzi used to measure the stellar positions for his catalogue (Pearson, 1829).

Two *putti*¹ are playing with the circle, while a marine deity is sitting in the left corner, pouring water from a vase. This deity is an allegory of the River Oreto which flows through Palermo. In the background of the engraving, just to the right of center, is Mt. Etna. The largest volcano in Europe, it lies on the east coast of Sicily.

The inclusion of *putti* may seem curious to modern eyes, but their allegorical significance is important. They first began to appear in depictions concerning natural philosophy in the early seventeenth century (Heilbron, 2000). "I dare say that if an observation is to be perfect and free from all error and falsehood, it must be made by an angel." Athanasius Kircher (1641: 483) made this remark while warning about the care that must be taken to achieve reliable measurements. Thus the tedious repetition for a mere mortal in making stellar measurements with the Ramsden circle.

Based on the long-standing practice of depicting *Urania* with a star or stars on her head, there can be no doubt that the figure in the engraving is *Urania*. However, the figure in this particular engraving was misidentified as *Ceres* in a recent scholarly publication. In Chinnici (2009: 323), the caption associated with this engraving states that "The female figure, crowned with spikes and a star, is *Ceres*, the goddess whose name Piazzi gave to the minor planet he discovered in 1801."

To show that *Urania*, and not *Ceres*, was associated with the Ramsden circle, there is a colour painting at the Palermo Observatory showing a reclining figure gazing at the circle (Figure 6). Again, two *putti* are playing with the circle, which is pictured under an archway. The winged female deity clearly has a circlet of stars on her head, the symbol of *Urania*.

6 CONCLUSION

In accord with the long-standing practice in Europe to commemorate important events, the achievements of Giuseppe Piazzi were celebrated in art that was rich with mythological allusions. Since his discoveries were in the realm of astronomy, it was natural to employ the *Muse of Astronomy*, *Urania*, in these artworks. The goddess *Ceres* was the other logical choice, since he chose to honour that deity by using her name for his great discovery of the first asteroid and dwarf planet. The fact that these deities are sometimes confused in modern literature may be due to the decline in the deeply-rooted classical education that was an integral part of the life of the *intelligensia* in earlier times.

Finally, it is interesting to note that William Herschel was not similarly depicted in art with the Muse *Urania*. At first this seems surprising, since his great discovery of 1781 was the planet Uranus, a name derived from the same Greek word as *Urania*. However, Herschel did not choose this name, instead deciding to honour his king (George III of Great Britain) by calling it the 'Georgian star'. It was the German astronomer Johann Bode who proposed the name Uranus. Thus, in the history of astronomy and art, it is Giuseppe Piazzi who is most closely associated with *Urania*.

7 NOTES

1. *Putti* were little boys depicted with wings and bare feet and were meant to represent angels.

8 ACKNOWLEDGEMENTS

We are grateful to Redding Antiques (Zurich), the Palermo Observatory for permission to publish Figures 2, 4 and 6 and to the Institute of Astronomy at Cambridge University for kindly providing access to Bonnycastle's *An Introduction to Astronomy* (see Figure 1).

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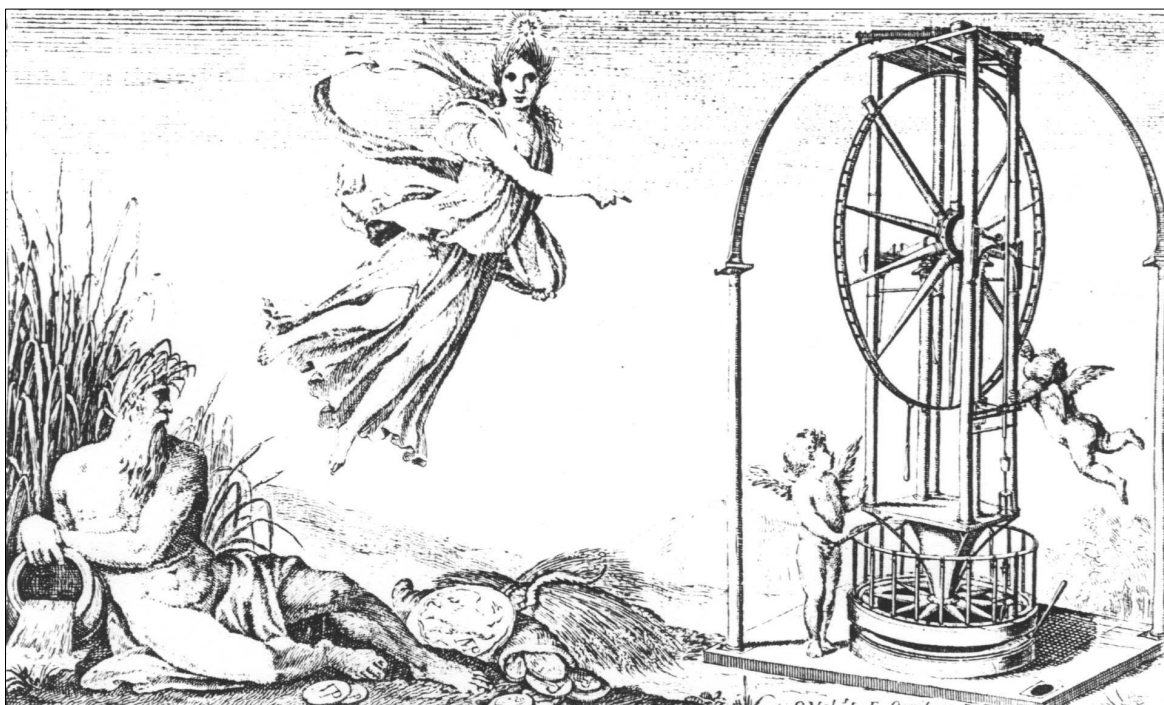


Figure 5: Engraving by Francesco Ognibene showing *Urania* and the Ramsden Circle (after Piazzi, 1814).



Figure 6: Painting of *Urania* and the Ramsden Circle (courtesy: Palermo Observatory).

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ASPECTS OF OBSERVATIONAL ASTRONOMY IN INDIA: THE VIDYASANKARA TEMPLE AT SRINGERI

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Abstract: The *navaranga* in the medieval stone temple of Vidyasankara at Sringeri, built around A.D. 1350, has twelve zodiacal pillars arranged in a square with the zodiacal signs carved on them. It has been claimed that the morning sunrise lights up the pillar that corresponds to the zodiacal constellation in which Sun is located at that time, so the temple can be used as an instrument to predict calendar days. We carried out observations to investigate this aspect by monitoring both sunrises and sunsets, and found that the correspondence between the illumination of specific pillars and the zodiacal sign of the Sun could only be maintained if the epoch for such an arrangement was around 2000 B.C. The implications of this finding are discussed in this paper.

Key words: Observational astronomy, medieval temples, zodiac, equinoxes, solstices, sunrises

1 INTRODUCTION

Observing and recording positions of the Sun, Moon, planets and stars as objects of wonder, and further, realizing that their movements were repetitive, was a major step in the intellectual growth of ancient man. In India some of the efforts to trace the progress of observational astronomy from ancient times rely upon old structures and monuments, like the megalithic alignments (see Rao, 2005; Rao and Thakur, 2010). In later periods, Hindu temples also became time-keepers. It is of interest to see how such temples in India have been utilized to monitor the passage of time, including the seasons, the year, the month, etc. Some examples are the Sun temples at Modhera and Marthanda (Rao, 1996). The light of the equinoxial sunrise is made to fall on the central deity in several Sun temples that were constructed even as early as the sixth to seventh centuries A.D. The Sun temple at Arasavalli in the Srirakulam district of Andhra Pradesh, which was probably constructed by rulers of early Ganga Dynasty, shows such a feature (although the present rebuilt structure shows the sunlight falling on the Sun god a few days earlier than the spring equinox and later than the autumnal equinox due to a slight misalignment of the windows). A unique temple which is said to illustrate in detail the monthly changes in the Sun's position during the year is the Vidyasankara Temple at Sringeri.

Sringeri (originally known as Rushyashringagiri) is located in the north-western part of Karnataka in the ghats and is well known as a religious centre where one of the four Sankar Mathas¹ is located. Adi Sankara (A.D. 788–820) is supposed to have established this Mutha and appointed one of his chief disciples as the first pontiff. The Matha maintains uninterrupted continuity in its activities from its origin to the present. The Vidyasankara Temple is part of the Sankar Matha complex (see Figure 1), and was built on the banks of the Tunga River by Sri Bharati Tirtha and Sri Vidyanaya, pontiffs of the Matha, during the period A.D. 1338-1350 as a memorial to their teacher, Sri Vidyasankara Tirtha (A.D. 1228– 1333), who also was

an earlier pontiff of the Matha (Shrinivas Ritti and Gopal, 2004; Venkataraman, 1976).² Sri Vidyanaya is also credited with providing the inspiration and motivation for the establishment of the Vijayanagara Empire by Harihara and Bukka.

The Vidyasankara Temple has a unique architectural plan and is built entirely of granite. The plan is almost elliptical (Figure 2), formed by the apparent union of two opposed apsidal parts (or *chapa*) which meet at their open ends, with the curved ends at their eastern and western extremities. The apse on the western side (towards the top in Figure 2) contains the *vimana* part of the temple, while shrines in the eastern apse comprising the *makhmandapa* enclose the *navaranga*, with its twelve distinctive zodiacal (rasi) pillars.

The two parts are connected by an intervening north-south corridor (or transept). With its principal entrance at the eastern apse end and a similar entrance at the rear on the west, "... the orientation of the *vrittayata* structure is of the end-on type." (Srinivasan, 1976: 5). The main interest astronomically is the *navaranga*, whose unique aspects have been commented on as follows by two famous archeologists:

The Navaranga which is a structure having twelve highly ornate pillars of the Dravidian type. On the rear side, of each pillar has an ornamental pilaster rising out of a Kalasa and bearing one of the twelve signs of the Zodiac. It is said that the sunlight falls upon the Ram pillar during the month of Aries and on the Bull pillar in the month of Taurus. (Krishna, 1936: 293).

Each of these twelve pillaikkals bear the image of a sign of the zodiac or rasi after which the pillar itself is called. It is said that sunlight falls in the early mornings upon the appropriate rasi pillar, during each of the twelve months of the solar year ... As stated before these twelve rasi pillars are so arranged that the morning Sun's rays fall on one of them, through one of the three openings in the order of the twelve solar months, named after twelve rasis or houses which the Sun is said to occupy (aspect) in the course of the year according to Indian astronomy the rasichakra ... The floor itself is marked by shadow lines in conformity with the Sun's movement round the twelve rasi pillars. (Srinivasan, 1976: 35).



Figure 1: The Vidyasankara Temple at Sringeri as seen from the east. The eastern doorway is in the front.

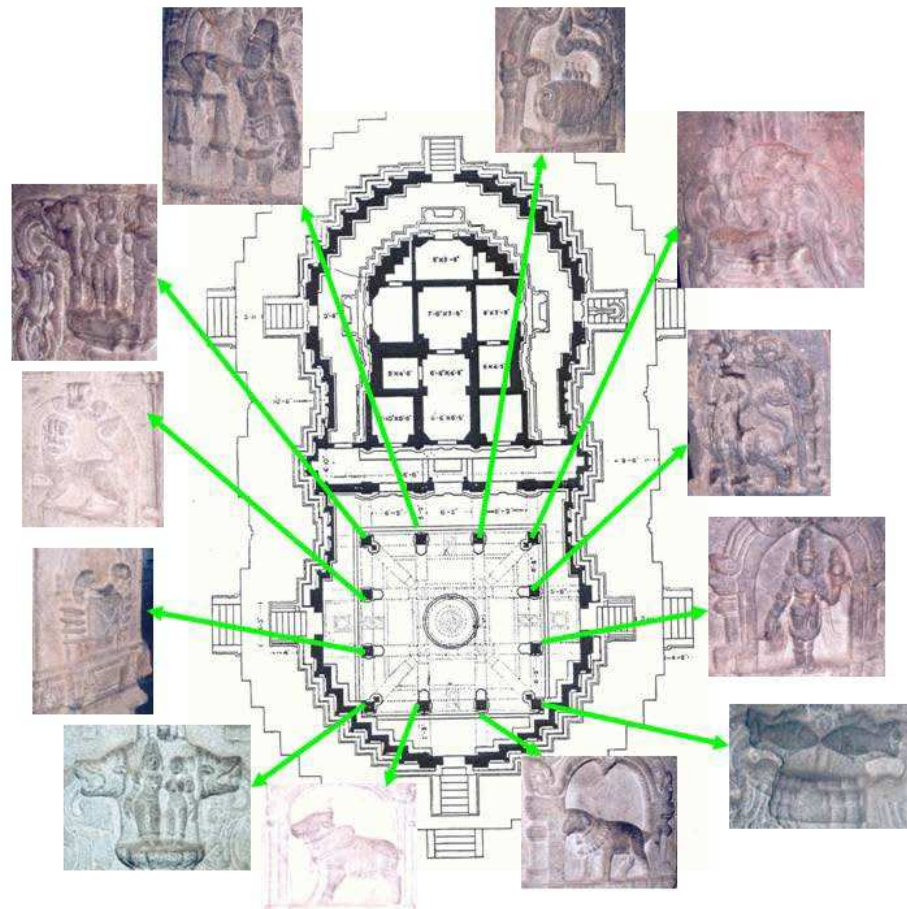


Figure 2: Plan of the Vidyasankara Temple (with north to the right). The arrangement of the zodiacal signs on the backs of the pillars in the *navaranga* is also shown.

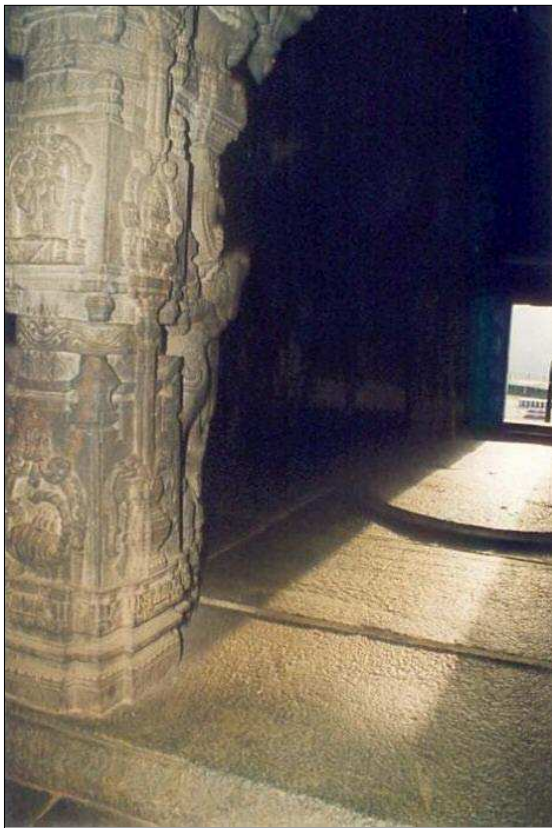


Figure 3: The beam of morning sunlight near the Scorpio pillar in the Vidyasankara Temple on 21 September 2002.

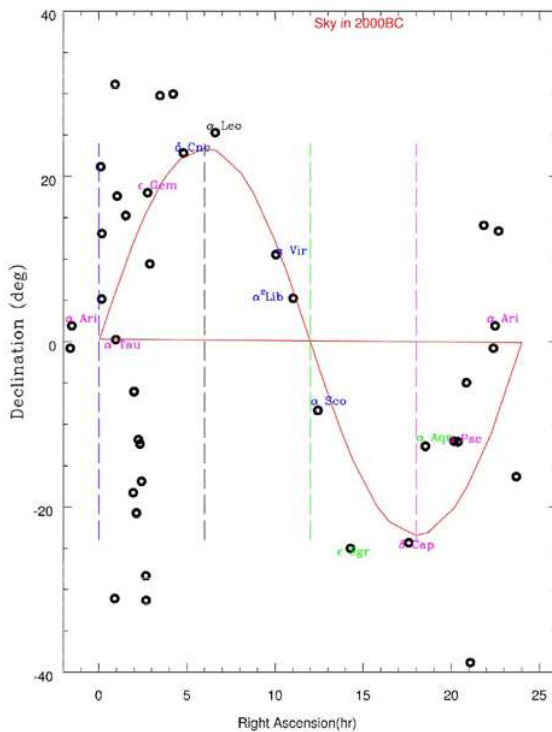


Figure 4: The sky in 2000 B.C. Positions of some bright stars, mainly in zodiacal constellations, are shown to illustrate Sun's path. Note that the position of the Sun around the autumnal equinox is in between Libra and Scorpio and at the spring equinox it lies between Aries and Taurus. The positions of the equinoxes and solstices are shown by dashed vertical lines.

In other words, the *navaranga* is devised as a calendrical device (or instrument) that can mark any particular day or season, etc. This is indeed a unique device if shown to be true, and this is precisely the aspect that we wanted to investigate by monitoring the sunlight on the rasi pillars. Recently Subbarayappa (2008: 258) re-emphasized this aspect:

Apart from its importance for appreciating the artistic tradition from Chalukyan to Vijayanagara, this temple illustrates the application of astronomical-astrological symbolism to temple architecture. It has a pillared hall (mandapa) supported by twelve pillars, each pillar representing the related sign of the zodiac of twelve signs (rasi-s). It is believed that the pillars are positioned in such a way that when the sun rises in the corresponding sign of the zodiac, its rays are supposed to fall on the related pillar, the shadow of which can be observed during that particular month. How far is it true needs a critical examination. However, the twelve pillars appear to be intended for portraying in a way the twelve solar months in the context of the twelve zodiacal signs.

As a national monument, the temple is under the control of the Archaeological Survey of India (ASI). We asked ASI to provide us with photographs of sunlight on the equinox day, 21 September 2002, which they kindly did (Figure 3). As this photograph shows, the beam of morning sunlight came close to, and almost touched, the Scorpio pillar, suggesting that the Sun was in the constellation of Scorpio at this time—if we accept the above-mentioned statements by Srinivasan and Krishna. However, on 21 September 2002 the Sun was actually in the constellation of Virgo, not Scorpio, an angular difference of about 60°, which does not agree with what has been asserted by Krishna and Srinivasan. On the other hand, if we ask when could such a situation arise so that the Sun was located in the constellation of Scorpio and also illuminated the pillar with the sign of Scorpio, the answer turns out to be in about 2000 B.C. (Figure 4), well before the construction of the temple.

In the fourteenth century, Indian astronomy was sufficiently well developed for astronomers to know (and be able to predict) the Sun's position on the zodiac. The builders of the temple were well versed in astronomy (see Srinivasan, 1976), and thus would have been aware of the Sun's position. It appears therefore that the mismatch of the observed sunlight on the rasi pillar and the corresponding position of the Sun in the sky was deliberate. Maybe it was not meant to be functional, but rather a ceremonial exercise. We therefore decided to investigate how consistent the movement of sunlight is with respect to the zodiacal pillars. Is it in the same order as the movement of the Sun in the sky (and on the horizon) in 2000 B.C.? How much use was made of practical astronomy? In the following sections we describe our observations as we monitored the beams of sunlight on the rasi pillars.

2 VIDYARANYA AND THE PLAN

The Vidyasankara Temple was constructed during the fourteenth century but no records or architectural plans (or inscriptions relating to them) currently exist (Sastry, 1976; and personal communication). The genius of two sages, Bharathi Krishna Tirtha and Vidyaranya, along with the skill of the architect, Jakkana, was collectively responsible for the construction of the Temple. Both gurus were supposed to have been very well versed in

Vedic and Upanishadic principles and practices. Vidyanaraya, in particular, wrote several commentaries and literary works relating to the Vedas and the Upanishads. He was supposedly a great teacher, and as an exponent of Vedic knowledge was second only to Adi Sankara (see Shrikantaya, 1990; Venkataraman, 1976). The plan of the Vidyasankara Temple is said to contain a synthesis of various architectural and religious traditions which were moulded into a unique structure (Srinivasan, 1976). The style of architecture was

... a fine blend of two major traditions of the south, the Calukyan, as it had evolved till the time of Hoyasalas, and the Pallavas, as it had evolved till the days of the later Pandyas of Tamilnadu, with a sprinkling of some of the features of north Indian styles. (Venkataraman, 1990: 217).

The Temple stands on a platform ~1.5 meters high called the *upapitha*, on top of which exists another structure, the *adhithana*, that raises the basic level of the Temple to a height of ~2.5 meters. This level is reached via a series of steps which lead up to the six doorways of the Temple, three on the eastern side (leading to the *navaranga*) and three on the western side, which contains the superstructure housing various shrines, the center of which is the Sri Vidyasankara *lingam* (Figure 2). Almost every part of the Temple has carvings or sculptures, the details of which have been described by Srinivasan (1976), Venkataraman (1990) and Alagaraja (2003).

In the present context, where the focus is on the *navaranga* and the morning sunlight, it should be noted that the doorways are at sufficient height such that the morning sun rising over the eastern horizon in this hilly region reaches the interior of the *mukhamandapa* without any problem. The north-eastern horizon has had structures built on it in recent years, and in addition there are now some coconut trees in front of the Temple which prevent the sunlight from reaching the shrine until the Sun attains an altitude of about 7°. On the western and northern sides of the Temple there are now various structures and other temples, and consequently the horizon in these directions cannot be seen. The setting Sun can only be seen when it is above 11°.

The *mukhamandapa*-apse, or the eastern half of the temple, contains three entrances, which are on the eastern, northern and southern sides. The eastern entrance is the primary entrance from which the central shrine is seen, as well as the rising Sun's direct light. The *navaranga* has the twelve massive monolithic pillars called *aniyottikkals* or *citrakambhas*, with large animal sculptures on their centre-facing sides, all placed on a slightly raised platform. These pillars depict elephants trodden upon by large lions (*vyalas*), with riders on top of them holding on to some sort of a bridle. In addition to the zodiacal signs, each pillar also has an *adhidevata* (the presiding deity), and a planet in human (anthropomorphic) form, depicted on it. As an example, the Leo sign has Surya as its *adhidevata*. These pillars are the main objects of the present investigation in relation to the morning sunlight. The central part of the *mukhamandapa* has a large, slightly elevated, stone circle with some line markings on it which are supposed to indicate the path of the sunlight. According to Alagaraja (2003, "The floor itself is marked by shadow lines which are cast in conformity with the sun's movement around the twelve rasi pillars." The western side the

mukhamandapa also has two small shrines, one on each side of the central shrine. The southern one has the god Ganapathi and the northern one the goddess Durga, with their *dwara-palakas* (celestial guardians of the doors).

The direct sunlight comes mainly through the eastern doorway, but also partly through the southern and northern doorways. There are also a few small gaps in the outer wall which allow the sunlight to enter, but whether this was intentional or not is not clear.

3 MONITORING THE SUNLIGHT

Even though observations to monitor and image the path of morning sunlight started in 2002 and continued until 2008, progress was slow because of cloudy and rainy days in any given month plus restrictions due to the religious and other functions of the Temple. Thus, most of the observations were obtained during 2008. In



Figure 5: The beam of sunlight on 21 June 2008 at 6:55 a.m (IST) just touches the Leo pillar, on the left, and also extends to the Virgo pillar (in the background).

the following section we present some of these observations as the Sun moved on the eastern horizon from summer solstice (*dakshinayana*) to winter solstice (*uttarayana*) and back.

3.1 From Leo to Aquarius

The morning sunlight on 21 June 2008 seemed to touch the base of the Leo (*Simha*) pillar, as shown in Figure 5. This was very close to the summer solstice (which actually occurred on 21.0 June U.T and 5:30 IST). The light also extended to the Virgo pillar.

Moving clock-wise to the next pillar, the sunlight first touched the base of the Virgo (*Kanya*) pillar on 14 May 2008, but was seen more prominently touching the pillar by 19 May (Figure 6) when part of the light extended to the entrance to the Sri Ganapathi shrine.



Figure 6: Sunlight touching the Virgo pillar on 19 May 2008 at 6:48 a.m.



Figure 7: Sunlight in the central shrine on 23 March 2004, at 6:42 a.m., close to the equinox.

On 9 April 2008 the morning sunlight touched the right side of the base of the Libra (*Tula*) pillar. Observations on 22 and 23 April 2004 and 2005 showed that



Figure 8: Sunlight on the Scorpio pillar on 12 March 2008 at 7:23 a.m. Note that the lines on the ground do not show any connection with the sunlight zone.

the sunlight illuminated the left of the base, suggesting that the pillar was centrally illuminated around 15 May. Similarly, observations made on 24 August 2004 also showed that the morning sunlight fell on the base of the Libra pillar, slightly to the right of centre.

The light from the equinox sunrise, which occurred around 21 March 2003, was seen falling directly on the Sri Vidyasankara *lingum* in the central shrine, and passing in between the Libra and Scorpio pillars (Figure 7).

The base of the Scorpio (*Vrischika*) pillar was touched by the sunlight on the morning of 12 March 2008, slightly to the right of centre, as shown in Figure 8. It was expected to illuminate the centre of the pillar by 15 or 16 March. Figure 8 also shows marked lines on the floor which do not seem to have any association with the direction of the sunlight.



Figure 9: Sunlight close to the Sagittarius pillar on 21 February 2008 at 7:45 a.m.

On 21 February 2008 during the Sun's journey northward (*uttarayan*), the outer edge of the beam of sunlight through the eastern door came very close to the Sagittarius (*Dhanus*) pillar, located to the right of the Scorpio pillar, as shown in Figure 9. Similarly, on 2222 October 2005 as the Sun moving southward (*daksh-nayan*), the rising Sun cast a similar beam pattern, close to the Sagittarius pillar.

The Capricorn (*Makara*) pillar was touched by the beam of sunlight on the morning of 22 January 2003, as shown in Figure 10. The width of the beam coming through the eastern door gets narrow because of the angle of the Sun and also because part of it falls on the Aries (*Mesha*) pillar. A similar beam of sunlight was observed on the morning of 21 November 2005 approaching the Capricorn pillar as the Sun was moving to the north after passing through the winter solstice.

As shown in Figure 11, on 22 December 2004 the beam of sunlight through the eastern door moved in the

direction of Aquarius (*Kumbha*), with the winter solstice occurring on 23 December. The beam of sunlight retraced its path after reaching the winter solstice. Thus, the systematic motion of the Sun from north to south on the horizon was traced by the beam of sunlight from Leo to Aquarius, and the occurrence of the beam on the respective pillars suggested that the Sun was entering that constellation. Thus, the duration of any month in the year could be monitored as the sunrise point moved along the horizon by tracing the position of morning sunlight on the different rasi pillars. However, this motion corresponded to the Sun's position among the constellations in about 2000 B.C., not at the present day.

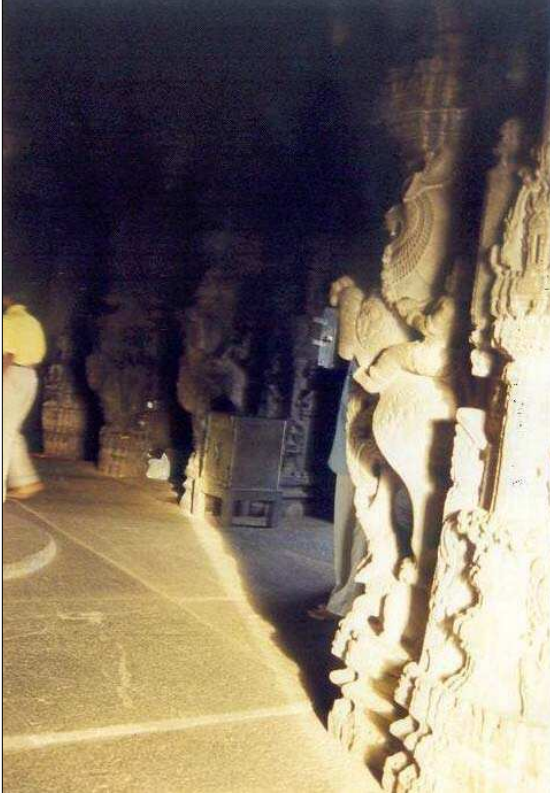


Figure 10: Sunlight on the Capricorn pillar (in the background) on 22 January 2003 at 8:01 a.m.

3.2 The Sky in 2000 BC

We have computed the positions of several bright stars for the epoch of 2000 B.C. using Hipparcos proper motions as given in ADS (Simbad) using a programme written and developed by A.V. Raveendran to trace the sky around the zodiac of that time. Figure 4 shows the position of the ecliptic on the sky in 2000 B.C. The summer solstice occurred when the Sun was in Leo and the winter solstice when it was in Aquarius, while it was between Libra and Scorpio when the autumnal equinox occurred and between Aries and Taurus at the time of the Spring equinox.

3.3 Other Zodiacal Constellations

Of the remaining five zodiacal constellations, Aries and Taurus are associated with the eastern entrance. In the course of more than one month the beam of sunlight falls on these pillars as it moves to other pillars in the Temple. The Aries pillar was illuminated from October to February by morning sunlight. Figure 12 shows the



Figure 11: The beam of sunlight is directed towards the Aquarius pillar on 22 December 2004, at 8:51 a.m.

sunlight on 22 February 2005 touching the southern side of the pillar, just like on 22 October 2005. The beam of sunlight was just able to graze the side of the Aries pillar before it moved away, around 25-27 February. This movement of sunlight was consistent with the Sun's motion in the sky in about 2000 B.C.

The Taurus pillar is on the opposite side of the Temple from the Aries pillar with respect to the eastern entrance. Our observations showed that the sunlight first grazed this pillar on about 9 May 2004. Observations made on 23 April 2004 showed that the beam of sunlight was still some distance from the pillar. This position of the Sun in Taurus at early May is not inconsistent with the epoch of about 2000 B.C., although it might be considered the outer boundary for this constellation.



Figure 12: Sunlight falling on the Aries pillar on 22 February 2003 at 9:30 a.m.



Figure 13: A narrow beam of sunlight enters the Temple through a hole in the wall, and falls on the Pisces pillar (centre left).

For the three constellations of Cancer, Gemini and Pisces, it appeared that the beam of direct morning sunlight would not reach them as the Gemini and Pisces pillars were at the southern and northern corners of the *navaranga*. However, we discovered that there is a small hole in the wall and sunlight seeped through it on 19 May 2008, and fell on the Pisces pillar (see Figure 13). We observed the sunlight falling on the Pisces pillar even in October.

A similar situation may also be true for Gemini, but no observations were made. There is also a possibility that on certain dates the setting Sun will illuminate the pillars for Cancer and Gemini, as there are gaps in the pillars so that the western sky could be seen through the southern door.

3.4 The 2000 B.C. Epoch and the Arrangement of the Pillars

With the exception of just two or three pillars, the correlation between the Sun’s location in a particular constellation in the sky and the occurrence of a beam of sunlight on the associated pillar seems to have been consistent for the epoch of about 2000 B.C. It would seem that the zodiacal ordering of the pillars and their positioning was carefully determined in order to be consistent for the epoch. We calculated the azimuths of the Sun’s position and the positions of the pillars at the time of our observations. The pillars have base widths of between 0.5 meters and 1.0 meter while the beam of sunlight entering via the eastern door has a width of between 0.12 meters and 0.9 meters, thus providing an uncertainty in the determination of 2°–4°. Within these uncertainties the azimuth of the sunlight and the positioning of the pillars appear to match (see Table 1).

Table 1: The azimuth and altitude of the Sun on various dates, and the temple pillars illuminated.

Day, Month, Day, and Time of Observation (IST)	Azimuth (°)	Altitude (°)	Illuminated Pillar
21/06/2008, 0655	68.22	10.75	Leo
19/05/2008, 0648	71.77	9.70	Virgo
09/04/2008, 0701	83.67	8.31	Libra
12/03/2008, 0723	95.15	9.19	Scorpio
21/02/2008, 0745	104.45	12.29	Sagittarius
22/01/2003, 0801	114.61	13.69	Capricorn
22/12/2004, 0851	124.52	25.49	Aquarius

There is another feature in the arrangement of the pillars that is an indicator of the epoch. Conventionally, depiction of zodiacal constellations in an Indian context starts with Aries and proceeds clockwise. Figure 14 shows this arrangement on the ceiling of another Indian temple. One would expect a similar arrangement in the *navaranga* of the Vidyasankara Temple. From the main (eastern) entrance one would expect Aries to be on the left, and Taurus etc. to follow in a clockwise direction, but the actual arrangement in the Vidyasankara Temple is not like that. From the main entrance Aries is on the right and Taurus is on the left, creating a break. It appears as though the arrangement starts with Taurus, and the entrance is between the two constellations. In 2000 B.C. the vernal equinox was between Aries and Taurus, very similar to the arrangement here, suggesting that the eastern doorway represents the vernal equinox of 2000 B.C.

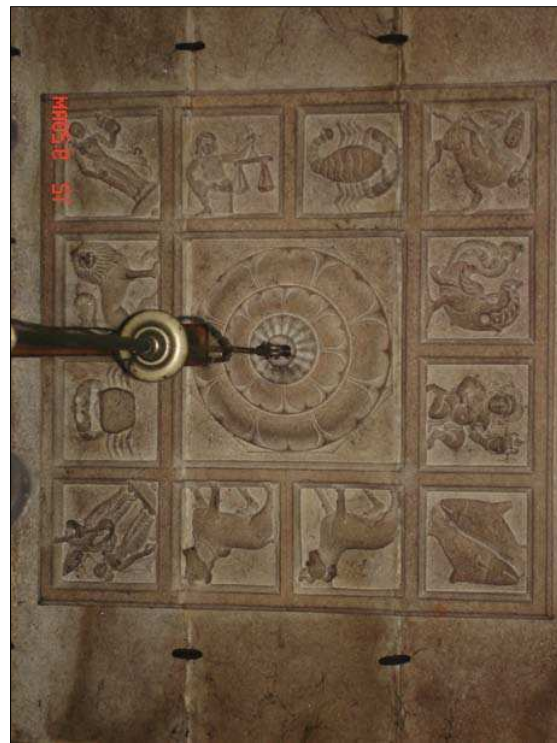


Figure 14: A conventional depiction of the zodiacal signs, as seen on the ceiling of the Thiruvisanallur Temple.

It is obvious that the rasi pillar arrangement was not meant to be functional at the time the Vidyasankara Temple was built (circa A.D. 1350). Rather, it was intended to be ceremonial, and was probably adopted from an older sacred (maybe Vedic) arrangement. So it was a replica of an earlier calendrical device, and with some minor changes to the arrangement—like the presence of a western entrance, to allow for sunsets—the present *navaranga mandapa* would have been a good functional calendrical device in 2000 B.C. Rao and Thakur (2010) have shown that the much earlier megalithic square stone array at Vibhuthihalli also acted as a calendrical device, and that both sunrises and sunsets played a role. Since the builders and promoters of the Vidyasankara Temple were renowned Vedic scholars and practitioners it is likely that they adopted a Vedic sacred or ritual platform which had astronomical, and hence calendrical, significance. In Section 4 we discuss

one such example which might be relevant in this context.

4 VEDIC ALTARS

According to Kak (1995), “The central idea behind the Vedic system is the notion of connections between the astronomical, the terrestrial and the physiological.” while many of the myths described in *vedas* and the *Brahmanas* deal with astronomical events (Kak, 1993). Many Vedic rites were performed for a full year and they were clearly meant to mark the passage of time. Apparently a considerable part of the *Satapatha Brahmana* deals with altar construction in the *agnicayana* rite. This rite is about a representation of the reckonings of the year. Kak (ibid.) also describes how the representation of the passage of time was organized in terms of sacred altars, a bird altar being one of them:

Time is represented by the metaphor of a bird. The months of the year were ordinarily divided into six seasons unless the metaphor of the bird for the year was used when *hemanta* and *sisira* were lumped together. The year as a bird had the head as *vasant*, the body as *hemanta* and *sisira*, the two wings as *sarad* and *grishma*, and the tail as *varsha*. (ibid.; see Figure 15).

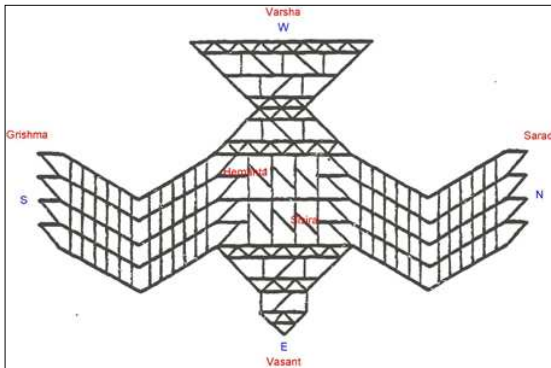


Figure 15: Drawing of a Vedic bird altar representing the passage of a year. Corresponding Indian seasons are also shown (after Kak, 1993).

Each Indian season consists of a period of two months, and this system has been in use since Vedic times (Abhyankar, 1993; Kak, 1993). *Vasant* consists of March and April, *grishma* May and June, *varsha* July and August, *sarad* September and October, *hemanta* November and December and *sisira* January and February, similar to the order of the zodiacal pillars in the Vidyasankara Temple. While adopting the representation of the year by seasons and reflecting this in their sculpture, the fourteenth century architects of the Vidyasankara Temple used zodiacal signs (which by then were an integral part of Indian astronomy) to represent seasons on a month-by-month basis.³ It is likely that the Vidyasankara temple-builders adopted one of these altars, like the bird (falcon) altar which was a real calendrical device, to represent the passage of time in the *mukha-mandapa*.

5 DISCUSSION

It is obvious that the builders of the Vidyasankara Temple deliberately planned the arrangement of the zodiacal pillars. Despite the statements of some archaeologists (e.g. see Srinivasan, 1976), the morning sunlight falling on a particular zodiacal pillar does not indicate the constellation in which the Sun is located,

either at the present day or at the time when the temple was built. Sidhantic astronomy was well developed in fourteenth century, more than enough to recognize this fact. The builder of the Vidyasankara Temple, Sri Vidyanaraya, was acknowledged as one of the great astronomers of that era (see Venkataraman, 1990), and the rasi pillar arrangement was adopted as a ceremonial structure rather than as a functional one. The calculations of *panchangas* (Indian almanacs) were done regularly. The inscriptions of that era, and earlier, usually mentioned the year, the month, the *thidhi* (phase of the Moon), the *vara* (day of the week) and the *nakshtram* (the asterism closest to the Moon on the given day), and maybe the *yoga* (the sum of the longitudes of the Sun and Moon in the *nirayana* system converted into minutes of arc and divided by 800) and the *karana* (half a *thidhi*). For further details see Balachandra Rao (2000). The squarish arrangements are often used for divine or celestial things.

The geometrical proportions of the pillar arrangement in the Vidyasankara Temple and the time taken for the beam of morning sunlight to move from one pillar to the next (about a month) matched very well the positions of the zodiacal constellations in 2000 B.C. Furthermore, the angular displacements of the sunlight towards the solstice directions on the northern and southern sides are smaller than on the western (equinoxial) side. This was not an *ad hoc* adoption of a pattern but rather a well-designed construction which was probably duplicated from an earlier design dating to 2000 B.C. That one half of the temple features this construction vouches for its importance and the sacred role that it played in the over-all scheme of things. The outer wall friezes (termed *bahya bhitti*) have several anthropomorphic images that related to astronomy (e.g. the Moon and the planets), and even *Prajapathi*, the Lord of the Year) is represented. Thus, astronomy and the passage of time played a substantial role in the design of this temple. The Vidyasankara Temple thus illustrates a calendrical arrangement that dates from 2000 B.C., and one that may have been adopted from Vedic literature.

6 CONCLUSIONS

The recent monitoring of morning sunlight on the rasi pillars in the *navarang* of the Vidyasankara Temple revealed that they do not indicate the position of the Sun in the zodiacal constellations of the present epoch but rather they match the zodiacal sky of 2000 ± 300 B.C. Although the temple was supposedly built around A.D. 1350, it is suggested that the rasi pillar arrangement might have been adopted from an earlier 2000 B.C. sacred calendrical device (or a Vedic altar).

7 NOTES

1. These are religious centres to teach, preach and practice advita philosophy. They were established by Adi Sankar, a great *guru* and sage.
2. However, Michel (1995) thinks the temple dates much later, to the sixteenth century.
3. The zodiacal signs were only standardized in Indian astronomy at a later date, through interactions with Greek astronomers.

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THE HOBART TIME BALL AND TIME GUN: A CRITICAL REVIEW

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Abstract: Discussion at the Royal Society in Hobart in 1865 and acoustic experiments in 1868 led to a combined time ball and time gun service in Hobart from March 1875. Complaints from residents led to relocation of the gun a month later, but it was then fired from Queen's Battery in the Domain for half a century. The drop of the ball at Battery Point was always the master signal; the gun was fired when the ball was seen to drop. During the early years, private citizens in Hobart provided the time reference. From September 1886, an electric telegraph signal from Hobart Observatory was used to provide correct time to the ball operator, but signals were of questionable accuracy. During February 1910, the source of the telegraph signal was changed from Hobart Observatory to Melbourne Observatory, but the service was still unreliable and there was pressure to re-equip Hobart Observatory. Finally, automatic dropping of the time ball by telegraph from Melbourne was introduced in November 1910. The time ball service ended in February 1927. The time gun had probably ceased to operate by the end of 1923, but before that date there were sometimes long gaps in the time gun service, particularly on Sundays.

Keywords: time ball, time gun, Hobart

1 INTRODUCTION

Time guns were a popular means of signalling time during the nineteenth century. They were favoured by business owners, who wanted to regulate their work forces, but they were often disliked intensely by those living nearby and by those of a fragile disposition. Sound propagates at only about 340 m/sec. Correction for the time delay to an observer was feasible, but wind and weather could have a significant effect if the distance was large.

Time balls were silent, at least to an external observer, but it was difficult to site them so that they could be seen by inhabitants across a city and there were problems with industrial pollution that restricted visibility. Public clocks could be regulated by an observatory, although most were not, but they also gave restricted visibility. Time balls at an elevated shore position were the signals favoured by ships at anchor, and various preparatory signals were used to alert them to an imminent drop. They were always preferred by the Admiralty. The origin and purpose of time balls for rating chronometers is well described by Bartky and Dick (1981).

Leading astronomers sought to provide signals that were accurate to a small fraction of a second, using high quality transit instruments to observe the passage of chosen stars across the local meridian, regulated master clocks, controlled slave clocks and automatic electric telegraphy. Those aims could be met at locations like Greenwich, Edinburgh, Melbourne and Sydney, which had fine observatories and clear processes for signalling any errors. They were easily degraded if instruments were not of the highest quality and if manual intervention was necessary.

A time gun service, accurate to a small fraction of a second, was introduced in Edinburgh in June 1861, complementing a time ball service which started officially in March 1854 (Kinns, 2011). Edinburgh's success encouraged experiments with time guns in many other places. It often took several years from initial experiments to the introduction of a time gun. Sometimes, they were abandoned altogether. Local politics and budget constraints played their part, as they do today. Religious observance mattered and a Sun-

day time gun service was often not provided or abandoned.

There were time guns at many locations in Australia, including as far north as Townsville in Queensland, but many were fired without reference to astronomical observations and they were often in error by several minutes. For example, complaints about intrusion and poor accuracy of the gun, as well as damage caused to property near the gun itself, were common in Brisbane from 1867 onwards.

The recent digitisation of Australian newspapers has made it possible to find long-forgotten editorials and published correspondence about the time signals in both Tasmania and mainland Australia. Of Australian locations, only Hobart was listed as having both a time ball and a time gun in Admiralty lists of time signals. This paper describes the story of Hobart time signals and illustrates the challenges that had to be met in providing a service that would be acceptable to both town residents and mariners, using modest resources. It is derived substantially from articles and correspondence in *The Mercury*, Hobart's principal daily newspaper.

1.1 Locations of the Time Ball and Time Gun in Hobart

A map of Hobart published by the Government Printer in 1922 showed the approximate locations of the time ball and time gun at that time. It can be related easily to modern maps, using the street layout. Figure 1 is a detail from that map, where the principal locations are highlighted. Note that N is on the left and E is at the top. The key areas are Battery Point and The Domain, which includes Queen's Battery, separated by Sullivan's Cove.

The time ball was always at Battery Point. The time gun was at Queen's Battery from April 1875. Lenna, erected in the late 1870s and now a hotel, features in almost all known photographs of the time ball.

Hobart Observatory was located in the Military Barracks, west of the time ball, but was only used for the time service between 1886 and 1910. An earlier (primarily geomagnetic) observatory had been estab-

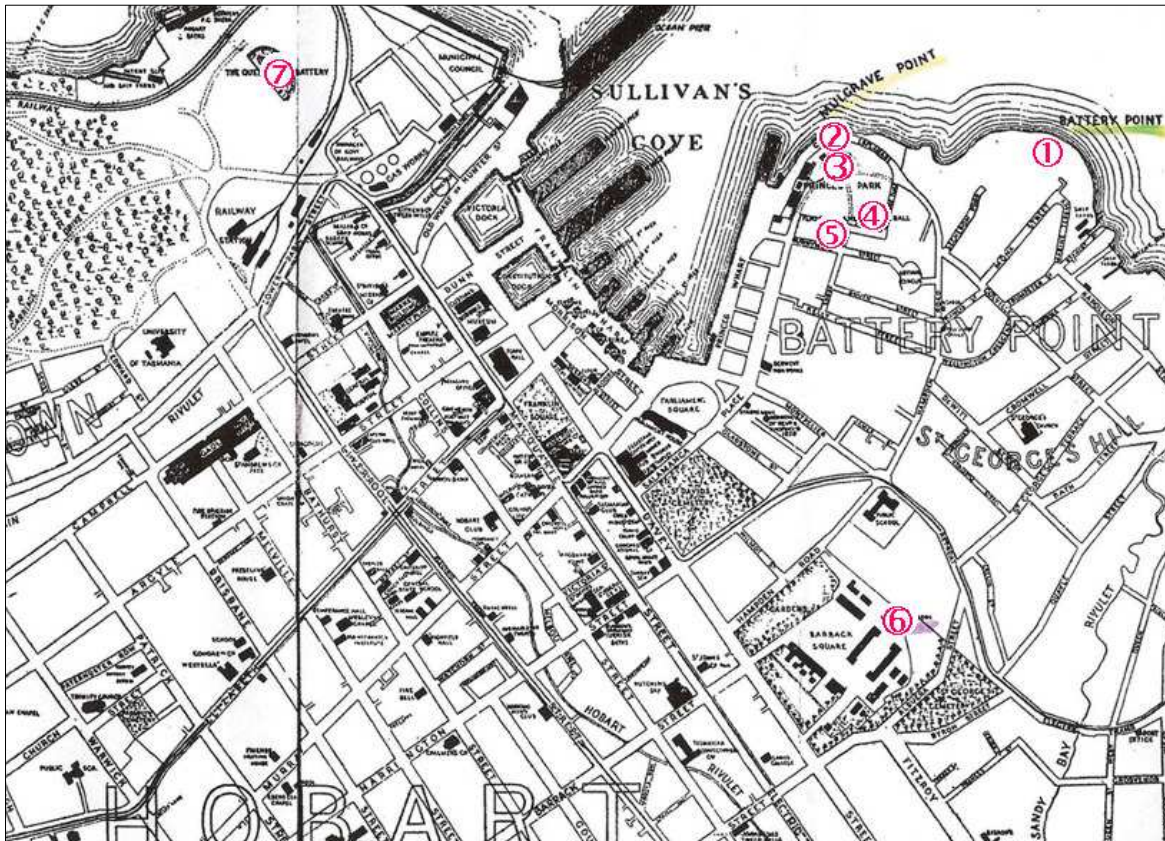


Figure 1: 1922 Map of Hobart, Tasmania, showing localities mentioned in the text. Key: ① = Battery Point; ② = Mulgrave Point; ③ = Harbour Master's Residence; ④ = Flag Staff & Time Ball; ⑤ = Lenna; ⑥ = Hobart Observatory; ⑦ = Queen's Battery (courtesy: Lesley Abell).

Table 1: The entry for Hobart in the 1880 Admiralty list

Signal Station Latitude and Longitude	Place	Signals Adopted	Situation of Time Signal	Time of Signal Being Made		Additional Details
				Greenwich Mean Time.	Local Mean Time.	
42° 53' 32" S. 147° 21' 13" E.	Hobart Town	Ball and Gun	Flagstaff at Fort Mulgrave	h. m. s. 15 10 35	h. m. s. 1 0 0	Ball dropped exactly at 1 ^h 0 ^m p.m. Hobart Town Mean Time

Table 2: The dual entry for Hobart in the 1898 Admiralty list

No.	Signal Station Latitude and Longitude	Place	Signal Adopted	Situation of Time Signal	Time of Signal Being made		Additional Details
					Greenwich Mean Time.	Local Mean Time.	
53	42° 53' 32" S. 147° 20' 28" E.	Hobart	Ball	Flagstaff on site of Fort Mulgrave. 85 feet above high water.	h. m. s. 15 0 0	h. m. s. 0 49 22	Ball hoisted half way up as preparatory at 10 minutes before signal. Ball hoisted close up at 5 minutes before signal. Ball dropped every day at 1 ^h 00 ^m 00 ^s p.m. standard time of Tasmania (see page 2).
54	42° 52' 45" S. 147° 20' 38" E.	Hobart	Gun*	Queen's Battery	-	-	Gun fired simultaneously with drop of ball. [Note. – The ball at the flagstaff is dropped by hand, and not to be implicitly relied on; when it fails, a red pennant will be hoisted at masthead for one hour.]

lished in 1840 at Rossbank by Captain James Clark Ross (Savours and McConnell, 1982). Francis Abbott then set up his private observatory, including a transit telescope, in 1855 (Orchiston, 1992). This was used to calibrate time signals until 1886, first by Francis

and then by his son, Charles. After 1910, the time ball was operated by telegraph from Melbourne Observatory. These developments are described in more detail later in this paper.

2 LISTING OF TIME SIGNALS

2.1 The Admiralty Lists

Between 1880 and 1898, the Admiralty in London published five editions of time signals for mariners. The first and last of these show the growth of time signal provision worldwide towards the end of the nineteenth century (*Lists of time signals*, 1880 and 1898). The number of distinct entries increased from 71 to 154 during that period, some having more than one type of signal. Errors did occur, including one in the 1880 Hobart entry where the location of the time gun was specified wrongly. The number of listed time balls had increased from 52 to 94 while the number of listed time guns had grown from 9 to 30. Other time guns, notably in Malta and Madras, were also mentioned under additional notes in 1898. Many others are known to have existed worldwide. There were no time gun entries for mainland Australia, so the time gun at Fort Denison, for example, was not regarded by the Admiralty as an official signal for Sydney.

2.2 The Entries for Hobart

The entries for Hobart in the 1880 and 1898 editions of the Admiralty list show how information was presented. The first edition contains the entry shown in Table 1 (*List of time signals*, 1880).

The 1880 "Situation of Time Signal" gave an incorrect location for the time gun. It had been at Queen's Battery, with different latitude and longitude, from 10 April 1875. This was corrected later. The 1898 list was organised by reference number and contained more detail than the 1880 list. The double entry (Nos. 53 and 54) for Hobart is shown in Table 2 (*List of time signals*, 1898).

Gun* in the fourth column of Table 2 is a reference to a general footnote to the 1898 list, which gives specific acoustic information. It reads:

When the flash of a gun cannot be distinctly seen, the sound of the report may be made use of as an approximate indication of the time, by allowing for the necessary interval for the sound to travel the intervening space.

Sound travels about 1,090 feet in a second of time, at the temperature of 32° Fahrenheit, and the speed increases at the rate of 1.15 per second for each degree of temperature above the freezing point. In fogs, however, the use of sound is not to be relied upon ...

A warning about the reliability of the Hobart signals was recorded in the 1898 list entry (Table 2) and there was a note on contemporary charts pointing out that the Hobart time ball was inaccurate (see Nunn, 1908).

2.3 Accuracy of Coordinates

There was a significant adjustment to the Hobart time ball longitude between the Admiralty lists of 1880 and 1898, which appeared to move the time ball 1.0 km further west (inland). This is likely to have been an attempted correction, because the revised locations for the gun and ball were still slightly too far east and south to be in accord with modern GPS coordinates. The 1898 differences in latitude and longitude between the time gun and time ball indicate that the gun was 1.45 km further north and 0.23 km further

east than the time ball. Although time signal locations are not known precisely, Figure 1 suggests that the actual separation was close to 1.2 km.

Coordinates for the Hobart observation point in the Barracks Reserve were estimated in 1874 by the United States Transit of Venus expedition in conjunction with Melbourne Observatory. The Hobart Observatory transit hut was 110 m south and 16 m east of the pier used for the 1874 transit instrument (*Government Departments*, 1913). The derived location of the Hobart Observatory transit instrument, stated by Purey-Cust (1894b), was about 40' too far west.

The locations estimated using Google Earth are listed in Table 3. These coordinates confirm that the time ball was approximately 1.0 km from the Observatory transit instrument in the Military Barracks, as previously noted by Nunn (1908).

Table 3: Locations of the Hobart time ball, time gun, Hobart Observatory and the 1874 transit of Venus site.

Location	Latitude (S)	Longitude (E)
Time ball	42°53' 16"	147°20' 10"
Time gun	42°52' 40"	147°20' 14"
Observatory transit instrument	42°53' 23"	147°19' 39"
1874 US transit of Venus pier (van Roode, 2011)	42°53' 19"	147°19' 38"

2.4 Entries in *Walch's Tasmanian Almanac*

Issues of *Walch's Tasmanian Almanac* between 1876 and 1928 contain entries concerning the time ball and time gun service, but their accuracy is uncertain. Newspaper announcements show that some changes were introduced more than a year before their inclusion in the *Almanac*. A daily time gun and time ball service was started on 6 March 1875 (The time gun (editorial), 1875c). The *Almanac* for 1875 would have been issued before the service became established, so it was not mentioned. The time ball entry for 1928 was certainly posthumous, as the service ended on 19 February 1927 and the time gun service earlier still.

The initial and final entries (*Walch's Tasmanian Almanacs*, 1876 and 1928) indicate that the time gun was at Queen's Battery throughout. It had been located from 6 March to 10 April 1875 at the Prince of Wales' Battery, at Fort Mulgrave near Battery Point, but this preceded the first *Almanac* entry. Figure 2 shows the gun being fired at Queen's Battery in the Domain.

The entries in *Walch's Tasmanian Almanac* changed from time to time. Those from 1884 to 1887 all read:

Time Signal. - Black ball drops daily at one o'clock p.m. on the Albert Battery staff, a time gun being simultaneously fired from the Queen's Battery.

The entry for 1888 was changed to:

Time Signal. - Black ball on flagstaff; ball half way up at 12.50 pm, ball close up at 12.55 pm, ball dropped at 1pm. Hobart mean time; gun fired simultaneously from Queen's Battery. *Note.* - when the signal fails in accuracy a red pennant is hoisted at mast-head for one hour.

The 1888 entry was maintained with only minor alterations until 1918, when a Sunday service was no

longer offered and daylight saving time was introduced as an experiment in Tasmania. The time reference was changed from “Hobart mean time” to “Hobart Observatory mean time” in 1890, then to “Hobart Observatory standard time” in 1899 and finally to “Melbourne Observatory standard time” in 1911. The Australian colonies had actually adopted international time zones on 1 February 1895. The pennant colour was changed from red to white in 1899, but the pennant was not mentioned in 1911 or later.

3 THE DEVELOPMENT OF TIME SIGNALS IN HOBART

Hobart offered a time ball and time gun service from 1875 until the 1920s, but it was a long time in gestation. Information about the time gun in Edinburgh was published in Hobart in 1861. There was serious debate and some preliminary time gun trials in 1865, followed by a remarkable experiment in 1868, but neither led to an early public service. The time ball service ended on 19 February 1927 (Collier, 1953a, 1953b); the final demise of the time gun service is likely to have occurred as early as 1923.

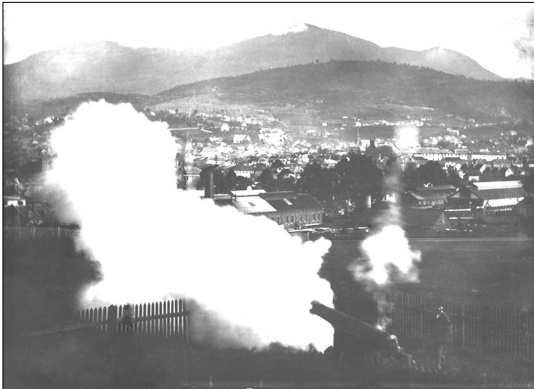


Figure 2: The Hobart time gun is fired at Queen’s Battery (courtesy: John Lennox).

3.1 Notice Concerning the Edinburgh Time Gun

The *Mercury* newspaper often published informative articles about events worldwide. In a column headed “Scotland” (1861) there was a detailed description of how the newly-introduced time gun in Edinburgh was fired. It set a new standard for time gun accuracy. Remarkably, a 1.3 km long telegraph wire was suspended directly between Nelson’s Monument and Edinburgh Castle and used to control the pendulum of the gun clock (Kinns, 2011). It was replaced 12 years later by a wire with intermediate supports (Ritchie, 1873).

The Astronomer Royal for Scotland, Charles Piazzi Smyth, reported details of time signal accuracy to Astronomer Royal Sir George Airy (Smyth, 1878):

With the Time-Ball the first instant of the fall is recommended to observers, but is in reality always about 0.15 sec. too late, on account of the time necessarily taken up in the action of the trigger.

With the Time-Gun the fire is 0.05 sec. too soon, owing to the difference of instants at which the escapement of the clock concerned is liberated, and at which the electrically controlled pendulum arrives at the end of the arc at each second.

An accuracy of a small fraction of a second was feasible, provided that fully-automatic operation by a controlled clock was used. Automatic operation was never used for the time gun in Hobart.

3.2 The Debate and Experiments in 1865

The Royal Society of Tasmania was a forum for active and well-informed debate about time signals for Tasmania. Francis Abbott (1799–1883) was the leading contributor. He had an extraordinary life, having been deported from England to Tasmania in 1845 for obtaining two watches by false pretences, before re-establishing himself in Hobart after 1849 as a respected citizen (Orchiston, 1992). He made extensive meteorological and astronomical observations, adopting the role of voluntary government meteorologist until almost the end of his life (ibid.).

Two articles entitled “Time Signals” by Abbott were published in the Hobart *Mercury* during 1865. The first (Abbott, 1865a) accompanied a report on a 9 May meeting of the Royal Society (Royal Society, 1865). Abbott argued strongly in favour of a daily one o’clock gun for Hobart, but he encountered opposition. There was a reported exchange about a time gun at the University of Melbourne:

Mr. DOBSON observed if a time gun was established it would be well to be careful in fixing upon a proper site. When he was in Melbourne in February last the firing of the time gun at the University was discontinued as it was supposed to be the cause of some mortality in the Lying-in Hospital, situated in the immediate vicinity.

Mr. ABBOTT said that subsequent observation must have shown this opinion to be erroneous, as when he was in Melbourne, at a much later date, the firing of the gun had been resumed.

There was also discussion about cost, Mr. Davies believing that a time gun would cost at least £150 to £200 per year. He was in favour of a time ball, as at Greenwich, and

... suggested that before any action could be taken, it would be necessary to determine with accuracy to what distance the sound of a gun could be heard. He thought, if requested by the Royal Society, that the Volunteer Artillery might be able to institute some experiments. (ibid.).

In the second article (Abbott, 1865b) gave a detailed summary of leading innovations worldwide. Parts of that second article are transcribed below, because it gives useful insight into the thinking of the period. Abbott remained a strong proponent of time guns, thinking more of business requirements than the needs of mariners. He reported on some preliminary experiments using time guns:

At the May meeting of the Society, some notes were read and a discussion took place as to the desirability of establishing time signals in the colony. In the opinion of that meeting further information was required on the subject, and a committee was appointed to make inquiry as to the size of gun necessary, the distance at which a report could be heard, and the amount of expense that would be incurred.

Part of this duty the committee has been relieved from, through the kindness of Colonel Chesney, who partly for this purpose and partly for military service, has caused three guns to be fired at 4 p.m., on the first Thursday in every month, provided the weather was

fine, and if not on the first day following. Through the Horological Institute of London, I am now in possession of further information on the subject, especially on the method for obtaining and transmitting correct time, and have therefore thought it desirable to bring the practical portion more fully before the Society, as time signals are now held to be of great importance in all manufacturing or commercial towns, in which either public or private works are carried on.

Abbott then gave considerable detail about the methods used for determining time at the Cantonal Observatory at Neuchatel in Switzerland and at the Royal Observatory at Greenwich, together with the telegraph systems that were used for wider distribution. He went on to describe time gun arrangements for Newcastle in England and Glasgow in Scotland:

Very general reference is made to these [Newcastle] guns, not only by the public generally, but also by manufacturers and ship-building companies, for regulating their works, and not less important are the facilities they give for rating chronometers.

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

The Glasgow arrangement was initiated on 1 October 1863 with firing of the first gun near Sauchiehall Street (Glasgow ..., 1863). It was highly controversial. The guns were controlled from Edinburgh Observatory, and the plan was declared without consulting Glasgow Observatory or the University, let alone the citizens of Glasgow. The trial with four guns was terminated in February 1864 (Discontinuance ..., 1864). There had been a Glasgow time ball between 1857 and 1864, but it had uncertain accuracy. Both time guns and time balls were abandoned in favour of public clocks controlled electrically from Glasgow Observatory (Kinns, 2010).

Abbott (1865b) also described the use of multiple time guns in Madras:

At Madras, measures have been taken by the astronomer, Mr. Norman Pogson, with funds supplied to him by the Governor-in-Council, to convert no less than five time guns, which are daily fired in and about that city, by connecting them electrically with the normal meantime clock at his observatory. Mr. Pogson says that "the smoke by day, and the flash by night of a time-gun, are far better and more conspicuous signals than any time ball".

Confusing multiple reports and sound reflections probably caused early discard of the multiple gun arrangement. Only one gun was noted for Madras in the 1880 Admiralty list, in a subsidiary note which pointed out that it was for local use, not for rating chronometers.

Abbott (ibid.) then summarised his views concerning the cost and benefits to large projects in Tasmania. He argued that the cost of powder for guns in both Hobart and Launceston, fired three times per week, would be only £15 12s per year, and

If the government expects to carry out the proposed railways, and other public works, a very large number of men will be required, and it is quite clear that if something approaching to correct time is not adopted,

a few minutes loss for each man every meal will very soon amount to a much more considerable sum than the cost of a few time signals.

The paper finished with reported observations by the Astronomer Royal at Greenwich, George Airy, about the economic and navigational benefits of time signals. The cost of the powder for guns featured strongly in the argument for guns at Hobart and Launceston. It featured also in later arguments—which lasted well into the twentieth century—about whether the time gun service should be continued.

3.3 The 1868 Acoustic Experiments

The Colonial Secretary in Hobart announced on 22 June 1868 that experiments with time guns were to be carried out on 30 June and sought written responses from members of the public. His announcement was published on successive days in *The Mercury* up to and including the day of the experiments (Daily time gun, 1868). Francis Abbott was nominated as the source of correct time in the notice, which is transcribed in full below:

Gentlemen interested in the establishment of the above, and resident in the vicinity of Hobart Town, are informed that certain experiments will be tried on TUESDAY, the 30th inst., commencing at 12, noon (Abbott's time), to test the question of "What nature of ordnance should be used for the purpose?"

At the time above-named a 10lb charge will be fired as a signal that the experiments are about to commence. Two minutes afterwards the first experimental gun will be fired; two minutes afterwards, a second; and so on until 25 rounds are completed.

The pieces of ordnance will be formed up in or near the Queen's battery, Domain, and pointed towards Drouthy Point.

The Colonial Secretary would feel obliged if gentlemen resident at Bridgewater, Brighton, Richmond, Sorell, Kingborough, Risdon, and other places within a radius of fifty miles from Hobart Town, would furnish a return to this Office on or before 8th day July, of the following description ...

Table 3 shows how respondents were expected to complete their returns.

The successful completion of the experiments was reported on the following day (A daily time gun, 1868):

Yesterday, by order of the Colonial Secretary, a number of experiments were made at the Queen's Battery to test the applicability of certain pieces of ordnance to the purposes of a daily time gun. There were a considerable number of gentlemen present to watch the experiments, which were conducted by Staff-Sergeant Major Eccleston of the Artillery. The signal gun was fired at noon, and twenty-five rounds were then discharged from six pieces of ordnance of different natures, the charges of course varying according to the nature of the piece ... The guns were discharged at intervals of two minutes and were distinctly heard all over the city. The effect in the outlying districts has, of course, yet to be proved ... Gentlemen who may have been on the look out for the guns in any of the districts, but who may not have heard them, would do well to notify that fact to the authorities, as a knowledge of it will assist in arriving at a decision.

It was an ambitious acoustic experiment, but the results appear to have remained unreported to the general public. Fifty miles (80 km) corresponds to a

sound propagation time of about 4 minutes. Signal delays would have been significant at any of the outlying locations. It was to be more than six years before a combined time gun and time ball service was implemented.

Table 3: Specification for returns concerning the time gun experiments of 30 June 1868.

EXAMPLE	
No. of Round.	Distinctness of the Report of each Round expressed in figures. Maximum 10.
1	4
2	1
3	10
4	6
5	7
6	2
And so on.	And so on.
The signal gun need not be included in this return.	
RICHARD DRY,	
Colonial Secretary's Office,	Colonial Secretary.
22 nd June, 1868.	30j

3.4 Introduction of the Service during 1875

An editorial (1874) published in *The Mercury* on 31 December 1874 noted that a Saturday time gun had been introduced recently at Queen's Battery, but argued in favour of a daily time ball:

Our complaint, on a recent occasion, respecting the great inconvenience caused by the want of a town clock to give correct standard time, had the effect of arousing the powers that be to the necessity for firing a gun from the Queen's Battery, in the Domain, at one o'clock precisely, on Saturday. The step was in the right direction, but a good deal remains to be accomplished before public convenience can be satisfied in respect of an approximate knowledge of the time of day. The firing of a gun once a week is a small mercy in its way, and one for which no insignificant section of the community is correspondingly grateful. But the particular class who would most be benefited by the signal, namely, seafaring people, might, in no restricted sense, remain totally ignorant of the fact. Dozens of ships might arrive at and depart from port on consecutive dates without ever hearing a gun, and consequently remain unacquainted with the correct time. This grave oversight could easily be remedied if the authorities of Hobart Town adopted a practice, in vogue in ports of much less consequence, we allude to the practice of dropping a time-ball at one o'clock precisely every day of the week. The ball could be placed under the charge of the Marine Board – a body not overburdened with work at any particular period of the year; and if placed in a conspicuous position of the city – Battery Point for instance – the diurnal descent of the ball would soon be regarded as a boon immeasurably in advance of the signal gun.

The intention to implement a daily time gun service was announced early in 1875 (The time gun (editorial), 1875a). The gun was not, however, to be located at Queen's Battery:

We understand that, by an arrangement between the Government, Marine Board and City Council, the firing of a gun daily will be secured. The gun will be fired from the Prince of Wales Battery, daily at noon, and the time regulated by a chronometer to be kept on the spot.

The Hobart time gun service was announced on Friday 5 March, with the statement that it would commence on the following Monday 8 March (The time gun (editorial), 1875b), the gun being fired at 1 p.m., not noon:

It has been arranged that an eight-day chronometer will be kept in the office attached to the flagstaff at Battery Point, and, as we some time ago said would be arranged, the Marine Board have undertaken to fire a gun every day at 1 p.m., in order to intimate the correct time to the public. This new arrangement will come into operation on Monday Next.

There was no mention of a time ball, but the announcement was inaccurate. A daily time ball and time gun service actually started on Saturday 6 March (The time gun (editorial), 1875c), both signals being made at 1 p.m.:

Arrangements have been made by the Marine Board, on and after to-day, under which a gun will be fired every day, including Sundays, at 1 p.m. At five minutes to one o'clock a ball will be hoisted at the top of the upper flagstaff, and will be lowered exactly at one by chronometer time, to be kept at the signal station. Simultaneously with the dropping of the ball, the gun will be fired by the Master Gunner from the battery adjoining the flagstaff.

The time gun was at Battery Point for the initial daily service, but it was soon moved back to Queen's Battery, where the 1868 acoustic trials had taken place and where it had been for the Saturday only service.

3.5 The Early Complaints

The difficulty in striking a balance between social impact and business needs can be illustrated by extracts from correspondence and editorials. The Hobart time gun attracted many complaints when it was positioned near the time ball. The charge had to be reduced to reduce local disturbance, but it then failed to serve its purpose. A letter signed "More Powder" (1875) made matters clear:

... it doesn't make half noise enough, and so in part does away with the gratitude the boom would otherwise inspire.

When the gun was weekly discharged from the Queen's Battery, in the Domain, the sound could be plainly heard all over the town, and even many miles away; and, therefore, I would suggest the continued use in the same place. It would not interfere with the simultaneous dropping of the ball – the flagstaff being in plain view – and I am sure those who can't see the ball will be very glad to hear the gun.

A letter signed "Howitzer" (1875) was supportive:

I see by this morning's *Mercury* that the inefficiency of the time gun is very justly complained of. Buried as it is in that model battery for all useful purposes, it had better be discontinued, and only the ball used.

I believe there is a 32 pounder brass Howitzer in the store, which is the only suitable gun for the purpose. Placed in the Queen's Battery, or better still in Franklin Square, I am sure there will not be any complaint then.

This was followed by an editorial (The time gun (editorial), 1875d) which included the observations: "We think we may safely say that the firing daily of the gun has given very general satisfaction ... [and] We understand that a remonstrance on the part of the people near the present place of firing has been sent

to the Government.” The complaints had an effect, and the time gun was moved on 10 April (Time gun (editorial), 1875e):

In consequence of certain of the residents in the vicinity of the Prince of Wales' Battery having represented to the Colonial Secretary that the firing of the gun had caused considerable annoyance, by the breaking of glass, &c., it has been decided to fire the gun for the future from the right flank of the Queen's Battery in the Domain. The new arrangement will come into operation today.

The 'Gun Clock', which can still be seen at Narxyna Heritage Museum in Hobart, was probably provided for the gunner at the Queen's Battery. It is too large to have been the chronometer used at Battery Point.

A letter signed "W.N." (1875) written on 5 July was published in *The Mercury*. The issue now was the Sunday firing:

The necessity of firing the gun on Sunday has never yet been understood, but plenty of reasons could be given why doing so for six days in the week would serve all good purposes ...

While the Holy Communion was being administered on Sunday last in Trinity Church, the gun was fired, and the report being so loud, made the windows rattle, and coming so unexpectedly, those within the building were much startled; in fact, the sensation produced was far from pleasant.

Secular interests appear to have prevailed until 1918 when *Walch's Tasmanian Almanac* first specified that no time signals were given on Sundays. There were intervening periods when the Sunday service was not provided, apparently to save money.

4 DETERMINATION OF TIME

4.1 By Horologists, Up to 1886

The skills and enthusiasm of individual Hobart citizens provided the means for determination of time during the early years of Hobart time signals (Mercer, 1999). David Barclay developed a successful business selling watches, clocks, instruments and jewellery. In about 1860 he imported a regulator clock from Edward J. Dent of London. It was said to have a variation of only half a minute per year from Melbourne Observatory standard time (*ibid.*). It is now in the Tasmanian Museum and Art Gallery.

Francis Abbott had been the author of papers concerning time signals in 1865 and was also the source of correct time for the gun experiments of 1868. He played that role in Hobart for many years afterwards. He would have used Barclay's clock, calibrated using his own regular transit observations, together with a chronometer to transfer time to the ball operator. Such transit observations were not usually subject to independent scrutiny and were viewed with suspicion by leading astronomers, as was the case in Glasgow (Kinns, 2010). Admiralty reservations about the accuracy of Hobart time signals are likely to have stemmed from this period.

Francis Abbott's declining health led to the end of his personal time service in 1880, as well as his meteorological observations. This forced the foundation of Hobart Observatory in 1882, with Captain Shortt as its first Director (Orchiston, 1992). The early emphasis was on continuing Abbott's meteorological

work. Charles Abbott continued his father's time service for several years, but he wished to relinquish responsibility for it in 1886 (Shortt, 1886a).

The accuracy of Barclay's clock was noted in later discussion at the Royal Society in Hobart, when methods for improving the accuracy of Hobart time signals were under discussion. Reported remarks by the Government Meteorologist (Kingsmill, 1894) included the following observations:

... he thought he was at liberty to mention that ere long there would be, through the generosity of a citizen, a better means of obtaining correct time than at present. (Applause.) Mr. David Barclay had very kindly placed his clock, known to be the best in the Southern Hemisphere, at disposal to be connected electrically with the observatory. With liberty to read Mr. Barclay's clock alongside the present instrument in cloudy weather, when it was often and for lengthy periods impossible to take observations, a better standard of time might be looked for in the future. When this was done he would not be afraid to see electrical signalling established. (Applause.)

Barclay's clock was used as the Observatory reference until 1910, being far superior to the Observatory's own solar mean time clock.

4.2 Telegraph from Hobart Observatory

Sufficient funds were available for the time service to be transferred from Charles Abbott to Hobart Observatory in 1886 (Shortt, 1886a). Captain Shortt was in favour of dropping the ball electrically. He received assistance from Robert Ellery, the Government Astronomer in Melbourne (Gascoigne, 1992), and Robert Henry, the Superintendent of Telegraphs in Hobart, concerning the necessary equipment and procedures (Shortt, 1886b). A press announcement about the new service was prepared (*ibid.*).

The announcement stated that significant improvements to the method of time ball operation would be made from 1 September 1886 (Time ball ..., 1886). From that date, the Battery Point signal station would receive telegraph signals from the Observatory clock, whereas time had been provided previously using a chronometer that was corrected weekly. The published announcement showed that fully automatic dropping of the ball was discarded in favour of manual response to telegraph signals:

On and after tomorrow arrangements have been made by which correct time will be communicated to the Mulgrave Battery every day at one o'clock by Captain Shortt, R.N. ... The giving of correct time has hitherto been well attended to by Mr. C. Abbott of Murray Street, who sent a man once a week to correct the chronometer, but as this mode was not so sure as an automatical and electrical system, it was resolved that the signals should be given from the astronomical clock at the observatory to Battery Point signal station, and also to the central telegraph office in order that they might be transferred daily to the various telegraph offices in the colony. The signals are given direct by the clock which completes the electrical circuit at 40, 30, 20, 10, 4, 2 and 0 seconds to 1 p.m., the last signal of course being at one o'clock, when the man in charge drops the time ball and also sends a return signal to the observatory by means of an electric bell to show that he had done so. The signals are given on galvanometers, which, while simple and very easy to understand, are still efficient for the purpose and are not liable to get out of order. In the event of

the clock getting out of order, which is not very probable or failing to send the signals, arrangements have been made to send them by hand. The clock and galvanometers were obtained through Mr. R. J. Ellery, of the Melbourne observatory, and Mr. R. Henry, the superintendent of telegraphs, has taken a great interest in making the electrical arrangements as complete as possible. The time-ball will be dropped by hand, and any error in the dropping will be clearly notified in the newspapers of the following day. Credit is due to Captain Shortt for his invaluable efforts to obtain accurate observations, and it is to be hoped that they will be attended with the greatest success.

The change to operation using a daily telegraph signal should have improved the signal accuracy relative to the earlier method of operation, but later evaluations by naval officers of the Hobart time ball showed there were serious deficiencies in observatory instruments and procedures. Henry Kingsmill was appointed as Meteorological Observer following the death of Captain Shortt in 1892, and he continued the time service.

4.3 The Method of Time Gun Operation in 1893

On 31 March 1893 a lengthy editorial in *The Mercury* (How Hobart time gun ..., 1893) explained how the time ball was then being operated. The first part of the editorial explained how time was determined using transit instruments to observe the passage of stars across the meridian. This was followed by a description of the procedure for dropping the ball and firing the gun:

The true time having been thus obtained, and the record of the Observatory clock checked, the dropping of the time-ball and the firing of the gun is a simpler matter. Mr. Shea, in charge of the time-ball at Mulgrave signalling station, is communicated with by wire. He receives the electric bell signals from Mr. Kingsmill to hoisting the ball, but for dropping it on the instant of 1 o'clock the signal flash is sent automatically and electrically from the Observatory clock. The dropping of the time-ball is effected by hand, because electrical apparatus have been found incorrect. Mr. Shea is first rung up at about a quarter to 1 o'clock, as a hint to get ready. At 12.50 he receives the signal to hoist the time-ball half-way up the pole, and this is also an indication to gunner Caulfield, on the Domain, to be also in readiness. At 12.55 Mr. Shea receives the last signal from Mr. Kingsmill, which means that the ball is to be sent to the top of the pole. Then comes the 1 o'clock signal from the Observatory clock, down goes the ball instanter; the gunner sees the ball drop, pulls a plug, and fires the gun, the total waste of time being usually 3sec. to 5sec. only. The true time to the second is the dropping of the time-ball. Anyone at Bellerive seeing the ball drop, would learn that it was 1 o'clock at least 10sec. before it is indicated by hearing the discharge of the gun, for sound only travels at the rate of about 4sec. to a mile. It will thus be seen that there are three persons concerned in the operation – Mr. Kingsmill the Meteorological Observer, the man in charge at the signal station, and the gunner in the Domain.

The gun is an old howitzer of 1848 ... The charge of gunpowder is put in a little bag, and weighs about 3lb, each discharge costing the Government 2s. for powder. The bag of powder having been rammed "home", a friction tube is inserted in the vent hole, to which is attached a piece of cord, and all is ready. The gunner holds the cord out straight in readiness as the moment for firing approaches, and keeping his eyes on the

ball. As the ball falls he pulls the cord and the gun is discharged by the time the ball is down. The muzzle of the gun points to the gasworks, and occasionally when the atmosphere is dense and foggy a strange phenomenon is witnessed when the gun is fired – it forms a long tunnel through the vapour.

Mr. Kingsmill communicates the time in the same way to the Post-office, whence it is wired to Launceston and different parts of the island [of Tasmania].

4.4 The Purey-Cust Report of 1894

In 1894 an important report concerning the time ball was prepared by Lieutenant Commander Purey-Cust, then in command of the survey yacht, *HMS Dart*. Herbert Purey-Cust later served as Hydrographer of the Royal Navy, from 1909 to 1914, and was knighted in 1919 (Obituary Notice ..., 1939). His Hobart report became a parliamentary paper (see Kingsmill, 1904).

In preparing his report, Purey-Cust worked for a month at Hobart Observatory, testing instruments and checking calculations (Kingsmill, 1904). His report was wide ranging and included comment on the transit instrument and its alignment (Purey-Cust, 1894b). He gave a lucid explanation of the procedure for dropping the ball using signals from Hobart Observatory, located in the Military Barracks:

Signals are sent from the observatory to the signalman at the flagstaff, Fort Mulgrave, where the time ball is situated, by electricity during the last minute previous to 1 p.m. The electrical fittings are so inferior that they frequently break down entirely for days together. Mr. Ellery, the Government Astronomer at Melbourne, whilst recently in Hobart, gave as his opinion that this might be remedied by a very simple alteration. Again, the ball is hoisted by a rope and winch, and, in order for the ball to appear to drop at 1 p.m., it is necessary for the signalman to let go the winch handle a certain time beforehand; this he does when he sees the last time signal at 2 seconds to 1 p.m., and the ball itself drops about half a second past 1 o'clock. By dint of long practice and habit this error is fairly constant, and varies from 0.5 seconds to 0.8 seconds too late; but it is obvious that that the error is liable to variation, and that under the circumstances it is absolutely impossible for the man to drop the ball exactly at 1 p.m. This, I think, might be obviated by some simple automatic method of dropping it to work with the assistance of a relay by the same electric current, from the Observatory, that works the time signal. It would be a good plan in future, when the time ball fails in accuracy, to hoist it again immediately half-mast, close up at 1.55, and drop it in the usual manner at 2 p.m, publishing the error in the next morning's paper. This is the usual method adopted in many ports in similar cases.

There was particular concern about the observatory clocks (Time service ..., 1910):

There were two clocks. One, a sidereal, in the transit hut, was exposed to every variation of temperature, and in consequence had an ever fluctuating rate. The other, a mean solar clock, in the observatory building, had to be corrected every day at noon to exact mean time for dropping the ball, and could therefore be said to have no known rate. Consequently in cloudy weather no dependence could be placed on either of them, and the time was regulated by a single box chronometer kept in the observatory building. There were no ready means of accurately forecasting the clock in the tourist [*sic*] hut used for observation with either the

chronometer or the mean solar clock. At small expense a clock face might be fitted close to the mean solar clock, electrically connected with the sidereal clock, affording a simple and extremely accurate method of comparison between the two. That was the method usually adopted in all observatories. A good standard clock was much needed. That could be placed in the cellar, for the sake of uniformity of temperature, and electrically connected, as above, with the room in which was the mean solar clock.

In a covering letter to the Premier of Tasmania, Purey-Cust (1894a) made the following observations:

The question of the correct time signals by the dropping of the ball is of extreme importance to the shipping world ... At present, I am confident that the time is ascertained at the Observatory with the requisite accuracy, but with the numerous defects of the small transit instrument alluded to in my report, it requires constant and very careful management.

Despite the many criticisms in the report, the response was complacent. A similar evaluation in 1908 showed that little was done for the next fourteen years. Barclay's clock was, however, reintroduced.

4.5 Transfer of Functions

In 1903 there was concern about a proposed transfer of the duties of the Meteorological Department to the University. Meteorologist Kingsmill made the mid-day observations of the Sun and star observations at night that allowed accurate regulation of the Hobart Observatory clock. There was a fear that members of University staff would not have the time to continue Kingsmill's work. A deputation from the Royal Society met the Chief Secretary on 9 July 1903 (The Meteorological Department, 1903). Deputation members reported on favourable comments from mariners:

The naval officers had expressed themselves highly gratified at the accuracy of the time gun, and as the port was visited by a large number of vessels accurate time was of the greatest importance. He hoped the Government would not take any steps that would militate against the efficiency of the department.

Mr. Morton quoted the remarks of captains of ocean-going steamers stating that the time was more accurate in Hobart than in any of the ports in the Southern Hemisphere, and that they always set their instruments by the Hobart time gun. The importance of accurate time in such matters was vital.

The accuracy of the Hobart signals is likely to have been overstated, when time balls at several locations in Australia had heavy-duty mechanisms with automatic control by electric telegraph from well-equipped observatories (Kinns and Abell, 2009). The Admiralty was more critical, as shown by a subsequent report (Nunn, 1908).

State functions were being transferred to the Federal Government during the early twentieth century and there was further concern in 1907 about continuation of the time gun service (The time gun ..., 1907):

The president of the Chamber of Commerce (Hon. W. H. Burgess) who was a member of a deputation which waited on the Premier yesterday, asked what provision was made for the continuance of the time service after the transfer of the Meteorological Department to the Federal Government. At present it was part of the work of the observatory. The Federal Government proposed to take over only the meteorological service,

leaving the astronomical work to the individual States. It was important in a seaport like Hobart that standard time should be daily recorded for the benefit of shipmasters who wished to regulate chronometers and he (Mr. Burgess), therefore, asked whether the time service would be continued. The Premier consulted the Under-Secretary (Mr. P. C. Douglas), and then informed the deputation that a sum had been placed in the Estimates and that the time gun would continue to be fired at 1 p.m. daily.

The time gun service survived, but it was already under budget pressure.

4.6 The Nunn Report of 1908

Despite the deficiencies highlighted by Purey-Cust in 1894, little was done to improve matters. Another report was produced by Commander Nunn, from *HMS Powerful*. It was made available in Hobart during February 1909 but was written during the previous year (Nunn, 1908). He made nine observations, of which the first six are reproduced below:

(1) The transit instrument is the same as that described in paragraph 1 of Lieut. Commander Cust's report dated April 5, 1894, and from the observations taken with it the errors and rates of the standard clock are determined. The standard clock at present used is the property of and in the house of a Mr. Barclay, who allows it to be used for the purpose, as the Observatory does not possess a clock reliable enough.

(2) Mr. Barclay's clock is electrically connected with the signalling clock, which is adjusted daily to exact time by movement of weights on its pendulum. The signalling clock is connected to [a] galvanometer at Fort Mulgrave, and works the galvanometer needle which gives the signal to drop the time-ball.

(3) The time-ball is dropped on the flagstaff at Fort Mulgrave, about half a mile from the Observatory. It works up and down the flagstaff, and is hoisted by hand-winch about half-way up at ten minutes, and close up at five minutes, before 1 o'clock, and a hand brake put on. The signalman releases the brake when the 1 o'clock signal is made by the deflection of the galvanometer needle, and the ball drops. This method renders it very liable to personal errors.

(4) The connection between the Observatory and the signal-station galvanometer is also apparently faulty, as there are frequent failures of the signal. When the galvanometer fails to give the signal, the signalman releases the ball by chronometer time.

(5) The chronometer which is used is a very old one. There are no records of it having been cleaned for years, and it has to be carried from the hand-winch, as the Establishment does not possess a suitable back or deck watch for the purpose.

(6) It would appear by reference to paragraphs 1, 2 and 3 of Commander Cust's report that no material improvement has been made in the state of the time service since Commander Cust reported on it as inadequate and liable to error 14 years ago.

Nunn's report showed that Barclay's clock was an important part of time determination in Hobart in 1908, having been connected electrically to the signalling clock even though it remained in a private house near Battery Point. The chronometer used to drop the ball when the electrical connections failed, as they did often, was clearly of doubtful accuracy. The time ball was described as being on the flagstaff at Fort Mulgrave in both the Purey-Cust and Nunn reports.

Nunn concluded with recommendations for changes that he considered essential if the time ball service was to reach the required standards. The aim was to remove the Admiralty qualification concerning accuracy, which had been in existence for a long time:

(7) I would suggest that if the following improvements were carried out, a satisfactory time service could be maintained, and that on a favourable report being made to the hydrographic office of the Admiralty the note referred to by the Master Warden of the Marine Board, Hobart, would be removed from the charts and sailing directions. It would be also removed from the Admiralty list of time signals, where it is to be found on page 25. Suggested improvements: -

(1) That a new and modern transit instrument be obtained.

(2) That a good standard clock be obtained, of a character and reliable enough for the work of a modern observatory.

(3) That all the electrical connections be made efficient.

(8) I am of the opinion that it would be a great advantage to move the transit instrument house from its present position, and place it on the site of the transit pier in the Barrack-reserve, which was used by the United States Transit of Venus Expedition of 1874 (mentioned in paragraph 6 of Lieut. Commander Cust's report), or better still, and more likely to meet future requirements, that a small observatory be built on that site, capable of conducting both the Tasmanian time service and also the branch of the Commonwealth meteorological work.

(9) The present transit instrument house being only a very old and small wooden hut, is not suitable for housing delicate instruments. A flagstaff could be erected and the time-ball dropped from near the Observatory, or on the Observatory itself, thus eliminating many chances of inaccuracy.

Henry Kingsmill died unexpectedly on 16 July 1909 (Death of Mr. Kingsmill, 1909; The late Mr. Kingsmill, 1909), and during the last weeks of his life was trying to establish the costs of new instruments (Time service ..., 1910). His widow, Helen Kingsmill, took over his duties as Meteorological Observer and continued the time service for several months (The one o'clock gun, 1910). Nunn's recommendations were never implemented.

4.7 Telegraph from Melbourne Observatory

During 1910 there was a significant change in the source of the time signal. It was to come by telegraph from Melbourne Observatory. The transition took place on 10 February (Government Departments, 1913). A plan to automate the time ball drop was agreed at a meeting of the Marine Board on 22 March (The time ball, 1910). Implementation was delayed and an editorial showed that the arrangement was still unsatisfactory six months later (Hobart time ball; the present ..., 1910):

The arrangements made by the Tasmanian Government with the Victorian authorities for the receipt of the one o'clock signal daily have been anything but satisfactory. When it was proposed some months ago that the position of astronomer in Tasmania should be done away with there was a good deal of opposition, but the Government of the day insisted upon the need for economy and the public were assured that the arrangements with the Victorian authorities for the transmission of time could be quite satisfactorily carried out. Indeed, the public were told that the

accuracy would be so great that the Admiralty could no longer find any reason for the statement on the charts that the dropping of the time ball was inaccurate. The following reports of the Marine Board's officer whose duty it is to receive the signals and comply with them will show what a farcical arrangement has been made:-

June 9. – Time gun did not fire. No gunner at the Battery.

June 13. – Time signal cancelled. No signals received from Melbourne.

June 14. – Received no signal; gun did not fire, the cause being, I am informed, that the Artillery were at Fort Nelson for firing practice.

June 21. – Time signal not received from Melbourne.

July 25. – Failure of time signal. I am informed failure was at Melbourne Observatory.

July 29. – Time signal cancelled, signals being quite useless and irregular.

August 1. – Time gun fired one minute five seconds late.

September 1. – No signal from Melbourne, reason being a holiday in Melbourne.

September 2. – No signal from Melbourne; failure of the cable.

September 16. – No signal from Melbourne.

The Marine Board forwarded the complaints to the Government, apparently without effect. A recent reply states, however, that the government is in communication with the Victorian authorities.

In all, there were 10 days between 9 June and 16 September when the gun did not fire or was seriously in error, a failure rate of about 10%. On 7 or 8 of these days, there was no time ball signal either. Operation of the gun was even more limited in early 1911 (Old Timer, 1911).

Pietro Baracchi at Melbourne Observatory responded to the complaints. Baracchi was then the second Government Astronomer for Victoria, having succeeded Robert Ellery in 1895 (Perdrix, 1979). He focused entirely on the time ball and suggested that occasional failures in the extended telegraph connection could be expected (Baracchi, 1910). His response was not well received in Hobart, although the Chief Secretary made the important point that "For shipping purposes, it did not matter so much if they did not get the exact time every day, so long as it was correct when they got it." (ibid.).

Baracchi referred to the time ball at Battery Point, not Fort Mulgrave. It is not clear whether this was just an alternative description of the location near Lenna, or implied a change in position.

4.8 Pressure to Upgrade Hobart Observatory

The frequent failures of the telegraph signals from Melbourne led to hope that it might after all be decided to upgrade Hobart Observatory. A long article was published in October 1910, highlighting the Purey-Cust and Nunn reports and arguing the case for upgrade (see Time service ..., 1910), but it was not to be.

4.9 Automation of the Time Ball Drop

It was a long time in coming, but automatic dropping of the Hobart time ball was at last introduced in November 1910 (Hobart time ball. Dropped ..., 1910):

The Hobart Marine Board, anxious for an accurate time service and for the black mark on the Admiralty



Figure 3: Part of the painting, “The Ethel at New Wharf (Prince’s Wharf)”, by Houghton Forrest, 1884. The time ball is shown as a small black circle high on the flagstaff to the left of Lenna (courtesy: Narryna Heritage Museum).

chart to be removed, has had an electrical apparatus fitted up at the Battery Point signal station, by which the time-ball is now automatically dropped from Melbourne at one o’clock, instead of by hand ... The circuit is so arranged that the one o’clock beat of the chronometer at the Melbourne Observatory releases a catch, which locks the winch handle at the signal station, and allows the ball to drop.

The automation was never extended to the time gun, as it had been in Edinburgh from the start of the City’s time gun service in June 1861 (Kinns, 2011).

4.10 Mount Nelson Signals

There is no mention in official notices of a time ball at the Mount Nelson signal station high above Hobart,

but in a book titled *Once Upon a Time ...* Sharland (1976) published anecdotes about a time ball there in a chapter entitled “Hobart’s 1 o’clock gun”:

So in the absence of radio or direct phone links in any of its three distinct stages the time signal ceremony came down to this:

First, a black ball went up on the Mt Nelson signal station about 12.45. Then, at the same time, a second ball went up on the Battery Point mast. At 1 p.m, the Mt Nelson ball was dropped. Simultaneously, or near enough, the Battery Point official who had been watching Mt Nelson let his ball drop. In smart succession, and again by vision, the man on the Domain responded and fired off his gun. And so it was.

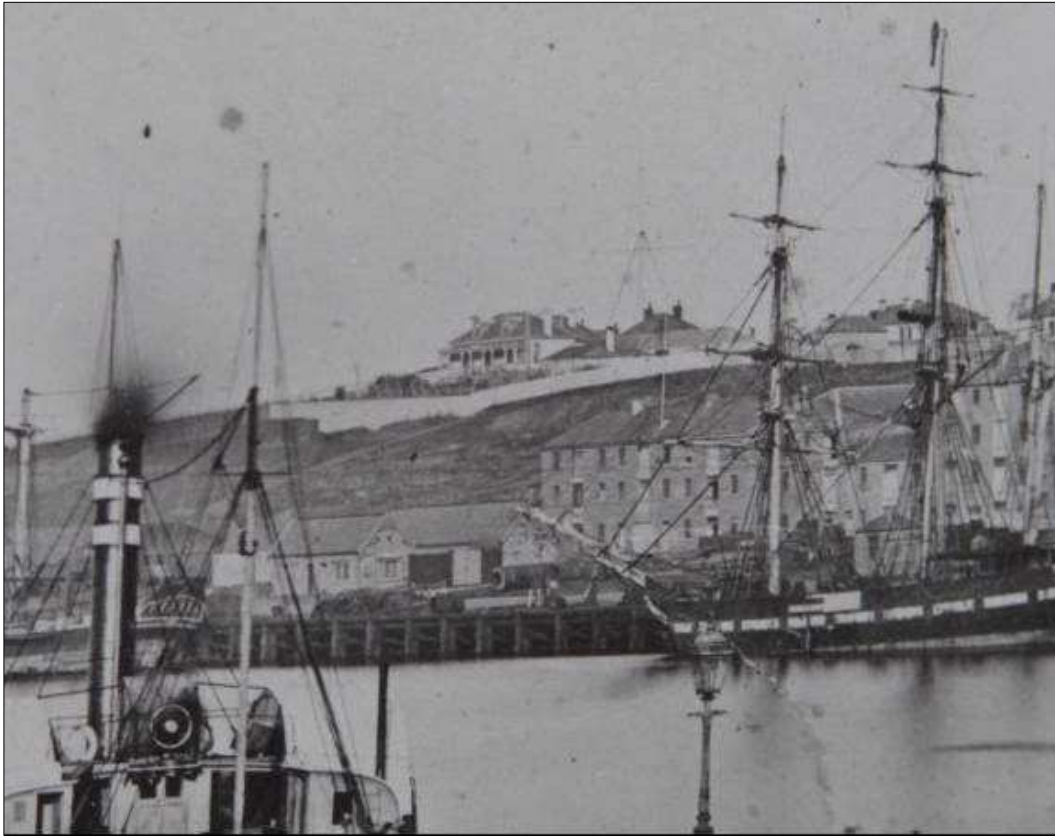


Figure 4: A photograph showing Bailey's house on the hill where Lenna now stands, and to the right of it the mast with the time ball (courtesy: Lenna; copy by Martin George).



Figure 5: The time ball and mast in the 1870s (courtesy: Lenna; copy by Martin George).



Figure 6: An 1878 photograph titled "New wharf ...", showing Lenna and the time ball mast (courtesy: W. L. Crowther Library, Tasmanian Archive and Heritage Office).

The existence of a time ball on Mt. Nelson cannot be discounted entirely, but no supporting written evidence or photographs showing a time ball at Mt. Nelson have been found. Curiously, Sharland makes no mention of telegraph links to either Hobart or Melbourne Observatories. If this other time ball existed at all, it was never assigned official status.

5 THE LOCATION OF THE TIME BALL

5.1 The Original Location

An 1884 painting by Haughton Forrest is on display at the Narryna Heritage Museum in Hobart. It shows the time ball on a tall flagstaff near 'Lenna', which by then was a completed building. Figure 3 is a close-up of part of that painting.

Lenna was a major development during the late 1870s on the site of a much smaller house belonging to Captain James Bailey (and known as the Bailey House). The extension to the left of Lenna in Figure 3 was subsequently replaced by a conservatory with a rounded roof, which appears in later photographs.

Photographs showing the house and time ball at various stages of development are on display at Lenna. Details from some of those photographs are included in this section. Figure 4 shows the original Bailey house, time ball and mast. Slanting stays are obvious in this photograph and it is just possible to see a very high topmast.

Figure 5 is part of a photograph which shows Lenna under construction during the late 1870s. It contains the clearest image of the time ball and mast found thus far, with slanting ropes that are either attached to the ball or to the mast behind it. The ball is raised above the transverse spar, but this was probably its original rest position above the stays. Slanting stays to the left of the mast are behind the spar and those to the right are in front of it. Vertical stays from the transverse spar to the ground and stays

between the spar and the topmast can also be seen. Ropes to the time ball itself may have acted as constraints in windy conditions, or to control its descent after the initial free fall.

Close examination of Figure 5 shows a high topmast, as in Figure 4, but with a conspicuous white flagpole to the right. The small building with twin roofs, in front of and to the left of the mast, was probably the signal station. The line of poles running downhill from the signal station is likely to have carried telegraph wires. The mast and time ball in a position above the spar are also obvious in a ship photograph taken in about 1880 ("Victoria barque ..."), but the resolution is insufficient to show the stays. The ball is at a lower rest position and the very high topmast is not visible in later photographs, so at some stage the topmast is likely to have been reduced in height.

The mast was located behind (south) and to the left (east) of Lenna when viewed from New Wharf. It was therefore shielded by Lenna in photographs taken by an observer from the northwest, but not by the smaller Bailey house in Figure 4. Panoramic views show changes to wharves during the period of interest. Stated dates of photographs are often approximate, so these changes help to reduce uncertainty. Figure 6 is a view of New Wharf, taken in about 1878 and viewed from Morrison Street. The unusually long transverse spar on the time ball mast is a striking feature from this angle. A photograph taken in 1895 shows a long open shed on New Wharf to the right of Lenna ("Waterman's Dock"), which does not feature in Figure 6 or in other early views.

Figure 7 is a detail from a photograph with the title "Lenna 1908 showing Signal Station mast with Black Basket at the Cross Trees position [the position of the ball at the transverse spar]". The date may not be precise, but the ball is invariably at this position in ship photographs taken after about 1886. The complete



Figure 7: Photograph titled “Lenna 1908 showing Signal Station mast with Black Basket at the Cross Trees position” (courtesy: Lenna; copy by Martin George).

photograph shows two long sheds on New Wharf, respectively to the left and right of Lenna when viewed from the wharf. The second shed to the left of Lenna was not present in the earlier panoramic views.

The time ball can sometimes be seen in the background in photographs of ships alongside New Wharf, which usually have uncertain dates. The time ball and mast can be seen in a photograph that is known to have been taken in October 1896 (“Kassa dismasted, 1896”). They are particularly clear in a ship photograph titled “Cynisca at New Wharf” that was thought to date to about 1910, but must be earlier as it was taken before erection of the second long shed on New Wharf (unless the suggested date of the photograph shown in Figure 7 is wrong).

5.2 The Size and Construction of the Time Ball

The time ball appears to have had a smaller diameter than the 1.5 m used at Sydney, for example, and for low cost and lightness is likely to have been made of wickerwork. This is consistent with a description of the ball as a “black basket”. A wickerwork ball with

a diameter of 0.9 m was in use at Newcastle, New South Wales, by January 1871, but a new wickerwork ball twice that size was erected in July 1874 (Kinns and Abell, 2009). Charles Todd in Adelaide wrote to Robert Ellery in Melbourne during 1869 about possible use of a wickerwork ball at Semaphore, South Australia, so there are Australian precedents for this type of ball construction (Abell and Kinns, 2010).

5.3 Photographs Appearing to Show a Different Time Ball Location

No explicit statement that the time ball was ever relocated has been found, but Figure 8 appears to show a relocated mast in a photograph of *SS Victory*, which was used as a postcard (courtesy: Peter Allan and Ross Ewington). The photograph may have been taken as early as 1904. The mast appears to be positioned below the signal station building, nearer the waterfront than the original shown in Figure 5. There is no sign of another time ball mast further away. There is some doubling of the image, so vertical poles are thickened. Significantly, a line of poles running downhill from the signal station appears in

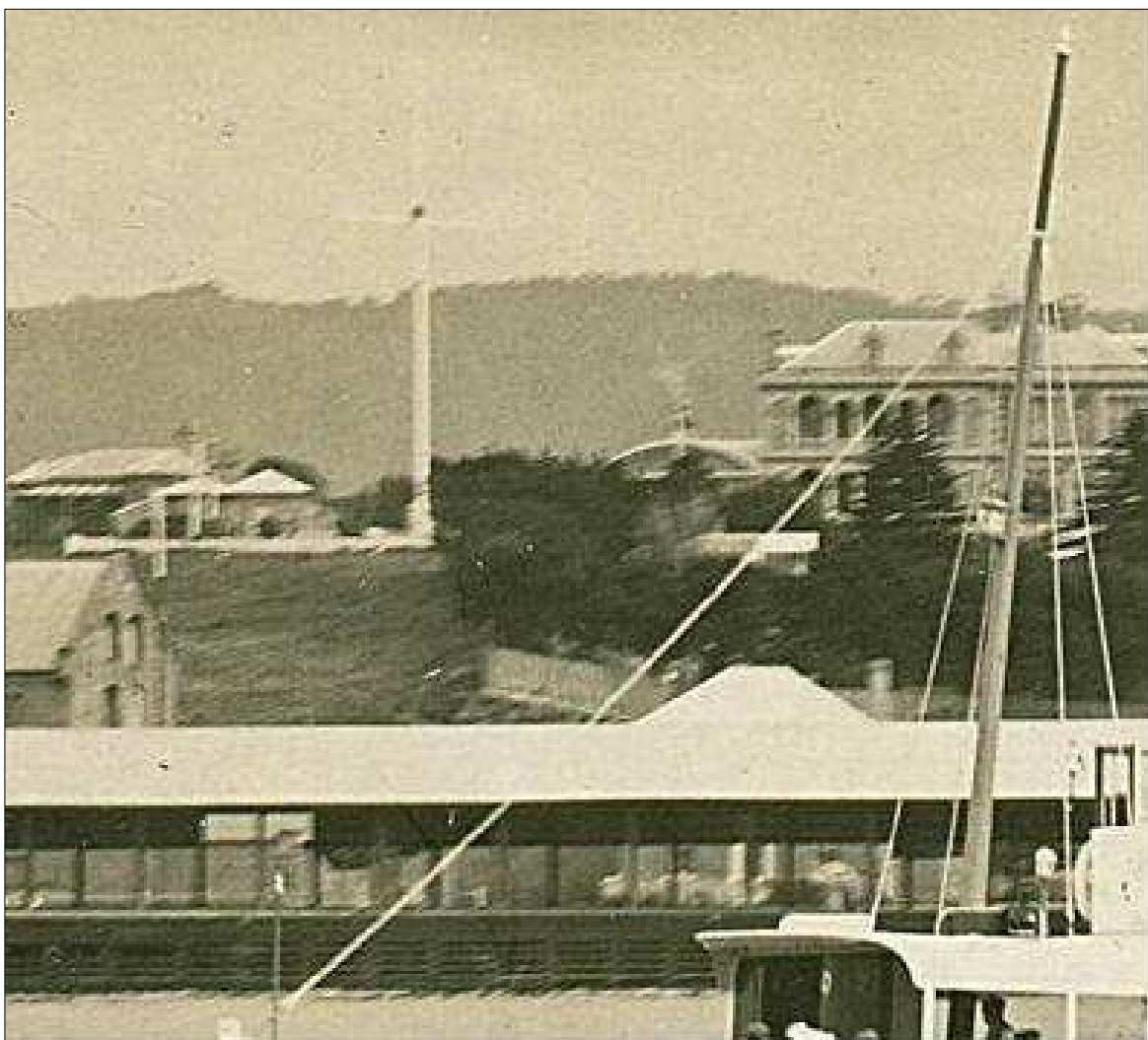


Figure 8: Detail from a postcard of the *SS Victory* by R.C. Harvey, showing what appears to be a different time ball mast and immediately to the left of it the signal station (courtesy: Peter Allan).

Figure 8, as it does in Figure 5. A puzzling feature of this photograph is that the mast appears to be nearer New Wharf than Lenna itself, but this may be an optical illusion. A similar mast can be seen near the right hand edge of a photograph of the barque *Edinburgh* in the W.L. Crowther Library, which was taken before the second long shed had been erected on New Wharf.

Figure 9 is a detail from the latest photograph found so far that shows the time ball. The complete photograph is of the Japanese training cruiser *HIJMS Asama*, which is known to have visited Hobart during 1924 (Vessels in port, 1924). In the full-size photograph the mast appears to be nearer the waterfront than in early photographs.

A single photograph has been found, which suggests that two time ball masts may have co-existed for a period, possibly when a new mast was first erected. Figure 10 shows part of that photograph (“Hobart wharves from the Customs House ...”) believed to date from about 1900, which shows Lenna in the background and the two long sheds on New Wharf. The resolution is insufficient to show much detail

near Lenna, but the signal station and two masts of equal height, perhaps 20 m apart, can be identified. Both masts appear to be carrying a ball. The mast further from the waterfront is in the position shown in Figure 7. It is conceivable that the other mast appears in Figures 8 and 9.

5.4 Final Time Ball Location

A 1950 editorial contained a statement that a new mast had been erected in 1904 and that the time ball had been located on it (Vigilant, 1950):

A few days ago, a new mast was erected at the Battery Point Signal Station. The old one, according to nearby residents, was beginning to show signs of wear. That was not surprising, because it was put up in 1904, to replace one which was erected as far back as 1865. Until 1927, it was customary for a round black ball – known as a time ball – to be hauled to the top of the mast ...

The original time ball location behind Lenna was usually described as on the flagstaff at Fort Mulgrave, rather than the flagstaff at Battery Point. The telegraph signal was, however, described as being

transmitted to the Battery Point signal station when it was first introduced (The one o'clock gun, 1886).

A contemporary report noted that a replacement flagstaff with a height of more than 34 m "... in the same locality ..." had been erected in July 1904, but there was no explicit mention of either the time ball or the long transverse spar (Shipping, 1904). Relocation by a short distance would be consistent with the report:

The erection of a new flagstaff at Battery Point for the signalling of ships was completed on Saturday [30 July 1904]. It is in the same locality as the one it has replaced. When the question of replacing the old mast was under consideration, other localities were suggested, but upon investigation the present position was found to be the most suitable from an all round point of view. The staff is of Tasmanian hardwood: the lower mast is 78 ft. high, and the topmast 36 ft.



Figure 9: Detail from a postcard, showing *HJMS Asama* and the time ball in January 1924 (courtesy: Ross Ewington and Graeme Broxam).

The final time ball location was described similarly in a statement made shortly before the time ball service ended (*The Mercury*, 12 January 1927). "Punctually at 1 o'clock each day a big black ball is dropped from the top of the signal flagstaff at Battery Point at Hobart to mark the hour."

There is sufficient ambiguity in published statements and uncertainty in the dates of available photographs to encourage further research into the location of the Hobart time ball mast. Ideally, official statements that the time ball mast was modified or relocated will be found. The most likely dates are in 1886, when the link with Hobart Observatory was established and it may have been decided to reduce the topmast height, and in 1904 when a new mast was erected.

6 DECLINE OF THE TIME SERVICE

6.1 Reduction of the Time Gun Service

Although the 1880 and 1898 Admiralty lists and *Walch's Tasmanian Almanacs* from 1876 to 1917 implied that there was a daily time gun service, the Sunday service was not offered for years at a time. A

letter (Time gun, 1899) pointed out the service deficiency, which appears to have arisen for economic reasons:

During the few years the 1 o'clock time gun has been unused on Sundays, disappointments, inconveniences, and annoyances to the public have increased. Since, for purposes of economy, the Sunday signal was discontinued, Government matters have fortunately altered.

Gratitude would be felt were any of the members for Hobart, or any member of the House of assembly, to move for the replacement on the estimates of the trifling sum necessary for continuing the SUNDAY TIME GUN.

It is clear from published correspondence that the gun was sometimes out of action altogether for extended periods and that the service was missed by many citizens (Old timer, 1911):

Some time ago it was notified in "The Mercury" that the firing of the time gun would be discontinued for a few weeks, as the gunner's time would be fully occupied attending camp. As the prescribed time has long since elapsed, can you inform your readers how it is that the gun is no longer fired? The citizens of Hobart have so long been accustomed to depend on the daily signal that many are wondering why this public convenience should be suddenly stopped, apparently without any particular reason. A good deal of irregularity in giving the signal has occurred since the Commonwealth Government took over the meteorological service, and it now seems we are to lose it entirely. Is it yet another of the benefits (?) we are expected to accept from the Federal authorities?

The time gun service was in fact continued, but with reduced Government enthusiasm for funding the service. It was only the generosity of individual citizens and businesses in Hobart that allowed the service to be continued into the 1920s.

6.2 Budget Problems

The cost of the time gun operation dominated arguments about whether it should be continued after WWI. The firing of the gun had been discontinued by May 1924, but there were frequent protests. An editorial indicated that there was considerable support for revival of the service, but that there was unlikely to be any government funding (The time gun ..., 1924). A letter and a supportive editorial were published a few days later (Sandy Bay resident, 1924; The one o'clock gun, 1924). An editorial on the following day (The time gun, 1924) gave the costs in previous years:

As bearing on the restoration of the time gun, which was for many years fired at Hobart at one o'clock daily, as advocated by many residents of the city, the cost of maintaining "the service" is of considerable interest. It was ascertained from the Town Clerk (Mr. W. A. Bain) yesterday that the expenditure for the year ended June 30, 1922, was £100 13s. 4d., and for the following year, ended June 30, 1923, £90 4s. 5d. For the six months ended December 31, 1923, the cost of the time signal was £54 5s. 3d. Mr. D. H. Harvey had for several years made a donation of £50 per annum towards the expense of firing the gun.

The necessary funding appeared to have been allocated at the end of 1924, but it may never have been used (One o'clock gun, 1924):

The Finance Committee reported to the City Council



Figure 10: Photograph titled "Hobart wharves from the Customs House ..." (courtesy: Photographs and Glass Plate Negatives Collected by E.R. Pretzman, Tasmanian Archive and Heritage Office).

last night that the arrangement made with the proprietary of "News" Ltd. for the firing of the 1 o'clock time gun expired on November 30. The proprietary, however, had intimated its willingness to continue to bear a third of the cost, and Mr. D. H. Harvey, who formerly donated £50 per annum for the purpose, was also willing to contribute a third. The committee recommended that these offers be accepted with thanks, and that the Council bear the remaining one third. The annual cost was estimated at from £140 to £150. The report was adopted.

The service was missed for years afterwards by at least some Hobart residents (Back, Tasmania, 1926):

I am surprised "The Mercury" has not had complaints – and a big number of them – about the demise of our old friend, the one o'clock gun. The population of Hobart and district, served by that old time signal, so faithfully for many years, is well over 50,000, and judging others by my own house, I should say that few families failed to set either clock or watch by the gun. Is the cost such a big item that we cannot afford it?

No direct evidence has been found that the time gun service was actually reinstated after 1923. It was said that Tattersalls provided the necessary funding until 1927, when the time service ceased altogether (Collier, 1953a, 1953b). David Hastie Harvey, who died in 1927, was part owner and manager of that company, so this is probably a reference to his donation (courtesy, Graeme Broxam). In fact, a statement that "... firing of the gun was discontinued some time ago ..." was made when it was announced that the time ball service would soon cease (*The Mercury*, 1927).

A history of Queen's Battery noted that

By Federation the battery was clearly obsolete – Tasmania's isolation provided its best protection. Its major function had become the firing of the one o'clock gun, a 70 pounder which enabled Hobartians to set their clocks until 1923 when modern clocks made it an unnecessary financial burden. (Terry, 1999).

It appears that the time gun service had ended by 1924.

6.3 The End of the Time Ball Service

The time ball service survived longer than the time gun, but its final demise was also attributable to budget limitations (*The Mercury*, 1927). The annual £5 1s 6d cost of the telegraph line to the signal station had been borne by the State Government, but budget transfer to the City and the increasing availability of radio signals led to cessation of the time ball service. It has been established from Marine Board records that the final drop occurred on 19 February 1927 (Collier, 1953b). It was reported a few days later, when it was noted that the ball had already been removed (The last drop, 1927).

7 DISCUSSION AND CONCLUDING REMARKS

Many town citizens greeted time guns with enthusiasm when they were introduced as a means of regulating clocks and watches, but others resented the intrusion. They were valued for their role in allowing mariners to check their chronometers, but the slow speed of sound propagation had to be taken into account. Naval officers and leading astronomers favoured time balls, dropped automatically to a fraction of a second accuracy using an electric telegraph

signal from a well-equipped official observatory. Hobart was the only Australian location to be listed by the Admiralty as having both a time ball and a time gun as official signals. The provision of time signals in Hobart mirrored international developments, but the budget was limited and skilled staff had to make do with inferior equipment.

The Hobart *Mercury* published reports about time signal developments worldwide, many in considerable detail. The 1861 introduction of a time gun in Edinburgh, deliberations by the Royal Society of Tasmania in 1865 and some remarkably sophisticated acoustic trials in Hobart in 1868 were early features.

The official time ball and time gun service in Hobart began in March 1875. The time ball was the primary signal, but it was operated manually until November 1910. The gun was always fired manually when the ball was seen to drop. The gun was relocated in April 1875 from near the time ball at Battery Point to Queen's Battery in the Domain, as a response to protests from residents. The gun was fired from Queen's Battery until the service ended almost half a century later.

The time ball mast was close to 'Lenna', now a hotel, at Battery Point. The ball was painted black and was made of wickerwork. Its diameter was smaller than the 1.5 m favoured at several Australian mainland locations. It can be seen in photographs taken between the 1870s and 1920s. The mast had a long transverse spar. Photographs taken before about 1880 show a very high topmast, with the ball in a rest position well above the spar. The topmast appears to have been reduced in height by 1886, with a lower rest position for the ball. A flagstaff with a height of 34 m, which may have been the time ball mast, was replaced in July 1904. Three photographs appear to show the time ball on a mast positioned nearer the waterfront than the original. Another appears to show two time ball masts separated by a short distance, as might have occurred temporarily if a new mast had been erected, but no written evidence has been found that the time ball was ever relocated.

Hobart astronomers and horologists, using private observatory and clock facilities, were the source of time until the end of August 1886. The time ball operator referred to a chronometer that was checked weekly against the regulator clock, itself calibrated using transit observations. From September 1886, an electric telegraph signal from Hobart Observatory in the Military Barracks was used. Preliminary signals led to raising of the ball and priming of the gun. Naval reports of 1894 and 1908 highlighted deficiencies in the instruments, clocks and procedures for dropping the time ball, which led to ongoing Admiralty qualifications about the accuracy of the time ball signal. They both recommended upgrading facilities in Hobart. The source of the telegraph signal was changed from Hobart Observatory to Melbourne Observatory during February 1910. The service was still unreliable and there was a new campaign to upgrade Hobart Observatory facilities during October 1910, but funds were not made available. After November 1910, the ball was released automatically by telegraph from Melbourne.

The transfer of telegraph signal costs from the State Government to the City precipitated the end of the time ball service in February 1927. By then, radio time signals were becoming widely available and the service was no longer essential. The costs of gun operation had been funded largely from private and business sources after the end of WWI. The time gun service probably ended in 1923, although it had been discontinued from time to time before that.

Further research is needed to resolve ambiguities in photographs and descriptions of time ball location during its period of service. Furthermore, was the time ball ever changed between introduction of the time service in 1875 and its final demise in 1927?

8 ACKNOWLEDGEMENTS

I am grateful to many Hobart residents for information and guidance. Ross Ewington and Peter Allan of the Tasmanian Philatelic Society; Graeme Broxam, Jonothan Davis and John Lennox from the Military Museum; Tony Marshall and his team at the Tasmanian Archive and Heritage Office; and the friendly staff at museums throughout Hobart all helped to make this paper possible. Lesley Abell inspired the investigation with her initial discoveries in Hobart archives. Martin George from the Queen Victoria Museum in Launceston, Jenny Andropoulos, Vicki Darlington, and other participants in the 2011 History of Astronomy Meeting at JCU in Townsville, helped greatly with comments, background references and interpretation of photographs, as did Kimberley Dunstan. Martin George visited Lenna and found key photographs there. Graeme Broxam investigated Marine Board files in Hobart. My colleague, Nicole Kessissoglou, at UNSW made many helpful comments during the final preparation of this paper. I also wish to thank the Science and Technology Facilities Council and the Syndics of Cambridge University Library for permission to use material in the Royal Greenwich Observatory archives. Finally, I am grateful to Ross Ewington, who was my well-informed guide during visits to places of interest in Hobart, including Mt. Nelson, the Domain and Battery Point.

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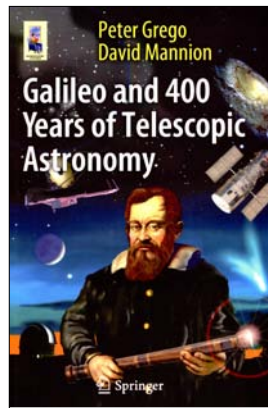
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Dr Roger Kinns carried out the research for this paper while holding a Senior Visiting Research Fellowship in the School of Mechanical and Manufacturing Engineering at the University of New South Wales in Sydney, Australia. He was the first Maudslay Research Fellow of Pembroke College, Cambridge, and is presently Honorary Treasurer of the Maudslay Society and Maudslay Scholarship Foundation. This association led to a recent fascination with the history of engineering and particularly time ball mechanisms. He joined YARD Ltd in Glasgow during 1975, to develop and apply techniques for the acoustic design of ships and submarines. He lives in Clynder, Scotland and has worked as an independent consultant since 1999, with principal research interests in underwater noise due to marine propulsion systems. He is presently the most remote member of the Tasmanian Philatelic Society.

BOOK REVIEWS

Galileo and 400 Years of Telescopic Astronomy, by Peter Grego and David Mannion (New York, Springer, 2010), pp. x + 300, many b&w and color figures, ISBN 978-1-4419-5570-8, 235 x 155 mm, US\$29.95, €32.05.

This is a book in the Astronomers' Universe series, featuring popularly-written texts that cover many topics, from the Big Bang to the future of the Universe, from terraforming to Tunguska. The book under review is one of the few of this series dealing with astronomical history. The authors are an amateur astronomer involved in planetary observations (and a writer of other books in this series), and an astronomy teacher.



At first glance, the bearded person on the cover looks as if he is a pop singer accompanying himself on a guitar. But no, the shiny thing is nothing but his perspicillum, held by Galileo, with an illuminated dome in the background, and the HST and the JWST floating in the air.

While Galileo is mentioned specifically in the title, and is the subject of an extensive chapter, the other chapters cover ancient astronomy, Newton, the Solar System, the Universe beyond the Solar System and non-optical astronomy. The book contains about 170 figures and some tables, and in addition, a few 'hands-on' experiments (like building a replica Galilean telescope, sketching lunar craters or observing the phases of Venus). The final 50 pages are filled with a listing of useful websites, pages of physical units and basic mathematics, a glossary, and a (rather incomplete) index. The narrative progresses at a quite fast pace, since the text is interrupted by tables and illustrations—some of which are quite rare pictures (although it may be questioned if the fantasy portrait of Robert Hooke should not have been replaced by sounder information). At the end of the book, listings of important books, facts and internet resources are given.

The emphasis of the book clearly lies on the Solar System—which is the first author's specialty—while stars, our Galaxy and the Universe beyond are treated on a mere 28 pages. Nevertheless, for someone who looks for a primer in astronomical history, this book is certainly an attractive option, and a quite good one since the number of flaws is remarkably small. Let me just mention two of these.

On page 212, the authors give the name of the Königsberg photographer of the corona during the 1851 solar eclipse as *Mikhail* [sic] Berkowski. Even the authors of a recent thorough study could not figure out his first name (see <http://www.museum-digital.de/thue/pdf/publicinfo.php?oges=566> for a picture and the reference.), but I just noted that the address on a card cabinet of about 1860 offered by eBay indicates that "J. Berkowski" is correct.

Among the German Moon-mappers, on page 132 the authors list Schröter, Mädler, and Löhrmann. However, not all German names have umlauts: for example, Wilhelm Lohrmann was the founder of the observatory of Dresden Technical University which now carries his name.

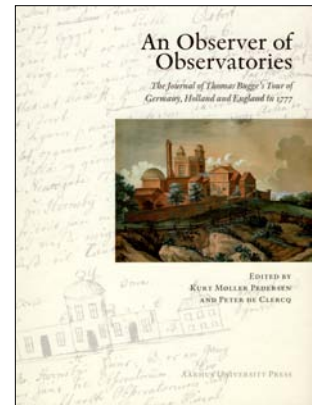
Quite a high percentage of the information gathered in the book seems to have been taken from the web, and detailed bibliographic information is lacking in the text. Yet some readers may be tempted to seek further information by surfing the web on their own.

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An Observer of Observatories: The Journal of Thomas Bugge's Tour of Germany, Holland, and England in 1777, edited by Peter De Clercq and Kurt Møller Pedersen (Aarhus, Aarhus University Press, 2010), pp. 220, many figures, ISBN-13: 978-87-7934-311-5, 275 x 215 mm, €40.95.

Several travel journals of astronomers offer glimpses of the state of astronomy in the second half of the eighteenth century. The first, and least known, is that of Bengt Ferrner (1724–1802), Professor of Astronomy at Uppsala, who describes trips to the Netherlands and England in 1758-1762, even though his account was published only (in Swedish) in 1956. Joseph-Jérôme de Lalande (1732–1807) wrote accounts on his trips to England in 1763 (available in English since 2002 on-line at <http://www.watkinsr.id.au/Lalande.pdf>), and Holland in 1774 (which remains unpublished). Jean (Johann) Bernoulli III (1744–1801), son and grandson of mathematicians of the same name and an astronomer at Berlin Observatory, wrote and published *Astronomical Letters Where an Idea is Given About the Present State of Practical Astronomy in Various European Cities* (which was originally written in French), and he continued this task with *Letters on Various Subjects Written During a Voyage Through Germany, Switzerland, Southern France and Italy in 1774 and 1775*.



Almost a quarter of a century later, the Danish astronomer, Thomas Bugge (1740–1815), Professor of Mathematics and Astronomy at the University of Copenhagen, travelled through Germany and on into post-revolutionary France, mainly to discuss the introduction of the metric system with French authorities. His 1798 report, first published in Danish, was soon translated into German and English. Bugge's *Travels in the French Republic Containing a Circumstantial View of the Present State of Learning ... in that Country* (1801) was a well-informed and objective report that was reissued by M.P. Crosland at the MIT Press in 1969.

But there exists another, earlier report by Bugge, written in 1777, i.e. almost at the same time as those by Bernoulli, giving supplementary information on activities in Germany, the Netherlands and England. At the time, Bugge was newly appointed to the Chair at the University of Copenhagen, and was keen to modernize the existing observatory on top of the famous *Round Tower*. Thus he undertook a trip through Germany to Holland and England to learn more about the state of astronomy and instrument-making in these countries. In his travel diary he noted what he saw, persons that he met and which books and instruments he bought. He also included dozens of sketches and drawings, which add greatly to the historical value of his manuscript.

This document lay undiscovered in the Royal Library in Copenhagen until 1969, when Kurt Møller Pedersen found it and prepared a provisional transcript. Forty years later, Bugge's diary is now available in an English translation, with an Introduction and notes by Pedersen and fellow-historian of science, Peter de Clercq. While Bugge's actual text covers hardly a quarter of any page, its margin is usually filled with his drawings and sketches of houses, instruments etc., and the remaining space is filled with portraits of academics and instrument makers, and with images of buildings and instruments, many of which survive in museums today. Brugge visited instrument-makers like Peter and George Dollond and Jesse Ramsden and clock-makers like John Arnold and Alexander Cumming. In Oxford, he visited Thomas Hornsby and the new Radcliffe Observatory, which was still under construction (and his sketch, showing a semispherical dome, is far from its later appearance). In Cambridge he saw the observatory at St. John's College; in Richmond the newly-established Kew Observatory; and at Greenwich Nevil Maskelyne

guided him through the Royal Observatory, where he saw marine chronometers by Thomas Mudge, and John Harrison's "... large and very composite ..." time-keepers H1 and H4.

The editors have done a magnificent task identifying individuals and instruments, and there are 249 footnotes to assist the reader in finding his/her way through the scientific world of 1777. This richly-illustrated volume will be of value to anyone who is interested in the history of science and technology in the eighteenth century.

Note 1. Although biographical material on Bugge can be found in the Danish and Swedish Wikipedia, he is not included in Thomas Hockey's 2007 *Biographical Encyclopedia of Astronomers*. He was one of the observers of the 1761 Venus transit, and his astronomical activities reached their peak in 1781-1783, after the refurbishment of Copenhagen Observatory. Later, he became Head of the Geodetic Survey in Denmark, Lecturer in Mathematics and an author of textbooks in mathematics and astronomy. A first biographical sketch, strangely not included in the bibliography of the book under review, was written by Brugge's son, Mathias, and was published in Linddenau's *Zeitschrift für Astronomie*, Volume II, pp. 245-250 (1816). There, on page 246, we find the sentence "A detailed description of this voyage [of 1777] was left behind as a manuscript." It is strange that more than 150 years had to elapse before it was discovered in the Royal Library in Copenhagen.

Note 2. The original manuscript of Bugge's diary can be inspected at <http://www.kb.dk/permalink/2006/manus/659/dan>.

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