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

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## COVER IMAGE

The present Brazilian Astrophysics Laboratory atop Pico dos Dias in southern Brazil, at an altitude of nearly 2,000 m. Inaugurated in 1981 under its original name as the Brazilian Astrophysics Observatory, it was the culmination of over half a century of astronomical development in the country. It is now home to a 1.6-m Perkin-Elmer and a 1.0-m Zeiss telescope. To learn more about the history of twentieth-century astronomy in Brazil, read the research paper by Cristina de Amorim Machado and Antonio A.P. Videira, starting on page 223.

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## EDITORIAL

It is with considerable sadness that we say goodbye to Professor Joe Tenn, who will now step down as an Associate Editor of this journal so that he can concentrate on the American Astronomical Society's 'Astronomy Genealogy Project', of which he is the founder and director.

Since joining the Editorial Board in 2008, Joe has been a constant source of support and inspiration, by discussing journal policy; suggesting referees for submitted papers; refereeing papers himself; encouraging colleagues to submit papers to the journal; editing and formatting papers; and serving as the editor of the July 2010 special issue on "The First Century of Astronomical Spectroscopy".

But personally, what I have valued more than anything else is his acumen as a proof-reader (which, in fact, began in 2007), in a bid to ensure that the issues of *JAHH* that were printed, and later that he would submit to ADS and the National Astronomical Research Institute of Thailand (NARIT), to be posted on their web sites, contained minimal 'typos' and other errors. Joe has also followed up these website postings by alerting the history of astronomy community to the research papers included in each issue of *JAHH*.

Since he became an Associate Editor in 2009 Joe has witnessed many changes as *JAHH* has evolved from a hard-copy printed journal into an e-journal (from the first issue of 2012), without subscriptions and free to all. He also had to farewell fellow-Associate Editor, Professor Hilmar Duerbeck, who died suddenly, and then welcome the replacement Associate Editor, the American-born radio astronomer and researcher of Chinese astronomical history, Professor Richard Strom (ASTRON, Netherlands) and, much later, a third Associate Editor—by coincidence also American-born—the ethno-astronomer Dr Duane Hamacher, from the University of New South Wales in Australia.

Joe also witnessed the close down of Astronomy at James Cook University (Australia) at the end of 2012, and the transfer of *JAHH* to its current home at NARIT, in Chiang Mai, following my own move from Australia to Thailand.

After Joe joined the Editorial team there were major changes in the appearance of *JAHH*, as it underwent a 'makeover' in layout and design, and increasing use was made of colour. Meanwhile, the number of pages per

issue expanded from about 90 (when it was a printed journal and airmail postage rates limited the size of each issue) to between 110 and 140 pages.

In the seven years that Joe has been an Associate Editor, *JAHH* has expanded its role as a journal that publishes papers in 'niche areas' of astronomical history, including archaeoastronomy, ethnoastronomy, the historic transits of Venus, the history of meteoritics, and the history of radio astronomy. However, we continued to publish in 'mainstream' areas of astronomy, like Mesopotamian and classical Greek, Islamic and Indian astronomy; the origin and development of astrophysics; and historically-significant telescopes and observatories and the development of astronomical instrumentation. There also have been papers on asteroidal, meteor and planetary astronomy; stellar proper motions; variable stars; time balls and time guns; and biographical accounts of notable astronomers. In 2011, Michael Crowe published his masterful "The surprising history of claims for life on the Sun" (14: 169–179), and the following year Helge Kragh followed with his equally-entertaining "Is space flat? Nineteenth-century astronomy and non-Euclidean geometry" (15: 149–158). For his part, Joe Tenn contributed "Long-publishing astronomers, or the problem of classification" (15: 47–56; 2012), amongst other papers.

Since Joe first joined the Editorial Board he also has helped us expand the geographical scope of *JAHH*, in our bid to document the world-wide development of astronomy. Consequently, over the past eight years papers have been published about aspects of astronomical history in: Australia, Austria, Brazil, Bulgaria, Canada, Chile, China, Denmark, England, Finland, France, Germany, Georgia, Greece, Hungary, India, Iran, Iraq, Ireland, Italy, Japan, Malta, Macedonia, Myanmar, New Zealand, Norway, Pakistan, Puerto Rico, Pitcairn Island, Portugal, Roumania, Russia, Serbia, Scotland, St Helena, Sweden, Ukraine, USA and Uzbekistan.

Finally, we are delighted to report that Joe has agreed to continue his association with *JAHH* as a member of the Editorial Board, so you will continue to see his name listed on the inside front cover of future issues.

Professor Wayne Orchiston  
Editor

# A MOUNTAIN OBSERVATORY AND THE BRAZILIAN ASTROPHYSICS PROJECT

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**Abstract:** The Brazilian astrophysics project is intimately linked to a scientific institution that came into existence in the 1980s: the National Astrophysics Laboratory. Responsible for enabling the development of Brazilian research in this area, its history dates back to a dream to build an observatory on a mountaintop conceived at an institution formed in the nineteenth century, the Imperial Observatory of Rio de Janeiro, later the National Observatory. It is a story of national and international scientific cooperation, especially in the second half of the twentieth century. This paper tells the story of this dream and how it was transformed into reality in the 1980s with the installation of what was then called the Brazilian Astrophysics Observatory, heralding a new era for astronomical research in Brazil.

**Keywords:** mountain observatory, Brazilian Astrophysics Project, National Observatory, Brazilian Astrophysics Observatory, Brazilian Astrophysics Laboratory.

## 1 INTRODUCTION

The National Astrophysics Laboratory (Laboratório Nacional de Astrofísica), the first of its kind in Brazil, is the current name (as of 1985) for what was originally the Brazilian Astrophysics Observatory (Observatório Astrofísico Brasileiro). It was formerly part of the National Observatory (Observatório Nacional), which in 1980 acquired a large-scale instrument (for the time), a 1.60-m Perkin-Elmer telescope, through the combined efforts of a number of individuals.

What we intend to show in this paper is that the institutionalization of astrophysics in Brazil as a field of knowledge only began as Brazilian astronomy developed. This resulted in the construction of the Brazilian Astrophysics Observatory and the installation of what is to this day the largest telescope on Brazilian soil—in other words, the creation and equipping of a scientific institution. This trajectory began with an apparent pipe dream to build an astrophysical observatory in Brazil, passed through the planning of the development of Brazilian astronomy in the 1960s, and the collaborative efforts in that and the following decade to have a large telescope installed in the country, and ultimately led to the observatory's actual establishment in 1980.

Obviously, none of this would have been possible without the people who

- 1) wanted to build an astrophysical observatory to leverage astronomical research in Brazil;
- 2) crafted concrete plans from this dream;
- 3) executed these plans until the dream became

a reality;

- 4) have maintained this reality for the last three decades; and
- 5) have worked hard to ensure this reality keeps up with transformations in Brazilian and international science.

Clearly, everyone who currently works at the headquarters of the National Astrophysics Laboratory in Itajubá (see Figure 1 for Brazilian locations mentioned in the text) and the observatories under its management is part of this story and is building the present-day history of this institution. But there are some recent retirees or people soon to retire who represent not only the institution's memory but also its present. There also are others who have passed away but who documented this journey in the most diverse of ways. They include a few generations of technicians, engineers, physicists, astronomers, and, more recently, astrophysicists, who have shaped and continue to shape the political and scientific nature of astrophysics in Brazil.

These are the protagonists of this story—key sources we have consulted through interviews, informal conversations, and documents of different kinds, ranging from letters, telegrams and other texts stored in the history of science archives at the Museum of Astronomy and Related Sciences (Museu de Astronomia e Ciências Afins) to a wide range of research papers, research journals, books, contracts, project reports, photographs and various other images, and documents, housed in the archives of the National Astrophysics Laboratory.



Figure 1: Brazilian localities mentioned in the text.

It is already clear that this is the history of an institution in transformation in a country in transformation, and that it took shape through national and international scientific cooperation—even when it was no more than a dream—and was led by people with vision and the staying power to see this dream through to reality.<sup>1</sup>

## 2 OF DREAMS AND DREAMERS

Domingos Fernandes da Costa (1882–1956; Figure 2),<sup>2</sup> or ‘Commander Costa’, as he was known at the National Observatory, being as he was an officer in the Brazilian Navy, joined the National Observatory in 1909, when it was still based on Morro do Castelo in the center of Rio de Janeiro. He continued to work there even after he retired (1954) right up to his death. He

enjoyed supervising students at the beginning of their scientific careers, and left behind many admirers.

For the purposes of this story, it is important to note that Costa was the person who devised the plans for the ‘mountain observatory’ that the National Observatory’s Director, Sodré da Gama, submitted to the Minister of Education, Gustavo Capanema (1900–1985), and President Getúlio Vargas (1882–1954) in 1936. However, the execution of these plans was thwarted by WWII. According to Léo Gama (1977: 12)—no relation to Sodré da Gama—“Domingos Costa put together the project to build a regional astrophysics observatory ...” on Serra da Bocaina. He adds that the scientific equipment was chosen by Costa after discussions with an expert

from Carl Zeiss (the German company working in the optics and optoelectronics industries), but the company withdrew from the project after the outbreak of war in 1939.

According to Luiz Muniz Barreto (1987: 201–202), Costa proposed a complete overhaul of the National Observatory during the Sodr  da Gama’s directorship, which was to include installing a ‘mountain observatory’. The site chosen for this was Serra da Bocaina, but as already explained the war frustrated Costa’s plans and delayed the whole process. He was also well aware of the need to have people trained in astrophysics to operate the future observatory, despite Barreto’s (1987: 291) later claim that: “We can learn that afterwards, because we’ll do it already as astronomers of the National Observatory.” Years later, in 1955, the National Observatory, which was then directed by L lio Gama, was enjoying a period of prosperity and the dream of building a mountain observatory had been all but forgotten. Although Costa still wanted to put it back on the agenda, he thought that first they should

... organize the lines of work the observatory was prepared for ... [and] develop the two points missing in the area of geophysics: seismology and gravimetry. (Barreto, 1987: 292).<sup>3</sup>

Costa died in 1956 without seeing his plans come to fruition, but his pupil, Barreto, and others revived them in the early 1960s. However, before we go into this ‘revival’, let us first meet Sodr  da Gama, the Director of the National Observatory at the time that ‘Commander Costa’ had his dream of a mountain observatory.

Sebasti o Sodr  da Gama (1883–1951; Figure 3) had a degree in mathematics and taught at the Polytechnic School (Escola Polit cnica) and two high schools in Rio de Janeiro. Amongst his many achievements, what interests us here is his submission in 1936 to the Federal Government of Costa’s proposal for the construction of an astrophysics observatory on Serra da Bocaina, his ‘mountain observatory’, and its subsequent approval. As we mentioned earlier, to take the project forward, Gama even ordered some instruments from Carl Zeiss, but with the outbreak of WWII the observatory ended up not being built. However, Gama did manage to get some of Costa’s objectives included in the National Observatory’s bylaws of 1940, namely, to develop astrophysics and international astronomical cooperation, and have a mountain observatory—yet to be built—as part of its facilities:

Art.1. The objective of the National Observatory ... is: a) to conduct research in astronomy, geodesy, geophysics, and astrophysics; b) to execute programs of astronomical, magnetic, seismological, and gravimetric observations in

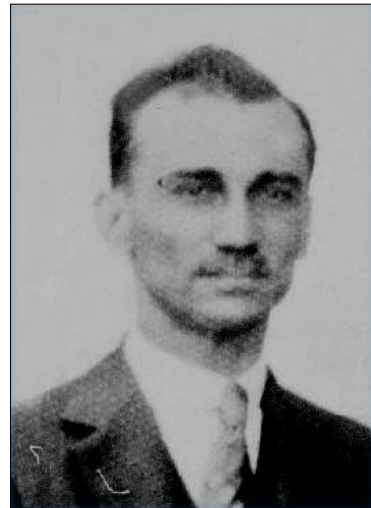


Figure 2: Domingos da Costa (courtesy: [www.on.br](http://www.on.br)).

order to contribute to the cultural development of the country and cooperate with foreign observatories for the development of science, especially in areas that may be of interest to Brazil; ... Art.3. The National Observatory shall be constituted of the following divisions: ... b) division of equatorial and related services, whose activities shall be conducted at two observatories, one of which is installed in the Federal District, and the other of which is to be installed on a mountain. (Minist rio da Educa o e Sa de, 1940: 3).

Years later, one of Costa’s former colleagues, L lio Gama, in his role as Director of the National Observatory, gave him *carte blanche* to resume the scientific cooperation project in collaboration with Muniz Barreto, which envisaged, amongst other things, the creation of an astrophysical observatory. However, in at least two letters, one written to Antonio Couceiro in 1961, and the other to Abrah o de Moraes in 1964, Gama (1961; 1964) expresses some reservations because of the formative state of Brazilian



Figure 3: Sodr  da Gama (courtesy: [www.on.br](http://www.on.br)).



Figure 4: Lélío Gama (courtesy: [www.on.br](http://www.on.br)).

astronomy at the time and level of training of the astronomers.

Lélío Gama (1892–1981; Figure 4) studied at the Polytechnic School of Rio de Janeiro, where he earned degrees in geographical engineering (1914) and civil engineering (1918). He lectured at the same institution, and also at the School of Science of the University of the Federal District (Universidade do Distrito Federal) and the University of Brazil (Universidade do Brasil). Outside academia, Gama was a key player in the founding of new scientific institutions, including the National Council for Science and Technology Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and the Institute of Pure and Applied Mathematics (Instituto de Matemática Pura e Aplicada).

Gama's career at the National Observatory began in 1917, when he was employed as an interim Calculator. In 1919 he was deployed on a scientific expedition that observed the total solar eclipse and confirmed Albert Einstein's General Theory of Relativity (Videira, 2007). Two



Figure 5: Abrahão de Moraes (courtesy: [www.on.br](http://www.on.br)).

years later he was officially employed as a Calculator, and also appointed Assistant Astronomer. He became an Astronomer of the National Observatory in 1937, where he headed the Meridian Services Division from 1946 to 1951. He was appointed Director of the Observatory in 1952, serving until 1967, during which time, together with Abrahão de Moraes, Director of the Institute of Astronomy and Geophysics at the University of São Paulo (Instituto de Astronomia e Geofísica da Universidade de São Paulo), he set up an historic partnership that effectively laid the groundwork for the Brazilian astrophysics project.

In 1967, when Gama reached retirement age, Barreto took over as Director of the National Observatory, where he continued the scientific cooperation with the Institute of Astronomy and Geophysics initiated by his predecessor and Moraes in 1957. So let us find out a little more about Moraes.

Abrahão de Moraes (1917–1970; Figure 5) earned his degree in physics in 1938 from the Faculty of Philosophy, Science and Letters of the University of São Paulo. In 1945 he earned the titles of Professor and Doctor of Science from the Polytechnic School. He lectured in rational mechanics, analytical mechanics, celestial mechanics and mathematical physics at the University of São Paulo. In 1949 he took over as Head of the Department of Physics, and in the same year was involved in founding the Association of Amateur Astronomers of São Paulo. In 1955 he was selected to run the Institute of Astronomy and Geophysics at the University, a position he held until the end of his life.

Well known for his interest in astronomy, Moraes was invited to write the chapter on "Astronomy in Brazil" for Fernando de Azevedo's book, *Science in Brazil*, first published in 1955. Considered a classic text on the history of Brazilian astronomy, the writing of this chapter offered Moraes a broad perspective on the nation's astronomy, which he believed could only prosper if an observatory was built in a suitable region and through scientific cooperation. Moraes (1955: 160) writes:

For our country to be able to cooperate effectively for the progress of astronomy, an observatory must be erected or an existing one must be transferred to a region whose climate is more propitious, far from the big cities. There is also a need to attract to our circle some very capable astronomers and send our young people interested in studying astronomy to leading European and American establishments. A similar procedure employed in other scientific domains has already yielded very commendable results.

According to Walter Maciel, one such young astrophysicist, Moraes, was the "... father of Braz-



ilian astrophysics ...”, even though he never was a research astronomer:

He was the one who had the vision to get together some promising young students and send them to France to do their doctorates. The students came back and started to plant the seeds. The seeds are here. (Maciel, 2004: 140).

Amongst his many scientific, teaching and administrative duties, Moraes was responsible for arranging the activities at the Institute of Astronomy and Geophysics during the International Geophysical Year (Videira et al., 2002); coordinating the recording of Sputnik I and Explorer I as they passed over Brazil; boosting investments in the institute’s library; and—together with Jean Delhaye (whom we introduce below)—preparing a plan to obtain instruments for astronomical work.

In “The Development of Astronomy in Brazil” Moraes (1961a) describes the state of Brazilian astronomy at the time and what it needed to develop further, including a budget for the program to install the Brazilian Astrophysics Observatory.<sup>4</sup> Besides discussing the choice of site and acquisition of equipment, the document also states that the training and retention of personnel were a priority, and that all this should be pursued in the context of national and international cooperation. Moraes also successfully applied to have Brazil readmitted to the International Astronomical Union at its 11<sup>th</sup> General Assembly, in Berkeley, USA, in August 1961.

In 1964 Moraes and Barreto formally initiated the partnership between the National Observatory and the Institute of Astronomy and Geophysics with a view to installing an astrophysical observatory (Barreto, 1987), an initiative that also counted on the assistance of a commission which included three French astronomers. Tasks were distributed as follows: the Institute was responsible for orienting and training technical staff and researchers, while the National Observatory would choose the site and acquire the instruments. Initially Barreto was in charge of selecting the site, and he took over the project after Moraes’ death and saw it through to completion, becoming one of the key people responsible for making the Brazilian Astrophysics Observatory a reality. Let us therefore investigate this important individual in more depth.

Luiz Muniz Barreto (1925–2006; Figure 6), or the ‘Man from the Moon’, as Israel Pinheiro (Governor of the State of Minas Gerais from 1966 to 1971) called him, joined the National Observatory in 1945 as an intern. He went on to serve as its Director for two separate periods, 1968–1979 and 1982–1985. He earned a degree in civil and electrical engineering in 1949 from the National School of Engineering (Escola

Nacional de Engenharia) and a degree in physics from the Faculty of Philosophy, Science and Letters of the State University of Guanabara (now the State University of Rio de Janeiro) in 1959. He earned a D.Sc. in rational mechanics and celestial mechanics in 1962, and the following year became a Professor of General Mechanics at the University of Guanabara. He worked at several universities in Brazil and other countries, including the State University of Rio de Janeiro, where he was Dean for Graduate Education and Research (1981). He was also a member of scientific societies, including the Astronomical Society of France and the International Astronomical Union. He was responsible for forming important research groups at the National Observatory, the Technological Institute

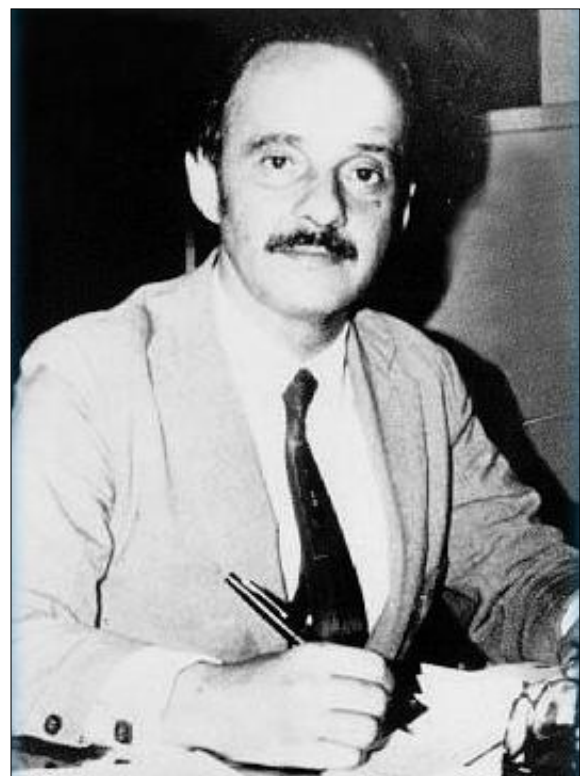


Figure 6: Luiz Muniz Barreto (courtesy: [www.on.br](http://www.on.br)).

of Aeronautics (Instituto Tecnológico de Aeronáutica) and the Federal University of Minas Gerais.

What most interests us here is this last-mentioned activity, in view of the three action lines he reported on in the “Project for the Development of Astronomy in Brazil” (Barreto, 1976), namely the training of personnel, the acquisition of instruments and the choice of site for the new astrophysical observatory. All this was part of his proposal for the reformulation of the National Observatory submitted during Lélío Gama’s administration. As well as these three areas, Barreto stressed the need to establish national and international scientific cooperation, and started taking measures to bring this about.

In his 1976 report, Barreto describes step-by-step everything that had been done up to that point for the establishment of a 'mountain observatory'. This includes his leadership in the acquisition of the telescope and in developing the associated support structure during the 1960s and 1970s, such as the training of specialized personnel and the actual installation of the Brazilian Astrophysics Observatory (now the National Astrophysics Laboratory). The new Observatory was responsible for raising astronomical research in Brazil to a new level, with the production of a great quantity of data used in countless scientific studies at an international level, and it also provided research opportunities for Masters and Doctoral students both inside and outside of the National Observatory (see Maciel, 1996; Steiner, 2009). We can say that much of this happened thanks to the 'Man from the Moon'.

### 3 MULTI-INSTITUTIONAL COOPERATION AND PREPARATIONS FOR THE BRAZILIAN ASTROPHYSICS OBSERVATORY

As we saw, Muniz Barreto spearheaded the project to develop Brazilian astronomy in the 1960s and 1970s. However, this would not have been possible without scientific cooperation, which first was established between the National Observatory and Institute of Astronomy and Geophysics (Barreto, 1976). We also have seen that Abrahão de Moraes was the mentor of the plan to develop astronomy in Brazil, which he discussed at length with French colleagues. Three of them, plus some Brazilians, set up the Rösch Commission under the auspices of the International Astronomical Union,<sup>5</sup> and in 1964 the French astronomers came to Brazil to help choose the site for the Brazilian Astrophysics Ob-

servatory. In addition, they were directly or indirectly involved in training some of the protagonists of this story, giving courses in Brazil and supervising young Brazilian doctoral candidates back in France.

The three French astronomers, Jean Delhaye (1921–2001), Jean Rösch (1915–1999) and Roger Cayrel (b. 1925), at the time were Director of the Besançon Observatory, Director of the Pic du Midi Observatory, and Head of Astrophysics at the Paris Observatory, respectively. As members of the Rösch Commission, it was they who would kick-start the work to choose an appropriate site for the long-awaited Brazilian Astrophysics Observatory. They based their discussions around the plan for the development of astronomy in Brazil, itself inspired by the Moraes' (1961a) document.

The task of selecting a site for the Observatory—assigned to the National Observatory—was, Delhaye acknowledged, a slow process, but he explains that this was because the selection criteria for a site for this type of observatory were stricter than those for an astrometric observatory. Commenting on the final choice, the installation of the telescope, and its first users, the French astronomer said:

Many sites were studied, of which Pico dos Dias (1860m) was chosen [see Figure 7], near Itajubá (Minas Gerais), where a 1.60m diameter telescope was first installed, which was inaugurated in 1981, almost 20 years after the beginning of the aforementioned collaboration. The first users of this telescope were trained throughout this lengthy period, and were the young doctors that had studied abroad and who, at this stage, had already constituted education of quality in Brazil. (Delhaye, 1994: 16).



Figure 7: Pico dos Dias, before the observatory was constructed (courtesy: National Astrophysics Laboratory Archive).

Delhaye (1994: 16) comments on what a pleasure it was to have been Abrahão de Moraes' main partner on this program, because he had the chance to take part in an exciting, rewarding enterprise. Furthermore, "The success of this undertaking must be credited to its instigator, his first students, and those who took it forward."

Jean Rösch chaired the Rösch Commission, which also undertook the first discussions about the plan for the development of astronomy in Brazil. He also was responsible for a report, *Preliminary Report on the Choice of the Site for an Astrophysics Observatory in Brazil* (Rösch, 1969), on which the first studies for this choice were based (Figure 8). This was the report that Muniz Barreto used as the basis for his Preliminary Report I, written in 1966, for use by researchers taking part in the choice of site, but which was published in 1967 under the title, *Notes for the Observations of Choice of Site* (Barreto, 1967). This was followed by a succession of publications by Barreto (1968; 1969a; 1969b; 1969c; 1969d; 1969e; 1973b; 1974; and 1975) that went into the subject from different angles, until the final report (Figure 9) was published in 1982 by Sylvio Ferraz Mello, Barreto's successor in coordinating the choice of site (from 1971 to 1975), with the support of the Institute of Aeronautics and the São Paulo Research Foundation. All of these reports make reference to the initial report by Rösch.

Ferraz Mello (1982) and Germano Quast (pers. comm., 2011), two important figures in the history of Brazilian astrophysics, recognized the positive points in the Rösch Commission report, but suggested that its errors were one of the reasons for the delay in choosing a site. For instance, Pico dos Dias, where the Observatory finally was built, was not even mentioned in the 'Rösch Report' as a possible site.

The other Frenchman on the Rösch Commission, Dr Roger Cayrel, also spent some time in Brazil in 1964 (see Cayrel, 1964) and again in 1967 when he gave an astronomy course (Pacheco, 1994: 23), and both Lício da Silva and José Antônio de Freitas Pacheco worked with him in Paris.

Lício da Silva (b. 1941; Figure 10) earned a degree in physics from the University of São Paulo in 1963, and a Doctorate in astrophysics from the Université de Paris VII – Université Denis Diderot, in 1973. He retired recently from his position as a Professor at the National Observatory, where he also served as Director from 1981 to 1982. He is a member of the Technical and Scientific Center of the National Astrophysics Laboratory and the Brazilian Astronomical Society. His expertise is primarily in stellar astrophysics, and he worked on stellar abun-

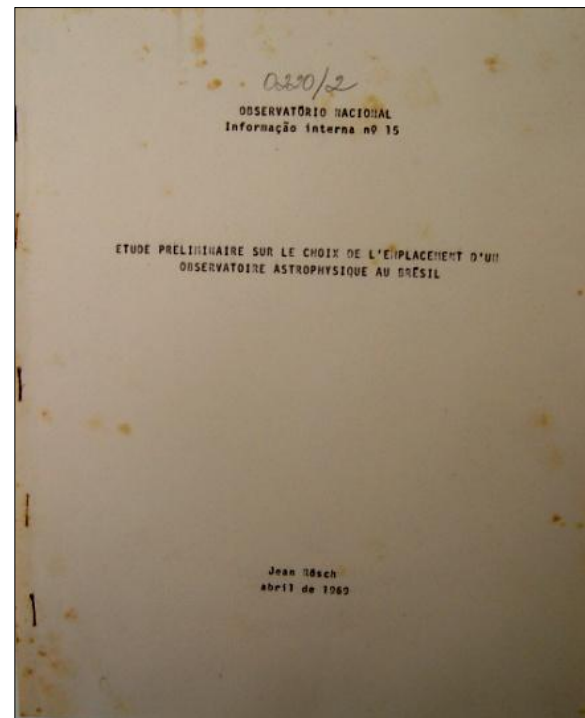


Figure 8: The Rösch Report (courtesy: MAST archive).

dances and stellar atmospheres, and also on the evolution of galaxies.

Together with Germano Quast and Carlos Alberto Torres, who will be introduced shortly, Silva is the living memory of the Brazilian Astrophysics Observatory, for he was responsible for establishing it and preparing a three-year plan for 1979 to 1981 (see Silva, 1978). With the administrative changes that took place at the National Observatory in 1979, Silva became coord-

Figure 9: The final report (after Mello, 1982).



Figure 10: Lício da Silva (courtesy: [www.on.br](http://www.on.br)).

inator of the Astrophysics Department. There were also Departments of Astronomy, Radio Astronomy, and Geophysics, headed by Ronaldo Mourão (1935–2014), Jaques Lépine (b. 1946), and Jean-Marie Flexor (b. 1939), respectively. The Director was José Antônio de Freitas Pacheco.

In Silva's three-year plan, we discover that as well as an administrative headquarters in Itajubá and an Observation Center on Pico dos Dias, there would be an Astrophysics Center in Brazópolis (which Silva considered indispensable), and a 1-m telescope would be built. Silva felt that the Astrophysics Center should be near the Observation Center because otherwise productivity would drop by 20%, considerably hampering Brazilian astronomy. In his plan he mentions Itajubá or the neighbouring area, and prom-



Figure 11: José Antônio de Freitas Pacheco (courtesy: [www.on.br](http://www.on.br)).

ises of support from local authorities. As we now know, nothing came of this since the Itajubá premises were only inaugurated in 1992, more than ten years after the installation of the Observatory, but as an administrative headquarters and not as an Astrophysics Center.

Before taking on the responsibility of coordinating astrophysics at the National Observatory in the final stages of the implementation of the Brazilian Astrophysics Observatory, Silva was already involved in the choice of instruments, even though he was in France, as we can see from this section of his testimonial about astronomy in Brazil:

I could give my 'hints' in letters to Muniz, who kindly kept me abreast of the process ... [and] warn of the flaws of the 60" telescope made by Reosc<sup>6</sup> for the ESO, which I knew well because I had used it and because I was a friend of the researcher responsible for its maintenance. (Silva, 1994: 89).

His involvement at this time is also recorded in letters written by Barreto to or about Silva between 1971 and 1973, especially on the subject of instruments, but also about practical matters such as the hiring of Silva and Quast by the National Observatory (e.g. see Barreto, 1971a; 1972a; 1973a).

In March 1982, now as Director of the National Observatory, Silva published an annual report on the institution's activities in *Boletim da SAB*, mentioning the delivery of the Brazilian Astrophysics Observatory to the Brazilian astronomical community the previous year, and how much it represented, given that thenceforth they would have access to "... internationally competitive instruments, which should give their research a new impetus ..." (Silva, 1982: 32), which is indeed what happened.

In his paper about astronomy in Brazil titled "The beginning of astrophysics at the National Observatory: a strictly personal testimonial", Silva (1994) reveals a few more of his opinions about the installation of the Observatory, more particularly about the choice of site. He recalls that he was not in Brazil at the time, but he believed that Pico de Caldas would be more advantageous as it was close to a more attractive town (Poços de Caldas), which would help the development of the Observatory and enable the creation of an Astrophysics Center near the telescope (Silva, 1994: 88–89).

Another pioneer of astrophysics in Brazil was José Antônio de Freitas Pacheco (b. 1942; Figure 11). With a degree in physics from the Faculty of Philosophy, Science and Letters of the University of São Paulo in 1965, he was one of the first generation to be captivated by Moraes and Barreto, the mentors of the Brazilian astrophysics project. Appointed a Professor of

Analytical Mechanics at Mackenzie University in 1966, Pacheco was transferred to the Institute of Aeronautics by Moraes in 1967 to teach astronomy and acquire observational experience. It was there that he met, amongst others, Germano Quast, who was concluding his studies, Muniz Barreto, who gave courses in astronomy on weekends, and Sylvio Mello, who was returning from his Doctoral studies in France.

In September 1967, Pacheco went to the Nice Observatory in France, where, in 1971, he defended his Doctoral thesis. Upon his return to Brazil he began lecturing at the Institute of Astronomy and Geophysics at the University of São Paulo, took part in structuring the institution and creating its graduate level courses, and went on to be the first Head of the Department of Astronomy and first coordinator of the Graduate Education Committee. At this same time, the Brazilian astrophysics project was led by Barreto, and a few misunderstandings came to a head. It is worth recalling that the Institute of Astronomy and Geophysics and the National Observatory had already established a clear division of labor, with the former being responsible for training personnel and the latter for choosing the site and instruments. However, the Institute acquired a 60-cm telescope for its graduate students, which, rather than being installed in Brazópolis as Pacheco wished, ended up being installed in Valinhos because of a decision made by the Dean, Miguel Reale. According to Pacheco (1994), Barreto was furious. Today, the telescope is at Pico dos Dias Observatory.<sup>7</sup>

Commenting on the meeting when the site was finally chosen, Pacheco (1994: 27) said that Barreto ‘pushed’ the decision. However, the fact is that all the institutions involved had made a commitment to choose the site in 1973 because the schedule had to be respected, not least when it came to acquiring equipment, which was already running late.<sup>8</sup> Meanwhile, it was no secret that from 1971 Barreto had complained of a lack of trust demonstrated by some of the people at the Institute of Astronomy and Geophysics (e.g. see Barreto, 1971b).

Pacheco returned to Nice in 1978, but came back to Brazil the following year to take over as Director of the National Observatory (until 1981), where he created the first image and data processing laboratory in the country and reformulated its graduate education area, setting up a course in geophysics and an extensive program designed to increase the number of National Observatory employees with doctorates. It was also at this time that the Brazilian Astrophysics Observatory was created. Pacheco returned to São Paulo in 1985 and took over as Director of the Institute of Astronomy and Geophysics four years later. He then served as Director of the

Côte d’Azur Observatory from June 1991 to May 1999. Now retired, he remains active in astronomy in Brazil and in France.

Another representative of the first generation of Brazilian astrophysicists was Sylvio Ferraz Mello (b. 1936; Figure 12), who earned a degree in physics from the University of São Paulo in 1959 and a Doctorate in mathematical sciences from the University of Paris in 1966. He studied the dynamics of the Solar System, especially asteroids, resonance, tides and chaos, plus extra-solar planets, but this was not free of difficulties. On his return to Brazil in 1967 Mello (1994: 33) recalls that

... the quarrels [with the Institute of Astronomy and Geophysics] continued ... [and] graduate physicists interested in astronomy had to work elsewhere ... I picked ITA [the Technological Institute of Aeronautics] ... [where] there was a lot of institutional support.

It was there that he met Germano Quast, Carlos Alberto Torres, Freitas Pacheco, and other young

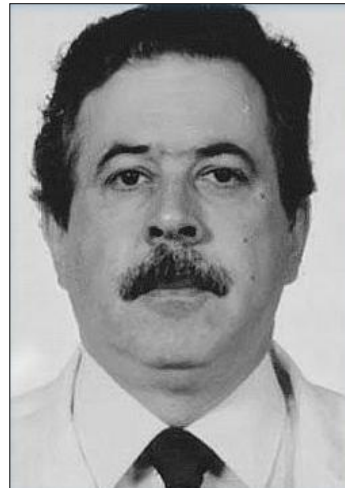


Figure 12: Sylvio Ferraz Mello (courtesy: [www.on.br](http://www.on.br)).

men involved in the Brazilian astrophysics project. Recalling this period, he also highlights the first years when the site was being chosen, the problem of the instruments, and the clearly cooperative nature of the project from the outset (ibid.).

Mello took over as coordinator of the studies necessary to choose the site for the Astrophysics Observatory in 1971. He managed to get funding from the São Paulo Research Foundation, and was the author of the final report, written in 1975, which was finally published in *Choice of a Site for the Brazilian Astrophysics Observatory* (Mello, 1982). This book records the period when Mello was responsible for these activities, which were coordinated by the Institute of Aeronautics. As well as the funding from the Institute and the São Paulo Research Foundation, another important source of support was

the 146/CT agreement between the National Observatory and FINEP (the Federal Government's Science and Technology funding agency), signed in 1972, for the construction of a Brazilian astrophysics observatory:

The acquisition, installation, testing, and entry into operation of the facility, together with the construction of buildings and support facilities, constitute a clear project which, under the responsibility of the National Observatory, has been the subject of an application to FINEP, which resulted in the 146/CT agreement. (Barreto, 1976: 4).

In his book, Mello justifies the choice of Brazópolis and highlights the field work undertaken by this new generation of researchers.

The group of young researchers that carried it through, doing the field work, deserve every consideration from future generations. And if Brazópolis isn't so wonderful, at least it was the best that could be found within the externally imposed limits of the work. (Mello, 1994: 35).

Several problems ensued because of certain political and scientific forces that were at stake in this project and which had all manner of impacts, especially when it came to institutional interests. The decisions Mello made, whether right or wrong, were largely carried through when it came to the installation of the Brazilian Astrophysics Observatory. He ends his testimonial about this phase of Brazilian astronomy, of which he was not merely a witness but also a key protagonist, by saying:

... every decision has multiple consequences

and deciding involves weighing up opposing elements. What we should never allow is cowardice in the face of a dilemma. The only decision we can be sure is wrong is one that is not taken. (Mello, 1994: 36).

Director of the National Observatory from 1999 to 2001, Mello is now Emeritus Professor at the University of São Paulo and Editor-in-Chief of the journal *Celestial Mechanics and Dynamical Astronomy*. The awards and honorary degrees that he has received include the Great Cross of the National Order of Scientific Merit (Grã-Cruz da Ordem Nacional do Mérito Científico) in 1998 and a Doctor Honoris Causa from the Paris Observatory in 2007. He also had an asteroid named after him (5201 Ferraz Mello, aka 1983 XF) by the International Astronomical Union.

Along with the National Observatory, another institution that played an active role in the Brazilian astrophysics project was the Technological Institute of Aeronautics at the University of São Paulo, which in the mid-1960s set up an Astronomy Department under Ferraz Mello. It was there that Muniz Barreto lectured on weekends, attracting a group of students to the project. Freitas Pacheco also taught there at the same time. Some important meetings were held at the Institute, such as one in 1971, where the São Paulo Research Foundation restricted the choice of sites to Caldas or Brazópolis; one in 1972, when 1973 was set as the deadline for the choosing of a site; and the meeting in 1973, when Brazópolis was finally chosen as the site for the Brazilian Astrophysics Observatory. Let



Figure 13: Germano Quast and Jair Barroso (wearing the cap) on an expedition to choose the site in the 1970s (courtesy: National Astrophysics Laboratory Archive).

us now look a little more closely at three young pioneers of Brazilian astrophysics who studied at the Technological Institute of Aeronautics in São Paulo: Germano Quast, Carlos Alberto Torres and Jair Barroso.

Germano Rodrigo Quast (Figure 13) was born in 1942 in the southern state of Santa Catarina, but he considers himself an honorary citizen of Minas Gerais, since he lived in Itajubá for over 30 years. He has an undergraduate degree in electronic engineering (1966) and a Masters in astronomy (1970) from the Technological Institute of Aeronautics, and a Doctorate in astronomy from the National Observatory (1998). He retired in 2012 as Senior Researcher at the National Astrophysics Laboratory, which he joined in 1989, specializing in young stars and instrument development. Before that he worked at the National Observatory from 1974 to 1989 and at the Technological Institute of Aeronautics from 1967 to 1974. He published extensively, supervised many Masters and Doctoral students, was on many examination panels, and presented his research at many conferences.

Quast's name crops up in all the testimonials and narratives relating to this story, not just concerning the installation of the Brazilian Astrophysics Observatory (the choice of site, training of personnel, and building of instruments), but in all subsequent stages of this story through to the present day, when new strategies are being traced out for the future of Pico dos Dias Observatory (the new name of the observatory), which is still host to the largest telescope in Brazil.<sup>9</sup>

Quast (pers. comm., 2011) has the following to say about the choice of the site:

I confess that we got into that without much experience, and we did a lot of things wrong, but in the end we made it through ... at that time we were trying to take into account only technical criteria. I don't know up to what point that's completely right, but that's the problem, if we started to also take political factors [like the interests of local mayors] into account the whole thing could get tricky.

Quast personally preferred Caldas, but felt that the final choice was technically sound.

Mello (1994: 33) supervised Quast's Masters thesis, and remembers his former student's work at the Institute of Aeronautics, where there was considerable institutional support: "In a short time, thanks to Germano Quast's competence, the first photoelectric photometer worked and the graduate program began." Quast's Masters thesis was the first from the Technological Institute of Aeronautics' graduate astronomy program.

In 1981, when the Brazilian Astrophysics Observatory was inaugurated under the auspices of the National Observatory, Quast was Head of the Astrophysics Department at the National Observatory, a position he held until 1983. In 1989 the National Observatory and the Brazilian Astrophysics Laboratory (the new name for the Observatory) parted ways, and Quast moved to the latter institution, where he was Deputy Director from 1991 to 1994. Shortly before retiring he joined the Program Committee of the Pico dos Dias Observatory and worked in the Scientific Support Department at the office in Itajubá.

Another pioneer of Brazilian astrophysics who came from the Technological Institute of Aeronautics was Carlos Alberto Pinto Coelho de Oliveira Torres (see Figure 14). Born in 1946 to a



Figure 14: Carlos A. Torres in the ramp of the OAB main building under construction (courtesy: National Astrophysics Laboratory archive).

traditional family in Belo Horizonte, he earned his Bachelors and Masters degrees in physics from the Federal University of Minas Gerais (in 1969 and 1970), a Masters in astronomy from the Technological Institute of Aeronautics (1972) and a Doctorate in astronomy from the National Observatory in 1998. Today, he is Senior Researcher at the National Astrophysics Laboratory, where he has worked since 1989. He also served as the first Director of this institution between 1989 and 1994, shortly after working as Associate Director of the Brazilian Astrophysics Observatory (1986–1989) and head of the same institution (1984–1986), when he was still at the National Observatory, where he was employed from 1973 to 1989. Before he joined the National Observatory, he worked at the Technological Institute of Aeronautics from 1971 to 1973 and at the Federal University of Minas Gerais from 1966 to 1971. His long scientific career includes numerous publications (with >1,000 citations), supervision of graduate students, participation in examination panels, and the presentation of many research papers at conferences and seminars.

Torres is another protagonist of this story because he was actively involved in the installation of the mountain observatory, and he pursued part of his career at this observatory, in much the same way as Quast did. While he was not involved in the selection of the site or the instruments for the Brazilian Astrophysics Observatory, he was one of the pioneers of Brazilian astrophysics and, together with others of his generation, came of age at this time with his sights set on taking full advantage of this observatory.

Mello (1994) supervised Torres' Masters thesis, *Luminosity Variations in Red Dwarfs*, and he has much praise for Torres and his peers from Minas Gerais. Torres conducted research in stellar astrophysics, and especially in pre-main-sequence stars, young stars, young associations, and infrared and X-ray sources, as can be seen from his doctoral thesis, *Pico dos Dias Survey of Young Stars*, which drew on research carried out at the new observatory. Silva (1994), who supervised Torres' Doctoral work, speaks of Torres in his testimonial about Brazilian astronomy, and also reveals the precarious state of Brazilian astrophysics at that time.

In 1981, when the Brazilian Astrophysics Observatory was inaugurated while still under the National Observatory, Torres was an Assistant Researcher there, a position he held until 1983. He was appointed Associate Researcher in 1986 and full Professor in 1988. In 1989, when the National Observatory and the Brazilian Astrophysics Laboratory parted company, Torres moved to the latter, where—as we have already

seen—he served as its first Director, from 1989 to 1994. He is currently interim Coordinator of Scientific Support at its headquarters in Itajubá. All this experience was recorded in a recent chapter of a book on astronomy in Brazil (see Torres and Barboza, 2014).

Another pioneer of astrophysics who studied at the Technological Institute of Aeronautics was Jair Barroso Jr. (b. 1937), who in 1959 earned his Bachelors degree and teaching certificate in physics from the State University of Guanabara (now the State University of Rio de Janeiro), and a Masters in astronomy from the Technological Institute of Aeronautics (1971), where he studied with Quast and Torres and was supervised by Mello. Even before he graduated he worked as an Assistant Astronomer at the National Observatory (in 1956). He retired in 1993 from this institution, which since 1976 was linked to the National Council of Scientific and Technological Development. Barroso devoted much of his life's work to astronomical instrumentation and observation. His main areas of interest were astronomical timekeeping using meridian observations; the installation and modification of telescopes; the choice and testing of astronomical sites; photoelectric photometry; light curve analysis; mutual phenomena of Jupiter's satellites; occultation of stars by the Moon and other Solar System objects; and the teaching and communication of astronomy.

Just like Quast, Barroso took part in all the three action lines in Moraes and Barreto's astrophysics project: the training of personnel, choice of site and instrumentation. Barroso's Master's thesis was titled *Analysis of Light Curves of Eclipsing Binaries. Applications to the Star BV590*, and Barreto (1972b) said that this broke new ground in astrophysics. From the early 1970s Barroso was actively involved in the selection of a site for the Brazilian Astrophysics Observatory, and he even had some special responsibilities, as can be seen from several personal and official letters, telegrams, and directives issued by the National Observatory.<sup>10</sup>

Other young astronomers and meteorologists also took part in this project to develop Brazilian astronomy, especially after the multi-institutional assault on the total solar eclipse of 1966. As Videira and Vieira (1997: 22) explain:

The opportunity to bring together researchers and institutions around the construction of a modern observatory emerged with the solar eclipse of Bagé (Rio Grande do Sul) in 1966. The integration of the scientific community proved fundamental for overcoming financial, political, and scientific hurdles. The realization of the longstanding ideal came 15 years later when, in 1981, the Brazilian Astrophysics Observatory, now the National Astrophysics Laboratory, was inaugurated in Brasópolis ...



According to one of the participants at this event, Oscar Toshiaki Matsuura (2014), the activity around the eclipse forged bonds and marked the beginning of the need for more frequent meetings of the Brazilian astronomical community. Another participant, Paulo Marques dos Santos (pers. comm., 1999), noted that there also were observing teams from Italy, the Netherlands and the USA) at the event, which was a milestone for Brazilian astronomy. Quast (pers. comm., 2011) also confirmed the important contacts that were made on this occasion, especially, in his own case, with Moraes and Barreto.

Paulo Marques dos Santos (b. 1927) has a degree and teaching certificate in physics, but before he earned his degree he already worked in meteorology at the Institute of Astronomy and Geophysics at the University of São Paulo, where he later lectured and earned his Masters and Doctoral degrees. Splitting his time between astronomy and meteorology, his story is very much the story of this Institute, where he continues to work every day, even though he retired in 1997.

As for his involvement in our story, it is important to note that between 1962 and 1973 Santos, along with fellow-Brazilians Moraes and Barreto, was a member of the Rösch Commission, which laid the groundwork for the installation and operation of the future Brazilian Astrophysics Observatory. Indeed, in a report on Brazilian astronomy Santos (1994) clearly links Brazil's re-admission to the International Astronomical Union to the creation of the Rösch Commission and this initial stage of the Brazilian astrophysics project.

In an interview with Videira and Matsuura, Santos (pers. comm., 1999) informally recounts his version of the choice of site for the mountain observatory, or the 'large-scale observatory' as it used to be called, and supplies some new details. Having attended the Rösche Commission's meteorology meeting, he recalls some of the criteria for the choice:

- as far south as possible,
- altitude
- not too far from a city
- isolation
- glare
- cloud cover
- temperature
- winds
- precipitation
- humidity

These should be chosen to enable the highest possible number of nights of observation and the best quality images (with specific instruments). About Brazópolis, Santos was categorical: it was too cloudy, and everyone knew there were better peaks in the region (like Maria da Fé), and it was too humid (it was full of banana trees). The US Air Force map shown in Figure 15 was used during the search for a suitable observatory site.

But this was the site that finally was chosen in 1973, after extensive studies by and discussions within the burgeoning Brazilian astronomical community. Then, seven years later, a 1.60-m Perkin-Elmer telescope was installed on the top of the mountain (see Figure 16).

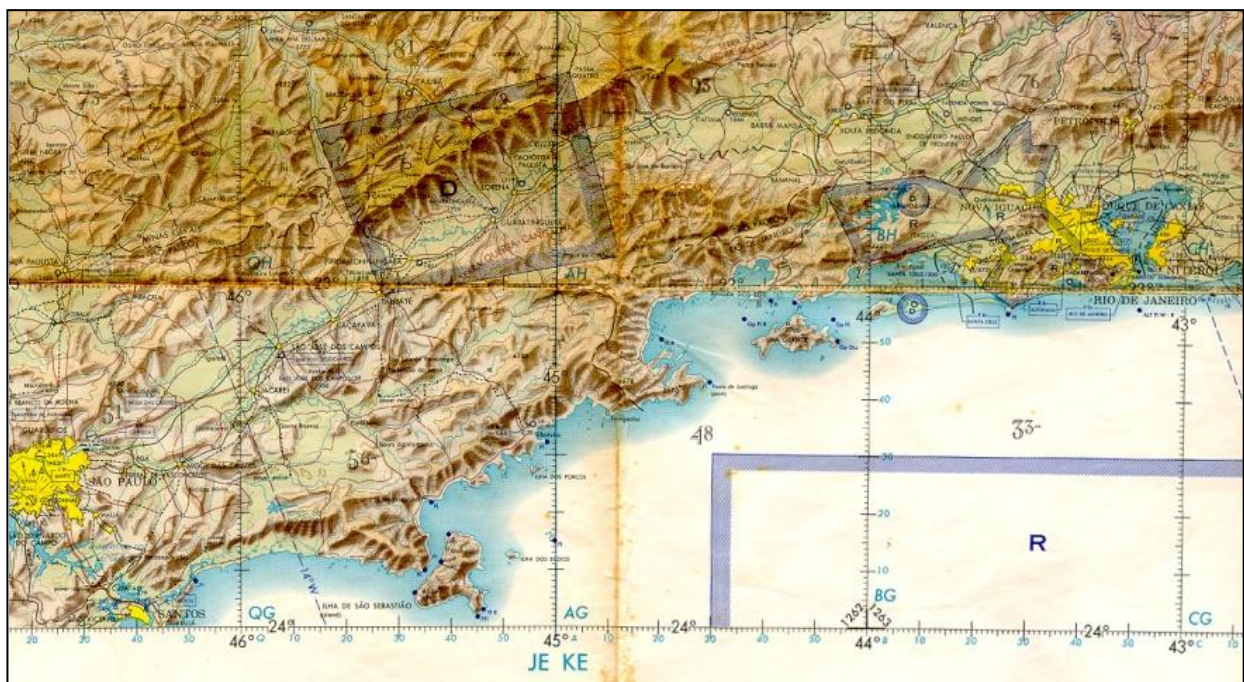


Figure 15: The US Air Force Operational Navigational Chart used during the search for a suitable observatory site (courtesy: National Astrophysics Laboratory).



Figure 16: Installation of the Perkin-Elmer telescope in 1980 (courtesy: National Astrophysics Laboratory archive).

#### 4 A NEWBORN OBSERVATORY

Despite all the difficulties, the long dreamt-of 'mountain observatory' finally became a reality, and first light was obtained on 22 April 1980 (before the official inauguration in 1981) by Ivo Busko and Francisco Jablonski according to Quast and Torres (pers. comm., 2011) when they observed a dMe flare star (see Busko et al., 1980). In the second paragraph of this paper they describe this historic moment:

In 4 nights between April and June 1980, the star was monitored photoelectrically in the U band with the 1.6m telescope of Brazilian Astrophysical [sic] Observatory. (Busko et al., 1980: 1).

The effective inauguration of the Brazilian Astrophysics Observatory took place on 19 February 1981. Two months later, according to Pacheco (1981: 7), who was then Director of the National Observatory, Brazilian astronomers could already submit proposals to the Program Committee and use the Observatory's Perkin-Elmer telescope, which was supplied with coude and Cassegrain spectrographs, a camera for direct photography, a photopolarimeter and a photometer. In 1982, a 60-cm Zeiss telescope also was installed at the Observatory. This instrument had been donated to the Federal University of Rio de Janeiro as the result of negotiations between Brazil and the German Democratic Republic in the early 1970s.

The first Program Committee responsible for allocating observing time on the telescope was chaired by Lício da Silva from the National Observatory, and other members of the Committee were Germano Quast and Jorge Ramiro de La Reza (also from the National Observatory), Miriani Pastoriza (b. 1952) from the Physics Institute at the Federal University of Rio Grande do Sul, and Eduardo Janot Pacheco (b. 1945) from the Institute of Astronomy and Geophysics at the University of São Paulo. The idea was that this committee should be representative of the community of users and that it should take into account the scientific merit of the researchers' track records and planned studies, using a system of arbitration (Director of SAB, 1982). In 1982, the Program Committee gained a new community member, and in 1984 a report was published on the use of the Perkin-Elmer telescope from 1981 to 1984. This provided some background information about the Committee, and explained its selection criteria, the frequency of its meetings and the time taken for it to decide on applications. It also included statistics on the use of the telescope and its efficiency, and listed publications that used data derived from the Observatory (Program Committee ..., 1984).

The most notable projects from these early days included: photometric observations of cataclysmic variables, mainly by Busko and Jablonski; the development of a Reticon detector in collaboration with the Harvard Center for Astrophys-



Figure 17: A view of the Brazilian Astrophysics Observatory (now the Brazilian Astrophysics Laboratory; courtesy: Dronestagr.am).

ics; the first version of the rapid photometer for the Brazilian Astrophysics Observatory by Jair Barroso; and the study and calculations for prime focus correctors for the Brazópolis telescope.

In terms of infrastructure, there was already a mechanics workshop with small machines, an optics laboratory, and an electrical/electronics laboratory, all three under the Engineering Department, which was headed by Clemens Darwin Gneiding. Three other departments made up what was known as the Brazilian Astrophysics Observatory Division of the Department of Astronomy, which was under the National Council of Scientific and Technological Development and the National Observatory: the Data Acquisition and Processing Department, the Administrative Support Department and the Operations Center (with instruments and a photographic laboratory). The Head of the Operations Center was Rodrigo Prates Campos, the only professional photographer in Brazil who specialized in astronomy. There also was a library managed by Carlos Alberto Torres. Observing time was divided between astronomers from the National Observatory and elsewhere in the country, as the Brazilian Astrophysics Observatory was deemed to be a 'national laboratory' along with other facilities under the National Council of Scientific and Technological Development. As a result, soon astronomical research papers were being produced as Brazilian astronomy entered a new era.

## 5 CONCLUDING REMARKS

Muniz Barreto's efforts to make the dream of his mentor, Domingos da Costa, come true; the

return to Brazil of young doctoral graduates like Ferraz Mello, Freitas Pacheco and Lício da Silva, who were encouraged to study abroad by Abrahão de Moraes; the attraction of these returning astronomers and local graduate students like Germano Quast and Carlos Alberto Torres to the Brazilian astrophysics project: these were just a few of the factors that combined in the second half of the 1960s to make the first steps for the creation of the Brazilian Astrophysics Observatory possible (Figure 17). During this period, these astronomers and others prepared and executed a program to choose a site, acquire and install a large telescope and train personnel for this Observatory. This was all uncharted territory and certainly involved much trial and error, but it also represented a great new impetus for astronomical research in Brazil.

Previously, astronomical research had tended to be theoretically-oriented, but with the founding of the new observatory observational astronomy quickly became the norm. Brazilian researchers could now gather data in Brazil. At the same time, graduate programs in astronomy were introduced at Brazilian universities, and astronomy was institutionalized throughout the country, especially through the annual meetings of the Brazilian Astronomical Society, and other events. All of these developments were interlinked. The Brazilian Astrophysics Observatory was actively involved not only in the institutionalization of the field, but also in training astrophysicists in instrumental and observational skills.

Throughout this period, national and international cooperation formed the backbone of the scientific and technological interchanges neces-

sary to develop astronomy. The Brazilian Astrophysics Observatory was intimately linked with this sustained drive to develop Brazilian science and science policies. The new Observatory, previously under the National Council of Scientific and Technological Development and the National Observatory, gained autonomy in the late 1980s and changed its name to the National Astrophysics Laboratory. It became the first national laboratory in the country, and was incorporated into the institutional structure of the National Council of Scientific and Technological Development as a research unit.

We might wonder about the political circumstances in Brazil throughout this period. Something that immediately stands out is that the project was conceived during a dictatorship—indeed, two dictatorships (Vargas and the military regime)—which certainly helped, since the regime facilitated decisions taken by small groups of people. But the Brazilian Astrophysics Observatory broke away from the National Observatory and was renamed after the return to democracy. At the turn of the century, under new political circumstances, it was reclassified as a research unit under the Ministry of Science and Technology (now the Ministry of Science, Technology, and Innovation). At the same time as it witnessed great national transformation, the Brazilian scientific community built this and other institutions, learnt how to manage them, developed astrophysics and carved out a place for Brazil in the international field of technology. In the midst of all this, the National Astrophysics Laboratory is reaching its prime, and is now also reaching out to the public to pay back the investment made over the years through a host of educational and science communication initiatives, such as open days at the Observatory, an on-line journal called *LNA em Dia*, and the ‘Observatory on the Rooftop’ program.

## 6 NOTES

1. A final introductory remark must be made. The revitalization of Brazilian astrophysics cannot be fully understood solely through the development of the Brazilian Astrophysics Observatory. At the same time that its construction was being debated, a small group of astronomers in the state of São Paulo built and put into operation some small radio telescopes, which were used mainly for research on radio emission from solar flares. For further information about the development of Brazilian radio astronomy see Barbuy et al. (1994) and Matsuura (2014).
2. In some references his name appears without the ‘da’. We have adopted the name as it appears in the National Observatory documents, and throughout this paper we use the same criterion for other proper names, both

Brazilian and foreign.

3. Throughout this research paper, the authors have translated the titles of books, theses, research papers and archival records, and quotations from these and other sources, into English.
4. For budget details see Moraes (1961b).
5. This collaboration between Brazil and France continued an astronomy partnership between these two countries that had existed during the late nineteenth and early twentieth centuries.
6. REOSC, a French optical company founded in 1937, was one of the three possible manufacturers being evaluated. The others were Carl Zeiss and Perkin-Elmer (Boller & Chivens Division), and it was the last of these which ended up being chosen.
7. It was installed in 1992.
8. See the papers about the National Observatory in the archives of the Museum of Astronomy and Related Sciences (Box 45, Folder about OAB).
9. For example, see the 69-page document titled “Preparation of Strategies ...”, 2011).
10. See papers about the National Observatory in the archives of the Museum of Astronomy and Related Sciences (Box 51, Letters and Cables of 1972).

## 7 ACKNOWLEDGEMENTS

We are grateful for the financial support given by the Ministry of Science, Technology and Information and the National Council of Scientific and Technological Development, as well as the kind support we received from staff at the archive of the Museum of Astronomy and Related Sciences and at the library of the National Observatory, both of which are in Rio de Janeiro. We also wish to thank Dr Germano Quast and Professor Paulo Santos for providing information used in this study. In addition, Cristina Machado is particularly grateful for the support and friendship she found among the scientists and other staff at the National Astrophysics Laboratory. Finally, the suggestions provided by the referees were important and useful, and we thank both of them.

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The following abbreviations are used:

MAST = Archive of the Museum of Astronomy and Related Sciences

ON = National Observatory

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## THE CONTRIBUTION OF GIORDANO BRUNO TO THE PRINCIPLE OF RELATIVITY

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**Abstract:** The trial and condemnation of Giordano Bruno was mainly based on arguments of a philosophical and theological nature, and therefore different from Galileo Galilei’s trial. Such elements contribute to unfairly devalue the scientific contribution of Bruno and do not properly account for his contribution to physics. This paper discusses the contribution that Bruno made to the principle of relativity. This was first discussed by Galilei in 1632 using the metaphor known today as ‘Galileo’s ship’, but we shall show that this same metaphor and some of the examples in Galilei’s book were already contained in a dialogue published by Bruno in 1584. In fact, Bruno largely anticipated the arguments of Galilei on the relativity principle, in particular to support the Copernican view. It is likely that Galilei was aware of Bruno’s work, and it is possible that the young Galilei discussed it with Bruno, since they both stayed in Venice for long periods in 1592.

**Keywords:** Galileo Galilei, Giordano Bruno, principle of relativity, heliocentric system, Nicolaus Copernicus, Doctores Parisienses, Jean Buridan, Nicole Oresme.

### 1 INTRODUCTION

The principle of relativity states that it is impossible to determine whether a system is at rest or moving at constant speed with respect to an inertial system by experiments internal to the system, i.e., there is no internal observation by which one can distinguish a system moving uniformly from one at rest. This principle played a key role in the defence of the heliocentric system, as it made the movement of the Earth compatible with everyday experience.

According to common knowledge, the principle of relativity was first enunciated by Galileo Galilei (1564–1642; Figure 1) in 1632 in his *Dialogo Sopra i Due Massimi Sistemi del Mondo* (*Dialogue Concerning the Two Chief World Systems*) (Galilei, 1953), using the metaphor known as ‘Galileo’s ship’: in a boat moving at constant speed, the mechanical phenomena can be described by the same laws holding on Earth.

Many historical aspects of the birth of the relativity principle have received little or scattered attention. In this short paper we put together some evidence showing that Giordano Bruno (1548–1600; Figure 2) largely anticipated Galilei’s arguments on the relativity principle (Bruno, 1975). In addition, we briefly discuss Galilei’s silence about Bruno, and the connection between the lives and careers of the two scientists.

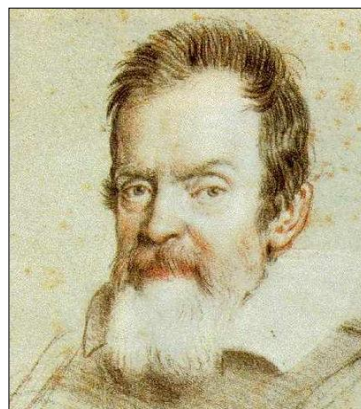


Figure 1: A portrait of Galileo Galilei by Ottavio Leoni (en.wikipedia.org).

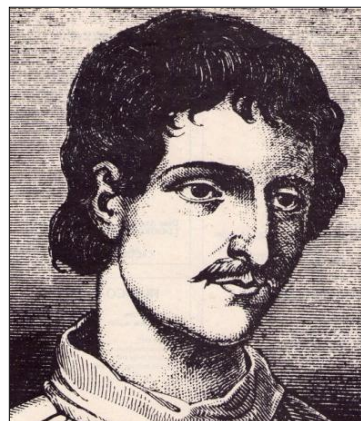


Figure 2: An eighteenth century engraving of Giordano Bruno (<http://www.thehistoryblog.com/wp-content/uploads/2012/02/bruno-giordano.jpg>).

## 2 GALILEI AND THE PRINCIPLE OF RELATIVITY

The *Dialogo Sopra i Due Massimi Sistemi del Mondo* is the source usually quoted for the enunciation of the principle of relativity by Galileo Galilei. However, its publication in 1632 was certainly not a surprise, as Galilei had expressed his views much earlier, in particular when lecturing at the University of Padova from 1592 to 1610. Some aspects of the evolution of Galilei's ideas, from the *Trattato della Sfera ...* (D'Aviso, 1656) in which the Earth is still placed at the centre of the Universe, towards the *Dialogo*, and passing through his heliocentric correspondence with Kepler from 1597 onwards (Galilei, 1890–1907), are examined, for example, by Barbour (2001), Crombie (1996), Clavelin (1968), Giannetto (2006), Martins (1986) and Wallace (1981; 1984).

In February 1616, the Roman Inquisition condemned the theory by Nicolaus Copernicus (1473–1543) as being foolish and absurd in philosophy. One month before, the inquisitor Monsignor Francesco Ingoli (1578–1649) addressed Galilei in the essay *Disputation Concerning the Location and Rest of Earth Against the System of Copernicus* (Ingoli, 1616). This letter listed both scientific and theological arguments against Copernicanism. Galilei only responded in 1624, and in his lengthy reply he introduced an early version of the 'Galileo's ship' metaphor, and discussed the experiment of dropping a stone from the top of the mast. Both arguments, as we shall see, had previously been raised by Bruno, and later were used again by Galilei, although with small differences, in the *Dialogo*.

In the *Dialogo Sopra i Due Massimi Sistemi del Mondo*, Galilei discusses the arguments then current against the idea that the Earth moves. The book is a fictional dialogue between three characters. Two of these, Salviati and Sagredo, refer to figures in the book that disappeared a few years after the publication of the book. Salviati plays the role of the defender of the Copernican theory, putting forward Galilei's point of view. The second character, Sagredo, is a Venetian aristocrat who is educated and liberal, and he is willing to accept new ideas. Thus, he acts as a moderator between Salviati and the third character, Simplicio, who fiercely supports Aristotle. The name of this last character (reminiscent of 'simple-minded' in Italian) is in itself a clear indication of Galilean dialectics, which are designed to destroy opponents. Despite being a famous commentator of Aristotle, Simplicio manifests himself with an embarrassing simplicity of spirit. Galilei uses Salviati and Simplicio as spokespersons for the two clashing world views; Sagredo represents

the discreet reader, the steward of science, the one to whom the book is addressed, and he intervenes during the discussions, asking for clarification, contributing conversational topics and acting like a science enthusiast.

On the second day, Galilei's dialogue considers Ingoli's arguments against the idea that the Earth moves. One of these is that if the Earth is spinning on its axis, then we would all be moving eastward at hundreds of miles per hour, so a ball dropped from a tower would land west of the tower that in the meantime would have moved a certain distance to the eastwards. Similarly, the argument goes that a cannonball shot eastwards would fall closer to the cannon compared to a ball shot to the west since the cannon moving east would partly catch up with the ball.

To counter such arguments Galilei proposes through the words of Salviati a *gedanken-experiment*: to examine the laws of mechanics in a ship moving at a constant speed. Salviati claims that there is no internal observation which allows them to distinguish between a smoothly-moving system and one at rest. So two systems moving without acceleration are equivalent, and non-accelerated motion is relative:

Salviati – Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed all these things carefully (though doubtless when the ship is standing still everything must happen in this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still. In jumping, you will pass on the floor the same spaces as before, nor will you make larger jumps toward the stern than toward the prow even though the ship is moving quite rapidly, despite the fact that during the time that you are in the air the floor under you will be going in a direction opposite to your jump. In throwing something to your companion, you will need no more force to get it to him whether he is in the direction of the bow or the stern, with yourself situated opposite. The droplets will fall as before into the



vessel beneath without dropping toward the stern, although while the drops are in the air the ship runs many spans. The fish in their water will swim toward the front of their bowl with no more effort than toward the back, and will go with equal ease to bait placed anywhere around the edges of the bowl. Finally the butterflies and flies will continue their flights indifferently toward every side, nor will it ever happen that they are concentrated toward the stern, as if tired out from keeping up with the course of the ship, from which they will have been separated during long intervals by keeping themselves in the air. And if smoke is made by burning some incense, it will be seen going up in the form of a little cloud, remaining still and moving no more toward one side than the other. The cause of all these correspondences of effects is the fact that the ship's motion is common to all the things contained in it, and to the air also. That is why I said you should be below decks; for if this took place above in the open air, which would not follow the course of the ship, more or less noticeable differences would be seen in some of the effects noted. (Galilei, 1953: 217).

Note that Galilei does not state that the Earth is moving, but that the motion of the Earth and the motion of the Sun cannot be distinguished (hence the name 'relativity'):

There is one motion which is most general and supreme over all, and it is that by which the Sun, Moon, and all other planets and fixed stars – in a word, the whole universe, the Earth alone excepted – appear to be moved as a unit from East to West in the space of twenty-four hours. This, in so far as first appearances are concerned, may just as logically belong to the Earth alone as to the rest of the Universe, since the same appearances would prevail as much in the one situation as in the other. (Galilei, 1953: 132).

### 3 RELATIVITY AND CELESTIAL MOTIONS BEFORE COPERNICUS

The possibility that the Earth moves had been discussed several times, in particular by the Greeks, mostly as a hypothesis to be rejected. Also an annual motion of the Earth around the Sun had been considered by Aristarchus of Samos (c. 310–c. 230 BC). Later, some medieval authors discussed the possibility of the Earth's daily rotation. The first was probably Jean Buridan (c. 1300–1361; Figure 3), one of the 'doctores parisienses'—a group of professors at the University of Paris in the fourteenth century, including notably Nicole Oresme.

Buridan's example of the ship, which was later used by Oresme, Bruno and Galilei, is contained in Book 2 of his commentary about Aristotle's *On the Heavens* (1971):

It should be known that many people have held as probable that it is not contradictory to

appearances for the Earth to be moved circularly in the aforesaid manner, and that on any given natural day it makes a complete rotation from west to east by returning again to the west – that is, if some part of the Earth were designated [as the part to observe]. Then it is necessary to posit that the stellar sphere would be at rest, and then night and day would result through such a motion of the Earth, so that motion of the Earth would be a diurnal motion. The following is an example of this: if anyone is moved in a ship and imagines that he is at rest, then, should he see another ship which is truly at rest, it will appear to him that the other ship is moved. This is so because his eye would be completely in the same relationship to the other ship regardless of whether his own ship is at rest and the other moved, or the contrary situation prevailed. And so we also posit that the sphere of the Sun is totally at rest and the Earth in carrying us would be rotated. Since, however, we imagine we are at rest, just as the man on the ship



Figure 3: Jean Buridan ([www.buscabiografias.com/biografia/verDetalle/576/Jean%20Buridan](http://www.buscabiografias.com/biografia/verDetalle/576/Jean%20Buridan)).

moving swiftly does not perceive his own motion nor that of the ship, then it is certain that the Sun would appear to us to rise and set, just as it does when it is moved and we are at rest. (Buridan, 1942: Book 2, Question 22).

Here we agree with Barbour (2001), that what Buridan is referring to is kinematic relativity. To Barbour,

... we have [here] a clear statement of the principle of relativity, certainly not the first in the history of the natural philosophy of motion but perhaps expressed with more cogency than ever before. The problem of motion is beginning to become acute. We must ask ourselves: is the relativity to which Buridan refers kinematic relativity or Galilean relativity? There is no doubt that it is in the first place kinematic; for Buridan is clearly concerned with the conditions under which motion of one particular body can be deduced by observation of other bodies. (Barbour, 2001: 203).

Later, Buridan (1942) writes:

But the last appearance which Aristotle notes is more demonstrative in the question at hand. This is that an arrow projected from a bow directly upward falls to the same spot on the Earth from which it was projected. This would not be so if the Earth were moved with such velocity. Rather, before the arrow falls, the part of the Earth from which the arrow was projected would be a league's distance away. But still supporters would respond that it happens so because the air that is moved with the Earth carries the arrow, although the arrow appears to us to be moved simply in a straight line motion because it is being carried along



Figure 4: A miniature portrait of Nicole Oresme included in his *Traité de la sphère. Aristotle, Du ciel et du monde* (n.d.) ([en.wikipedia.org](https://en.wikipedia.org)).

with us. Therefore, we do not perceive that motion by which it is carried with the air.

Buridan already expresses some concerns about the dynamics involved, but his conclusion is that

... the violent impetus of the arrow in ascending would resist the lateral motion of the air so that it would not be moved as much as the air. This is similar to the occasion when the air is moved by a high wind. For then an arrow projected upward is not moved as much laterally as the wind is moved, although it would be moved somewhat. (ibid.).

Thus, the theory of impetus is not pushed to the limit in which one would identify it with the prin-

ciple of inertia, nor with a dynamical concept of relativity.

A further step was implicitly taken a few years later by Nicole Oresme (c. 1320–1382; Figure 4). Oresme first states that no observation can disprove that the Earth is moving:

... one could not demonstrate the contrary by any experience ... I assume that local motion can be sensibly perceived only if one body appears to have a different position with respect to another. And thus, if a man is in a ship called *a* which moves very smoothly, irrespective if rapidly or slowly, and this man sees nothing except another ship called *b*, moving exactly in the same way as the boat *a* in which he is, I say that it will seem to this person that neither ship is moving. (Oresme, 1377; our English translation).

Oresme also provides an argument against Buridan's interpretation of the example of the arrow (or stone in the original by Aristotle) thrown upwards, introducing the principle of composition of movements:

... one might say that the arrow thrown upwards is moved eastward very swiftly with the air through which it passes, with all the mass of the lower part of the world mentioned above, which moves with a diurnal movement; and for this reason the arrow falls back to the place on the Earth from which it left. And this appears possible by analogy, since if a man were on a ship moving eastwards very swiftly without being aware of his movement, and he drew his hand downwards, describing a straight line along the mast of the ship, it would seem to him that his hand was moved straight down. Following this opinion, it seems to us that the same applies to the arrow moving straight down or straight up. Inside the ship moving in this way, one can have horizontal, oblique, straight up, straight down, and any kind of movement, and all look like if the ship were at rest. And if a man walks westwards in the boat slower than the boat is moving eastwards, it will seem to him that he is moving west while he is going east. (ibid.).

Also, Nicolaus Cusanus (1401–1461) stated later, without going into detail, that the motion of a ship could not be distinguished from rest on the basis of experience, but some different arguments need to be invoked—and the same applies to the Earth, the Sun, or another star (Cusanus, 1985).

All this happened before Copernicus: a discussion of how things could be, not so much about how things really are. This viewpoint would change after Copernicus.

#### 4 GIORDANO BRUNO AND THE PRINCIPLE OF RELATIVITY

In April 1583, forty years after the publication of the book by Copernicus and nine years before

the 28-year old Galilei was called to the University of Padova, Bruno went to England and lectured in Oxford, unsuccessfully looking for a teaching position there. Still, the English visit was a fruitful one, for during that time Bruno completed and published some of his most important works, the six 'Italian Dialogues', including the cosmological work *La Cena de le Ceneri* (*The Ash Wednesday Supper*, 1584) (see Bruno, 1975).

This latter book consists of five dialogues between Theophilus, a disciple who exposes Bruno's theories; Smitho, a character who was probably real but is difficult to identify, possibly one of Bruno's English friends (perhaps John Smith or the poet William Smith)—the Englishman has simple arguments, but he has good common sense and is free of prejudice; Prudencio, a pedantic character; and Frulla, also a fictional character who, as the name in Italian suggests, embodies a comic figure, provocative and somewhat tedious, with a propensity towards stupid arguments.

In the third dialogue, the four mostly comment on discussions heard at a supper attended by Theophilus in which Bruno—called in the text 'il Nolano' (the Nolan), because he was born in Nola near Naples—was arguing in particular with Dr Torquato and Dr Nundinio, representing the Oxonian faculty. Bruno starts by discussing the argument relating to the air, winds and the movement of clouds, and he largely uses the fact that the air is dragged by the Earth:

Theophilus ... If the Earth were carried in the direction called East, it would be necessary that the clouds in the air should always appear moving toward west, because of the extremely rapid and fast motion of that globe, which in the span of twenty-four hours must complete such a great revolution. To that the Nolan replied that this air through which the clouds and winds move are parts of the Earth, because he wants (as the proposition demands) to mean under the name of Earth the whole machinery and the entire animated part, which consists of dissimilar parts; so that the rivers, the rocks, the seas, the whole vaporous and turbulent air, which is enclosed within the highest mountains, should belong to the Earth as its members, just as the air does in the lungs and in other cavities of animals by which they breathe, widen their arteries, and other similar effects necessary for life are performed. The clouds, too, move through happenings in the body of the Earth and are based in its bowels as are the waters ... Perhaps this is what Plato meant when he said that we inhabit the concavities and obscure parts of the Earth, and that we have the same relation with respect to animals that live above the Earth, as do in respect to us the fish that live in thicker humidity. This means that in a way the vaporous air

is water, and that the pure air which contains the happier animals is above the Earth, where, just as this Amphitrit [ocean]<sup>1</sup> is water for us, this air of ours is water for them. This is how one may respond to the argument referred to by Nundinio; just as the sea is not on the surface, but in the bowels of the Earth, and just as the liver, this source of fluids, is within us, that turbulent air is not outside, but is as if it were in the lungs of animals. (Bruno, 1975: 117).

The Dialogue then moves to discussing the motion of projectiles, and Bruno starts by explaining the Aristotelian objection to the stone thrown upwards:

Smitho – You have satisfied me most sufficiently, and you have excellently opened many secrets of nature which lay hidden under that key. Thus, you have replied to the argument taken from winds and clouds; there remains yet the reply to the other argument which Aristotle submitted in the second book of *On the Heavens*<sup>2</sup> where he states that it would be impossible that a stone thrown high up could come down along the same perpendicular straight line, but that it would be necessary that the exceedingly fast motion of the Earth should leave it far behind toward the West. Therefore, given this projection back onto the Earth, it is necessary that with its motion there should come a change in all relations of straightness and obliquity; just as there is a difference between the motion of the ship and the motion of those things that are on the ship which if not true it would follow that when the ship moves across the sea one could never draw something along a straight line from one of its corners to the other, and that it would not be possible for one to make a jump and return with his feet to the point from where he took off. (Bruno, 1975: 121).

In Theophilus' speech, Bruno then gives the following reply (in reference to the ship shown in Figure 5):

Theophilus – With the Earth move ... all things that are on the Earth. If, therefore, from a point outside the Earth something were thrown upon the Earth, it would lose, because of the latter's motion, its straightness as would be seen on the ship AB moving along a river, if someone on point C of the riverbank were to throw a stone along a straight line, and would see the stone miss its target by the amount of the velocity of the ship's motion. But if someone were placed high on the mast of that ship, move as it may however fast, he would not miss his target at all, so that the stone or some other heavy thing thrown downward would not come along a straight line from the point E which is at the top of the mast, or cage, to the point D which is at the bottom of the mast, or at some point in the bowels and body of the ship. Thus, if from the point D to the point E someone who is inside the ship would throw a stone straight up, it would return to the bottom along the same line however far the ship mov-

ed, provided it was not subject to any pitch and roll. (Bruno, 1975: 121).

He then continues with the statement that the movement of the ship is irrelevant for the events occurring within the ship, and he explains the reasons for this:

If there are two, of which one is inside the ship that moves and the other outside it, of which both one and the other have their hands at the same point of the air, and if at the same place and time one and the other let a stone fall without giving it any push, the stone of the former would, without a moment's loss and without deviating from its path, go to the prefixed place, and that of the second would find itself carried backward. This is due to nothing else except to the fact that the stone which leaves the hand of the one supported by the ship, and consequently moves with its motion, has such an impressed virtue, which is not had by the other who is outside the ship,

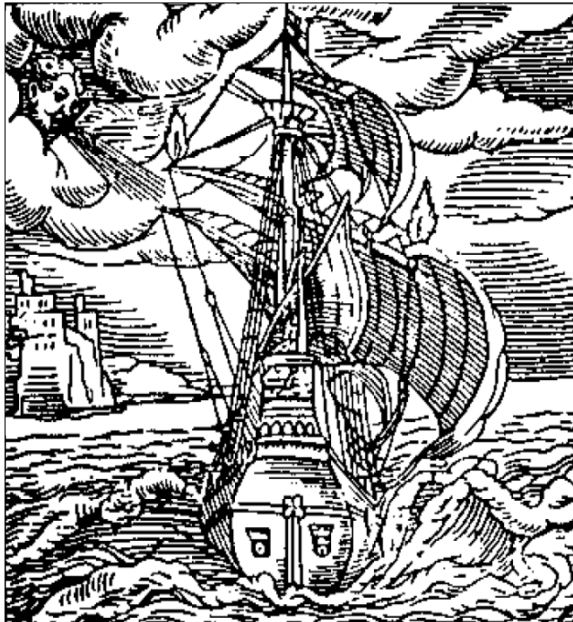


Figure 5: The ship referred to in the dialogue; note that the letters are missing (math.dartmouth.edu).

because the stones have the same gravity, the same intervening air, if they depart (if this is possible) from the same point, and arc given the same thrust.

From that difference we cannot draw any other explanation except that the things which are affixed to the ship, and belong to it in some such way, move with it: and the stone carries with itself the virtue of the mover which moves with the ship. The other does not have the said participation. From this it can evidently be seen that the ability to go straight comes not from the point of motion where one starts, nor from the point where one ends, nor from the medium through which one moves, but from the efficiency of the originally impressed virtue, on which depends the whole difference. And it seems to me that enough consideration was given to the propositions of Nundinio. (Bruno, 1975: 123).

The experiments carried out in the ship are thus not influenced by its movement because all the bodies in the ship take part in that movement, regardless of whether they are in contact with the ship or not. This is due to the 'virtue' they have, which remains during the motion, after the carrier abandons them. Bruno thus clearly expresses the concept of inertia, using the word 'virtu', in Italian meaning 'quality', which is carried by the bodies moving with the ship—and with the Earth. Bruno's arguments certainly constitute a step towards the principle of inertia.

## 5 DISCUSSION AND CONCLUDING REMARKS

We have seen that in *La Cena de le Ceneri* Giordano Bruno anticipates to a great extent the arguments of Galileo Galilei on the principle of relativity. In fact, his explanation contains all of the fundamental elements of the principle. The idea that the only movement observable by the subject is the one in which he does not take part, was presented earlier by Jean Buridan and Nicole Oresme, together with the notion of the composition of movements, which was alien to Aristotelian mechanics (see Barbour, 2001). Similar arguments were used by Nicholas Copernicus (1543). The main missing ingredient was the idea of inertia, which explains the fact that projectiles move along with the Earth. In fact, while there is a continuous line between Buridan, Oresme, Copernicus, Bruno and Galilei, the arguments of Bruno on the impossibility of detecting absolute motion by phenomena in a ship constitute a significant step towards the principle of inertia and providing a dynamical context for relativity. What is new in Bruno, and what brings him almost exactly to where Galilei stood, is a clear understanding of the concept on inertia.

The arguments and metaphors used in discussions concerning the world systems were common to different authors, and were largely derived from Aristotle, Ptolemy and their commentators. Often they were used without referencing, and sometimes they were attributed to the wrong source. For example, in his *On the Heavens*, Aristotle uses as experimental argument the one about the stone that is sent upwards. In their comment on this work, Buridan and Oresme used a modified version of this experiment in which an arrow is sent upwards in a ship—although this was possibly introduced by an earlier unidentified commentator/translator. Nevertheless, the description by Galilei of exactly the same ship experiment that Bruno used in the *Cena* makes it very likely that Galilei knew this work. The use of the dialogue form with a similar choice of characters can also be seen as a possible sign that Bruno influenced Galilei.

However, Galilei never mentions Bruno in his works, and in particular there is no reference to him in Galilei's large *corpus* of letters, even though he references the 'doctores parisienses' in his MS 46 (Galilei, c. 1584),<sup>3</sup> a 110-page long manuscript containing physical speculations based upon Aristotle's *On the Heavens*. Some authors (e.g. Clavelin, 1968) have commented on Galilei's silence about Bruno, putting forward reasons of prudence, but as pointed out by Martins (1986) this can hardly explain the absence of any mention also in his personal correspondence. Furthermore, although Galilei himself never mentions Bruno's name in his personal notes and letters, several of his correspondents do mention the Nolan. In a letter to Galilei dating to 1610, Martin Hasdale tells him that Kepler had expressed his admiration for Galilei, although he regretted that in his works the latter failed to mention Copernicus, Giordano Bruno and several Germans who had anticipated such discoveries—including Kepler himself:

This morning I had the opportunity to make friends with Kepler ... I asked what he likes about that book of yourself and he replied that since many years he exchanges letters with you, and that he is really convinced that he does not know anybody better than you in this profession ... As for this book, he says that you really showed the divinity of your genius; but he was somehow uneasy, not only for the German nation, but also for your own, since you did not mention those authors who introduced the subject and gave you the opportunity to investigate what you found now, naming among these Giordano Bruno among the Italians, and Copernicus, and himself.

Thus, we can say that Galileo Galilei was probably aware of Giordano Bruno's work on the Copernican system. When Galilei arrived in Padova in 1592 it is also possible that the two scientists met, because Bruno was a guest of the nobleman Giovanni Mocenigo in Venice at the time and Galilei shared his time between Padova and Venice. In 1591, Bruno had unsuccessfully applied for the Chair of Mathematics that was assigned to Galilei one year later. Although it might be impossible to prove that the two astronomers met, it is hard to believe, given the motivations and characters of the two men and the circumstances of their lives during those years, as well as the small size of the Italian scientific community in those days, that they failed to discuss their respective arguments concerning the defence of the Copernican system.

## 6 NOTES

1. Amphitrite was in Greek mythology the wife of Poseidon, and therefore the Goddess of the Sea.
2. See Aristotle (1971: Section 296b).
3. Although Antonio Favaro, the Curator of the

National Edition of Galilei's works, dates it to 1584, Crombie (1996) and Wallace (1981; 1984) prefer a date of around 1590.

## 7 ACKNOWLEDGEMENTS

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## ABŪ'L FAẒL, INDEPENDENT DISCOVERER OF THE GREAT COMET OF 1577

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**Abstract:** Abū'l Faẓl, the celebrated Prime Minister of the Mughal Emperor Akbar, recorded in the *Akbarnāmā* (a highly-acclaimed biographical account of the Emperor) the appearance of a comet during the 22<sup>nd</sup> year of Akbar's reign, in 985 A.H. From the recorded date, it turns out that Abū'l Faẓl was an independent discoverer of one of the most famous comets in history—the Great Comet of 1577 (C/1577 V1).

**Key words:** Mughal chronicles, Abū'l Faẓl, *Akbarnāmā*, the Great Comet of 1577

### 1 INTRODUCTION

Abū'l Faẓl (1551–1602), who came to the court of the Mughal Emperor Jalāl ud-Din Muḥammad Akbar (1542–1605; ruled 1556–1605) in CE 1575, was a very knowledgeable person, having trained in the traditional as well as the rational (natural) sciences. He wrote in Persian the official biographical account of Akbar, the *Akbarnāmā*, and presented this to his Emperor (see Figure 1). This book would become one of the most important sources of Indian history. Abū'l Faẓl's work *Ā'in-i Akbari* (*Institutes of Akbar*, 1590), the third and concluding volume of the *Akbarnāmā* (which itself comprised five books, in Persian, translated into English in three volumes by The Asiatic Society of Bengal), is a great documentation of life, both material and spiritual.

Abū'l Faẓl was not an astronomer by profession, but in his works he presents a worldview that is scientific to the core. In the *Ā'in-i Akbari* (Blochmann and Jarrett, 1907) he describes cosmogony, geography, medicine and veterinary science, as well as the boundaries of Hindustan, the Hindu philosophy and way of life, its customs and beliefs and languages. In this he draws on parallels from the Greek scientific knowledge, and we can but marvel at his insight.

Referring to the *Sūrya Siddhānta*, Abū'l Faẓl introduces to us the concept of *byomni* (*ākāsha*, or ether), the heavens and the Earth, and the measurement of time, determination of the equinoxes, precession, assignment of stellar magnitudes, terrestrial latitude and longitude, and seasons, that he describes by means of movement of the Sun through the zodiac.

Notably, Abū'l Faẓl underlines the Emperor's interest in the study of astronomy, and a "... part of the Astronomical Tables of Ulugh Beg which we have noticed in Bābar's reign was translated under the supervision of Amīr Faṭḥullāh Shī-rāzī ..." (Law, 1916). In the *Akbarnāmā*, Abū'l Faẓl, writing in 1596, mentions that

Maulāna Chānd, the astrologer ... was possessed of great acuteness and thorough dexterity in the science of the astrolabe, in the scru-

tinizing of astronomical tables, the construction of almanacs and the interpretation of the stars ... (Beveridge, 1897–1939, Volume 1: 69).

The astronomical tables *Tahsilāt-i-Akbar Shā-hī* constructed by Maulāna Chānd were used later by Sawāi Jai Singh II (*ibid.*). There was no clear demarcation between astronomy and astrology, and in imperial life—both private and administrative—astrologers and astronomers had important roles to play. They were required to be present near birth chambers at the critical moments to determine exactly the celestial circumstances and draw up astrological prognostications about the newborn (e.g. see Figure 2). A manuscript, *Tuzuk-i Jahangīrī* (*Memoirs of Jahāngīr*) in the Museum of Fine Arts, Boston, features a miniature dating to ca. 1615–1620 attributed to the artist Bishandās, which depicts the birth of Prince Salīm (Jahāngīr 1569–1627), with some astrologers in attendance who are working on the horoscope. Astronomers or astrologers are featured in a number of Mughal miniatures working with water or sand clocks, or holding ring dials (to take altitude) and celestial globes (e.g., see Sarma 1992). We also note how

Emperor Akbar paid very great attention to the education of his sons and grandsons, and appointed learned men of very high reputation to superintend their studies. (Law, 1916: 160).

Mughal memoirs mention several astronomical phenomena, namely, fireballs and comets, and the occurrence of a number of solar and lunar eclipses. Abū'l Faẓl writes about comets in detail, and cites a few past occurrences recorded elsewhere. His interest in comets apparently was prompted by the appearance of a spectacular comet in the twenty-second year of Akbar's reign (which began in 963 A.H.).<sup>1</sup> Abū'l Faẓl records his observations of this comet in the *Akbarnāmā*, made during an expedition from Rajasthan to Punjab, and he also presents his own treatise on comets—even though technically this work is meant to be a biographical account about somebody else, his Emperor, and not autobiographical. Elliot (1873: 407) has identified the reference as being to the famous comet of CE 1577.

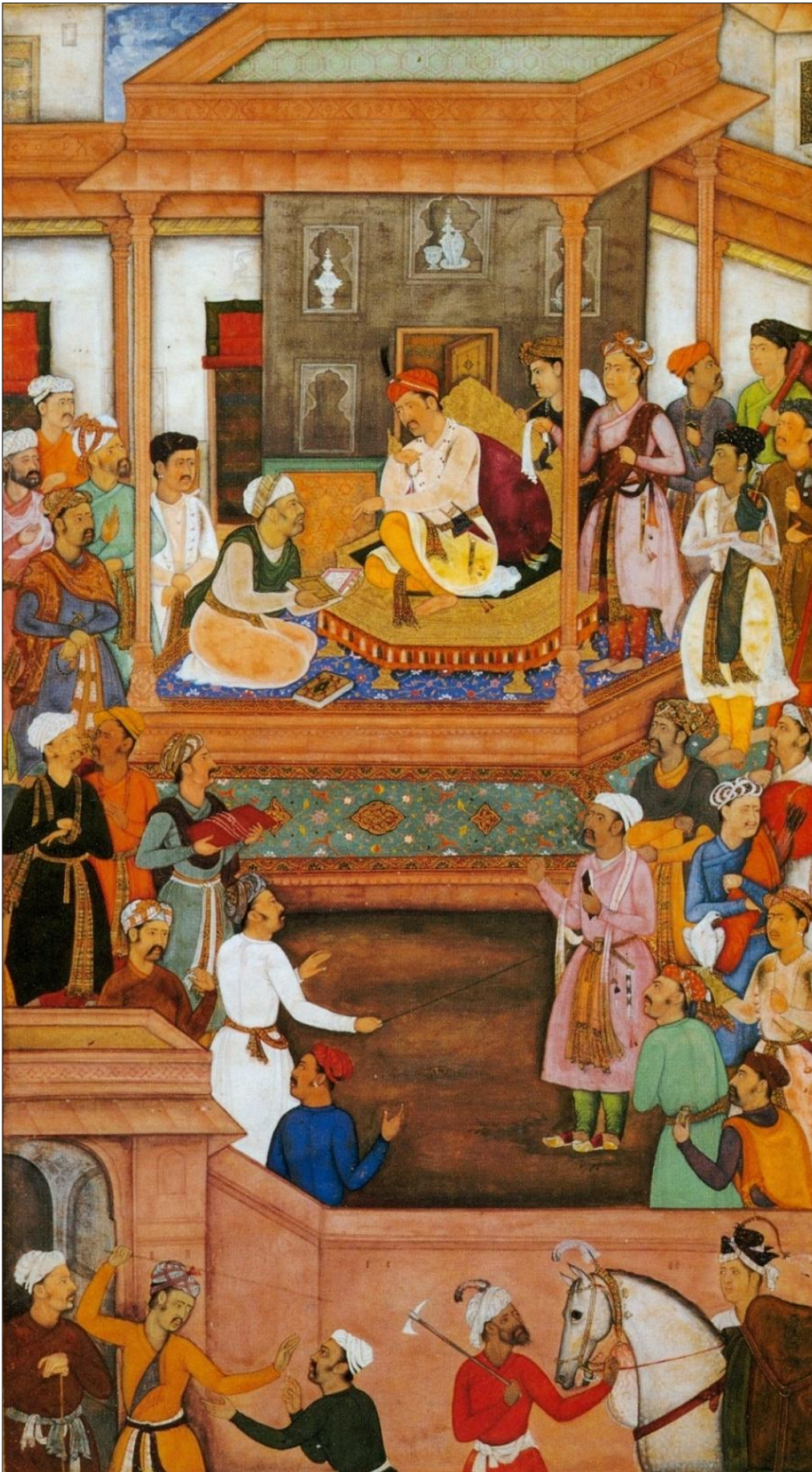


Figure 1: A miniature showing Abū'l Faḍl presenting the *Akbar-nāma* to Emperor Akbar (Wikimedia Commons).



Considering the account and the date, Abū'l Faḍl would appear to have been an independent discoverer.

## 2 COMET REFERENCES IN WRITINGS OF THE MUGHAL PERIOD

Unexpected phenomena like eclipses, comets, meteors, and earthquakes were regarded as ill omens by rulers and emperors, and the recording of such events in political histories was a well-established tradition in the Middle Eastern empires. Although these works are not astronomical texts, and they contain little scientific content, because they are from different cultures and ages they allow us to see how astronomical perceptions changed over time.

The most significant aspect of these writings is the dates, or sometimes the weekdays, that the scribes wrote down. While keeping in mind the text and the context in which the original references were made, these recorded dates and details can provide valuable information when they are tested against modern back-calculations. The tradition of recording 'politically-significant' cosmic events had a long uninterrupted history and, not surprisingly, even was found in India. Northern India was dominated by the Mughal Empire during the sixteenth and seventeenth centuries, and its chroniclers mentioned fireballs, comets, and a number of solar and lunar eclipses. The records reveal that these rulers were seriously concerned about the auspiciousness of such serendipitous apparitions, and that they sought counsel to tide over their possible consequences and even looked for remedial measures.

Of the numerous comet apparitions during the Mughal period, we find reference only to the Great Comets of 1577 and 1618 in the Mughal writings, namely, the *Akbarnāmā*, the *Tuzuk-i Jahāngīrī* and a few chronicles (Elliot, 1873; 1875; Modi, 1917). Here, I shall focus only on the records of the Great Comet of 1577, as those relating to the Great Comets of 1618 will be discussed in a later paper (Kapoor, n.d.).

The 1577 comet is mentioned by Abū'l Faḍl's fellow chroniclers as well, namely, Mullā Abd ul-Quādir Badāūnī (d. 1615), Nizām ud-Din Ahmad Bakhshi (d. 1594) and 'Ārif Qandahārī (Hadi, 1995: 86). Badāūnī was a scholar and historian who came to the Royal Court in 1574, and his work, *Muntakhab-ut Tawārīkh*, is a general history of the Muslims in India up to the fortieth year of Akbar's reign. Nizām ud-Din, also was Akbar's courtier, and he authored *Taba-qāt-i Akbarī* (*Generations of Akbar*), which covers the general history of the Muslim rule, beginning with the coming of Islam to India and through to the thirty-ninth year of Akbar's reign. Qandahārī, who in 1580 completed his historical account,

*Tārīkh-i Akbar Shāhī*, was a revenue officer during Akbar's reign and is appreciated for the chronological details that he provides (Hadi, 1995; Majumdar et al., 2007).

These references assume significance in view of the fact that observations from Europe of the very same comets made a decisive impact on the course of astronomy. To glean some of this one should read the books by Hellman (1944) and Drake and O'Malley (1960). However, among

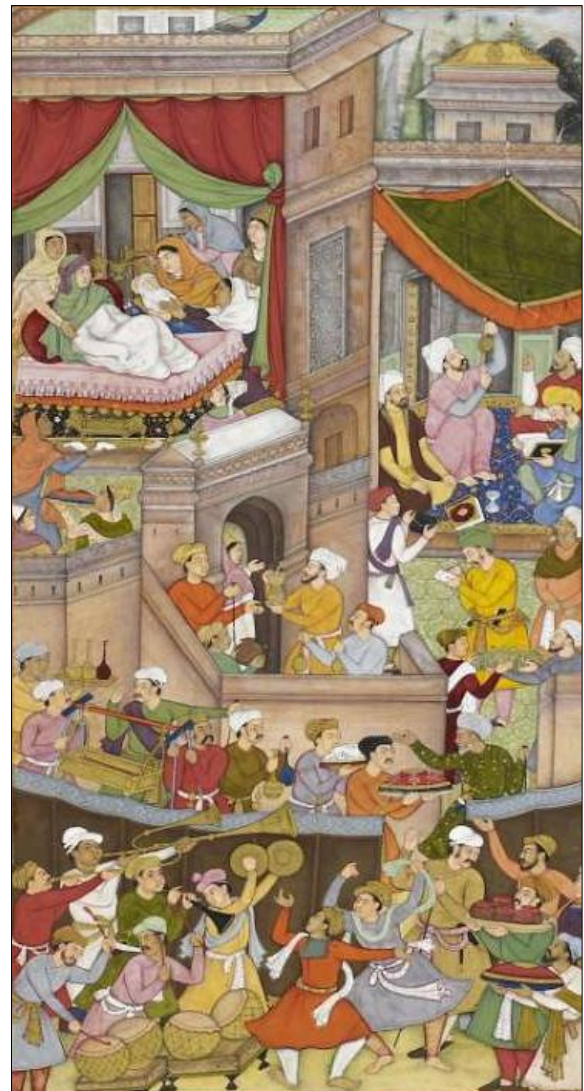


Figure 2: A painting attributed to Sūrdās Gujarātī showing the birth of Timur, with astrologers on the right drawing up the prince's horoscope. This painting is in the British Library and is thought to date to ca. 1602–1603 (after Abu l-Faḍl's *Akbarnāmā*, Or.12988, f. 34v. [http://www.bl.uk/manuscripts/Viewer.aspx?ref=or\\_12988\\_f034v](http://www.bl.uk/manuscripts/Viewer.aspx?ref=or_12988_f034v)).

the comets that shaped our worldview, the Great Comet of 1577 stands ahead of all others. When hardly any theory of comets existed, Tycho Brahe's observations of the comet were a milestone in the history of astronomy when he placed it in a supra-lunar position. This challenged the Aristotelian perception that comets were atmospheric phenomena.

Brahe's work was preceded only by the important observations made by the German geographer and astronomer Petrus Apianus (1495–1552), who viewed the Great Comet of 1531, 1P/Halley, and showed from five consecutive observations made between 13 and 17 August that its tail was always directed away from the Sun, as documented in his famous work *Cosmographia* (Kronk, 1999).

Meanwhile, the comets of 1618 belong to that era when Galileo's telescopic observations had created a paradigm shift in our perception of the heavens, and Johannes Kepler introduced a fundamental change in mathematical astronomy by redefining the planetary motion around the Sun.

### 3 COMETS IN THE ISLAMIC WORLD

According to Aristotle (384–322 BCE), comets were dry and warm exhalations in the upper atmosphere that belonged to the sub-lunary sphere (see his book *Meteorologica*, which dates to about 330 BCE). Islamic astronomers also regarded comets and meteors as atmospheric rather than heavenly phenomena, and so they were largely ignored. However, Ja'far ibn Muḥammad Abū Ma'shar (CE 787–886), the famous Persian astronomer, astrologer and philosopher, considered comets celestial. In *Albūmasar in Sadan*, the noteworthy information recorded by his student Abu Sa'id Schadsan in CE 829, he observes that

The philosophers say, and Aristotle himself, that comets are in the sky in the sphere of fire, and that nothing of them is formed in the heavens, and that heavens undergo no alteration. But they all have erred in this opinion. For I have seen with my own eyes a comet beyond Venus. And I know that the comet was above Venus because its colour was not affected. And many have told me that they have seen a comet beyond Jupiter and sometimes beyond Saturn. (Heiderzadeh, 2008: 29).

Upon checking modern cometographies, we find that the comet seen in CE July 821 or that in CE September 828 could be Abū Ma'shar's candidate, as Venus, too, was nearby.

Ibn Rushd (CE 1126–1198), the great philosopher and astronomer, cited Hippocrates as saying that the tail was vapour pulled by the Sun as the comet passed by it (Cook, 2008), but he also observed that in such a case a comet should sometimes be seen with a tail and at other times without one.

### 4 ABŪ'L FAẒL'S TREATISE ON COMETS

Abū'l FaẒl begins by introducing the subject of 'tailed stars', observing that comets belong to the realm of the physical sciences. The commen-

tary is prefaced by a description of the formation of vapour versus steam rising from the Earth by the heat caused by the rays of the Sun. As a formation from vapour rising from the Earth, a comet is thus a terrestrial meteorological phenomenon. Abū'l FaẒl also discusses meteors, but separately from comets. In light of his gathered information, Abū'l FaẒl classifies comets into four categories:

- those possessing locks of hair (*zawāt'ul zawab*)
- those with tails (*zuzanab*)
- those resembling a lance in the hands of a person
- those resembling an animal.

In the *Akbarnāmā*, Abū'l FaẒl quotes the views on comets expressed by Greek, Roman, Egyptian and Hindu scholars, and the calamities associated with them:

The wise men of India divide them into two kinds and take them to be auspicious and inauspicious (respectively). All are unanimous in saying this, that its (i.e., the comet's) influence is reflected upon the country over whose zenith it passes or whose best inhabitants see it. It moves according to the position of the constellation in which it appears, and in accordance with the strength of the motion of the region of fire ... Its influences appear in proportion to (the time of) its stay (i.e., the larger it appears, the greater its influence as to good or bad luck to the country). In the writings of the ancients *nirangs* (incantations) for (counteracting) these influences are mentioned more than can be described. (Beveridge, 1897–1939, Volume III: Chapter XL).

Abū'l FaẒl also refers to Ptolemy, who said that comets presented an omen that was especially unfavourable to kings.

We may wonder: what astronomy texts and other scholarly works served as Abū'l FaẒl's references? In the *Ā'in-i Akbari* (Jarrett, 1891) Abū'l FaẒl lists works of several well-established individuals in Greek and Islamic literature and science, such as Hipparchos, Pythagoras, Theon of Alexandria, Ma'sha'llah, Khawarazmi, al-Bīrūnī, Naṣīr al-Dīn al-Ṭūsī and Ulugh Beg, just to name a few. His last Hindu sources on comets would be Varāhamihira's *Br̥hat Samhitā* (CE 505) and Vallālsena's *Adbhutasāgara* (which was composed along the lines of the *Br̥hat Samhitā*, beginning in CE 1168). However, those areas of Hindu astronomy texts that deal with *ketus* (comets) are thoroughly unsatisfactory from an astronomical point of view.

#### 4.1 The Comets of 1264, 1402 and 1433

Drawing on ancient Persian and Pahlavi texts, Abū'l FaẒl writes at length about three notable comets seen in the past, namely the hairy comet

of 662 A.H. and the tailed ones of 803 A.H. and 837 A.H. He mentions what they looked like, their angular positions from the Sun, the number of days over which they were seen, and the countries from which they were viewed. To indicate the nature of his description, rather than paraphrasing his account we quote below a long passage (after Modi, 1917: 73–74):

Out of all (these comets) one hairy comet appeared in the year 662 Hijri. The increaser of the splendour of the world (*Farugh afzāe-i-ālam*) was in the sign of Leo and had gone about 11 fingers<sup>2</sup> down the earth (i.e., had set) in the night. The strange thing was, that it (i.e., the comet) appeared to be of the proportion of the head of a big man and emitted steam from its front. It passed (i.e., appeared) in the countries of Tibet, Turkestan, China, Kashgar, Fargana, Ma'wara'u'n-nahr (Transoxania) and Khorasan. It appeared for 85 days. In all these countries, there arose rebellions. In Transoxania and Khorasan, calamities of thunder<sup>3</sup> and lightning and such other (phenomena) appeared.

Many years and months had passed over this event, and then, in 803, a tailed comet appeared in the zenith at Rum (Constantinople). Mulana Abdallalasan and Mahiad-din Magrabi with other astrologers of that time informed Timur, that from what the wise and the experienced have said it appears that an army (coming) from the direction of the East will be victorious in that country, and a general from that country will assist (him). Timur (lit. that illuminator of the face of fortune), who was always expecting an invasion of the country, but whose companions of poor intelligence did not acquiesce, attended to that (prediction) and convinced the great and the small (of his court) of the truth (lit. gem) of his resolution and of the insight of the star-seers.

In the year 837 on the occasion of a new moon in the first part of Libra, a tailed comet appeared (lit. gave brilliancy to the day) near the 17th lunar mansion in the north. It rose and set with it. After the lapse of several days, its special motion appeared. From that 17th lunar mansion in the north (a form like that of) a lance-holder separated (lit. assumed the face of separation), and in 8 months, took the path of the camel. A great pestilence, spreading misery (round about), appeared in Herat and its dependencies. Every day more than a thousand persons died. Mirza Ibrahim, the governor of Fars and Mirza Bysangar Arghun, the King of Badakshan, and Shaikh Zai-ud-din Khafi died in this calamity. A fierce quarrel, which took place between Mirza Shah-rokh and Sikandar Kara Yusaf, was also the consequence of this (comet).

The learned in the mysteries of the Heavens are convinced of this, that, if it appears within the boundaries of a country, its king or its vice-regent dies. If it is declined towards the boundary, the property, i.e., the country of the governor passes away from his hands, and

plague and diseases and afflictions add to the sickness of the country. Sudden deaths occur among the common people ...

The three Great Comets of 662 A.H., 803 A.H. and 837 A.H. are identifiable and are now designated as C/1264 N1 (perihelion on 20.29 July), C/1402 D1 (21 March), and C/1433 R1 (8.27 November). There are no records of any of these comets from India. About the first Great Comet, Abū'l Faḥl says that it was sighted while the Sun, then in Leo, had set. About the Great Comet of CE 1402, he has no astronomical information to share, while the Great Comet of CE 1433 in Abū'l Faḥl's account also figures in two Muslim texts of CE 1442 and 1524 from Egypt, where it is mentioned as a shining star with locks of hair having a 9° long train stretching eastwards (Cook, 1999: 150, Kronk, 1999: 268). It was discovered by the Chinese, in *Teen Tsang* ( $\theta$ ,  $\iota$ , and  $\kappa$  Boötis) on 15 September, high in the evening sky and with a 10° tail (Williams, 1871: 76). It also was observed from Korea, Japan and Europe. By the second week of October the comet was conspicuous as it headed southeast and passed close to the Earth.

The comet of CE 1433 interests us in view of the fact that part of Abū'l Faḥl's account of it is intriguing. This is about the phrase that the new Moon was in the first part of Libra. This also fixes the position of the Sun. The corresponding date should be 14 September 1433 (Julian Calendar), but mention of the comet setting with the 17<sup>th</sup> lunar mansion (*al ikliil*) in the north does not agree with this date. For the lunar mansion and the comet to rise and set together, their positions need to be in agreement. Orbital computations reveal that this would only have happened towards the last days of the recorded sighting of the comet, namely, around 4 November.

What did Abū'l Faḥl mean when he stated

After the lapse of several days, its special motion appeared. From that 17th lunar mansion in the north (a form like that of) a lance-holder separated (lit. assumed the face of separation)?

Either, one saw a curved dust tail developing and separating from the straight plasma tail, or the comet's nucleus split as it approached the Sun. Abū'l Faḥl's sources need to be revisited to clarify this important observation. The Muslim texts cited by Kronk (1999: 268), both from Egypt, speak of the sighting of a comet in September-October with locks of hair and a tail 9° long that pointed towards the east, but there is no mention of observations made in November. Furthermore, there is no reference to the separation mentioned by Abū'l Faḥl. Biela's Comet (3D/Biela), is the first comet that was

observed to have split when at the 1846 apparition two comets arrived together. They had a perihelion of  $q = 0.8606$  AU, greater than that of the Great Comet of 1433.

To further confuse the issue, the account of this comet published in Beveridge's translation is different, as it mentions the neither 17<sup>th</sup> *man-āzil* nor the new Moon:

In the year 837 (1433) a tailed comet appeared in the first degrees of the Sign of Libra near the Northern Crown. It used to rise and set there. When some days had elapsed a singular movement of it took place. It became spear-bearing (*nezadār*) and went off to a distance from the Northern Crown, and in eight months it disappeared. A great pestilence occurred in Herat and its neighbourhood. (Beveridge, 1897–1939, Volume III, Chapter XL).

The first statement in this translation cannot be correct, as the 'Northern Crown' is the popular name for the constellation Corona Borealis.

## 5 THE GREAT COMET OF 1577

The year 1577 witnessed two, probably three comets, namely: the 1577 comet, comet 1577 II (X/1577 U1) and the Great Comet 1577 I (C/1577 V1). The first of these comets is mentioned only in Korean records that speak of a 'broom star' sighted during the period 15 July–13 August. Nothing more is known about it. Com-

et 1577 II is a doubtful entity (Kronk, 1999).

The third of the 1577 comets is the Great Comet that stirred viewers like none before it. One can make this out from the numerous writings on the sightings of this comet in Europe, which are listed by Hellman (1944). On 8 November the Japanese recorded its curved white tail stretching  $50^\circ$ . The glorious form of the comet showed up most impressively in the famous engraving by Jiri Daschitzsky that depicted its passage over Prague on 12 November 1577 (geocentric distance  $\Delta = 0.6327$  AU). This is reproduced here as Figure 3.

The Great Comet of 1577 is truly an historical one because of observations of it by the Danish astronomer Tycho Brahe (1546–1601), who saw it first on 13 November with a tail that was  $2.5^\circ$  wide and  $22^\circ$  long, settling the important question of the distance to comets (Hind, 1852). Aristotelian cosmology regarded comets as exhalations from the Earth that were ignited in the upper layers of the atmosphere. Observing from his observatory at Uraniborg on the island of Hven near Copenhagen, Brahe determined the comet's celestial position with respect to certain reference stars using large quadrants that had a precision of four arc minutes, and compared these positions with those obtained at around the same time by another observer, Hagecius, who was 600 km away in Prague. Brahe show-



Figure 3: The woodcut by Jiri Daschitzsky showing the Great Comet of 1577 (Wikimedia Commons).

ed that the comet had an inappreciable horizontal parallax, of <15 arc minutes. This indicated that the comet's distance was in excess of 230 Earth radii ( $R_{\oplus}$ ), which is approximately four times the distance to the Moon (LD). According to Brahe, the distance to the Moon was  $52 R_{\oplus}$ ; Ptolemy's value for the maximum distance to the Moon, as given in the *Almagest*, was  $64 R_{\oplus}$ ; the modern value is  $63.821 R_{\oplus}$ . On 13 November 1577 the Moon actually lay at  $60.4 R_{\oplus}$ , and the comet at 250 LD. Upon determining the parallax Brahe was able to argue that (1) comets lay beyond the atmosphere of the Earth, and (2) they followed circular paths between the orbits of the Moon and Venus. He professed a geocentric Universe, where the Moon and the Sun orbited the Earth, and Mercury and Venus orbited the Sun. This view was contrary to the established worldview. In 1578 he wrote a treatise in German on comets, including the one of 1577, and his views became known more widely when his book, *De Mundi*, was published in 1588; this also included the Tychonic Universe (see Yeomans, 1991). Tycho Brahe did not accept Copernicus' concept of the Universe, but his assistant, the great German mathematician and astronomer Johannes Kepler (1571–1630), did. Kepler saw the Great Comet of 1577 from a hilltop where his mother had taken him when he was just six years of age (Hudon, 2009). In 1600 he joined Tycho Brahe in Prague at the latter's invitation, and eventually inherited a large body of valuable observational data that Brahe had collected over the years.

According to A.G. Pingré, the Great Comet of 1577 was first sighted in Peru on 1 November at dusk as a very bright object that "... shone through clouds like the Moon ( $-7$  mag)." (Vsekhsvyatskii, 1964: 106). For an evening observation, the UT of the observation based on the calculated orbit is 2.0 November (Kronk, 1999: 317). By then the comet had already passed perihelion (at  $q = 0.1775$  AU), which occurred on 27.448 October UT, when it was even inside Mercury's orbit. With  $i = 104^{\circ}.883$ , its motion was retrograde, and its orbit was near vertical with respect to the plane of the ecliptic. On 8 November, the comet was described in Japanese texts as being as bright as the Moon and with a tail  $\sim 50^{\circ}$  long. Chaim Vital, who observed the comet from Safed in Palestine in the evening, when it was in the southwestern sky, described it as a large star with a long tail that pointed upwards. Part of the tail pointed eastwards too. It remained visible for the next three hours, and then was observed for fifty nights. According to Silverman (2008: 123), the Jewish date of Vital's observation was the first of Kislev in the Jewish year 5338, which corresponds to 11 November in the Julian Calendar. Since the Jewish day begins at sundown and the observation was

made in the evening, he suggests that the date of first observation was 10 November. On 28 November, Cornelius Gemma in Belgium noticed that the comet had two tails. The comet passed closest to the Earth on 10 November (0.6271 AU), and it was last seen on 26.8 January 1578 (Kronk, 1999). Until then, it continued to trail the Sun (Full Moon on 26 October, 25 November and 25 December 1577, etc.). Comet C/1577 V1 is included in Yeomans' list (2007) of Great Comets, and according to him it reached a maximum magnitude of  $-3$  on 8 November.

## 6 ABŪ'L FAẒL ON THE COMET OF 1577

In the *Akbarnāmā*, in the part relating to the expedition of the Emperor from Rajasthan to the Punjab, Abū'l FaẒl records the appearance of a comet in the twenty-second year of Akbar's reign (i.e. 985 AH):

In the matter of the appearance of a tailed comet which appeared after sunset (lit. after the time of the sitting of the great luminary which bestows favours upon the world on the chair of the crust of the earth).

A thousand thanks to God, that, owing to the benedictions of the holy soul of the King (Akbar), (bad) influences and misfortunes have disappeared from his dominions. If, in case, such a terrible sign (i.e., a comet) appears, a great calamity does not overtake this country. In spite of such Divine protection, that intelligent person of the assembly of information (i.e., the intelligent and well informed King Akbar), ordered alms to be distributed on a large scale according to the customs of the Mahomedans and Brahmans, and people of all places became cheerful. The most beautiful thing of this great liberality (i.e., the result of this alms giving) was this ...

On the day Arad (Arshisang), the 25th of the Ilahi month Aban, at the time when the sun made his conspicuous appearance in the sign Scorpio, this heavenly sign (i.e. the tailed comet) kindled its brilliant face in the sign of Sagittarius, faced towards the west (and) inclined towards the north. It had a long tail. It had reached such a limit, that in many towns they saw it for five months ... (Modi, 1917: 70, 74).

During the Emperor's journey from Ajmer to the Punjab, he camped at Mahrot (now Marot, in Nagaur district) on the 9<sup>th</sup> of Ābān, at Amber (now Amer, part of the present-day Jaipur) on the 27<sup>th</sup> of Ābān, and so on, passing subsequently through Kot Putli, Narnaul, Delhi and other centres. Thus, the comet was first noticed before the Royal entourage reached Amber. Abū'l FaẒl does not mention if Akbar also had observed it, although it is recorded that his attention was drawn to it. Around this time of the year the rainy season is normally over, so one can presume that the sky would have been

clear. As the Sun set, and with only a few days until New Moon, the Great Comet would have been a magnificent spectacle in the evening sky, where Mercury and Saturn shone at  $\sim 14^\circ$  and  $\sim 34^\circ$  above the horizon respectively. At this time, Venus was a morning object.

In 1582 Emperor Akbar proclaimed a new religion, *Dīn-i Ilāhī* (divine faith), which was based on the solar year, and he also introduced a new era, the *Tārīkh Ilāhī*. The *Ilāhī* calendar was Persian, or the Jalāli solar calendar, and it had Zoroastrian names for days and months that commenced at his accession, on Friday, Rabi'ath-Thani 2, 963 AH (that is, CE 14 February 1556). Abū'l Fazl records the comet's appearance as on 25 Ābān, 22 *Ilāhī*, i.e., in the twenty-second year of the reign of the Emperor. Beveridge (1897–1939, Volume III: 310–323) gives 5 November 1577 for Abū'l Fazl's date, whereas Mousavi (2000: 113) puts it at 7 November 1577 and Modi (1917: 83) at 10 November 1577. Modi (*ibid.*) notes that since Brahe's first observation was on 13 November, "... the time is well nigh the same." Let us determine the precise date.

'Ārif Qandahārī records the comet's appearance on the evening of Thursday 25 Sha'aban, 985 A.H. The corresponding (Julian) date given by Mousavi (2000: 111) is 7 November 1577, and from <http://calendarhome.com/> we get Thursday 7 November 1577 at 00 UT. However, in Qandahārī's description, the phrase 'night of Thursday' means the night whose following morning is a Thursday. In that case, his observation was made on the evening of Wednesday. The likely UT of the observation is 6.5 November 1577 if he observed just after sunset.

Qandahārī's date corresponds to the Persian date 26 Ābān, 956 Panjshanbeh. Abū'l Fazl's recorded date is 25 Ābān. The day of his observation would therefore be Tuesday and the UT of Abū'l Fazl's observation is CE 5.5 November 1577.

The comet in the Mughal chronicles can be identified with only one object, namely the famous Great Comet of 1577, now designated C/1577 V1. It moved towards the northeast and, as Abū'l Fazl notes, it was seen for many months and observed from several locations. For a few crucial dates, we computed the apparent position and altitude of the comet in the sky, and also that of the Sun, as viewed from Lima (Peru) and Amber ( $26^\circ 58' N$ ,  $75^\circ 51' E$ ) respectively. The positions were with respect to the Earth's true-equator and the meridian containing the Earth's true equinox of date. It turns out that the comet was leading the Sun until 1 November, and it then began to trail the Sun. It was still nearing the Earth, passing its closest, 0.6270 AU, on 10 November at 04:41 UT. Be-

ing a low declination object through the period, it was easier to spot from locations far south of Europe. For instance, at Uraniborg ( $55^\circ 54' N$ ,  $12^\circ 42' E$ ), where the Sun set on 5 November at about 15:00 UT, the comet lay at Alt.  $-02^\circ 22'$  and Az.  $41^\circ 55' S-W$ . By comparison, at Amber, where the Sun set on 5 November at 12:05 UT, the comet lay at Alt.  $5^\circ 35'$  and Az.  $56^\circ 04' S-W$ . Its ephemeris for that day places it near the present-day border of the constellations of Scorpius and Ophiuchus. The comet must have been really bright for its altitude was only  $\sim 4^\circ$  at sunset when it was first discovered on 1 November from Peru. So, even though the altitude was low on dates around its discovery, the comet was bright. In fact, it is described to have "... shone through clouds like the Moon ( $-7$  mag.) when it was first sighted in Peru on November 1 at dusk." (Vsekhsyatskii, 1964: 106).

Abū'l Fazl's zodiacal system is tropical. His observation

... at the time when the sun made his conspicuous appearance in the sign Scorpio, this heavenly sign (i.e. the tailed comet) kindled its brilliant face in the sign of Sagittarius ...

is consistent with the computed positions for 5 November 1577 at 12:05 UT; we have the Sun at longitude  $\lambda = 233^\circ$ , i.e., in the zodiacal sign of Scorpius ( $210^\circ$ – $240^\circ$ ), whereas the comet is at  $\lambda = 247^\circ$ , in the zodiacal sign of Sagittarius ( $240^\circ$ – $270^\circ$ ). Against the starry background, the comet is placed right in Scorpius. In Figure 4 we depict the sky (a  $45^\circ$  field) where the bullseye corresponds to the comet's position as on 5 November 1577 at sunset (12:05 UT). The comet lies a few degrees south-west of Mercury. The following day, on 6 November 1577 at 12:04 UT (sunset) the comet is still within the longitudes of the sign of Sagittarius, at  $\lambda = 250^\circ$ , and about  $7^\circ$  east of  $\alpha$  Scorpii (Antares).

As the observations are in date order, on 5 November and 6 November 1577 respectively we have Abū'l Fazl and 'Ārif Qandahārī among the earliest to have independently recorded the apparition of one of the most brilliant comets in history. By then the comet was a low declination object and was relatively easier to spot from southern latitudes, even the Indian region. Abū'l Fazl and 'Ārif Qandahārī both mention that the comet was visible over a long period.

It is not known from where 'Ārif Qandahārī observed the comet. In his account in *Tārīkh-i Akbar Shāhī* he describes the comet as a bright star in the west,

... inclining towards the south with numerous tiny stars flowing from its top, making it look like a cypress tree; it remained visible for four *gharīs* (1 hour, 36 minutes) in the cities of Agra, Delhi and Lahore. It disappeared in the month of Shawwāl of the same year (12 Dec-

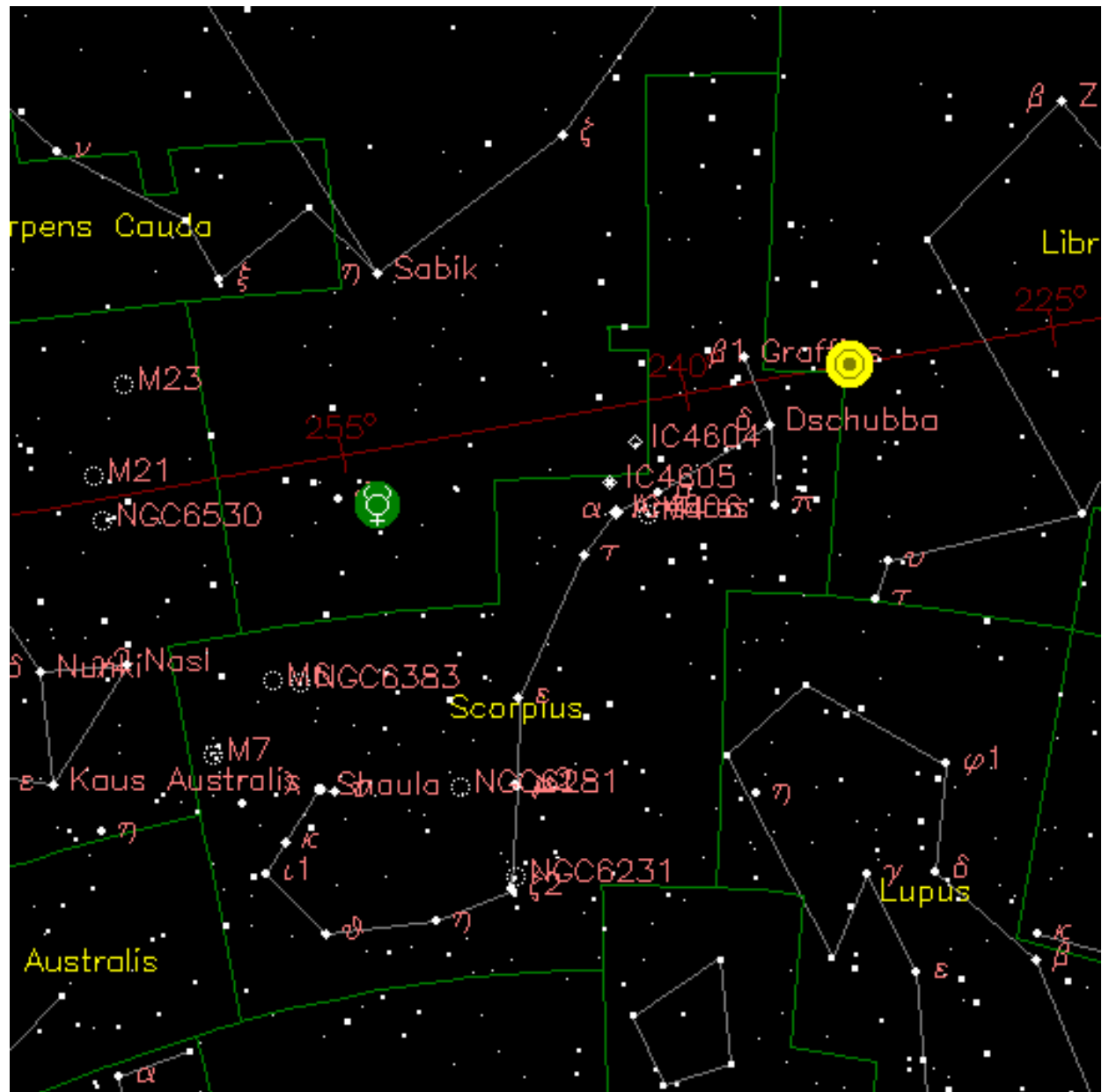


Figure 4: The Scorpius region as it appeared on Tuesday 5 November 1577 at 12:05 UT. The location of the comet is indicated by the bullseye at RA 16h 15m 01s and Dec  $-27^{\circ} 11' 08''$  (base star map after Walker, 2013).

cember 1577–9 January 1578) and became known as the long tailed-star (*siṭāra-i dum-i darāz*). (Mousavi, 2000: 111–112).

From the information provided it looks more like an observer's description rather than a chronicler's account. Importantly, it differs from Abū'l Fazl's description in that it records the inclination towards north.

In contrast, Nizām ud-Din and Badāūni just chronicle the event, but they also introduce the apocalyptic angle. Nizām ud-Dīn, the author of *Tabaqāt-i Akbarī*, records that the comet appeared in the twenty-third year of the reign of the Emperor Akbar, and he describes it as follows:

At this period, at the time of evening prayer, a comet appeared in the sky towards Arabia, inclining to the north and continued very awful for two hours. The opinion of the Astrologers

was that the effects would not be felt in Hindustan, but probably in Khurasan and Irak. Shortly afterwards, Shah Ismail, son of Shah Tahmasp Safawi, departed this life, and great troubles arose in Persia. (Elliot, 1873: 407).

Shāh Ismā'īl was assassinated on 14 Ramzān, 985 A.H. (25 November 1577). While presenting Nizām ud-Din's narration, Modi (1917: 76) makes one correction to Elliot's translation: for 'dar-tari-i', instead of 'towards the East' he claims that it actually means 'towards Arabia'. That also would imply 'towards the West', for Arabia is to the west of India, which is consistent with Badāūni's and Abū'l Fazl's descriptions, "... as appearing in the West." He also cites Elliot's explanation of how Nizām ud-Din incorrectly placed the appearance of the comet in the twenty-third year when it should actually have been the twenty-

second year.

Badāūnī's *Muntakhab-ut Tawārīkh* is a general history of the Muslim world, recorded in three volumes and beginning with Bābur. In Volume II, which deals with Akbar's reign until the 40<sup>th</sup> year, or CE 1594 (Majumdar et al., 2007), Badāūnī describes the appearance of the comet in 1577:

And among the events of that year was the appearance of a comet in the west. And, when Shāh Maṇṇūr took to wearing a long tail to the back of his turban, they dubbed him 'The Star with a tail'. And through his excessive economy and stinginess in the army expenses, and the pitch that he reached in grasping in season and out of season; people forgot the tyrannies of Rājāh Muzaḥḥar Khān and kept heaping upon him abundance of abuse:—"For many bads are worse than bad" ... And this same year news arrived that Shāh Ismail, son of Shāh Tahmāsp, Emperor of Persia had been murdered ... And the effect of the comet in that country became manifest, and in Irāq the greatest perturbation resulted, while the Turks conquered Tabriz, Shirwān, and Māzandarān ... (Ranking et al., 1889: 240–241).

In Modi (1917: 76), the description is a little different:

Among the unexpected events (one) was this, that in the same year, a comet appeared from the direction of the West. When Shah Maṇṇūr left a long tail from behind in the corner of his turban, they named him (in joke) 'a tailed comet.' ... The effects of this comet appeared in that country.

Badāūnī rightly places the event in the twenty-second year of the reign of the Emperor Akbar.

## 7 CONCLUDING REMARKS

The Great Comet of 1577 (C/1577 V1) initially generated curiosity, but this soon turned to awe owing to its brilliant form and its persistence in the night sky. Abū'l Faḥr devoted long passages in the *Akbarnāmā* to a discussion of comets in general, apparently prompted by the spectacular appearance of the 1577 comet. He specifically mentions that the Sun was in Scorpius at the time, and Figure 4 shows that the comet also was in Scorpius, although tropically it was not. In Islam, the sign of Scorpius is regarded as evil, and it forewarns of affliction to the populace. Was the comet's sidereal position responsible for Abū'l Faḥr's apprehension about this apparition?

An examination of Akbar's horoscope as discussed in the *Akbarnāmā* is appropriate here. He was born on 15 October 1542, and the moot point is whether this was under the sign Virgo or under Leo. Akbar's horoscopes were cast at the time of his birth according to the Indian sidereal system by a 'Jotik Rai' (possibly a title, not a

name) and by Maulāna Chānd who was present outside the birth chamber to determine the exact time of the birth. He had used a Greek astrolabe to take altitudes and Ulugh Beg's *Gurgani* tables that were computed for 1437. Maulāna Alyas cast the horoscope on the basis of the *Ilkhani* tables of Naṣīr al-Dīn al-Ṭūsī (CE 1201–1274). Maulāna Chānd put the ascendant at the time of Akbar's birth at 7° in Virgo, whereas Hindu astrologers placed it in Leo. In Islamic and Hindu astronomy, the Sun is the lord of the sign Leo, and this sign is most appropriate for emperors.

It is worth reading Abū'l Faḥr's discussion about fixing the sign under which Akbar was born, which takes into consideration the movement of the zodiacal system by 17° in the span of 1,190 years before Ulugh Beg (as a result of precession), since this was not allowed for in the Indian calculation that fixed the birth under Leo. Also interesting are Beveridge's (1897–1907, Volume 1: 125–128) notes on this matter. Abū'l Faḥr's preference was for the tropical system, and he brought the discrepancy to the attention of the scholar Amīr Faḥrullāh Shīrāzī (who had joined Akbar's court in 1583), and asked him to resolve this matter. The latter then cast a fresh horoscope according to the Greek and Persian rules. Using older star tables that dated to around CE 830 gained him ~8.5°, and he was able to successfully place the ascendant in Leo. Abū'l Faḥr regarded this horoscope as the most reliable one.

As for the comet of 1577, it was in Sagittarius when first sighted. However, a few days earlier it would have been in Scorpius. On 3 November at 15:00 UT it transited into Sagittarius, as it constantly moved in ecliptic longitude. Abū'l Faḥr only spotted the comet two days later but, noting its motion, he would have realized where it came from. The Emperor, for his part, took the comet apparition very seriously, and he asked his minister, Rājā Todar Mal, for astrologers to explore the possible consequences of such an apparition, and he ordered alms to be distributed on a large scale as per the customs of the Mohammedans and Brahmans. Nizām ud-Din and Badāūnī readily placed blame on the comet for many untoward incidents that occurred nearby and afar. Abū'l Faḥr, however, tried to minimize the perceived adverse impact of the comet by underlining that it was through the benedictions of the Emperor that the country was spared any calamity. The reasons why he did this are not difficult to guess. The traits of a natural philosopher clearly show in the treatise, but it would seem that Abū'l Faḥr was unaware of the most important aspect of his record—that he was an independent discoverer of what would prove to be one of the Great Comets of history.



Curiously, the Great Comet of 1577 brought calamity to astronomy in Istanbul. In the wake of its occurrence, certain horrifying incidents occurred, which prompted astrologers to destroy Taqī al-Din's astronomical observatory, which had only been constructed in 1575 (Heiderzadeh, 2008).

Finally, we should note that although Abū'l Fazl speaks about many past comets in the *Ak-barnāmā*, he does not mention the appearance of a bright new star in the constellation of Cassiopeia only a few years earlier. This was the historic supernova of 1572, which became popular as 'Tycho's Nova' (see Stevenson and Green, 2002). It quickly rose in brightness, eventually matching Venus, and even was visible during the day-time.

## 8 NOTES

The following notes belong to the passage we have quoted here, on page 253, which is from Modi (1917: 73–74).

- 1 Most dates listed in this paper follow the Gregorian Calendar and are years CE or BCE. However, some dates, like this one (963 A.H.), are given using the Hijri or Islamic Calendar, which is a lunar calendar that consists of 12 months in a year of 354 days. The first year (1 A.H.) of the Hijri Calendar began in CE 622, when Muhammad moved from Mecca to Medina. The current Islamic year is 1437 A.H., and in the Gregorian Calendar it runs from approximately 14 October 2015 to 2 October 2016.
2. A 'finger' was a unit of measurement and equalled  $\sim 1^\circ$ .
3. Taking the word to be *ra'd*. The Bengal Asiatic Society's text gives the word as the last star in the tail of the Lesser Bear. It also means a governor. But these words seems to have no proper meaning here. In the footnote to this quotation it gives *rāyad* as found in another manuscript, but I think that it is mistaken for *ra'ad*, which suits well with the next word, *barāk* ('flashing'). Note that the original quotation footnote 2 also has *ra'ad*, *rāyad* and *barāk* in the Persian script.

## 9 ACKNOWLEDGEMENTS

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## JAMES HENRY MARRIOTT: NEW ZEALAND'S FIRST PROFESSIONAL TELESCOPE-MAKER

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**Abstract:** James Henry Marriott was born in London in 1799 and trained as an optician and scientific instrument-maker. In 1842 he emigrated to New Zealand and in January 1843 settled in the newly-established town of Wellington. He was New Zealand's first professional telescope-maker, but we have only been able to locate one telescope made by him while in New Zealand, a brass 1-draw marine telescope with a 44-mm objective, which was manufactured in 1844. In 2004 this marine telescope was purchased in Hawaii by the second author of this paper.

In this paper we offer a biographical sketch of Marriott, describe his 1844 marine telescope and discuss its provenance. We conclude that although he may have been New Zealand's first professional telescope-maker Marriott actually made very few telescopes or other scientific instruments. As such, rather than being recognised as a pioneer of telescope-making in New Zealand he should be remembered as the founder of New Zealand theatre.

**Keywords:** J.H. Marriott, New Zealand, telescopes

### 1 INTRODUCTION

In one of his historical papers the noted New Zealand seismologist and astronomer George Allison Eiby (1918–1992) mentioned J.H. Marriott as a "... maker of astronomical telescopes ..." (Eiby, 1978: 123) and New Zealand's first professional telescope-maker, and this alerted us to his existence (e.g. see Orchiston, 1998; 2001). Subsequently, one of us (CR) acquired a marine telescope that was manufactured by Marriott in 1844, and this inspired the present study.

In this paper we provide information about Marriott and early scientific astronomy in Wellington, describe his 1844 marine telescope, and speculate on its origin. Finally, we evaluate the suggestion that Marriott should be recognized as New Zealand's first professional maker of astronomical telescopes.

### 2 J.H. MARRIOTT AND EARLY WELLINGTON ASTRONOMY

James Henry Marriott (Figure 1) was born in London in 1799, the son of William and Alice (née McGuinness) Marriott, and received his schooling in England. On 19 May 1822 he married Sarah Bateman in Hackney, Middlesex, and they had three daughters and two sons. Marriott

spent a period working as a reporter for *The Times*, but for many years he also was able to indulge "... an enormous passion for the theatre by acting and producing, especially Shakespearean plays, and became a talented painter, engraver and musician." (Downes, 1990). However, he "... also followed the example of his father by acquiring the skills of optician and mathematical instrument maker." (ibid.).

Marriott's father, William Marriott, is listed by Clifton (1995) in her authoritative *Directory of British Scientific Instrument Makers 1550–1851* as an optician who was active in Leeds during the early 1820s. He followed a long and successful tradition of British telescope-making (e.g. see King, 1979; Warner, 1998), and was succeeded by a son, William Marriott II, who plied his trade at four different London addresses between 1827 and 1845. He is listed in Clifton's *Directory ...* as an optician, philosophical instrument-maker, mathematical instrument-maker, telescope-maker, brass tube manufacturer and optical turner, all skills he undoubtedly acquired through his father. William (junior) was succeeded in the business by his wife Mrs A. Marriott, who practised as an optician from 1846 to 1848.

While there is no mention of a James Henry Marriott in Clifton's tome, it is a fair assumption that he also learnt the art of telescope-making

and the manufacture of other scientific instruments when William junior and his wife were being trained in the trade.

On 27 July 1842 J.H. Marriott emigrated to New Zealand in the *Thomas Sparks*, arriving in Port Nicholson on 31 January 1843 (Scholefield, 1939: 28) after a very eventful 6-month voyage (see Neale, 1982).<sup>1</sup> At this time he was "... already in his forties and full of worldly experience." (Scholefield, 1939: 28), and was looking forward to establishing a new life in this distant British colony. As a European settlement, Wellington was a product of the New Zealand Company in England (see Olssen, 1997), and had only been in existence for just over three years.



Figure 1: James Henry Marriott, who was one of the founders of the Oddfellows Lodge in Wellington (courtesy: Warwick Marriott).

Wellington was located on the shores of Port Nicholson at the southern extremity of the North Island of New Zealand (see Figure 2). To the east and west Port Nicholson was flanked by rugged mountains that in the 1840s for the most part were heavily forested, while the Hutt Valley—much of which also was covered in forest—extended northeastwards from the shores of the harbour, fed by the flood-prone Hutt (Hertanga) River. Initially, European settlement was concentrated on the flood plain of the Hutt River at Petone and on the narrow coastal flat at

Thorndon, but as Figure 2 shows, with continuing forest clearance during the early and mid-1840s, small settlements, scattered houses and farms appeared in various places to the north, west and south of Thorndon; in the Porirua area; at several locations in the lower Hutt Valley to the north of Petone; and at Trentham in the upper Hutt Valley (see Bremner 1981; Mulgan, 1939; Ward, 1928). Although no firm figures have been published, a variety of evidence suggests that when Marriott arrived in early 1843 the total European population of the Wellington region numbered between 2,500 and 3,500, the great majority of whom hailed from England (e.g. see Immigration ..., n.d.). As such, they represented a cross-section of British society (reflecting the philosophy of the New Zealand Company), but the class system that was dominant back in the British Isles was not entrenched in the new colony, where ability, commitment and dedication—rather than ancestry alone—were paramount.

Long before the arrival of the first Europeans in Port Nicholson, Maori astronomers practised their craft in the Wellington area. However, their system of celestial beliefs was intricately interwoven with religion and mythology (see Best, 1922; Orchiston, 2000), and as such differed markedly from the nautical and positional astronomy typical of European observatories in the 1840s. At this time, surveyors and the captains and officers of sailing ships learnt and regularly used astronomy in the course of their occupations, and they were Wellington's first non-indigenous astronomers. After studying this period, Orchiston (2016: Chapter 21) felt "... justified in identifying William Mein Smith ... as Wellington's first resident European astronomer ..." Smith (1799–1869) was born in Cape Town, educated in England, joined the British Army, and trained as a surveyor. In 1839 he was employed by the New Zealand Company as their Surveyor General, and in January 1840 he and his team of three other surveyors arrived in Port Nicholson. One of his first tasks was to lay out the towns of Wellington and Petone. Smith spent the rest of his life in the Wellington region (see Jones, 1966; Smith, 1990).

The public first became aware of William Mein Smith's talents as an astronomer in March–April 1843 when the Great Comet of 1843 (C/1843 D1) graced Wellington skies and he wrote about it in one of the local newspapers (Orchiston, 2016: Chapter 21). Note that this comet made its spectacular appearance very soon after Marriott reached Wellington, as if to welcome him to this new land. Less than two years later Smith and Marriott were greeted by another Great Comet, C/1844 Y1, which was a prominent naked-eye object in December 1844 and January 1845 (ibid.). We know from newspaper

reports that both comets generated considerable public interest, which should have created a demand for telescopes. Thus, the timing of Marriott's arrival in Wellington would appear to have been particularly fortuitous.

### 3 J.H. MARRIOTT AS A PIONEERING NEW ZEALAND TELESCOPE-MAKER

We are bound to wonder whether this public interest in comets in 1843–1845 translated into telescope orders for Marriott. If it did, we would expect to see advertisements by Marriott in the Wellington newspapers of the day, and this is precisely what George Eiby claims. In promoting Marriott as Wellington's—and indeed New Zealand's—first professional maker of astronomical telescopes, he claims that during the 1840s Marriott advertised himself as a "... maker of astronomical telescopes ..." (Eiby, 1978: 123) in the *Wellington Spectator and Cook's Strait Guardian* newspaper. What evidence is there for this? The actual name of this newspaper

was the *New Zealand Spectator and Cook's Strait Guardian*, which was launched in 1844 and ceased publication in 1865. This newspaper has been digitized, and the contents of each issue, including all advertisements, can be searched electronically using selected key words. Our searches on 'Marriott', 'telescope' and 'astronomy' did not reveal any advertisements (or editorial comments or news reports) about Marriott as a telescope-maker or scientific instrument-maker. So perhaps Eiby simply confused the name of the newspaper, as there were two others in Wellington at this time, the *New Zealand Colonist and Port Nicholson Advertiser* (1842–1843) and the *New Zealand Gazette and Wellington Spectator* (1839–1844). However, electronic searches of both of these also produced the same results: no evidence that Marriott advertised as a telescope-maker during the 1840s. Instead, all three newspapers were peppered with advertisements and reports relating to Marriott's theatrical activities, including his

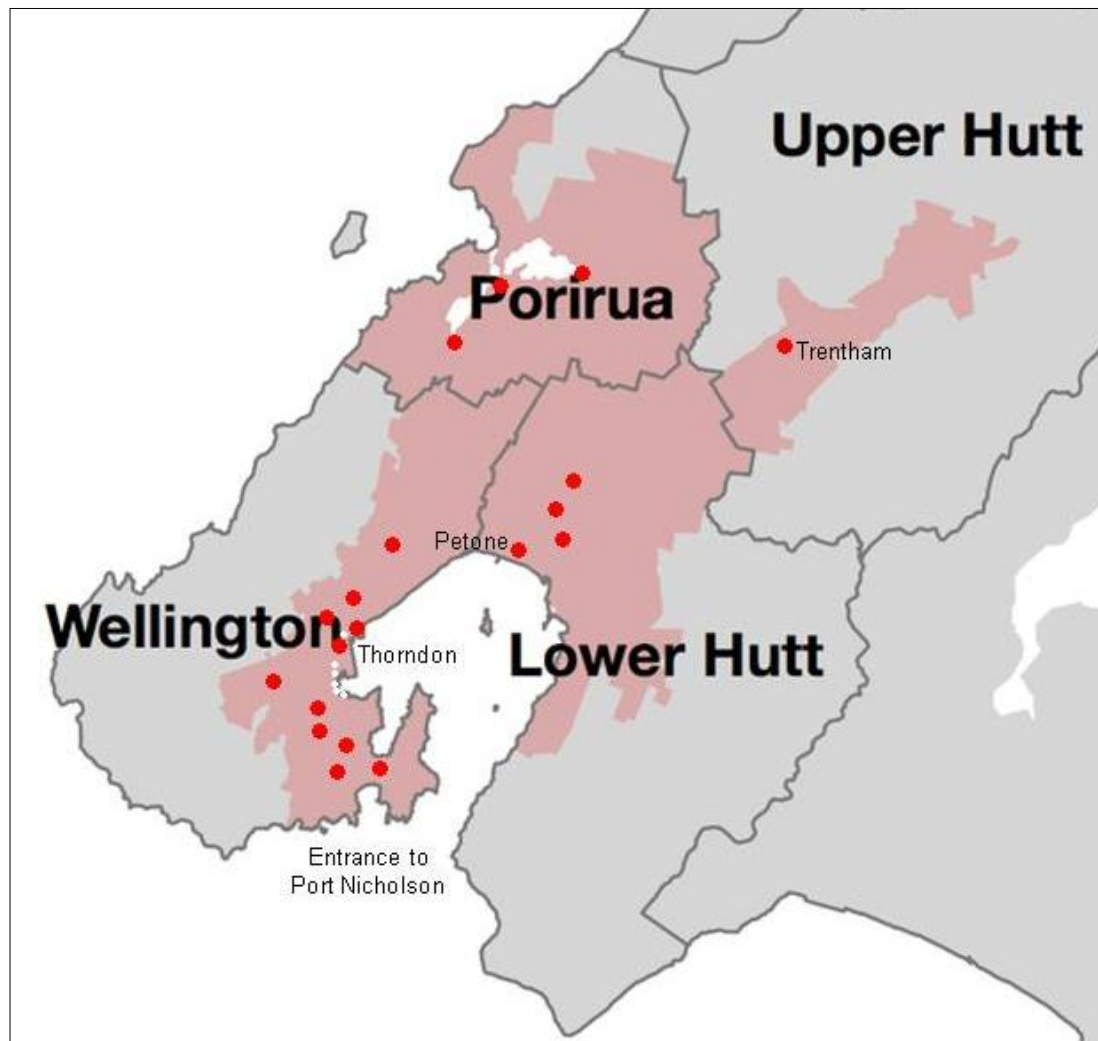


Figure 2: A map of Port Nicholson and the Wellington region. The red dots show the locations of the first European settlements at Petone and Thorndon, and other locations where Europeans settled during the early to mid 1840s in the Wellington and Porirua areas and in the lower and upper sections of the Hutt Valley. The present-day distribution of population is indicated by the pink shading. Since the initial settlement of Thorndon, there has been extensive land reclamation in the area around Wellington city, and the series of small white dots to the north and south of Thorndon show the original location of the shoreline (map: Wayne Orchiston).

Dancing Academy, and this is consistent with suggestions by Downes' (1990) and Scholefield (1939) that James Henry Marriott was a pioneer of New Zealand theatre. One of the present authors discussed Marriott in an earlier paper (Brown, 2014), and upon researching early Wellington newspapers in relation to Eiby's claim he also was unable to find any reference to Marriott and astronomical telescopes.

The reason for Marriott's apparent disinterest in comets and telescope-making is obvious when we examine his preoccupation at this time:

Marriott quickly involved himself in his first love, theatre. In the months following his arrival he organised, promoted and took part in a season of popular plays which opened on 11 May 1843, in the saloon of the Ship Hotel. These were the first plays to be staged publicly in Wellington, and the first serious attempts at presenting regular dramatic entertainment in the colony.

Encouraged by the success of these performances, Marriott persuaded the owner of the Ship Hotel to build a hall on some vacant land at the rear of his establishment. On 12 September 1843 this was opened with much fanfare as the Royal Victoria Theatre, the first theatre to be built in New Zealand, with the indefatigable Marriott having been involved in almost every facet of its construction. The theatre closed under Marriott's management in November 1843, but in September 1845 he opened the Britannia Saloon (later renamed the Royal Lyceum Theatre) in Willis Street ... his enthusiasm and energy were always in evidence as an actor, singer, dancer, musician, scene painter, producer or stage director. (Downes, 1990).

Furthermore,

... in 1844 Marriott helped to design and build the Olympic Theatre. He carried out the decorations and scenery, and even manufactured from whale oil the gas for lighting the theatre. (Scholefield, 1939: 28).

Comet or no comet, Marriott simply was far too busy to be bothered with telescope-making, and besides, those living in or near Wellington in 1843–1844 and interested in acquiring telescopes already were adequately catered for by three different firms that imported telescopes. Thus, between 3 February and 10 March 1843 the firm of Samuel and Joseph advertised "Day and Night Telescopes" (e.g. see Now's your time ..., 1843), while between 7 March and 1 August 1843 Johnson & Moore, advertised "... Ship Telescopes ..." (e.g. see Ex Indus, 1843) and from 4 April until 1 August 1843 H. Hardeman, Tailor and Draper placed many advertisements for "... first-rate Day and Night Telescopes ..." (e.g. see H. Hardeman, Tailor and Draper, 1843). Yet Marriott still liked to promote his original calling, for a little later his occupation is listed as 'optician' in a "List of all persons qualified to serve as Jurors for the

District of Port Nicholson ..." (1847), and various rolls in the 1840s all referred to him as either an optician or an engraver.

Over the years Marriott became very well known in Wellington, but not as a maker of telescopes. Thus,

From the early 1850s until 1885 he ran a small but highly esteemed bookselling and stationery business on Lambton Quay ... and was a tireless worker for the Mechanics' Institute and the Tradesmen's Club. Marriott also held several minor provincial government offices, including sergeant at arms, inspector of weights and measures, registrar of cattle brands and registrar of dogs. (Downes, 1990).

Apart from his theatrical talents, he wrote poetry and was an accomplished engraver and artist. Some of his sketches of public functions appeared in the *Illustrated London News* (e.g. see Figure 3), which prompted the New Zealand historian and Parliamentary Librarian, G.H. Scholefield (1939: 28–29) to reflect: "I often wondered whether the public halls of Wellington really looked so substantial and seemly as they appear in Marriott's engravings in the *Illustrated London News*."

After a life full of varied interests and achievements, James Henry Marriott died in Wellington on 25 August 1886 following "... a few days illness, brought on, no doubt, by the recent severe weather ..." (Death ..., 1886). At the time he was 87, and was described as "... one of the fathers of Wellington ..." (ibid.). His wife had died a year and a half earlier (ibid.).

## 4 IN SEARCH OF MARRIOTT TELESCOPES

### 4.1 Introduction: The Documentary Evidence

How many telescopes did Marriott make? Books and research papers about New Zealand astronomy do not mention any telescopes made by J.H. Marriott, but what do the newspapers reveal? As mentioned earlier, New Zealand newspapers have now been digitized, which makes searching them using selected 'key words' much easier. During the period that Marriott lived in New Zealand (31 January 1843 to 26 August 1886) at one time or another eight different newspapers were published in Wellington and the neighbouring Wairarapa (see Table 1).

When these newspapers were searched for 'Marriott' and 'telescope' they produced just three articles about Marriott telescopes. The earliest dated to 1852, and it reports that on 26 August Marriott gave a well-received lecture titled "On the Telescope" at the Wellington Athenaeum and Mechanics' Institute:

On Thursday evening Mr. Marriott delivered a very interesting lecture on the telescope, during which he gave a brief history of the instru-

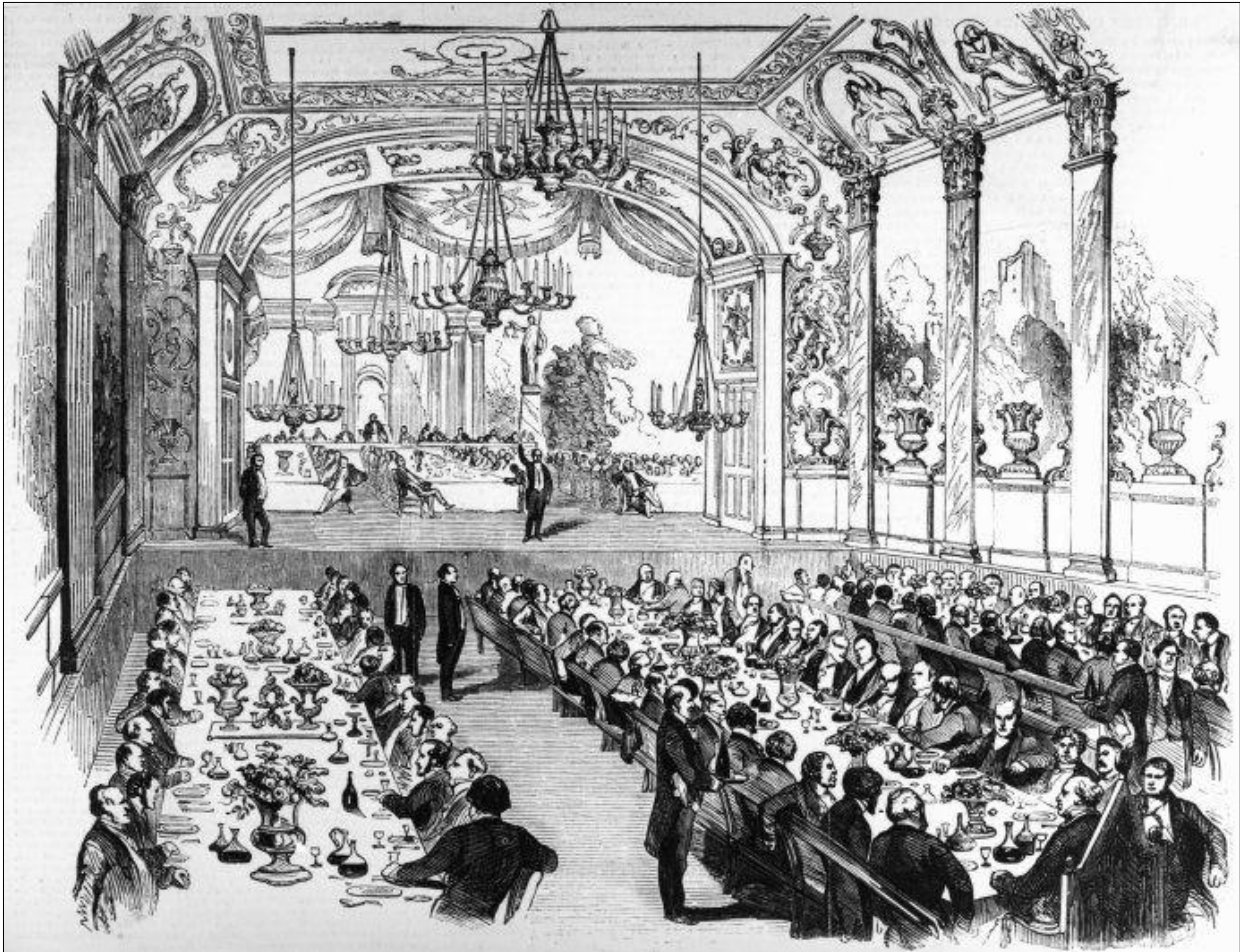


Figure 3: Marriott's sketch of the 3 March 1849 Reform Banquet in Wellington which was published in the *Illustrated London News* in 1850 (after *Illustrated London News*, 1850).

Table 1: Wellington area newspapers, 1843–1886; those that began publication prior to 1843 have dates in parentheses.

Newspaper	Years Published
<i>New Zealand Gazette and Wellington Spectator</i>	(1839) – 1844
<i>New Zealand Colonist and Port Nicholson Advertiser</i>	(1842) – 1843
<i>New Zealand Spectator and Cook's Strait Guardian</i>	1844 – 1865
<i>Wellington Independent</i>	1845 – 1874
<i>Karere o Poneke</i>	1857 – 1858
<i>Evening Post</i>	1865 – 1886+
<i>Wairarapa Standard</i>	1867 – 1887
<i>Wairarapa Daily Times</i>	1879 – 1886+

ment, and explained in a clear and practical manner the various operations connected with its manufacture, both as regards the nice operations of cutting the lenses, and the construction of the metal tubes, which latter was more fully illustrated by a neat little model, constructed by Mr. Marriott for the occasion, of the machine used for this purpose; numerous diagrams were also exhibited to show the interior construction of the different kinds of telescopes. The lecture was well attended, and the audience, by their frequent applause, gave sufficient evidence of being well pleased with the manner in which the subject was treated. (Athenaeum and Mechanics Institute, 1852).

It is clear from this account, and a similar one that appeared at the same time in the *Wellington Independent* newspaper (1852), that Marriott

was still *au fait* with the manufacturing of refracting telescopes, but noticeably absent were any completed Marriott telescopes on display during the lecture. Here was *the* perfect opportunity for him to promote his telescopes before a captive audience, and the fact that he did not do so suggests to us that he had little—if any—personal involvement in telescope-making at this time.

The second Marriott telescope mentioned in the newspapers was in a consignment from Wellington destined for the 1865 New Zealand Exhibition in Dunedin (List of Articles ..., 1864). Unfortunately, there is no description of this instrument, so we do not know when it was made, or whether it was a small land or marine telescope or a larger astronomical telescope.

The third Marriott telescope mentioned in the newspapers is a marine telescope that was manufactured in 1844 but only became known to the public in 1931:

An interesting souvenir of the days when watermen used to ply between the shore and the sailing ships which came to Wellington is now in the possession of the Wellington Harbour Board. It is a telescope in excellent condition and of very creditable workmanship, made, according to the inscription, by T.H. Marriott, of Wellington, in 1844. The telescope was presented to Mr. A.G. Barnett, secretary of the [Wellington Harbour] board, by Mr. J. Thompson, aged 86, who is the last surviving member of the company of watermen who were such an interesting feature of Wellington's early life. (Last of the Watermen, 1931).

While the newspaper survey produced surprisingly few Marriott telescopes, it did reveal that Marriott advertised extensively while resident in Wellington (but—as we have already seen—not in the earliest years he was in New Zealand). Nonetheless, the total number of newspaper advertisements alone was 242, and for some unknown reason these were restricted to just one of the eight available newspapers, the *Wellington Independent*. Even more remarkably, Marriott's first advertisement appeared on 17 November 1849, more than six years after he arrived in Port Nicholson, and his last one was published on 30 October 1873, nearly thirteen years before his death (see Table 2).

An analysis of these advertisements is interesting. Over the 24-yr period from 1849 to 1873 only four different advertisements were used, and these are listed in Table 2 and are shown in

Figures 4–7. The first of these advertisements was published in late 1849, not long before Marriott returned briefly to England (to arrange for his wife and some of the children to join him in Wellington), and he only returned to New Zealand in 1851 (Death ..., 1886), which would account for the absence of any advertisements in 1850 and the first half of 1851. The fact that the first advertisements specifically listing him as a "Telescope Manufacturer ..." appeared in 1853 made us wonder if these were inspired by Comet C/1853 L1 (Klinkerfues), which was a conspicuous naked eye object in New Zealand skies at this time, but the fact that the even more appealing appearances of Comets C/1858 L1 (Donati) and C/1861 J1 (Great Comet, Tebbutt) a little later did not translate into a flurry of 'telescope' advertisements shows that Marriott did not correlate his advertising with the appearance or imminent appearance of major astronomical objects or events. This is confirmed by the fact that he did not advertise at all in 1874, despite the stunning presence of Comet C/1874 H1 (Coggia) and a transit of Venus that not only captivated local astronomers but also motivated teams of professional astronomers from England, France, Germany and the United States to base themselves on the New Zealand mainland or its surrounding islands (see Orchiston, 2004). Furthermore, there was no astronomically-motivated reason to advertise in 1866, 1867, 1868 or 1869—and throughout the whole year in each case. Nor were 1871, 1872 and 1873 astronomically remarkable in any way, yet nearly three-quarters (72.7%) of Marriott's advertisements were published in these three years.

Table 2: The number of advertisements by J.H. Marriott in the *Wellington Independent* newspaper, 1849–1873.

Year	No.	Dates(s) or Date Range	Title of Advertisement
1849	2	17 November & 22 December	"Optician and Mathematical Turner" (Figure 4)
1850	0		
1851	2	12 July & 20 September	"Optical and Mathematical Instrument Maker" (Figure 5)
1852	2	17 January & 8 May	
1853	6	23 July – 22 October	"Telescope Manufacturer, and Metal Turner" (Figure 6)
1854	0		
1855	0		
1856	0		
1857	0		
1858	1	6 October	"Telescope Manufacturer" (Figure 7)
1859	2	28 June & 2 September	
1860	2	11 May & 17 July	
1861	1	19 February	
1862	0		
1863	2	3 & 6 October	
1864	3	7 April – 15 November	
1865	2	26 & 29 August	
1866	8	13 March – 11 December	
1867	15	15 January – 12 December	
1868	11	2 January – 31 October	
1869	6	18 March – 6 December	
1870	1	1 February	
1871	25	14 January – 19 December	
1872	95	24 January – 23 December	
1873	56	7 January – 30 October	



The wording of the four different types of advertisements Marriott used also is interesting, as the focus shifts increasingly from optical and mathematical instrument-making to telescope-making, so by as early as 1858 Marriott wanted to be recognised as a specialist telescope-maker rather than a (more general) maker of mathematical instruments. Marriott's obituary mentions that "He was the only person in Wellington in the early days who could regulate a compass or repair sextants and other nautical instruments." and it is noteworthy that sextants are specifically mentioned in the first three types of advertisements he used (i.e. up to 1853), while quadrants are only listed in the second type of advertisement. Compasses are included in the last three forms of Marriott's advertisements, while the last two types of advertisements show he also was a spectacle-maker. So he was able to make or repair different types of optical aids (spectacles) or scientific instruments, but note that all of his advertisements referred only to 'telescopes', never to 'astronomical telescopes', and they give no indication of the different types of telescopes that he was willing to manufacture.

Apart from advertisements in the *Wellington Independent* Marriott also placed somewhat more attractive advertisements in six different issues of *The Wellington Almanack* (1862: 37; 1865: 21; 1872: 57; 1873: 97; 1875: 105; 1878: 57). In all of these he specifically advertised as a "Telescope Manufacturer" and he specified that he made and repaired telescopes (e.g. see Figures 8 and 9). Note that all but one of these advertisements appeared after he last advertised in the *Wellington Independent* newspaper. Again, it is significant that he did not advertise in 1874, despite an imminent transit of Venus.

Clearly, it was Marriott's advertisements that inspired Eiby's claim that Marriott was a "... maker of astronomical telescopes ..." but it is interesting that he never advertised as such. Even when his first advertisement appeared in May 1849—more than six years after his arrival in Wellington—it only mentioned 'telescopes' not *astronomical* telescopes. From Eiby's text, the inference is that Marriott was actively involved in astronomical telescope-making from the time he reached Wellington, but the historical documentation does not support this—as the following section also will testify.

**J. H. MARRIOTT.**  
**Optician, and Mathematical Turner,**  
 TE ARO,

---

TELESCOPES MADE AND REPAIRED—INDEX AND HORIZON GLASSES TO SEXTANTS RE-SILVERED.  
*Crests and Cyphers neatly engraved—Gold and Silver Turning.*

ORDERS received at Mr. ROE'S Fancy Repository Lambton-quay, punctually attended to.  
 Wellington, May 25, 1849.

**J. H. MARRIOTT,**  
**Optical and Mathematical**  
**INSTRUMENT MAKER,**  
 LAMBTON QUAY.

---

**GOLD, SILVER, AND METAL TURNER**  
 IN GENERAL.

---

Quadrants and Sextants repaired.  
 Index and Horizon Glasses re-Silvered.  
 Superior Object and Magnifying Glasses.  
 Compasses repaired and Needles re-touched by very powerful Magnets.  
 Engraving neatly executed.  
 Cyphers, Crests, &c.  
 Wellington, May 6.

**J. H. MARRIOTT.**  
**Telescope Manufacturer,**  
**AND METAL TURNER.**

---

J. H. M. begs to announce that he has resumed his business on his old premises, Lambton Quay, where he trusts to meet again the patronage so liberally extended towards him during his residence in the colony.

Telescopes made and repaired  
 Spectacles to suit all sights  
 Compasses, &c., repaired  
 Engravings, &c., &c.  
 Wellington, 13th May, 1853.

**J. H. MARRIOTT,**  
**TELESCOPE MANUFACTURER.**

---

Telescopes Made and Repaired.

---

Spectacles to suit all Sights, Compasses, &c.,  
 Repaired.

---


Engravings, &c., &c.

Figure 4 (left, top): The advertisement that appeared in the *Wellington Independent* in 1849.

Figure 5 (left, bottom): The advertisement that appeared in the *Wellington Independent* in 1851–1852.

Figure 6 (right, top): The advertisement that appeared in the *Wellington Independent* in 1853.

Figure 7 (right, bottom): The advertisement that appeared in the *Wellington Independent* in 1859–1873.

**J. H. MARRIOTT,**  
  
**TELESCOPE MANUFACTURER,**  
 OPPOSITE THE ODD FELLOWS' HALL.

~~~~~

**TELESCOPES MADE AND REPAIRED.**

~~~~~

SPECTACLES TO SUIT ALL SIGHTS.

~~~~~

**COMPASSES, SEXTANTS,**  
 &c., &c., &c.,  
 REPAIRED AND ADJUSTED.

~~~~~

**ENGRAVING**

~~~~~

**JUVENILE BOOKS, &c.**

~~~~~

Superior Fancy and other Stationery.

~~~~~

LOCAL VIEWS OF  
**OUR PUBLIC BUILDINGS ENGRAVED**

In a superior style on note paper for transmission abroad.

**J. H. MARRIOTT,**  
**TELESCOPE MANUFACTURER**  
 OPPOSITE THE ODDFELLOWS' HALL.

~~~~~

TELESCOPES MADE & REPAIRED.

~~~~~

SPECTACLES TO SUIT ALL SIGHTS.

~~~~~

**COMPASSES, SEXTANTS**  
 &c., &c., &c.,  
 REPAIRED AND ADJUSTED.

~~~~~

**ENGRAVING.**

~~~~~

JUVENILE BOOKS, &c.

Figure 8 (left): The advertisement that appeared in *The Wellington Almanack Directory, Calendar and Diary* in 1873 (page 97).

Figure 9 (right): The advertisement that appeared *The Wellington Almanack Directory, Calendar and Diary* in 1875 (page 105).

#### 4.2 Marriott Telescopes in Museum and Private Collections

Did Marriott's advertising translate into orders for new telescopes? As we have seen, there certainly is no sign of them in the newspapers of the day or in the nineteenth century literature on New Zealand astronomy, but what of museum and private collections?

If only 10% of Marriott's advertisements produced results, this translates to ~25 telescopes, and if he only made one telescope a year (hardly an income!) while living in New Zealand, this translates to 41 or 42 telescopes (allowing for time he spent back in England). These are minimal figures—if Marriott really was an active telescope-maker—and we would expect to find some of these instruments preserved in museum and private collections, primarily in New Zealand.

We therefore decided to survey New Zealand museums and other institutions that may hold historical telescopes in order to see whether any Marriott telescopes or other scientific instruments made by him were in their collections. Consequently, e-mails and letters were sent to fifty carefully-selected institutions (Table 3). Replies were received from 92% of these, and none of

them held Marriott instruments.<sup>2</sup> A similar result emerged from major overseas museums, with significant astronomical collections, that also were surveyed.<sup>3</sup>

Nor were we able to track down any Marriott telescopes in private collections in New Zealand, although a descendent passed on anecdotal evidence of such instruments still within the family (Wayne Marriott, pers. comm., 2004 and 2005).

Thus, the only extant Marriott telescope we could trace was the marine telescope that initiated this research project, the instrument owned by one of the authors of this paper (CR). This telescope is discussed below in Section 5.

## 5 ROMICK'S MARRIOTT TELESCOPE

### 5.1 A Description of the Telescope

Romick's Marriott telescope is a single draw 'spyglass' (marine telescope) that magnifies 12x. It is 51 cm in length when collapsed and extends to 82 cm when focused at infinity (Figure 10). The body of the scope is 60 mm in diameter. When fully opened, the dust cover over the objective lens has a clear aperture of 28 mm, and the eyepiece has a 12-mm opening. The body of the telescope, draw tube, eyepiece assembly and objective assembly were all made of brass.

Table 3: New Zealand institutions surveyed for Marriott telescopes. Those that did not provide information for this study are shown in red print.

No	Name and Location
01	Te Aru Heritage Museum (Kaitaia)
02	Dargaville Maritime Museum
03	Russell Museum Te Whare Taonga o Kororareka
04	Devonport Historical and Museum Society Inc. (Auckland)
05	New Zealand Maritime Museum (Auckland)
06	Auckland War Memorial Museum
07	MOTAT (Auckland)
08	Helensville Pioneer Museum (Auckland)
09	Waiuku Museum (Auckland)
10	Raglan & District Museum
11	Kawhia Regional Museum and Gallery
12	Thames Historical Museum
13	Mercury Bay Regional Museum
14	Brian Watkins House Museum (Tauranga)
15	Waikato Museum Te Whare Taonga o Waikato (Hamilton)
16	Rotorua Museum Te Whare Taonga o Te Arawa
17	Whakatane Museum
18	Tairāwhiti Museum (Gisborne)
19	MTG Hawkes Bay (Napier)
20	Petone Settlers Museum Te Whare Whakaaro o Pito-One (Petone)
21	Wellington Museum
22	Carter Observatory (Wellington)
23	Museum of New Zealand Te Papa Tongarewa (Wellington)
24	Pataka Museum of Arts and Culture (Porirua)
25	Kapiti Coast Museum (Waikanae)
26	Foxton Historical Society Museum
27	Te Manawa (Palmerston North)
28	Whanganui Regional Museum
29	Aotea Utanganui – Museum of South Taranaki (Patea)
30	Taranaki Museum (New Plymouth)
31	Tainui Historical Society Museum (Mokau)
32	West Coast Historical Museum (Hokitika)
33	Golden Bay Museum and Art Gallery (Takaka)
34	Nelson Provincial Museum
35	Marlborough Provincial Museum and Archives (Blenheim)
36	Kaikoura Museum
37	Fyffe Museum (Kaikoura)
38	Canterbury Museum (Christchurch)
39	Lyttelton Historical Museum
40	Okains Bay Maori and Colonial Museum
41	Akaroa Museum
42	South Canterbury Museum (Timaru)
43	North Otago Museum (Oamaru)
44	Waikouaiti District Museum
45	Otago Museum (Dunedin)
46	Toitū Otago Settlers Museum (Dunedin)
47	Port Chalmers Museum
48	Owaka Museum – Wahi Kahuika
49	Bluff Maritime Museum
50	Southland Museum and Art Gallery (Invercargill)

The interior of the brass parts was blackened, and two blackened baffles were built into the eyepiece and the telescope tube. All parts are threaded, so that they can easily be disassembled. The body of the telescope is covered with hand-stitched brown leather. Near the eyepiece, the draw tube contains the following engraved inscription:

“J.H. Marriott Maker Wellington, NZ 1844”  
(see Figure 11).

There are six lenses in the telescope; two each in the objective, eyepiece, and image erector. All but the objective are permanently mounted in brass and still tightly held in their fixtures. Several have scratches but are in generally serviceable condition. The objective is a 44-mm twin achromat. The lenses are mount-

ed in a threaded housing. When the telescope was purchased it would not focus, and it was discovered that the front element of the objective had been glued into the middle of the eyepiece, and then damaged when removed. Several chips are evident in the outer 8 mm of the objective (see Figure 12), although this does not prevent use as these areas are outside of the 28-mm opening in the dust cover. The surface of the rear element of the objective shows some faint clouding.

The error in placement of the objective may have occurred when a major repair was carried out. The brass draw tube at some time cracked, and a brass plate has been soldered inside the tube to reinforce the cracked area, and the damaged area has been filled with solder. It is



Figure 10: A view of the extended telescope (photograph: Carl Romick).

not known how long ago this repair was done.

In an interesting paper titled "Telescopes for land and sea", Deborah Jean Warner (1998) from the National Museum of American History in Washington explores small non-astronomical telescopes made, mainly in London, during the eighteenth and early nineteenth centuries. This



Figure 11: A close-up showing the inscription on the telescope draw tube (photograph: Carl Romick).

was a time in England when

... an industrial revolution and expanding empire went hand in hand, and where numerous soldiers, sailors and civilians were able and eager to purchase the[se] latest high-tech consumer goods. (Warner, 1998: 33).

As the title of her papers foreshadows, Warner describes and discusses the various types of portable telescopes designed for terrestrial and maritime use, by day or night, and shows that the tubes of single-draw telescopes like the one made by Marriott were first made of metal towards the end of the eighteenth century (Warner, 1998: 43).<sup>4</sup> Warner (1998) identifies the following types of land and sea telescopes: perspective glasses, pocket telescopes and day and/or night telescopes. Marriott's 'spyglass' (as Romick likes to call it) falls comfortably into this last category.

The telescope was mounted on a tripod for astronomical observing (Figure 13). Testing during the day showed an image sharp to the edge of the field with almost no chromatic aberration. Testing at night gave a sharp image of the Moon with little color, but there was excessive scattering around the Moon, which could have been caused by the damage to the front objective lens or by the slight clouding of the rear objective, or both. When observing from Richmond, California, the Andromeda Galaxy was well contrasted against a reasonably dark background, and most of the Messier objects in the southern Milky Way were easily visible. A photograph of a lunar eclipse taken with this telescope is reproduced here in Figure 14.

## 5.2 The Provenance of the Telescope

Regrettably, nothing is known of the provenance of this marine telescope, other than that it was purchased from an antique dealer in Maui, Hawaii, in August 2004, and that dealer had owned it for at least three years, originally having purchased it from another antique dealer in Maui. All we can conclude, given its far from pristine physical condition, is that the telescope must have enjoyed a long working life.

How could a marine telescope that was manufactured in Wellington, New Zealand, in 1844 end up about 8,500 km away, in Hawaii? There would seem to be two distinct possibilities. During the mid-1840s marine telescopes were widely used by officers and crew members of ships plying the Pacific, and New Zealand was a popular destination, both for revictualling and for its commercial stocks of whale oil, timber, flax, pigs, potatoes, maize, seal skins and other produce (McNab, 1908). Following the signing of the Treaty of Waitangi in 1840 between the British Crown and the Maori chiefs of New Zealand, there was accelerated Euro-

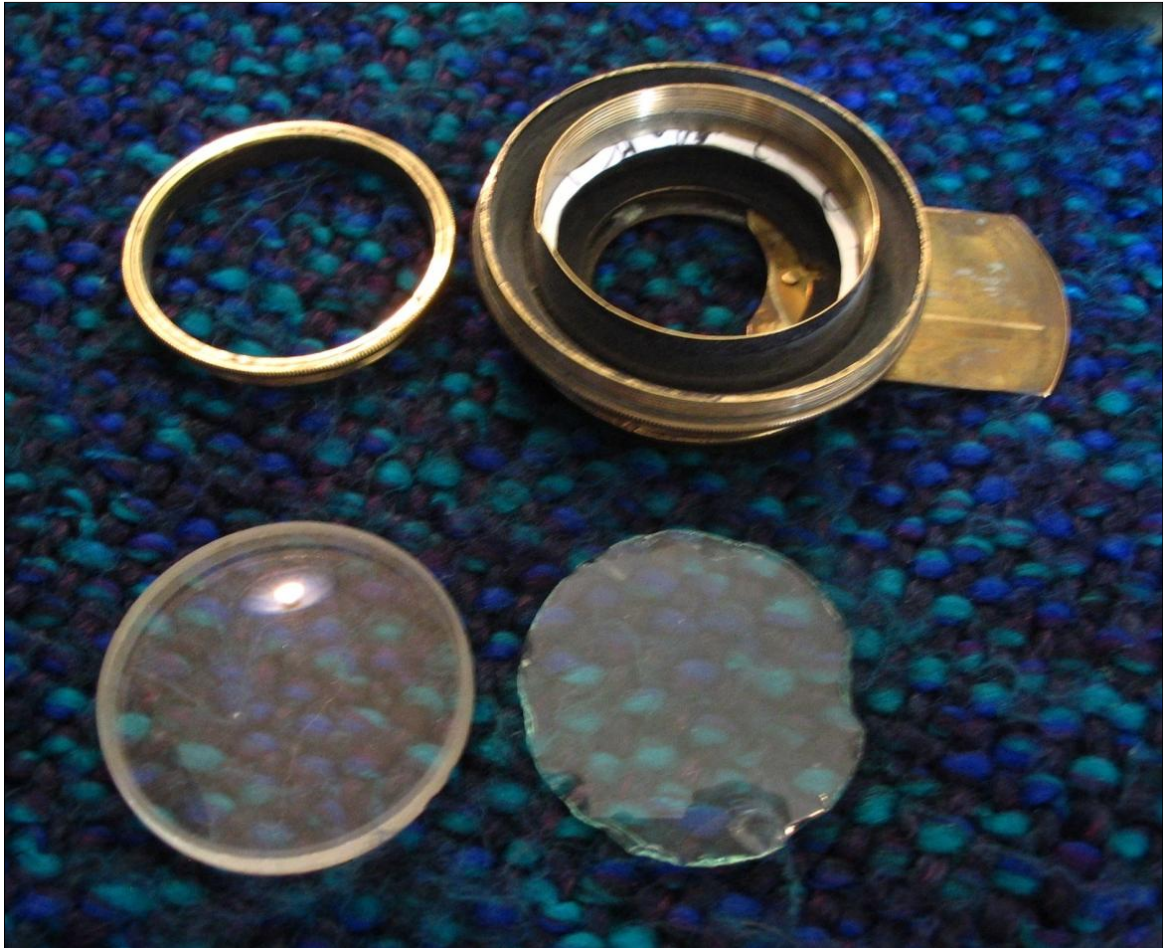


Figure 12: A close up of the brass assembly and twin objectives (photograph: Carl Romick).



Figure 13: The telescope mounted on a tripod for astronomical observing (photograph: Carl Romick).



Figure 14: The lunar eclipse of 28 October 2004, photographed with a Canon A75 digital camera through the Marriott telescope (photograph: Carl Romick).

pean occupation of the country, and by 1850 there were many settlements scattered round the long coastlines of the North and South Islands of New Zealand. Those that also served as international ports are shown in Figure 15.



Figure 15: The red dots show the location of international New Zealand ports in 1850 (map: Wayne Orchiston).

As we can see, Wellington, where Marriott lived from January 1843, was one of these.

We have no statistics on shipping movements into and out of the port of Wellington during the 1840s, but data for the Bay of Islands during the period July-December 1839 inclusive (Table 4) give an indication of the prevalence of American vessels (cf. McNab, 1914: 612–613). However it was feared that the signing of the Treaty of Waitangi in January 1840 would impact profoundly on American commerce in New Zealand:

The British Government have now assumed the entire Sovereignty of these Islands and have enacted laws and levied Imposts peculiarly harassing to our Citizens and most destructive to their Commercial pursuits, whilst they offer the most marked protection to their own commerce.

Many of our Countrymen are extensively engaged in general mercantile pursuits—some in the valuable Timber trade of the Country and others in that very important branch of our Commerce the Whale Fishery—for carrying on each of which, lands have been purchased from the Chiefs and establishments erected at a great outlay of capital but H.B.M. Government here have passed laws which they declare to be now in force, by which they assume to the Queen of Great Britain all lands purchased of Native Chiefs prior to the Treaty with the Natives and during the acknowledged Independence [sic.] of the Islands of New Zealand ...

The destructive effect of many of the laws passed here on our Commerce is too general to detail, the duties imposed on produce of the United States varies from Ten to Five Hundred per Centum ad valorem ...

Our whaling and shipping interests are deeply affected by the loss of rights and privileges long enjoyed by those engaged in that lucrative undertaking, inasmuch as Establishments on shore exclusively American can no longer exist and numerous Citizens hitherto fully and profitably employed must either sacrifice their hard earned property or serve where they should be masters—those of our ships which for the last 30 years have frequented the Ports of New Zealand to refresh, refit and whale as being the most central and best adapted to their purposes of the South Sea Islands are now forced to abandon them on account of the prohibition to the disposal of any of their cargo, the assumed possession of all the Timber lands by the British Government ... (Mayhew, 1842).

Commercial activities did indeed prove more challenging for American entrepreneurs, as forecast above by Richard Mayhew, the U.S. Consul in New Zealand, and the number of American vessels visiting the Bay of Islands dropped significantly following the signing of the Treaty of Waitangi (see Table 5). Nonetheless, throughout the 1840s American vessels *did* continue to visit New Zealand ports, including Wellington, and in this scenario Romick's Marriott telescope was purchased in 1844, or a little later, by the captain or a crew member of an American ship and ended up in Hawaii, where it remained until 2004 when Romick transferred it to California.

An alternative hypothesis is that the Romick Telescope is actually the Marriott telescope that was described in Wellington's *Evening Post* newspaper in 1931 (see Section 4.1 above). Let us now examine this possibility.

The A.G. Barnett mentioned in this article was Arthur George Barnett (1883–1940; Figure 16), who joined the Wellington Harbour Board as a message boy in 1898. He must have displayed considerable acumen, for the records of the Wellington Harbour Board in the Wellington City Archive reveal that he worked his way up within the organisation, becoming Secretary of the Board in 1924 (see also Ward, 1928: 423), and as we have seen still held this position in 1931 when the Board acquired the Marriott Telescope. From 1932 to 1934 he was Chief Executive Officer and Secretary of the Board, and in 1934 he became the General Manager, a post he retained until his sudden death on 6 September 1940 (Board's Tribute ..., 1940; Late Mr AG Barnett ..., 1940; Obituary ..., 1940), not long after he wrote an article about the Petone Wharf (Barnett, 1940). But Barnett's service extended beyond Wellington, for he also served as Secretary of the Harbours Association of New Zealand for a number of years, starting in 1911 (Board's tribute ..., 1940; Harbour dues ..., 1916).

While there is a relative abundance of biographical material in the Wellington City Archives about Mr Barnett, strangely these records say nothing at all about the Marriott telescope. The donation of the telescope is not even mentioned in the Harbour Board Minutes (Wellington Harbour Board Rough Minutes, 1930–1931; 1931–1932) or the 1931 Annual Report (Statement of Accounts ..., 1932), and without access to the 1931 *Evening Post* article we would not be aware that this telescope ever existed!

Nonetheless, the Marriott telescope *did* exist, but what became of it after it came into the "... possession of the Wellington Harbour Board." (Last of the watermen, 1931) is a mystery. Lauren Sadlier (pers. comm., 13 October, 2015) has explained that

In the very early days ... if something of inter-

Table 4: Ships visiting the Bay of Islands between July and December 1839, inclusive (after McNab, 1908: 756–758).

Home Port	No. of Vessels	% of Total
America	26	35.1
New South Wales	24	32.4
France	13	17.6
England	8	10.8
New Zealand	1	1.4
Portugal	1	1.4
Tahiti	1	1.4
Totals:	74	100.1

Table 5: The number of American ships visiting the Bay of Islands in 1840 and 1841.

Time Period	Number of Vessels	Reference McNab (1914)
1 July 1840–1 January 1840	16	Page 617
1 January–30 June 1841	19	Page 619
1 July–31 December 1841	10	Page 622

est was found [in the Wellington Harbour Board collection] ... it was given to the National Museum of New Zealand which is now Te Papa Tongarewa ...

but there are no Marriott telescopes in the Te Papa collection (ibid). In 1972 the Wellington Harbour Board established the Wellington Maritime Museum in a majestic multi-storeyed historic building down on the Wellington waterfront, then in 1989 the Harbour Board was dissolved and replaced by PortCentral, and the Maritime Museum was transferred to the Wellington City Council only to become the Museum of Wellington City and Sea and subsequently the Wellington Museum. Apparently the collections of the Wellington Maritime Museum never included a Marriott telescope, and when one of us (WO) first enquired in 2005, it was not in the collections



Figure 16: A.G. Barnett, in 1929 (courtesy: Wellington City Archives, AC127:2:1 WHB Members Album II, 1900–1923 p 30A).

of the Museum of Wellington City and Sea (Laureen Sadlier, pers. comm., 2005). This would indicate either that

(1) Sometime between 1931 and 1972 the Wellington Harbour Board sold the Marriott telescope, or perhaps presented it to a distinguished visitor to Wellington as a memento; or that

(2) Mr Barnett personally retained the telescope, and later he or his heirs disposed of it.

The records of the Wellington Harbour Board are now housed in the Wellington City Archives, but they do not provide any information that allows us to adjudicate on these two options. However, the 1931 newspaper article does favour the first alternative, and given that Marriott made so few telescopes, the fact that the telescope described in this newspaper article is a well-used marine telescope that was made in 1844 would seem to be more than a coincidence. Moreover, upon examining Figure 11 it is easy to see how the 'J.' in J.H. Marriott could be mistaken for a 'T' (as recorded in the newspaper article). We believe that Romick's Marriott Telescope is likely to be the same telescope that was presented to the Wellington Harbour Board in 1931, but current evidence does not allow us to explain how it made its way to Hawaii and was there in 2004 when Romick purchased it.

## 6 CONCLUDING REMARKS

During the forty-three years that Marriott lived in New Zealand, Wellingtonians were treated to major naked eye comets in 1843, 1844, 1858, 1861, 1865, 1874, 1880, 1881 (two of them) and 1882 (again two of them—see Orchiston, 1998: 107). There also were transits of Venus in 1874 and 1882 (Orchiston, 2004; 2016: Chapter 14), and the year before Marriott died a total solar eclipse was visible from central New Zealand (Orchiston, 2016: Chapter 16; Orchiston and Rowe, 2016). Collectively, these astronomical spectacles generated enormous public interest in astronomy, which should have translated into an ever-increasing demand for telescopes. Marriott was in the ideal position to respond to this demand, and he advertised extensively during the 1860s and early 1870s, but there is no evidence in publications, newspapers, museums or private collections that he made more than two or three telescopes—a handful at most—while living in New Zealand. Given the total cost of placing 242 advertisements in the *Wellington Independent* newspaper, and additional advertisements in *The Wellington Almanack* ..., we have to wonder whether he received enough orders to at least recoup the financial outlay. We very much doubt it.

So if Marriott's primary income did not derive from telescope-making where did it come from?

We know that from 1851 until 1885, one year before his death, Marriott and his wife ran a bookshop on Lambton Quay (a leading Wellington Street), and presumably this generated his main source of income. However, he probably was not particularly affluent, for his obituary describes how "Mr. Marriott's career in Wellington for the last thirty-five years [i.e. from 1851] has been that of a steady, plodding, business man." (Death ..., 1886). Before this, during his early years (prior to visiting England in 1850–1851), telescope-making and the theatre did not provide a reliable income, so, although

By occupation he was an optician and mathematical instrument maker ... as might be expected at the time he arrived [in Wellington], he found very little to do in his own line, and for the first few years of his colonial life (to use his own words) he did a bit of everything "from chisseling tombstones to putting in ladies teeth." (ibid.).

The accumulated evidence shows clearly that Marriott's heart lay with the theatre and not with astronomy or telescope making, and it is better that we salute him as the founding father of New Zealand theatre rather than as the nation's first professional telescope-maker.

The sole Marriott telescope we have been able to inspect was manufactured in 1844 and is owned by one of the authors of this paper (CR) and is now in Richmond, California. This is a well-made brass marine telescope that still performs well, despite some chips around the edge of one of the two objective elements. Given the absence of conflicting evidence, we conclude that this unique telescope is probably the 1844 marine telescope made by Marriott that was handed to the Wellington Harbour Board in 1931, and subsequently was disposed of and eventually made its way to Hawaii (where it was purchased, in 2004). On present evidence, we can identify this as the first telescope that was manufactured in New Zealand. Given its historical associations, its antiquity and its unique nature, this telescope is an important part of New Zealand's astronomical heritage.

## 7 NOTES

1. By this time James and Sarah Marriott already had five children. Sarah Marriott and the two youngest children (a boy and a girl) only moved to Wellington in 1853, and in 1865 they were joined by the eldest daughter. The two remaining children never emigrated to New Zealand. The eldest son went to California early in the gold-rush era and remained there, while the second daughter stayed in London where she became a celebrated actress (Death ..., 1886).
2. It is significant that when the late George Eiby searched for Marriott telescopes in the Wel-



lington region some years ago he also was unable to locate any (Laureen Sadlier, pers. comm., 2005).

- Likewise, the database of astronomical collections housed in Canadian museums contained no Marriott telescopes (Randall Brooks, pers. comm., 2004), and requests circulated through the *Oldscope* (Antique Telescope Society) and *Rete* e-lists, also produced no Marriott telescopes.
- Prior to this, pasteboard and wood commonly were used.

## 8 ACKNOWLEDGEMENTS

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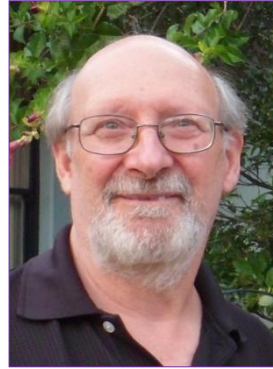
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omy, and the history of radio astronomy. He currently is the Vice-President of IAU Commission C3 (History of Astronomy), and is on the Organising Committee of the IAU Working Group on Historic Instruments. In 1998 he co-founded the *Journal of Astronomical History and Heritage* and is the current Editor, and in 2013 the IAU recognised his contribution to history of astronomy research by naming minor planet



48471 Orchiston after him.

Carl Romick was born in 1957 in Fairbanks, Alaska, where his father was a geophysicist at the University. After a long career at the Pacific Stock Exchange, he now works as an Equity Option Trader at Wells Fargo Prime Services in San Francisco, California. Carl has been an amateur astronomer for thirty years and holds a B.A. in Writing from the University of California at Irvine. His many interests include astronomy, glass bead making, music video recording and producing, and orchid growing.



Pendreigh Brown was born in New Zealand in 1937, is a retired anaesthetist who worked in public and private hospitals in Wellington, and has life-time hobbies in astronomy and family history. His prolonged interest in James Henry Marriott began when he learnt that Marriott was the first to administer ether for surgical procedures in Wellington (and in New Zealand) in September 1847. Pendreigh has written about this early Wellington pioneer in "Who was Mr Marriott?", which was published in the January/February 2010 issue of *The New Zealand Genealogist* (Volume 41, pages 15–19).



## LUDWIG FRANZ BENEDIKT BIERMANN: THE DOYEN OF GERMAN POST-WAR ASTROPHYSICS

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**Abstract:** Ludwig Biermann was a major figure in theoretical astrophysics in Germany in the twentieth century. His work on stellar interiors, comets and magnetic fields advanced our knowledge. He also predicted the existence and the nature of the solar wind. His predictions were vindicated by space probes. Ludwig Biermann also was an important figure behind the scenes working on the revival of German astronomy after the demise of WWII. For his work he earned important national and international honors.

**Key words:** Ludwig Biermann, stellar interiors, comets, solar wind, Max Planck Institutes

### 1 INTRODUCTION

Ludwig Biermann (Figure 1) was born on 13 March 1907 in Hamm/Westfalia and died on 12 January 1986 in Munich at the age of 78 years. He is closely associated with the rise of German astronomy and astrophysics after the demise of WWII. Biermann made outstanding contributions to astrophysics and plasma physics for over fifty years.

Ludwig Biermann attended school in the Hammese Gymnasium in Hamm/Westfalia where his interest in physics was aroused. He started his studies at the Technische Hochschule in Hannover, moving to universities in Munich and Freiburg before earning his doctoral degree in Göttingen in 1932. Biermann was influenced by Hans Kienle (1895–1975), who persuaded him to concentrate on astrophysics. Another important person to influence him was Ludwig Prandtl (1875–1953), who taught in Göttingen and was a pioneer of rigorous mathematic methods in applied science.

Biermann's doctoral thesis was titled "Konvektionszonen im Inneren der Sterne" ("Convection Zones in the Interiors of Stars"), defended at the Göttingen University in December 1932, and understandably his first publications dealt with stellar atmospheres. This was a glorious time to be carrying out such research with numerous charismatic astrophysicists developing the subject. In his early publications (Biermann, 1931a; 1931b; 1932a; 1932b) the question of convection in the interior of stars was discussed. Biermann applied rigorous mathematical methods to the solution of the models. A post-doctoral visit to St Andrews University in Scotland followed. This must have been the time when Biermann first made contact with Thomas George Cowling (1906–1990) who was working independently in a similar direction. A long-term friendship resulted from their correspondence.

The dramatic political changes in 1933 resulted in the departure of nearly half of the physics faculty of Göttingen University in view of the

Nazi racial laws. The glorious days of Göttingen University were over, and a new era began. After returning from Scotland, Biermann joined Heinrich Friedrich Siedentopf (1906–1963), then the Professor of Astronomy in Jena. Here he presented his 'Habilitationsschrift' (Biermann, 1935) a prerequisite for an academic post in a German university. In 1937 Biermann moved again, this time to the Babelsberger Sternwarte in Potsdam. This gave him many new contacts,



Figure 1: Professor Ludwig Biermann (courtesy: Astronomische Gesellschaft).

and also access to the Kaiser-Wilhelm-Institut für Physik with its broad range of research directions. In Potsdam Biermann also was in close contact with Karl Wurm (1899–1975) who worked in the Hamburg-Bergedorf Observatory and pointed out to him that there were problems in interpreting the observations of cometary tails. As a result of these contacts Biermann became interested in researching cometary phenomena, and this would develop into a major interest. Also in Potsdam was the Astronomisches Recheninstitut, where Biermann's first serious encounters with astronomical computing occurred. His life-

long interest in computing possibly dated from these contacts.

Towards the end of WWII Biermann and his family had to leave Potsdam and move to a village near Detmold, then once the war was over his first contacts were with the Hamburg-Bergedorf Observatory. The foundation of the Max-Planck-Gesellschaft, as a continuation of the Kaiser-Wilhelm-Gesellschaft, took place in 1948, and Ludwig Biermann was asked by Werner Karl Heisenberg (1901–1976) to join the Max-Planck-Institut für Physik in Göttingen and build up a Department for Astrophysics.

Biermann (1951) predicted the nature of the solar wind, arguing that corpuscular emission from the Sun was needed to produce the tails of comets, and when he reassessed data from the 1910 passage of Comet 1P/Halley he found that they supported his predictions. The existence of the solar wind later was confirmed by satellite observations.

Another direction of research that Ludwig Biermann pursued with Arnulf Schlüter (1922–2011) was the study of the role of magnetic fields in the interstellar medium. The idea of the ‘Biermann Battery’, a possible mechanism for forming primordial magnetic fields, dates from these investigations. Several papers were published on the question of cosmic rays as sources of synchrotron radiation, and other directions of research were studies of cross-sections and oscillations in various atomic elements, and data needed to refine the computation of the radiation from stellar interiors. Most of this work was done in collaboration with Eleonore Treffitz (b. 1920).

In 1958 the Max-Planck-Institut für Physik was moved from Göttingen to Munich and became the Max-Planck-Institut für Physik und Astrophysik with Werner Heisenberg continuing as Director of the Physics Institute and Ludwig Biermann becoming the Director in charge of the Astrophysics Institute. Within the framework of the Max-Planck-Gesellschaft, as the leading scientific research organization in Germany, from 1958 Biermann became an important figure on the committees that decided on the development of German astronomy and astrophysics.

On the basis of Biermann’s theoretical work, campaigns to create ionized clouds of strontium and barium in the Earth’s atmosphere were pursued, starting in 1961. This research involved collaboration with Reimar Lüst (b. 1923), and numerous rocket launches were made which showed that the method allowed the study of the interactions between the Earth’s ionosphere and the solar wind. This led, in 1963, to the foundation of the Max-Planck-Institute für Extraterrestrische Physik (MPE), with Reimar Lüst as the inaugural Director. Meanwhile, Biermann’s inter-

est in plasma physics was in large part responsible for the founding of the Max-Planck-Institut für Plasmaphysik (IPP) in Garching. In addition, Biermann also was active in the foundation of the Max-Planck-Institut für Radioastronomie (MPIfR), in Bonn, in 1966.

Numerous space projects to study comets were actively followed by Biermann, even after his retirement, and he was involved in the very successful Giotto Halley multi-color camera project, which took place during the encounter with Comet 1P/Halley on the exact date of his birthday, but almost two months after he had died. Numerous awards, prizes and memberships of academies crowned his scientific career.

## 2 THE EARLY YEARS

Biermann’s doctoral thesis and all of his early publications deal with the problem of stellar structure. The theory of stellar interiors was initiated by J. Homer Lane (1819–1880), followed up by August Ritter (1826–1908) and Jacob Robert Emden (1862–1940), and then rapidly developed by Karl Schwarzschild (1873–1916), Arthur Stanley Eddington (1882–1944), Albrecht Otto Johannes Unsöld (1905–1995), among others. Biermann became fascinated by the theory of stellar interiors and made considerable contributions to its advance. His early publications (in German) appeared in *Zeitschrift für Astrophysik* and *Veröffentlichungen der Sternwarte Göttingen* (Biermann, 1931a; 1931b; 1932a). The development of the interior of a star with a point-like nucleus and stellar atmosphere was discussed in detail. In particular, the methodology of Ludwig Prandtl’s ‘mixing-length’ was successfully applied by Biermann to the astrophysical problems of energy transfer from the interior of stars. The results of these early computations are valid even today. For the builders of models, the importance of convection for the energy transport was a great simplification. However, at the end of the discussions the point was made that the mechanism of energy production was unknown—this was some years before the work of Carl-Friedrich Freiherr von Weizsäcker (1912–2007) and Hans Albrecht Bethe (1906–2005) showed that nuclear physics could explain the source of energy in stars (see the Bethe-Weizsäcker-cycle). The work on convection zones in interiors of stars gave us an understanding of phenomena such as sunspots and the solar corona (e.g., see Biermann, 1932b). In his post-doctoral visit to St Andrews University in Scotland Biermann made contact with Cowling, resulting in extensive correspondence and later in a joint publication (Biermann and Cowling, 1940). In this publication the need to consider chemical elements other than hydrogen in the computation of energy

transfer in stellar interiors is stressed. Also the realization of the need to include magnetic fields in the models was a result of this encounter.

This research by Ludwig Biermann was continued during his short stay in Jena, in the group of Professor Siedentopf, who also worked on stellar interiors. It was there that Biermann (1935) presented his 'Habilitationsschrift', which was titled "Konvektion in Inneren der Sterne" ("Convection in the Interiors of Stars"). The importance of convection in cosmic objects became a sort of 'hobby horse' for Biermann, and later was very important in some of his astrophysical investigations.

When he moved to Babelsberg (Potsdam) in 1937 Biermann got involved in interpreting observations of stellar spectra (Biermann and Hachenberg, 1939). Biermann (1943a) became interested in oscillator strengths of the atoms Na I, K I and Mg II, which led to quantum mechanical computations. He also discussed the chemical composition of the Sun (Biermann, 1943b).

The war years did not affect Biermann's scientific output, although he had to get involved in the work of the Astronomisches Rechen-Institut in Potsdam. For Biermann these contacts were very important, as the development of computing methods—which was the main purpose of the Institut—obviously was needed for his research on stellar interiors.

### 3 THE BEGINNINGS IN GÖTTINGEN

Biermann's family lost their home during the bombing of Berlin, and they moved first to Brüntrup, near Detmold, and later to Göttingen where they were when the war ended. Biermann's first contacts were with staff at Hamburg University, which led him to spend a short time at the Hamburg-Bergedorf Observatory. Werner Heisenberg then managed to persuade Biermann to move to Göttingen and build up a Department of Astrophysics in the newly-founded Max-Planck-Institut für Physik (see Figure 2). Research on the high temperatures in the solar corona was followed by an important paper on the reasons for chromospheric turbulence of the Sun (Biermann, 1948). It also was at this time that a close collaboration was established with Eleonore Trefftz on the subject of cross sections, wave functions and oscillations of various elements found in stars. This was one step away from considering the hydrogen atom only in stellar interiors. The discussion that began with Unsöld's suggestion of an 'Ultrastrahlung' as the reason for cosmic radio waves emitted by the Sun also was taken up by Biermann and Bragge (1949) and Biermann et al. (1951b).

The concept of a solar wind was essentially implied by Eddington (1910) in his discussion of the Comet C/1908 R1 (Morehouse). However,



Figure 2: Ludwig Biermann at his desk in Göttingen, in about 1948 (courtesy: Archiv der Max-Planck-Gesellschaft, Berlin-Dahlem).

no physical explanation was attempted at that time, other than to imply that cometary heads and tails must be formed by some interaction with the Sun. Biermann then discussed the 1943 observations of Comet C/1942 X1 (Whipple-Fedke-Tevezadze) made by Cuno Hoffmeister (1892–1968) in 1943 and proposed an interpretation. This work led to his most important prediction: that of the existence and the nature of the solar wind (Biermann, 1951). Biermann argued that solar radiation cannot inject sufficient momentum to make the ionic tails of comets, and that corpuscular plasma also was required. Biermann developed a scenario of the physical interactions that were necessary to produce the rapid changes in cometary tails, and when he examined the tail of Comet 1P/Halley in 1910 he found that it supported his predictions. This was the beginning of his life-long interest in comets and the solar wind. Meanwhile, in 1957 he provided a general discussion of the solar wind (Biermann, 1957), and his ideas were vindicated by satellite probes, beginning with Luna 1 in 1959. Details of the solar wind were observed by later space probes (e.g. Luna 2, Luna 3, Venera 1, Mariner 2 and Ulysses), and there was good agreement with the theoretical predictions made by Biermann.

Biermann's incursion into the study of magnetic fields resulted from correspondence with T.G. Cowling about the necessity of including

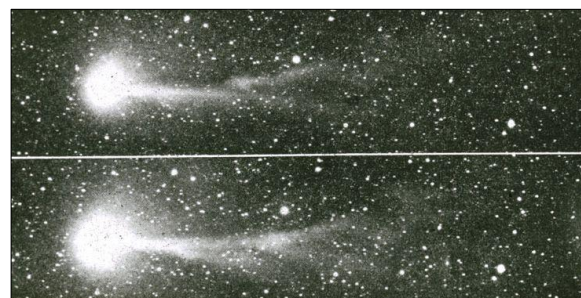


Figure 3: Two photographs of Comet C/1942 X1 (Whipple-Fedke-Tevezadze) taken just 1.776 hours apart showing the rapid development of the comet's tail (after Hoffmeister, 1944).



Figure 4: Heinz Billing with the G1 computer (courtesy: Astronomische Gesellschaft).

magnetism in stellar models. Cowling's 'antidynamo theorem' (1933) suggested that a rotating object like a star cannot generate a magnetic field, but Biermann (1950; 1952b) discussed the origin of cosmic magnetic fields in interstellar space and suggested a mechanism that would allow the creation of a magnetic field. Basically, in a plasma electric currents can flow due to charge separation, and this leads to a magnetic field. This mechanism has been named the 'Biermann Battery' (Mestel and Roxburgh, 1962). An interesting footnote is found in Biermann (1950), which says:

A large part of the contents of the publication is a result of work carried out in 1939–1945 that have been put together in an unpublished report.

An appendix to the Biermann (1950) paper was published by Schlüter and Biermann (1950), and the clear implication is that the solution of Maxwell's Equations in the interstellar plasma is the way to handle cosmic magnetic fields. The 'Biermann Battery' was very important in any discussion of the origin of magnetic fields, a topic that was elaborated on by Biermann and Schlüter (1951). Their paper was the starting point for the later development of the Dynamo Theory by Parker (1955). This concept required convection in the interior of the rotating object. The possibility of such a scenario, the presence of forced convection in stellar interiors, was discussed by Biermann and Temesváry (1956). The Dynamo Theory, which requires seed fields (like the Biermann Battery), was first applied to explain the magnetic field of the Earth, and later was extended to explain the magnetic fields of the Sun and stars (e.g. Krause and Steenbeck, 1965; Steenbeck and Krause, 1966). The Dynamo Theory is widely used for the interpretation of magnetic fields in cosmic objects today, and it has even been used to account for the magnetic fields in galaxies (e.g. see Wielebinski and Krause, 1993).



Figure 5: The official opening of the MPI für Physik und Astrophysik in Munich-Freimann on 9 May 1960. Ludwig Biermann is second from the right (courtesy: Max-Planck-Institut für Astrophysik).

In addition to his main interests in comets and magnetic fields Biermann continued to collaborate on other projects of current interest in astrophysics. The origin of non-thermal radio emission, a lively subject at the time, was also considered and published by Biermann and Lüst (1957), and a return to the subject of stellar interiors led to a joint publication by Kippenhahn et al. (1958). For this work, computational programs were developed for the G2 computer that allowed the prediction of the evolution of giant stars. The collaboration with Leverett Davis Jr. (1914–2003) led to the development of considerations about the role of magnetic fields in the structure of our Galaxy (Biermann and Davis, 1960). In Göttingen, the Institute became known internationally for its studies of comets, plasmas and magnetic fields, with a very strong emphasis on computing in astrophysics, and Biermann gathered together a group of excellent collaborators: Arnulf Schlüter, Eleonore Treffitz, Reimar and Rhea Lüst, Rudolf Kippenhahn, Friedrich Meyer and Stefan Temesváry.

This interest in computing led to the appointment in 1952 of Heinz Billing (b. 1914; Figure 4), a pioneer in computing machines, who developed the G1 computer specifically to solve astrophysical problems. Billing's innovation, dating back to 1948, was the use of a magnetic drum memory. The G1 computer could make two operations per second, had a drum memory of 26 words each with 32 bits. The development of further computers, the G2 and the G3, followed. At this time no commercial electronic computers were available and Billing's work was state of the art. Billing had full support from Biermann, who saw in the development of computers a great potential for solving astrophysical problems.

#### 4 THE MOVE TO MUNICH

In 1958 a move of the Max-Planck-Institut für Physik to Munich was completed. The new institute became known as the Max-Planck-Institut für Physik und Astrophysik, with Heisenberg and Biermann as Directors (Figure 5). At first the Institut was sited at Munich-Freimann, and later the independent Institut für Astrophysik moved with many other Max-Planck institutes to Garching. With good support from the Max-Planck-Gesellschaft (MPG) many new possibilities opened up. One of these was the development of new computers (see Figure 6), first the G2 and later the G3. The latter computer had 4096 word memory, with 42 bits and a cycle time of 10  $\mu$ sec. The G3 computer (Figure 7) was used for astrophysical problems by staff at the Max-Planck-Institut für Physik in Munich-Freimann until 1970.

Working in another direction, the earlier stud-

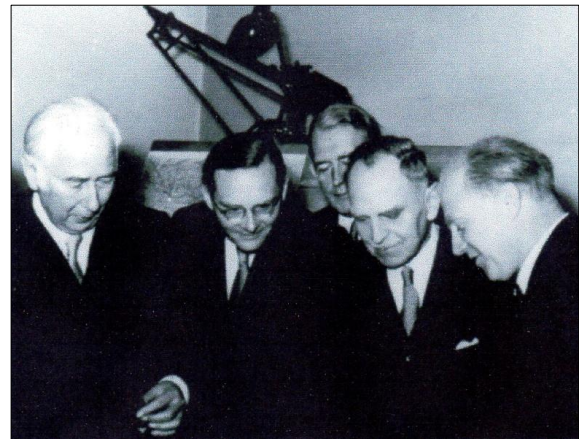


Figure 6: A photograph of the German Federal President, Theodor Heuss, inspecting the G1 computer in 1961. Those in front row (left to right) are: Theodor Heuss, Ludwig Biermann, Otto Hahn, Werner Heisenberg (courtesy: Astronomische Gesellschaft).

ies of cometary tails, led to the suggestion of researching the interplanetary medium by creating artificial ion clouds. This proposal was made by Biermann et al. (1961) and led, ultimately, to the formation of the Max-Planck-Institut für Extraterrestrische Physik (MPE)—see Figure 8. The first experiments were performed in 1963 with strontium and barium clouds (see Figure 9) launched by rockets (see Föppl et al., 1967), and the evolution of the clouds in the Earth's magnetic field confirmed predictions made earlier by Biermann et al. (1961). However, Biermann personally did not participate actively in these experiments, which were left to other staff at the MPE.

The use of nuclear power for peaceful purposes was promoted at a large international conference in Geneva in 1954. Meanwhile, the Federal German Ministry of Science also decided to support fusion research, and Biermann's work on plasmas led to a discussion about the prospects for fusion. In 1960 the Max-Planck-Institut für Plasmaphysik (IPP) was founded (also in Garching) with very strong financial support (90%) from the Federal Government. One

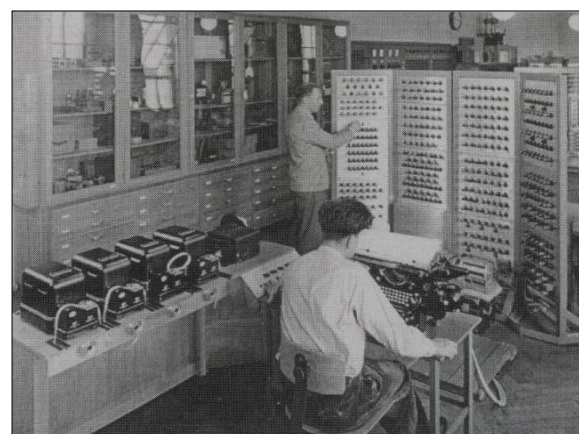


Figure 7: The G3 computing centre in Munich (courtesy: Astronomische Gesellschaft).



Figure 8: Ludwig Biermann (right), talking with the President of the MPG, Professor Adolf Butenandt, during the inauguration of the Max-Planck-Institut für Extraterrestrische Physik on 15 February 1965 (courtesy: Max-Planck-Institut für Astrophysik).

of the early Directors of the IPP was Biermann's friend Arnulf Schlüter. The IPP went on to develop many fusion experiments, first in Garching, later in the European JET experiment in Culham, U.K., and finally on an international scale at ITER, in Cadarache, France.<sup>1</sup>

Biermann's interest in magnetic fields led to his active participation in the foundation of the Max-Planck-Institut für Radioastronomie, and he visited several radio astronomy observatories in the USA in 1961, and the Sugar Grove project that was then under construction (e.g. see Figure 10). In July 1963 the author (Richard Wielebinski) was invited to give a colloquium about the detection of radio polarization in our Galaxy which was made at Cambridge and Dwingeloo

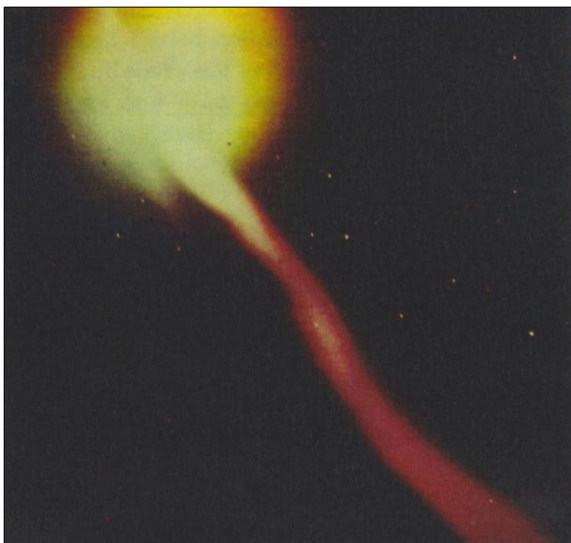


Figure 9: An artificial barium cloud injected into the ionosphere and glowing in the Earth's magnetic field (courtesy: Professor Dr G. Haerendel).

in 1962. This work was of great interest to Biermann since it finally provided proof of the existence of magnetic fields in our Galaxy. The founding of the Max-Planck-Institut für Radioastronomie, in Bonn in 1966, was due in part to the active support offered by Ludwig Biermann through different Max-Planck-Gesellschaft committees.

## 5 LUDWIG BIERMANN—THE 'COMET GURU'

Ludwig Biermann continued all the while to work in his major discipline, the study of comets. The interaction of the solar wind with a comet was treated in detail in Biermann et al. (1967). In this paper many details of the expected flow patterns were computed.

The mechanism of ionization in cometary atmospheres was discussed by Biermann and Trefftz (1967a). The discovery of huge hydrogen atmospheres around the heads of two bright comets, C/1969 T1 (Tago-Sato-Kosaka) and C/1969 Y1 (Bennett) by the Orbiting Astronomical Observatory (Code and Savage, 1972) was discussed by Biermann (1971a) in a review paper. The point was made that these space observations gave support to theoretical models that had previously been based on inferences or deductions, not on direct observational evidence.

Further research on the interaction of comets with the solar wind was presented by Biermann (1971b) in a symposium devoted to problems of magnetized plasmas, and held to honor T.G. Cowling. The observations of the ultraviolet 900 Å line and the 1216 Å Lyman  $\alpha$  line were used to make a detailed interpretation of cometary physics. A commentary on Comet C/1973 E1 (Kohoutek) was given by Biermann (1973)—although it was a somewhat disappointing comet, it still provided important new data.

In his 1980 Karl-Schwarzschild Lecture to the Astronomische Gesellschaft Biermann reviewed thirty years of cometary research, and the resulting published paper (Biermann, 1981) was an important contribution to the history of cometary astronomy.

The presence of molecules in comets was discussed in Biermann et al. (1982). This work was based on the recent comet observations that allowed a close comparison with established theoretical models. The composition of a comet with an ice nucleus and numerous molecules was studied. Observations of comets and their evolution were considered, and scenarios of chemical kinematics also were theoretically investigated.

The aphelion clustering of distant comets, seen as star tracks in the Oort Cloud, was discussed by Biermann et al. (1983). In this work, the puzzling clustering of long-period com-



ets was investigated. By this stage of his life, Ludwig Biermann was an unchallenged authority on comets.

In the last years of Ludwig Biermann's life two successful spacecraft designed to investigate comets were launched. In 1977 NASA and ESA began a program of three spacecraft in the framework of the International Sun-Earth Explorer (ISEE) investigations. The International Cometary Explorer (ICE; ISEE-3) was launched in 1978, and on 11 September 1985 this spacecraft passed through the plasma tail of Comet 21P/Giacobini-Zinner at a point about 7,800 km from the nucleus. The era of 'fly-by studies' of comets had begun.

The last cometary research program in which Ludwig Biermann participated involved the multi-color camera that was flown past Comet 1P/Halley in 1986 (Johnstone et al., 1986). This camera was developed by H.U. Keller (b. 1941), one of Biermann's former students. This experiment, known as the Giotto Mission, gave unprecedented visual information during a close approach to the comet. During the night of 13–14 March 1986 Giotto came within 596 km of the comet and pictures of the nucleus were transmitted back to Earth. For the first time a detailed study of the chemical composition of a comet could be carried out but, alas, Ludwig Biermann—who had devoted much of his professional life to the study of comets—died two months before this historic event. Appropriately, Giotto's approach to Comet Halley took place on 13 March, Biermann's birthday.

## 6 SUMMARY

Ludwig Biermann was a charismatic figure in the post-war German astrophysics community. He was a very reticent person, always working quietly in the background, but with great success in achieving his visions. Through his active committee work several Max Planck Institutes were founded, and he certainly made an important contribution to the development of German science in general and to the German astronomical community in particular. The results of his excellent research work also left their legacy, and his work on comets, magnetic fields and the prediction of the existence and nature of the solar wind earned him many international honours, including the Bruce Medal of the Astronomical Society of the Pacific in 1967, the Gold Medal of the Royal Astronomical Society in 1974 and the Karl Schwarzschild Medal of the Astronomische Gesellschaft in 1980.

## 7 NOTES

1. The concept of ITER, a large international fusion facility designed to generate a new, cleaner, more sustainable source of energy,

was launched at the Geneva Superpower Summit in November 1985. Initial participants were the European Union, Japan, the Soviet Union and the USA, with China and South Korea joining the collaboration in 2003. In 2005 it was agreed that the ITER facility would be constructed at Cadarache in the south of France.

## 8 ACKNOWLEDGEMENTS

I am grateful to Frau von Berlepsch (Astronomische Gesellschaft) for supplying Figures 1, 4, 6 and 7. Figure 2 was supplied by the Archiv der MPG Berlin-Dahlem, while Frau Dr. Hämmerle (Max-Planck-Institut für Astrophysik) kindly supplied Figures 5 and 8. The photograph of the barium cloud (Figure 9) was provided by Professor Dr G. Haerendel, a participant in these experiments. Figure 10 comes from the collection of Hastings Pawsey, by courtesy of Miller Goss (NRAO). I also am grateful to Sebastian von Hoerner who in an interview in 2000 recalled his memories of Ludwig Biermann.



Figure 10: Professor Biermann (centre) with two technicians visiting the Sugar Grove radio telescope project in West Virginia in 1961. Note the construction towers in the background (courtesy: Hastings Pawsey and Miller Goss).

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Professor Richard Wielebinski was born in Poland in



1936, but moved to Hobart, Tasmania, while still a teenager. He completed B.E (Hons.) and M.Eng. Sc. degrees at the University of Tasmania, then joined Martin Ryle's radio astronomy group in Cambridge and completed a Ph.D. in 1963 on polarised galactic radio emission. In 1970 he was appointed Director of the Max Planck

Institute for Radio Astronomy in Bonn, where he built up a research group that became involved in mapping the sky in the radio continuum, studying the magnetic fields of galaxies, and pulsar research. Richard has been awarded honorary doctorates by three universities. Currently, he is the Chairman of the IAU Working Group on Historic Radio Astronomy.

# THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 4: KERR, SHAIN, HIGGINS AND THE HORNSBY VALLEY FIELD STATION NEAR SYDNEY

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**Abstract:** Between 1949 and 1952 the CSIR's Division of Radiophysics was a world leader in low frequency radio astronomy, through research conducted mainly by Alex Shain and Charlie Higgins at their Hornsby Valley field station near Sydney. In this paper we discuss the personnel, radio telescopes and research programs (mainly conducted at 9.15 and 18.3 MHz) associated with the Hornsby Valley site.

**Keywords:** Australian low frequency radio astronomy, CSIRO Division of Radiophysics, Hornsby Valley field station, Alex Shain, Charlie Higgins, Frank Kerr.

## 1 INTRODUCTION

As documented elsewhere (see Orchiston et al., 2015; 2016; George et al., 2015a) Australia was an early international leader in low frequency radio astronomy, with two centres of excellence. One was near Sydney, and the other was in the island state of Tasmania to the south of the Australian mainland.

The Sydney initiatives were under the auspices of the CSIRO's Division of Radiophysics (henceforth RP),<sup>1</sup> which from 1946 through into the early 1960s maintained a large number of field stations and remote sites, mainly in and around Sydney (Orchiston and Slee, 2005a; Robertson, 1992; Sullivan, 1988). Their distribution is shown in Figure 1. Two of these field stations, Hornsby Valley (Orchiston and Slee, 2005b) and Fleurs (Orchiston and Slee, 2002), were involved in low frequency radio astronomy—that is, research conducted at frequencies below 30 MHz.

This paper details the pioneering low frequency radio astronomy that was carried out at the Hornsby Valley field station between 1946 and 1952.<sup>2</sup>

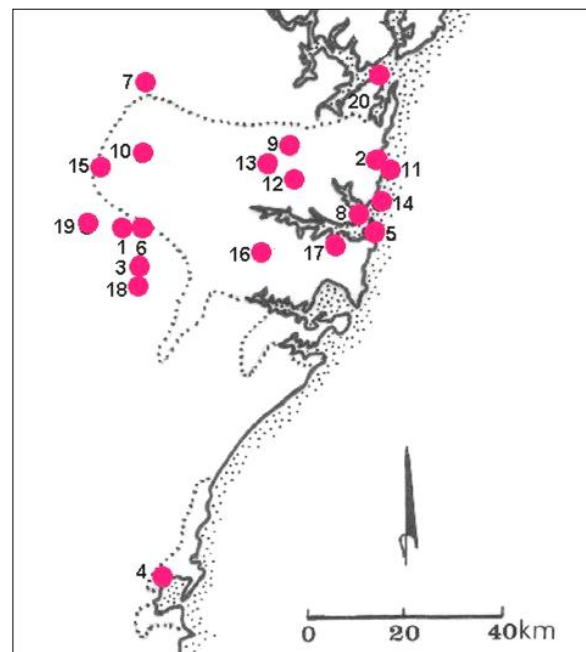


Figure 1: A map showing the field stations and remote sites, mainly in the Sydney region, maintained by the CSIRO's Division of Radiophysics between 1946 and 1965. Hornsby Valley is Site 9. The approximate present-day boundary of suburban Sydney is indicated by the upper dotted line.



Figure 2: A view across Old Man Valley towards the distant farm house on the hillside, and showing the collection of ex-WWII buildings associated with the field station's early research programs (courtesy: CSIRO RAIA B1266-15).



Figure 3: A close-up of the assemblage of huts, trailers, poles and wiring associated with the Moon bounce experiment (courtesy: CSIRO RAIA B1266-5).

## 2 THE HORNSBY VALLEY FIELD STATION

### 2.1 Introduction<sup>3</sup>

The Hornsby Valley field station (Orchiston and Slee, 2005b), site 9 in Figure 1, was established in 1946 on farmland in a picturesque valley surrounded by low tree-covered hills (see Figure 2).<sup>4</sup> Locally, this radio-quiet location was referred to as ‘Old Man Valley’, and at the time it lay just beyond Sydney’s most northerly suburbs.

From the start, the field station featured a centralised cluster of ex-WWII portable huts and mobile trailers that were used to house the scientific equipment. These are shown in close up in Figure 3.

The first scientists to carry out research at this new field station were Frank Kerr and Alex Shain. Frank John Kerr (1918–2000; Figure 4) was born in St Albans while his Australian parents temporarily were in England. After graduating with B.Sc. and M.Sc. degrees in physics from the University of Melbourne he joined RP in 1940. There he was involved in a range of radar research and followed up by carrying out radar research at the Hornsby Valley field station immediately after WWII. In 1948 he transferred to the Potts Hill field station (site 16 in Figure 1) and later became an authority on H-line emission (see Kerr, 1984; Wendt et al., 2011). He went to the USA in 1951, where he built up his astronomical knowledge and expertise by completing a Masters in Astronomy at Harvard University. After returning to RP and beginning H-line research, Kerr later followed a pattern established in 1955 by his distinguished RP colleague, Ronald Newbold Bracewell (1921–2007; Thompson and Frater, 2010), and accepted a Chair in Astronomy at the University of Maryland in 1966. He remained in the USA until his death in 2000 (Westerhout, 2000).

Charles Alexander (‘Alex’) Shain (1922–1960; Figure 5) was born in Melbourne, and after completing a B.Sc. at the University of Melbourne and serving briefly in the military he joined the CSIR’s Division of Radiophysics in November 1943 (Orchiston and Slee, 2005b). He assisted in the development of radar during WWII, and from late 1946 he was one of those scientists charged with identifying peace-time research that would take advantage of the war-time technological achievements of the Division. It is important to remember that at this time

Radiophysics was CSIR’s glamour division, arguably containing within its walls the densest concentration of [radar-related] technical talent on the continent ... (Sullivan, 2009: 122).

Shain was among a coterie of young researchers who would quickly make Australia a world leader in the emerging field of radio astron-



Figure 4: Frank Kerr in 1952 (cropped close-up taken from CSIRO RAIA B2842-45).

omy,<sup>5</sup> and he pioneered research at low frequencies. Unfortunately, Shain’s inspiring lead in this field was cut short prematurely when he succumbed to terminal cancer on 11 February 1960, just five days after his 38th birthday. This was a tragic loss for Australian and international radio astronomy, as documented by Dr Joseph Lade (‘Joe’) Pawsey (1908–1962), the Deputy Chief of the Division of Radiophysics, who described Alex Shain as “... a wonderful colleague in the laboratory, imaginative, well balanced, exceedingly unselfish, and a real friend to all.” (Pawsey, 1960: 245).

Aiding Kerr and Shain at Hornsby Valley was Technical Assistant Charles S. (‘Charlie’) Higgins (Figure 6), who came to Radiophysics from a radio company. He had a certificate in radio engineering and an interest in astronomy.

### 2.2 The Moon-Bounce Experiment

It is interesting that the first scientific research conducted at Hornsby Valley field station had nothing to do with radio astronomy, or astronomy. Rather it focussed on radar astronomy, and was motivated by ionospheric research.

It was natural that this research should be led by Frank Kerr, who wished to use Moon-bounce experiments to investigate the ionosphere. But while he and Alex Shain were the first Australians to employ radar astronomy in this way, they



Figure 5 (left): Alex Shain in 1952 (cropped close-up taken from CSIRO RAIA B2842-133).

Figure 6 (right): Charlie Higgins in 1952 (cropped close-up taken from CSIRO RAIA B2842-132).

were not the first to attempt radar astronomy. As Sullivan (2009) has documented, in 1940 Kerr and Shain's RP colleague, Jack Hobart Piddington (1910–1997), produced a 3-page report that included the following perceptive comments:

With the enormous powers available from R.D.F. [radio direction finding; i.e. radar] equipment, the possibility of obtaining echoes from the Moon appears worthy of investigation. (Piddington, 1940).

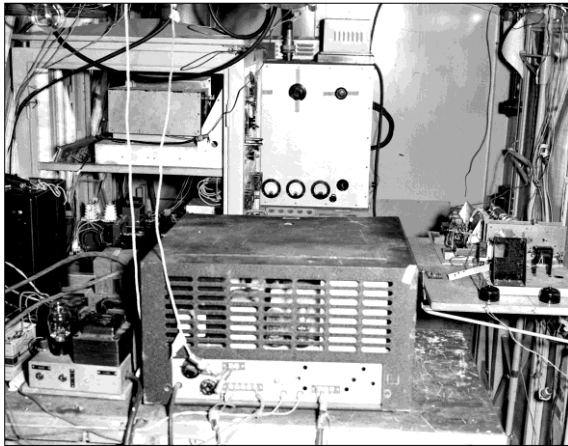


Figure 7: Two different views of some of the equipment used by Kerr and Shain for their 1947 Moon-bounce experiment (courtesy: CSIRO RAIA B1266-14 and B1266-21).

However, Brown (1999) reveals that it was two German radar experts, Wilhelm Stepp and Willi Thiel, who in the winter of 1943–1944 bounced radar signals off the Moon using an experimental radar set near Göhren on the island of Rügen, about 200 km northeast of Hamburg.

The first published accounts of successful Moon-bounce experiments occurred in early 1946 when an American team led by John Hib-

bert DeWitt (1906–1999) carried out 'Project Diana' (see Clark, 1980), and Zoltán Bay (1900–1992; Wagner, 1985) and his collaborators also had success in war-torn Hungary (see Bay, 1946). In the extensive report on their investigations at 111.5 MHz, DeWitt and Stodola (1949) noted that the received signal, which should have been 100 times greater than the receiver noise level, only occasionally reached this figure but usually showed severe fading and sometimes could not be detected at all! Pawsey and Bracewell (1955: 294; our italics) remark that

This low signal and its occasional disappearance is a remarkable result ... The only known factor is the obstruction offered by the ionosphere ... *There is either some important unknown factor influencing transmission between us and the moon or reflection from the moon, or the Signal Corps' observations were at fault. The data given do not permit us to exclude the latter possibility.*

It was against this background that Kerr and Shain planned their own Moon-bounce experiment, but whereas the deWitt and Bay projects were undertaken as technical challenges the Hornsby Valley project had clear scientific objectives. Thus, Kerr and Shain wanted to know

... why the echoes recorded by DeWitt's team had behaved so erratically .... This, they thought, might well be an ionospheric effect, or even caused in interplanetary space by streams of charged particles shot from the sun. (Sullivan, 2009: 274).

Their Hornsby Valley experiment was carried out during 1947–1948, and in the opinion of Pawsey and Bracewell (1955: 294) was

... a very neat arrangement. Instead of building special transmitting equipment they utilized an existing short-wave 100-kilowatt transmitter, Radio Australia, and an aerial system normally used to broadcast to North America. (ibid.).

This was a rhombic aerial, attached to a receiver that was tuned to receive 17.84 and 21.54 MHz signals broadcast by Radio Australia from Shepparton, Victoria (~600 km south of Hornsby Valley). The transmissions were triggered by Kerr and Shain using a landline connection, and when the Moon rose through the beam of the rhombic aerial they searched for echoes that exhibited the expected 2.5-second delay. Figure 7 shows some of the equipment used in this experiment. The receiver was an

R.C.A. type AR88 communication receiver, with the band-width adjusted to 70 c/s. The stability with regulated [power] supplies was such that slight retuning was necessary every 10–15 minutes ... [while the display comprised a] (a) Long-persistence cathode-ray tube, and photographic recording ... [and] (b) Loud-speaker, using the beat-frequency oscillator of the receiver. The aural method was the more

sensitive for the detection of weak signals. (Kerr et al., 1949: 310).

The times when observations could be made were limited to two periods of several successive days each month when the Moon passed through the beam of the rhombic aerial, and only when Radio Australia was not broadcasting, i.e. between 0230 and 0530 and from 0930 to 1230 Eastern Australian Standard Time. However, because of atmospherics, observations normally were restricted to the first of these intervals.

For this experiment three different types of signals were broadcast:

- (a) A group of three  $\frac{1}{4}$ -second pulses (used in searching for echoes and for identification of weak echoes).
- (b) A single pulse 2.2 seconds long (for studying short-period amplitude variations of the echo).
- (c) A group of pulses of length 1 millisecond and recurrence frequency 40 cps, extending over a total period of 2.2 seconds (for examining the fine structure of the echo) ...

The pulse group repetition period was 6 seconds in all cases. (Kerr and Shain, 1951: 230–231).

From July 1947 Moon-bounce transmissions were made on every possible occasion over a period of slightly longer than one year. In all, 28 experiments were carried out at Hornsby Valley and echoes were received on 22 of these. Figures 8 and 9 are included here to show the types of results obtained. The first of these shows the use of three short pulses, received directly from Shepparton via *E*-region scatter (the direct signals), followed ~2.5 seconds later by three echo pulses from the Moon, which are "... generally unequal in amplitude." (Kerr and Shain, 1951: 232). By way of contrast, Figure 9 shows

... a series of three successive signals of the long pulse type (only the first of these is labelled in the figure). By this method a record of echo intensity is obtained over a series of

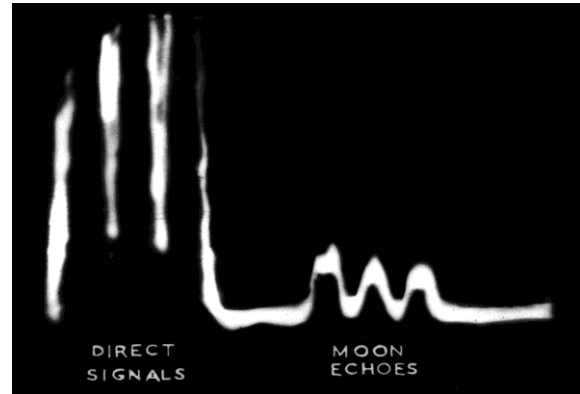


Figure 8: An example of a photographic record showing the results obtained from using a group of three short pulses (after Kerr and Shain, 1951: 232).

2.2-second periods interrupted by breaks 3.8 seconds long. (ibid.).

Through this research, Kerr and Shain were able to show that

... the reduced echo intensity ... was connected with obstruction in the F2 region of the ionosphere, though it could not be accounted for on current models. *Their investigations therefore led fundamentally to a geophysical discovery ... [and] showed there are gaps in our knowledge of the ionosphere.* (Pawsey and Bracewell, 1955: 294–295; our italics).

However, what particularly interests us here is the astronomical conclusion that Kerr and Shain (1951: 230; our italics) were able to draw on the basis of their observations:

The received echoes showed two types of fading. One type was consistent with an ionospheric origin. The second has been shown to be due to the moon's libration, effective reflection taking place over a large proportion of the moon's surface. This, together with the elongation of short pulses on reflection, *demonstrates that the moon is a "rough" reflector ...*

This project was Frank Kerr's sole post-war exploration at low frequencies.

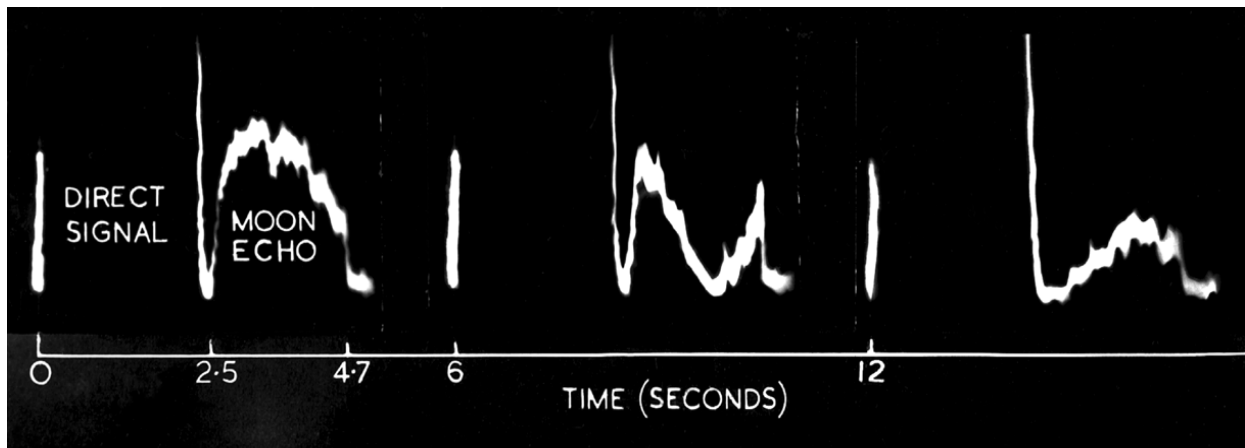


Figure 9: A photographic record showing three successive Moon-bounce echoes obtained with 2.2 second signals. These echoes show rapid fading caused by the *F*-layer, while the small fluctuations present are due to cosmic noise (after Kerr and Shain, 1951: 232).

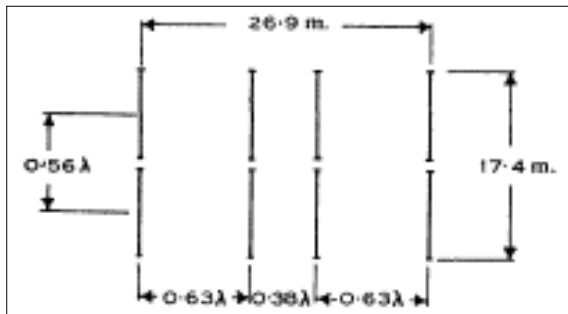


Figure 10: Plan of the dipole array (after Shain, 1951: 259).

### 2.3 The 18.3 MHz Galactic Survey

In mid-1948 at the end of the Moon-bounce experiment Kerr moved to the Potts Hill field station, leaving the Hornsby Valley in the capable hands of Alex Shain and Charlie Higgins. They and Dr Joe Pawsey had decided to chart a new course for RP by developing Hornsby Valley as the Division's forefront low frequency radio astronomical facility.

In deciding to conduct their first experiments at 18.3 MHz, Shain (1951: 258) perceptively pointed out that previously

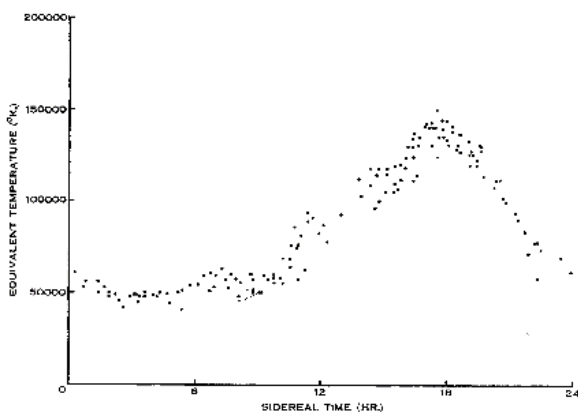


Figure 11: A corrected plot of equivalent aerial temperature versus sidereal time (after Shain, 1951: 264).

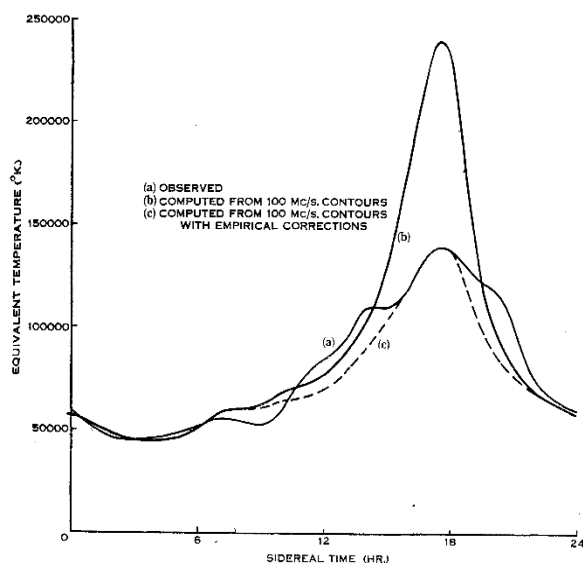


Figure 12: Equivalent aerial temperature versus sidereal time at 18.3 MHz (a) and 100 MHz (b and c) (after Shain, 1951: 265).

The most useful series of observations ... [at about this frequency] has been the early work of Jansky (1937) on frequencies near 20 Mc/s.

Jansky was, of course, the founder of radio astronomy, and it is telling that Shain and Higgins were the first to carry out serious low frequency observations since the 1930s.

Their equipment comprised

... an array of eight half-wave dipoles connected in phase, supported 0.2 wavelengths above ground, and arranged in plan ... [as shown here in Figure 10, and connected to a] standard communications receiver with a bandwidth of 400 c/s. ... The output was indicated by a milliammeter with D.C. amplifier connected to the second detector. (Shain, 1951: 259).

Observations were carried out between May and November 1949. Because the latitude of the Hornsby Valley site was 34° S and

... the direction of maximum sensitivity of the aerial was fixed vertically upwards ... [the] observations therefore give a weighted average of the radio emission from a zone of sky about Declination -34°. This zone includes both the centre and south pole of the Galaxy. (Shain, 1951: 258).

After allowing for ionospheric effects, a plot of equivalent aerial temperature versus sidereal time was prepared (Figure 11), which clearly showed the anticipated maximal emission along the plane of our Galaxy.

However, Shain (1951: 264) noted that

Because the observations were limited to a fixed aerial direction, and since the aerial has an angular beam width comparable to the dimensions of certain features of the galactic noise distribution, the result of the observations ... gives only a rough indication of the noise distribution across the sky.

Shain then used the 100 MHz contour diagram obtained by Bolton and Westfold (1950) to calculate the equivalent aerial temperatures at this frequency, and compared the corrected results with his 18.3 MHz plot (see Figure 12). He found that

... although the shape of the two curves is roughly similar, the observed ratio of maximum to minimum is considerably lower than that expected from 100 Mc/s. results ... [Nonetheless] a good fit could be obtained using the relation

$$T_{18.3} = 200,000(1 - e^{-T_{100}/1900})^{\circ}\text{K. [sic],}$$

where  $T_{18.3}$  is the temperature to be attached to the contour corresponding to  $T_{100}$  in the 100 Mc/s. survey. (Shain, 1951: 264–265).

However, it is not a perfect fit, as there are notable differences between curves (a) and (c) in Figure 12 at sidereal times 11–15 hours and 19–22 hours. Shain (1951: 266) suggests that "One possible explanation of at least part of the



discrepancy is the effects of radiation from discrete sources of noise.” One of these is the strong source Centaurus A. Allowing for these discrete sources, Shain then converted his 18.3 MHz diagram into an isophote plot, and this is shown in Figure 13.

Shain (1951: 267) concludes this pioneering paper:

These observations confirm that the intensity of galactic radiation at 18.3 Mc/s. is high and of the order of magnitude suggested by the observations of Jansky ...

The observations indicate anomalies in the attenuation of radio waves penetrating the ionosphere, F-region attenuation being higher and lower-layer attenuation being lower than expected ...

The observations are reasonably consistent with the hypothesis that contours of equal intensity of galactic radiation have the same shape at 18.3 Mc/s. as at 100 Mc/s. Certain discrepancies indicate that at least some discrete sources radiate at this frequency, the intensity being approximately that expected from the results of Stanley and Slee [1950].

Despite this excellent result, Shain and Higgins (who had assisted with the observations) were quick to recognise their shortcomings:

Although these observations gave some indication of the way in which the intensity of cosmic noise at 18.3 Mc/s should vary over the sky, it was apparent that a detailed survey should be made with an aerial of smaller beam width, at least over the important regions near the galactic centre and at some distance from the centre. (Shain and Higgins, 1954: 130).

Accordingly, an array of 30 horizontal half-wave dipoles was constructed. The aerials were positioned 0.2 wavelengths above the ground, and were arranged as shown in Figure 14.

Coaxial feeder lines ran from each dipole to a centrally-located hut, and

As the lengths of feeder were large, about 100 ft, the attenuations in the cables feeding each dipole were equalized as far as possible by making all the feeders from the north-south rows 2, 3, 4, and 5 ... the same length (five half-wavelengths) and those from rows 1 and 6 one wavelength longer. (Shain and Higgins, 1954a: 131).

In the hut the feeder lines from the eastern and western columns of dipoles were connected separately in threes (A1, A2, A3; B1, B2, B3 ... E1, E2, E3; and A4, A5, A6; B4, B5, B6 ... E4, E5, E6), and after their impedances were matched the outputs from all five groups of eastern and western feeder lines then were combined separately and their impedances once again were matched (as shown in Figure 15 for the western feeder lines). Then the two cables were taken to a

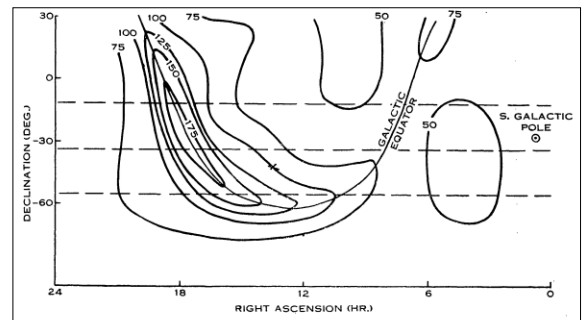


Figure 13: Estimated contours of equal equivalent temperature at 18.3 MHz, in thousands of degrees (after Shain, 1951: 266).

feeder bridge that was located in a separate hut outside the array, and this contained the receiving and recording equipment. Details of the feeder bridge are shown in the right hand diagram in Figure 15.

Attached to the feeder bridge were two 18.3 MHz receivers that were independent of each other, where receiver 1 mentioned in Figure 15 used signals from the eastern and western halves

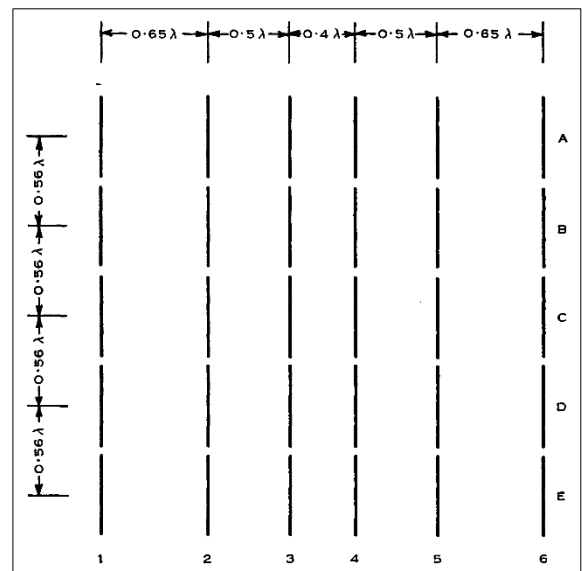


Figure 14: The plan of the array. The columns and rows are labelled so that individual dipoles can be referred to, if necessary. Note that the array is oriented 4.7° west of north. The unequal spacing between the columns was designed to reduce the effect of the side lobes (after Shain and Higgins, 1954a: 132).

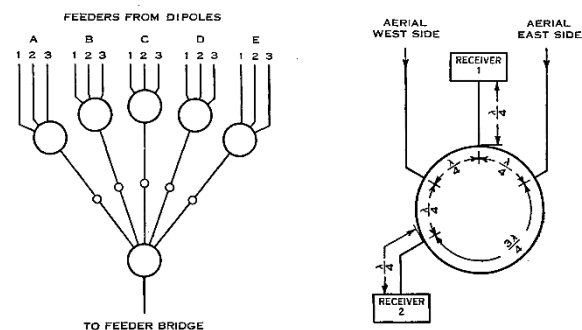


Figure 15: The left hand schematic diagram shows the matching arrangement for feeder lines from the western half of the array. The right hand diagram shows the arrangement of the feeder bridge (after Shain and Higgins, 1954a: 133).

of the array in phase, while receiver 2 had signals from the two halves out of phase. Shain and Higgins (1954a: 132–133) found that

The use of the two receivers simultaneously was helpful in recognizing some interfering signals and also permitted some accurate direction-finding observations in some circumstances.

Both receivers were standard communications-type receivers with bandwidths  $\sim 1$  kHz.

This radio telescope (see Figure 16) had an overall half-power beam width of  $17^\circ$ , which was a considerable improvement on that of the earlier Hornby Valley 18.3 MHz array. Like its predecessor, the new array functioned as a transit instrument, but in this instance the beam could be moved electronically by inserting cables of known length at the positions of the small circles shown in the left-hand diagram in Figure 15 (and the corresponding locations for the eastern combination of feeder lines). In this way, a strip of sky extending from declination  $-12^\circ$  to  $-50^\circ$  could be surveyed. It was calculated "... that with the aerial beam in the normal position the proportion of power in the main lobe was 89 per cent, this proportion decreasing to 84 per cent when the beam was swung through  $20^\circ$ ." (Shain and Higgins, 1954a: 134). This was caused by foreshortening of the array..

Astronomical observations were made between June 1950 and June 1951,

... in several series at intervals of a few months, and during each series, records were taken on at least two nights with the aerial di-

rected to each of the declinations  $-12^\circ$ ,  $-22^\circ$ ,  $-32^\circ$ ,  $-42^\circ$ , and  $-52^\circ$ . After each of these series of observations, readings of noise power were taken from the records at intervals of about 6 min and plotted as equivalent aerial temperatures against sidereal time. (Shain and Higgins, 1954a: 135).

Sometimes there was interference from a distant radio station that transmitted at close to 18.3 MHz and at other times thunderstorm activity was a problem, but overall the time lost in this way was minimal and useful records "... were obtained for practically every day during the year's observations." (ibid.).

The initial results are shown in Figure 17, where aerial temperature is plotted against right ascension for the five different declinations observed. This shows that the overall profile and the peak intensity are similar to those obtained with the earlier 18.3 MHz array. Data in this diagram then were used to generate the isophote plot shown in Figure 18. Shain and Higgins (1954a: 137) noted that

The ratio of maximum to minimum for the present observations is greater than the ratio observed previously, owing to the narrower aerial beam used, but also the absolute intensities have been raised slightly, owing mainly to a better estimate of the aerial system losses.

This isophote plot shows the concentration of emission along the Galactic Plane, with maximal emission at the Galactic Centre, the site of the discrete source Sagittarius A. In comparing their isophote plot with the one derived by Bolton and



Figure 16: A photograph showing part of the second 18.3 MHz array at Hornsby Valley. Once again, the ground served as a reflector (courtesy: CSIRO RAIA B2802-5).

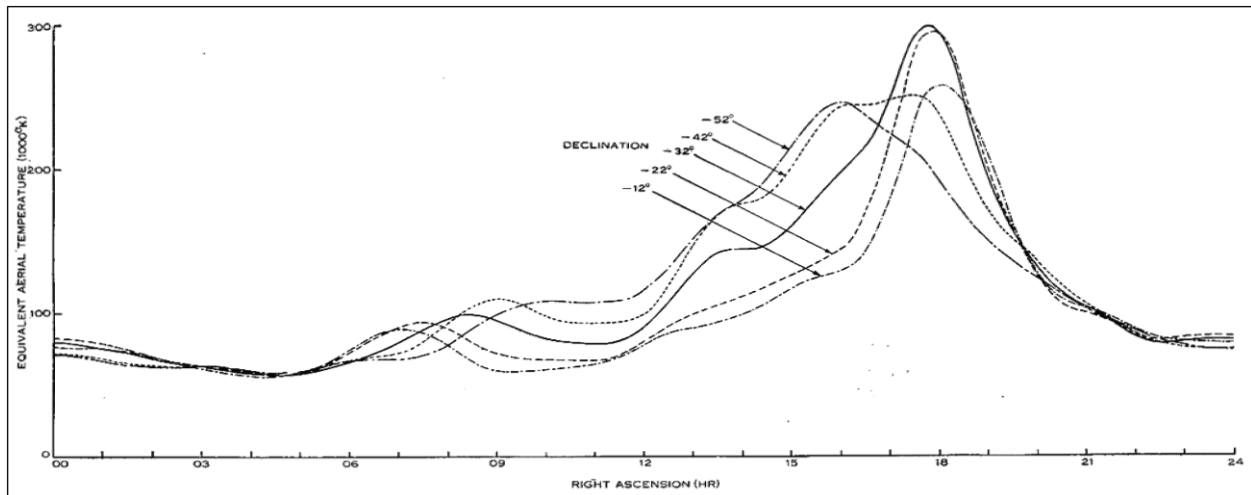


Figure 17: Plots of equivalent aerial temperature against right ascension for five different declinations (after Shain and Higgins, 1954a: 136).

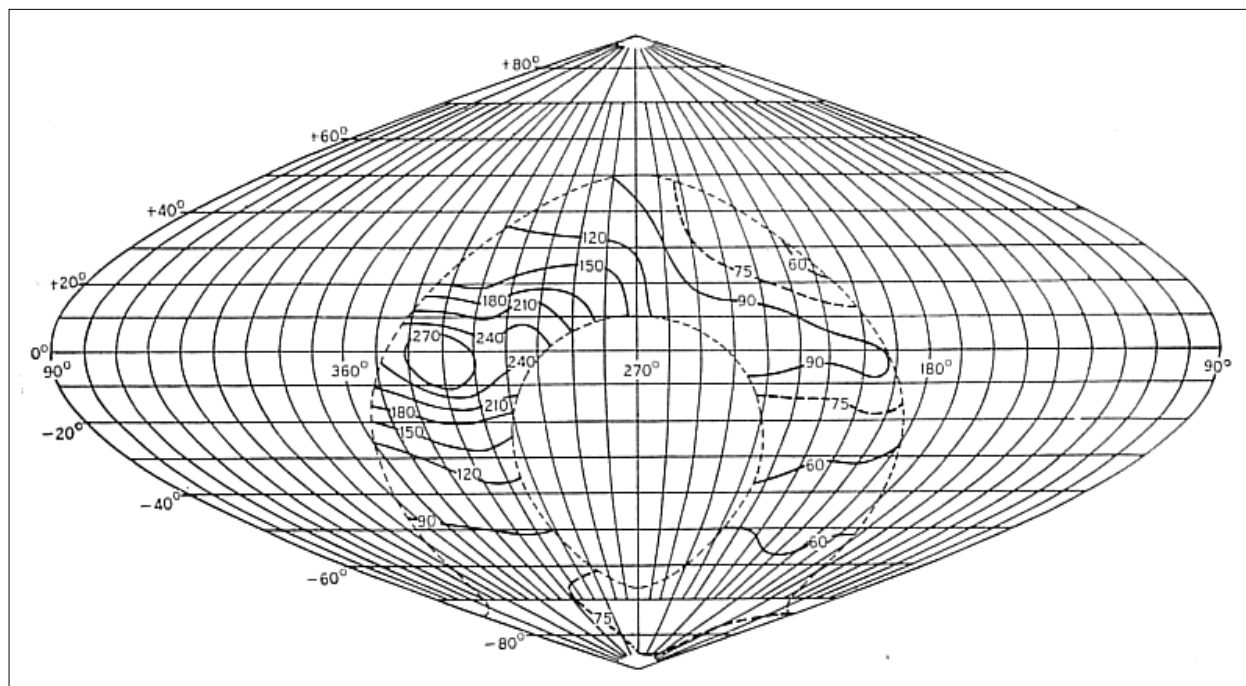


Figure 18: Contours of equivalent aerial temperature at 18.3 MHz plotted in galactic co-ordinates (after Shain and Higgins, 1954a: 137).

Westfold (1950), Shain and Higgins (1954a: 138) suggest that

Local differences in the shapes of the contours, for example in the regions near  $l = 80^\circ$ ,  $b = +20^\circ$  and  $l = 305^\circ$ ,  $b = +5^\circ$ , are probably due to the effects of discrete sources.

Shain and Higgins (1954a: *ibid.*) noted a number of other deviations in the contours, which they also attributed to discrete sources:

Since the objects giving rise to the localized increases in intensity must subtend an angle somewhat less than the beam width of the aerial and some at least correspond in position with discrete sources observed at higher frequencies, they have been called discrete sources; it should be remembered that they could have an angular size of several degrees. However, associated with some of these increases were short duration (order of 1 min)

fluctuations in the received intensity and, as discussed later, this observation suggested that some at least of the discrete sources would subtend angles of the order of  $1^\circ$  or less.

A careful analysis of the observational results produced a total of 37 discrete sources, and these are listed below in Table 1 and numbered following the scheme suggested by Mills (1952), where the hour of right ascension is followed by the sign and tens of degrees of the declination, "... so that the designation of a source gives an indication of its position." (Shain and Higgins, 1954a: 141). In order to differentiate their own sources from those detected by Mills, Shain and Higgins prefixed their sources with an 'S' (thus S00-1, etc.). In commenting on entries in this table, Shain and Higgins (1954a: 141) noted that

Table 1: Discrete sources observed at 18.3 MHz (after Shain and Higgins, 1954a: 140).

Source (S)	R.A. (hr min)	Decl. (°)	<i>l</i> (°)	<i>b</i> (°)	Flux Density (S) ( $10^{-23} \text{W m}^{-2} \text{Hz}^{-1}$ )	Level ( $L = 25 + \log_{10} S$ )	Notes
00-1	00 23	-19	65	-81	1500	3.2	
01-2	01 34	-20	150	-75	1100	3.0	
03-4	03 24	-41	211	-54	350	2.5	
04-2	04 22	-21	185	-39	700	2.8	
05-4	05 12	-45	217	-35	350	2.5	
06-1	06 05	-18	192	-16	1000	3.0	
06-3	06 22	-33	209	-18	350	2.5	
06-5	06 21	-51	227	-24	850	2.9	
07-1	07 10	-18	199	-02	1200	3.1	
08-4	08 20	-43	228	-03	700	2.8	
09-1	09 23	-12	214	+28	400	2.6	
09-3	09 20	-34	234	+12	700	2.8	
09-5	09 55	-53	246	+02	800	2.9	
10+1	10 45	+16	199	+61	1300	3.1	
10-1	10 20	-10	224	+39	800	2.9	
12+1	12 30	+11	262	+73	1100	3.0	
12-0	12 53	-01	277	+61	4100	3.6	Intensity uncertain: confusion with S12-1
12-1	12 24	-14	263	+47	1500	3.2	
13-2	13 20	-22	284	+40	2000	3.3	
13-3	13 44	-33	285	+27	650	2.8	
13-4	13 25	-43	279	+18	5300	3.7	Centaurus A
13-5	13 00	-58	273	+05	3300	3.5	Declination uncertain
14-4	14 45	-42	293	+15	5300	3.7	
15-1	15 21	-16	317	+31	1000	3.0	
15-6	15 35	-61	290	-05	6300	3.8	Declination uncertain
16-3	16 02	-39	308	+08	3800	3.6	
18-2	18 20	-28	332	-09	5700	3.8	
19+0	19 30	+02	08	-10	1100	3.0	
19-2	19 40	-20	349	-23	650	2.8	
20+x	20 02	+x	--	--	(660000)	(4.8)	Influenced by Cygnus A?
20-4	20 06	-47	320	-34	350	2.5	
21-1	21 20	-15	05	-42	1400	3.1	
21-2	21 50	-25	354	-52	500	2.7	
21-3	21 05	-30	344	-44	800	2.9	
21-5	21 56	-52	311	-51	250	2.4	
23-2	23 20	-25	05	-72	1550	3.2	
23-5	23 30	-51	295	-64	250	2.4	

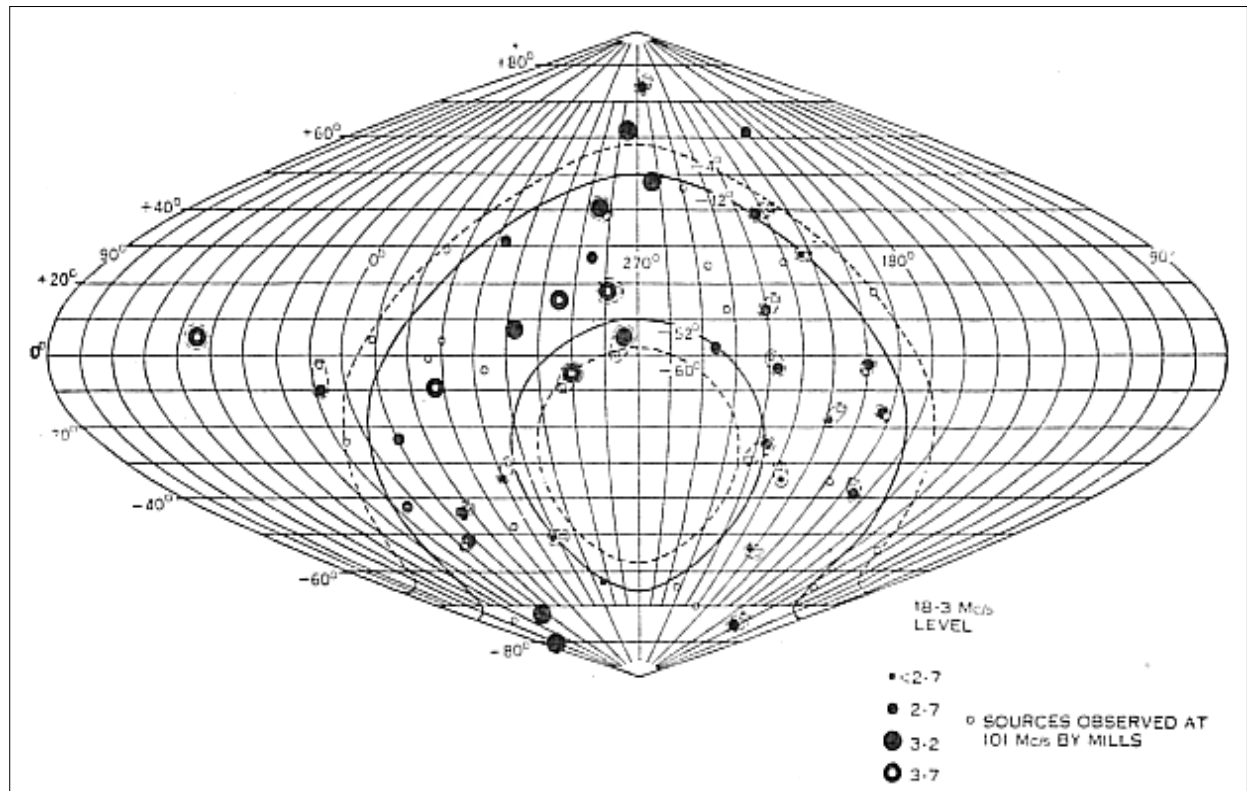


Figure 19: The galactic distribution of discrete sources detected at 18.3 MHz, compared with those recorded by Mills at 101 MHz (after Shain and Higgins, 1954: 142).

In general, for all the sources, positions could be assigned only roughly, with an estimated probable error of up to 5° for the weaker sources, although the uncertainty was somewhat lower for the stronger sources. Similarly, the estimated probable errors in the intensities vary from about ±20 per cent, for the strongest to a factor of 2 for a few of the weakest sources.

With these concerns about positional accuracy in mind, Shain and Higgins then plotted the distribution of these discrete sources in galactic co-ordinates, as shown in Figure 19. Source intensities were plotted using the values of 'L' included in Table 1, with the solid lines and the dashed lines indicating the limits of the array's maximum and half-power points during the survey. Also shown in this plot are the positions of discrete sources detected by Mills (1952) at 101 MHz from the Badgers Creek field station. Sources that probably were detected in both surveys have dashed lines drawn around them.

Shain and Higgins then analysed their 18.3 MHz sources using the same method that had been adopted by Mills (ibid.), namely:

The logarithm of the number of sources with level  $L$  or greater is considered as a function of  $L$ . If there is a random distribution of a large number of sources, this function should be a straight line having a slope  $-1.5$ . (Shain and Higgins, 1954: 142).

When they plotted their sources (Figure 20), Shain and Higgins, found that they lay on a straight line with a slope of  $-1.1$ , which was similar to Mills' results. Then, upon carrying out further analyses of their sources, Shain and Higgins found that sources lying  $>18^\circ$  from the galactic plane did have a slope of  $-1.5$ , while a figure of  $-1.3$  was obtained for sources nearer the galactic plane, indicating that sources located at  $>18^\circ$  "... are distributed homogeneously whereas the ... [remaining sources] include some other class of source." (Shain and Higgins, 1954: 143). They do not speculate on the nature of these 'anomalous' sources.

Shain and Higgins also tried to use scintillations to investigate the angular sizes of their sources. They noticed that

Soon after recording began it was noticed that there were often irregular fluctuations in intensity at times when it appeared that a discrete source was passing through the aerial beam, although there were some sources which were rarely, if ever, seen to fluctuate in intensity. (Shain and Higgins, 1954: 143–144).

Scintillation indices were then calculated for 12 sources and plotted as a function of month of the observations (Figure 21) and the time when the observations were made (Figure 22, where the dashed curve shows the diurnal variation of the scintillation index determined by Ryle and Hewish (1950) for four northern sources).

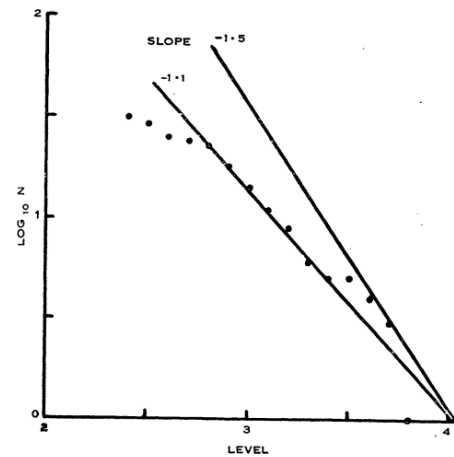


Figure 20: A plot of  $L$  versus  $\text{Log}_{10} N$  for all sources between  $-04^\circ$  and  $-60^\circ$  (after Shain and Higgins, 1954: 143).

As Shain and Higgins (1954: 145–146; our italics) noted,

Both figures show a considerable scatter in the values of scintillation index. Although high values ... have not been observed during the winter nor during the midday and afternoon hours, this does not imply marked seasonal and diurnal variations since the sources with high scintillation indices have not been observed at these times. *In fact, no significant trends can be deduced from these data ...* and there are wide differences in the scintillation indices for different sources, even when observed at approximately the same time of day in the same season.

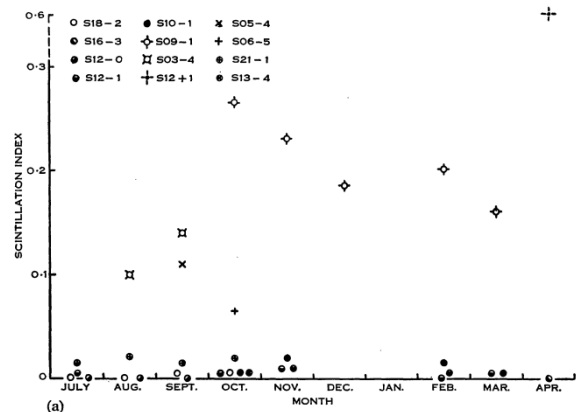


Figure 21: A plot of scintillation indices versus month of observations for 12 sources (after Shain and Higgins, 1954: 145).

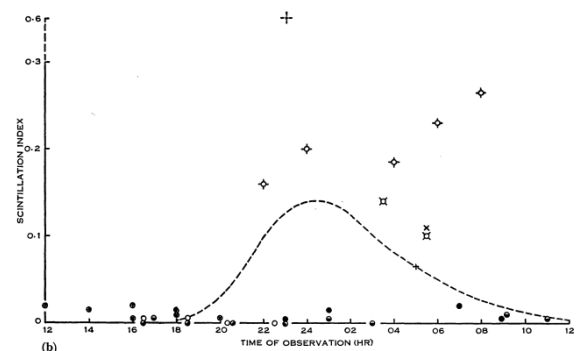


Figure 22: A plot of scintillation indices versus time of observations for 12 sources (after Shain and Higgins, 1954: 145).

Table 2: A list of the scintillation indices of different discrete sources observed at 18.3 MHz (after Shain and Higgins, 1954: 147).

Scintillation Index			
<0.01	0.02	0.1	>0.2
S12-0	S10-1	S03-4	S09-1
S12-1	S13-4	S05-4	S12+1
S16-3	S21-1	S06-5	
S18-2			

Nevertheless, on the assumption that the derived scintillation indices relate directly to the angular sizes of the sources, Shain and Higgins went on to assign the different sources in Figures 21 and 22 to the four categories shown in Table 2, where the four columns (from left to right) equate to angular sizes of  $\geq 1^\circ$ ,  $0.5-1^\circ$ ,  $\sim 0.5^\circ$  and  $<0.5^\circ$  respectively. They noted that "Although there may be some doubt as to the absolute scale of sizes, the table should give a good indication of relative angular sizes." (Shain and Higgins, 1954: 147).

Shain and Higgins then discuss the irregularities in the ionosphere responsible for the source scintillations on the basis of their 18.3 MHz sources and results obtained by Hewish (1952) and Bolton, Slee and Stanley (1953) at frequencies near 100 MHz and Ryle and Hewish (1950) at 81 MHz. They conclude:

Several authors (e.g. Little and Maxwell 1951) have shown that the lateral dimensions of the irregularities are about 4 km. This would be the diameter of the first Fresnel zone for 18.3 Mc/s at a height of about 500 km ... [but] such a height would be an upper limit. A lower limit cannot be set definitely. For example, if the irregularities causing scintillations were in the E

region (at a height of about 120 km) a size of about 1 km would be only about twice the diameter of the first Fresnel zone, so that this height could not be excluded.

Of course these arguments break down if the irregularities causing the scintillations at higher frequencies are different from those affecting the 18.3 Mc/s radiation. (Shain and Higgins, 1954: 148).

Finally, Shain and Higgins (ibid.) make an interesting point in the concluding section of their paper:

Although, for different frequencies there are important differences both in absolute intensities and in the distribution of brightness over the sky, these [18.3 MHz] observations have confirmed earlier conclusions that the variation with frequency of the characteristics of cosmic noise is smooth, so that useful comparisons can be made between observations at comparatively widely-spaced frequencies.

In fact, Shain (1954a) followed up this suggestion by publishing a separate paper titled "A comparison of the intensities of cosmic noise observed at 18.3 Mc/s and at 100 Mc/s", but this will not be discussed here as it lies outside the scope of this paper.

### 2.4 The 9.15 MHz Galactic Survey

After completing their 18.3 MHz survey Shain and Higgins decided to focus on a lower frequency, and between July 1951 and September 1952 they surveyed the sky at 9.15 MHz (the lowest frequency attempted by radio astronomers to that date, apart from a few observations made at 9.5 MHz by Friis and Feldman in 1937).

The aerial consisted of an array of 12 horizontal half-wave dipoles arranged as shown in Figure 23. In order to reduce ground losses,

... wires parallel to the dipoles and extending  $\frac{1}{4}$  wavelength beyond each end of the array were laid 2 ft apart on the ground underneath the array. (Higgins and Shain, 1954: 461).

Each dipole

... had a balance-unbalance transformer and a separate coaxial feeder which was taken to a hut in the centre of the array. In this hut the feeders were grouped as shown in Figure 1 (b) [Figure 24, here] with a matching network at each junction to match the impedances to the characteristic impedance of the cables used. (ibid.).

A line was taken from the central hut to another outside the array, which contained a standard communications receiver with a bandwidth of 400 kHz. This radio telescope had a half-power beamwidth of  $31^\circ$  NS  $\times$   $26^\circ$  EW, and was directed at a strip of sky centred on declination  $-32^\circ$ . Note that there was no facility for beam-switching, so the array could operate only as a transit instrument at the declination of the zenith.

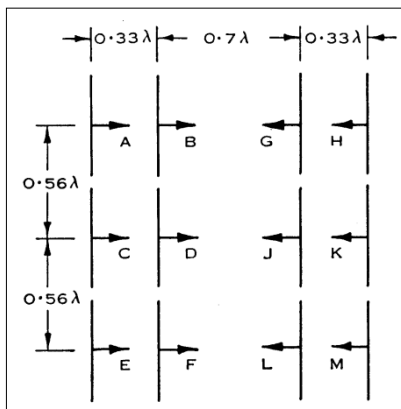


Figure 23: Plan of the 9.15 MHz array (after Higgins and Shain, 1954: 461).

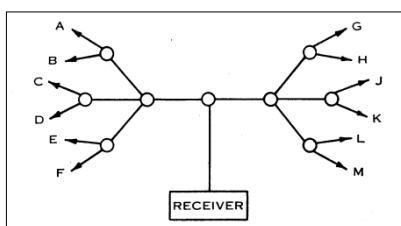


Figure 24: A schematic diagram showing feeder connections. The letters relate to the dipoles in Figure 23 (after Higgins and Shain, 1954: 461).

As might be expected at 9.15 MHz, interference from atmospherics and radio stations was an issue, and this is clearly illustrated in Figure 25. But at times when such interference was absent and ionospheric absorption was small, "... a background intensity, which varied with sidereal time, was observed consistently and this was undoubtedly due to cosmic noise." (Higgins and Shain, 1954: 460). Most of the useful observations were carried out between midnight and sunrise, the objective being "... to obtain as large a number of records as possible ... [even if] only an hour's duration ... In the course of a year sufficient samples to cover a full sidereal day could be obtained." (Higgins and Shain, 1954: 463).

When combined, and corrected for ionospheric absorption at 9.15 MHz, these drift scans showed clear evidence of galactic plane emission (see Figure 26), but Higgins and Shain (1954: 464–465) cautioned that "... a contribution from atmospherics to the received noise ... cannot be completely ruled out ... [although it] must be very small."

Higgins and Shain (1954) noted that the smoothed curve plotted in Figure 26 is similar to their 18.3 MHz curve and the one for 100 MHz, although the peak intensities differ significantly, and this is illustrated in Figure 27. However, the 18.3 and 100 MHz curves in this figure are calcu-

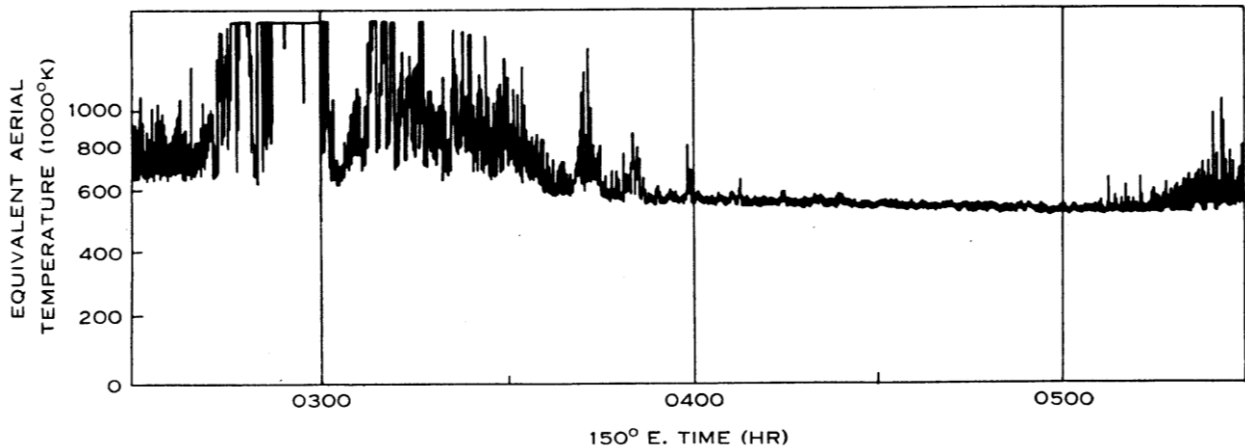


Figure 25: A record made on 23 August 1951 showing interference caused by atmospherics and radio stations. Atmospherics, which appear on the record as spikes, are very frequent at about 0230 hr, while radio station interference is strong at around 0240 hr. Both diminish after 0400 and the record is largely clear of interference until after 0410. The gradual drop in received power between 0400 and 0500 represents a genuine decline in cosmic noise intensity (after Higgins and Shain, 1954: 463).

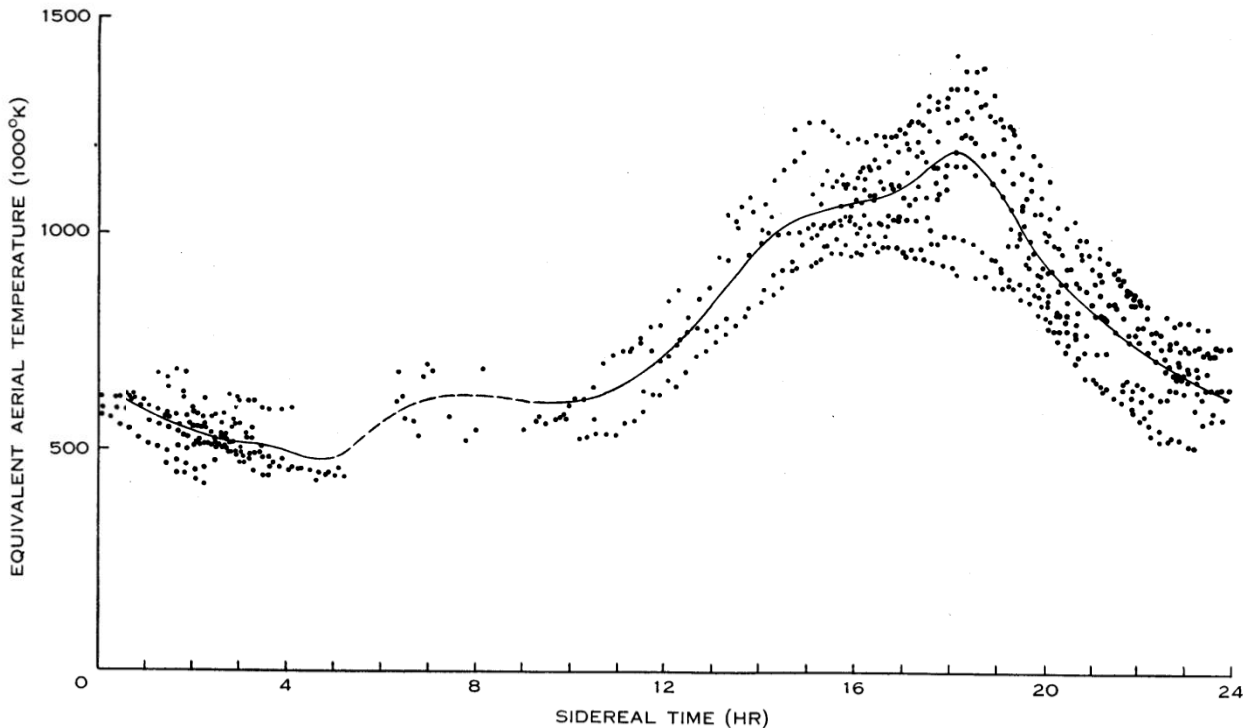


Figure 26: Plots of equivalent aerial temperature against sidereal time for all successful observations, and corrected where necessary for the effects of ionospheric absorption. The curve is drawn through hourly averages, except for the dashed section where there are inadequate data. The accuracy of the solid curve is estimated to be better than 10%, and the dashed section ~20% (after Higgins and Shain, 1954: 466).

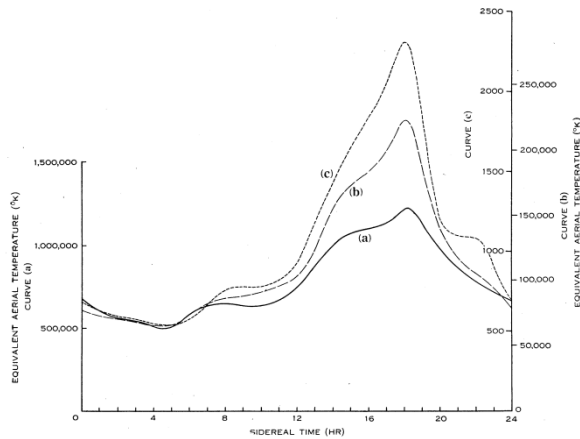


Figure 27: A comparison of the equivalent aerial temperatures at three different frequencies, 9.15 MHz (a), 18.3 MHz (b), and 100 MHz (c) (after Higgins and Shain, 1954: 467).

lated values, as Higgins and Shain (1954: 466) explain:

The equivalent aerial temperature is the average, weighted according to the aerial sensitivity in different directions, of the brightness temperatures over the visible sky. If observed equivalent aerial temperatures are available for a single lobe aerial, aerial A, say, having a comparatively small beam width, it is possible to determine the equivalent temperature that would be observed by a broader-beamed aerial by taking suitably weighted averages of the equivalent temperatures seen by aerial A when pointed in appropriate directions. This procedure was adopted to obtain the equivalent aerial temperatures that would have been observed at 18.3 Mc/s and at 100 Mc/s with an aerial having the same directivity (and side lobes) and pointed in the same direction as that used for the 9.15 Mc/s observations.

It is these curves that are plotted in Figure 27.

When Higgins and Shain plotted the maximum and minimum values of equivalent aerial temperature shown in Figure 27 against frequency (see Figure 28) they found that the points followed the relation

$$T \propto f^{-2.8} \tag{1}$$

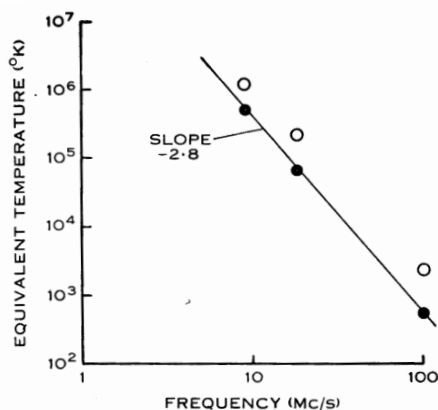


Figure 28: A plot of minimum and maximum equivalent aerial temperatures (dots and circles, respectively) versus frequency (after Higgins and Shain, 1954: 468).

where  $T$  (in K) is the minimum equivalent temperature observed at a frequency  $f$  (in MHz).

Higgins and Shain also examined the minor irregularities in the 9.15 MHz curve plotted in Figure 27, and used the existence of discrete sources to explain these:

Calculations showed that passage of the aerial beam over discrete sources previously observed at 18.3 Mc/s could account for these bumps at 18.3 Mc/s, and the presence of similar bumps at 9.15 Mc/s suggests that discrete sources are contributing appreciably to the radiation at 9.15 Mc/s. No accurate evaluation of source intensities can be made, but it appears that at 9.15 Mc/s they stand out against the background at least as clearly as at 18.3 Mc/s, possibly more so. (Higgins and Shain, 1954: 468).

In the concluding pages of this pioneering paper, Higgins and Shain (1954: 468) note that

Quantitatively, at least, the 9.15 Mc/s results fit the assumptions of an origin in discrete sources together with an absorbing (at 9.15 Mc/s) disk of interstellar gas ... From Shain's result [at 18.3 MHz] it would be expected that near the galactic centre the optical depth for 9.15 Mc/s radiation would be greater than unity for latitudes within  $10^\circ$  of the galactic equator. This could then account for the comparatively low value of the maximum temperature at 9.15 Mc/s ...

Meanwhile, these results "... are in accordance with what would be expected on current theoretical ideas." (Higgins and Shain, 1954: 470).

### 2.5 The Positions of 18.3 MHz Solar Bursts

In 1959 Shain and Higgins published a paper about the positions of solar bursts observed with the 19.7 MHz Shain Cross at the Fleurs field station. What interests us here is that this paper also includes data on solar bursts observed in 1950–1951 with the second 18.3 MHz array at Hornsby Valley, and we discuss these here.

Because the 18.3 MHz aerial was a linear array (not a 'Shain Cross'), the positions of solar bursts could be measured only in one coordinate. With this caveat in mind, Table 3 lists the derived positions of 18.3 MHz bursts recorded at Hornsby Valley in the course of the galactic observations. Note, however, that these positions, which are listed to the nearest  $5'$ , have an uncertainty of  $\pm 0.3^\circ$  because of problems in estimating atmospheric refraction. Furthermore, the 'Optical Regions' (using numbers listed in the *Quarterly Bulletin of Solar Activity*) are those most likely to have been associated with the radio events, and 'F' indicates that a flare occurred when the radio observations took place.

When data listed in the second and fourth columns in this table are plotted (Figure 29), we see that there is a strong correlation between the



two parameters, although this is partly due to observational selection in that optical regions were chosen to fit the radio data. Nonetheless,

... we deduce that in 1950–1951 the 18.3 Mc/s sources were at a radial distance of  $3.5R_{\odot}$  from the centre of the Sun ... although this value is rather uncertain because of the scatter of the points and the basic uncertainties in identifying the optical sources. (Shain and Higgins, 1959: 367).

Yet Potts Hill data available at 97 MHz at that time tended to confirm the 18.3 MHz heights, and indicate that

... the sources of emission were rather higher in the corona than might have been expected on the basis of the Baumbach-Allen model of the corona ... (Shain and Higgins, 1959: 357).

As we shall see in a later paper in this series, the 19.7 MHz results obtained at Fleurs field station subsequently would confirm this contentious Hornsby Valley result.

### 2.6 The Pre-Discovery of Jovian Decametric Emission

There is one final aspect of the Hornsby Valley research that deserves to be told and this is the serendipitous ‘pre-discovery’ of Jovian decametric emission.

As we have seen, terrestrial interference was a common problem encountered by radio astronomers who worked at low frequencies, and Shain and Higgins probably regarded this as a nuisance and a distraction. This, too, was the initial attitude of the U.S. duo of Bernard Flood Burke (b. 1928; Figure 30) and Kenneth Linn Franklin (1923–2007) when they encountered ‘interference’ while conducting research with the Carnegie Institution of Washington’s 22 MHz Mills Cross-type radio telescope (Figure 31)<sup>6</sup> that was located at Seneca, Maryland, ~32 km northwest of Washington DC. However, when they analysed their ‘interference’ they discovered, to their surprise, that it originated from Jupiter. Accordingly, in 1955 they announced their discovery in a paper published in the *Journal of Geophysical Research*. This was not a journal that habitually was read by radio astronomers, but the magnitude of this discovery—the first detection of radio emission from a planet in our Solar System other than the Earth—guaranteed that it found its way into *Nature* (Radio emission from Jupiter, 1955), and this gave it a very wide audience (cf. Franklin and Burke, 1956; Franklin, 1959).

Franklin (1959: 37–38) later described the excitement of the discovery. Early in 1955 he and Burke were observing near the Crab Nebula (Taurus A), and the records

... showed the characteristic hump as the Crab Nebula passed through the pencil beam

Table 3: 18.3 MHz solar bursts observed at Hornsby Valley in 1950–1951 (adapted from Shain and Higgins, 1959: 361).

Date	$HA_r - HA_s$ (°)	Optical Region	$HA_o - HA_s$ (°)
• 1950 •			
Nov 16	00	8 F	00
Nov 17	+20	----	----
• 1951 •			
Jan 30	+10	7	+04
Feb 01	+40	7 F	+09
Feb 02	+20	5 F	+06
Feb 24	-05	13	-01
Mar 16	-40	18	-13
Mar 17	-25	18	-12.5
Mar 18	-35	18	-12
Mar 19	+10	18	-09.5
Mar 20	-10	18	-07
Mar 22	-10	18	-0.5
Mar 24	+05	18	+05.5
Mar 25	+50	18	+08.5
Mar 26	+80	18	+11

\* Key:  $HA_r$  = Hour angle of the Radio Source  
 $HA_s$  = Hour angle of the Sun  
 $HA_o$  = Hour angle of the Optical Region

... followed by a smaller hump ... attributed to IC443. At times the records exhibited ... interference ... [after] the passage of the two known sources. This intermittent feature was curious, and I recall saying once that we would have to investigate the origin of that interference some day. We joked that it was probably due to the faulty ignition of some farm hand returning from a date.

[Later] ... Burke assembled all the records of the Taurus region for the first three months of 1955 ... [and was] startled to find that the interference always occurred at almost the same sidereal time. A strange rural romance this was turning out to be! As spring drew nearer, our swain was returning home earlier

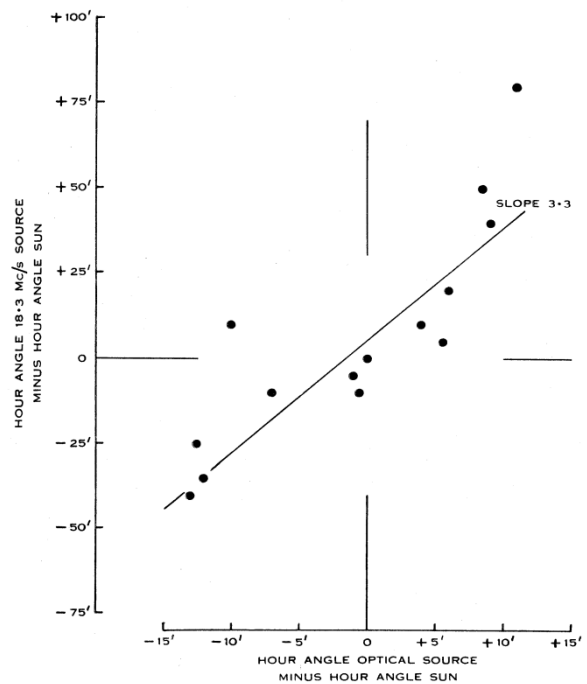


Figure 29: A plot of the observed E-W displacements from the centre of the Sun of the 18.3 MHz sources listed in Table 3 (after Shain and Higgins, 1959: 362).



Figure 30: Bernard Burke (left), and Radio Jove's Chuck Higgins (right)—no relation to Australia's Charlie Higgins—meet in April 2005 during the dedication ceremony of an historical marker on the 50<sup>th</sup> anniversary of the discovery of Jovian decametric emission near Seneca, Maryland (<http://radiojove.gsfc.nasa.gov/library/newsletters/2009Apr/>).

and earlier, each evening ...

The late Howard Tatel, a man of many parts, was present in the Laboratory ... [and] somewhat facetiously suggested to Burke and me that our source might be Jupiter. We were amused at the preposterous nature of this re-

mark, and for an argument against it I looked up Jupiter's position in the American Ephemeris and Nautical Almanac. I was surprised to find that Jupiter was just about in the right place, and so was Uranus. Here was something which needed clearing up ....

[After investigating and eliminating Uranus] I began to plot the right ascensions of Jupiter. As I plotted each point, Burke, who was watching over my left shoulder, would utter a gasp of amazement. Each point appeared right between the boundary lines representing the beginning and end of each event. The meaning was exquisitely clear: these events were recorded only when Jupiter was in the confines of the narrow principal beam of the Mills Cross. Not only did the source have the same direction in space as Jupiter, but it also exhibited the same change of direction as Jupiter did its retrograde loop of 1955. No other object could satisfy the data: the source of the intermittent radiation was definitely associated with Jupiter.

Among the international colleagues Burke and Franklin contacted following their discovery was Alex Shain in Australia, and "He set up operations at 19 MHz and confirmed that Jupiter was busy." (Franklin, 1983: 255). But Shain actually did more than this. He recalled those periods of intense 18.3 MHz 'static' that he and Higgins had recorded (e.g. see Figure 32) at the Hornsby Valley field station in 1950 and 1951, and he decided to revisit these.



Figure 31: A view looking along one of the arms of the 22 MHz Mills Cross at Seneca, Maryland. Each arm was 624 metres long, and contained 66 dipoles (courtesy: Carnegie Institution of Washington).

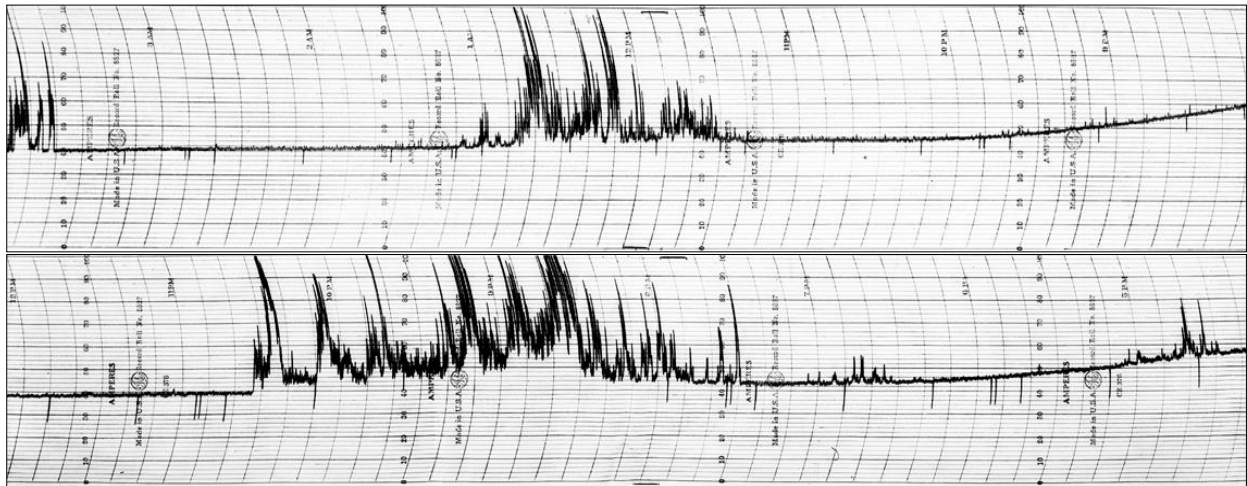


Figure 32: Examples of 18.3 MHz Jovian bursts recorded at Hornsby Valley in 1950–1951. Dates of the observations are 17 October 1950 (top) and 29 October 1950 (bottom) (adapted from CSIRO RAI: B3719-13).

Shain (1955b) reported his initial results in a paper published in *Nature* on 29 October 1955, a mere four months after the appearance of Burke and Franklin's 'discovery paper'. He noted that there were two chronological series of Hornsby Valley records:

(1) October 1950–April 1951, when the beam-width of the aerial was  $17^\circ$ , and Jovian emission was recorded on about half of all days when the antenna was directed towards Jupiter and terrestrial interference was absent. Moreover,

For some of these records more accurate direction-finding was possible using a split-beam technique, and these records proved that the position of the source was within  $\pm 1^\circ$  of Jupiter. (Shain, 1955b: 836).

This was clear confirmation of Burke and Franklin's results.

(2) 15 August–2 October 1951, when the array had been modified so that it was narrow in declination but very broad in hour angle. This allowed continuous observations for nearly 8 hours, which encompassed almost one complete rotation of Jupiter. During this period, Jovian bursts were recorded on 27 of the 30 days when suitable records were obtained.

However,

A most interesting new fact coming out of the examination of these records was the very close relation between the times of occurrence of bursts and the rotation of Jupiter. (*ibid.*)

Jupiter exhibits differential rotation, with the polar regions rotating more slowly than the equatorial zones. Accordingly there are two different recognised periods of rotation, which are referred to as System I (9h 50m 30.003s) and System II ( $\sim$ 9h 55m 40.632s). When Shain plotted the occurrence times of Jupiter bursts against the Jovian longitude of the central meridian for the two different Systems he found two distinct patterns—as illustrated in Figure 33. Jovian

bursts varied widely in Joviocentric longitude in the System I plot, but were almost aligned under one another in the System II plot, indicating that the rotation period ( $P$ ) of the source of the emission was close to that of System II. Upon allowing for the slight negative drift in the System II plot, Shain (1957: 398) was able to derive a value of

$$P = 9\text{h } 55\text{m } 13 \pm 5\text{s}$$

for the source. Furthermore, when a histogram of the Joviocentric longitude of the emission was plotted (Figure 34) it showed that

... for a band of longitudes centred on  $67^\circ$  and extending from  $0^\circ$  to  $135^\circ$ , the frequency of occurrence was much greater than outside this band. This suggests an origin in a very localized source on Jupiter. Since there are about 120 rotations of Jupiter during the period of observations on which the figure is based, the probability that the effect observed is due to chance is extremely small. (Shain, 1955b).

But Shain took his analysis one step further and actually identified the source of the emission! He noted that the Jupiter Section of the British Astronomical Association had provided him with a drawing by E.J. Reece (Figure 35) that showed a conspicuous white spot

... at the boundary between the South Temperate Zone and the South Temperate Belt, which was observed for several months, [and] had an observed rotation period of  $9^{\text{h}} 55^{\text{m}} 13^{\text{s}}$ , that of the radio source ... although the identification is not proved beyond all doubt, *it seems very probable that this visually-disturbed region was responsible for the radio radiation* ... (Shain, 1957: 398–399; our italics).

Shain (1956) elaborated on these initial investigations in a more detailed paper that was published in the *Australian Journal of Physics* in 1956. In a preamble, he noted that

During the rapid development of radio astronomy in the last 10 years, the question has some-

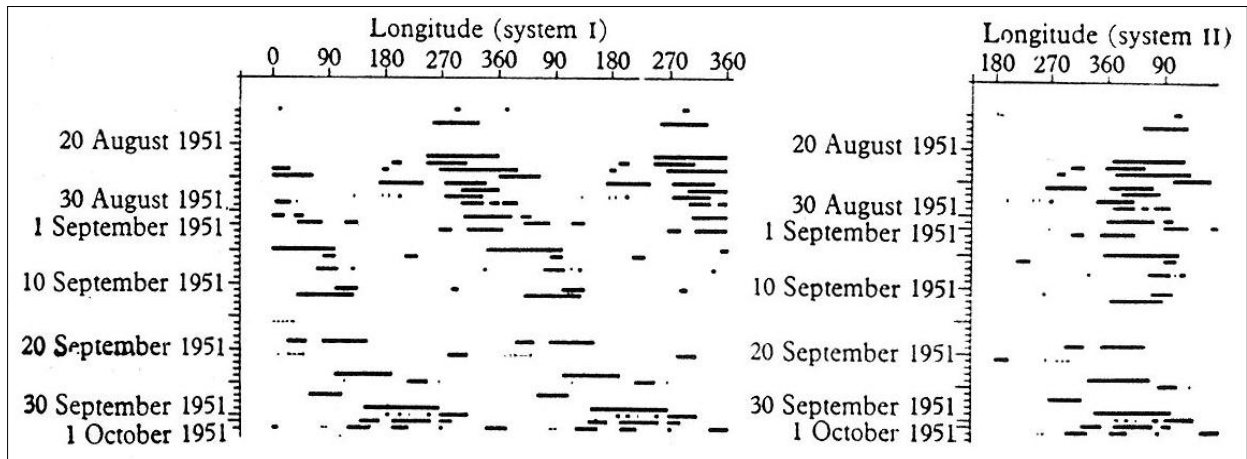


Figure 33: Periods of occurrence of 18.3 MHz emission in 1951 plotted against Jovicentric longitude (after Shain, 1957).

times been raised as to whether radiation from any of the planets could be detected. The detection of thermal radiation would appear to be at present impracticable, but it has been suggested (Higgs 1951) that electrical discharges analogous to terrestrial lightning flashes may occur in the atmosphere of Venus and that radiation from such discharges may be detectable. In 1955, however, came the quite unexpected announcement by Burke and Franklin (1955) that very intense radiation at 22 Mc/s had been received from ... Jupiter ...

Upon discussing the 18.3 MHz Hornsby Valley galactic survey records from 1950–1951 Shain explained that

... a watch was kept for peculiarities on the records, especially for bursts of solar noise and for variations caused by abnormal ionospheric attenuation. Quite frequently there was interference from atmospherics and radio stations; *thus no particular significance was attached to the occurrence of occasional groups of bursts during the night.* (Shain, 1956: 62; our italics).

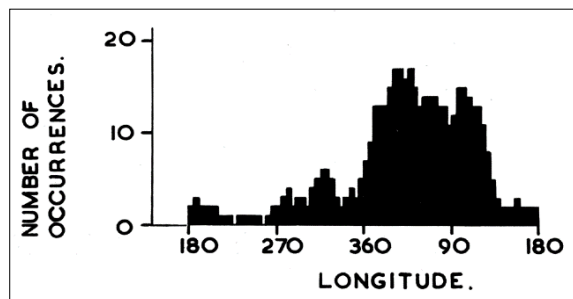


Figure 34: Histogram of the occurrence frequency of 18.3 MHz Jovian emission plotted against System II Jovicentric longitude (after Shain, 1956: 68).

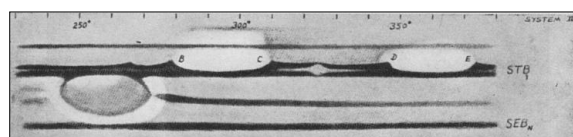


Figure 35: A drawing of part of Jupiter's disk on 29–30 November 1951 UT. The radio emission was observed only until 2 October, but its extrapolated longitude on 29 November is 354° the precise position of the right hand white spot (after Shain, 1956: 70).

The focus was very much on the distribution of galactic emission and discrete sources and much less so on solar emission and atmospherics at 18.3 MHz, so there simply was no time (and perhaps inclination) to investigate these occasional groups of anomalous bursts—which were dismissed as interference.

In this paper, Shain (1956: 62) also explains how it was that the 1951 Jovian observations were possible:

In June 1951 part of the original aerial had been dismantled, but a single receiver was used to measure the noise picked up by the remaining ten dipoles, which had an aerial diagram narrow in the north-south direction but very broad in the east-west direction.

Although it certainly was not anticipated at the time, fortuitously this aerial proved to be ideal for the monitoring of Jupiter over the course of almost one entire rotation each time an observation was recorded. Thanks to this the Jovicentric longitude distribution of the emission could be investigated and this in turn suggested that much of the emission came from a single source.

During the first suite of observations, made with the full array, sometimes the sound of what later proved to be Jovian bursts was noted:

Notes written on some records indicate that many bursts sounded like “swishes” (similar to solar bursts, with which they were confused) and therefore the recorder followed these noise variations faithfully. On some other occasions there were sounds suggesting the presence of short impulses which the recorder would not follow. (Shain, 1956: 63).

So, unknowingly, Shain and Higgins were the first to hear Jovian bursts (and record radio emission from another planet in our Solar System).

In his detailed paper, Shain also comments on the primary emission peak shown in Figure 33, and he provides several explanations for it, assuming all along that it is a single source of radiation on the basis that “... the emitting reg-

ion was probably small in extent to give an “emission polar diagram” of much less than  $180^\circ$ .” (Shain, 1956: 69). Surprisingly, there is no suggestion that the ‘primary peak’ may comprise three overlapping Gaussian curves associated with strong sources located at Joviocentric longitudes of  $\sim 40^\circ$ ,  $70^\circ$  and  $110^\circ$ , plus a fourth, very much weaker, source at  $\sim 315^\circ$ .

An interesting new section in Shain’s 1956 paper relates to three Jovian satellite occultations that occurred when the radio observations were made. The records were examined

... to see whether there were any marked changes, corresponding to occultations, which would help to locate the source. On one occasion there was no effect at all, and on a second there was only a very doubtful suggestion of an occultation ...

On the third occasion, during the transit of Satellite II on September 24, there was a sudden cessation of the noise as the satellite reached the meridian of the source, at  $03^h 10^m$ . This may have been a coincidence, since the noise had already been received for over 2 hr, but on one or two other days noise had been received continuously for over 4 hr. At  $03^h 10^m$  the source was still within  $25^\circ$  of the central meridian and as there was weak noise again  $32^m$  later, there is a reasonable probability that the sudden decrease in intensity was due to an occultation of the source.

All of this is academic of course, if more than one primary source of emission was involved.

Finally, in another expansion of the material presented in his *Nature* paper, Shain (1956: 71) discusses how variations in the intensity of the Jovian emission can potentially be used to investigate

... propagation conditions in interplanetary space near the plane of the ecliptic and especially along ray paths that pass near the Sun ... The observations described in this paper did not cover a very long period of time, but in the course of the year there were noteworthy changes in the characteristics of the radiation from Jupiter.

The changing duration of bursts is discussed as a possible mechanism that can be used to explore scattering in the outer corona.

### 3 DISCUSSION

#### 3.1 The 1952 URSI Congress

Every three years the International Union of Radio Science (or Union Radio Science Internationale, URSI) holds a Congress in a different international city. In recognition of Australia’s important contributions to ionospheric research and radio astronomy a decision was made to hold the 1952 meeting in Sydney. This was the first time a major URSI meeting had been held outside Europe or North America, and was fitting rec-

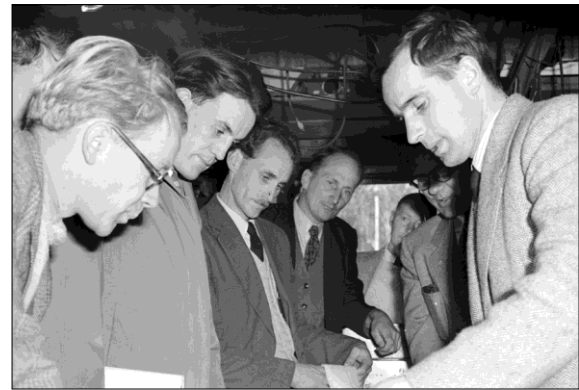


Figure 36: During the URSI visit to Hornsby Valley, Alex Shain (on the extreme right) discusses chart records with (left to right) Francis Graham Smith, Robert Hanbury Brown, Jim Hindman, Charlie Higgins, Joe Warburton and unidentified person X (mostly obscured) (courtesy: CSIRO RAIA 2842-133).

ognition of Australia’s important place in international radio science (see Robinson, 2002).

An important component of each URSI Congress was the field trips, and in 1952 visits were arranged to RP’s Dapto, Hornsby Valley and Potts Hill field stations. The Hornsby Valley visit offered Shain and Higgins an excellent chance to showcase their low frequency research and instrumentation to not only their RP colleagues (Chris Christiansen, Jim Hindman, and Joe Warburton), but also the leading British radio astronomers, Francis Graham Smith and Robert Hanbury Brown, and Marius Laffineur from France.

Fortunately, fair weather greeted those who chose the Hornsby Valley field trip, which was documented by RP’s photographers.<sup>7</sup> Figures 36 and 37 show Shain and Higgins discussing their observations with Graham Smith, Hanbury Brown and their RP colleagues, while Figure 38 shows the whole group assembled outdoors at the field station.



Figure 37: From left to right, Joe Warburton, Francis Graham Smith, Charlie Higgins, Robert Hanbury Brown, Jim Hindman (partly obscured), unidentified person X (almost totally obscured) and Alex Shain examine some of the chart records (courtesy: CSIRO RAIA 2842-132).



Figure 38: Radio astronomers from the 1952 URSI Congress shown at the Hornsby Valley field station. Alex Shain is on the extreme left, seated between Robert Hanbury Brown and unidentified person X. Francis Graham Smith (glasses) and unidentified person Y are at the end of the table. Opposite Shain and Hanbury Brown are (from left to right): Joe Warburton, Marius Laffineur (standing), Charlie Higgins (standing), Chris Christiansen and Jim Hindman. The antennas in the background formed part of the 9.15 MHz array (courtesy: CSIRO RAIA 2842-131).

### 3.2 Other Research in Radio Astronomy Conducted at Hornsby Valley

Along with Dr Alexander in New Zealand (Orchiston, 2005a), RP's Ruby Payne-Scott (1912–



Figure 39: Ruby Payne-Scott (courtesy: CSIRO RAIA).

1981; Figure 39; Goss and McGee, 2010; Goss, 2013) was a pioneering female radio astronomer. In 1947 she was carrying out solar research at Dover Heights field station, sharing the blockhouse and Yagi antennas with John Gatenby Bolton (1922–1993; Robertson, 2015), Gordon James Stanley (1921–2001; Kellermann et al., 2005) and Owen Bruce Slee (b. 1924; Orchiston, 2004; 2005b) who were researching what at the time were termed 'radio stars' (Robertson et al., 2014). However, tension soon arose between Bolton's group and Payne-Scott:

Part of the problem was that both groups often wanted to use the same piece of equipment at the same time, or one group wanted to carry out routine maintenance which might create radio interference for the other group. With space in the blockhouse limited, the two groups were getting in each other's way.

The main problem however was a personality clash between Bolton and Payne-Scott ...

[and] it is doubtful whether he had ever come across anyone like her. Most of his life had been spent in a largely all-male environment ... [Moreover,] Ruby had forthright views on all sorts of issues such as politics and women's rights. Many of the young Radiophysics staff held left-wing views, but Payne-Scott went one step further. She and her husband were card-carrying members of the Communist Party, earning her the nickname 'Red Ruby'. (Robertson, 2015: 65).

Eventually, the feud between the two came to a head, and Payne-Scott was forced to leave Dover Heights.

At the end of 1947 she transferred to Hornsby Valley, where she set up single 60, 65 and 85 MHz Yagi antennas (Figure 40). From January through to September 1948 she used these, plus an 18.3 MHz broadside array and Kerr and Shain's 19.8 MHz Moon-bounce rhombic antenna, to study solar emission. Most of the observations were made at 60 and 85 MHz, and crossed Yagis were used at 85 MHz to investigate the polarization of the solar bursts.

From these observations Payne-Scott (1949: 215) identified two different types of variable high-intensity radiation: 'enhanced radiation' and 'unpolarized bursts'. With the first of these,

The intensity reaches a high level and remains there for hours or days on end; there are continual fluctuations in intensity, both long-term and short-term. The short-term increases are

somewhat similar to [isolated] bursts ... but usually have a lower ratio of maximum to background radiation. This type of radiation will be called "enhanced radiation" ... Superimposed on it may be bursts ... There may be short periods during which the polarization is indefinite, either because two sources of opposite polarization are superimposed or because the radiation is linearly or randomly polarized, but for the great part of its life the enhanced level shows circular polarization of one sense or the other. (Payne-Scott, 1949: 216–217).

Figure 41 shows an example of this 'enhanced emission', which later was found to be characteristic of spectral Type IV solar emission.

The second type of solar radiation Payne-Scott investigated at Hornsby Valley was the 'unpolarized bursts', which showed

... a very good correspondence on different frequencies, though their shapes and relative amplitudes may vary considerably ... the closer the frequencies and the larger the bursts, the closer their relationship. Corresponding bursts do not appear to skip frequencies. Thus, if a burst appears on 95 and 19 Mc/s., there will be a corresponding burst on 60 Mc/s. ... A characteristic unpolarized burst shows a finite rise time, rounded top, and slow decay, reminiscent of the transient response of a medium with a natural resonant frequency ... There is no marked connexion between the rate of decay and the intensity of the burst ... [but bursts recorded at 18.3 and 19.8 MHz] have a mark-



Figure 40: The 60 MHz and 85 MHz Yagi antennas (on the left) and the 19.8 MHz rhombic antenna (centre and right) used by Ruby Payne-Scott for her solar observations in 1948 (courtesy: CSIRO RAIA B1266-2).

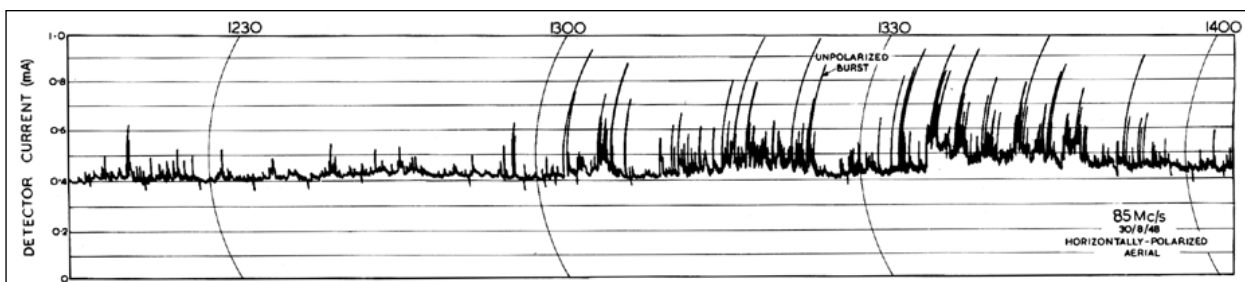


Figure 41: An example of 'enhanced emission' recorded on 30 August 1948 at 85 MHz. Observations were made with crossed Yagis and this chart record shows emission received with the horizontally-polarized aerial (after Payne-Scott, 1949: 218).

edly slower decay rate ... (Payne-Scott, 1949: 219–221).

This was important research, but since most of the solar emission investigated by Payne-Scott was recorded at 60 or 80 MHz, it lies beyond the scope of this paper (but, for further details, see Goss and McGee, 2010; Orchiston et al., 2006).

### 3.3 Low Frequency Radio Astronomy and the Ionosphere

The focus of this paper is the radar and low frequency radio astronomy that was carried out at the Hornsby Valley field station, but atmospheric effects played a key role in allowing or preventing the later investigations, as we have seen. Therefore, it is not surprising that Shain and a visiting Indian radio astronomer, A.P. Mitra, also wrote papers on changes in the different levels of absorption in the ionosphere.

Mitra and Shain (1953) showed that

...although the *D*-region generally makes the greater contribution to the absorption of 18.3 Mc/s cosmic noise during daylight hours, the *F*-region may produce considerable attenuation when  $f_oF_2$  is high. (Shain, 1955a: 347).

Meanwhile, Shain (ibid.) noted that

During ionospheric storms  $f_oF_2$  often departs considerably from its usual value for short periods, and it would be expected that, for at least the largest increases, there would be corresponding increases in the attenuation of cosmic noise.

Finally, Mitra and Shain (1954) demonstrated that variations in 18.3 MHz 'cosmic noise' could be used to detect short-term increases in *D*-region absorption following solar flares.

### 3.4 The Sequel: Fleurs

After completing the 9.15 MHz survey, Shain and Higgins were keen to develop a larger array with improved resolution, so they could continue their low frequency research, but there was a problem. While Hornsby Valley was radio-quiet, and was accessible by car and rail from central Sydney, there simply was not enough relatively flat land for a much larger low frequency array.<sup>8</sup>

Consequently, Shain (1952) recommended that their research should be transferred to another RP field station. Initially he favoured Badgerys Creek on the western outskirts of suburban Sydney (Site 1 in Figure 1), but for various reasons this did not happen. Instead it was the nearby Fleurs field station (Site 6 in Figure 1) that benefited from the eventual close down of the Hornsby Valley field station in 1955, and over the next decade or so Fleurs would play a leading role in international low frequency radio astronomy (e.g. see Orchiston and Slee, 2002;

2005a; Robertson, 1992). This will be the subject of a later paper in this series on early Australian low frequency radio astronomy.

## 4 CONCLUDING REMARKS

During the late 1940s and early 1950s, the CSIRO's Division of Radiophysics field station at Hornsby Valley near Sydney was a world leader in low frequency radio astronomy, but the first research that occurred there was in radar astronomy. This was carried out in 1947–1948 by Frank Kerr and Alex Shain, and built on pioneering projects conducted in Hungary and the USA in 1946. Kerr and Shain made important contributions to our understanding of the ionosphere, and they also were the first to use radar techniques to pronounce on the nature of the lunar surface. After moving to the Potts Hill field station Kerr would build an international reputation through his H-line work, and he would never again conduct low frequency research in radio or radar astronomy. But, as a farewell to radar astronomy, in 1952 he published the hallmark paper, "On the possibility of obtaining radar echoes from the Sun and planets", in the *Proceedings of the Institute of Radio Engineers*.

Between May 1949 and June 1951 Alex Shain and Charlie Higgins built Hornsby Valley into the world's leading low frequency radio astronomy facility. They began with an 'all-sky' survey at 18.3 MHz, and after upgrading the original transit array so that beam-switching was possible, were able to produce an isophote plot of galactic emission and a map showing the distribution of 37 discrete sources, a vast improvement on what Karl Jansky was able to achieve at a similar frequency back in the 1930s. Through their Hornsby Valley work Shain and Higgins were able to significantly expand the frequency range of non-solar research at RP, which to that time had predominantly been conducted at around 100 MHz.

In June 1951, after completing their 18.3 MHz research, Shain and Higgins began a survey of emission at 9.15 MHz. They were able to detect galactic plane emission at this frequency, and infer the presence of discrete sources (although they lacked the resolution to investigate these). Note that 9.15 MHz would remain the lowest frequency at which radio astronomy was carried out until Ellis and Reber conducted their successful 2.13 and 1.435 MHz surveys from Cambridge, Tasmania, in 1955 (see George et al., 2015b).

In addition to their galactic research, at a later date Shain and Higgins were able to examine 18.3 MHz solar bursts detected at Hornsby Valley in 1950–1951, and show that the sources of these bursts were located somewhat higher in the corona than anticipated using the Baumbach-



Allen model. This was a significant result.

Another significant Hornsby Valley result, and one that also was obtained belatedly, was the discovery that during their 1950–1951 galactic survey Shain and Higgins had in fact detected bursts from Jupiter on numerous occasions, but dismissed them as troublesome interference. It was only after Burke and Franklin announced their discovery of Jovian decametric emission in mid-1955 that Shain revisited the old Hornsby Valley chart records and was able to report these pre-discovery observations. Upon examining these, he would claim that the emission came from a single source, with a rotation period of 9h 55m 13s (very close to System II). But he went further and suggested that the source was associated with a conspicuous white spot that was located on the boundary of the South Temperate Belt and South Temperate Zone. While these ideas were revolutionary at the time we now know they were simplistic—in 1955 no-one could ever have imagined that the Jovian decametric emission was associated with the magnetic torus between Jupiter and its anomalous inner satellite Io. With the benefit of hindsight, we can understand why Shain and Higgins failed to identify Jovian bursts in 1950–1951, but this should not prevent us from identifying this as one of RPs most notable ‘missed opportunities’. Meanwhile, research on Jovian decametric emission would be avidly pursued by RP staff at the Fleurs field station, as a later paper in this series will document.

It is interesting that Shain never chose to examine any of the 9.15 MHz chart records from 1951–1952 for possible Jovian emission (or if he did, there is no mention of this in his published papers).

Because of the special problems that the ionosphere introduced for those conducting low frequency radio astronomy, it is no surprise that Shain and his Indian collaborator, A.P. Mitra, also wrote papers about ionospheric absorption that led to an improved understanding of the operation of the *D*-layer and the *F*-layer, information that was of interest to ionospheric scientists worldwide. In this way, the Hornsby Valley field station was able to enhance its reputation as an international centre of low frequency radio science, but as we have seen, it also contributed briefly to 60–85 MHz solar radio astronomy through the research carried out there by Australia’s first female radio astronomer, the remarkable Ruby Payne-Scott, before she, too, transferred to the Potts Hill field station.

By the time the Hornsby Valley field station was closed, Frank Kerr, Alex Shain and Charlie Higgins had made important low frequency observations of the Moon and our Galaxy, and later some of them would use data from this

field station to make valuable contributions to low frequency solar and Jovian astronomy. Alex Shain and Charlie Higgins would then continue some of these investigations from Fleurs field station.

## 5 NOTES

1. In 1949, after “... the biggest upheaval in Australian science in the country’s history.” (Peter Robertson, pers. comm., 2015), the Australian Government’s Council for Scientific and Industrial Research (CSIR) was replaced by the Commonwealth Scientific and Industrial Research Organisation (CSIRO).
2. This is the fourth in a series of papers aimed at documenting early low frequency radio astronomy in Australia. The first two papers overviewed the activities of staff from the Division of Radiophysics, near Sydney (Orchiston et al., 2015) and radio astronomers in Tasmania (George et al., 2015a). The third paper in the series was the first of the detailed case studies, and examined the research carried out by Ellis and Reber at the Cambridge field station near Hobart (George et al., 2015b).
3. Originally, the first and second authors of the present paper were employed by the Division of Radiophysics, and although they never worked at the Hornsby Valley field station, between them they personally knew *all* of the individuals whose research is discussed in this paper.
4. During this period RP also had field stations at Dover Heights (site 5 in Figure 1), Georges Heights (site 8), Penrith (site 15) and Potts Hill (site 16) and, in addition, research was carried out from the roof of the Radiophysics Laboratory (site 17). For summaries of the research conducted at these locations see Orchiston and Slee (2005a) and Robertson (1992).
5. Initially, the term ‘radio astronomy’ did not exist, and those who researched ‘cosmic noise’ and ‘solar noise’ predominantly had backgrounds in radio or radar, not in astronomy. It was only in 1948 that the term ‘radio astronomy’ began to be used internationally (see Sullivan, 2009: 423–424), after being coined by Joe Pawsey and first mentioned in a letter he wrote in January 1948 (see Robertson, 1992: 31).
6. In 1952 Australian radio astronomer, Bernard Yarnton Mills (1920–2011; see Mills, 2006) invented a new type of radio telescope that dramatically improved the resolution of radio telescopes (see Mills, 1963). Built in the shape of a cross, the E-W arm produced a N-S fan beam and the N-S arm an E-W fan beam. By electrically switching the signals from the two arms in phase and out of phase,

the radio telescope produced a pencil beam where the two arms of the array intersected. Mills and Little (1953) constructed a prototype 'Mills Cross' at RP's Potts Hill field station in suburban Sydney (Wendt, Orchiston and Slee, 2011), and when this proved that the concept was viable, a new much larger Mills Cross was constructed in 1954 (Mills and Little, 1953) at the Fleurs field station, which is site 6 in Figure 1 (Orchiston and Slee, 2002; 2005a). The prototype Mills Cross and the later Mills Cross at Fleurs inspired the construction of other Mills Cross radio telescopes around the world, and one of the earliest of these was the Carnegie Institution's Mills Cross near Washington DC.

7. During the War years the CSIR's Division of Radiophysics established a Photographic Laboratory, staffed by professional photographers, and over the years they assembled an outstanding pictorial record of early Australian radio astronomy (see Orchiston, 2001; Orchiston et al., 2004).
8. An additional factor that hastened the abandonment of the Hornsby Valley as a radio astronomy field station was a bushfire that swept through the region near the end of 1952 and destroyed buildings and equipment (Patricia Dewey, pers. comm., 2004; John Murray, pers. comm., 2004).

## 6 ACKNOWLEDGEMENTS

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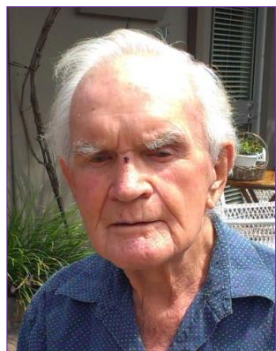
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Professor Wayne Orchiston was born in New Zealand in 1943 and works as a Senior Researcher at the National Astronomical Research Institute of Thailand and is an Adjunct Professor of Astronomy at the University of Southern Queensland in Toowoomba, Australia. In the 1960s Wayne worked as a Technical Assistant in the CSIRO's Division of Radiophysics in Sydney, and forty years



later joined its successor, the Australia Telescope National Facility, as its Archivist and Historian. He has a special interest in the history of radio astronomy, and in 2003 was founding Chairman of the IAU Working Group on Historic Radio Astronomy. He has supervised six Ph.D. or Masters theses on historic radio astronomy, and has published papers on early radio astronomy in Australia, England, France, Japan, New Zealand and the USA. He also has published extensively on the history of meteoritics, historic transits of Venus and solar eclipses, historic telescopes and observatories, and the history of cometary and asteroidal astronomy. He is a co-founder and the current Editor of the *Journal of Astronomical History and Heritage*, and currently is the Vice-President of IAU Commission C3 (History of Astronomy). In 2013 he was honoured when the IAU named minor planet 48471 Orchiston.

Dr Bruce Slee was born in Adelaide, Australia, in 1924 and is one of the pioneers of Australian radio astronomy. Since he independently detected solar radio emission during WWII he has carried out wide-ranging research, first as a member of the CSIRO's Division of Radiophysics, and then through its successor, the Australia Telescope National Facility. After working with Bolton and Stanley on the first discrete



sources at Dover Heights, he moved to the Fleurs field station and researched discrete sources with Mills using the Mills Cross, and radio emission from flare stars with the Mills and Shain Crosses. He also used the Shain Cross and a number of antennas at remote sites to investigate Jovian decametric emission. With the commissioning of the Parkes Radio Telescope he began a wide-ranging program that focussed on discrete sources, and radio emission from various types of active stars. He also used the Culgoora Circular Array (*aka* Culgoora Radioheliograph) for non-solar research, with emphasis on pulsars, source surveys and clusters of galaxies, and continued some of these projects using the Australia Telescope Compact Array. Over the past two decades he also has written many papers on the history of Australian radio astronomy, and has supervised a number of Ph.D. students who were researching the history of radio astronomy.

Martin George is the Collections and Research Manager at the Queen Victoria Museum and Art Gallery in Launceston, Tasmania, and also is responsible for the Museum's astronomy collections and the planetarium. He is a former President of the International Planetarium Society. Martin has a special research interest in the history of radio astronomy, and is completing a part-time Ph.D. on the development of low frequency radio astronomy in Tasmania through the University of Southern Queensland, supervised by Professors Wayne Orchiston and Richard Wielebinski (and originally also by Professor Bruce Slee). Martin is the Administrator of the Grote Reber Medal, and is a member of the IAU Working Group on Historic Radio Astronomy.



Professor Richard Wielebinski was born in Poland in 1936, and moved with his parents to Hobart, Tasmania, while still a teenager. Richard completed B.E (Hons.) and M.Eng. Sc. degrees at the University of Tasmania. In his student days he met Grote Reber and was involved in the construction of a low frequency array at Kempton. After working for the Postmaster General's Department in Hobart he joined Ryle's radio astronomy group at the Cavendish Laboratory, Cambridge, and completed a Ph.D. in 1963 on polarised galactic radio emission. From 1963 to 1969 Richard worked with Professor W.N. (Chris) Christiansen in the Department of Electrical Engineering at the University of Sydney, studying galactic emission with the Fleurs Synthesis Telescope and the 64-m Parkes Radio Telescope. He also was involved in early Australian pulsar research using the Molonglo Cross. In 1970 Richard was appointed Director of the



Max-Planck-Institut für Radioastronomie in Bonn, where he was responsible for the instrumentation of the 100m radio telescope at Effelsberg. In addition, he built up a research group that became involved in mapping the sky in the radio continuum, studying the magnetic fields of galaxies, and pulsar research. Further developments were the French-German-Spanish institute for mm-wave astronomy (IRAM), and co-operation with the Steward Observatory, Univer-

sity of Arizona, on the Heinrich-Hertz Telescope Project. Richard holds Honorary Professorships in Bonn, Beijing and at the University of Southern Queensland. He is a member of several academies, and has been awarded honorary doctorates by three universities. After retiring in 2004 he became involved in history of radio astronomy research, and is currently the Chairman of the IAU Working Group on Historic Radio Astronomy.

## THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 5: REBER AND THE KEMPTON FIELD STATION IN TASMANIA

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**Abstract:** After initially making low frequency observations with Graeme Ellis near Hobart, Tasmania, in 1955, Grote Reber returned to Tasmania to carry out further observations in 1956–1957 near Kempton, to the north of Hobart. He chose to investigate at 520 kHz, and used four dipoles, each about 670m long, about 300m apart and approximately 100m above a valley floor. Reber deduced that there was a celestial component which appeared to have a maximum, with an intensity he stated to be  $4 \times 10^{-20} \text{ Wm}^{-2}\text{Hz}^{-1}\text{sr}^{-1}$ , around right ascension 22 hours, declination  $-6^\circ$ . By 1960, he had re-interpreted the results and concluded that the maximum emission actually came from a declination of about  $+42^\circ$ , in the constellation of Cygnus. However, two decades later, he expressed doubt that he had actually observed cosmic emissions at all. In 1957, Reber briefly also made observations from Kempton at 143 kHz. One of us (MG) has visited the Kempton site on several occasions in recent years and has located artefacts that have remained relatively undisturbed for nearly 60 years.

**Keywords:** Low frequency radio astronomy, Tasmania, Kempton, Reber

### 1 INTRODUCTION

Grote Reber (1940; 1944) had made the first radio maps of the sky in the early to mid-1940s and continued his interest in this new field. He made observations of radio emission from the quiet Sun (Reber, 1946), and between 1951 and 1954 he worked atop Mount Haleakala on the island of Maui in Hawaii, constructing and using a sea interferometer at frequencies between 20 MHz and 100 MHz (Reber 1955).

The results from Hawaii were unsatisfactory, and Reber then turned his attention to observing the sky at lower frequencies. The problem was ionospheric transparency, which places a lower, but variable, limit on the frequency of cosmic radiation that can reach the Earth's surface—typically just a few MHz. Reber (1982: 148) had gathered "... vast amounts ..." of ionospheric data from many parts of the world, and he discovered that the best conditions for low frequency radio astronomy occurred in winter at or near sunspot minimum, and around  $40^\circ$ – $50^\circ$  latitude. He chose Tasmania as an ideal location,<sup>1</sup> because of its more favourable climate (than Canada—especially in winter) and access to the southern sky, aspects of which he had earlier expressed an interest (Reber, 1949).

Reber arrived in Tasmania in November 1954. During 1955 he worked with Graeme Ellis from the Ionospheric Prediction Service at Cambridge, near Hobart airport (see George et al., 2015b). Together they made many recordings between about 0.5 MHz and 2 MHz, in an effort to detect celestial emissions at much lower frequencies than 9.15 MHz, which at the time was the lowest frequency at which successful observations had been carried out (see Higgins and Shain, 1954). This Cambridge research resulted in the paper "Cosmic radio-frequency radiation near one megacycle" (Reber and Ellis, 1956), in which the authors concluded that the recordings at the higher end of their frequency range were certainly of extraterrestrial origin, but that there was less certainty that the same could be said of the lower-frequency results. This Cambridge work would later inspire Ellis to establish University of Tasmania low frequency radio astronomy at nearby Llanherne (Hobart Airport), Penna and Richmond (for Tasmanian locations see Figure 1).

Encouraged by this preliminary work, Reber made a decision to carry out further low frequency observations, and after a brief period overseas he returned to the State in early 1956 (Reber, 1956a; 1982). Realising that it was es-

essential to minimise artificial interference and that antennas would need to be strung high above the ground, Reber sought a location with a sufficiently deep north-south valley that was distant from Hobart, Tasmania's capital city.

The site chosen was about three kilometres west of the town of Kempton, ~50 kilometres by road north of Hobart. It was a valley at longitude  $147^{\circ} 10'$  east, latitude  $42^{\circ} 33'$  south, running approximately north-south and with hills on the western and eastern sides that Reber decided offered adequate height for suspension of dipoles across the valley. It is officially known as Irish Valley, but Reber occasionally referred to it as Johnson Valley. At the bottom of the valley there was a creek, which still exists today and became known as Astronomers Creek, presumably because of Reber's presence there. This name has clearly been adopted by the Nomenclature Board of Tasmania: it appears on topographic maps of the region and is listed as 'official' in the Geoscience Australia database of place names.

The valley and its surroundings were spread over two properties that at the time were owned by Cecil Johnson (western section) and Neil Johnson (eastern section).

This paper describes Reber's research that was carried out at Kempton between April 1956 and August 1957.<sup>2</sup>

## 2 BIOGRAPHICAL NOTE

Grote Reber (Figure 2) was born in Chicago, USA, on 22 December 1911. At an early age he developed a passion for radio. Then he took a great interest in the work of Karl Jansky (1905–1950), who in the early 1930s was the first to detect radio emission from our Galaxy.

In order to investigate this phenomenon further, in 1937 Reber constructed the world's first purpose-built radio telescope and mapped the sky at a frequency of 160 MHz (Reber, 1940; 1944). This was the first detailed radio map of the sky.

Reber maintained his interest in radio waves from celestial sources and eventually decided to make a study of low frequency emission. His first results in Tasmania were in collaboration with Graeme Ellis. Then, after his work at Kempton, he constructed a 2.085-MHz array at Bothwell (and this will be discussed in a later paper in this series).

Although he often travelled back to the USA and to other countries, Reber effectively made Tasmania his home for the second half of his life.

He was awarded a number of prizes—including the 1962 Bruce Medal (from the Astronomi-

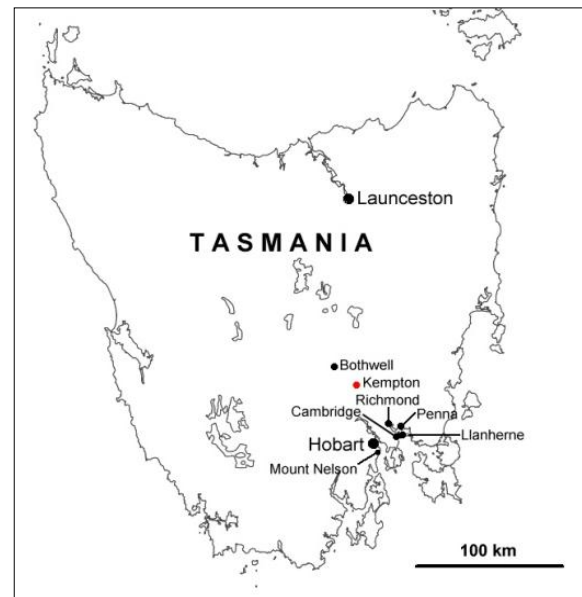


Figure 1: Key radio astronomy sites in Tasmania. This paper discusses Grote Reber's research at Kempton, to the north of Hobart (map: Martin George).

cal Society of the Pacific)—and an honorary D.Sc. from Ohio State University in the USA.

Grote Reber died in Tasmania on 20 December 2002, two days before his 91st birthday. For further biographical information about him, see George et al. (2015b) and Kellermann (2004).

## 3 INSTRUMENTATION

### 3.1 General Layout

Grote Reber's Kempton antenna array consisted of four dipoles stretched across Irish Valley. They were spaced about 300 metres apart and



Figure 2: Grote Reber in 1957, during the period when he was conducting research at Kempton (courtesy: George Swenson).

100 metres above the valley floor, and were intended primarily for use at 520 kHz. Reber kept detailed handwritten diary notes of the layout, and mentions that the valley floor was  $0.20\lambda$  below the dipoles (Reber, 1956b).

In each case the 'wire', as Reber called it, consisted of two 1100-ft lengths in the centre, forming the dipole itself, and extra wire(s) at each end which were connected to anchor points on the hills on each side of the valley. Typically, each wire was therefore ~3,500 feet long and the dipoles were insulated from the supporting sections of wire at each end.

The anchor points were (a) trees, in the case of the eastern end of Antenna 3 and the western ends of Antennas 1 and 2; (b) short posts embedded into the ground, in the case of the eastern ends of Antennas 1 and 2; and (c) tall poles for the eastern end of Antenna 4 and the western end of Antenna 3. Five of these sites—all four anchor points on the eastern side and the anchor point for Antenna 3 on the western side—have been identified and contain artefacts. The exact locations of the other western ends have not been determined, although there are surviving photographs taken by Reber of the western anchor points (trees) for Antennas 1 and 2. No record or image of the western anchoring method of Antenna 4 has yet been found. The positions of all western anchor points other than that of Antenna 3 have been calculated from Reber's notes on the antenna lengths and bearings (see, e.g., Reber, 1956c; 1956d).

A feeder cable from the centre of each dipole led down to a post with a tuner box on the valley floor. Another coaxial lead—buried, to avoid be-

ing affected by animals—connected that box to the hut that contained the receiving equipment.

Phasing of the array, allowing for observations at different declinations, was accomplished by inserting extra lengths of cable between the down cable and the receiving equipment, so as to increase the path length by an appropriate amount.

Initially only two dipoles were used, which Reber called the *South Antenna* (Antenna 1) and the *North Antenna* (Antenna 2). A shed (Figure 3) was placed approximately midway between the two. Later, Reber erected two more dipoles farther north, calling these the *Centre North Antenna* (Antenna 3) and the *Far North Antenna* (Antenna 4). Because of this increase in the number of antennas, Reber erected a second shed between Antennas 2 and 3, so that once again the receiving equipment would be near the middle of the array.

The array was effectively a transit instrument, although the perpendicular line through the system was directed toward an azimuth of about  $6^\circ$  (i.e.  $6^\circ$  east of true north). The array could be directed toward different declinations by introducing extra lengths of cable between selected dipoles and the receiver.

Figure 4 shows the positions of the four wires and the two sheds in Irish Valley.

### 3.2 The Establishment of the Array and Sheds

By April 1956 Reber had obtained permission from the two landowners, Neil Johnson and Cecil Johnson, to use the site for his research.



Figure 3: The first shed, on the valley floor near Kempton (courtesy: Archives, National Radio Astronomy Observatory/Associated Universities, Inc., hereafter ANRAO).



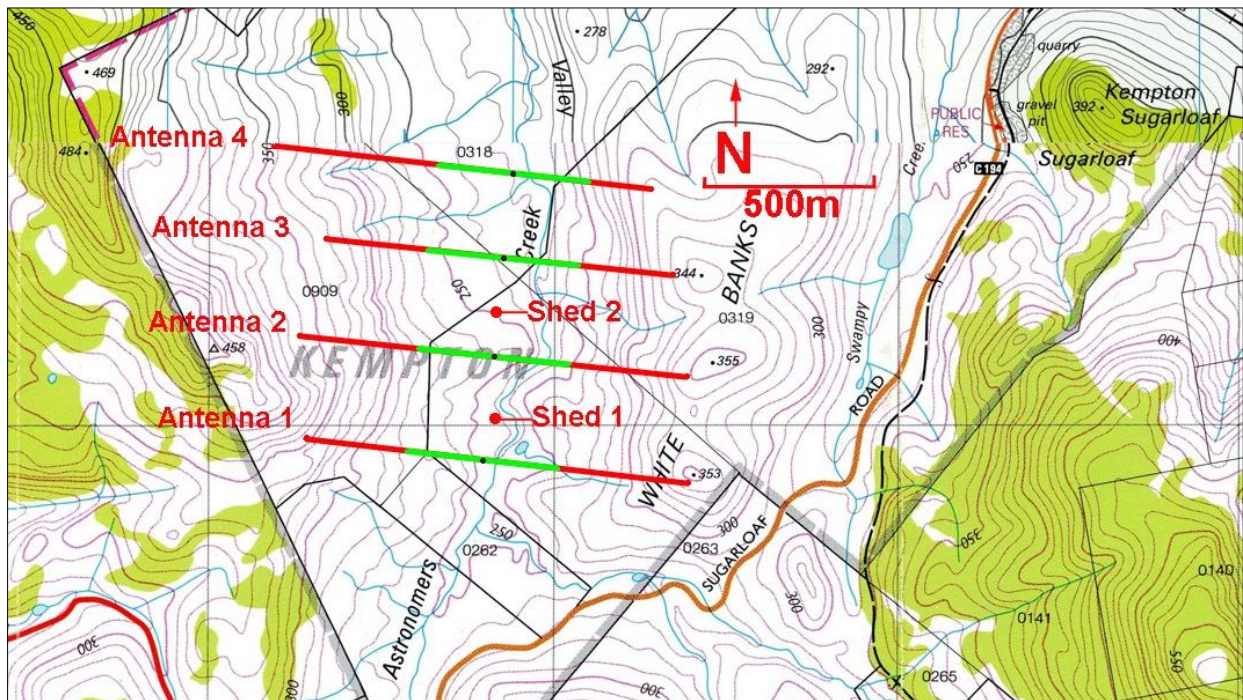


Figure 4: The locations of the four wires over Irish Valley, near Kempton. The dipole sections are shown in green and the supporting wires in red. Rear anchoring wires extending beyond the poles, etc., and stay wires, are not included. The positions of the two sheds are shown (adapted from 1:25000 topographic map, reproduced courtesy of the Department of Primary Industries, Water, Parks and Environment, Tasmania).



Figure 5: A photograph taken by Reber on 28 April 1956 during his initial survey of the area. This shows surveying equipment, and looks west across the valley, from near the future site of the eastern end of Antenna 1 (courtesy: ANRAO).

First he conducted a survey of the site (see Figure 5) and planned where to place the anchor points for Antennas 1 and 2 on each side of Irish Valley.

The first two antennas—the *South Antenna* (Antenna 1) and the *North Antenna* (Antenna 2)—were erected on 23 June and 30 June 1956

respectively (Reber, 1956d; 1956e), near the southern end of the useful part of the valley (Figure 6).

On 3 July 1956 Reber laid foundations for the first shed that was to contain his equipment, and the building was erected two days later (Reber, 1956f; 1956g). This was on the valley



Figure 6: The eastern end of Antenna 1 looking west across the valley, photographed about 28 September 1956 (courtesy: ANRAO).

floor approximately midway between the two antennas (Figure 3). A work bench was inside. The shed was used to house receivers and other equipment (see Section 3.3).

An amusing example of Reber's extensive note-keeping is his diary entry for 5 July 1956:

Put up building on foundations and spent an hour looking for empty cable spool which was lost on 23/6/56 southwest of post A down slope. No success. Probably in clump [of] grass which will have to be burned off before spool can be seen. (Reber, 1956g).

By September 1956, Reber was planning the installation of the other two antennas. On 24



Figure 7: The second shed erected by Reber. This was placed midway between Antennas 2 and 3 (courtesy: ANRAO).

September he began marking out their positions:

Made two rock cairns about 900 ft and 1800 ft to north of north red post along top of east ridge. These mark possible sites for east ends of two additional spans across valley ... All very speculative at present state of affairs. (Reber, 1956h).

Antenna 3 was erected on 1 December (Reber, 1956i) and Antenna 4 on 31 December (Reber, 1956j). Now that there were four antennas, it was clearly necessary to house the receiving equipment close to the centre of the array, as the original building had been erected when only the first two antennas were in use. Therefore, on 3 December 1956 a new shed (Figure 7) on the valley floor was erected between Antennas 2 and 3 (Reber, 1956k) and this was in use by 11 January 1957, on which date Reber moved everything from the first shed to this new building (Reber, 1957a).

Reber engaged the assistance of several people in establishing the Kempton site.

At the time, one of the authors of this paper (RW) was an engineering student at the University of Tasmania. He and at least two other fellow students were employed by Reber on weekends to assist with the erection of the Kempton antennas. Wielebinski recalls:

He [Grote] was given a corner of the downstairs power laboratory of the Electrical Engineering School [in Hobart] to work in. This was partly because he was on good terms with Gordon Newstead.<sup>3</sup> I was then doing electrical engineering and this is how I got involved. He [Reber] went around asking which students were prepared to come on weekends to help him with some work. This is how I got involved.

The work done by the students did not involve actually making observations, but he called on them to assist with many tasks. Wielebinski further remembers:

We did all the digging, and we put these nails [footholds] into the 'tree' to go up; that was done by students ... He had these nails from somewhere for free. We once had a confrontation with him saying it's easy to fall down.

Geoff Webb, a local radio enthusiast, was asked by Reber for his assistance in providing the tall poles for the eastern end of Antenna 4 and the western end of Antenna 3 (see Figure 8). He confirms (Webb, pers. comm., 2009) that these two were the only tall poles used for the antennas, suggesting that the western end of Antenna 4 was anchored by a tree or a short post. Webb (ibid.) selected "... trees from the forest ..." for these two poles, and gave them to Reber free of charge. Their regular appearances led to locals calling them "... those couple of crazy blokes." (ibid.)

Each of the tall poles was made stable by stay wires attached to short posts on the ground (Figure 8), and each had a pulley on top; the antenna-supporting wire, which led across the valley from the top of each pole, had a rear section running some 300 metres behind the pole before being anchored at ground level (see Figure 9).

With such a long cable run across the valley and the need for an adequate stay wire system of the two tall poles, it was important to have insulators of sufficient strength. Insulators that were considered for use at first often failed, which led Reber to source a different manufacturer to obtain a supply of insulators that were sufficiently strong for the job.<sup>4</sup> Reber had them tested in Hobart, either at the University of Tasmania or at the Mines Department. Similar considerations were important for the wires themselves (ibid.).

Wielebinski recalls that the entire length of each wire, with the supporting wires and dipole, was laid out across the valley floor and that a winch, or winches, were used to raise the wire into position. This is confirmed by Figure 10, which shows Reber operating a winch. We have identified this as almost certainly being the eastern end of Antenna 4.

The feeder lead from the centre of each dipole was an RG213 coaxial cable (ibid.). Webb expressed surprise at this, because of the weight of up to about 100 metres of cable being suspended from the dipole; this was an additional reason why the support mechanism, including the insulators, had to be sufficiently strong.



Figure 8: The upper part of the 20m-tall western pole of Antenna 3, one of only two tall poles used to support the wires (courtesy: ANRAO).

### 3.3 Receiving and Other Equipment

Each shed contained a receiver or receivers (see Figure 11), batteries, a chart recorder, a clock, and extensive rolls of coaxial cable that were used for the delay lines, with the length of each clearly marked (ibid.).

Reber made use of valve-operated radio receivers, at least partly based on equipment that he had brought with him from overseas in 1954 in advance of his initial work with Graeme Ellis (see, e.g., George et al., 2015b). Students assisted with the preparation of this equipment, and as always, Reber was keen to economise as much as possible. Wielebinski recalls that

Regarding the 'junk' equipment Grote brought with him [from overseas]—the equipment that the wharf strike held up—we had it laid out in this electrical engineering laboratory, and we

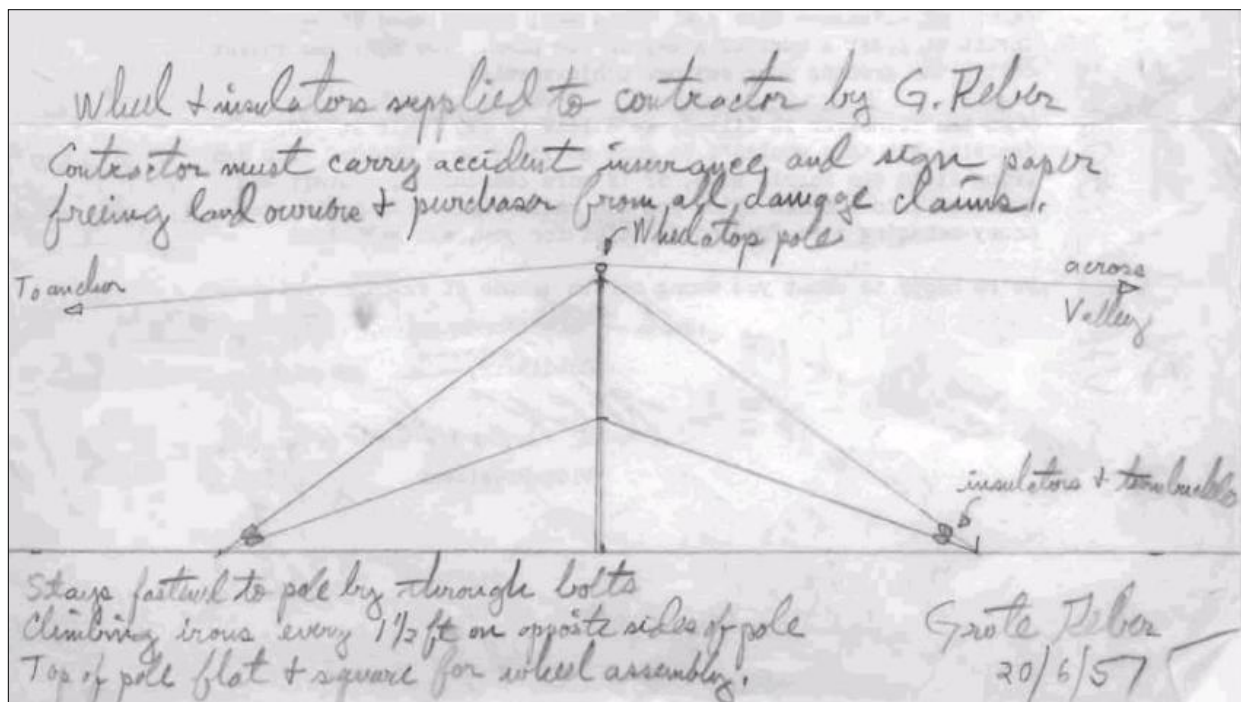


Figure 9: A June 1957 diagram by Reber illustrating the setup, including an anchor, stay wires and a pulley, when a tall pole was in use (courtesy: ANRAO).



Figure 10: Reber with a winch. This is almost certainly at the eastern end of Antenna 4 (courtesy: ANRAO).

students had to unsolder the resistors and measure them, because he wouldn't use new resistors. He always insisted on stripping these old US navy receivers to reuse everything.

Reber used a set of batteries to provide energy to run the equipment. He made no use of the mains electricity supply, for not only was the site far from the nearest mains but the voltage and frequency of the supply were both unreliable.

In addition to retrieving the observations recorded on the chart rolls, Reber performed other tasks on each of his visits.

Of necessity, Reber regularly checked the condition of the batteries, which he always recorded in his diary notes. He needed to carefully maintain the pen recorder to ensure that the ink level was appropriate and that it was flowing properly. Another important activity was to check his clock against a radio time signal. A fine example of this attention to detail in his diaries is his regular entry of information about clock-winding: he recorded whether the clock was fast or slow, by how much, and even the number of turns of the key required to completely wind it up.<sup>5</sup>

### 3.4 Equipment Problems

Throughout the period of observations (see Sec-



Figure 11: An example of receiving equipment inside one of Reber's sheds on the floor of Irish Valley (courtesy: ANRAO).

tion 4), Reber encountered many problems with the equipment. This included the occasional contact between animals and the tuner boxes located beneath the antennas.

The receiving equipment occasionally needed parts to be replaced, but generally it seems to have performed well, apart from occasional troubles with the pen recorder, as evidenced, for example, by the following diary entry made on 25 January 1957:

3:45 pm. Put in to use a new large square ink well. Put 1/8" into it. Seems a bit shallow. Also cleaned tip of pen which had a blob of ink on it. Removed blob. This made pen run smoother and vibrate uniformly. (Reber, 1957b).

The high winds in late February 1957 were a significant setback. After being absent from the area for several days and returning on 1 March, Reber discovered that Antennas 1, 3 and 4 had all been blown down, most likely on 28 February which Reber (1957c) learned was the windiest day. Antennas 1 and 3 were re-erected on 4 March and 16 March respectively. No record has yet been found of the date for re-erection of Antenna 4, but it is likely to have been between 5 and 25 April.

After commencing work with the University of Illinois in the USA to construct a large radio telescope, George Swenson (pers. comm., 2008) visited the Kempton site with Reber in 1957. Although he did not record the date, Swenson recalls that it was very hot, and it was therefore likely to have been summer or very early autumn—during the first few months of the year. At that time, one of the antennas was down, and this is likely to have been Antenna 4 for the aforementioned reasons. Reber engaged Swenson's help in trying to determine the cause of the failure.

## 4 THE OBSERVATIONS

The main frequency at which Reber observed was 520 kHz, despite the fact that the dipole, with an overall length of 2,200 feet (670m), would have operated as a 'full wave' dipole at 450 kHz. Subsequently, observations at 143 kHz were made from June to August 1957.

It is apparent from Reber's notes that the equipment was operating for as great a proportion of time as possible. He ran the chart recorder at a rate of 2.375 inches per hour, and the equipment was used to produce a wealth of data, both during the day and in the evening. Typically, Reber would arrive at the site in the morning, and determine whether the equipment had operated correctly overnight. At the end of each day that he visited the site, he took away the chart records for analysis.

Reber would often insert delay lines—most commonly 64, 96, 128 and 192 feet in length—in order to ‘aim’ the array at different declinations, and record these changes in his diary notes.

Reber was aware of ‘atmospherics’, which generally were emissions caused by lightning, hence the title of his 1958 paper (“Between the Atmospherics”). During mid-1957 he obtained data on storm activity over Tasmania (see, e.g., Bureau of Meteorology, 1957). He also was aware of ‘precipitation static’, in which water droplets cause a build-up of charge on antennas. On several occasions he noted the rainy conditions, including ‘rain squalls’ and other weather-related phenomena. For example, on 21 December 1956, he noted

Arrive 950am. Everything going. On way across from Kempton there was a sharp cold front and rain squall. This lasted only a few minutes and sun came out again. The strong precipitation static was recorded just before my arrival. (Reber, 1956l).

His aim at Kempton, therefore, was to study the background intensity when these sources of interference were minimised.

Reber (1958) obtained “... nearly continuous records ...” at 520kHz between August 1956 and May 1957. The observations were conducted by Reber himself; he visited the site every few days and retrieved chart recorder rolls. However, Geoff Webb occasionally tended to necessary work at the site during Reber’s absence (Reber, 1958).

From his observations, Reber deduced that there was a celestial component which appeared to have a maximum, with an intensity he stated to be  $3.9 \times 10^{-20}$  Jy/sr, at around R.A. 22h, Dec.  $-6^\circ$ . Indeed, Reber’s plot of his 520 kHz observations shows this maximum (Figure 12). However, his calculation of the intensity was *actually*  $3.9 \times 10^{-20}$  Wm<sup>-2</sup>Hz<sup>-1</sup>sr<sup>-1</sup>; at the time, Reber was defining the Jansky to be the same as this unit (but note that it is now defined as  $10^{-26}$  Wm<sup>-2</sup>Hz<sup>-1</sup>sr<sup>-1</sup>). He also comments on a minor maximum near R.A. 4h. However, this

does not appear to be a ‘maximum’. Rather, it is a slight, yet noticeable, change in the rate of drop of intensity with increasing right ascension.

There is no clear celestial reason for such a peak to exist at the coordinates Reber found, which are located a few degrees south of the star Alpha Aquarii and some  $40^\circ$  from the plane of our Galaxy. Indeed, in his 1958 paper Reber did not offer any clear explanation for this as a source direction, other than suggesting that the source of the radio emission was in a region relatively close to the Sun, thereby removing the connection between the pattern of emission and the galactic plane.

This celestial interpretation has been disputed by others. Apart from the ‘atmospherics’, of which Reber was well aware, a component of the received radiation that Reber observed may well have been due to auroral emissions (see, e.g. Dowden, 1959; Ellis, 1957).

Reber also was clearly interested in learning of any connection between his results and any auroral activity, but concluded that there was little or no such connection other than suggesting that some intense auroral displays caused abnormal *D*-region absorption at night and that some emissions may be caused by low-energy particles not capable of producing an aurora (Reber, 1958). In his handwritten notes (Reber, 1957d) there is one mention of a visit, in order to enquire about auroral activity, to the ‘Bisdee Observatory’, presumably the one in Niree Heights, Sandy Bay (Hobart), which was the residence of Colin Bisdee, a well-known member of the Astronomical Society of Tasmania.

Reber (1960) later reinterpreted his 520 kHz Kempton observations. In explaining the lack of coincidence between his deduced position of maximum intensity and an obvious astronomical feature, he commented that

The measurements had been repeated several times with good consistency. Apparently the trouble was not in the observations but in the interpretation.

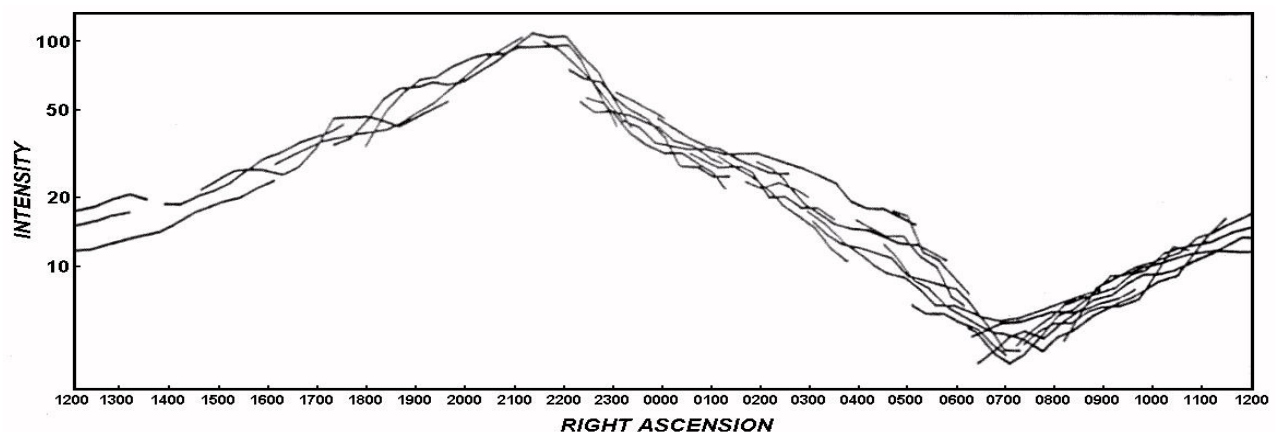


Figure 12: Reber’s plot of received intensity against right ascension at declination  $-6^\circ$  (adapted from Reber, 1958).

Reber's new interpretation was based on the 520 kHz gyro level intersecting the magnetic line of declination at an angle of 42°, and that the radiation was coming not from declination -6° but from declination +42°, in the constellation of Cygnus. It was Reber's view that the coupling at this point of intersection, between the ordinary and extraordinary longitudinal propagation modes O and X, could lead to radiation from this specific declination passing through to the Earth's surface.

The question of incoming wave direction is also connected with ionospheric variations, because changes in the  $f_0F2$  values would be responsible for changes in the modes and hence in the direction of reception.

During June, July and August 1957, just before the array was dismantled, Reber carried out a series of observations at 143 kHz. Surprisingly, Reber (1958) commented that the 143 kHz results "... confirm the above in a general way ...", indicating that they supported the 520 kHz results. This would not be the case, even if Reber was indeed correct about the celestial nature of some of the 520 kHz results. It appears that the basis for his comments (*ibid.*) was that he observed that the changes in intensity of the 520 kHz signal were occasionally paralleled at 143 kHz.

However, Reber (1982: 150) later wrote

... it was doubtful that any of the results were really of celestial origin. Most seemed to be natural phenomena generated in the Earth's upper atmosphere and the probable cause was charged particles from interplanetary space. Clearly these frequencies were too low, so the observations were discontinued and the results published.

It is likely that these comments, made more than two decades after Reber's time at Kempton, were retrospective, rather than simply being an explanation of his feelings in the 1950s. Supporting this possibility was a letter written from Hawaii on 21 May 1958 to the Astronomical Society of Tasmania in which Reber commented that

I expect to find my way back to the land of the Southern Cross in the autumn of 1960 and string up my wires again at Johnson Valley. (Bisdee, 1958).

There is no indication as to exactly what he intended to do if he did return to that site, but as it turned out, no further observations were made at Kempton.

Another type of 'observation' made by Reber was the effect of the local electricity supply on his readings. To achieve this aim, he organised to have the power disconnected from the entire area on one Saturday afternoon, having placed

a notice in Hobart's *Mercury* newspaper to warn residents. He observed that there was a considerable reduction in the interference, and he concluded that all of the interference was generated within 15km of Kempton.

## 5 HERITAGE AT THE SITE

Once the series of observations was complete, the four antennas were dismantled. This took place in July and August 1957.

The original 1956 shed was moved to the Lauriston property, and used as a playhouse by Neil Johnson's children. It was later used as a storage shed, but sadly, it fell into disrepair and was demolished in the late 1990s (Tim Johnson, pers. comm., 2007). No record has yet been found of the eventual fate of the second shed.

The eastern pole for Antenna 4 was eventually cut up by Tim Johnson (the current owner of the property) and used as firewood.

However, several artefacts remained at the site. The western pole for Antenna 3 fell in about 2002 (Figure 13). It remains on the ground where it fell, with many of the original footholds still in place, and is just resolvable on Google Earth images. Some stay wires also have been found. The uppermost two-metre section of the pole, including the pulley, was removed by the Queen Victoria Museum (Launceston) in 2008. This was treated by conservation staff, and is now on display to the public at the Museum.<sup>6</sup>

Other artefacts that have been found on the ground include stay wires, insulators, loose footholds, and some remains of all four eastern antenna supports (e.g., see Figure 14).

It is unlikely that any western artefacts, apart from the abovementioned pole, will ever be found. Two extensive but unsuccessful searches were made by one of the authors (MG) in 2009 and 2015. A likely explanation for this is that the devastating bushfires of 7 February 1967 caused considerable destruction west of Astronomers Creek (Tim Johnson, pers. comm. 2015). In view of this, it is remarkable that the abovementioned pole has survived.

## 6 DISCUSSION

Reber's decision to perform his Kempton work below 1 MHz was clearly influenced by his success with Ellis at Cambridge in 1955, even though there was some doubt about the celestial nature of the lower-frequency Cambridge results. Looking back at Reber's work at Kempton, however, it would seem that rather than being an effort of major scientific importance, the project was an example of Reber accepting a challenge and pushing the boundaries of what could be achieved to their limits.



Figure 13: The western pole for Antenna 3, in 2015. It stood until about 2002, when it finally fell (photograph: Martin George).

It is surprising, however, that Reber saw fit to initially relate his 143 kHz observations to those at 520 kHz, as he would certainly have understood that the former frequency, at least, was clearly too low to allow the detection of emission of cosmic origin from the Earth's surface.

In his notes and research papers Reber does not elaborate on the specific reason(s) for choosing to erect four antennas at Kempton, each spaced half a wavelength apart, rather than selecting flat land and erecting a cross-type array modelled on the 1954 Mills Cross at Fleurs, near Sydney (see Mills and Little, 1953; Mills et al., 1958), which would have provided a circular beam and greatly-improved resolution. However, in his first paper, Reber (1958) does include a diagram showing his calculations of the various nulls in the antenna pattern that were obtainable using his configuration.

It is notable that Reber did not orientate his Kempton dipoles in an exact east-west direction; instead, they were directed toward azimuths  $96^\circ$  and  $276^\circ$ . Although he did not offer an explanation, this may have been because, in 1956–1957, the perpendicular through such a line was half way between geographic north and magnetic north. Later he made it clear, however, that the orientation of the valley was important: "After a brief stay in the States, I returned to Tasmania in 1956 to look for a deep north-south valley." (Reber, 1982: 150). We should note that Reber certainly had adequate

resources—trees, posts and poles—to install the antennas where ever he wished.

At 520 KHz, it is interesting that Reber's value for the peak intensity (allowing for his 1957 use of the suggested Jansky unit) was consistent with results obtained in the 1960s (e.g., see Novaco and Brown, 1978).

It is a matter of conjecture as to when Reber came to accept that Kempton produced little or nothing in terms of useful results. His 1958 letter to the Astronomical Society of Tasmania, in which he foreshadows a return to Kempton within two years, suggests that at that stage he felt positive about a continuation at such low frequencies. However, by 1961 he was erecting his 2.085-MHz array near Bothwell, northwest of Kempton, and it is likely that his thoughts were already focussed on this new project.<sup>7</sup>



Figure 14: The post at the eastern end of Antenna 1 looking west, on 7 June 2009 (photograph: Martin George).

Nonetheless, Reber continued to reflect on the possibilities of making detailed studies of the sky at frequencies at or below those used at Kempton. Later (Grote Reber, pers. comm. 1995) he mentioned to one of us (MG) that much could be gained from such an effort, even suggesting that at times of sufficiently low solar activity it may be possible.

## 7 CONCLUDING REMARKS

Although at the time Reber considered that he had detected evidence of celestial radiation at 520 kHz, this remains highly doubtful, despite later space-based research that does indeed suggest that there is at least one preferred direction—although not corresponding with Reber’s—for cosmic radiation at such a frequency (e.g., see Brown, 1973). Reber (1982) later took a quite different view of his research, commenting that most of his results seemed to be atmospheric phenomena and that the frequencies at which he was observing were too low for the detection of celestial emissions. The Kempton project was Reber’s last attempt to observe at such low frequencies.

Reber’s presence in Kempton had an impact, which apparently was generally positive, on the local community, and presented a fine and inspiring example of practical science.

## 8 NOTES

1. Tasmania is an island to the south of the Australian mainland and is one of the States of Australia. The latitude of Hobart, the capital city of Tasmania, is  $-42.9^\circ$ , well within Reber’s preferred latitudinal range. Peter Robertson (pers. comm. 2015) has suggested that Reber’s decision to move to Tasmania may partly have been motivated by the problems he encountered in Hawaii.
2. This is the fifth paper in this series. The first two papers overviewed the early low frequency radio astronomy research carried out by staff from the CSIRO’s Division of Radio-physics near Sydney (Orchiston et al., 2015a) and research by Ellis, Reber and their collaborators in Tasmania (George et al; 2015a). Papers 3 and 4 were detailed case studies of Ellis and Reber’s work at the Cambridge field station near Hobart Airport (George et al., 2015b) and research mainly by Shain and Higgins at Hornsby Valley on the northern outskirts of suburban Sydney (Orchiston et al., 2015b).
3. Gordon Newstead (1917–1987) was then a Senior Lecturer in Electrical Engineering at the University of Tasmania, and he collaborated with Graeme Ellis over a long period.
4. Wielebinski noted that in order to economise, Reber initially sourced insulators that previ-

ously had been used by the Post Office, and sometimes were in poor condition.

5. As a somewhat amusing *finalé* to this, on 31 August 1957, after the observations had ended and the equipment was finally being removed, Reber noted in his diary: “Did not wind clock.”
6. Observations by one of us (MG) in 2015 indicated that there has since been notable degradation of the section of the pole that remains on the ground at the site.
7. The Bothwell array will be the subject of a future paper in this series.

## 9 ACKNOWLEDGEMENTS

We wish to thank Ellen Bouton (National Radio Astronomy Observatory, USA), for her wonderful support in providing Figures 3 and 5–11, and Tim Johnson of ‘Lauriston’ in Kempton for his invaluable assistance with access to, and information about, the Kempton site. We also are grateful to Heather Johnson, Liz Swain and Geoff Webb for their recollections; the Department of Primary Industries, Water Parks and Environment in Tasmania for permission to reproduce Figure 4; and Karenne Barnes, who provided on-site assistance with locating historical artefacts.

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Martin George is the Collections and Research Manager at the Queen Victoria Museum and Art Gallery in Launceston, Tasmania, and also is responsible for the Museum's astronomy collections and the planetarium. He is a former President of the International Planetarium Society. Martin has a special research

interest in the history of radio astronomy, and is completing a Ph.D. part-time on the development of low frequency radio astronomy in Tasmania through the University of Southern Queensland, supervised by Professors Wayne Orchiston and Richard Wielebinski (and originally also by Professor Bruce Slee). Martin is the Administrator of the Grote Reber Medal, and is a member of the IAU Working Group on Historic Radio Astronomy.



Professor Wayne Orchiston was born in New Zealand in 1943 and works as a Senior Researcher at the National Astronomical Research Institute of Thailand and is an Adjunct Professor of Astronomy at the University of Southern Queensland in Toowoomba, Australia. In the 1960s Wayne worked as a Technical Assistant in the CSIRO's Division of Radiophysics in Sydney, and forty years later joined its successor, the Australia Telescope National Facility, as its Archivist and Historian. He has a special interest in the history of radio astronomy, and in 2003 was founding Chairman of the IAU Working Group on Historic Radio Astronomy. He has supervised six Ph.D. or Masters theses on historic radio astronomy, and has published papers on early radio astronomy in Australia, England, France, Japan, New Zealand and the USA. He also has published extensively on the history of meteoritics, historic transits of Venus and solar eclipses, historic telescopes and observatories, and the history of cometary and asteroidal astronomy. He is a co-founder and the current Editor of the *Journal of Astronomical History and Heritage*, and currently is the Vice-President of IAU Commission C3 (History of Astronomy). In 2013 he was honoured when the IAU named minor planet 48471 Orchiston after him.



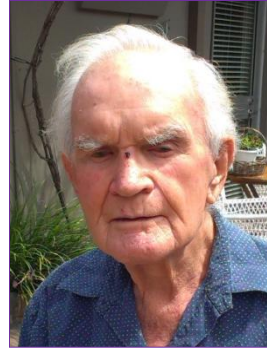
Professor Richard Wielebinski was born in Poland in 1936, and moved with his parents to Hobart, Tasmania, while still a teenager. Richard completed B.E (Hons.) and M.Eng. Sc. degrees at the University of Tasmania. In his student days he met Grote Reber and was involved in the construction of a low frequency array at Kempton. After working for the Postmaster General's Department in Hobart he joined Martin Ryle's radio astronomy group at the Cavendish Laboratory, Cambridge, and completed a Ph.D. in 1963 on polarised galactic radio emission. From 1963 to 1969 Richard worked with Professor W.N. (Chris) Christiansen in the Department of Electrical Engineer-



ing at the University of Sydney, studying galactic emission with the Fleurs Synthesis Telescope and the 64-m Parkes Radio Telescope. He also was involved in early Australian pulsar research using the Molonglo Cross. In 1970 Richard was appointed Director of the Max-Planck-Institut für Radioastronomie in Bonn, where he was responsible for the instrumentation of the 100-m radio telescope at Effelsberg. In addition, he built up a research group that became involved in mapping the sky in the radio continuum, studying the magnetic fields of galaxies, and pulsar research. Further developments were the French-German-Spanish institute for mm-wave astronomy (IRAM), and cooperation with the Steward Observatory, University of Arizona, on the Heinrich-Hertz Telescope Project. Richard holds Honorary Professorships in Bonn, Beijing and at the University of Southern Queensland. He is a member of several academies, and has been awarded honorary doctorates by three universities. After retiring in 2004 he became involved in history of radio astronomy research, and is currently the Chairman of the IAU Working Group on Historic Radio Astronomy.

Dr Bruce Slee was born in Adelaide, Australia, in 1924 and is one of the pioneers of Australian radio astronomy. Since he independently detected solar radio emission during WWII he has carried out wide-ranging research, first as a member of the CSIRO's

Division of Radiophysics, and then through its successor, the Australia Telescope National Facility. After working with John Bolton and Gordon Stanley at Dover Heights on the first discrete sources, he moved to the Fleurs field station and researched discrete sources with Bernie Mills using the Mills Cross, and radio emission from flare stars with the Mills and

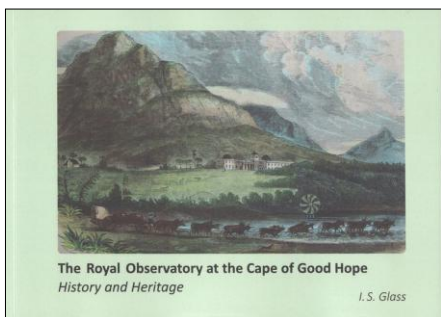


Shain Crosses. He also used the Shain Cross and a number of antennas at remote sites to investigate Jovian decametric emission. With the commissioning of the Parkes Radio Telescope he began a wide-ranging program that focussed on discrete sources, and radio emission from various types of active stars. He also used the Culgoora Circular Array (*aka* Culgoora Radioheliograph) for non-solar research, with emphasis on pulsars, source surveys and clusters of galaxies, and continued some of these projects using the Australia Telescope Compact Array. Over the past two decades he also has written many papers on the history of Australian radio astronomy, and has supervised a number of Ph.D. students who were researching the history of radio astronomy.

## BOOK REVIEW

***The Royal Observatory at the Cape of Good Hope. History and Heritage*, by I.S. Glass. (Cape Town, Mons Mensa, 2015), pp. [iii] + 80. ISBN 978-0-9814126-2-7 (paper back), 290 × 207 mm, ~US\$18.00 (see comments at the end of this review).**

When I first saw this book I immediately thought, “What a pretty cover, but is yet another book about the famous



royal famous

Royal Observatory at the Cape of Good Hope (henceforth ‘Cape Observatory’, for short) *really* warranted?” After all, I already had copies of Brian Warner’s various tomes (1979; 1983; 1995) in my library.

However, Ian Glass’ latest book is quite different from Brian’s earlier productions: it covers the history of the Cape Observatory through to the present day, and is designed not just for astronomers (both amateur and professional) but also for those with a lay interest in South African history. As the ‘blurb’ on the back cover says,

This book draws attention to a unique institution that has been part of Cape Town’s heritage for nearly two centuries. The former Royal Observatory ... has been the scene of several important advances in astronomy and deserves to be treasured not only for this reason but also because it is a unique architectural complex ...

[In this book] Emphasis has been placed on the remarkable work done there and on the extraordinary astronomers who carried it out.

And who better to write such a book than Dr Ian Glass. For much of his working life, Ian was employed by the Cape Observatory where he specialised in infrared astronomy. Fortunately for us, though, he also had a passion for astronomical history and was able to devote more and more time to this following his retirement. By my count, this is the fourth such book of his that I have had the pleasure of reviewing.

Ian relays the history of the Cape Observatory through its “... large collection of instruments and historic images ...” (back cover) via an introductory chapter and six chronologically-ordered chapters. The Introduction gently reminds us that astronomical history is not just

about what happened in Galileo’s day or during the nineteenth century—with its giant telescopes and the emergence of astrophysics. It is also about much more recent developments, and in the case of South Africa this was the remorphing of the Cape Observatory into the South African Astronomical Observatory and the appearance of the Southern African Large Telescope (SALT), one of the world’s elite 11-m class telescopes.

In just two pages, the first of the chronological chapters ‘sets the astronomical scene’ at the Cape prior to Britain’s founding of the Royal Observatory there, mentioning in particular the French Jesuit, Guy Tachard (he was *en route* to present-day Thailand and is the subject of some of my own research), and the remarkable Nicholas-Louis de la Caille, the topic of Ian’s previous book (Glass, 2013).

Chapter Three, “The Story of the Royal Observatory”, introduces us to some very familiar names, including Thomas Henderson, Sir Thomas Maclear, Sir David Gill, Harold Spencer Jones and Richard Stoy. Their research and that of other staff members, including J.K.E. Halm, the Observatory’s “... first real astrophysicist ...” (page 18), is summarised. Also mentioned is John Herschel’s sojourn at the Cape from 1834 to 1838.

The next chapter focuses on “The Buildings of the Royal Observatory”, and in 28 pages Glass takes us on a tour of the various buildings that comprise the Observatory complex, with emphasis on the telescopes. Given the plethora of illustrations, this is a special treat for those of us interested in historical instruments.

“The Work of the Royal Observatory” is a 16-page chapter that not only briefly discusses the positional, photographic and photometric astronomical research conducted by staff, but also the Observatory’s role as the nation’s official ‘time-keeper’. Personally, I enjoyed the photographs on page 48 of two of the Observatory’s different time-ball towers.

The very brief penultimate chapter talks about the reorientation of the Observatory in the 1960s as an astronomical research institution, its rebirth as the South African Astronomical Observatory (SAAO) in 1972, the development of the Sutherland observing site and the acquisition of its most famous occupant, SALT. How fondly I recall the opening ceremony on 10 November 2005.

The final chapter, titled “Conservation and Heritage”, not only discusses the Astronomical Museum and heritage status of the Observatory

buildings and some of the instruments, but also the natural history of the Observatory site. For example, I did not realise that

The site is to some extent isolated from its urban surroundings by the two rivers, the Liesbeek and the Black. To the north and east are wetlands that form a sanctuary for bird life. Near its northern boundary is a bird hide that overlooks the vlei area. In winter, flamingos, geese, ducks and many other birds can be seen.

Meanwhile, the Observatory grounds still include areas of original vegetation, which boast an endangered plant and the equally-endangered Western Leopard Toad.

*The Royal Observatory at the Cape of Good Hope. History and Heritage* was a pleasure to read, and brought back nostalgic memories of my one and only visit there. Ian Glass writes well, and his book is a pictorial *tour de force*, with its many historical and recent photographs, cartoons, sketches, architectural plans and Observatory site maps. It is an excellent 'guide book' for those visiting the Observatory, but also deserves to grace the bookshelves of anyone with an interest in South African astronomical history. Note that the final price of copies will be determined by the cost of airmail postage to the purchaser. For enquiries and/or orders email the author (ian.glass@gmail.com) or Ms Thembela Matungwa (tm@sao.ac.za).

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***Perspectives on Early Astronomy in Indian Context*, by M.N. Vahia, Nisha Yadav and Srikumar Menon. (Kolkata, National Council of Science Museums, 2015), pp. [iv] + 112. Paper back, 140 × 218 mm.**

For some time I have been following the research, mainly in ethnoastronomy and archaeoastronomy, of Professor Mayank Vahia from the Tata Institute of Fundamental Research in Mumbai, so it is a great pleasure to be able to review this little book, which he wrote

with two of his colleagues.

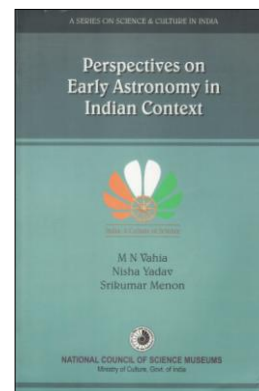
In the "Author's Note" Professor Vahia, Nisha Yadav and Srikumar Menon explain that in this book they try

... to summarise our perspective on how human interest in skies might have evolved.

This book aims to provide a phenomenological overview of the growth of our understanding of astronomy. It does not provide technical details of how to measure locations of stars and planets or details of astronomical records in Sanskrit literature, something that has been done much better by other more competent authors. (page 3).

Following this are six chapters.

The first is titled "Evolution of Human Understanding of Astronomy". After briefly reviewing human evolution, prehistoric cultural phases and environmental change during the Pleistocene and Holocene, the authors try to answer the following question: "So how did humans gather and evolve their ideas of astronomy from the first stages of their evolution and understanding?" (page 8). In so doing, the authors look at the Sun, Earth, Moon and stars, and the seasons. While much of this is basic fare for astronomers, novices will find it useful.



The next chapter, "Astronomy in the Context of Human Intellectual Growth", largely provides a background

context for the more detailed analysis of Indian astronomical history, which will follow. The authors point out that "Attempts made by humans in trying to understand the heavens are of profound interest and importance." (page 24), and they proceed to discuss the following topics: myths, the splendour of the night sky, early monumental architecture, religious ideas, and expression through art. In the process, they briefly introduce some Indian examples.

However, it is only Chapter 3, "Indian Megaliths and Astronomy", that fully immerses us in Indian astronomy. The authors stress that

Most of the megaliths in India are found in the southern part or [*sic*] peninsula India, though there are other pockets of megalithic sites found at Vidarbha, Kumaon, Rajathan, Jharkand etc. (pages 35–36).

Specific megalithic sites we are introduced to are at Aaraga Gate, Byse, Hanamsagar, Hergal, Mumbaru, Nilaskal and Vibhutihalli, all in southern India, plus the stone circles near Nagpur in central India. Most of these meg-

alithic sites appear to have astronomical associations. Chronologically, Indian megalithic sites date between 2,500 BCE and CE 300.

After this archaeoastronomical focus the book moves forward in time and examines aspects of Indian ethnoastronomy. This occurs in Chapter 4, "Astronomical Myths of India", which begins with an analysis of the Banjaras, the Gonds and the Kolams from central India. These are among the oldest tribes of India, and were studied by Mayank Vahia and his anthropological associates. Particularly interesting are Tables 4.2 and 4.3, which compare the astronomical and meteorological perspectives of the three tribes and show that

Most of the [astronomical] observations of the sky relates [*sic*] to the sky seen in the period close to the monsoonal season—from March till July. They seem to assume that the sky is the same at other periods or do not bother to look at the sky. This indifference to the sky is also interesting in the sense that even though visually striking, these societies do not seem to be impressed by it as a matter of curiosity. (page 58).

As the authors point out, this contrasts markedly with the situation in prehistoric southern India, where the megalithic sites reveal that there was a profound interest in astronomy. Vahia, Yadav and Menon then shift their attention to the Hindu and Jain religions, and spend the next 15 pages of this chapter recounting 'Astronomical Stories' (and verses) relating to astronomy, time and the origin of life.

The penultimate chapter in this little book is titled "Astronomy and Civilisation", and begins by identifying four different evolutionary phases in astronomy:

- (1) The Initial Phase
- (2) The Settlement Phase
- (3) The Civilisation Phase
- (4) The Technology Based Phase

Vahia, Yadav and Menon then devote the next 28 pages to explaining these, using India as their case study. In the process they spread their net widely to illustrate their scheme, snaring examples drawn from rock art, megalithic sites (with some inevitable repetition from Chapter 3), Vedic astronomy, the Harappan civilisation, 'Modern Astronomy', and so on. They emphasize that a great deal has already been published relating to Phases 2 and 4. Re the former, the *Vedanga Jyotisa*, an astronomical appendix of the *Rig Veda*, is particularly apposite. Although this interesting four-phase paradigm for astronomical evolution is developed here specifically for Indian astronomy, it has international applications and should be tested in other geographical regions.

Rounding out this book is a 2-page "Con-

clusion", with the following comment and challenge:

We are sure that we have only touched rather limited perspectives of astronomy in this little book but we hope that it will instigate our readers to think of other perspectives and enjoy the journey and exploring those ideas. We have deliberately explored less-travelled avenues of thought in the hope that some of the readers may carry these ideas forward and confirm or negate them. (page 104).

After this are 8 pages of references.

All in all this is an interesting book, and the repeated reference (both here, and in the book itself) to it as a "little book" is slightly misleading. Admittedly, the cover is of modest dimensions, and the book spans a mere 116 pages, but most of these pages are jam-packed with text (rather than diagrams)—in small print—so the amount of reading and the information imparted, is by no means 'little'. Thus, the book contains many thought-provoking ideas and passages. Admittedly, I had encountered some of these previously, for much of the book's contents has appeared in earlier publications (including in this journal), but there is merit in bringing this scattered material together under one cover.

The National Council of Science Museums (of India) is to be congratulated on agreeing to publish this book. It is a free publication and so is excellent value, especially for those with an interest in Indian ethnoastronomy and/or archaeoastronomy. Copies can be ordered from: National Council of Science Museums, 33, Block - GN, Sector - V, Bidhan Nagar, Kolkata 700 091, West Bengal, India.

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***Catchers of the Light. The Forgotten Lives of the Men and Women Who First Photographed the Heavens*, by Stefan Hughes. Two Volumes (Paphos (Cyprus), ArtDeCiel Publishing, 2013), pp. [xviii] + 735, and [vi] + 736–1612 + [i]. ISBN 978-1-4675-7992-6 (hard copy), 215 × 302 mm, US\$199 (e-book \$39.99).**

The emergence of astrophysics during the nineteenth century is one of the great achievements of international astronomy, as spectroscopy and photography collectively revolutionised our discipline.

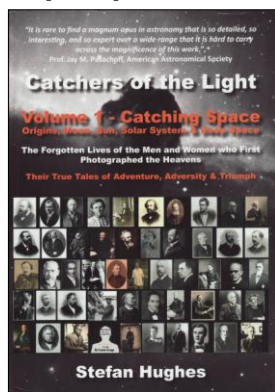
John Hearnshaw produced the classic tome on the history of astronomical spectroscopy long ago, and a second edition recently appeared (Hearnshaw, 2014), but until Stefan Hughes published *Catchers of the Light ...*, no detailed

historical account of astronomical photography existed.

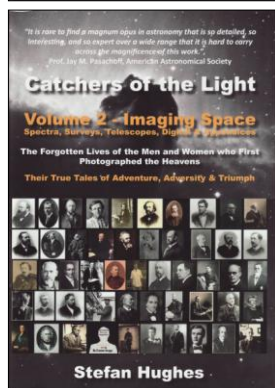
But to call his work a “... detailed historical account ...” is a gross understatement, for Dr Hughes has produced not one, but two massive large-format volumes totalling well over 1,600 pages, each volume chock-a-block with historical photographs.

In the front pages of the first volume Stefan Hughes speaks of the “... many thousands of hours of exertion, necessary to finish this magnum opus of Astronomy.” (page v), which on the previous page he had fondly described as

... a ‘Family History’ of Astrophotography ... [which] tells the story of the lives and achievements of the great pioneers of Astrophotography.



Volume 1 is about “Catching Space. Origins, Moon, Sun, Solar System & Deep Space”, and is composed of five Parts, which deal respectively with “Firstlight”, “Moonlight”, “Sunlight”, “Planets & Comets” and “Starlight”. There are 26 chapters in these five Parts.



Volume 2 is about “Imaging Space. Spectra, Sky Surveys, Telescopes, Digital & Appendices”, and is composed of four Parts, which deal respectively with “Spectra”, “Cartes du Ciel”, “Astrograph” and “Amateur”. The 17 chapters in these four Parts are followed by 8 appendices, a list of abbreviations and an Index.

Individual chapters deal with people who were seminal either to the development of photography itself (Part I, Chapter 1) or astronomical photography, but the last chapter in each of the Parts is typically a review relating to the theme(s) of that particular Part.

The biographical chapters are very well illustrated—with many images that I have never seen reproduced previously—and end with genealogical data, followed by Acknowledgements and then Notes (sometimes pages of them, filled with amazing detail). The final chapters in each of the Parts lack the genealogies but instead include one or more summary tables, before the Acknowledgements and Notes. Thus, the final chapter in Part 1, on “Astronomical Photograph-

ic Processes & Technologies”, has a 3.25-page table on “Photographic Processes Chronology”, which spans the period 1800–2004 and from 1969 focuses on CCDs, while the end of Chapter IV.5 (“Wandering Stars’. Imaging the Solar System”) has a 2-page table that provides a “Solar System Photography Timeline” for the period 1851 to 1956.

Near the start of his book Stefan Hughes advises that

The reader can choose which part to read either in sequence, in the order that takes their interest or any chapter of their choosing. They will lose nothing no matter how they read the book or in what order.

[Furthermore] ... the book can be used at a number of levels; either as a biography of the lives of the pioneers of astrophotography; a source of reference for a student or researcher; and finally as a technical compendium on the historical development of photographic equipment, processes, technologies and techniques, that are relevant to Astrophotography. (page iv).

These comments highlight the fact that this massive two-volume work is more like an encyclopaedia of astronomical photography than a ‘regular’ textbook, and I suspect that most astronomers will use it for reference purposes as demand inspires or inspiration demands.

This is precisely what I did with Volume 1. With research interests in solar, Solar System and cometary astronomy and galactic astrophotography, I carefully read Parts II, III, IV and V (after skimming chapters in Part I), and—as expected—ran into many familiar names, including E.E. Barnard, William Cranch and George Philipps Bond, Warren De La Rue, Henry Draper, Benjamin Apthorp Gould, Paul and Prosper Henry, Jules Janssen, James Keeler, Maurice Loewy, William Pickering, Isaac Roberts and William Wilson.

In the process of reading these chapters I also encountered familiar objects and instruments, like two photographs (on pages 272 and 439) of one my favourite comets, C/1881 K1 (Tebbutt), otherwise known as the ‘Great Comet of 1881’ (see Orchiston, 1999). I was a little surprised, though, to see that Schaberle’s 40-ft Camera was missing. This was the instrumental mainstay of the Lick Observatory’s solar eclipse expeditions from 1893 onwards (Pearson et al., 2011), and during totality produced what at the time were unprecedented images of the chromosphere, prominences and the corona (see Pearson and Orchiston, 2008).

I also really enjoyed reading the Janssen chapter, and about his observations of the 1868 total solar eclipse and the 1874 transit of Venus. Since Dr Hughes researched this book, evi-

dence has emerged to show that Norman Pogson, Director of the Madras Observatory and founder of the visual magnitude scale, is the one who, during the 1868 eclipse, should be assigned most of the credit for noting an anomalous emission line in the solar spectrum that later would be associated in the laboratory with the element helium. Biman B. Nath (2013) provides details of this in his recent book.

After finishing with Volume 1, I found Volume 2 equally rewarding. Again there were chapters on very familiar astronomers, including Andrew Common, Henri Crétien, David Gill, Edwin Hubble, Sir William and Lady Huggins, Milton Humason, Ernest Mouchez, William Parsons (the 3<sup>rd</sup> Earl of Rosse), Edward C. Pickering, George W. Ritchey, Lewis Rutherfurd, Bernhard Schmidt, Angelo Secchi and Hermann C. Vogel, and the range of supporting photographs, sketches, maps, plans and other diagrams was impressive. When coupled with relevant entries in the *Biographical Encyclopedia of Astronomers* (Hockey et al., 2014) and Hearnshaw's (2014) authoritative tome on astronomical spectroscopy, these chapters in *Catchers of the Light* will provide readers with a 'complete picture' of these famous astronomers.

But Volume 2 has more to offer, for there also are the informative review chapters at the ends of Parts VI–VIII ("Imaging Astronomical Spectra", "Mapping the Heavens" and "Telescopes in Astrophotography"), plus two chapters in Part IX ("Amateur"), one on "Pioneers of Amateur Astrophotography" and the other on "Modern Astrophotography". The first of these final two chapters identifies the Hungarian, Eugene von Gothard, as one of the first to open the eyes of professional astronomers to the research potential of astronomical photography:

On the 1<sup>st</sup> of September 1886, he obtained a photograph of the famous planetary nebula in the constellation of Lyra known as the 'Ring' Nebula (M57). It was a remarkable photograph not only for the fact it was the first ever taken of this beautiful 'smoke ring' in space, but more importantly it showed its 15<sup>th</sup> magnitude central star.

The significance of this was not lost on all who saw Von Gothard's photograph. This star at that time could only be seen [visually] under the best conditions with only the largest of telescopes, but for it to stand out like a tiny bright torch amid the black velvet of the night sky and be revealed so easily by a mere 10-inch mirrored telescope must have caused many a missed heart beat of Observatory Directors across the world (page 1272).

In addition to his astrophotographic prowess, von Gothard also was one of those who pioneered astronomical spectroscopy and photometry (see Vincze and Jankovics, 2012).

In just 64 pages, "Modern Astrophotography", the final chapter in this amazing book, takes us from the nineteenth century, through the development of various films suitable for astronomical photography, to affordable telescopes and CCD cameras for amateurs, image-manipulation software, and electronic catalogues. This well-illustrated chapter, and the preceding one, is mandatory reading for all current or budding amateur astrophotographers, as are Appendices A and E, on "Astrophotographic Resources" and "Charge Coupled Devices", respectively.

The other Appendices deal with "Important Astronomical Photographs", "Chemistry of Photographic Processes", "Telescope Optical Systems", "Useful Astrophotography Formulas", "A Brief Glossary of Terms" and "Astrophotographer Family Pedigrees". This last-mentioned 81-page Appendix contains photographs and genealogies that complement those found earlier in the various biographical chapters.

After 2 pages listing abbreviations used throughout the book, Volume 2 closes with a 66-page Index that will greatly help those readers who wish to find information about particular astronomers, telescopes, and even astronomical objects.

Like my colleague Jay Pasachoff, who wrote the Foreword, I am in awe of Stefan Hughes, the amount of research that went into this enormous book, and the wealth of text and images he offers readers. Although the printed version may be outside the price range of some individuals I hope that astronomical libraries worldwide will purchase this book. It is an incomparable resource, and will long remain the standard reference in this field.

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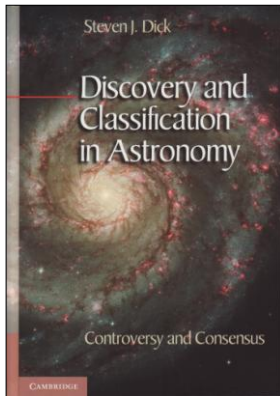
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***Discovery and Classification in Astronomy: Controversy and Consensus*, by Steven J. Dick (New York, Cambridge University Press, 2013), pp. xviv + 458. ISBN 978-1-107-03361-0 (hard copy), 180 × 255 mm, US\$45.00.**

Steve Dick, NASA's former Chief Historian, is



well known for his books on astrobiology and the history of astronomy, and it is a great pleasure to see yet another book penned by him. But this one is a little different from his earlier tomes, in that it is about discovery and classification in astronomy.

As stated in the first of the front pages,

Astronomical discovery involves more than detecting something previously unseen. The reclassification of Pluto as a dwarf planet in 2006, and the controversy it generated, shows that discovery is a complex and extended process – one comprising various stages of detection, interpretation, and understanding.

This book is composed of five Parts, titled “Entrée”, “Narratives of Discovery”, “Patterns of Discovery”, “Drivers of Discovery” and “The Synthesis of Discovery”. Each Part contains anywhere from one to four sections, that in total contain 36 short chapters.

Given the reference to the ‘Pluto affair’ in the first of the front pages it is fitting that Pluto’s discovery as the Solar System’s ninth planet in 1930, and its demotion to dwarf planet status in 2006, are the focus of the first and last chapters in Part I, “Entrée”. Like, Steve Dick, I was there at the Prague General Assembly of the IAU and voted on Pluto’s fate. Moreover, I was one of the rather sizable minority group that voted to retain Pluto as a planet, but when the outcome of these deliberations entered the public domain, all of us were tarred with the ‘destruction of Pluto’ brush and, like Steve, I too personally received abuse from members of the public and amateur astronomers. Everyone erroneously assumed that all (or almost all) of those at the Prague General Assembly wanted to demote Pluto.

Part I includes two other chapters, one about Pluto’s satellite, Charon, and the other on the discovery of Kuiper Belt objects.

Part II also starts with the Solar System (“Moons, Rings, and Asteroids: Discovery in the Realm of the Planets”) before examining stars and nebulae in our Galaxy (“In Herschel’s Garden: Nebulous Discoveries in the Realm of the Stars”, and “Dwarfs, Giants, and Planets (Again!): The Discovery of the Stars Themselves”) and then “The Galaxies, Quasars, and Clusters: Discovery in the Realm of Galaxies”).

In the various chapters in Parts I and II, Dick takes us on a ‘Cooks’ tour’ of the Solar System, our Galaxy and the distant reaches of the Universe, and covers all of the key astronomical discoveries.

This astronomical focus is replaced in part in the remaining Parts of the book by philosophical themes. Thus, Part III has sections on “The Structure of Discovery”, “The Varieties of Discovery” and “Discovery and Classification”; Part IV on “Technology and Theory as Drivers of Discovery”; and Part V on “Luxuriant Gardens and the Master Narrative” and “The Meaning of Discovery”. Some of the chapters in these sections contain material that will be new to many historians of astronomy, and this is one of the great strengths of this book: the mixing of history of astronomy and philosophy of science. Thus.

... we have noticed that ... a discovery is not an event at a discrete moment in time ... it has a structure, and this structure consists most often of detection, interpretation, and multiple stages of understanding ... discovery is sometimes preceded by a “pre-discovery” phase, and (less surprisingly) is always followed by a “post-discovery” phase, both of which delimit the structure of discovery itself in both time and space. (page 177).

This is largely inspired by Thomas Kuhn’s ideas, as best outlined in his well-known book, *The Structure of Scientific Revolutions*, and Steve Dick then proceeds to recount various examples drawn from the annals of astronomy.

Dick then discusses the microstructure of discovery:

A study of the microstructure of each component would likely be even more revealing, uncovering particular forms of detection, interpretation, and understanding, as well as the problems associated with each, such as the problematic nature of observations ... Even more importantly, the conceptual elements we have emphasized so far inevitably had technological, social, and psychological components, revealing even more about the nature of discovery. (pages 190–191).

In discussing the social dimension of astronom-



ical discoveries, our old friend Pluto once again stars, followed by quasars and pulsars (and, by association, black holes). In the case of quasars, the papers by Waluska (2007) and Kellermann (2014) are particularly apposite.

In the seventh chapter, on “The Varieties of Discovery”, Dick asks

... to what extent the telescopic discoveries differ from those made before the telescope, from discoveries of the few classes that can only be inferred indirectly by their effects, and from discoveries of new members of already established classes. (page 202).

One of the examples presented is the Great Comet of 1577 (C/1577 V1), and it is a happy coincidence that there is a paper in this very issue of *JAHH* documenting the independent discovery of this noted comet by Abū’l Fazl, the Prime Minister of the Mughal Emperor, Jalāl ud-Din Muḥammad Akbar (see Kapoor, 2015). In Dick’s book there is then a discussion of super-novae and meteor showers, leading to

... the following important conclusion: *casual sightings of astronomical objects with the naked eye, or telescopic observations that go unreported, unrecognized, or undistinguished as new classes of objects, constitute what we shall call a pre-discovery phase.* (page 211; his italics).

This takes us to instrument-aided indirect discovery, with cosmic rays, the solar wind and black holes presented as examples. As Dick notes, the ideas of John Michell and Pierre-Simon Laplace constitute the pre-discovery phase of black holes (Montgomery et al., 2009).

In the “Discovery of New Members of a Known Class”, the detection of Mars’ two moons and the rings around Jupiter, Uranus and Neptune are then cited as examples, and Pluto’s discovery—as a planet—and later demotion, are also mentioned.

The last chapter in the section on “Varieties of Discovery” deals with ““Object” Discovery vs. “Phenomena” Discovery in Astronomy”, on the basis that “... some of the landmark discoveries in astronomy have not been of objects, but of phenomena.” (page 223). In this context, over the next 10 pages, Dick looks at three well-known phenomena: the expansion of the Universe (1920s); the accelerating Universe (1990s) and the discovery of extra-terrestrial radio emission (1930s) and later the 3° cosmic microwave background (1960s).

The final Section in Part III is about “Discovery and Classification” and Dick points out that

In contrast to the discovery of new laws, processes, or properties, one of the hallmarks of the discovery of localizable natural objects

such as we have been discussing in this volume is an almost irresistible temptation to classify them. (page 233).

Not surprisingly, Dick begins by returning to the philosophy of science and looking at ‘class’ and ‘classification’ as used in the natural sciences, before turning to astronomy. First he focuses on the complicated issue of stellar spectroscopy, culminating in the MKK system and its subsequent MK refinements, before the focus shifts to galaxy classification, and then the place of ‘class’ in Solar System astronomy (with our old friend Pluto once again entering the fray). Finally, he constructs a hierarchical so-called Three Kingdom classification system for astronomy, extending from Kingdom to Family to Class, with possible extension to Type and even Subtype. This is developed fully in Appendix 2. Rounding out Part III are 6 pages on “Negotiation and Utility in Discovery and Classification”, where negotiation, simplicity and utility are applied to stellar and galaxy classification.

Part IV is about “Technology and Theory as Drivers of Discovery” and begins by examining the role of optical telescopes and then the expansion of the electromagnetic spectrum to encompass radio astronomy and microwave, infrared, ultraviolet, X-ray and gamma ray astronomy. Then follow 10 pages on “Theory as Prediction and Expansion in Discovery”, with Dick concluding that

... while there may have been a general theoretical background behind many discoveries in the twentieth century, rarely did this background actually motivate discovery ...

The role of theory in the prediction of objects that actually led to their discovery is therefore very limited ...

[But] In the next stages of discovery – interpretation and understanding – theory indeed played an extremely important role. (pages 310–311).

The final Part (V) in *Discovery and Classification in Astronomy* is about “The Synthesis of Discovery”. The first section, with the mysterious title “Luxuriant Gardens and the Master Narrative”, begins by discussing cosmic evolution. Dick asks

By what means, with what insights and motivations did astronomers “discover” the idea of cosmic evolution? Was it, in fact, through the synthesis of many of the discoveries addressed in this volume, or through some other more overarching principle? Does it in fact exhibit the extended structure typical of the classes it embodies, or some different structure? (page 317).

The question then emerges: is the endpoint of cosmic evolution planets, stars and galaxies (the physical Universe) or life, mind and intelli-

gence (the biological Universe)? Dick then looks at the ways in which the concept of cosmic evolution has entered the human consciousness in contemporary society, in part through the writing and television programs of the late Carl Sagan. I have no doubt that the late Sir Patrick Moore also played an important role in this regard. Consequently, the idea of cosmic evolution has been

... interwoven into the fabric of society well beyond its scientific content ... [although] The ultimate meaning of cosmic evolution is not yet apparent ... (page 328).

The final chapter, on “The Meaning of Discovery”, reviews the findings of the preceding 328 pages of this book by looking first at “The Natural History of Discovery” and finally at “Beyond Natural History: The Evolution of Discovery”. We are warned that although the scheme presented in this book accommodates most astronomical discoveries,

... we should take care not to shoehorn *all* discoveries into this structure ... [as] *There are interesting exceptions* ... [and] each of the components of discovery – detection, interpretation, and understanding – has its own *gray areas*. (pages 331–332; my italics).

Dick then discusses problems associated with the definition of ‘discovery’ and sings the merits of collective discovery. Thus,

... Galileo detected what we now know to be the rings of Saturn in 1610, Huygens interpreted them as such in 1655, and Maxwell showed how such an object could exist in theory in 1857 – a process encompassing more than two centuries. To say what is often said, that Galileo discovered the rings of Saturn, is to do violence to history, to conflate discovery beyond recognition, and to do a disservice to the beauty and complexity of science and discovery. The same may be said for other classes of astronomical objects. (page 336).

He then looks at the role played by developing technology in the occurrence and pace of discoveries, and produces Figure 11.1, a fascinating histogram that plots the number of discoveries against time for the past 450 years. This shows distinct decadal peaks that reflect Galileo’s access to the telescope in 1610, William Herschel’s use of large telescopes in the 1780s,

and a “... mountain of discoveries in the twentieth century, three times greater than the sum of the previous 350 years.” (page 338). The data used in compiling this diagram are assembled in a 23-page Appendix (number 2), at the end of the book.

Figure 11.1 automatically raises the thorny question of “Are we at the end of discovery or only the beginning, or somewhere in between?” (page 339). Different astronomers offer different answers, depending very much on how the term ‘discovery’ is defined. Only time will tell!

Ending the book are the two previously-mentioned appendices, 58 pages of Notes, a short “Select Bibliographical Essay”, a glossary and a detailed Index.

I hope that the foregoing account imparts some of the flavour of this remarkable book. It is an intellectual banquet, but too large for most of us to consume in just one sitting. It is composed of different courses: first an introductory entrée, followed by a main course comprising historical narrative garnished with theory provided by the history of science, and then a dessert that looks at the the present and the future of astronomical discovery. It is masterfully written (as are all of Steve Dick’s books), and is full of thought-provoking ideas and discussion. At just US\$45.00 it is very well-priced, and should join the bookshelf of many astronomers—not just those committed to the history of astronomy.

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## CORRIGENDUM

Unfortunately there is an error in the caption of Figure 4 in the following research paper, that was published in the July/August issue of this journal:

Steinicke, W., 2015. William Herschel and the ‘Garnet Stars’:  $\mu$  Cephei and more. *Journal of Astronomical History and Heritage*, 18(2), 199–217.

The new figure caption should read:

Figure 4: Herschel’s ‘large 20-ft’ telescope, shown here at Datchet in its original form (after Dreyer, 1912: Volume 1, Plate B).

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