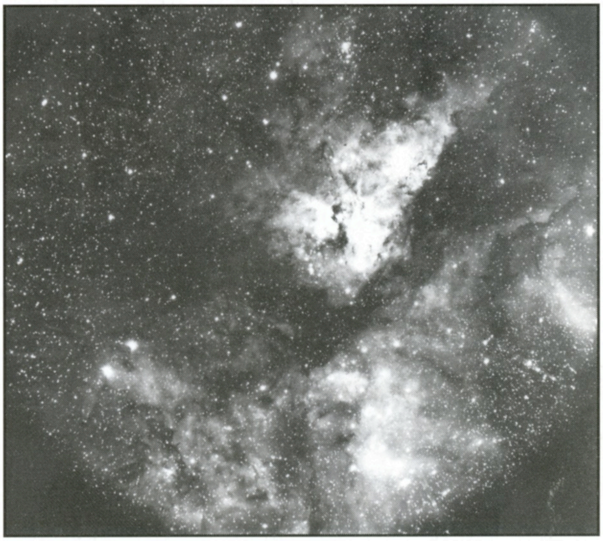
Journal of Astronomical History and Heritage

Volume 5 No. 1 Number 9 2002 June

JAH² is published twice-yearly, in June and December, and features review papers, research papers, short communications, correspondence, book reviews. Papers on all aspects of astronomical history are considered, including studies which 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 authors receive 25 offprints of their paper free of costs.

Contributions should be sent to the Papers Editor, Dr Wayne Orchiston (preferably by e-mail at: wo@aaoepp.aao.gov.au), Anglo-Australian Observatory, PO Box 296, Epping, NSW 2121, Australia and queries regarding subscriptions, book reviews, and production should be directed to the Managing Editor, John Perdrix at Astral Press, PO Box 107, Wembley, WA 6913, Australia. A Guide for Authors was published in Vol. 2 No. 1 of the journal and is on the website.

E-mail: astral@iinet.net.au
Telephone: +61 8 9387 4250, Facsimile: + 61 8 9387 3981
Website: http://www.astralpress.com.au

The annual subscription is AU$35.00 or Stg£14.00

Published by Astral Press, Registered Office, 46 Oceanic Drive, Floreat, WA 6014, Australia.

ISSN 1440-2807

Journal of Astronomical History and Heritage

2002

Volume 5

Edited by
John Perdrix
and
Wayne Orchiston

Published by
ASTRAL PRESS
WESTERN AUSTRALIA
MMII

Journal of Astronomical History and Heritage 5(1):1-8 2002

Astronomy in the Xia-Shang-Zhou Chronology Project

Ci-yuan Liu
Shaanxi Observatory, Chinese Academy of Sciences,
Lintong, Shaanxi, 710600, China
liucy@ms.sxso.ac.cn

Abstract
The Xia-Shang-Zhou Chronology Project was undertaken in order to set up a chronological framework for the Xia, Shang, and Zhou Dynasties in early China. There are 12 Working Groups involved in the Project that focus specifically on ancient astronomical records. Some of these have already reached precise chronological conclusions that have been generally accepted.

Keywords: *chronology, ancient astronomical records, history of astronomy – Chinese history*

1 INTRODUCTION

China claims a history of 5000 years but precise chronology can only be traced back to 841 BC, the first year of the reign of Gonghe. This date is based on documentation provided by Sima Qian, the great first century BC historian. For a long period historians did their best to refine Chinese chronology, but little progress was made. Then a new opportunity arose thanks to developments in modern science and technology and to new archaeological discoveries. The Xia-Shang-Zhou Chronology Project brought together scholars from archaeology, astronomy, history, and radiocarbon dating in a bid to break the deadlock. After five year's effort, the Project published its initial report (The Expert Group ..., 2000). This is in Chinese, but an English version will be published soon. At its core is a chronological list, which includes approximate dates for the beginning of the Xia Dynasty (2070 BC) and the early Shang Dynasty (1600 BC), and precise commencement dates for the reigns of some kings in the late Shang Dynasty (1300–1046 BC) and every king in the West Zhou Dynasty (1046–771 BC).

There are various astronomical records included in the ancient Chinese literature, and by using modern astronomical methods some of these (but particularly eclipses, and positions of the Sun, the Moon, and the planets) can provide useful information. These sorts of historical astronomical records have also been used in this way in other countries.

The Xia-Shang-Zhou Chronology Project was carried out by forty-four different Working Groups, twelve of which used mainly astronomical evidence. One of the four Project Chairmen, Professor XI Zezong, co-ordinated and led all of the astronomical investigations, which eventually will be brought together in a book. Listed below are the twelve different Working Groups reports and their authors.

G1. JIANG, Xiao-yuan: *The Star Dahuo in the Three Dynasties and Chronology*.
G2. XU, Zhen-tao: *Conjunctions of the Five Planets and the Changes of the Dynasties*.
G3. LIU, Ci-yuan and JIANG, Lin-chang: *A Complementary Study on the War of Sanmiao*.
G4. HU, Tie-zhu: *Stellar Phenomena in Xiaxiaozheng and Chronology*.
G5. WU, Shou-xian: *A Re-study of the Solar Eclipse in Shangshu*.
G6. ZHANG, Pei-yu: *Astronomical Records and Calendar on the Oracle Bones in Shang Dynasty*.
G7a. JIANG, Xiao-yuan: *Astronomical Events and King Wu's Conquest*.
G7b. LIU Ci-yuan: *Astronomical Events and King Wu's Conquest*.
G8. CHEN, Jiu-jin: *Reconstruction of the Calendar of the West Zhou Dynasty from Bronze Inscriptions*.
G9. LIU, Ci-yuan: *The Double Dawn and the First Year of King Yi*.
G10. CHEN, Mei-dong: *The Calendar Regulations in the Periods of West Zhou and Chunqiu*.
G11. SUN, Xiao-chun: *Foreign Astronomical Records in the Period of Xia-Shang-Zhou*.
G12. NING, Xiao-yu: *Astronomical Computation Center and Data Base for the Study of History*.

2 THE INDIRECT ASTRONOMICAL EVIDENCE

Working Group G11 looked at overseas astronomical events during the Xia-Shang-Zhou period. The chronologies of ancient Babylon and Egypt depend largely on astronomical records. Because of precession, astronomical phenomena change slowly from century to century, and records of Sirius rising with the Sun, for example, have been used to push the chronology of Egypt back to the twentieth century BC. The Working Group also examined two possible solar eclipses recorded by the Hittites. A group of records relating to Venus found on excavated clay tablets pushed Babylonian chronology back to the twentieth-nineteenth centuries BC. These astronomical conclusions were based on various assumptions, including the places of observation, the calendars in vogue at that time, and the exact meanings of certain special terms; they also relied on historical and archaeological evidence. However these uncertainties do not invalidate the overall results, and *Chronology of Ancient Civilizations of the World* ..., published in Beijing (Northeast Normal University, 1999), provides a good overview of the findings of this Working Group.

In ancient Egypt, Sirius played an important role in determining the seasons, but in ancient China it was Alpha Scorpii that served this purpose. Known as *Dahuo*, the 'Fire Star', it is mentioned in many ancient Chinese records including:

> "In the middle of summer, the day is the longest, the Fire Star transits [at dusk]." (*Shangshu. Yaodian*)

> "In the 5th month, Shen stars [Orion] appear [before sunrise], Fire Star transits [at dusk]." (*Xiaxiaozheng*)

> "The 7th month, Fire Star flows [to the west]; the 9th month, cloths [for winter] are ready." (*Shijing*)

Working Group G1 discussed the relationship between those phenomena and the times. It was useful to understand the background circumstances, although it was not possible to derive exact chronological results because of the crudeness of these records.

Conjunctions of the five planets were considered as important omens to changes of dynasties, and such records are associated with most early Chinese dynasties:

> "At the time of King Yu [founder of the Xia Dynasty] the five planets were strung together like a necklace. They shone as brilliantly as chained jade disks." (*Xiaojing Goumingjue*)

> "In the 10th year of King Digui [the last King of Xia Dynasty], the five planets were in disorder, stars fell down like rain." (*Bamboo chronicle*)

> "In the 32nd year of King Dixin [the last King of Shang Dynasty], the five planets gathered in constellation Fang." (*Bamboo chronicle*)

> "The five planets gathered in constellation Ji before Duke Qihuan became the overlord." (*Songshu*)

> "In the 1st year, 10th month of Han Dynasty, the five planets gathered in constellation Jing." (*Hanshu*)

What we are particularly interested in are the first three. Working Group G2 showed the first two events possibly took place in 1953 BC and 1513 BC, and that the third event could not have taken place during this period. Meanwhile, the last two records are obviously wrong because there were no such planetary conjunctions at the times indicated (see Zhang, 1991). In fact this sort of record was often suspect in earlier times because of its strong astrological associations.

Xiaxiaozheng is a chapter of *Liji* compiled during the West Han Dynasty, and was considered as a calendral source for the Xia Dynasty. It records a dozen stellar phenomena, including:

> "In the 1st month, Ju stars appear [before sunrise]; Shen stars transit at dusk and Dou stars hung."

> "In the 3rd month, Shen stars disappear [in the sunlight]."

> "In the 4th month, Mao stars appear [before sunrise]; Nanmen stars transit at dusk."

Ancient people used these phenomena to estimate seasons, and it is important also to remember that these phenomena were changing gradually because of precession. Working Group G3 showed that these events occurred throughout the whole Xia-Shang-Zhou period, and that it therefore was not possible to reach any direct chronological conclusions (see Hu, 2000).

King Yu was the first king of the Xia Dynasty. *Muozi* say "The sun appears in the night before Yu crusaded against the Sanmiao tribe." and Pang and Yau (1996:103) believe this possibly refers to a solar eclipse at sunset. Upon linking related ancient literature and new archaeological discoveries, Working Group G4 was able to discuss the historical background and the geographical location. By using the astronomical 'double dawn' method, and allowing for uncertainty in the rotation of Earth, eleven different solar eclipses in three different centuries were found that matched this record. But we still need more information to confirm this as a record of an eclipse, and the reign of King Yu also needs to be shortened.

Shangshu records a horrible event during the reign of King Zhongkang, in the middle of the Xia Dynasty: "On the first day of late autumn, the Chen was not harmonious in constellation Fang, the blind beat drums, junior officers galloped, people ran around..." This famous story has been documented in the literature since the sixth century BC, with most people thinking that it relates to a solar eclipse. Since ancient times, many scholars have tried to identify the eclipse so as to date the reign of King Zhongkang. Working Group G5 carried out a thorough analysis of these earlier investigations (see Wu, 1998, 2000). Thirteen different conclusions contained in them were analysed, and some apparent mistakes were found. The calculations made by these earlier researchers were also analysed (Li & Wu, 1999). Finally, the Working Group reviewed all solar eclipses that occurred during a three-century period, and came up with four possible dates: 2043 BC, 2019 BC, 1970 BC, and 1961 BC.

The calendar in the West Zhou Dynasty is an important chronological base, but we have very little information about it while there are many clues in the succeeding Chunqiu period. Working Group G10 reconstructed the calendar in the Chunqiu period, which is a useful reference for us to understand information from West Zhou. The Working Group also showed that some kings would count their reign from the very first year in which they ruled, while most kings began counting from the following year. Another conclusion of this Working Group was that the 'Jupiter chronology' was only in vogue during the Zhanguo period (Chen, 2000).

3 EXACT CHRONOLOGICAL CONCLUSIONS FROM ASTRONOMICAL RECORDS

3.1 Eclipses on the Oracle Bones

Since their initial discovery in AD 1899, a great many oracle bones have been unearthed in Anyang, the capital of the late Shang Dynasty, and the inscriptions on these bones provide invaluable information about this period of Chinese history. Working Group G6 investigated these oracle bones, and astronomy played an important role in their study (see Zhang, 1999). Altogether, about ten records of solar and lunar eclipses have been found. There are usually sexagenary days listed in the records, but the name of the king, the year, and the month are typically absent. A group (Group Bin) of five lunar eclipses was documented by the same powwow, and historians believe that he served King Wuding or a slightly later king. Assuming that the sexagenary days can be continually traced back to that time (we have independent evidence only to 720 BC), many possible combinations were found by computing eclipses that would have occurred during the approximate period of King Wuding's reign. Archaeological and palaeographical investigations also provided useful information, including the relative dating of different oracle bones, but did not produce reliable absolute dates. Date boundaries were set at around 3 a.m. as a result of studying the oracle bones and astronomical history. Under these circumstances, the only possible set of five lunar eclipses was found to date between 1201 and 1181 BC. Table 1 gives the original records and the identified dates, plus the magnitudes and times of maxima (in Beijing Time). These identifications also provide support for the continuation of the sexagenary dating system.

Table 1: The five lunar eclipses of Group Bin and their identifications

Record	Date	Magnitude	Time h m
guiwei (20) night Moon eclipsed	1201.7.12 BC	0.51	00 04
[jia]wu (31) night Moon eclipsed	1198.11.4 BC	0.72	22 17
jiwei (56) night to gengshen (57) Moon eclipsed	1192.12.27 BC	1.67	22 51
renshen (9) night Moon eclipsed	1189.10.25 BC	0.51	21 06
yiyou (22) night Moon eclipsed	1181.11.25 BC	1.73	20 16

This conclusion has been accepted as a basis for determining the reign of King Wuding, which then became an important reference for other kings of late Shang Dynasty.

In addition, another group (Group Li) of four eclipses has also been identified, but these have not yet been incorporated into the formal findings of the Project.

Finally, we should note that the group re-evaluated the famous "tree flames eat the Sun" event which is typically associated with a solar eclipse, and found instead that it was best explained as a record about the weather (Li, 1999).

3.2 King Wu's Conquest

King Wu conquered King Zhou and founded the new dynasty of West Zhou. This was an important event in Chinese history, although the precise date of this event is in doubt. However, it is a key to the Xia-Shang-Zhou Chronology Project. There are quite a number of related chronological and astronomical records, but they are generally concise, vague, even suspect, and at times are contradictory. Moreover, different choices, interpretations, and explanations lead to different conclusions. As a result, previous investigations produced forty-four different conclusions, spanning a 110-year period, and these various papers have recently been brought together and published in a book (Beijing Normal University, 1997). The main astronomical records include:

> "The first month, day Renchen [29], it was Pang Siba. The next day was Guisi [30]; King Wu departed from Zhou [state] to crusade against King Zhou [of Shang Dynasty]. Counting from the day Ji Siba of the third month, the fifth day was Jiazi [1] when King Zhou was killed. Counting from the day Jipang Shengba, the sixth day was Gengxu [47] when King Wu prayed at the grand temple of Zhou [state]." (*Wucheng*)

> "When King Wu conquered King Zhou, Jupiter was in the constellation Chunhuo; the Moon was in the constellation Tiansi; the Sun was in the constellation Ximu; 'Chen' was in the constellation Doubing; 'the star' was in the constellation Tianyuan." (*Guoyu*)

Other records involve conjunctions of the five planets, a lunar eclipse on day Bingzi (13), and Jupiter and a comet in the east sky. These events do not limit the time strictly. In addition, an inscription on a bronze Ligui possibly mentions Jupiter (in the middle of the sky or in the constellation Chunhuo).

The latest archaeological discoveries compress the possible period to between 1050 BC and 1020 BC (Wang and Xu, 2000). An important initial problem was the terms used for the lunar phase, such as Shengba and Siba, and these have been satisfactorily explained (see the next paragraph). Many astronomical, calendrical, and historical clues imply the event should have taken place in winter, and on this basis the diary (i.e. month, day, and lunar phases) listed in Wucheng was analysed and five candidates were found: in 1046, 1041, 1037, 1031, and 1020 BC (Liu, 1999). Then the condition of "Jupiter in constellation Chunhuo" was added, and the only choice of date for King Wu's conquest was 20 January in 1046 BC (Liu, 2001). This conclusion, reached by Working Group G7b, is independently supported by the Bingzi lunar eclipse and other lunar phases mentioned in *Shangshu*. It also accords with most astronomical, archaeological, and historical information, and supports the late Shang Dynasty and later West Zhou Dynasty chronology derived by other Working Groups involved in the Xia-Shang-Zhou Chronology Project. This conclusion has been accepted as a key result by the Project. In fact, Pankenier (1981-1982) arrived at the same date, using other clues. Meanwhile Working Group G7a suggests that the correct year is 1044 BC (Jiang and Niu, 1999).

3.3 Bronze Inscriptions and the Kings of West Zhou Dynasty

According to reliable history, the sequence of kings of the West Zhou Dynasty was: Wu, Cheng, Kang, Zhao, Mu, Gong, Yi, Xiao, Yii, Li, Gonghe, Xuan, and You. There are many surviving bronzes from the West Zhou Dynasty, and more than sixty have characters on them that contain the 'four elements': year, month, sexagenary day, and lunar phase. Upon utilizing lunar phases computed by astronomical methods, every single bronze could be limited to several dating possibilities (see the last section). Ideally, combining all sixty bronzes should lead to much stricter limits, and it should be possible to set up the whole chronological system of kings of the West Zhou Dynasty. However, there were major difficulties. The records list only the year and not the name of the king, so we can only roughly assign the inscriptions on each bronze to a particular king on the basis of their form, figure, pattern, and characters. 'Shengba', 'Siba', 'Jiwang' and 'Chuji' are special terms for lunar phase, but their exact meanings have been argued for two thousand years. In addition, there were still some unanswered questions on calendar regulations during West Zhou times (and especially the beginning of the year).

The following examples in Table 2 are useful for an understanding this work, and summarize some of the findings of Working Group G8. In this Table, 'Original Record' includes the name of the bronze, the year, month, sexagenary day (and its sequence number), and lunar phase, while the second column gives the name of the king to whom the bronze possibly relates. After a comprehensive analysis, it should be possible to date every bronze to a particular calendar year BC by correlating the lunar age (i.e. lunar phase) with the original historical record. This is a basic analytical technique for the study of West Zhou chronology, and although many scholars carried out their own investigations of these bronze inscriptions, unfortunately they came up with quite different results. These are collected together in a new book edited by Zhu and Zhang (1998).

Table 2. Some examples of bronze inscriptions

Original Record	Associated King	Interpretation	Date BC
Xiangui: 34th year 5th month day Wuwu(55), Jiwang	King Mu	King Mu 34y 5m day Wuwu(55) l.a.17	943
Weiding: 9th year 1st month day Gengchen(17), Ji Siba	Around King Gong	King Gong 9y 1m day Gengchen(17) l.a.24	914
Shihugui: 1st year 6th month day Jiaxu(11), Jiwang	Around King Yi	King Yi 1y 6m day Yihai (12) l.a.20	899
Mugui: 7th year 13th month day Jiayin(51), Ji Shengba	Around Yii and Li	King Yi 7y 13m day Jiayin(51), l.a.7	893
Shiduigui3: 3rd year 2nd mon. day Dinghai(24), Chuji	Around King Li	King Yii 3y 2m day Dinghai(24), l.a.3	883
Nizhong: 1st year 3rd month. DayGengshen(57), Ji Shengba	Around Yii and Li	King Li 1y 3m day Gengshen(57), l.a.11	877

Throughout a synthesized investigation using data drawn from astronomy (Jing, 1999), ancient literature, and palaeography (Wu, 1999), the Project adopted the following interpretation:

- 'Ji Shengba' = crescent to full Moon
- 'Jiwang' = days around full Moon
- 'Ji Siba' = waning Moon to New Moon
- 'Chuji' = the first ten days of every month

Astronomy and the historical literature offered seven vital key points that underpinned the chronology of the West Zhou Dynasty, including King Wu's conquest (1046 BC), the double dawn event (899 BC, see Section 3.4 below), and the first year of Gonghe (841 BC).

Based on the archaeological classification (Wang *et al.*, 1999), the above explanations for the different lunar phase terms and the seven key points, the G8 Working Group reviewed all the bronzes and drew up a chronological list for the West Zhou Dynasty, including the reign of every king. In this way it proved possible to assign dates to most bronzes, including those examples listed in Table 2 (although there were still difficulties with three bronzes). However, this overall result was one of the most important conclusions of the Project, and as we have seen astronomy played an important role in this work.

3.4 Double Dawn and the First Year of King Yi

The *Bamboo Chronicle* contains the following record: "The first year of King Yi, the sky dawned twice at Zheng." This has been considered evidence of a total solar eclipse at dawn so that before sunrise the sky became bright, then the eclipse took place and it darkened, and following the eclipse it brightened again, just like a second dawn. Identifying this eclipse would give a date for the reign of King Yi, and previous studies have produced six or seven different conclusions (see Liu and Zhou, 1999b), mainly because there have been inadequate investigations of the physical process involved. On the other hand, Stephenson (1992) has questioned whether this record does in fact signify a solar eclipse record.

The physical process of a total solar eclipse involves three different elements: the brightness change of a normal morning, the actual brightness change during the eclipse itself, and the perceived change in visual brightness as experienced by observers. The intensity of a 'double dawn' can be defined as the change of this visual brightness, so we can draw intensity contours of double dawn on the map for every eclipse. Then we can compute when and where an historical double dawn would have taken place. Generally speaking, this phenomenon takes place at the western end of the central belt of a solar eclipse, and its intensity and geographical area depend on three factors: eclipse magnitude, solar altitude, and the weather (Liu and Zhou, 1999a). What we needed was a practical investigation of our methodology, and by good fortune a total solar eclipse was visible from China on 1997 March 9, with the western end of the central belt located at the northern part of Xinjiang. We arranged for popular observations of this event to be carried out, and sixty people sent us thirty-five different reports from eighteen different locations. As a result, these reports included different eclipse magnitude, solar altitude, and weather details, plus personal comments on visual brightness, which allowed us to fully test our theory and to verify it. We therefore searched for solar eclipses during the period 1000-840 BC and found only one identification at Zheng: on 21 April in 899 BC (see Figure 1). We believe that the *Bamboo Chronicle* double dawn record relates specifically to this eclipse

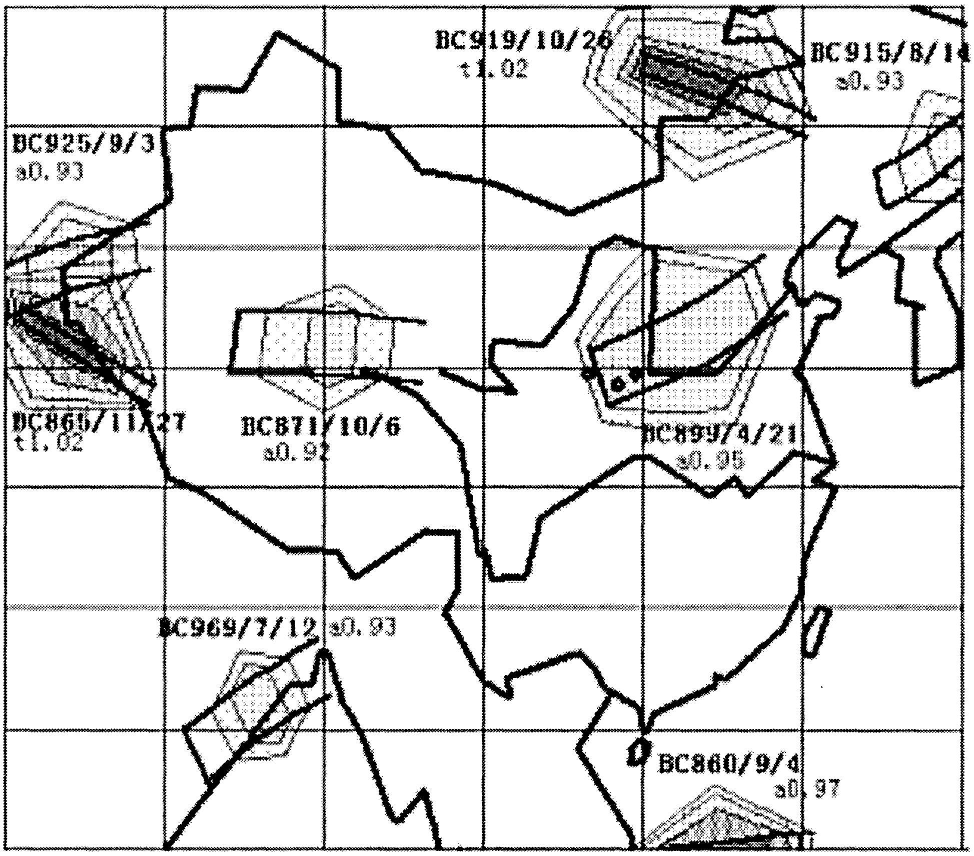


Figure 1. Double dawn events during 1000-840 BC (after Liu, Li and Zhou, 1999)

(Liu, Li and Zhou, 1999), a conclusion that is independently supported by a bronze inscription (The Expert Group ..., 2000). This conclusion has been accepted by the Xia-Shang-Zhou Chronology Project, and is one of the seven key points underpinning the West Zhou chronology system proposed by Working Group G9.

This work strongly supports much earlier conclusions reached by Fang (1975) and Pang *et al.*(1988), both of whom also suggested 899 BC for this event.

4 CONCLUSION

On 2000 November 9 the Xia-Shang-Zhou Chronology Project announced the following chronology list for the three dynasties:

Xia: 2070-1600 BC
Shang (early): 1600-1300 BC
Shang (late): 1300-1046 BC
- Pangeng-Xiaoxin-Xiaoyi (1300 BC)
- Wuding (1250 BC)
- Zugeng-Zujia-Lingxin-Kangding (1191 BC)
- Wuyi (1147 BC)
- Wending (1112 BC)
- Diyi (1101 BC)
- Dixin (1075 BC)

West Zhou: 1046-771 BC
- Wu (1046 BC)
- Cheng (1042 BC)
- Kang (1020 BC)
- Zhao (995 BC)
- Mu (976 BC)
- Gong (922 BC)
- Yi (899 BC)
- Xiao (891 BC)
- Yii (885 BC)
- Li (877 BC)
- Gonghe (841 BC)
- Xuan (827 BC)
- You (781 BC).

This list is a useful reference frame for Chinese history, and will be adopted by dictionaries, textbooks, and museums. As a result of future investigations, we expect to make further progress in archaeological discovery, C^{14} determination technology, and astronomical computation, and hope that the ancient literature will provide new discoveries and fresh interpretations.

5 ACKNOWLEDGEMENTS

I am grateful to Dr Wayne Orchiston from the Anglo-Australian Observatory for his help in refining the English in this paper.

6 REFERENCE

Note: in the following references (C) indicates books, research papers and articles written in Chinese. Most of these have English abstracts.

Beijing Normal University (ed)., 1997. *Chronology of King Wu's Conquest*. Beijing, Beijing Normal University Press (C).

Chen Mei-dong, 2000. Calendar table used in state Lu during the spring and autumn periods and calendars used in the spring and autumn periods and Western Zhou. *Studies in the History of Natural Sciences*, **19**:124- 142 (C).

Fang Shan-zhu, 1975. Some problems with the chronology of West Zhou. *Dalu Magazine*, **51**(1):15-25 (C).

Hu Tie-zhu, 2000. Research on the adoption years of Xia-xiao-zheng. *Studies in the History of Natural Sciences*, **19**:234-249 (C).

Jiang Xiao-yuan and Niu Wei-xing, 1999. Astronomical phenomena in Guo-yu and the year and calendar of King Wu's conquest over Yin. *Studies in the History of Natural Sciences*, **18**:353-365 (C).
Jing Bing, 1999. A study of four time-recording terms of Chuji, Jiwang, Jishengpo and Jisipo in the Western Zhou Dynasty. *Studies in the History of Natural Sciences*, **18**:55-68 (C).
Li Yong and Wu Shou-xian, 1999. Recovery of the ancient calculation of the Zhongkang solar eclipse. *Studies in the History of Natural Sciences*, **18**:234-240 (C).
Li Xue-qin, 1999. *Theses on Xia-Shang-Zhou Chronology*. Shenyang, Liaoning University Press (C).
Liu Ci-yuan, 1999. Analysis on dates in Wucheng. *Studies in the History of Natural Sciences*, **18**:366-373 (C).
Liu Ciyuan, 2001. Analysis of the astronomical records on King Wu's conquest. *Science in China A*, **44**:1216-1224.
Liu Ci-yuan and Zhou Xiao-lu, 1999a. The sky brightness when the rising Sun is in eclipse. *Chinese Astronomy and Astrophysics*, **23**:249-257.
Liu Ci-yuan and Zhou Xiao-lu, 1999b. An examination into the ancient records of the double dawn. *Studies in the History of Natural Sciences*, **18**:48-54 (C).
Liu Ci-yuan, Li Jianke and Zhou Xiaolu, 1999. Study on double dawn. *Science in China A*, **42**: 1224-1232.
Northeast Normal University, 1999. *Chronology of Ancient Civilizations of the World. History and Present Situation*. Beijing, World Book Company (C).
Pang, K.D. and Yau, K.K., 1996. The need for more accurate 4000-year ephemerides, based on lunar and spacecraft ranging, ancient eclipse and planetary data. In S. Ferraz-Mello, B. Morando and J.-E. Arlot. (eds.). *Dynamics, Ephemerides and Astrometry of the Solar System*. Dordrecht, Kluwer (IAU Symposium No. 172), pp. 113-116.
Pang, K.D., Yau, K., Chou Hung-hsiang and Wolff, R., 1988. Computer analysis of some ancient Chinese sunrise records to determine the Earth's rotation rate. *Vistas in Astronomy*, **31**:833-847.
Pankenier, D.W., 1981-1982. Astronomical dates in Shang and Western Zhou. *Early China*, **7**:2-37.
Stephenson, F.R., 1992. A re-investigation of the 'double dawn' event recorded in the Bamboo Annals. *Quarterly Journal of the Royal Astronomical Society*, **33**:91-98.
The Expert Group ..., 2000. *The Concise Report of Xia-Shang-Zhou Chronology Project, 1996-2000*. Beijing, World Book Company (C).
Wang Shi-min, Chen Gongrou and Zhang Changshou, 1999. *Bronze Classification of West Zhou*. Beijing: Wenwu Press (C).
Wang Wei and Xu Liang-gao, 2000. Archaeological investigation of the culture of pre-Zhou. *Chinese Journal of Archeology*, **3**:285-310 (C).
Wu Zhen-wu, 1999. The investigation of the terms for lunar phase on bronzes. Unpublished report of the XSZ Project (C).
Wu Shou-xian, 1998. A second look at the Zhongkang solar eclipse record. *Studies in the History of Natural Sciences*, **17**:250-253 (C).
Wu Shou-xian, 2000. Research on determining the age of the Zhongkang solar eclipse during the Xia Dynasty. *Studies in the History of Natural Sciences*, **19**:114-123 (C).
Zhang Pei-yu, 1991. Conjunctions of the five planets and historical records. *Renwen Magazine*, No. **5**:103-106 (C).
Zhang Pei-yu., 1999. The identification of oracle bone inscriptions relating to solar and lunar eclipses and Shang Dynasty dating. *Social Sciences in China*, **5**:172-197 (C).
Zhu Feng-han and Zhang Rong-min (eds.), 1998. *Chronology of the Kings of West Zhou*. Guiyang, Guizhou People's Press (C).

Dr Ciyuan Liu is a research professor of Shaanxi Observatory (National Time Service Centre of China). He has worked in the observatory since 1973, in astrometry, then in the history of astronomy. His main interest is ancient Chinese astronomical records. His work deals with Earth's rotation, astronomical chronology, local relics and archives, analysis of various ancient astronomical records.

Journal of Astronomical History and Heritage 5(9-20 2002

Acceptance and adaptation of octants and sextants in Japan during the eighteenth and nineteenth centuries

Tsuko Nakamura
National Astronomical Observatory of Japan,
Osawa, Mitaka, Tokyo 181-8588, Japan
Email: tsuko@cc.nao.ac.jp

Abstract
This paper[1] overviews the introduction, acceptance, and adaptation of octants and sextants in Japan during the eighteenth and nineteenth centuries. Octants first appear in the Japanese literature in the 1770s. In 1783 Motoki Ryoei, a well-known interpreter and scholar, first translated a Dutch book on octants by Cornelis Douwes. From that date, octants continued to attract wide interest from Japanese professional and amateur astronomers and land surveyors, and a considerable number of books on octants and sextants were published up to the 1860s. Around 1806, an octant was made for the first time in Japan. Owing to the strict seclusion policy adopted by the Tokugawa shogunate during the Edo period, the Japanese adapted octants as a convenient instrument for land surveying rather than for navigation, and even unique range finders were also invented as a modification. It was not until after the mid-1850s that octants were used for marine navigation.

Keywords: *Octants, sextants, Vernier scale, Japan, latitude, land-surveying*

1 INTRODUCTION

Japan is a geographically-isolated country, and as a terminal station of the Silk Road throughout its history was often under the strong cultural influence of foreign countries. Astronomy was no exception. For about a millennium from the sixth century, the influence came exclusively from China and Korea. Then, from the second half of the sixteenth century until the completion of Sakoku (the national seclusion policy) in the 1630s, which was intended to protect against invasion of Christianity, Western astronomical influences were introduced from Europe, mainly by the Portuguese. After the relaxation of import prohibitions that had been put in place in 1720 allowing the entry of foreign books unconnected with Christianity, modern Western astronomical knowledge in the form of books and instruments was introduced to Japan, starting with Chinese translations of Western books made by Jesuit missionaries and later through the strictly regulated trading channel of the Dutch East-India company (for the historical background of Japanese astronomy, see Nakayama, 1969).

Octants were typical of the Western astronomical instruments imported directly from Europe to Japan, without interposing by the Chinese, and were widely welcomed among the Japanese in the Edo era because of their novelty, portability, and high performance. The present paper describes how the Japanese understood the principle and functioning of octants and sextants, and accepted and modified them in a handicapped state of seclusion. We also briefly compare the situation of accepting octants in China with ours.

2 ORIGIN AND CHARACTERISTICS OF OCTANTS

Octants were a handy and accurate navigational apparatus that was used mainly on board ships to measure the elevation of celestial bodies. They were invented nearly simultaneously by Thomas Godfrey of the US in 1730 (Hindle, 1972) and John Hadley of Britain in 1731 (Hewson, 1951). At that time, the invention was referred to as a Hadley's quadrant or simply a quadrant. However, the name often caused confusion because of the much larger astronomical quadrants used earlier by such people as Tycho Brahe, so during the reign of Queen Victoria Captain Leckey and his contemporaries assigned it the name 'octant', rather than quadrant (ibid.). Before the introduction of octants, cross staffs, back staffs, and Davis quadrants had long been used for navigational reckoning (see Waters, 1958; Wynter and Turner, 1972).

For the purposes of later discussion, we shall briefly summarize the structure and measuring principle of an octant and its superiority over the previously-used instruments mentioned in the above paragraph. Figure 1 shows the conceptual structure of an octant, which basically consists of the sector-shaped frame IAA' with two mirrors attached vertically to the plane of the frame. One mirror H (half of which is transparent glass) is fixed to the frame, while another mirror can be rotated with the mobile bar IB around the axis I. Note that the two mirrors become parallel when the bar IB coincides with IA. On the arc AA' is inscribed a precise angular scale. In practical usage, the observer's eye E first views the sea horizon through the glass part of H along the line of sight EG, and by adjusting the position of IB, places the reflected image of the Sun, for example (in the direction of C) at the same position in H as that of the horizon. Then, according to a basic theorem of optics, twice the angle of the mirror I (α) is always equal to the deflected light-ray angle CIG', namely the elevation of the Sun (β). Hence, by doubling the scale of the angle inscribed on the arc AA', one can immediately read the elevation of the Sun on AA'. This is the principle of the octant.

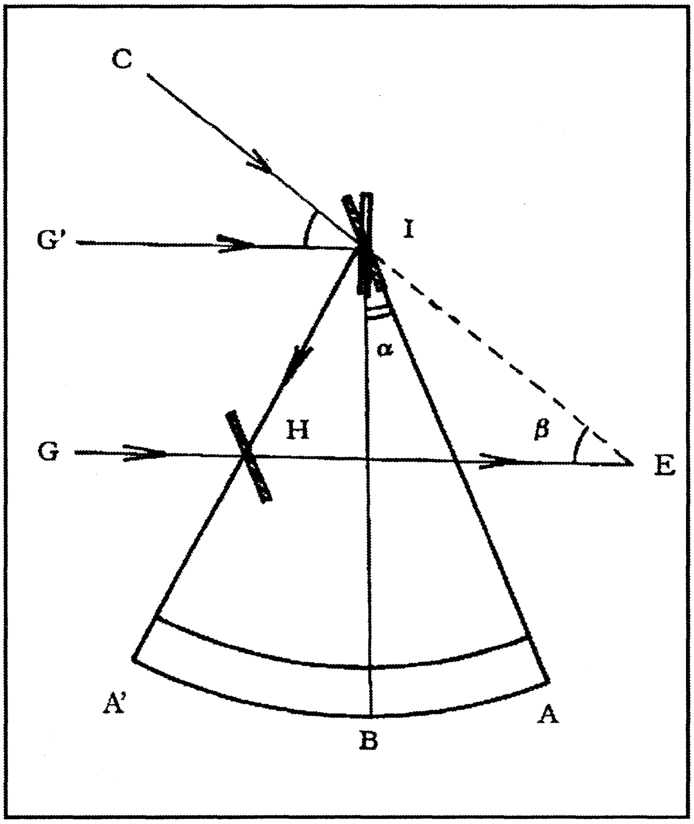


Figure1. Diagram showing the conceptual structure and functioning of an octant. Half of the mirror, H, is transparent glass in ordinary models. Note that 2α = β.

A typical octant could measure elevation with an accuracy of one minute of arc by using the Vernier subscale. For solar observations, sunglasses were usually inserted in the light path (IH and GH). It sometimes happened that the sea horizon was invisible due to clouds, and to accommodate such inconvenient situations improved models were produced which could aim at the opposite horizon by adding another sighting hole near the mirror H (back-sight type). However, these became unpopular in later times (e.g. see Wynter and Turner, 1972). The name 'octant' comes from the fact that the arc AA' is $^1/_8$ (i.e. 45°) of 360° so that this allows us to measure angles up to 90 degrees. Sextants, which were invented by Captain John Campbell in 1757 (Peterson, 1997), are characterized by $^1/_6$ of a full circle for the frame angle, and gave a better measuring accuracy (up to 10 arc seconds) through the introduction of a small telescope for sighting and sometimes also a magnifying lens for reading the scale.

The octant was much superior to previous instruments like back staffs and Davis quadrants in the following respects: 1) Owing to a simultaneous viewing of the horizon and the Sun at the mirror H, measurements made with an octant could allow for the movement of the ship. 2) In addition to the Sun, an octant could also be used to observe the Moon and stars at night. 3) Because the light-paths are folded by two mirrors and a diagonal or Vernier scale was adopted, the octant was light-weight and handy so that it could even be used in stormy conditions. Because of these reasons, octants had become popular among European and US officers and seamen by the middle of the eighteenth century, and this situation continued until the beginning of the nieteenth century (Hewson, 1951).

3 INTRODUCTION OF OCTANTS INTO JAPAN

Now let us see when and how octants were introduced to Japan. The earliest description of an octant appears in the travel essay, *Kizan Roku* (Coming to the Home Mountain),[2] written in 1778 by Miura Baien, the noted natural philosopher. To learn about Western natural sciences in this year he made a trip to Nagasaki where many interpreters lived (because of the presence there of the Dutch East-India company). In Nagasaki Miura saw an octant at the home of the senior interpreter, Yoshio Kogyu, who exhibited for visitors various scientific instruments imported from Europe, such as microscopes, thermometers, and armillary spheres. However, it does not seem that Yoshio knew how to use his octant, though Miura explained in one part of the essay that octants were an indispensable apparatus for Dutch trading ships if they were to sail safely to Nagasaki. Otsuki Nyoden (1926:83) also wrote that although a certain Daimyo (warlord) purchased an octant in the 1770s, "... it had only been stored in vain at the bottom of the stock box, since nobody knew its usage." This indicates that in 1770-1780 Japanese owned at least two octants, but they had neither spoken nor written information on how to use them; they did, however, recognize the important role of octants in marine navigation.

In 1749 a Dutchman, Cornelis Douwes, published a booklet on octants, and in 1783, the famous interpreter and scholar, Motoki Ryoei, and one of his collaborators provided a translation of this titled *Shogengi Yoho* (Usage of Quadrants).[3] Strangely enough, Shizuki Tadao, one of Motoki's alleged interpreter disciples, independently translated the same Dutch booklet in 1798, giving it the title *Hachiengi Ki* (On Octants). From the translations by Motoki and Shizuki it is clear that these Japanese learned nothing about the principle of the octant from the Dutch booklet, because it exclusively described measuring techniques and how to adjust the mirror setting. Moreover, in the Douwes booklet there is no mention at all of how to use the Vernier scale, which was included in a diagram of the octant in the Dutch booklet (Figure 2). This is probably because the Vernier scale was so commonly known in Europe that its use did not need to be explained. However, as will be mentioned later, this was to cause worry to the Japanese at the initial stage of their understanding of the octant.

Figures 2 and 3 respectively show drawings of octants from Douwes' booklet and Motoki's translation, and a comparison of the two figures indicates that at the time he made the translation Motoki actually saw a different model of octant from that described by Douwes. But one can also see that both of the octants depicted are of the back-sight type, since there is a sighting hole near the fixed mirror. For a long time, this type continued to affect the design of octants used in land-surveying in Japan.

Here we shall briefly describe the career of Cornelis Douwes and the role he played in the history of Japanese astronomy. The life and works of Douwes were extensively investigated by Crone (1941). Throughout his professional career, Douwes was a leading figure in navigational and maritime education as a teacher and principal at the Naval Academy of Netherlands, as well as a member of the Dutch Science Association. He published important books on dead reckoning using octants and seamen's tables, which were widely used even after his death (e.g. Freiesleben, 1978). Among them, the booklet on octants of 1749 was the first by Douwes, and this is considered to be an important work in the maritime history of Netherlands because it was the first guidebook of this kind written in Dutch (Davids, *c*.1985).

We notice that the Japanese of that time also owed much to Douwes for making available for the first time an "... advanced treatise on contemporary Western astronomy ..." (Bartholomew, 1989:17), namely *Astronomie*, which was written by J J F de Lalande (1771), the pre-eminent French astronomer of the eighteenth century. Through the Dutch translation of

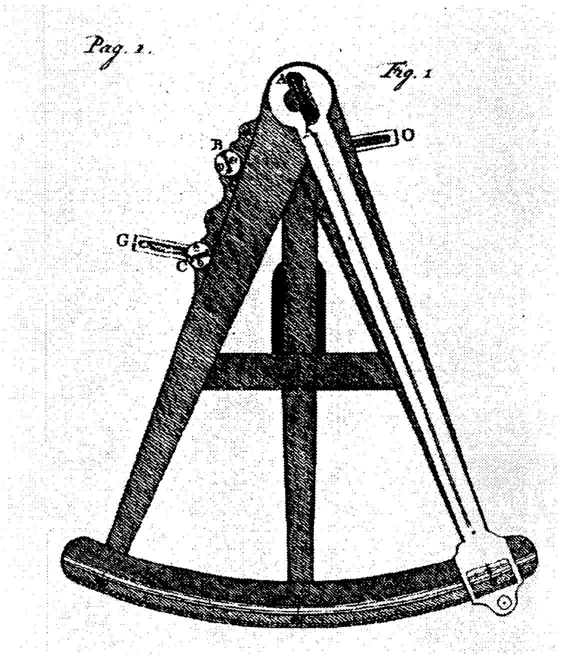


Figure 2. The drawing of an octant that appeared in the booklet *Beschryvinge van het Octant en Deszelfs Gebruik* by C. Douwes (1749).

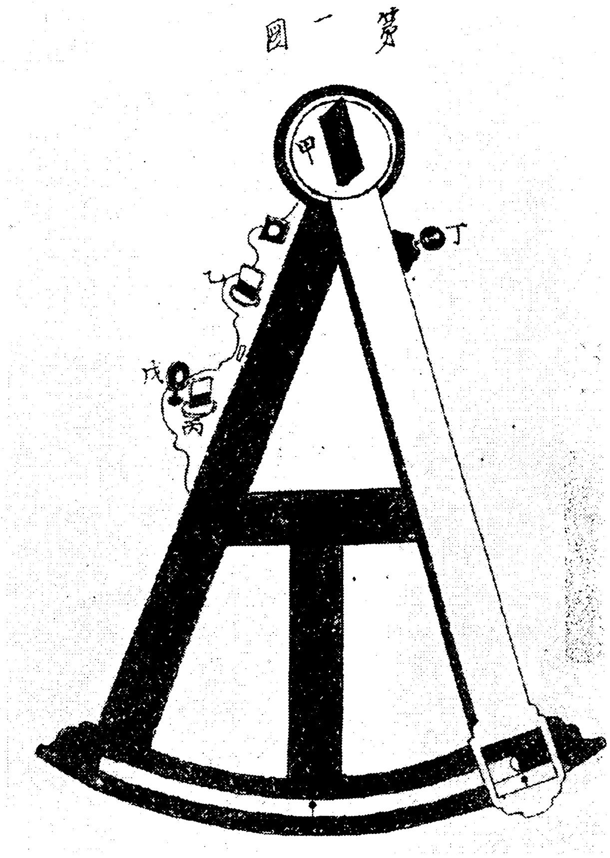


Figure 3. Drawing of an octant in *Shogengi Yoho Shogengi Yoho*,a translation of Douwes' book by Motoki Ryoei (1783).

Lalande's book (Strabbe, 1773), Japanese scholars were able to recognize the decisive superiority of Western astronomy when compared to traditional Japanese astronomy, which was of Chinese origin (Nakayama, 1969). Douwes was the organizer and supervisor of this translation enterprise (Zuidervaart, 1999); his status and career are proudly displayed on the cover page of the first volume of the Dutch edition. Therefore, we can say that Douwes made a significant contribution to Japanese society toward the end of the eighteenth century by introducing modern Western astronomy through two important books.

4 UNDERSTANDING AND MAKING OF OCTANTS IN JAPAN

Although Dutch interpreters at Nagasaki were the first to introduce new information on Western science to Japan, as represented by the Copernican system, they did not possess enough expertise in astronomy and mathematics to be able to understand the technical aspects of European scientific achievement. In Japan, the professionals in astronomy were the official astronomers of the Shogun's government. Since the establishment of the Shogunal astronomical office in the 1680s, their mandatory roles had been to devise calendars which could provide better predictions of celestial events such as the solar and lunar eclipses, a long-standing tradition of Chinese origin. Hence, they had little interest in and could not understand astronomy that was not directly connected to their purposes.

Nevertheless, they showed strong interest in the octant, probably because of the novelty and unknown principle for this instrument. In his reply letter of 1796 to the Shogunal astronomer Takahashi Yoshitoki,[4] Asada Goryu, a teacher of Takahashi, wrote: "I am grateful to hear that you could comprehend the octant that Hazama (Takahashi's colleague) acquired for you. I also feel wonderful that, with the marvellous machine allowing you to measure a very minute angle, you were too excited to sleep at night." (Arisaka, 1983:215). It is not clear from the letter itself whether Takahashi actually understood the principle and usage of the octant, including the Vernier scale. The reason for this doubt is that in a letter about a sextant that Takahashi wrote to Hazama in 1798 he confessed that he could not understand how the sextant works (Arisaka, 1983:272-273). This letter is important because it provides the first description of the sextant in Japan.

Honda Rimei, who was a mercantile economist and ran a private school for navigation and astronomy in Edo (Tokyo), wrote *Okudanto Yohoki* (Usage of Octants) around 1799. This book was a modified version of Motoki's translation, annotated with Honda's own navigational experience. What is important about this work is that Honda later attached to his original manuscript (preserved at Tohoku University) a slip of paper saying that "Since someone asked me how to use the Vernier scale of octants, I started thinking about it and I at last realized the principle." This note, which includes some numerical examples and provides the first clear evidence that the Japanese now understood the Vernier scale, must have been written between 1799 and 1809.

Various sources indicate that by the end of the first decade of the nineteenth century, the Shogunal astronomers and others had also mastered the principles and use of the octant and sextant, including the Vernier scale. As a result, they left many writings on octants and sextants. For instance, Takahashi Yoshitoki authored *Sekutanto Sokuho* (Usage of Sextants) in around 1800. *Okutanto Genri* (Principle of Octants) was written by Hazama Shigetomi in 1809, and was later augmented by Shibukawa Kagesuke in around 1851-1852,[5] the greatest Shogunal astronomer of the nineteenth century and the second son of Yoshitoki. This is one of the earliest books in Japan to treat the correct derivation of the relation $2\alpha = \beta$ (see Figure 1) and the basis of optics. In addition, some other astronomers from the Asada school also wrote on the octant.

There were instances where octants were used in the observation of comets. At the observatory of the Shogunal astronomical office it was common at that time for positional observations of celestial bodies to be made with a meridian wire-transit, a quadrant and an astronomical pendulum clock. But in the case of comets this technique often failed because they often appeared in the eastern or western twilight sky. Hazama Shigeyoshi, the son of Shigetomi, used an octant at Osaka to measure the altitude and angular distance from selected stars of two bright comets, C/1807 R1 (Great Comet) and C/1811 F1 (Flaugergues) (see Watanabe, 1943). Considering that in general comets are shapeless and have low surface brightness, they are most inappropriate targets for viewing with an octant, and so Shigeyoshi must have had a difficult time making the positional measurements. For altitude observations, he made use of the surface of mercury in a tray as the artificial water horizon; this technique is described in *Huyo Chihei Sokukodoho* (Method for measuring altitudes without using the sea horizon) by Takahashi Kageyasu (*c.* 1807-1808), the first son of Yoshitoki, which was presented in the appendix of *Okutanto Genri.* Shigeyoshi performed various experiments with water, mercury, and some heavy oils, in a search for a surface that was unaffected by wind or vibration (Watanabe, 1943).

Octants and sextants acquired considerable popularity among dilettante intellectuals as well. Curiosity led some rich Osaka merchants who were patrons of Western learning to purchase octants, even though they were very highly priced. By the beginning of the nineteenth century, there was already a kind of network in place in Edo and Osaka for the exchange of the information on octants and related matters. Shiba Kokan, who was at the central hub of the network, was a talented painter in the Western style as well as an eager supporter of the Copernican system, though his understanding was sometimes insufficient or even wrong. Through communication with people belonging to the network, professional or non-professional, he became more and more interested in Western astronomy and published some enlightenment books on astronomy and sciences. In one of those books, *Kopperu Tenmon Zukai* (Illustrated Book on Copernican Astronomy) published in 1808, Shiba maintained that octants had never been made in Japan, and this statement should be seen as reliable given his numerous contacts with people in Edo who were interested in Western science.

So who was the first to produce an octant in Japan? It has been claimed in the literature (Ogawa Kendo, 1814) that the first octant was made in 1813 by Takamori Kanko, who served a local Daimyo as his official astronomer.[6] In 1999, however, we discovered that Kume Michikata, a low-ranking vassal of a warlord in the Shikoku island, produced an octant prior to 1806 (at least seven years before Takamori), and that this instrument still exists (see Figure 4).

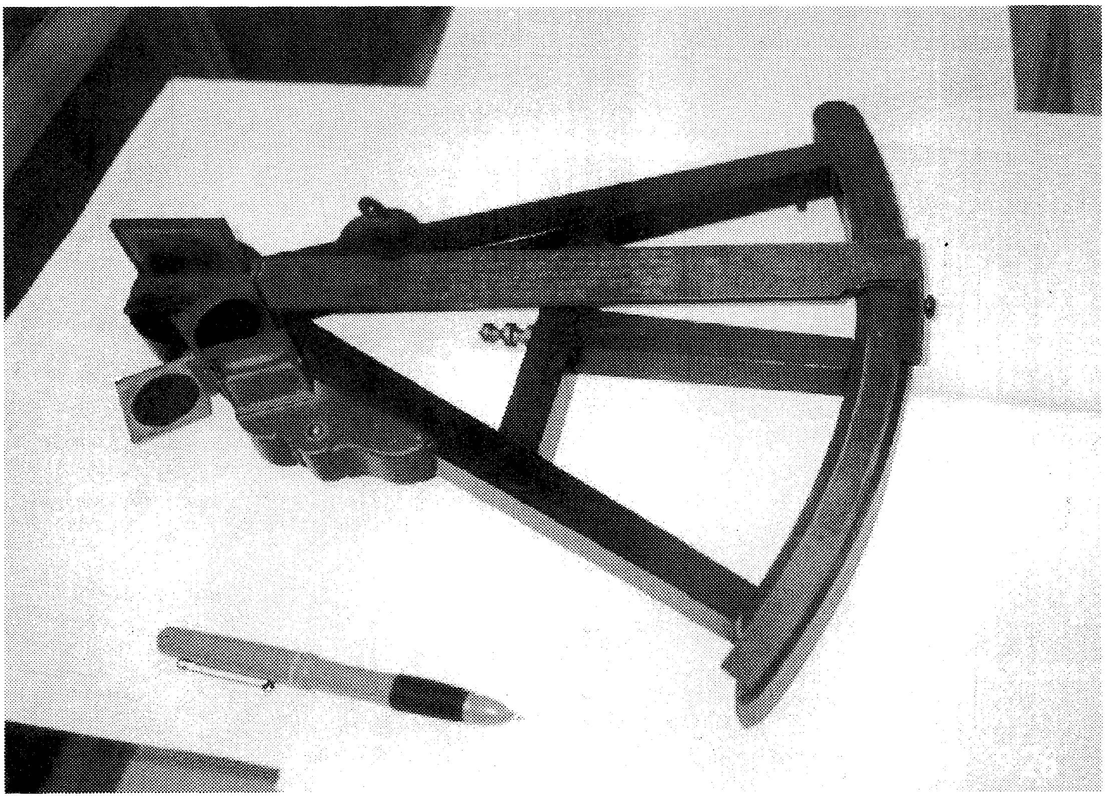


Figure4. Octant produced by Kume Michikata prior to 1806. The frame is made of hard wood, and the mobile bar and the scale-inscribed arc are of brass. The octant is equipped with two red sun-glasses of different density. The vernier is simply L-shaped and is more similar to those found on modern calipers than on traditional European octants. The minimum reading is one arc minute. (Photograph courtesy Kamada Corporation Museum).

Although it is certain that he made it by imitating an imported octant that Hazama then possessed, part of the Vernier on Kume's octant has a unique construction and is quite different from that found on European models (see Nakamura *et al*, 2000). Prior to World War II Kume had been well known as an ingenious inventor of various firearms and artillery and as the developer of the modern salt farm on Shikoku. For about four years starting from age 19, he also learned practical astronomy from Hazama Shigetomi in Osaka, and after returning home to rural Shikoku he began manufacturing telescopes, clocks, and land surveying instruments, despite his geographical and intellectual isolation.

In 1806, Kume was ordered by his Daimyo lord to construct a precision map covering the whole area that the warlord ruled over. For this purpose, Kume manufactured a Chiheigi (azimuthal circle) and a Shogengi (quadrant), and he then carried out a land survey of the region. It is interesting that he decided to adopt the Vernier scale for the two instruments since other astronomical and land surveying instruments that were in use in Japan at this time were all equipped with pre-modern diagonal scales. Considering that the Verniers on Kume's octant, Chiheigi, and Shogengi all had different spacings between the main scale and the sub-scale, and with measuring accuracies of between 1 and 2.5 arcminutes, it is obvious that he knew how to design and manufacture Vernier scales, even though he has left no written records about this. It is also apparent that Kume, like Honda Rimei, was one of the first Japanese to understand the principle of the Vernier scale.

5 ACCEPTANCE AND MODIFICATION

As the Sakoku policy had strictly prohibited people from going abroad or constructing large ships for oceanic navigation, the Japanese had no chance to use octants for their original purpose. However, octants provided measurements not only of altitudes above the horizon but also of angular distances between two targets. Under the restrictions placed by the Sakoku, the Japanese called attention to this latter function of the octant; this has already been suggested in the sentences inscribed on the mobile bar of Kume's octant (Figure 4). Murata Sajuro used to be an assistant at the Shogunal astronomical observatory, and in the preface of his book *Rokubungi Ryochi Tebikiso* (Handbook of Land-surveying with Sextants) published in 1852 he testified that his grandfather began using octants and sextants for land surveying in 1822-1823. It seems that Murata's grandfather developed a method of using a sextant to measure the distance of a battleship at sea for cannon shots from the ground, which he probably learnt from an imported Dutch book on naval gunnery.

Increased need for gunnery and land surveying in Japan at this time was motivated by growing pressure from foreign powers such as Russia and Britain for Japan to abandon its seclusion policy. As a result, many books on land surveying were published toward the 1850s. When an octant (or a sextant) was used for land surveying, the problem that worried the Japanese was the parallax inherent to these instruments. In measuring angles subtended by two target points at short distances an octant did not give correct readings, due to the parallax caused by the two mirrors being separated by 6-10 cm, which was the typical spacing in standard models. With instruments like the theodolite, which can measure azimuth and elevation angles independently, no such problem exists.

One way to avoid the parallactic problem of an octant was to prepare a table listing the corrections to be added to the measured angles. In fact, some books that dealt with land surveying using the octant were equipped with such a table as a function of distance. Another way of coping with the parallax problem was to modify the design of the octant, and Figure 5 shows an octant that was specifically intended for land surveying (after Murata, 1852). This octant has a lever on the back side of the frame so that the tilt of the fixed mirror (H in Figure 1) can be adjusted slightly to compensate for the parallax error.

Such sextants or octants have been described by Murata, and although no surviving examples have been discovered as yet their former existence seems assured because one of these octants is shown in an advertisement prepared by Osumi Genkichi (Figure 6), who produced various scientific and mathematical instruments in Edo from about the 1840s and ran a glass production factory after Japan opened the gate to the world with the Meiji restoration (1868). Although octants and sextants were featured in books on land surveying, it is doubtful that these instruments were as widely used as theodolites. After all, land-surveying carried out with an octant always required some trigonometric calculations, troublesome work for people at the time, and in drawing maps it was much easier to use the plane-table and a theodolite-like instrument.

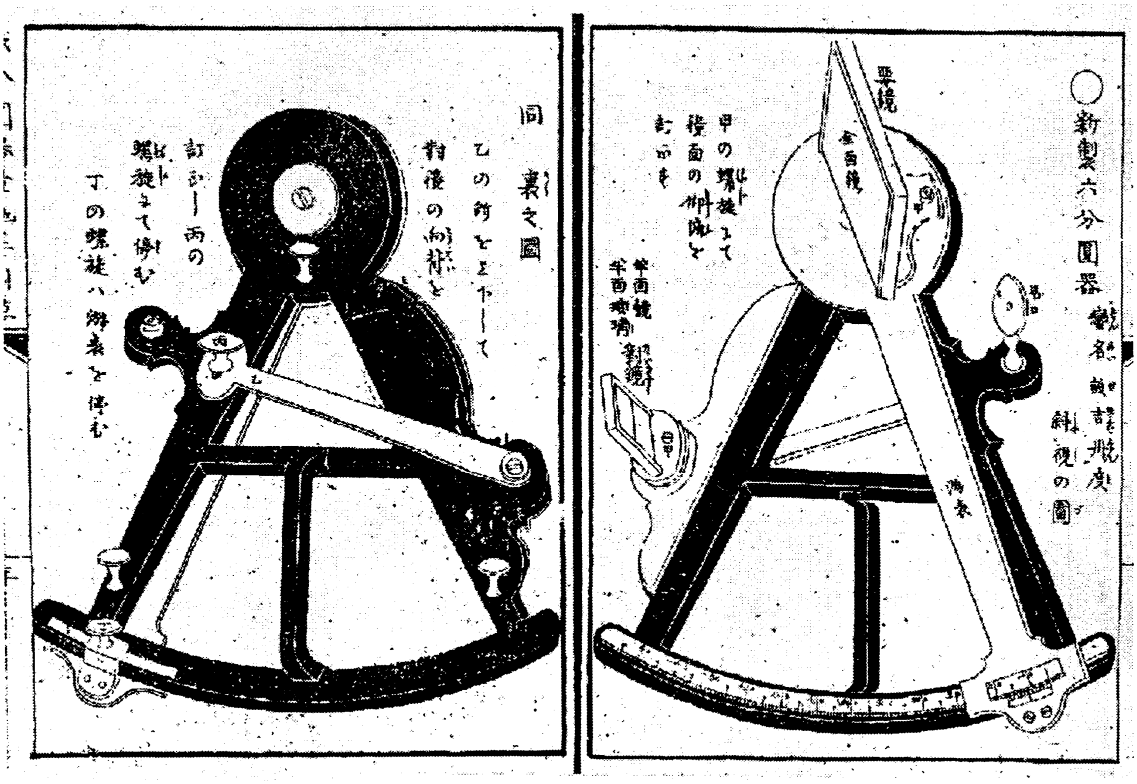
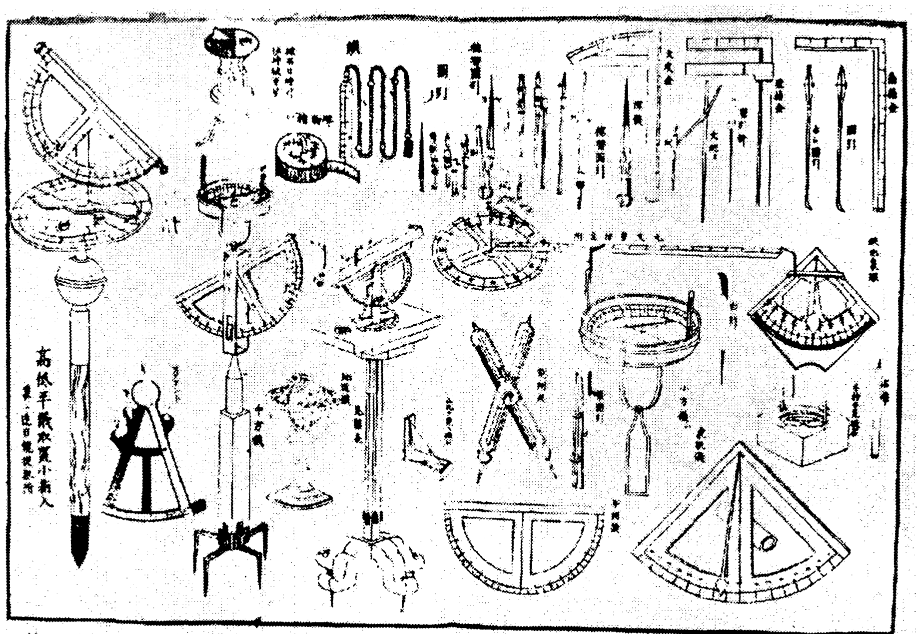


Figure 5. Diagram of a sextant designed for land-surveying (after Murata Sajuro, 1852). Front and back views are shown. The absence of sun-glasses and an adjustable lever on the rear side clearly indicate that this was intended for land surveying only, and not for observing the Sun. The height of this sextant is about 18 cm.



口絵13 同 表

Figure 6. An octant is included in this advertisement prepared in the 1850s by Osumi Genkichi. (Courtesy Koju-kai bunko Library).

One unusual aspect seen in Japanese books on octant-based land surveying written in the 1840s to 1860s, with a few exceptions (including the book by Murata), is that these books also explain how to use octants of the back-sight type. But as already indicated in Section 2, back-sighting was a totally unnecessary function if an octant was to be used for land surveying. In his book *Shogengi Yoho*, Motoko Ryoei (1783) clearly explained the introduction of back-sighting in a maritime context, and it seems that the conceptual structure of the octant shown in this book continued to influence authors of land surveying books in later times, even though back-sighting was no longer relevant.

Although the parallactic problem pertinent to octants was a nuisance for practitioners of land-surveying, some bright people made use of the parallax to measure distances. In his book *Rokubungi Ryochi Tebikiso*, Murata (1852) introduced a range finder called *Shakaku kangi*, and this is illustrated here in Figure 7. The structure looks fairly similar to those used on modern battleships. The book says that a standard model of this instrument had a separation of 1.8 m (baseline) between two mirrors with a small telescope at the sighting hole, and even the ones with baselines of 3.6 m and 5.4 m were also constructed. The measuring accuracy was 30 arc seconds with the scaled arc of 3.5 degrees, allowing us to measure angles up to 7 degrees. The book included a table for converting measured angles to distances, and the maximum distance in the table was about 1100 m. From Figure 7, it is apparent that this range finder was mainly used for military purposes to determine the distance of a ship at sea. It is not yet clear whether *Shakaku kangi* was a Japanese invention or an adaptation of an European model; Murata simply mentioned that this instrument was newly-produced at the time.

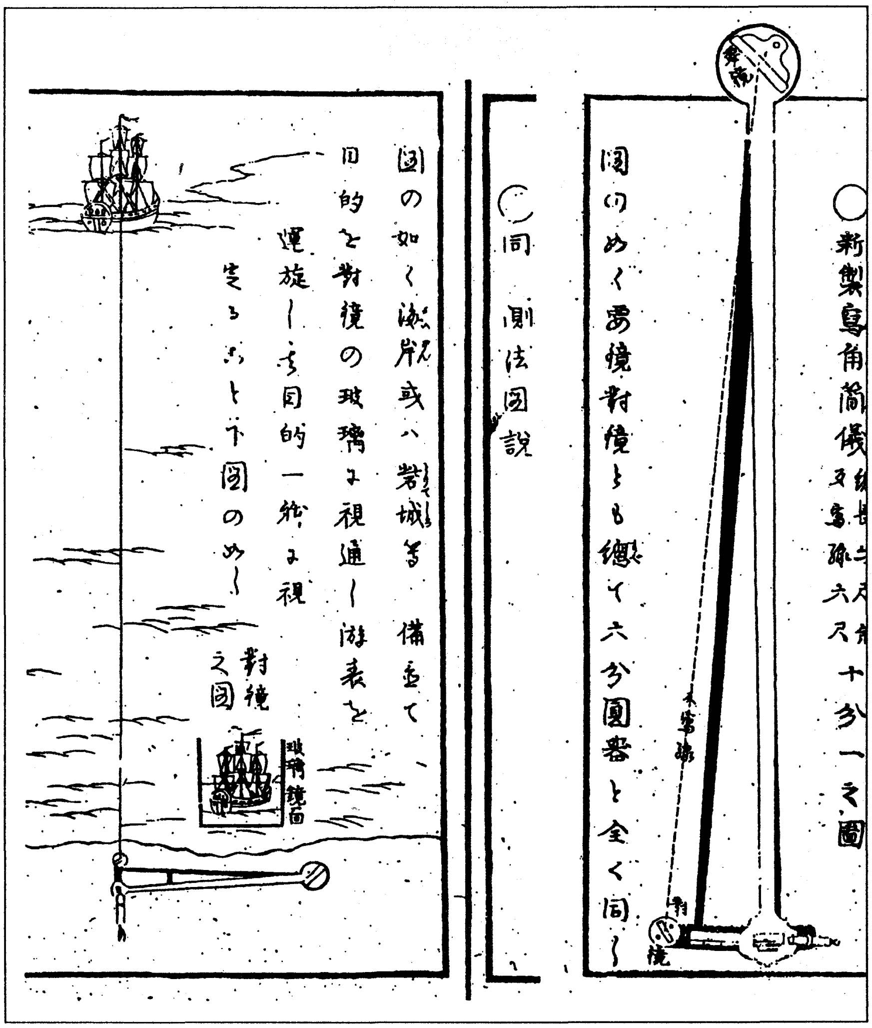


Figure 7. Drawing of a *Shakaku Kangi*, or range finder (after Murata, 1852).

In 1860, the Shogunal government sent a delegation to the United States for the first time as a prelude to opening the country to foreign influences and joining the international community. The frigate *Kanrin-maru* of only 300 tons and with a Japanese crew crossed the Pacific Ocean to San Francisco, and octants and sextants were used for the first time during this voyage (although maritime education had started three years earlier at the Naval Training School, which was established by the Shogunal government). Then from 1872 the first Japanese textbook about navigational techniques, including the use of the sextant, was published. This nine volume work, titled *Kokai Kyojusho* (Naval Ministry of Japan, 1872), was prepared for students at the Meiji government's Naval Academy.

6 CONCLUDING REMARKS

From the above discussion, one may understand how the Japanese responded to novel navigational instruments imported from Europe. The introduction of octants into Japan could be regarded as an appropriate case study of east-west cultural transfer, seen through a channel of astronomy. Hence, it may be worthwhile to compare the case in China, for instance, with ours.

Wan (2000) recently wrote a paper on the introduction of octants into China, where the first possible description of an octant is suggested by the term *Liangtian-chi* (instrument to measure the heaven), which appeared in the book *Haidao yizhi* (Sea-Island Unofficial History) published in 1806. Wan is not certain that this actually refers to an octant, but it is likely that imported octants would have attracted Chinese attention early in the nineteenth century. In 1843, Ding Gongchen published the book *Yanpao Ttushuo Jiyao*, (Illustrated Summary of Gunnery), where he explained the principle and use of the octant for the first time in China. One of Ding's contemporaries, Zheng Fuguang also wrote the book *Jingjing Lingchi* (Questions on Mirrors) in 1847, saying that "For 20 years since I got an octant, I had been thinking about how to use it. But I at last understood it by looking at an illustration shown in Ding's book." This indicates that the Chinese started to master octants during the 1840s.

Therefore, one can see that although there was a time lag of about four decades between Japan and China, scholars in both the nations were initially challenged by the appearance of this unknown European instrument. But eventually they managed to understand the principles involved and to use octants for marine navigation and for land-surveying.[7]

7 ACKNOWLEDGEMENTS

I am grateful to the following people for their assistance: the late Emeritus Professor M Kanai (University of Tokyo), Professor T Tsukahara (Kobe University), and Ms S Ichimura and Ms S Ito (National Astronomical Observatory). I should also like to thank the Kamada Corporation Museum and the Kojukai Bunko Library for permission to publish Figures 4 and 6 respectively. Finally, my gratitude is due to Dr W Orchiston, whose advice and comments were a great help in improving the original version of this paper.

8 NOTES

1 This paper is based on a paper written in Japanese by Nakamura in 2001 (see references). In the text, the Japanese and Chinese names were expressed in order of family and given names.

2 *Kizan Roku*, Volume 1, p.753, in *Collected Works of Miura Baien*, reprint version from Nippon Tosho Center (1979).

3 Shogengi literally means a quadrant in the Chinese terminology. Motoki used the word in his translation probably because the original Dutch book bore a drawing of an octant (Figure 2) in which the scale up to 90 degrees was inscribed on its arc. It is noted that the subtitle of *Shogengi yoho* (MS.) is *Okutanto* (octant) *yoho*.

4 Asada Goryu (1734-1799), after abandoning the position as a medical vassal of a certain Daimyo, fled to Osaka and opened a private school for medicine and astronomy in 1772, and started studying Western astronomy through Chinese translations. His excellent students such as Takahashi Yoshitoki and Hazama Shigetomi later became Shogunal astronomers, and the people from the Asada school played a leading role in nineteenth-century Japanese astronomy (Arisaka, 1968).

5 The augmentation by Shibukawa Kagesuke was probably made sometime after 1850, because he mentions in the preface of *Okutanto Genri* that for detail of the optics readers should refer to the Dutch book by Jacob Swart (1850).

6 Ogawa Kendo, who documented Takamori's octant, was the medical doctor of a Shogunal clinic. In 1998 we located one of Takamori's descendant in Tokyo, and he reported that in his childhood he actually used to see the octant in the warehouse, but it was destroyed by a US bombardment during World War II.

7 In Japan, writings and researches on astronomy, land surveying, and mathematics in particular were much less distributed as printed matter than in China and the West, but mainly communicated in the form of hand-copying. One reason for this inefficiency was that factionalism in each discipline kept its achievements secret from other factions. In addition, the market for such publications was small and premature.

9 REFERENCES

Note: in the following references, (J) and (C) indicate books and texts that were written in Japanese and Chinese respectively.

Arisaka, Takamichi, 1968. Activities of the Asada school of astronomy in the beginning of the 19th century: Introduction of *Seigaku shukan* (Collected letters on astronomy). In Arisaka, T. (ed.). *Nihon Yogakushi no Kenkyu (Studies on Western Learning). Volume 1*. Sogensha, Osaka, pp. 159-330 (J).

Arisaka, Takamichi, 1983. Activities of the Asada school of astronomy in the 1790s: Introduction of *Seigaku shukan* (Collected letters on astronomy). In Arisaka, T. (ed.). *Nihon Yogakushi no Kenkyu. Volume 5*. Sogensha, Osaka, pp. 205-302 (J).

Bartholomew, J.R., 1989. *The Formation of Science in Japan*. Yale University Press, New Haven.

Crone, Ernest, 1941. *Cornelis Douwes, 1712-1773: Zijn Leven en Zijn Werk; Met Inleidende Hoofdstukken over Navigatie en Zeevaart-onderwijs in de 17e and 18e Eeuw*. H.D. Tjeenk Willink & Zoon, Haalem.

Davids, C.A., *c*.1985. *Zeewezen en Wetenschap*. De Bataafsche Leeuw, Amsterdam.

Ding, Gougchen, 1843. *Yanpao Tushuo Jiyao (Illustrated Summary of Gunnery)*. Cited in Wan, 2000.

Douwes, Cornelis, 1749. *Beschryvinge van het Octant en Deszelfs Gebruik*. Joannes van Keulen, Amsterdam.

Freiesleben, Hans-Christian, 1978. *Geschichte der Navigation*. Franz Steiner Verlag, Wiesbaden.

Hazama, Shigetomi, 1809. *Okutanto Genri (Principle of Octants)*. Manuscript, Tohoku University, Sendai (J).

Hewson, J.B., 1951. *A History of the Practice of Navigation*. Brown, Son & Ferguson, London.

Hindle, Brooke, 1972. Thomas Godfrey. In C.C. Gillispie (ed.), *Dictionary of Scientific Biography. Volume 5*. Scribner, New York, p. 434.

Honda, Rimei, *c*. 1799. *Okudanto Yohoki (Usage of Octants)*. Manuscript, Sonkei-kaku Library, Tokyo (J).

Lalande, Joseph J. François de, 1771. *Astronomie*. Four volumes. La Veuve Desaint, Paris.

Miura, Baien, 1778. *Kizan Roku (Coming to the Home Mountain)*. See Notes, 2 (J).

Motoki, Ryoei, 1783. *Shogengi Yoho Shogengi Yoho (Usage of Quadrants)*. Manuscript, Tohoku University, Sendai (J).

Murata, Sajuro, 1852. *Rokubungi Ryochi Tebikiso (Handbook of Land-surveying with Sextants)*. Suharaya, Edo (Tokyo) (J).

Nakamura, Tsuko, Sawada, Taira and Hasegawa, Keiko, 2000. Astronomical and land-survey instruments produced by Michikata Kume in the beginning of the 19th century in Japan. *Kokuritu Tenmonndai-ho (Research Reports of the National Astronomical Observatory of Japan)*, **5**:1-18 (J).

Nakamura, Tsuko, 2001. Octants and sextants in the Japanese history of astronomy. In H. Kobayashi (ed.), *Higashi Ajia no Tenmon Rekigaku ni kansuru Takakuteki Kenkyu (Multilateral Studies of East-Asian Astronomy and Calendars)*. Daito-bunka University Press, Tokyo, pp. 71-119 (J).

Nakayama, Shigeru, 1969. *A History of Japanese Astronomy: Chinese Background and Western Impact*. Harvard University Press, Cambridge.

Naval Ministry of Japan, 1872. *Kokai Kyojusho* (*Textbook on Navigation*). In Sumita, S. (ed.). *Kaiji-shiryo Sosho (Maritime Libraries)*. Seizando (1930), Tokyo (J).

Ogawa, Kendo, 1814. *Chirizuka Dan (Dust Pile Stories)*. Reprint version from Gendaishicho-sha (1981), Tokyo (J).

Otsuki, Nyoden, 1926. *Shinsen Yogaku Nenpyo (A Newly Edited Chronology of Dutch Learning in Japan)*. Rikugo-kan, Tokyo (J).

Peterson, C.J., 1997. Sextant. In J. Lankford (ed.), *History of Astronomy, An Encyclopedia*. Garland, New York, pp. 459-460.

Shiba, Kokan, 1808. *Kopperu Tenmon Zukai (Illustrated Book on Copernican Astronomy)*. Shunparo, Edo (Tokyo) (J).

Shibukawa, Kagesuke, *c*.1851-1852. *Okutanto Genri (Principle of Octants)*. Manuscript, Tohoku University, Sendai (J).
Shizuki, Tadao, 1798. *Hachiengi Ki (On Octants)*. Manuscript, Tohoku University, Sendai (J).
Strabbe, Arnoldus Bastian, 1773. *Astronomia of Sterrekunde*. Five volumes. Jan Morterre, Amsterdam.
Swart, Jacob, 1850. *Handleiding voor de Praktische Zeevaartkunde*. De Wed. G. Hulst van Keulen, Amsterdam.
Takahashi, Kageyasu, *c*.1807-1808. *Huyo Chihei Sokukodoho* (Method for measuring altitudes without using the sea horizon). In Shibukawa's *Okutanto Genri* as an Appendix.
Takahashi, Yoshitoki, *c*.1800. *Sekutanto Sokuho (Usage of Sextants)*. Hazama Library, Osaka (J).
Wan, Miao, 2000. Early introduction and studies on the western double reflecting octants in China. *Zhongguo Keji Shiliao (China Historical Materials of Science and Technology)*, **21**:340-347 (C).
Watanabe, Toshio, 1943. *Tenmon Sokuryoshijo ni okeru Hazama Shigetomi to sono Ikka (Hazama Shigetomi and his Family in the Japanese History of Astronomy)*. Yamaguchi Shoten Publisher, Kyoto (J).
Waters, D. W., 1958. *The Art of Navigation in England in Elizabethan and Early Stuart Times*. Yale University Press, New Haven.
Wynter, H. and Turner, A., 1972. *Scientific Instruments*. Studio Vista, London.
Zheng, Liguang, 1847. *Jingjing Lingchi (Questions on Mirrors)*. Cited in Wan, 2000 (C).
Zuidervaart, Huibert Jan, 1999. *Van "Konstgenoten" en Hemelse Fenomenen*. Erasmus, Rotterdam.

Tsuko Nakamura is an Associate Professor at the National Astronomical Observatory of Japan. He has been working mainly in the field of small bodies in the Solar System, both dynamical and observational, in parallel with the study of the history of Japanese astronomy during the seventeenth to nineteenth centuries. He is a member of the Organising Committees of IAU Commission 41 (History of Astronomy) and the Inter-Union Commission for History of Astronomy. He wrote, with Tetsuo Yamamoto, the book *Suisei (Comets)* in Japanese (Koseishe-Koseikaku, Tokyo, 1984), and is the author of some other books.

Journal of Astronomical History and heritage 5(1):21-34 2002

Ingenuity and initiative in Australian radio astronomy: the Dover Heights 'hole-in-the ground' antenna

Wayne Orchiston

Anglo-Australian Observatory. PO Box 296, Epping, NSW 2121, Australia, and Australia Telescope National Facility, PO Box 76, Epping, NSW 2121, Australia
E-mail: wo@aaoepp.aao.gov.au

and

Bruce Slee
Australia Telescope National Facility, PO Box 76, Epping, NSW 2121, Australia
E-mail: bslee@atnf.csiro.au

Abstract
During the 1950s staff from the CSIRO's Division of Radiophysics based at the Dover Heights field station employed ingenuity and initiative in response to a lack of funding and support for a new radio telescope. In order to obtain the requisite aperture for the resolution sought they spent their own time excavating a 21.9-m parabolic depression in the sand at the field station, and when the viability of this prototype transit instrument was established its diameter was increased to 24.4 m, making this the largest radio telescope in Australia at the time. Operating at 400 MHz, this instrument was employed to map the galactic centre region and in a search for new discrete sources. It also was used to investigate polarization in the plane of the Galaxy, and in an unsuccessful search for the newly-proposed deuterium line. Today the Dover Heights 'hole-in-the-ground' antenna lies buried beneath Rodney Reserve, and there is little at this public playing field to remind visitors of the important contributions made by this radio telescope, and others at this site, during the formative years of Australian radio astronomy.

Keywords: *radio astronomy, Dover Heights, galactic centre, source surveys, Rodney Reserve*

1 INTRODUCTION

Australia has a first class reputation in radio astronomy, in part because of the research that has been accomplished with radio telescopes of innovative design. The Mills and Christiansen Crosses at Fleurs and the Culgoora Radioheliograph, built in the 1950s and 1960s, respectively, serve as excellent examples of the way in which new concepts in instrumentation led to major advances in our understanding of radio sources and solar radio emission. However, this Australian tradition of designing new and novel radio telescopes began much earlier. This paper discusses the Dover Heights 'hole-in-the-ground' antenna, which was constructed half a century ago.

2 THE DEVELOPMENT OF POST-WAR RADIO ASTRONOMY

Initial post-war developments in non-solar radio astronomy were inspired by Hey, Phillips and Parson's 1946 discovery of an intense source of radio emission in Cygnus. This 'radio star' was unlike anything previously detected, and its interpretation raised innumerable questions and in the process opened up a whole new field of investigation that has been "... central to the development of radio astronomy ... [through] to the present day." (Sullivan, 1982:221).

The challenge was initially taken up in Sydney, where John Bolton, Gordon Stanley (Figure 1) and one of the authors (BS) from the CSIRO's Division of Radiophysics used a sea interferometer employing the Lloyd's Mirror principle to investigate the enigmatic Cygnus source and soon discovered others. By observing from Dover Heights as these sources rose above the eastern horizon Bolton, Stanley and Slee were able to obtain approximate celestial positions for Cygnus A, Sagittarius A, Centaurus A, Taurus A, and Virgo A, but it was only after a field trip to New Zealand in 1947, when accurate rising *and* setting times were obtained, that they were able to fine-tune the positions of these sources and begin to search for optical correlates. This was one of the earliest collaborations between optical astronomers and their radio colleagues and led to the realization that Taurus A was associated with the Crab Nebula, a well-known supernova remnant, and Centaurus A and Virgo A with extra-galactic nebulae (see Bolton, 1955; Orchiston, 1994). These pioneering efforts led to the first all-sky surveys in England and in Sydney.

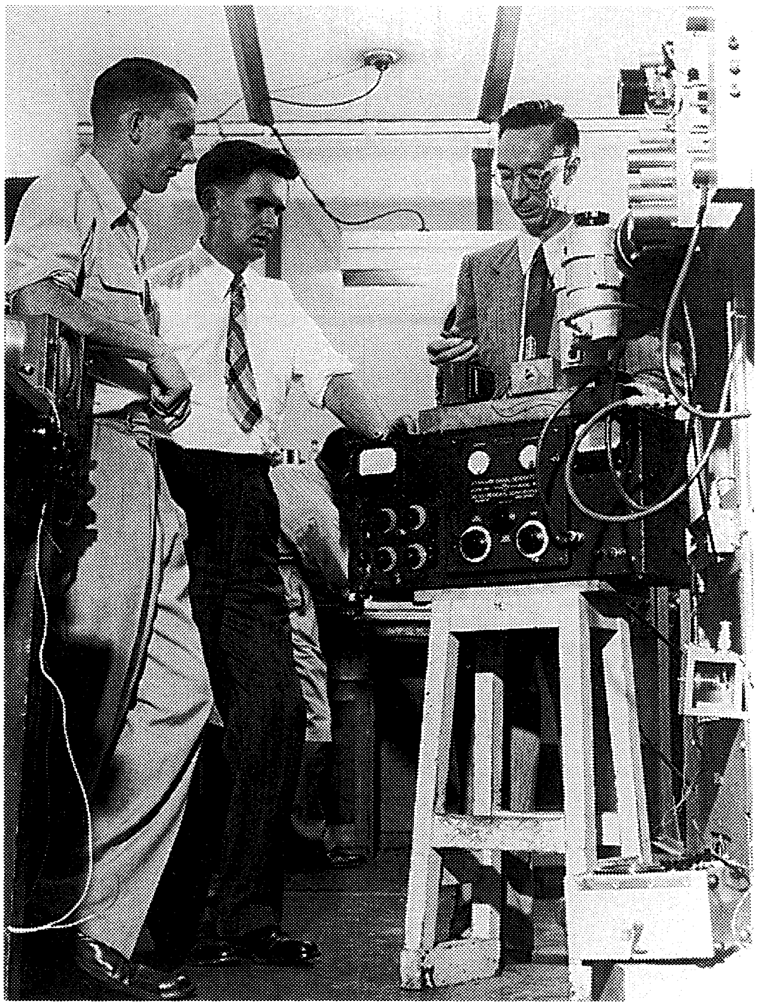


Figure 1. John Bolton (left) and Gordon Stanley (centre) with radio astronomy group leader Joe Pawsey at the Radiophysics Laboratory in Sydney. (ATNF Historic Photographic Archive: 15070)

These techniques gave interesting results, but in order to make substantial progress new ways had to be found to increase the resolution of the radio telescopes. There were two basic alternatives: to further develop interferometry, or to construct single large-aperture radio telescopes. While small parabolic radio antennas were already in use in both England and Australia, at that time engineering constraints prevented the construction of large steerable dishes. Ingenuity and a new initiative were therefore called for, and the Division of Radiophysics field team at Dover Heights responded to this challenge by constructing an imaginative new radio telescope of large aperture and innovative design, the 'hole-in-the-ground' antenna.[1]

3 THE HOLE-IN-THE-GROUND ANTENNA

The hole-in-the-ground antenna was the brainchild of John Bolton, one of the legends of radio astronomy (e.g. see Goddard and Haynes, 1994; Kellermann, 1996) and "... an extremely talented researcher, with a yen for working on his own with a minimum of assistance." (Bowen, 1984:91). It was inspired by the Jodrell Bank 66.4 m (218-ft) above-ground fixed antenna that was constructed in 1947 for cosmic ray work but was quickly re-assigned to radio astronomy and used with great success by Hanbury Brown and Hazard (see Hanbury Brown, 1984). After the simple Yagi arrays and a small parabolic dish they had previously employed, the mooted new antenna would not only offer the Dover Heights radio astronomers increased resolution but also a means of escaping the various problems associated with sea interferometers (Stanley, 1994).

The Dover Heights field station of the Division of Radiophysics was located at a 5 ha coastal wartime radar station in eastern suburban Sydney, 5 km south of the entrance to Sydney Harbour. The 73-m high coastal cliffs in this vicinity were vital for the success of the sea interferometry investigations, but now the site offered a further attraction: a large sandy expanse adjacent to the cliff top that would soon be transformed into one of Australia's most remarkable early radio telescopes (see Figures 2 and 3).

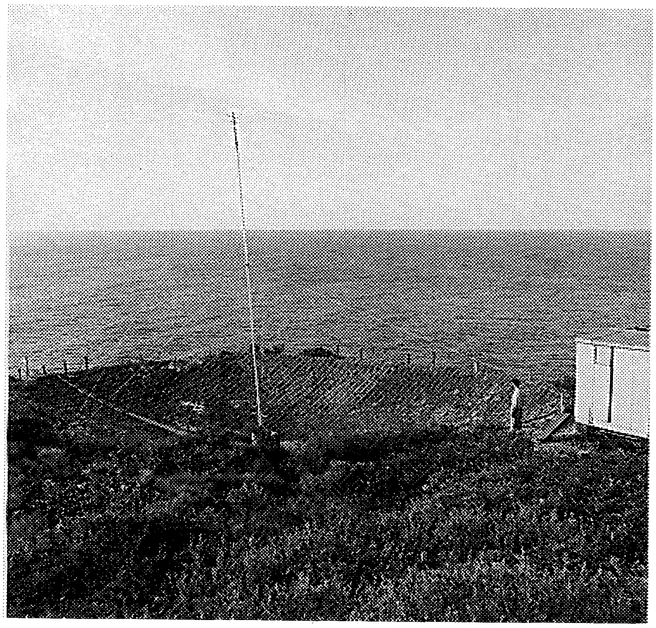


Figure 2. The 21.9m antenna in June 1952, with the small instrument hut on the extreme right. (ATNF Historic Photographic Archive:2763-3)

During a three month period in the second half of 1951 John Bolton and one of the authors (BS), with some assistance from Gordon Stanley and Kevin Westfold, spent their lunchtimes excavating a 21.9 m (72-ft) diameter parabolic depression in the sand near the cliff top (Bolton, 1982; Bolton, Westfold, Stanley, and Slee, 1954; Slee, 1994). Shovels were used to remove the sand, which was heaped into a wheelbarrow and dumped round what would become the rim of the antenna. In order to generate an appropriate parabolic shape they used a crude wooden jig. When the excavations were finished 12.7-mm metal strips from packing cases were used to obtain good reflectivity, and these were laid across the surface at 30-cm intervals and pegged in place. Finally, a mast was installed at the centre of the dish to carry a dipole that was connected to a modified ex-WWII receiver tuned to 160 MHz (Slee, 1994; Westfold, 1994). By employing this novel tactic, the Dover Heights team was able to acquire a far larger antenna than would otherwise have been available, and with a beam width of only 6° – an impressive figure in those days (Bolton, Westfold, Stanley, and Slee, 1954).

It is important at this point to place this new radio telescope in chronological perspective. As Figure 4 illustrates, the largest steerable parabolic antenna in the world at that time was the Naval Research Laboratory's 16-m (50-ft) parabolic dish in Washington, and this was only

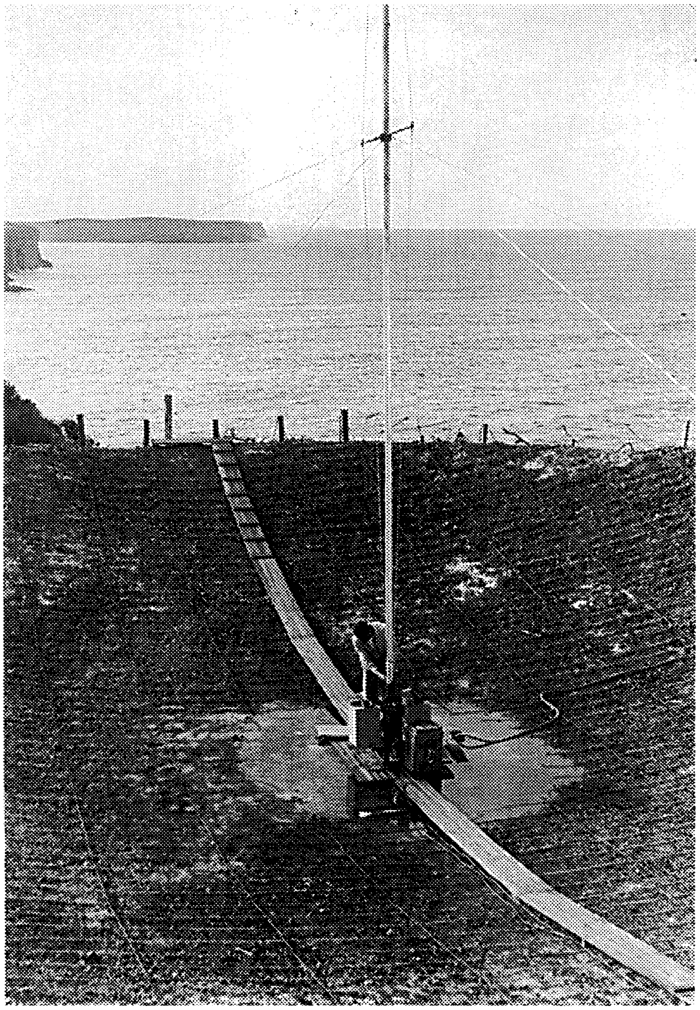


Figure 3. Close-up of part of the 21.9-m antenna after rain, showing the aerial mast and the boardwalk used to access the equipment boxes at the centre of the dish. (ATNF Historic Photographic Archive: 2763-7)

eclipsed in 1955 when the 19-m Harvard dish and the 25-m Dwingeloo Radio Telescope (in the Netherlands) were completed. The 21.9-m Dover Heights hole-in-the-ground antenna therefore was a substantial instrument by any account (although it is important to remember that it was

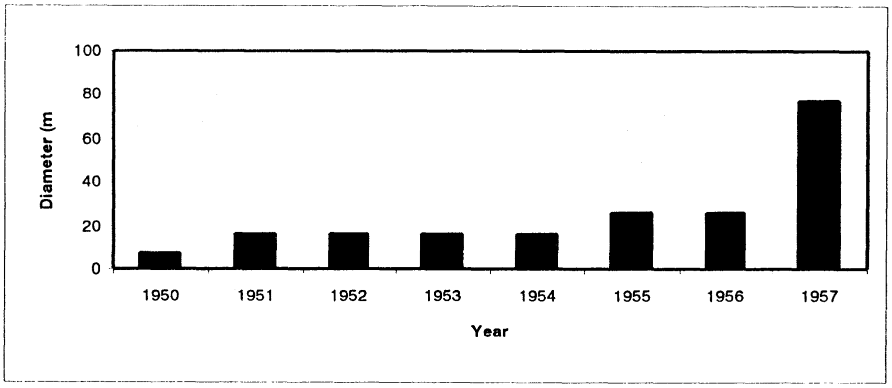


Figure 4. Histogram illustrating the increase in diameter of the world's largest steerable parabolic antenna with time (data after Kerr, 1994:7).

dwarfed in aperture by its Jodrell Bank prototype), but its very name echoed its major downside: that it was to all intents and purposes a transit instrument. Only by manipulating the supporting guy ropes and altering the position of the aerial mast was it possible to access a small region of sky adjacent to the zenith.

Observations were carried out with the new Sydney antenna in late 1951 and early 1952 between RA 14 h and 18 h and dec. –20° to –50° (1950), resulting in a map of radio emission along the galactic plane (Figure 5). This isophote plot, which clearly shows the Sagittarius A source, was published in 1954 by Bolton, Westfold, Stanley and Slee. The fact that the hole-in-the-ground antenna was capable of producing useful results finally allowed its existence to become common knowledge.

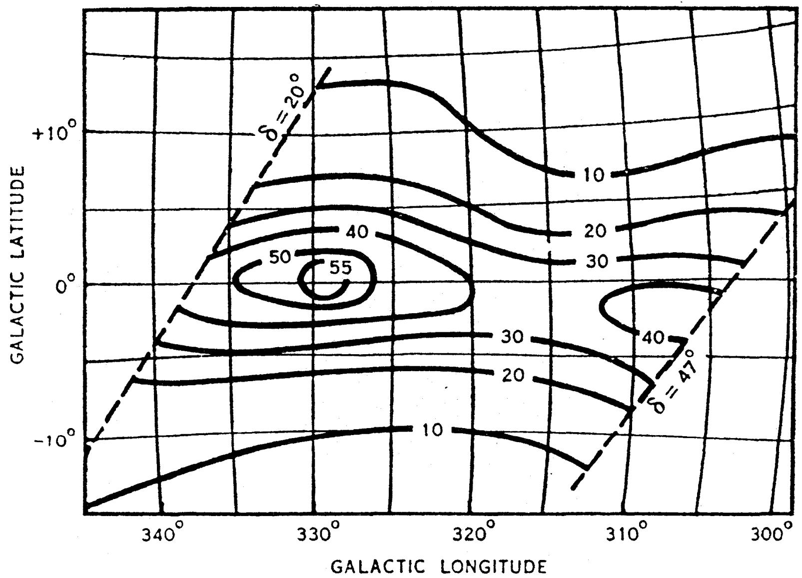


Figure 5. 160 MHz contour plots showing the Sagittarius A source (after Bolton, Westfold, Stanley, and Slee, 1954: 98).

Prior to this, the construction and use of this new antenna had been cloaked in secrecy, and when they had selected the site for the excavation the Dover Heights team had made sure that it was not easily visible from the old WWII blockhouse where the other radio telescopes were located. The reason for this tactic was simple: the team was supposed to be using sea interferometers for their celestial observations, and the leader of the Division's radio astronomy group, Joe Pawsey, was an absolute stickler for having staff keep religiously to assigned projects. John Bolton (1982:349-350) recounts that earlier in the history of Dover Heights when he and Bruce Slee were meant to be observing the Sun they decided also to use their Yagis to search for non-solar emission, a project that was "... cut short by an unheralded visit from Pawsey, who noted that the aerials were not looking at the Sun. Suffice to say that he was not amused and we were both ordered back to the Lab." and assigned to other projects. It was some time before they were permitted to return to Dover Heights!

Although E G (Taffy) Bowen, Chief of the Division, knew of the hole-in-the-ground antenna and even visited the field station when the excavation was in progress, it was only after the 160 MHz isophotes had been generated that Pawsey was informed of these developments. To everyone's surprise he was not angered by this illicit activity; to the contrary, he was excited by the research potential of this new radio telescope (Bolton, 1982). However, Haynes *et al.* (1996:226) believe that "This collusion with Bowen and simultaneous exclusion of Pawsey, prefigured an alliance that, a decade later, was to instate Bolton as autonomous director of the Radiophysics flagship [i.e. Parkes] and leave Pawsey without a function in the Division."

The move now was to improve resolution and fill a gap in other all-sky continuum surveys, and a decision was therefore made to expand the aperture of the antenna to 24.4 m (80-ft) and to use an operating frequency of 400 MHz. Extending the antenna involved further excavation, and a wooden jig was constructed in the Radiophysics Workshop and was used to refine the parabolic shape of the new dish surface that was subsequently coated in concrete.

The concrete was then covered with 12.7-mm wire mesh, and the full aperture was realized by cantilevering the periphery of the expanded dish beyond the rim in-fill using a base of aluminium tubes and annular tension wires. These are visible in Figure 6, which shows the new dish. In this context, Robertson (1992:57) reminds us that "With all this physical labour, the title Ph.D. among radio astronomers jokingly came to mean 'Post-hole Digger'."

To complete the antenna a 7.6-cm diameter aluminium mast was installed to carry a prime focus conical dipole and plane reflector, but on this occasion a preamplifier was situated at the very top of the mast in order to reduce line loss. This connected to a Dicke switch (which proved particularly troublesome (see Bolton, 1982:356-357), a mixer (fed by a local oscillator), and an I.F. preamplifier. All of these were located at the base of the mast, in a water-tight wooden instrument box that could float should water accumulate in the antenna after rain (but in fact a plug in the centre of the dish and a drainage system leading towards the cliff edge normally prevented this from occurring). The final stage of the 400 MHz superheterodyne receiver, comprising an I.F. amplifier, diode rectifier, synchronous detector, DC amplifier and finally a chart recorder, was housed in a small instrument hut adjacent to the southern rim of the dish. The Dicke switch in the wooden instrument box at the base of the mast also fed signals to the synchronous detector in the instrument hut. This hut is visible on the extreme right of Figure 2. Centaurus A was found to be "... a convenient daily reference for calibrating the overall sensitivity of the aerial and receiver." (McGee and Bolton, 1954:986).

Construction of the revitalized, enlarged hole-in-the-ground antenna took about six months, resulting once again in a transit instrument, but this time with a focal length of 12.2 m (40-ft) and an angular resolution of 2°. The position of the aerial mast was maintained by guy ropes, but could be altered in the north-south plane to allow declination strips of the sky adjacent to the zenith to be observed. Whenever the mast was realigned it was important to measure its precise position, and this was accomplished with a theodolite. For this purpose, a platform was constructed adjacent to the western margin of the dish, and this contained position markers for the tripod legs that supported the theodolite. This arrangement is illustrated in Figure 6, taken when Gordon Stanley was busy using the theodolite.

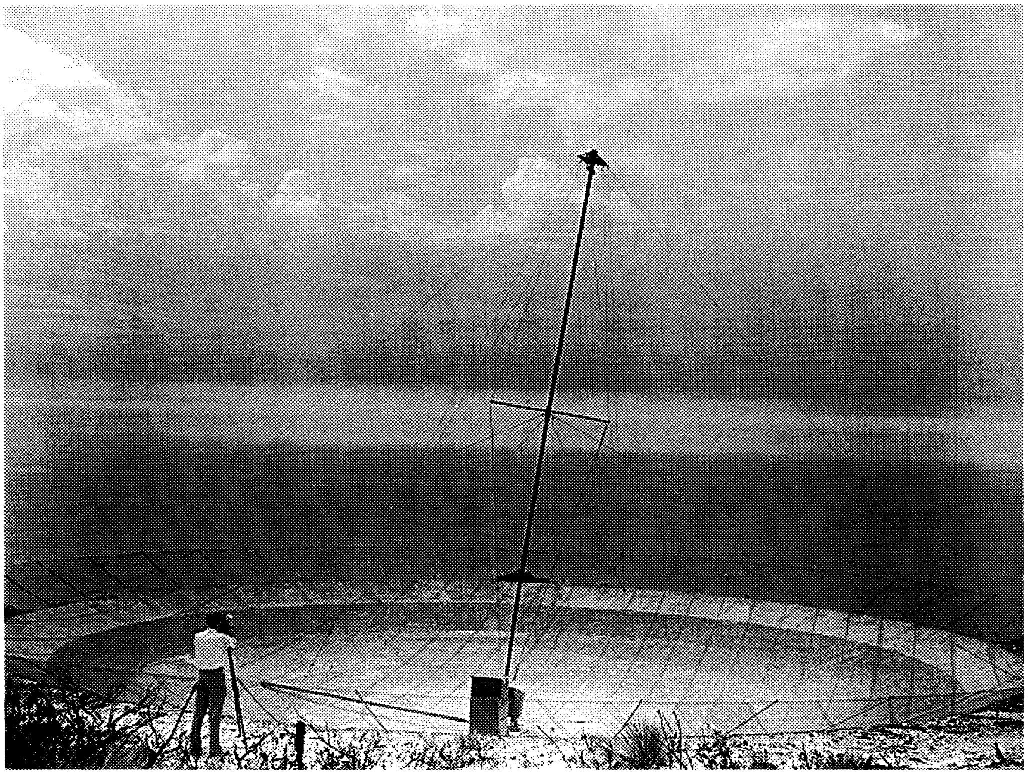


Figure 6. The enlarged concrete-coated 24.4-m antenna in September 1953, with Gordon Stanley using a theodolite to record the position of the aerial mast. (ATNF Historic Photographic Archive: 3150-2)

The first research project carried out with the new antenna was a survey at 400 MHz, modelled on the earlier one achieved with the prototype dish at 160 MHz, and this was to occupy most of 1953. Much of the observing and data-reduction was carried out by a new member of the Dover Heights group, Richard (Dick) X McGee, assisted from time to time by Bolton, Slee, and Stanley who were otherwise engaged in an all-sky search for discrete sources at 110 MHz and in a detailed investigation of selected sources using the Dover Heights 12-Yagi array that was also constructed in 1951 (Bolton, 1982; see, also Bolton, Stanley, and Slee, 1954). It should also be noted that in mid-1953 Bolton temporarily left radio astronomy when he transferred to the Division's Cloud Physics group.

The primary effort of the 400 MHz survey

> ... was concentrated on the Milky Way in the zone of declinations from –17° to –49°. The Milky Way was observed on one fixed declination per day, changes in Right Ascension occurring as the rotation of the Earth swept the aerial beam across the sky. In a preliminary survey observations were made at intervals of 1° in declination. Later, in order to cover the more interesting regions in greater detail, intervals of ½° were used. The record obtained at a particular declination was repeated until features of the variation of equivalent temperature with sidereal time were either satisfactorily reproduced or revealed as spurious and discarded. (McGee, Slee, and Stanley, 1955:353)

The main account of the survey was published by McGee, Slee, and Stanley (1955) in the *Australian Journal of Physics*, but only after an abbreviated version had appeared in *Nature* (McGee and Bolton, 1954).

As Figure 7 illustrates, the most important outcome of this survey was the clear delineation of Sagittarius A, the strong source at the old galactic co-ordinate position of l^I = 327°.9 and b^I = –1°.0 or RA 17 h 42 min and dec. –28°.5 (1950), which McGee, Slee and Stanley correctly identified with the nucleus of our Galaxy, and it is illuminating to compare this result with the earlier isophote plot shown in Figure 5. We should note in relation to Figure 7 that in a footnote added when their paper was in press, McGee *et al.*, (1955:349) pointed out that the conspicuous contour 'bulges' that extend obliquely from l^I = 348°, b^I = –23° to l^I = 341°, b^I = –7° and also from l^I = 318°, b^I = –17° to l^I = 310°, b^I = –3° are not real: they are artefacts generated by the coma that is associated with this type of antenna system.

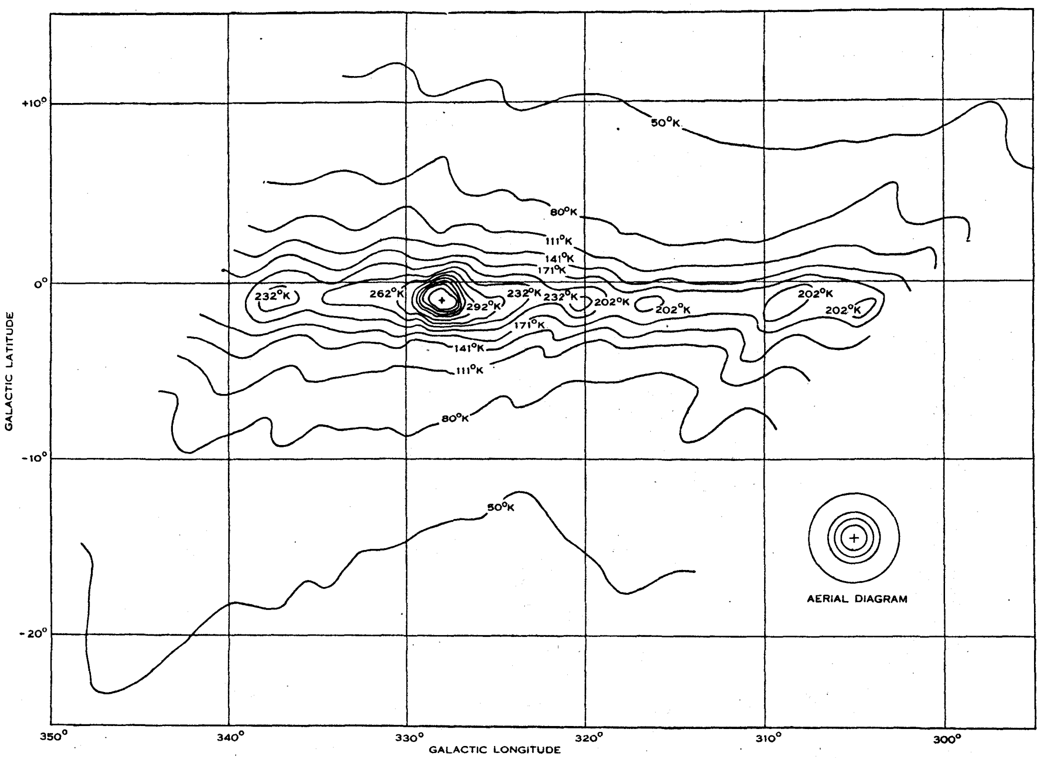


Figure 7. 400 MHz contour plots showing the strong emission source associated with the galactic centre (after McGee *et al.*, 1955:356).

Earlier investigations had already shown that "... the contours of radio brightness ascend to a rather broad peak close to the calculated position of the galactic centre." (op cit.:347), but there was considerable confusion about the location and nature of the radio source and the authors of the hole-in-the-ground survey were happy to report that their research "... clears up this confusion to a large extent and indicates considerable detail in the fine structure of the Milky Way." (op. cit.:348). This is precisely what Walter Baade would have hoped for when he first suggested this project to the Sydney radio astronomers (McGee and Bolton, 1954).

Before the papers reporting these results were published Pawsey took the precaution of sending a copy of the isophotes shown in Figure 7 to Baade for his evaluation. His reply of 1954 February 16 must have been very pleasing to Pawsey:

> Now to the object in the center of the galaxy, the contour diagram of which you kindly included in your letter. Frankly I jumped out of my chair the moment I saw what it meant. I have not the slightest doubt that you finally got the nucleus of our galaxy!! ... The strongest argument at present is its position which coincides with the expected place of the nucleus... It is very improbable that the coincidence between inferred and observed position of the nucleus is accidental. (cited in Morton, 1985:219).

Van de Hulst happened to be visiting Pasadena at the time, and when Baade showed him the Sydney plot he immediately also penned a letter to Pawsey, mentioning that "Baade got really excited about your fine observations of the galactic nucleus and shows your plot to anyone who comes near his office. The position agrees quite well with the best we can do on the basis of the 21-cm observations ..." (ibid.). At the same time Baade also sent a copy of the plot to Oort, who likewise was impressed:

> I have been excited by Pawsey's diagram that I received from you this morning. The longitude of the concentration which the Sydney observers have found co-incides exactly with the longitude of the centre that Mr Westerhout has now deduced with considerable accuracy from the 21cm observations. (ibid.).

These comments, from some of the world's leading astronomers, reinforced Pawsey's belief that the hole-in-the-ground antenna had produced an important research result.

Publication was the next step, and although the detailed account of this project was published in the *Australian Journal of Physics*, it was the earlier preliminary account in *Nature* that reached a wider audience and had more impact. Dual publication of particularly important results was a feature of the Radiophysics publishing strategy at this time, with the recognizd status of *Nature* a primary factor, but all papers had to go through "... a system of rigid internal reviews ... often to the frustration of the authors." (Sullivan, 1988:333) before they were approved for submission. The 'galactic centre' paper was no exception, and its review generated considerable Divisional interest among senior members of staff (see Goss and McGee, 1996). Most were concerned about the claimed association between Sagittarius A and the galactic centre, and as a result the original manuscript was extensively modified and during the review process witnessed a succession of title changes. The final title, however, was decided unilaterally by Pawsey, despite concerns from some on the Radiophysics publications committee, but "Probable observation of the galactic nucleus at 400 Mc./s." was bound to generate international interest and reflect positively on the research work of the Division.

Since the original hole-in-the-ground papers were published in 1954 and 1955, the resolution of radio telescopes has improved dramatically. As a result, Sagittarius A has been resolved into a number of adjacent discrete sources (e.g. see Burke, 1965), and as long ago as 1995 one of these, Sgr B2, was itself known to contain almost sixty components. As Palmer and Goss (1996) have demonstrated, this increasing complexity has been accompanied by an evolving – and at times rather confusing – nomenclature.

Apart from the galactic centre result, another important outcome of the 400 MHz survey was the detection of a number of other discrete radio sources. Even though "... there was not the same attention given to establishing their presence as was given to checking the features in the central region of the Milky Way." (Mc Gee *et al*., 1955:359, 362), this resulted in a list of 14 different sources (see Table 1, which includes Sagittarius A).

Table 1: Discrete sources observed at 400 MHz (adapted from McGee *et al.*, 1955:359-364).

Constellation	**Position (1950)**		**Flux (Jy)**	**Notes**
	RA (h min)	dec. (deg)		
Fornax	03 20±1	−37.25 ± 0.5	140	
Pictor	05 09±1 05 16±1	−42.75 ± 0.5 −45.0 ± 0.5	150	Two maxima of approximately equal intensity, slightly spread.
Puppis-Vela	08 24±2 08 35±2	−43.2 ± 1 −45.1 ± 1	150	The first of these is Puppis A and it is superimposed on an extended source with peak intensity at the second position listed.
Antlia	09 59±1	−28.5 ± 0.5	90	Only one observation of this was obtained.
Vela	10 41±1	−43.7 ± 0.5	200	
Centaurus	13 22.5	−42.75 ± 0.1	600	Centaurus A.
Lupus	15 04.1	−30.9 ± 0.5	60	
Ara	16 34±1	−47.7 ± 0.5	230	Associated with an HII region?
Scorpius	17 04±1	−44.4 ± 0.5	260	
Scorpius	17 13±1	−38.1 ± 0.5	330	Associated with an HII region?
Scorpius	17 23±1	−35.0 ± 0.5	510	Associated with an HII region?
Sagittarius	17 42±1	−28.5 ± 0.2	1640	Sagittarius A, associated with the galactic centre.
Sagittarius	17 59±1	−21.5 ± 0.5	280	Associated with an HII region?
Sagittarius	18 07±1	−19.6 ± 0.5	360	

With the benefit of hindsight and improved resolution, about half of these 'sources' have since been shown to be a result of confusion, where several adjacent sources were unresolved with the Dover Heights beam.

As one brief investigation that formed part of the 400 MHz survey, trial polarization measurements were taken in two different areas of the sky, but McGee *et al.* (1955:359) found that "... at regions centred in R.A. 16 hr 54 min, Dec. –42.75° and R.A. 17 h r55min, Dec. – 23.5° plane polarization of the radiation at 400 Mc/s is less than 2 per cent." Given the 2° beam of the antenna, these locations were probably chosen at random, although it is interesting to note that the former position happens to coincide with the 400 MHz emission peak at l^I = 309° and b^I = –2° in Figure 7, a region that is populated by conspicuous HII regions.

After the 400 MHz sky survey, the hole-in-the-ground antenna was used for just one further research project: a search for the 327 MHz deuterium line, which would be expected to show up as an absorption feature in the region of the galactic centre. This search was undoubtedly inspired by the detection of the 21-cm hydrogen line in 1954, and the widely held belief that other radio spectral lines must exist. In 1952 Shklovsky had shown that a weak deuterium line may exist, and he later noted that its detection "... would have great astronomical and cosmological significance ... [and] shed light on the question of the isotopic composition of the interstellar gasses." (Shklovsky, 1960:258-259). Since the Radiophysics Laboratory was already actively involved in H-line work the search for a deuterium line was a natural progression, and on this occasion the investigators were Stanley and a visiting U.S. Fulbright Fellow named Price. Their search was carried out in 1954, and the hole-in-the-ground antenna was attached to a receiver centred on 327.369 MHz, which fed a bank of filters, each with a bandwidth of 16 KHz and spaced 48 KHz apart. The observations were made in the area of the galactic centre and in the region of the galactic plane at l^I = 220° by

> ... automatically scanning with the receiver through 200 kc./s as the direction of the galaxy passed through the antenna. Such methods failed to detect any radiation. In the later records graphical integration was performed to increase the sensitivity. (Stanley and Price, 1956:1221).

These integrations also failed to reveal the deuterium line, but these negative results were only published in *Nature*, in 1956, after a Russian team reported their own unsuccessful search. Later investigations revealed that these negative results were wholly to be expected, since the relatively higher abundance of deuterium in the solar system is not a valid indication of its concentration throughout the Galaxy. So instead of deuterium, it was the two main lines of OH that were next to be detected, in 1963 (Weinreb *et al.*, 1963). Since then, many other spectral lines have been found, and Radiophysics staff has played an important role in this research (e.g. see Robinson, 1994; Whiteoak, 1994). However, the deuterium line has remained elusive. It has still to be detected!

4 DISCUSSION

4.1 Sagittarius A and the Galactic Centre

Because of the wide 'visibility' of papers published in *Nature*, the Dover Heights team is generally credited with formally identifying Sagittarius A with the galactic centre (e.g. see Robertson, 1992), but as Goss and McGee (1996) have pointed out this association really belongs to two other Radiophysics staff members, Jack Piddington and Harry Minnett. In 1950 they used a 4.9-m × 5.5-m (16-ft × 18-ft) equatorially-mounted rectangular parabolic antenna at the Potts Hill field station in suburban Sydney to carry out a study of galactic radiation at 1210 MHz. This radio telescope had a beamwidth of 2°.8, and their survey revealed "... a new, and remarkably powerful, discrete source.... [at] the position of the galactic centre." (Piddington and Minnett, 1951:465). This new source was located on the Sagittarius-Scorpius border at l^I = 328° and b^I = –3° or RA 17 h 44 min and dec. –30° (1950), and although they noted "... an estimated uncertainty in Right Ascension of about 2 minutes and in Declination of about 1°" (Piddington and Minnett, 1951:467), their values are remarkably similar to those obtained later by McGee *et al.* with the hole-in-the-ground antenna. Piddington and Minnett published their results in 1951, but unfortunately they chose the rather obscure *Australian Journal of Scientific Research*, and although this journal was beginning to build an international reputation their paper did not reach a wide audience within the radio astronomical community. As Sullivan, (1988:328) has observed:

> ... the *Australian Journal of Scientific Research* ... started by CSIR in 1948 [was] ... a further sign of the growing independence of Australian science. RP sent thirty full articles to the journal in its first four years, but only eight to British journals (plus eight letters to *Nature*). Although this corpus in the end probably lent more stature to the journal than did any other single field, it took a while for a world readership to develop.

An interesting sequel to this Sydney-based radio astronomical work occurred at the 1958 General Assembly of the International Astronomical Union when a resolution was passed adopting the Sydney position of Sagittarius A as the location of the galactic centre, thereby re-calibrating the datum point of the galactic co-ordinate system (see Sadler, 1960).

4.2 Personalities, Politics, and the Demise of the Dover Heights Site

As it happened, the search for deuterium marked the death knell for radio astronomy at Dover Heights. The sea interferometer concept (and consequently the Dover Heights field station) had pretty much reached the end of its viable lifetime, and new options were called for (see Stanley, 1994). However, staff at the Division of Radiophysics was vehemently divided over what form future instrumentation should take. While Bowen (1984) strongly favoured a large steerable parabolic reflector, preferably with an aperture exceeding that of Bernard Lovell's new Jodrell Bank Radio Telescope, most of the radio astronomers argued in favour of interferometry (see Robertson, 1992). John Bolton (1982:357) had three possibilities in mind, all of which were interferometers:

> One was to form a second hole-in-the-ground to form an interferometer with the first. The second, inspired by Taffy [Bowen] was to build two rolling barrels – parabolic cylinders inside circular cylinders – to form an interferometer. The third and my own choice was to build a large sea interferometer for use at 400 MHz. This would have consisted of a cylindrical paraboloid 20 ft high and 200 ft long with a focal length of about 150 ft fed by a vertical stack of dipoles. The construction of the mirror would have been similar to the fence round a tennis court and would have been rebuilt for each 40° of azimuth; the 40° interval covered by moving the dipole stack. The primary beamwidth would have been 1° in azimuth and the interference fringes 15' arc apart.

It is ironic that one of Bolton's options was inspired by Bowen, in the light of his open opposition to interferometers at this time.

For his part, Stanley (1994:511) also favoured interferometry, but had a different scheme in mind, one that involved a two-element interferometer, where

> ... two cylindrical parabolas were mounted on tracks. These were to have line feeds capable of multiple frequency operation. It was my misconception that the antennas could have been built cheaply from wood! The idea was never developed, nor did it have the enthusiastic support of the rest of the Dover Heights group... Paul Wild invited me to join him on a trip down the south coast of New South Wales in September 1950 ... [which] would be an opportunity for me to find a site suitable for the interferometer ... I chose a site at Jervis Bay and although it was never used, the idea of the interferometer was the genesis of the one built at Owens Valley in California.

In the final outcome neither of these schemes prevailed, and with support (and ultimately funding) going to the 64-m Parkes dish (see Bowen, 1981) and an interferometer in the guise of the Mills Cross at Fleurs (Mills *et al.*, 1958) there was great upheaval in Radiophysics (see Haynes *et al.*, 1996). It was some time before either of these new radio telescopes became a reality, and in the interim the Division's research focus shifted from Dover Heights to Dapto (solar astronomy) and Potts Hill (mainly solar and H-line work). It was at Potts Hill that Mills constructed a small prototype of the Mills Cross, to establish the viability of this innovative new design. By this time, those at Radiophysics realized that the end of an era was at hand, and that "... more and more sophisticated instruments would be necessary. The days of hasty improvisation were over – more and more planning would be required and much more money would be needed for capital expenditure. Little did we realize how large these sums would become." (Bowen, 1984:96). Writing in 1994, Minnett had this interesting perspective on subsequent developments:

> Over 30 years ago, Radiophysics was divided over the better path to follow in developing telescopes for future observations. The giant reflector approach pursued by Taffy Bowen created the Parkes radio telescope and its associated stream of technology. But it also swept aside the development of high-resolution interferometry for cosmic astronomy, nurtured so successfully by Joe Pawsey. Transplanted to the University of Sydney and developed by Mills at Molonglo and by Christiansen at Fleurs, interferometry returned to Radiophysics some 20 years later with Bob Frater. The two streams of development, both essential to a large modern synthesis telescope, have now merged in the Australia Telescope, a splendid national facility which has at last put the old controversy to rest. (Minnett, 1994:18).

Although radio astronomy ceased at Dover Heights at the end of 1954 (Bolton, 1982), for a while the Division's Cloud Physics group made use of the site. Finally, in 1959, the field station was closed, and most of the site was converted into a playing field known as Rodney Reserve. In the process, the remarkable hole-in-the-ground antenna was filled with spoil and then grassed over. Today it lies a little north of the northern soccer goal post, and apart from a few individuals who might quite by chance notice an inconspicuous plaque hidden away in one corner of the Reserve, most of those who use this popular recreational facility would be totally unaware of the amazing scientific contribution that this site made in the early days of Australian radio astronomy. However, if they should venture across to the fence near to the cliff edge and know precisely where to look, they can still catch a glimpse of the rusting mount that supported the 12-Yagi array erected back in 1951. This, unfortunately, is all that now remains of those pioneering radio telescopes that once graced the Division of Radiophysics' Dover Heights field station.

4.3 Other Hole-in-the-Ground Antennas

Although Australian radio astronomers pioneered the hole-in-the-ground antenna concept they were not alone in thinking of this cheap and innovative way of acquiring a large parabolic antenna. In 1954-1955 F.I.A.N. scientists in Russia went one step further, constructing not one, but two, 30-m hole-in-the-ground antennas 740 m apart at their Crimean radio astronomy field station (see Figure 8). Initially these two antennas were used as an interferometer for studies of the solar super-corona and the Crab Nebula, and later the surface of one of the antennas was recast in concrete and this stand-alone instrument was used to continue these experiments at a number of different frequencies (Kalachov, 1963).

Figure 8. One of the two 'hole-in-the-ground' antennas at the F.I.A.N. radio astronomy field station in Crimea, USSR. (ATNF Historic Photographic Archive: 12766-9)

If we wish to seek modern-day analogues for the Dover Heights and Crimean antennas we need look no further than the famous Arecibo Dish, even if those who constructed it simply decided to exploit a freak of geography in order to achieve its apparent 'hole-in-the-ground' status.

5 CONCLUDING REMARKS

The Mark I and Mark II versions of the Dover Heights hole-in-the-ground antenna were interesting responses to specific research needs that arose in Australian (and international) radio astronomy during the early 1950s. This was a time when radio astronomical hardware was still affordable, and within the annual budget allocation of a single research institute, but in the case of the Dover Heights antennas expenditure in lunchtime-manpower and constructional man-hours made these even more cost-effective enterprises than would normally have been the case!

The first hole-in-the-ground antenna demonstrated the viability of the system, and the second, slightly larger radio telescope was then used for the most detailed survey of the Sagittarius A source carried out up to that point in time. The association of this discrete source with the galactic centre was a significant identification, and the subsequent re-calibration of the international galactic co-ordinate system by the IAU was a reflection of the importance of the Sydney results. Apart from Sagittarius A, this antenna was used to document a number of other discrete sources, and the integrity and importance of about half of these have withstood the passage of time. Finally, this novel hole-in-the-ground antenna was used to search for a deuterium line. Although inspired by the discovery of the famous H-line, with the benefit of hindsight we now realize that this study was premature and doomed to failure. This should not, however, blind us to the valuable contributions to science made by this radio telescope in just a few short years.

Those associated with the Division of Radiophysics' field stations remember with some nostalgia an era long gone, a time when radio astronomers were personally involved in the maintenance and sometimes even the design and construction of radio telescopes and their component parts (see Sullivan, 1988). This was the time when the 'fix it with fencing wire' ethos that permeated Australian culture reigned supreme. After all, how many radio astronomers today would be prepared to sacrifice their lunchtimes in order to construct a radio telescope with which to carry out fundamental research? The Dover Heights hole-in-the-ground antenna is a fitting reminder of a time when ingenuity, dedication, and minimal financial outlay were capable of producing significant scientific results. Today's radio astronomy, with its sophisticated multi-million dollar arrays and milli-arcsecond resolutions, is a very different world!

6 ACKNOWLEDGEMENTS

We are grateful to Dr Miller Goss (National Radio Astronomy Observatory, USA) and Drs Brian Robinson and Gregory Tsarevsky (Australia Telescope National Facility) for their comments and assistance. We also wish to thank the Australia Telescope National Facility for supplying Figures 1-3, 6 and 8.

7 NOTES

1 For a brief, popular, account of this radio telescope see Orchiston, 2002.

8 REFERENCES

Bolton, J.G., 1955. Australian work on radio stars. *Vistas in Astronomy*, **1**:568-573.
Bolton, J.G., 1982. Radio astronomy at Dover Heights. *Proceedings of the Astronomical Society of Australia*, **4**:349-358.
Bolton, J.G., Stanley, G.J. and Slee, O.B., 1954. Galactic radiation at radio frequencies. VIII. Discrete sources at 100 Mc/s between declinations +50° and –50°. *Australian Journal of Physics*, **7**:110-129.
Bolton, J.G., Westfold, K.C., Stanley, G.J. and Slee, O.B., 1954. Galactic radiation at radio frequencies. VII. Discrete sources with large angular widths. *Australian Journal of Physics*, **7**:96-109.
Bowen, E.G., 1981. The pre-history of the Parkes 64-m telescope. *Proceedings of the Astronomical Society of Australia*, **4**:267-273.
Bowen, E.G., 1984. The origins of radio astronomy in Australia. In Sullivan 84:111.
Burke, B.F., 1965. Radio radiation from the galactic nuclear region. *Annual Review of Astronomy and Astrophysics*, **3**:275-295.
Goddard, D.E. and Haynes, R.F. (eds.), 1994. Pioneering a new astronomy: Papers in memory of John G. Bolton. *Australian Journal of Physics*, **47**(5).
Goddard, D.E. and Milne, D.K. (eds.), 1994. *Parkes. Thirty Years of Radio Astronomy*. CSIRO, Melbourne.
Goss, W.M. and McGee, R.X., 1996. The discovery of the radio source Sagittarius A (Sgr A). In R. Gredel (ed.), *The Galactic Center. 4th ESO/CTIO Workshop*. Astronomical Society of the Pacific, San Francisco (Conference Series, Volume 102), pp. 369-377.
Hanbury Brown, R., 1984. Paraboloids, galaxies and stars: memories of Jodrell Bank. In Sullivan 84:213-235.
Haynes, R., Haynes, R., Malin, D. and McGee, R., 1996. *Explorers of the Southern Sky. A History of Australian Astronomy*. Cambridge University Press, Cambridge.
Hey, J.S., Phillips, J.W. and Parsons, S.J., 1946. Cosmic radiations at 5 metres wave-length. *Nature*, **157**:296-297.
Kalachov, P.D., 1963. Some radio telescopes in the U.S.S.R. *Proceedings of the Institute of Radio Engineers, Australia*, **24**:237-242.
Kellermann, K.I., 1996. John Gatenby Bolton (1922-1992). *Publications of the Astronomical Society of the Pacific*, **108**:729-737.
Kerr, F., 1994. The proposal for a giant radio telescope. In Goddard and Milne:7-11.
McGee, R.X. and Bolton, J.G., 1954. Probable observation of the galactic nucleus at 400 Mc./s. *Nature*, **173**:985-987.

McGee, R.X., Slee, O.B. and Stanley, G.J., 1955. Galactic survey at 400 Mc/s between declinations –17° and –49°. *Australian Journal of Physics*, **8**: 347-367.
Mills, B.Y., Little, A.G., Sheridan, K.V. and Slee, O.B., 1958. High-resolution radio telescope for use at 3.5m. *Proceedings of the Institute of Radio Engineers*, **46**:67-84.
Minnett, H., 1994. The construction of the Parkes 210-ft radio telescope. In Goddard and Milne:12-18.
Morton, D.C., 1985. The centre of our Galaxy: is it a black hole? *The Australian Physicist*, **22**:218-222, 250-252.
Orchiston, W., 1994. John Bolton, discrete sources, and the New Zealand field-trip of 1948. In Goddard and Haynes:541-547.
Orchiston, W., 2002. The Dover Heights 'hole-in-the-ground' radio telescope. *Anglo-Australian Observatory Newsletter*, **99**:26-27.
Palmer, P. and Goss, W.M., 1996. Nomenclature of the Galactic Center radio sources. *Galactic Center Newsletter*, **2**:2-5.
Piddington, J.H. and Minnett, H.C., 1951. Observations of galactic radiation at frequencies of 1210 and 3000 Mc/s. *Australian Journal of Scientific Research A*, **4**:459-475.
Robertson, P., 1992. *Beyond Southern Skies. Radio Astronomy and the Parkes Telescope*. Cambridge University Press, Cambridge.
Robinson, B., 1994. Spectral line astronomy at Parkes. In Goddard and Milne:106-118.
Sadler, D.H. (ed.), 1960. *Transactions of the International Astronomical Union. Vol. X. Tenth General Assembly Held at Moscow 12-20 August 1958*. Cambridge University Press, Cambridge.
Shklovsky, I.S., 1960. *Cosmic Radio Waves*. Harvard University Press, Cambridge (Mass.).
Slee, B., 1994. Some memories of the Dover Heights field station, 1946-1954. In Goddard and Haynes:517-534.
Stanley, G.J., 1994. Recollections of John G. Bolton at Dover Heights and Caltech. In Goddard and Haynes, 507-516.
Stanley, G.J. and Price, R., 1956. An investigation of monochromatic radio emission of deuterium from the galaxy. *Nature*, **177**:1221-1222.
Sullivan, W.T., 1982. *Classics in Radio Astronomy*. Reidel, Dordrecht.
Sullivan, W.T., 1984. *The Early Years of Radio Astronomy*. Cambridge University Press, Cambridge.
Sullivan, W.T., 1988. Early years of Australian radio astronomy. In R. Home (ed.), *Australian Science in the Making*. Cambridge University Press, Cambridge, pp. 308-344.
Weinreb, S., Barrett, A.H., Meeks, M.L. and Henry, J.C., 1963. Radio observations of OH in the interstellar medium. *Nature*, **200**:829-831.
Westfold, K.C., 1994. John Bolton – some early memories. In Goddard and Haynes:535-539.
Whiteoak, J.B., 1994. John Bolton as a pioneer of OH spectroscopy. In Goddard and Haynes:577-584.

Wayne Orchiston is a Research Associate at the Anglo-Australian Observatory and Archivist at the Australia Telescope National Facility, in Sydney, and has research interests in Cook voyage astronomy, Australian and New Zealand astronomical history and the history of radio astronomy. He has written numerous research papers, and the book *Nautical Astronomy in New Zealand. The Voyages of James Cook* (Wellington, 1998). He is Secretary of IAU Commission 41 (History of Astronomy) and of the Inter-Union Commission for History of Astronomy.

Bruce Slee retired as a Principal Research Officer at the Australia Telescope National Facility in 1989, and has continued his research since then as an ATNF Research Fellow. During the 1940s, 50s and 60s, his research interests related mainly to Jovian emission, source surveys, flare stars, and the interplanetary medium, but in more recent years the focus has shifted to studies of radio emission from active stars, galaxies, and clusters of galaxies using mainly the Australia Telescope Compact Array and the Very Large Array. Over the last fifty years or so he has written a large number of research papers on a wide variety of radio astronomical topics.

Journal of Astronomical History and Heritage 5(1):35-40 2002

The contribution of José Luis Sérsic to celestial mechanics

Adrián Brunini and Octavio Ismael Miloni

Facultad de Ciencias Astronómicas y Geofísicas,
Universidad Nacional de La Plata & IALP-CONICET
Paseo del Bosque, La Plata (1900), Argentina
E-mail: abrunini@fcaglp.unlp.edu.ar

Abstract:
In this paper, we shall review some aspects of José Luis Sersic's Ph.D. thesis: "Application of a certain type of canonical transformations to Celestial Mechanics", presented in 1956 to obtain the degree of Doctor in Philosophy in Astronomy of the National University of La Plata (La Plata, Argentina). We have found that Sérsic's work shares deep similarity to the method now known as Hori's Method although this was published ten years later. We shall discuss possible connections between both works, and the circumstances whereby Sérsic's work remained hidden to the international astronomical community.

Keywords: *celestial mechanics, J L Sérsic, Hori's Method, La Plata National University*

1 INTRODUCTION

José Luis Sérsic (Figure 1) was one of Argentina's most distinguished astronomers. Sérsic (1933-1993) received his Ph.D. in Astronomy from the Escuela Superior de Ciencias Astronómicas (High School of Astronomy) at the La Plata National University (Argentina), now the Facultad de Ciencias Astronómicas y Geofísicas of this University. His thesis advisor was Reynaldo Cesco, who at that time was Professor of Celestial Mechanics at this institution.

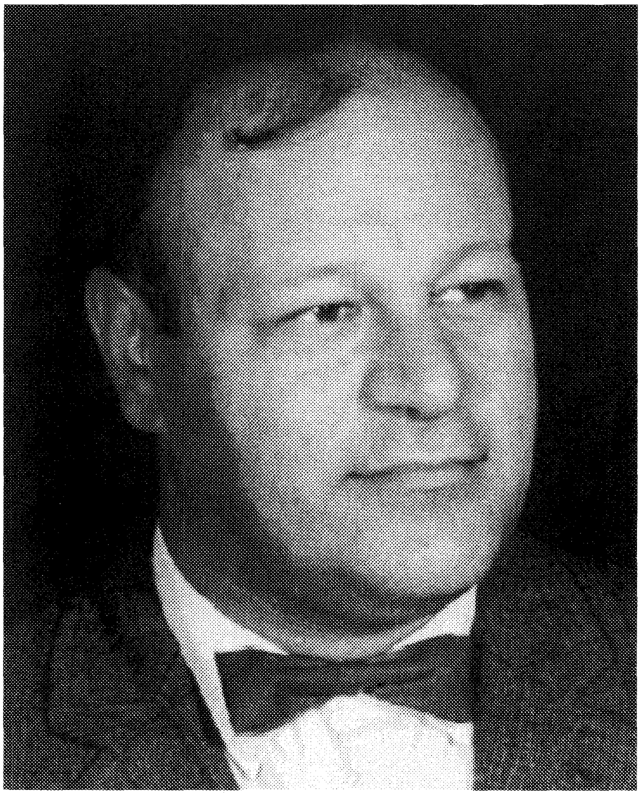


Figure 1. José Luis Sérsic (1933-1993).

Sérsic's Ph.D. thesis, titled "Application of a certain type of canonical transformations to Celestial Mechanics" written in Spanish (Sérsic, 1969), was presented to a thesis tribunal comprising Professors Reynaldo Cesco, Livio Gratton, and Pedro Zadunaisky on 1956 August 7.

Soon after graduating, Sérsic decided to focus his research efforts on problems associated with extragalactic astronomy. One year later he moved to the National Observatory of Cordoba (Argentina), dedicating the rest of his professional life to this field of astronomy, in which he received international recognition.

In our opinion, this change of research interest was one of the reasons (but perhaps not the most important one) why Sérsic's Ph.D. thesis remained almost unknown to the international community of celestial mechanicians. Although it was reproduced in Spanish, in the *Contributions of the La Plata Astronomical Observatory*, a publication with a wide international circulation, unfortunately this only occurred in 1969, thirteen years after the thesis had been approved (Sérsic, 1969). This delay was probably due to problems with the University publisher. Following, in Table 1, is a translated table of the contents of Sérsic's thesis, which may be found in the Library of the Facultad de Ciencias Astronómicas y Geofísicas of La Plata University (and we are happy to furnish copies of it upon request).

Table 1: A table of contents of Sérsic's Ph.D. thesis (translated from the Spanish original).

CONTENTS

1. Introduction.
2. General considerations.
3. Canonical transformations.
4. Canonical operators.
5. Extension of the operation.
6. Nature of the transformations.
7. Properties of the transformations.
8. Extension to more than two variables.
9. Transformation with a functional parameter.
10. Associated system of differential equations.
11. Analyticity of the transformation groups.
12. Convergence of the transformation groups.
13. Convergence of special groups.
14. Direct integration of the canonical equations.
15. Dynamical systems depending on one parameter.
16. Formal integration.
17. Intermediary orbit.
18. Determination of the characteristic function.
19. Convergence of the expansions of V and K.
20. Theorem of Poincaré.
21. Existence of periodic solutions.
22. Computation of periodic solutions.
23. General expressions for the solutions.

We are convinced that Sérsic's thesis was of a great originality at the time of its presentation, and that even now most of its contents will be of interest to celestial mechanicians. Its impact on perturbation theories could have been very significant. But this is not the only reason for presenting this review on Sérsic's work: in 1966, G Hori published a celebrated paper on a perturbative method known today as Hori's Method, and we believe that this is very similar to what Sérsic wrote in his Ph.D. thesis one decade earlier.

In this paper, we shall present the most important aspects of Sérsic's thesis, emphasizing those points that are similar to Hori's Method (although we shall not reproduce Hori's well-known results, which may be found in his paper). Our aim is to make colleagues more aware of J L Sérsic's contribution and also of the importance of celestial mechanics at La Plata during the mid-twentieth century.

2 THE SÉRSIC DOCTORAL THESIS

In this section we shall describe the main contents of Sérsic's thesis in the context of Hori's work.

The first two Sections of Sérsic's thesis are devoted to general considerations, presenting the basic aspects of Hamiltonian dynamics. Questions such as the definition of canonical transformations and the invariance of the Poisson brackets under these kinds of transformations are the main points reviewed there.

After this, in the third Section (Canonical Operators) Sérsic presents the basic ideas upon which his method of canonical transformations is based. There, at variance with the method proposed by Poincaré (1892) – a set of canonical transformations in implicit form – Sérsic presents a canonical transformation from the couple of conjugate variables (q,p) to a new one (q',p') by means of an *explicit transformation*:

$$q' = S(q)$$
$$p' = T(p)$$

where S and T are arbitrary functions that can be expanded in powers of a certain parameter α (not yet specified), in the form

$$S = 1 + \alpha\,\sigma_1 + \alpha^2\,\sigma_2 + \alpha^3\,\sigma_3 + \ldots.$$
$$T = 1 + \alpha\,\tau_1 + \alpha^2\,\tau_2 + \alpha^3\,\tau_3 + \ldots.$$

where the σ_j and τ_j are operators over p and q. Thus, formally, the transformations will be

$$q' = q + \alpha\,\sigma_1\,q + \alpha^2\,\sigma_2\,q + \alpha^3\,\sigma_3\,q + \ldots.$$
$$p' = p + \alpha\,\tau_1\,p + \alpha^2\,\tau_2\,p + \alpha^3\,\tau_3\,p + \ldots.$$

By application of properties of the Poisson brackets, such as its invariance under canonical transformations, Sérsic arrives to a particular form for the operators S and T:

$$S \equiv T.$$

He also found recurrent relations for the determination of the operators σ_j and τ_j $(\sigma_j \equiv \tau_j)$:

$$\sigma_1 = V(q\,,p)$$

$$\sigma_{i+1} = \frac{1}{(i+1)!}\,[V(q,p), \sigma_i\,],$$

where V is some defined function in phase space. The brackets denote the well-known Poisson brackets.

As it can be appreciated, in this Section, the author presented a kind of canonical transformation never applied before to problems of celestial mechanics or even classical dynamics. Nevertheless, at the time this methodology was widely used in quantum mechanics, as Sérsic himself points out in the introduction to his thesis, where he states: "The possibility to express the previously mentioned transformations in the form of operators may be found in the chapter V of the Principles of Quantum Mechanics of P A M Dirac, where an intensive use of the Poisson brackets is found, and operators of the form $e^{iS/h}$ are also used ...".

Having defined the operators S and T, Sérsic writes them in an exponential form (as in Dirac's book):

$$S \equiv T \equiv E^{\alpha V} \equiv 1 + \alpha\,[V,\,] + \frac{\alpha^2}{2!}[V,[V,]] + \frac{\alpha^3}{3!}V,[V,[V,]] + \ldots$$

where E is the basis of the natural logarithms.

With this form for the operators, the transformations in the variables q and p are written in a much more compact form:

$$q' = E^{\alpha V}\,q$$
$$p' = E^{\alpha V}\,p$$

In Section 4 the operator of the transformation is applied to arbitrary functions H of (q,p). In the following Sections 5 to 12 Sérsic analyses general properties of the operators, such as composition of operators, analytic domains, convergence regions, etc..

Section 13, Direct integration of Dynamical Systems, is completely devoted to presenting the formal integration of systems of canonical equations

$$\frac{dp}{dt} = [H,q]$$

$$\frac{dq}{dt} = [H,p]$$

in the same notation of operators.

Finally, in Section 14, Dynamical systems depending on one parameter, the perturbation theory takes its form. In this section, Sérsic applies the preceding results to a Hamiltonian of the form

$$H = H_0 + \alpha H_1 + \alpha^2 H_2 + \ldots$$

where α is a small parameter, so H_0 is the principal part Hamiltonian, being the rest a small perturbation. Usually when $\alpha = 0$ the solution of the problem is known (as in the case of the three-body problem).

Sérsic points out that the central problem is to search for the function V, in such a way that the system can be integrated. This is the scope of Section 17 (Determination of the characteristic function). Writing the new Hamiltonian as

$$K = K_0 + \alpha K_1 + \alpha^2 K_2 + \ldots$$

Sérsic arrives to the set of equations

$$K_0 = H_0$$
$$K_1 = H_1 + [H_0, V_1]$$
$$K_2 = H_2 + [H_0, V_2] + 0.5\,[H_1 + K_1, V_1]$$
$$\cdots = \cdots$$

which are completely identical to the equations 16'-20' in Hori's paper. The characteristic function is equivalent to the so-called *determining function, S,* in Hori's theory.

Through the operator, Sérsic also defines an *intermediary orbit* that is a concept like (although not totally equal to) the one defined as 'fictitious time' in Hori's equations 23 and 24.

The following chapters are devoted to using the method developed in the thesis to analyse the existence of periodic orbits in generic cases, and in the last chapter, Sérsic applies his results to a specific Hamiltonian.

3 DISCUSSION AND CONCLUDING REMARKS

To what extent are the Ph.D. thesis of Sérsic and the method of Hori the same? Hori (1966) presented his method to obtain canonical transformations and, for the integration of the specific problem of the motion of an artificial satellite in the field of an oblate planet, he determined the appropriate generating function through the 'averaging' principle proposed by Poincaré (1892) and used by Von Zeipel (Danby 1992). All the applications of Hori's Method where made in connection with this technique of averaging.

Therefore, to start our discussion we formulate the following question: Is the search for these kinds of canonical transformations with Lie generators the method referred to as Hori's Method in the literature or is it the search for the appropriate generating functions to particular problems of celestial mechanics? The answer to this question can be searched for within the title of Hori's paper itself, (General perturbations with unspecified canonical variables) as well as within the abstract of this paper ("A theorem by Lie in canonical transformations is applied to the theory of general perturbations ..."). The abstract indicates that Hori's paper is centred on the presentation of the canonical transformation with Lie generator and not on the search for the generating function. We believe that this fact is explicitly stated by Deprit (1969), Campbell and Jefferys (1970), and Henrard and Roels (1973), to cite just three papers that appeared soon after the publication of Hori's paper.

The work of José Luis Sérsic remained hidden to the eyes of the rest of the scientific world for almost half of a century. The particular circumstances of this unfortunate fact are not completely clear. However, some comments may help to shed light on this situation. Publication of research carried out at the Observatorio Astronómico de La Plata in international journals only become a common practice in the 1960's. It is worth mentioning that Sérsic's thesis advisor, Reynaldo Cesco, almost never published his results in journals with an international circulation, and this circumstance may have conspired against the publication of his disciple's doctoral thesis. There is also the already-mentioned fact that soon after the presentation of the doctoral thesis Sérsic transferred his research allegiance from celestial mechanics to astrophysics.

We have found few references to Sérsic's Ph.D. thesis in the literature, and they all appear in papers written by Professor Sylvio Ferraz-Mello following a visit to La Plata in 1987. We know that Ferraz-Mello obtained a reprint of Sérsic's thesis at this time, and it is interesting that in all of his references to Sérsic's work Ferraz-Mello presents it as an antecedent of the application of Lie series to celestial mechanics rather than as a precursor of Hori's Method (e.g. see Ferraz-Mello, 1997).

The last and perhaps most difficult question to answer is this: To what extent were the developments that Hori presented in his celebrated paper of 1966 completely independent of the results contained in Sérsic's Ph.D. thesis? To our knowledge, there is no direct evidence that Hori knew of Sérsic's work, but in Sérsic's 'Introduction' there is a sentence that may possibly suggest a connection between the two works: "It is, however, in the method of Peano-Baker and in its applications to Celestial Mechanics made by Yusuke Hagihara where the logic antecedents of this work must be searched for ... ". It is likely that G Hori attended courses in advanced celestial mechanics offered by Hagihara (Kozai, 1998), and he perhaps is the source of inspiration that links both works.

We wish to end this paper by proposing that in future *Hori's Method* should be known as the *Lie-Sérsic-Hori Method* (or simply the *L-S-H Method*) as a part tribute to the beautiful piece of work that was independently developed by José Luis Sérsic in 1956.

4 ACKNOWLEDGEMENTS

AB wishes to thank S Ferraz-Mello for suggesting this investigation to him many years ago.

5 REFERENCES

Campbell, J.A. and Jefferys, W.H., 1970. Equivalence of the perturbation theories of Hori and Deprit. *Celestial Mechanics*, **2**:467-473.

Danby, J.M.A., 1992. *Fundamentals of Celestial Mechanics*. Willmann-Bell, Richmond.

Deprit, A., 1969. Canonical transformation depending on a small parameter. *Celestial Mechanics*, **1**:12-30.

Ferraz-Mello, S., 1997. On Hamiltonian averaging theories and resonance. *Celestial Mechanics*, **66**:39-50.

Henrard, J. and Roels, J., 1973. Equivalence for Lie transformations. *Celestial Mechanics*, **10**:497-512.

Hori, G., 1966. General perturbations with unspecified canonical variables. *Publications of the Astronomical Society of Japan*, **18**:287-296.

Kozai, Y., 1998. The development of celestial mechanics in Japan. *Planetary and Space Science*, **46**:1031-1036.

Poincaré, H., 1892. *Les Méthodes Nouvelles de la Mécanique Céleste*. I Gautier- Villars et Fils, Paris.

Sérsic, J.L., 1969. Aplicación de un cierto tipo de transformaciones canónicas a la Mecánica Celeste. *Serie Astronómica. Observatorio Astronómico de La Plata*, **XXXV**:5-30.

Adrián Brunini is a Professor in the Facultad de Ciencias Astronómicas y Geofísicas of La Plata (Argentina), where he conducts research on planetary sciences as an independent researcher of the National Research Council (CONICET). He is Head of the Department of Celestial Mechanics and a researcher of the La Plata Astrophysical Institute, and has more than 50 publications.

Octavio Miloni is a graduate student in the Facultad de Ciencias Astronómicas y Geofísicas of La Plata (Argentina). At present he is at Sâo Paulo (Brazil), carrying out doctoral studies on resonances and averaging of Hamiltonian systems under the supervision of Professor Sylvio Ferraz-Mello.

Journal of Astronomical History and Heritage 5(1):41-64 2002

Early astronomy in America: the role of The College of William and Mary

Jeffery R Shy
AIM, University of Western Sydney, Australia
Address for correspondence: 5 Buford Road, Williamsburg, VA 23188, USA
jeffshy@cox.net

Abstract
During the late eighteenth century, The College of William and Mary in Virginia, led by its president, Bishop James Madison, became a leading institution in the USA for the study of Natural Philosophy, and especially astronomy.

In 1768, the College acquired scientific apparatus that had no equal in the colonies, and among the items in this collection were astronomical instruments that were the finest in America. In 1778, Bishop Madison constructed what was certainly the first observatory at any college in the nation, and possibly the first permanent observatory established anywhere in America. Madison's educational reforms and his personal involvement in the teaching of the natural sciences led to the first complete elective system of college courses in the USA.

Unfortunately the Revolutionary War devastated William and Mary and depleted its resources. Subsequently, the College was never able to achieve the great contributions to astronomy that may otherwise have been possible. Nonetheless, through its teaching programme, William and Mary contributed significantly to the education of many of the nation's early leaders, and it continues today as one of the foremost institutions of higher education in the USA.

Keywords: *The College of William and Mary, Bishop James Madison, early American astronomy, early American observatories, astronomical education*

1 INTRODUCTION

The English colonies in America wished, in many ways, to emulate English society, and to that end the colonists in Virginia petitioned the King and Queen to charter a college in Virginia, which, in 1693, became known as The College of William and Mary. Through many early trials and tribulations, including a disastrous fire that gutted the original main building, the College continued to grow during the eighteenth century.

Located in Williamsburg (for localities mentioned in the text see Figure 1), the College acquired wealth, purchased apparatus for the teaching of Natural Philosophy, and became a University with a complete faculty. A young man, Bishop James Madison (1749-1812), was appointed its President in 1777, and he built an observatory at William and Mary. Together with his friend Thomas Jefferson, he instituted reforms at the College which included the first elective system of study and the first honour system at any educational institution in America.

During the Revolutionary War,[1] the College suffered many major setbacks. The Royal grants of duties were withdrawn, rents for College lands went unpaid, the students left William and Mary to enlist in the army, and several College buildings were damaged or destroyed by occupying armies.

Madison managed to rebuild the College following the war. In doing so, he not only reconstructed most of the buildings that had been damaged, but he also rebuilt the faculty and instituted a complete programme of academic studies. He introduced additional reforms into the curriculum, including the requirement that students have a basic knowledge of astronomy at graduation. Throughout his tenure at the College, Madison maintained a programme of astronomical observations, and a variety of his observations is recorded in letters or other documents.

In the late eighteenth century, astronomy was largely an emerging science in America (e.g. see Bell, 1964; Mitchell, 1942; Milham, 1938; and Williams, 1996). This paper documents the important contributions that The College of William and Mary made to early American astronomy.

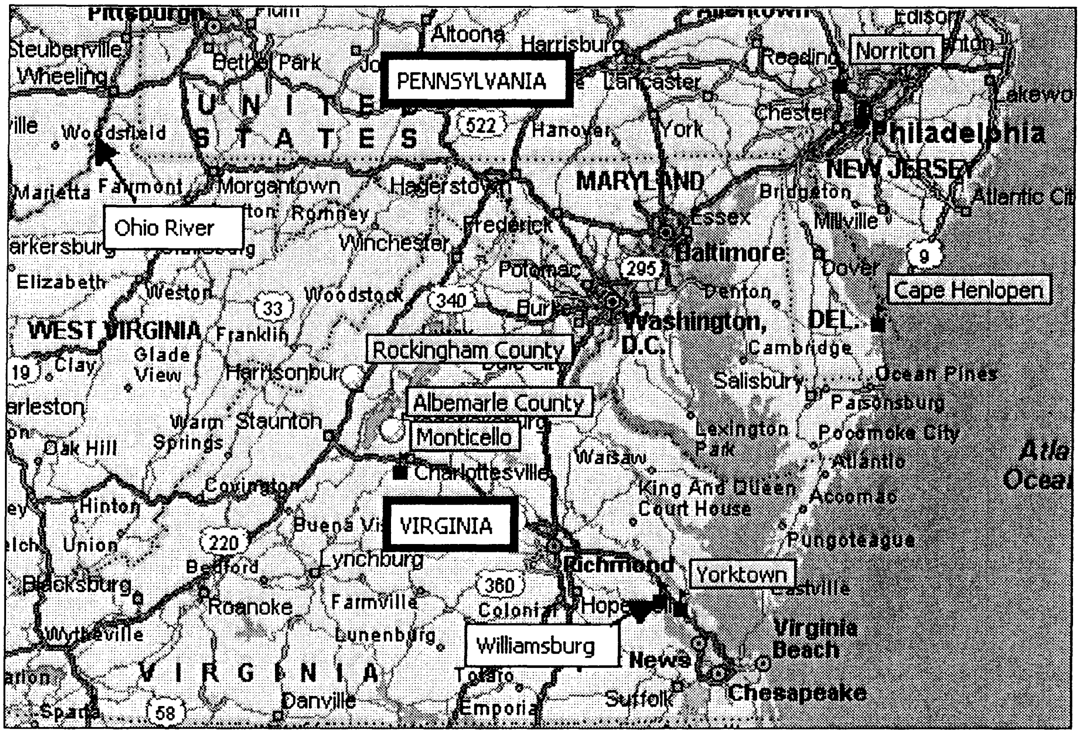


Figure 1: US localities mentioned in the text.

2 BISHOP JAMES MADISON: A BRIEF BIOGRAPHY

A student once said of Bishop James Madison, the eighth President of The College of William and Mary:

> The character of James Madison is an interesting one. In his life and habits he is perfectly systematic and regular; in his disposition, placid and indulgent; in his manner, the perfect gentleman; and in point of scientific knowledge, he is undoubtedly a finished scholar. As a tutor, he certainly stands in the first rank. (Morpurgo, 1976:168).

Bishop James Madison (Figure 2), second cousin of the more famous President James Madison of the United States, served as President of The College of William and Mary longer than any other President save its first, James Blair. Born in rural Rockingham County, Virginia, in 1749, he came to William and Mary in 1768 at the age of nineteen – which at that time was rather old for an entering student. But he excelled academically and was elected to a scholarship in 1770, receiving the Botetourt Medal in 1772 as the outstanding student in his class. Some months before his graduation he was employed by the College as writing master, and began to demonstrate the promise that would later bring him recognition as a scientist. When the Chair of Natural Philosophy was vacated in 1773, Madison was elected to that post. Then at age 28, within five years of his graduation, he became President of William and Mary, and he served in that post from 1777 until his death in 1812.

Unfortunately for Madison (but perhaps fortunately for William and Mary), he acceded to this post at what was to prove the most difficult period in history for the young American colonies. While he was away in London from the spring of 1775 to the fall of 1776, his world was thrown into turmoil when the colonies declared their independence from Great Britain and the United States of America was founded.

During his stay in London, Madison was ordained as an Anglican priest. He also found time to study under Tiberius Cavallo, known for his experiments and investigations of air, electricity, and magnetism, topics which were later to become favourites among students attending Madison's Natural Philosophy lectures (see Sprague, 1859).

Madison gave the first lecture course on political economy in the United States, and in 1774 he became the second professor of chemistry in America (after Dr Benjamin Rush of

Philadelphia). In 1845, the then chairman of the faculty of the University of Virginia, future founder of the Massachusetts Institute of Technology and William and Mary graduate, William Barton Rodgers, noted of William and Mary that "... in her halls were delivered by Bishop Madison the first regular course of lectures on physical science and political economy ever given in the United States." (Tyler, 1905:8). It is said that Madison lectured four to six hours a day (Gill, 1995), and his teaching has been described as part of the "... beginning of Natural History in America." (Goode, 1991:83).

Figure 2. James Madison, 1749-1812 (after Milham, 1938:29).

Madison's favourite topic, and that of his students also, was Natural Philosophy, which was never far from his thoughts. In a letter to another one of his correspondents, Edmund Randolph, he said: "I had a letter ready to acknowledge your favours of the 13th of last Month, which afforded us so much Consolation ... but it would be easy to calculate the time of an Eclipse, as to determine the times ... of one of Clarkson's Riders." (Madison, 1789b).

On 1780 January 27 he was elected to the American Philosophical Society, the same day as his close friend Thomas Jefferson, and some of his astronomical work was later to be published in the *Transations* of the Society.

Madison and Jefferson carried on a lifelong correspondence on all manner of topics, including astronomy. In a remarkable letter written on 1786 March 27, Madison covers a wide range of astronomical topics. This letter was written in response to a 1785 October letter from Jefferson who at the time was in Paris serving as the US diplomatic representative. He thanks Jefferson for information relative to "... ye Planet Herschel..." and relates it to "... that valuable work ye Conn. Des Temps." He mentions that he had not heard "... of the observations of Mr. Piggott ...", who in 1784 had discovered that the star Delta Cephei was variable. A century later, this star would become the prototype of a very important class of variable stars. In his letter, Madison also discusses the history of variable stars and some of the theory behind these objects, and raises several other scientific findings before closing (see Madison, 1786).

During the siege of Yorktown in 1781 the French army occupied the College and used the main building and the President's house as a hospital. Unfortunately, the house burned on the night of 1781 November 22-23 and Madison's personal library and instruments were destroyed. Greatly saddened, he wrote to Yale's President Stiles that he had lost "... every Book and Paper which I had." (Rouse, 1983:82).

After that conflict, Madison worked hard to reform the College, collaborating with Thomas Jefferson on a bill which would have substantially expanded the College's programme. Although the bill was never presented, Madison implemented as many reforms as possible and oversaw the expansion of William and Mary from a college to the first university in the United States. In 1792, he instituted the Statues of the University of William and Mary, which established a set of requirements for graduation that included a basic knowledge of astronomy.

It has often been said that the quality of a teacher may be gauged by the accomplishments of his students. During Madison's tenure at William and Mary, he taught two future Presidents of the United States (James Monroe and John Tyler), one Chief Justice (John Marshall), five Attorneys General of the United States, eight governors, ten United States Senators, sixteen Congressmen (including two Speakers of the House of Representatives), twenty-eight judges, six general officers of the armed services, and innumerable teachers and natural philosophers. All of these were drawn from classes that graduated an average of only fifteen to twenty students per year (Faculty compilation, 1874).

One of Madison's students once penned: "Fish and oysters are very good food at times, but in my opinion not near equal to Mr. Madison's lectures with which I am enamoured, and without which I think no man can boast of a good education." (see Godson *et. al.*, 1993:192). This is high praise indeed.

3 ASTRONOMY AT THE COLLEGE OF WILLIAM AND MARY

3.1 The Place of Natural Philosophy at the College in the early eighteenth Century

The College of William and Mary was founded by Royal charter on 1693 February 8 "... to make, found and establish a certain place of universal study..." (cited in Morpurgo, 1976:1). One President and six Masters or Professors were to be appointed at the establishment of the College. In 1695, the College opened its main academic building; now know as the Wren Building, named after its supposed designer, Sir Christopher Wren. This building became the centrepiece of the College, where its students lived, ate, and studied (see Kale, 1985; Kornwolf, 1989; Sacks, 1984).

Amongst those early areas of study was to be the subject of Natural Philosophy. Bishop Madison defined Natural Philosophy in his lectures as: "... that Science which points out & explains the Laws by which the material universe is governed; & thereby accounts (as far as maybe) for the various Phanomina [sic.] of Nature." (see Watson, 1796).

The young colony was justifiably proud of its College and of the Wren Building, which was even used for meetings of the General Assembly of Virginia from 1700 until 1705 when the building was destroyed by fire. That disastrous fire of 1705 October 29, when everything in the building was lost, including the library and 'philosophical apparatus', was to be the first of three that would strike the Wren Building over the next three centuries.

For the first twenty years or so of its existence, the College was primarily a grammar school. Slowly it began to emerge as a College. The accounts of the first fire, however, do provide us with the evidence that William and Mary, almost from its very beginning, included apparatus necessary for the study of natural philosophy.

In the spring of 1716, Hugh Jones was appointed the first Professor of Natural History and Mathematics. By 1729, a full complement of six professors and a President had been appointed. Once a student had passed his exams in grammar school, he graduated to a study of either Moral or Natural Philosophy. The study of Natural Philosophy included physics, metaphysics, and mathematics. Four years of study were required to obtain a bachelors degree and seven years of study for a Masters Degree. A divinity school was also established (Tyler, 1905).

While these developments were occurring in Williamsburg, Harvard also began to emerge as a College. Harvard had also been founded as a grammar school, and in 1736 Departments of Latin, Greek, Logic, Metaphysics, Mathematics and Natural Philosophy were set up. John Winthrop, often considered America's first astronomer, was appointed to the Chair of Natural Philosophy in 1738, a post that he was to hold for forty years (Brasch, 1916).

In the spring of 1758, William Small came to Virginia and shortly thereafter was appointed to the Chair of Natural Philosophy at The College of William and Mary. Jefferson (1778) said of Small that he, more than any other man, "... fixed the destinies of my life." It was Small who, upon his return to England in 1764, acquired the scientific apparatus mentioned later in this paper which was, by most accounts, the most extensive collection in the colonies at that time. Small also introduced the lecture system to College life and "... left a lasting impression by popularizing the study of Natural Philosophy." (Tyler 1905: 6).

By 1769, the President was being paid £200 sterling and Professors received £80/2/-. The President also received remuneration for his post as Bishop, and therefore was paid a total of around £550 per annum. The entire faculty was also entitled to 10,000 lb. (4536 kg) tobacco per year. According to Tyler (1905:4), at this time the faculty of William and Mary was ".. probably better paid than at any other college in America."

There is little evidence in the College's library collections of any holdings in Natural Science or Mathematics during the early eighteenth century. By contrast, both Harvard and Yale were actively teaching science and conducting scientific research before 1735 and had libraries to support that study. But on 1772 December 8, the College purchased the library of James Horrocks (a former President of William and Mary), which included works in the physical sciences and mathematics that represented most of the significant thinking of the previous one hundred years (Neiman, 1968). Among the books purchased from the Horrocks estate were Newton's *Principia*, two copies of Newton's *Optics*, and Ferguson's *Astronomy Explained*... as well as his *Astronomical Tables and Precepts for Calculating the Times of New and Full Moons, Showing the Method of Projecting Eclipses from the Creation to AD 7800 to which is Prefixed a Short Theory of the Solar and Lunar Motions* (ibid.) Other books utilized by Professors at the College included Lacaille's *Astronomy*, Gregory's *Astronomy*, and Reilo's *Astronomy*.

Madison assumed the Chair of Natural Philosophy in 1773 and in 1777 became the President of William and Mary, which by now had a full, well-paid faculty, a fine collection of scientific apparatus, and a reasonably complete scientific library. It was poised to rival any College in America in its teaching programmes, and especially in the area of Natural Philosophy. Then in 1779, under reforms instituted by Madison and then Governor Thomas Jefferson, William and Mary became the first university in America. The elective system of study was introduced (which initially was roundly criticized in the North), as well as the first honour system.

However, all was not well. Throughout much of its history, the administration and governance of William and Mary had been marked by bickering between its faculty and the Board of Visitors. The Board tended to reflect political tendencies that were in opposition to the Crown, while the faculty possessed more loyalist tendencies which were derived in no small measure from their educational backgrounds in England. The Revolution brought these problems to a head, and within a short time of Madison's ascension to the Presidency, the College and its faculty openly supported the independence movement.

But there was a price to be paid. Whereas there were sixty to seventy students before the Revolutionary War, as the war wore on more and more students left the College to join the campaign, and by 1780 October the campus was largely deserted. Madison wrote to his second cousin and President-to-be, James Madison, that "The University is a Desert. ... We were in a very flourishing way before the first invasion. We are now entirely dispersed. The student is converted to Warrior..." (Madison, 1781a).

Sources of income for the College began to disappear. Duties that had been supplied to the College by the Crown were suspended and the College was forced to subsist on the rent from its lands, and even then it had a very hard time collecting these. According to Zech (2001), income dropped from £3048 per annum prior to the War to a mere £712 in 1777, but in a letter dated 1780 July 12 to President Ezra Stiles of Yale, Madison (1780a) quotes quite different figures: a decrease in revenue from £5000 or £6,000 to only about £500 per annum.

When the Capital was moved to Richmond in 1780 the economy of Williamsburg suffered tremendously as a result. Then in 1781 the French occupied the College's Wren Building, and used it as a hospital. One wing of the Wren Building burned on 1781 November 23 along with the President's House, and several outbuildings were also destroyed during the War. The French eventually agreed to pay £12,000 in damages – which many thought an outrageously low figure – but by 1786 they still owed half that sum (Morpurgo, 1976).

Despite these not inconsiderable 'diversions', Madison managed to resume classes at William and Mary in the fall of 1782. By 1795, there were between fifty and sixty scholars at the grammar school and thirty or forty studying philosophy or law.

In 1803, Samuel Miller wrote that:

> In natural philosophy there is a regular course of Lectures, attended with every necessary experiment. In this course, the works generally referred to, and recommended, are those of Rowning, Helsham, Martin, Desaguliers, Muschenbroeck, Cavallo, Adams, Lavoisier, Chaptal, etc.
> The number of Students in this College, in the beginning of the year 1801, was 53. The Library contains about 3000 volumes. The Philosophical Apparatus, when procured in 1768, was well chosen, and tolerably complete. Having been in constant use for more than 30 years, it stands in need of repairs, and is less complete than at first. (Miller, 1803).

The College had managed to withstand the ravages of the Revolution, but barely so. It became the task of Madison and the faculty to begin rebuilding. But the College's undoing came at the hands of the man who had previously been one of its most ardent supporters, Thomas Jefferson.

The reforms that Jefferson desired to propose in 1779 were never considered by the state legislature. Many thought the College ought to move to Richmond. Jefferson began to believe that the best way to serve Virginia's educational needs was to provide for a new university, and in 1800 he said of William and Mary: "We have in [Virginia] a college (Wm. & Mary) just well enough endowed to draw out the miserable existence to which a miserable constitution has doomed it." (cited in Goodwin, 1967:282). He continued to explain that Williamsburg was an unhealthy place and "... we wish to establish in the upper & healthier country, and more centrally for the state, an University..." (ibid.) Of course, the University of which he spoke was to be the University of Virginia, often known as 'Mr. Jefferson's University', located just a few miles from his Albemarle County home, Monticello.

3.2 The Acquisition of Scientific Apparatus

The College had not been without scientific apparatus during the early eighteenth century, although some was lost in the fire of 1705. We do know that Major General Alexander Spotswood bequeathed his 'mathematical instruments' to the College in 1740, and that the College

> ... may have owned a few surveyor's instruments, and navigation instruments, for use in the mathematics course; terrestrial and celestial globes were available; there may have been a telescope; and there were probably a few pieces of "apparatus" available for the study of "fluxions" and "optics" prior to 1767. (Goodwin 1967:61).

Eventually, the Board of Visitors was persuaded to expand the apparatus, and towards that end Professor William Small, holder of the Chair of Natural Philosophy and Mathematics and favourite tutor of Thomas Jefferson, was sent to London to make appropriate purchases.

Small had apparently badgered the Governor, who in turn pressured the House of Burgess for sufficient funding for the apparatus. In 1762 December the Board of Visitors set aside £450 for the purchase "... of a proper Apparatus for the instruction of the Students of the College in Natural and Experimental Philosophy." This was enough to provide for "... the best collection of scientific equipment in America." (Morpurgo, 1976:138).

A fragment of the original list of items purchased by Small survives in The College of William and Mary archives. It is written on a small sheet of paper about 4 inches by 8 inches, folded in half so as to form four pages. Each of those pages lists equipment and associated purchase prices, together with a financial balance brought forward from the previous page. Following is a transcription of these pages; see, also, Figure 3.

The first page:

Balance forwards	£178	10	0
The Fountain Experiment in Vacuo c. in open air with A Bason &c. -	3	3	0
A Lung's Glass -		10	6
The Barometer Exper[t] -		15	0
Wire Cage for breaking Glasses with 6 brass caps with Valves	1	11	6
Plates for Attraction & Cohesion -	0	15	0
A Pendulum to swing in Vacuo -	2	2	0
A Set of Glasses for the Air Pump - - - - - - - - - - - - - - - - - -	3	13	6
6 Pound of Quicksilver -	1	4	0
A Dipping Needle Compass 9 Inches Diam. With Needles for the Dip- -	15	15	0
A Horizon[l] needle with a center Pin Work for it to stand on for the variation - - - - - - - - - - - - - -	0	18	0
	£208	17	6

The second page:

Brought over - - - - - - - -	£208	17	6
E monochord - - - - - - - -	4	4	0
A machine for the Resistance of the Air according to M[r] Robinson	3	13	6
A Standard Barometer -	2	12	6
The 5 Platonic Bodies -	1	5	0
A Cone dissected -	0	12	0
To Packing all the above -	2	0	0
Peter Dolland			
The Arcromatic Telescope with a Triple Object Glass 3 ½ feet focus, two Eye Tubes for Astronomy & one for Day Objects	15	15	0
A best double microscope &c. -	7	7	0
A Solar Microscope with Apparatus - - - - - - - - - - - - - - - - - -	5	10	0
The Reflecting mirror a true parallel Glass - - - - - - - - - - - - - - -			
	£251	16	6

The third page:

Brought forward - - - - -	£251	16	6
A 12 Inch Concave Mirror, a flat Mirror - - - - - - - - - - - - - -	4	0	0
A 6 Inch Concave Mirror -		15	0
5 Lenses of different Sorts in Frames - - - - - - - - - - - - - - - - -	3	10	0
A Water Prism -	2	5	0
A Set of small Prisms in e Case -	1	11	6
Two Specule on a Frame to shew a number of Reflexions - - - -	1	5	0
3 Parall: Glasses 2 Inch: Diam. For taking the Sun's Altitude in Mercury	0	6	0
A Square Par: Glass 6 Inch: Diam. In a Frame - - - - - - - - - - -	1	1	0
An Object Glass for shewing the Rings of colors to be us'd With the Plane Glass -	1	11	6
A Square Mahogany Tube with an Object Glass & a Number of Eye Glasses to shew the Direction of the Rays of Light In Eye Glasses -	2	12	6
Packing the above - - - - - - - - - - - - - -	0	5	0
	£273	19	0

The fourth page:

	£	s	d
Brought over - - - - - - -	£273	19	0
An Electrical Machine -	10	15	0
A Glass Jarr -	2	8	0
5 Glass Syphone -		7	6
A Model in Gloass to show the manner of Intermitting & Reciprocating Springs -	2	14	0
17 Capillary Tubes -		6	6
2 Glass Models of Pumps -	4	4	0
2 Glass Parallal Plains -		18	0
A Glass Jarr, for the Hydrostatic Balance, the Screw, wheel & Axle Compound & other levers & Weights, Wedges & Weights, Pullies & Weights & y^{e} 6th Mechanic Power, all fix on 2 Brass Pillars	20	7	0
A Brass Circular Carriage -	3	8	0
A Mahogany inclin'd Plane ^{wth} a Quadr^{t} which sets to any Angle wth Scale & Nest of weights 164 ^{oz} Troy - - - -	4	16	0
Dr. Barker's Mill -	4	4	0
An Instrument to try the Force of falling Bodies - - - - - - - - - -	3	17	0
	£332	4	0

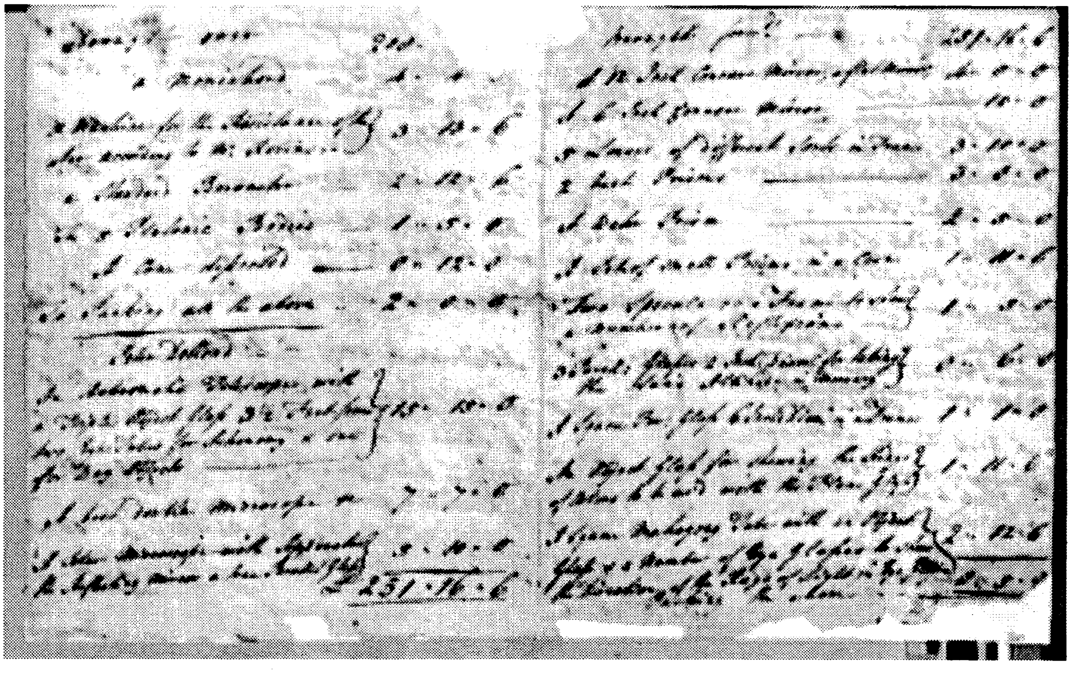


Figure 3: The second and third pages of Small's equipment purchase list (courtesy The College of William and Mary Library).

There are a number of very interesting things to note about this list. Firstly, page one begins by bringing forward a balance of more than £178. One has to wonder what was purchased with these funds and whether they may have related in some way to astronomy. In our discussion of Madison's observations (Section 3.4, below) we shall note that he had access to astronomical instruments not in the above list, including at least one reflecting telescope, an astronomical clock and a transit telescope. At least one of these telescopes was manufactured by James Short (Madison, 1789c), and could have been purchased on this trip.

Secondly, we note that the Board of Visitors set aside £450 for the purchase of apparatus. What became of the remaining £118? Was this money spent elsewhere and accounted for on yet another list? Madison was justifiably proud of the College's collection of scientific instruments, and on 1780 July 12 he advised Ezra Stiles (President of Yale University) that "We have a well chosen Apparatus which cost £500 made by the best Hands in London" (see Goodwin, 1967:237-238). Does this indicate that even more than the allocated £450 was eventually spent on scientific equipment?

Finally, we should note that the above listing includes a 12-inch concave mirror, a 6-inch concave mirror and a flat mirror. Were these purchased for use in the construction of telescopes?

So much equipment was purchased that the College needed to take extraordinary steps to clean and maintain this rapidly-growing collection, and according to the minutes of the faculty on 1772 August 11, the College directed that "Mr. Matthew Davenport be appointed to clean and take care of the College Apparatus, and that he be allow'd a salary of 10£ pAnn." (College ... Faculty minutes, 1729-1784).

Unfortunately, Small was at heart a loyalist and constantly at odds with the other members of the faculty and the Board of Visitors, so he decided to remain in England and never returned to Williamsburg after his London shopping trip. But clearly he had shopped well. Even the American Philosophical Society had to wait twenty years before it would own a telescope of the quality of the Dolland achromatic refractor at William and Mary, and the collection brought considerable prestige to the College (Morpurgo, 1976). In this context, Hornberger (1945:61) notes that at this time "Harvard's greatest rival in Physics was probably William and Mary...", and that it was safe to say that the apparatus at William and Mary "... was comparable to the apparatus at Harvard."

With Small gone there was no one at the College who was qualified to actually put the apparatus to work, and five years after Small "... had shipped to Virginia the superb paraphernalia which should have served to make William and Mary the head and the heart of scientific teaching in America ..." (Morpurgo, 1976: 140) the collection lay in disuse. This situation was roundly criticized by the local newspaper but in the 1771 August 15 issue it noted that Small's successor, Thomas Gwatkin, was willing to make use of some of the apparatus, "... but only if it could be appropriately housed and maintained." (Morpurgo, 1976:162).

Once Madison was appointed to the Chair of Natural Philosophy he began to use the apparatus, and he continued to look for other scientific instruments that would enhance the collection and could be utilized in his teaching. In 1778 Thomas Jefferson and others prepared a "Bill for Amending the Constitution of the College of William and Mary", and this included the following interesting proposal:

> And that this commonwealth may not be without so great an ornament, nor its youth such an help towards attaining astronomical science, as the mechanical representation, or model of the solar system, conceived and executed by that greatest of all astronomers, David Ryttenhouse; Be it further enacted, that the visiters [sic.] ... shall be authorized to engage the said David Ryttenhouse ... To make and erect in the said College of William and Mary, for its use, one of said models ... the cost and expense... be paid by the Treasurer of this commonwealth ... (cited in Goodwin, 1975: 237).

Acquisition of an 'ornament' such as this certainly would have put William and Mary on a par with Princeton in this area, but unfortunately this bill was never put before the House of Delegates.

Other evidence exists of Madison's on-going quest for additional apparatus. In a letter dated 1782 October 3, he asks Colonel Randolph to contact Rittenhouse "... to furnish some electrical apparatus ..." that he has been trying to get built (Madison, 1782b). Madison had apparently been unsuccessful in getting Rittenhouse to work on the apparatus and thought that Randolph might be able to use his influence. No evidence exists that the apparatus was ever obtained.

Madison was highly protective of the instruments in his possession. Upon his appointment to the commission to undertake a survey of the Virginia-Pennsylvania border, Madison received a letter from the Governor of Virginia, Thomas Jefferson, indicating that "... for the Pittsburg observations we must sollicit the proper Instruments from your Corporation [The College of William & Mary] which we will undertake to return in good order, or if injured to replace them. I therefore beg the favor of you to sollicit the Loan of those Instruments..." (Jefferson 1781). In his reply Madison (1781b) insisted that if the College's astronomical clock was damaged then it should be repaired if possible, or else replaced just as soon as peace would allow a replacement to be obtained from London. In this same letter, dated 1781 April 8, he carefully gives instructions for the transportation of the clock: "... if carried in a covered Waggon which shall be provided, well packed, laid on a feather bed ... or otherwise on Straw, or perhaps swung it cannot receive Injury." (ibid.). Madison (1785) later boasted that the College's astronomical clock was more accurate than the one used by the Pennsylvania delegation, which was led by none other than David Rittenhouse.

Madison continued to use the collection of scientific apparatus throughout his tenure at the College, and although "... well chosen and tolerably complete ..." when procured in 1768, by 1803 it was deemed to be "... in need of repairs ... [and] less complete than at first." as a result of constant use over more than 30 years (Miller, 1803). By 1824, when the Commonwealth was studying the possibility of moving the College to the capital in Richmond, a report concluded that it was "... impossible to give a very accurate statement of the philosophical and chemical apparatus. The former was purchased in Europe many years ago. Part of it is very valuable, but it is not extensive." (Report ..., 1824:317).

Disaster again struck the College in 1859. For the second time in its history there was a major fire in the Wren building, and the cabinet containing the collection of scientific instruments was destroyed. This cabinet it said to have contained "... several old instruments valued for their antiquity as the relics of the science of the former ages." (Faculty Minutes ..., 1859:269). Thus the equipment that was purchased with such enthusiasm and promise in 1767 met its end almost one hundred years later in this second conflagration of the Wren Building. A newspaper report published at the time indicated that among the items lost was "... an astronomical clock, of very curious mechanism, and some two or three centuries old." (Faculty compilation, 1874:554). This sounds like the very same clock that Madison expressed such pride in during his work on the Virginia-Pennsylvania boundary.

3.3 Founding of the College Observatory

In *Early American Observatories: Which Was the First Astronomical Observatory in America*? Willis Milham presents a history of observatory building in America. He concludes that the Hopkins Observatory at Williams College is the oldest extant astronomical observatory building in America. But he also acknowledges that "... the reader is left to judge which was the first Astronomical Observatory in America." (Milham, 1938:52).

Milham classifies observatories as (1) temporary observatories, (2) makeshift observatories, (3) mere repositories of apparatus, and (4) regular permanent observatories. He notes that if a telescope were mounted in the open on a pier and then covered in some way so that the instrument did not have to be taken indoors following use, that this might be considered a temporary observatory. If a mere shack or building of temporary construction were used to house an instrument for a few months or even a few years, this still might be appropriately considered temporary. If a telescope were placed in a building in order to view through its windows, this might well be considered a makeshift observatory. If the telescope or other instrument were kept in some other location, then moved to the observatory for use, then the building would be a mere repository of apparatus. But a permanent observatory should have a pier for the mounting of the instrument, some sort of opening rooftop, and be built in such a way to last for a number of years.

It has been generally considered that the first astronomical observatory in America was one constructed for David Rittenhouse. In preparation for the transit of Venus in 1769, the American Philosophical Society arranged to build three temporary observatories in the general area of Philadelphia, one at Cape Henlopen on the Delaware Bay, one in Philadelphia, and one at Norriton. Milham (1938) describes the observatory in Philadelphia as an uncovered raised wooden platform, while others say that it had stone foundations, but was little more than a covered platform above (e.g. see Bell, 1964:7). The Norriton structure was spoken of as a log-observatory (Milham, 1938), and when Rittenhouse moved to Philadelphia in 1770 it was torn down.

Meanwhile, the observatory platform in Philadelphia was used for public rallies, the most memorable of which was the reading of the Declaration of Independence on 1776 July 8. After the evacuation of Philadelphia by the British, the instruments were again brought out for occasional use. However, the observatory was poorly designed for an ongoing observational programme and was razed in 1783. Clearly, the observatories build for the transit were temporary in nature.

Rittenhouse received a grant from the Pennsylvanian legislature, and constructed another observatory in Philadelphia in 1781. This octagonal brick building housed some of his instruments and from it he recorded many observations which were later published. In 1790, Franklin bequeathed his Short reflecting telescope to Rittenhouse. Upon his death in 1796, Rittenhouse was buried beneath this building, and his will stipulated that the observatory be set aside for the use of the American Philosophical Society. In fact, members used it so seldom that the property was returned to the Rittenhouse family in 1810, which effectively marked the end of its use as an observatory.

Back in 1778, Bishop Madison arranged for the erection of an observatory at The College of William and Mary. Humphrey Harwood was retained to build this observatory, and his Account Book survives in the Archives of the Colonial Williamsburg Foundation, and includes the following entries (Harwood, 1778):

May 2^{d}	To 15 bushels of lime @ 1/6. laying floor, & Build^{g} pillers to Observitory 30/	2:12: 6
	To 4 Days labour @ 4/ for M^{r} Madison	:16: -
June 12	To 40 bush^{s} of lime @ 1/6. 3 d^{o} of hair @ 3/9. & Cart^{g} 3 loads of Sand @ 4/.	4: 3: 3
15	To 80 D^{o} @ 1/6, to 5 days work @ 12/. 6 D^{o} @ 8/. & 6 Days labour @ 6/	13:14: -
20	To 11 Days work @ 12/. To 11 D^{o} @ 8/. 11 Days labour @ 6/	14: 6: -
24	To 9 D^{o} of d^{o} @ 12/. To 9 D^{o} @ 8/. & 8 D^{o} labour @ 6/.	11: 8: -

While it is not clear whether the work done during the month of June was for the observatory or some other purpose, it is clear that an observatory was built at the College, under the direction of Bishop Madison, beginning in May of 1778. Harwood's usual practice was to cite the location of the project in the first line detailing billings for that particular project. On June 27 he details repair work in the College laundry and kitchen, so it is quite likely that all the materials and labour documented from June 12 through June 24 related to the observatory.

It is also important to note how the materials that are listed here might have been utilized. The lime and sand would likely have been used to prepare mortar or a paved area. Perhaps the notation on May 2 regarding the laying of a floor amounted to paving the floor with mortar made with the lime and bricks. Meanwhile, the 'pillers' that were mentioned were certainly destined to become piers for a transit instrument, and perhaps for other telescopes. The hair would have been used in plaster. What might all this lime and the 81 man-days of skilled workers and labourers recorded from June 12th have been for? Apart from the observatory, there were no other constructional projects in progress at the College at this time.

The key to the puzzle may lie in the knowledge that the College had its own brick kiln as well as its own access to lumber. Lumber was typically milled on the building site in eighteenth century Virginia. Bricks for College buildings were made on campus from the founding of the College until after the American War of Independence. The likelihood is that the large amounts of lime were used together with bricks made at the College to construct a building. The 80 bushels of lime purchased beyond that used for the floor would probably have been sufficient for the purpose of laying approximately 10,000 bricks, on the basis of the ratio of lime to bricks used in other building projects noted in Harwood's records. Therefore, one might conclude that the observatory project involved a brick structure of 10,000 bricks build with 81 man-days of labour. Unfortunately, there are no archaeological records of brick remains that can, with certainty, be attributed to an observatory, and until such foundations or other archival evidence is identified, the location and construction of the observatory will remain a mystery.

Nor are we certain of the instruments that were housed in the observatory, although a letter that Madison wrote Rittenhouse on 1789 November 5 indicates that a transit instrument was definitely located there: "... the observatory in which the transit instrument had been formally placed, was not, at this time, rebuilt ..." (Madison, 1789c). It is logical to assume that the astronomical clock was located in the transit room at the observatory, and this is most likely the same clock that is referred to in the records of the Virginia-Pennsylvania survey and again in the accounts of the 1859 fire.

We also know from the Small apparatus purchases, that the College had in its possession a fine Dollond 'arcromatic' telescope and, from observational records, an '18-inch' reflecting telescope made by James Short. In astronomical circles, Dollond and Short were well-known names in the eighteenth century. The British father and son pairing of John and Peter Dollond respectively patented and developed the achromatic refracting telescope (see Andrews, 1992; King, 1979), and one of these instruments so impressed the Astronomer Royal that these telescopes were taken on Cook's second and third voyages to the South Seas (see Orchiston, 1998a, 1998b). It is clear that The College of William and Mary also possessed one of these excellent telescopes. Meanwhile, the William and Mary Short telescope also came from a manufacturer with impeccable credentials. Scottish-born James Short was a "... most celebrated personality ... [who] accrued a fortune by supplying excellent instruments (about 1360) to amateurs and professionals." (Andrews, 1996:99). His forté was the Gregorian reflecting telescope, although he occasionally fabricated Cassegrain and Newtonian reflectors. All of his telescopes were known for their optical superiority (see Bryden, 1968; Turner, 1969), and two Short reflectors accompanied the astronomers on Cook first voyage and were used to successfully observe the 1769 transit of Venus from Tahiti. Short's telescopes were generally described in terms of their focal length. Thus, the William and Mary reflector had a focal length of 18 inches (45.7 cm), and the aperture of the mirror would have been about 9 cm.

Although the College's transit telescope was undoubtedly installed in the observatory we cannot be certain that the Dollond and Short telescopes were also housed there, for both were small enough that permanent mountings would not have been necessary for their use.

In addition to its astronomical occupants, it is also possible that the observatory served as a meteorological station. Among the items in Small's list of purchases is "A Standard Barometer", and it is likely that other meteorological instruments were acquired. Madison certainly had an interest in meteorology, and various observations that he made are discussed in a 1779 letter to Rittenhouse, and were subsequently published in the *Transactions of the American Philosophical Society* under the title "Meteorological observations" (see Madison, 1779).

It is not clear when the observatory was destroyed, other than that this event predated 1789 November 5 when Madison (1789c) wrote Rittenhouse. The French occupied the College's main building in 1781, and the Wren Building for use as a hospital. Apparently, more space was needed for that purpose and was requested from the College, and on 1781 October 15, John Blair wrote to George Washington informing him that "... the Commissary has demanded of him the Keys of an out-building called the Granary other Houses near it..." (Blair, 1781). The letter specifically lists items in the buildings that cannot be moved or saved if this action should occur, but no astronomical equipment is mentioned nor is there any reference to the observatory. Washington, however, would not relent and just two days later replied: "... nothing but absolute Necessity could induce me to desire to occupy the College with its adjoin^{g} Buildings for Military Purposes ... [although] many of the Articles are easily removeable [sic]." (Washington, 1781).

Nevertheless, we know that "... some outbuildings were extensively injured ..." (Goodwin, 1967:247), and we can assume that the brick kiln was among the buildings that were destroyed since from that date records show that the College began buying bricks. Subsequently, the College attempted to recover some of the losses suffered during the American War of Independence, and a paper submitted to Congress noted that it was "... unable to complete the repairs of the other buildings rendered necessary by the injury done them whilst in occupation by the French until the year 1788." (Committee ..., 1928:246).

Based on present evidence, all that we can be certain of is that the observatory was constructed in the spring of 1778 and destroyed prior to 1789 November 5, but it is logical to conclude that its destruction was accidental, and occurred during the French occupation of the College. A key question now arises: despite its untimely destruction, was the building erected by Harwood for Madison intended as a 'regular permanent observatory'? If it was – and the evidence tends to support this – then this would have been the first observatory constructed in America that meets the criteria suggested by Milham, and it would almost certainly have been the first documented observatory of any kind associated with an American educational institution. Furthermore, its construction occurred long before 1802 when the observatory at Bogota, Colombia, was built, even though Donnelly (1973:55) regards this as "... the first permanent observatory in the New World ...".

It is interesting to reflect on whether the William and Mary observatory was ever rebuilt. No archival records have been located which document such a reconstruction, but Madison's 1789 November letter to Rittenhouse mentions that the observatory "... was not, at this time, rebuilt ..." (Madison 1789c), which could be seen to imply that a rebuilding was in fact planned. Park Rouse, noted Williamsburg historian, thinks that this did occur. In his book about the President's House he discusses attractions that the College offered its students, noting that: "Some of them were privileged to view the cosmos through Madison's observatory, which he had built in 1778 and reopened after the Revolution." (Rouse, 1983:87). Unfortunately, there is no firm documentation to support Rouse's assertion, and as if only to confuse the issue further, in his 1789 November 5 letter to Rittenhouse, Madison (1789c) reports on that day's transit of Mercury which was observed at William and Mary from two different rooms with two different telescopes but utilizing the same clock for timing. Where were these observations carried out if the observatory had not been rebuilt?

Nothing more is to be found in the College records regarding an observatory until after the fire of 1859 which completely gutted the Wren Building. Following this disaster, a new building was planned utilizing the walls of the original Wren Building but with a façade that included two towers. One of those was for the College bell, and other was to be used as an observatory (Lively, 1859). This new building was completed later in 1859, only to be destroyed in 1862 by yet another accidental fire, during yet another military occupation, this time by the Union Army (see Dearstyne, 1951; Savedge, 1969).

3.4 Madison's Astronomical Observations

No records exist that provide a complete picture of Madison's astronomical observations. However, correspondence and other notes demonstrate that he made many different kinds of observations, and over an extended period.

We have evidence that over the years he used three different telescopes: the Dollond refractor, an 18-in telescope by Short, of unknown origin but possibly also purchased in London by Small; and a transit instrument (that was originally housed in the observatory).

Largely because of losses sustained in the 1781, 1859, and 1862 fires, no observational material in Madison's own hand remains, although original notes of observations that he made with John Page have survived. Other than those notes, all of the information that we have regarding Madison's astronomical observations is derived from letters where he discusses his observations with others. Some of these letters were subsequently published in the *Transactions of the American Philosophical Society*.

In addition to those letters that mention specific observations, Madison refers to many non-specified observations in his letters. For example, on 1789 February 10 he tells Jefferson that he hopes to send him some astronomical observations with his next letter in return for some favours that Jefferson once granted him (Madison, 1789a), and in 1804 he informs Samuel Miller of Williamsburg that he intends sending him some copies of observations (Madison, 1804).

It is interesting to note that the surviving records of Madison's observations begin almost immediately after his return from London in 1776, and that his interest in astronomy continued unabated until the time of his death, as evidenced by the following letter from Jefferson dated 1811 December 29 which Madison would no doubt have read just weeks before his death in 1812:

> I had observed the eclipse of September 17th with a view to calculate from it myself, the longitude of Monticello, but other occupations had prevented it before my journey. The elaborate paper of Mr. Lambert shows me it would have been a more difficult undertaking than

> I had foreseen, and that probably I should have foundered in it. I have no telescope equal to the observation of the eclipses of Jupiter's satellites, but as soon as I can fit up a room to fix my instruments in, I propose to amuse myself with further essays of multiplied repetitions and less laborious calculations (Jefferson, 1811).

What follows is a chronological listing of all documented specific astronomical observations made by Bishop James Madison, as well as intended observations which were unsuccessful for a variety of reasons. Throughout we have noted the sources of the documentation, which in many instances are the letters written by Madison to his friends and peers. We have attempted in each case to give some context for Madison's astronomical observations, either through historical references or by attempting to verify the stated observation with a commercial planetarium program such as *SkyMap Pro* or *Starry Night Pro*. We have not, however, attempted to make an accurate conversion of the exact times of each observation, given the differences in timekeeping between the eighteenth century and the present day, but rather we have used these programs to help fill in details of the observation which are lacking in the original documentation.

3.4.1 Observations to Determine the Latitude of Williamsburg in 1776

During his years as a member of the William and Mary faculty, Madison sometimes carried out astronomical observations in collaboration with his friend, John Page. Six years his senior, Page frequently corresponded on many matters, including astronomy. In a letter, to Rev. William Smith written in 1776, Madison relays some observations from Page, as well as some of his own: "... Mr. Page had resolved to send you his Papers upon y^{e} last Transit, which he observed at his seat, but y^{e} hurry of Business at present prevents him from putting y^{e} finishing hand to them." (Madison, 1776). The transit in question was most likely the 1776 November 2 transit of Mercury, which is referred to below.

Madison continues the letter with some personal observations.

> I believe there is no doubt of y^{e} accuracy of y^{e} Observations upon y^{e} Longitude & Latitude of y^{e} places mentioned. I might add y^{e} Longitude of Williamsburg, which I have found by a Mean of several Observations = 5° 6' 22". (ibid.).

Madison apparently was rather proud of his ability to determine the longitude and latitude of a location, and he went on to use these skills for the benefit of his home state during the survey of the Virginia–Pennsylvania border in 1781. Much later, he carefully instructed Jefferson on just how easily latitude could be found using a simple handmade quadrant (see Madison, 1805).

3.4.2 The 1776 November 2 Transit of Mercury

One of Madison's fellow 'philosophers' and observing partners, John Page, kept a memorandum book of some of the observations that he and Madison made. On 1776 November 2 he wrote:

> I observe the transit of ☿ at Wm & Mary College with an 18 Inch reflector magnifying about _____ times. Mr. Madison noted down the Time by the Clock (made by Shelton, with Gridinon Pendulum) as corrected by him
>
> external contact 4:12:29
> internal contact 4:14:29 (Page, 1762-1797).

The 18-in reflector mentioned here is almost certainly the Short reflector owned by the College. It is interesting to note that Page left the magnification blank as though he intended calculating it at a later date.

The above times agree within minutes of those predicted by *SkyMap Pro*, which also indicates that in Williamsburg the Sun set on this day at 17 h 08 m, within minutes of the end of the transit – making this phase of the event virtually impossible to observe. In this context, note that in the above account Page makes no mention of observing the end of the transit.

3.4.3 The 1778 June 24 Total Eclipse

In a letter to Thomas Jefferson dated 1778 July 26, Madison acknowledges receiving notes on observations from Jefferson. He then proceeds to describe his own observations:

> I was very glad to see your Observations, tho they differ considerably from those we made here. The same Misfortune of a cloudy Morning prevented us from seeing y^{e} Beginning – but we had a very good View of y^{e} End which Mr. Page made at 11^{h} 3' 25" – and myself at 11^{h} 3' 27" – tho I think y^{e} Altitude of y^{e} Sun was such as must render y^{e} Observations uncertain to a few Seconds. The End of total Darkness was at 45'.30" – This was pretty nearly determined, for y^{e} Return of Light was almost instantaneous. There was really something awful in y^{e} Appearance w^{ch} all Nature assumed. You c^{d} not determine your most intimate Acquaintance at 20 yds distance. Lighting Buggs were seen as at Night.
> I began on y^{e} 17th to make corresponding Observations & had y^{e} Time very accurate. Rittenhouse got to Phila Time eno' to make an Observation, but he likewise saw only y^{e} End, and informs that it was at 11. 14' 40" [?] M. [?] Time. The Effect of Parallax will doubtless make a considerable difference. (Madison, 1778).

According to *SkyMap Pro*, a total solar eclipse was visible from Williamsburg on 1778 June 24, and no doubt this is the eclipse discussed in the letter to Jefferson. *SkyMap Pro* indicates that this event began at 08 h 38 m 33 s, reached totality at 09 h 48 m 31 s, which lasted for 3 minutes and 43 seconds, and ended at 11 h 09 m 37 s. Madison's notations about the end of total darkness seem unclear, but his measurement of the ending of the eclipse corresponds reasonably with the time provided by *SkyMap Pro*.

3.4.4 Planned Observations of Jovian Satellites in 1778 October

Madison also notes the upcoming immersion of Jupiter's moons in his 1778 July 26 letter to Jefferson:

> If you sh^{d} be at Home in October you may have an Observation on an Imm. Jup. Sat. on y^{e} 5th at 8^{h} 25' 11" and another y^{e} 12th at 10^{h} 20' 56" for this Planet. They are more to be depended upon than other Observations because ye Theory is better known. (ibid.).

Both of these predictions agree within minutes of those calculated by *SkyMap Pro*. It is interesting to see the teacher in Madison as he explains to Jefferson why he is able to predict so many months in advance the precise times of these events.

3.4.5 The Aurora Borealis in 1779

In a letter written to David Rittenhouse in 1779 November, Madison documents a number of meteorological observations that he had made over the course of the preceding year. Among these are changes in barometric pressure recorded during the observation of an aurora borealis. Madison (1779) also notes that these barometric observations

> ... not only shew us the different states of the atmospheres, but, perhaps, may throw farther light upon the true cause of the Aurora Borealis. That fact is, that a fall of the barometer always succeeds that phenomenon. The frequency of its appearance lately, gave me an opportunity of observing this effect at different times.

In his letter Madison explains that this theory was first proposed by Benjamin Franklin and that the more rarefied air evident during a time of low pressure could lead to auroral displays in the same way that similar displays can be produced in a laboratory by a rarefaction of air and electricity.

Late 1778 and early 1779 marked the peak of the sun-spot cycle, which would certainly have contributed to an increase in auroral displays at this time.

3.4.6 The 1780 October 27 Solar Eclipse

In a letter to David Rittenhouse written in 1780 November Madison discusses, among other things, two failed observations of eclipses: "But a cloudy day, had no other circumstance intervened, effectually prevented all observations. I was attentive to that of May also, the last ... eclipse, and am satisfied it was not visible here. The Reflection magnifying at that time about 130." (Madison, 1780b). From this letter it is not clear what sort of eclipses Madison was trying to view. The more recent observation was prevented by cloudy weather, but no mention is made of bad weather in relation to the earlier eclipse. It appears that he attempted to observe this event with the Short reflecting telescope, but was unable to see an eclipse and concluded that it was not visible from Williamsburg.

In 1779-1780 there were three lunar eclipses that would have been visible from Williamsburg, weather permitting: a total eclipse on 1779 May 30, and partial eclipses on 1780 May 18 and November 12. Interestingly, there was also an annular eclipse of the Sun on 1780 May 4, but it was not visible from Williamsburg. However, there was a total eclipse of the Sun on 1780 October 27, and at mid-eclipse ~75% of the Sun would have been obscured as viewed from Williamsburg.

Although no date is given in the letter for Madison's second attempted observation, it is likely that this occurred in November since he specifically said that he delayed the completion of the letter until this planned observation had taken place. Since he describes the weather during the day and since even a partial solar eclipse would have been a major event, it is reasonable to conclude that he was attempting to view the solar eclipse of 1780 October 27.

The earlier observation is more of a puzzle. It would seem that Madison had accurate enough information to be able to ascertain whether any particular eclipse would be potentially viewable from Williamsburg. The 1780 May annular eclipse was visible only from Africa and the extreme south of South America, and while the partial lunar eclipse in this same month was indeed visible from Williamsburg the Moon was only at an elevation of 15°.9 when it entered the penumbra and at 5°.4 when it entered the umbra. Therefore, it is likely that Madison was asserting that none of the totality (or perhaps any of the eclipse) was observable from Williamsburg.

3.4.7 Observations of Jovian Satellites in 1780

In his 1780 November letter to David Rittenhouse, Madison describes several Jovian satellite observations that he had made the previous May:

> Having made during the summer several observations upon Jupiter's Satellites, I send such as appeared the best.

		Time at Paris	Time here	Difference
May 4th	Em.	2.39.45	9.23.30	5.16.15
May 20th		0.50.10	7.42	5.16.10
	2. lat			
May 30th	2. lat.	0	9.24.51	5.26.9

> The last observation, this upon the 2nd satellite, was much the best, both on account of the remarkable time of the night, and accuracy of the timekeepers, and the addition also of another observation with a very good Refractor, who observerd the emersion the instant almost that I noticed it with our Reflector. (Madison, 1780b).

These observations seem rather sophisticated. Two instruments were used, undoubtedly the Dollond refractor and the Short reflector, and once again Madison relied upon his accurate timekeepers.

SkyMap Pro quite closely matches the May 4 observation, but its time for the May 20 event (which so pleased Madison) differs by about an hour. Meanwhile, this software package does not show any Jovian satellite event that can be associated with Madison's May 30 observation, which may simply reflect a problem in our understanding of the notation that he uses in describing these events.

3.4.8 Aurorae Observed in 1781

According to a letter dated 1782 June 19 sent to President Stiles of Yale, Madison observed "... several Auroras ... " in 1781 and made notes on these. In his letter he explains that he is not able to send details of these observations because the fire which gutted his house on the night of 1781 November 22-23 destroyed all his books and papers (Madison, 1782a). Apparently, in addition to books, at this time Madison lost all his observational notebooks and other records.

Aurorae were relatively rare in Virginia, so perhaps the aurorae referred to in this letter were the same ones he observed in 1779.

3.4.9 The Comet Observation of 1784 January

In a letter to Thomas Jefferson dated 1784 January 22, Madison describes a comet which he assumes Jefferson has also seen:

> You have no doubt observed the Comet w^ch^ made it's Appearance here last Friday Even^g^ for y^e^ first Time. The Cloudiness of y^e^ Evening prevented observations till last Night y^e^ Night before. Its Situation is near, I, in y^e^ Pircis Australis. I shall endeavour to trace its Progress will send you y^e^ Results. (Madison, 1784).

This object was C/1783 X1, the so-called 'Great Comet of 1784' (Marsden and Williams, 1999), which was discovered in the southern sky by de la Nux on 1783 December 15, observing from Réunion Island (Kronk, 1999). By 1784 January 16, when it became visible from Williamsburg, this comet was already a conspicuous naked eye object with a short tail (see Kronk, 1999 and Vsekhsvyatskii, 1964 for details), and from this date on it would have generated considerable public interest.

3.4.10 Planned Observations of Jovian Satellites in 1784

In 1783 Madison was appointed to lead a commission from the Commonwealth of Virginia for the purpose of fixing the boundary line between Pennsylvania and Virginia. David Rittenhouse was appointed as his counterpart for the state of Pennsylvania. On 1783 October 16 Madison wrote to the Pennsylvania commissioners about the survey, and proposed that the following observations be carried out in 1784:

> ... that the Astronomical Observations on which we are to depend in this Matter must be those of the Emersions and Immersions of Jupiters Satellites, and that an equal Number of them before and after [Jupiter's] oppositions to the Sun should be taken if possible to compensate the Errors that may arise from the different Apertures of the Telescope we may use. This Opposition will be in the month of August; and as every second of time will give an uncertainty of a Quarter of a Mile, a sufficient Number of them must be taken to bring the Decision as near as possible. Six weeks or two Months will then be necessary to be employed in making the observations both before and after the Opposition. (Madison, 1783).

It is interesting to note that Madison believed he had access to more instruments for this survey than might be available to Rittenhouse: "We would be glad to know what Instruments you can furnish, that we may provide the Remainder here. We can furnish two clocks, two equal altitude Instruments and Telescopes for each of our observers ... " (ibid.).

Madison provides a report on the survey in a letter to Thomas Jefferson dated 1785 April 10:

> We were engaged last Year in determining the 5 degrees of longitude claimed by Pennsa. And I believe few Points on the Globe are better ascertained. Our Instruments were good, the Time piece I carried from this Place exceeded even Mr. Rittenhouse's. Our Observations were continued for more than three months. I had some Thoughts at first of sending you the Observations, as they tend not only to establish the Point in Dispute between the two States, but also the Measurement of a greatere, or longer Line upon the Globe that has ever yet been effected, and thus shew with more Certainty the real Length of a Degree of long. In that Lat. It appears to be less than has been hitherto supposed. The Termination of the 50s falls short of the Ohio about 15 or 16 Miles. (Madison, 1785).

This report reveals three very interesting pieces of information. Firstly, given his earlier note to Rittenhouse about equipment and the reference to his time piece in this note to Jefferson, Madison clearly felt that his equipment was superior to that used by Rittenhouse, thereby reinforcing the notion that at this time The College of William and Mary perhaps owned the best astronomical instruments in America. Secondly, through his survey and calculations Madison determined a more accurate way of determining the length of a degree of longitude at a particular latitude. Indeed, he claims that his calculations were more accurate than "... has ever yet been effected." (ibid.). And finally, Madison's letter explains the rather odd configuration of the state of West Virginia (which was part of Virginia at the time of the survey). Apparently, the southern border of Pennsylvania was originally to extend a certain distance, at least to the Ohio River. However, Madison found that the real termination fell some 15-16 miles short of the Ohio River, and as a result Virginia was left with a small finger of land between 3 and 15 miles wide and about 60 miles long extending north between Pennsylvania and Ohio.

3.4.11 The 1789 November 2 Lunar Eclipse

Madison sent David Rittenhouse information about two different observations made in late 1789 that he wanted read before the American Philosophical Society. He began his notes by mentioning that the observatory in which the transit instrument had formerly been placed had not been rebuilt and as a result he was not "... enabled to attend to the going of the time-keeper." He then went to considerable pains to explain how he computed accurate time for the observations by using "... correspondent double altitudes, taken with a sextant."

His observations of this lunar eclipse are as follows:

	App. Tim.		
	H.	'	"
Penumbra–thought to touch the) at	6	8	46
Eclipse begins,	6	21	0
Tycho begins to immerge	6	38	45
Wholly immerged	6	43	"
	Shadow		
Shadow reaches mare nectaris	7	34	0
Tycho begins to emerge,	7	57	44
Wholly emerged,	8	1	26
End of the Eclipse.	8	30	0

> These observations were made with an achromatic telescope, magnifying about 60. – The immersion and emersion of tycho were particularly noted, as those times may be more accurately ascertained, than either the beginning or end of a lunar eclipse – The weather was remarkably favourable for astronomical observations. (Madison, 1789c).

The software package *Starry Night Pro* is able to track this eclipse as it passes over Tycho, and the times shown in this simulation agree with Madison's to within a few minutes.

3.4.12 The 1789 November 5 Transit of Mercury

In the same communication to Rittenhouse reporting the November 2 lunar eclipse, Madison reports observations of a transit of Mercury:

> The 1st internal contact, was not seen. When I first discovered ☿, he was somewhat advanced upon the sun's limb, and had an oval appearance, the longer axis directed towards the body of the sun. – But at $8^h.3'.10"$ The planet suddenly assumed a round figure, and the first internal contact was according noted.
>
> The 2d, internal contact, 12. 53 42.
>
> The 2d, external contact could not be determined with any tolerable accuracy on account of the remarkable undulatory motion which appeared upon the sun's limb, soon after the 2d internal contact. Mercury disappeared to me, at, $12^h\ 55'\ 2"$. I made use of an achromatic, magnifying about 150.
>
> Mr. Andrews, professor of mathematics, with a reflector made by Short, and with a magnifying power of 90-made the following observations.
>
> The 2d internal contact - - $12^h\ 53"\ 48"$
> 2d external contact - 12 55 19
>
> The same undulatory appearance was not seen in the reflector, and therefore the 2d external contact observed by it, may be more relied upon – The times of our observations were taken from the same clock, but noted in different rooms – The day was remarkably favourable, being clear, and sufficiently calm. (ibid.).

This is yet another case where Madison put two instruments to use simultaneously in order to confirm his observations. It is uncertain where these observations took place, but clearly the instruments were indoors at the time, perhaps in Madison's house or in the Wren Building.

Simulations using *SkyMap Pro* and *Starry Night Pro* produced times that were remarkably close to those reported by Madison.

3.4.13 The 1804 January Eclipse of the Moon

Always the teacher, Madison apparently required (or inspired) his students to observe with him. Towards the end of 1804 January, a student named George Blow wrote to his father from Williamsburg:

> Since my arrival here I have been in tolerable good health, at present I am little indisposed owing to my want of sleep. The night before that last I did not go to bed at all being with Mr. Madison at College viewing through the Telescope an Eclipse of the Moon, which, from the commencement of the Penumbra to the termination of the whole eclipse continued from one until ten o'clock in the morning, and last night I was at a ball which kept me up until twelve. (Blow, 1804).

Although there was an eclipse visible from Williamsburg on 1804 January 26, the times in no way match those noted by this student. In fact the eclipse began in the afternoon at 13 h 48 m local time, and ended at 18 h 54 m. The Moon was only at an elevation of 15°.9 at the end of the eclipse, which occurred as the evening began and not in the morning as Mr Blow indicated.

3.4.14 The 1806 June 16 Solar Eclipse

In a letter written to Thomas Jefferson on 1811 November 19, just months before his death, Madison acknowledges Jefferson's observations "... upon the late solar Eclipse." Madison then arranged for Mr W Lambert in Washington to calculate the Longitude of Monticello based upon Jefferson's data. In his letter to Jefferson, Madison also states that:

> By my Observation upon the Solar Eclipse of 1806, the End of which was accurately noted, & the Time well ascertained, Williamsburg is 5^h 17' 4" from Paris 9' 20" Greenwich which compared with the Long. Of Monticello, gives the strait-lined Distance, I believe, very accurately, or rather nearly. (Madison, 1811).

Madison goes on to observe that, based upon his calculations, the time difference between Monticello and Williamsburg is 1 h 39 m10 s.

The total eclipse of 1806 June 16 was visible in Williamsburg, but only 90-95% of the Sun was obscured. It is not clear that this was the same eclipse for which Jefferson supplied notes to Madison. There were two other partial solar eclipses that were visible during this period, on 1809 April 14 and 1811 September 17, and either of these may have been the eclipse noted by Jefferson, but it is less likely that the 1811 eclipse was the one observed since it would have been difficult to get the notes from Jefferson to Lambert and then on to Jefferson in just two months.

3.5 Astronomy in the College Curriculum after the War of Revolution

Following the war, many thought that the College had seen its best days. Jedediah Morse, Noah Webster, and Ezra Stiles, among others, visited Williamsburg and announced that Virginian civilization had vanished and that the College was filled with lazy students and run in a disorganized manner (Morpurgo, 1976).

There can be no doubt that William and Mary was not as regimented as its northern counterparts. But there also can be no doubt that the demands placed upon the students at William and Mary equalled if not exceeded those placed upon students elsewhere, because at William and Mary students were expected to do so much for themselves by the way of regulating their classes and exams. The examination process, in particular, was very rigorous. Jefferson described it as a way of "... raking out the rubbish." (Morpurgo, 1976: 218).

The Statues of 1792 were introduced to provide a new framework for the College. Attendance rules were revised, and a new core curriculum was established:

> For the degree of Batchelor of Arts, the Student must be acquainted with those branches of the Mathematics, both theoretical and practical, which are usually taught as far as Conic Sections, including, viz. The first six books of Euclid, plain Trigonometry, the taking of Heights and Distances, Surveying, Algebra, the 11th and 12th books of Euclid, Spherics, Conic Sections: must have acquired a knowledge of Natural Philosophy as far as it relates to the general principles of Matter, Mechanics, Electricity, Pneumatics, Hydrostatics, Optics, and the first principles of Astronomy ... (cited in Morpurgo, 1976:219).

Thus William and Mary became possibly the first American institution of higher learning that required a basic knowledge of Astronomy for a Bachelor's degree, and Madison liked to include astronomy and examples drawn from astronomy throughout his lectures on Natural Philosophy.

We are fortunate to have in The College of William and Mary Archives, the complete original lecture notes from seven students who attended Madison's classes between 1796 and 1811 (e.g. see Anonymous, 1800-1801; Groghan, 1808; Murchie, 1809; Peachy, 1809-1811). These notes are interesting in that one can see the lectures growing longer year by year as the body of relevant knowledge increases. Perhaps most illuminating is the 'Head' or first lecture, where the content of the course is summarized. After an introduction to and definition of 'Natural Philosophy', Madison briefly speaks of the great Natural Philosophers down through the ages to the end of the eighteenth century. He begins with a discussion of Copernicus and his examination of the 'Ptolemaic system of Astronomy.' This is followed by a brief overview of the work of Tycho Brahe and his view of the cosmos. He then discusses Kepler, his work with Brahe, and his theory of planetary orbits. He then moves to Galileo, noting that "... his knowledge in Astronomy & natural Philosophy was superior to any man of the age." He continues with the work of Bacon, and on to Newton of whom he said "... of the abilities of Newton as Philosopher, it's unnecessary to say any thing." Following his explanation of some of Newton's work, Madison concludes that "... since the time of Newton, so many eminent Philosophers have appeared that it would be doing injustice to point out any [particular] individuals." (Watson, 1796). At the heart of what Madison taught was fundamental knowledge of the cosmos, which he wanted each of his students to understand and to appreciate.

4 DISCUSSION

The research undertaken for this paper has raised some interesting questions. Even with the list of apparatus purchased by Small, we are left wondering what additional items he purchased with the £178 that has not been unaccounted for. Was the Short telescope obtained at that time, and if not, when and from whom was it acquired? What other apparatus was purchased and was any of it used for the study of astronomy? It is unlikely that further research will reveal the missing pages of Small's list, but it may be possible to find references to other instruments that the College had in its possession during this period. A more thorough examination of the apparatus purchased at this time might throw light on the types of demonstrations that various instruments were used for and precisely what was taught to the students. Back in the 1970's some research was carried out in this area by a member of the William and Mary faculty, but follow-up studies are required.

And what became of the observatory? Was it destroyed in the War of Revolution? Was it rebuilt? What did it look like? How large was it? What instruments were housed there? The Colonial Williamsburg Foundation has done a thorough job excavating on the grounds of the colonial campus. However, most of their efforts have centred on the three main buildings: the President's House, the Brafferton building used for an Indian School, and the Wren Building. All of these buildings exist today. A few of the outbuildings have been reconstructed as well, but most have not been. It is possible that more archaeological studies, particularly with the requirements of an observatory in mind, will yield relevant information. It is also possible that more references to the observatory, its use, and its potential repairs exist in archival sources. The College possesses several collections of letters written by individuals associated in one way or another with the College. Perhaps relevant information exists in those letters, or in letters and other documents now in private collections. Further research could throw important new light on what, in Milham's terms, may very well be the first 'regular permanent observatory' build in America.

It is unfortunate that none of Madison's original observational records and associated notes survived the fires in the President's House and the destruction of the observatory. As we have seen, letters in the William and Mary archives, in the Jefferson papers in the Library of Congress, and in the Owens Papers contain many useful references to the observations that he made, and it is likely that additional material exists in private and public collections, and is simply waiting to be discovered.

5 CONCLUSIONS

The study of Natural Philosophy and astronomy had an important place at The College of William and Mary during the second half of the eighteenth century. Its importance accelerated in the mid-eighteenth century under the tutelage of William Small, and expanded still further after the purchase of an impressive collection of scientific instruments, including telescopes, in 1768. But it was the application and determination of Bishop James Madison, first as Professor of Natural Philosophy and later as President of the College, that established William and Mary as one of the foremost astronomical centres in the country and allowed it to play an important role in the development of astronomy in eighteenth century America.

Madison must also be credited with constructing what may very well be the nation's first 'regular permanent observatory', and certainly the first observatory erected at an educational institution in the USA. He also integrated astronomy into the overall educational curriculum, and created an educational system that focussed on the importance of the pupil-teacher relationship and stressed analytical thinking over mere recitation of facts.

It is clear that by the end of 1778 The College of William and Mary was poised to become a major contributor to the study and teaching of natural sciences and astronomy in America. It had an excellent library; arguably the best collection of scientific apparatus in the nation; a transit telescope and excellent astronomical clock; two other telescopes of impressive provenance; and an observatory. It also had an outstanding astronomical role model in the person of Madison, and one of the best-paid faculty of any College in the country. Then the War of Revolution intervened and almost forced the College to close permanently. It was only Madison's drive, his enthusiasm for science, and his love of teaching that helped to keep it open and allowed astronomy to continue and indeed to flourish.

Following Madison's death, the fortunes of the College ebbed and flowed with the currents of history. The Wren Building suffered from further fires in 1859 and 1862, and the College's investments were once again lost as a result of the Civil War. In 1906, William and Mary became a state institution, and it experienced a resurgence of growth and prosperity following the end of the Second World War.

Today, The College of William and Mary has about 5,600 undergraduate students, and is ranked first among American public universities in terms of commitment to undergraduate teaching. It is also the highest ranked small public university in the country, and while it continues to support a strong physics programme, sadly there are only two courses on offer in astronomy.

6 ACKNOWLEDGEMENTS

This research would not have been possible without the assistance of many people. In particular, I should like to thank the staff at the Library of Virginia, The College of William and Mary Library, and the Colonial Williamsburg Foundation library; archivists at the William and Mary Department of Special Collections, especially Susan Riggs and Margaret Cook; Gary Kronk; and Tom Williams (Rice University).

This study formed part of the research requirements for the Topics in History of Astronomy double unit in the Astronomy Internet Masters (AIM) degree at the University of Western Sydney, and I am grateful to Dr Wayne Orchiston for his guidance and enthusiasm. He made it possible for me to combine two of my personal passions, history and astronomy, and to do so by researching the early history of astronomy at my *alma mater*.

Finally, I wish to thank The College of William and Mary for permission to publish Figure 3.

7 NOTES

1 In this paper the term 'War of Revolution' relates to the eighteenth century War of Independence with Great Britain, and not to the American Civil War of 1861.

8 REFERENCES

Andrews, A.D., 1992. Cyclopaedia of telescope makers. *Irish Astronomical Journal*, **20**:102-183.

Andrews, A.D., 1996. Cyclopaedia of telescope makers. Part 5 (Sae-Sim). *Irish Astronomical Journal*, **23**:57-117.

Anonymous, 1800-1801. Heads of Lectures on Natural Philosophy as delivered in the University of the Wm & Mary there by the Right Revd James Madison. Unpublished notes in The College of William and Mary Archives, Williamsburg.

Bell, Whitfield J., 1964. Astronomical observatories of the American Philosophical Society, 1769-1843. *Proceedings of the American Philosophical Society*, **108**:7-14.

Blair, John, 1781. Letter to George Washington dated October 15. Noted in College of William and Mary Notes, Volume 2. Unpublished notes in the Colonial Williamsburg Library.

Blow, George, 1804. Letter to father from Williamsburg dated January. Richard Blow Papers, Manuscripts and Rare Books Department, Swem Library, The College of William and Mary, Williamsburg.

Brasch, Frederick E., 1916. John Winthrop (1714-1779), American's first astronomer, and the science of his period. *Publications of the Astronomical Society of the Pacific*, **28**:153-170.

Bryden, D.J., 1968. *James Short and His Telescopes*. Royal Scottish Museum, Edinburgh.

College of William and Mary. Faculty minutes, 1729-1784. State Government records collection, The Library of Virginia.

Committee on Revolutionary Claims, Thirty-first Congress, Second Session, Senate Report No. 219. Cited in Swem, 1928.

Dearstyne, Howard, 1951. The Wren Building of the College of William and Mary: Architectural History. Volumes 1 and 2. Unpublished notes in the Colonial Williamsburg Library.

Donnelly, Marian Card, 1973. *A Short History of Observatories*. University of Oregon Press, Eugene.

Faculty compilation, 1874. *The History of the College of William and Mary from Its Foundation 1660 to 1874.* Richmond.

Faculty Minutes, 12 February 1859. Cited in Swem, 1928.

Gill, Harold B., 1995. James Madison: "as worthy a man that lives". *Colonial Williamsburg: The Journal of the Colonial Williamsburg Foundation*, **17**:48-51.

Godson, Susan H., Johnson, Ludwell H., Sherman, Richard B., Tate, Thad W., and Walker, Helen C., 1993. *The College of William and Mary. A History. Volume I, 1693-1888*. The College of William and Mary, Williamsburg.

Goode, George Brown, 1991. The origin of the natural scientific and educational institutions in the United States. Cited in Kohlstedt, Sally Gregory. *The Origins of Natural Sciences in America – The Essays of George Brown Goode*. Smithsonian Institution Press, Washington

Goodwin, Mary R. M., 1967. The College of William and Mary. Unpublished notes in the Colonial Williamsburg Library.

Goodwin, Mary R.M., 1975. The President's House and the Presidents of the College of William and Mary 1732-1975. Unpublished notes in the Colonial Williamsburg Library.

Groghan, John, 1808. Heads of Lectures on Natural Philosophy delivered in the College of William and Mary by the Rt. Rev. Js Madison taken by John Croghan student in the course ending in 1808. Unpublished notes in The College of William and Mary Archives, Williamsburg.

Harwood, Humphrey, 1778. Unpublished Account Book in the archives of the Colonial Williamsburg Foundation.

Hornberger, T., 1945. *Scientific Thought in the American Colleges*. Noted in Historical Notes, College of William and Mary Notes, Volume 2. Unpublished notes in the Colonial Williamsburg Library.

Jefferson, Thomas, 1778. The Works of Thomas Jefferson, Collected and Edited by Paul Leicester Ford. Cited in Goodwin, R.M., 1975. Historical Notes, College of William and Mary, Volume 2:237. Unpublished notes in the Colonial Williamsburg Library.

Jefferson, Thomas, 1781. Letter to Rev. James Madison and the Rev. Robert Andrews. Cited in Historical Notes, College of William and Mary, Volume 2: 239. Unpublished notes in the Colonial Williamsburg Library.

Jefferson, Thomas, 1811. Letter to James Madison dated December 29. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg.

Kale, Wilford, 1985. *Hark Upon the Gale. An Illustrated History of William and Mary*. Donning, Norfolk.

King, H.C., 1979. *The History of the Telescope*. Dover, New York.

Kornwolf, James D., 1989. *"SO GOOD A DESIGN" The Colonial Campus of the College of William and Mary: Its History, Background, and Legacy*. The College of William and Mary, Williamsburg.

Kronk, G.W., 1999. *Cometography. A Catalog of Comets. Volume 1: Ancient-1799*. Cambridge

University Press, Cambridge.
Lively, E. H., 1859. *Weekly Gazette and Eastern Virginia Advertiser*. Noted in Historical Notes, College of William and Mary, Volume 4: 527. Unpublished notes in the Colonial Williamsburg Library.
Madison, James, 1776. Letter to Rev. William Smith. In Smith, 1880:566-567.
Madison, James, 1778. Letter to Thomas Jefferson dated July 26. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg.
Madison, James, 1779. Letter to David Rittenhouse dated November. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg. Subsequently published, through Rittenhouse, under the title 'Meteorological observations', in *Transactions of the American Philosophical Society*, **2**:141-144 (1786).
Madison, James, 1780a. Letter to President Ezra Stiles dated July 12. Noted in The President's House and the Presidents of the College of William and Mary 1732-1975. Unpublished notes in the Colonial Williamsburg Library.
Madison, James, 1780b. Letter to David Rittenhouse dated November. In the James M. Owens Collection of Madison Family Material, Box 4, Folder 4 in the William and Mary Archives.
Madison, James, 1781a. Letter to President James Madison dated January 18. In the MSS Madison Papers, Library of Congress, XIII:31.
Madison, James, 1781b. Letter to Thomas Jefferson dated April 8. Noted in Historical Notes, College of William and Mary, Volume 2: 239. Unpublished notes in the Colonial Williamsburg Library.
Madison, James, 1782a. Letter to President Stiles of Yale dated June 19. Cited in The President's House and the Presidents of the College of William and Mary 1732-1975, p. 111. Unpublished notes in the Colonial Williamsburg Library.
Madison, James, 1782b. Letter to Col. Edmund Randolph dated October 3. In the James M. Owens Collection of Madison Family Material, Box 4, Folder 4, in the William and Mary Archives.
Madison, James, 1783. Letter to Commissioners of Pennsylvania–Virginia Border Commission dated October 16. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg.
Madison, James, 1784. Letter to Thomas Jefferson dated January 22. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg.
Madison, James, 1785. Letter to Thomas Jefferson dated April 10. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg.
Madison, James, 1786. Letter to Thomas Jefferson dated March 27. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg. Madison, James, 1789a. Letter to Thomas Jefferson dated February 10. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg.
Madison, James, 1789b. Letter to Edmund Randolph dated September 18. In the James M. Owens Collection of Madison Family Material, Box 4, Folder 4 in the William and Mary Archives.
Madison, James, 1789c. Letter to David Rittenhouse dated November 5. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg. Subsequently published, through Rittenhouse, in *Transactions of the American Philosophical Society*, **3**:150-154 (1793).
Madison, James, 1804. Letter to Samuel Miller dated July 23. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg.
Madison, James, 1805. Letter to Thomas Jefferson dated September 9. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg.
Madison, James, 1811. Letter to Thomas Jefferson dated November 19. In Bishop James Madison Papers, University Archives, Swem Library, College of William and Mary, Williamsburg.
Marsden, B.G., and Williams, G.V., 1999. *Catalogue of Cometary Orbits 1999*. Minor Planet Center, Cambridge (Mass.).
Milham, Willis I., 1938. *Early American Observatories: Which was the First Astronomical Observatory in America?* Williams College, Williamstown.
Miller, Samuel, 1803. A Brief Retrospect of the Eighteenth Century. Noted in Historical Notes, College of William and Mary, Volume 2: 284. Unpublished notes in the Colonial Williamsburg Library.
Mitchell, S.A., 1942. Astronomy during the early years of the American Philosophical Society. *Proceedings of the American Philosophical Society*, **86**:13-21.
Morpurgo, J.E., 1976. *Their Majesties Royall Colledge: William and Mary in the Seventeenth and Eighteenth Centuries*. The College of William and Mary, Williamsburg.
Murchie, Robert D., 1809. Bishop James Madison Natural Philosophy Lecture notes 1809. A Compendium of Lectures as delivered by James Madison, President of William and Mary. Unpublished notes in the College of William and Mary Archives, Williamsburg.
Neiman, Fraser, 1968. The Henley-Horrocks Inventory. Boutetourt Bibliographical Society and the Earl Gregg Swem Library, Williamsburg.
Orchiston, W., 1998a. From the South Seas to the Sun: the astronomy of Cook's voyages. In M. Lincoln

(ed.). *Science and Exploration in the Pacific. European Voyages to the Southern Oceans in the Eighteenth Century*. Woodbridge, Boydell Press, in association with the National Maritime Museum. Pp. 55-72.

Orchiston, W., 1998b. *Nautical Astronomy in New Zealand. The Voyages of James Cook*. Carter Observatory, Wellington.

Page, John, 1762-1797. John Page Memorandum Book. Manuscripts and Rare Books Department, Swem Library, College of William and Mary, Williamsburg.

Peachy, Thomas Griffin, 1809-1811. Madison Lecture Notes 1809-1811. Unpublished notes in The College of William and Mary Archives, Williamsburg.

Report of the Committee of Schools and Colleges on the subject of the removal of the college. 1824. Cited in Historical Notes, College of William and Mary, Volume 2: 282-283. Unpublished notes in the Colonial Williamsburg Library.

Rouse, Parke, 1983. *A House for a President*. Hennage Creative Printers, Richmond.

Sacks, David, 1984. The History of the William and Mary Campus. Unpublished Thesis, in The College of William and Mary Archives, Williamsburg.

Savedge, M. Catherine, 1969. The Wren Building, College of William and Mary, Architectural Summary, Interim Restoration. Unpublished notes in the Colonial Williamsburg Library.

Smith, Horace W., 1880. *Life and Correspondence of Rev. William Smith D.D. First Provost of the College of Philadelphia. Volume 1*. Ferguson, Philadelphia.

Sprague, William B., 1859. *Annals of the American Pulpit*. Carter, New York.

Swem, E.G., 1928. Some notes on the four forms of the oldest building of William and Mary College. *Quarterly Historical Magazine*, **8**:217-307.

Turner, G.L'E., 1969. James Short, F.R.S., and his contribution to the construction of reflecting telescopes *Royal Society Notes and Records*, **24**:91-108.

Tyler, Lyon G., 1905. Early courses and Professors at William and Mary College. *William and Mary Quarterly Historical Magazine*, **14**(2):71-83.

Vsekhsvyatskii, S.K., 1964. *Physical Charactieristics of Comets*. Israel Program for Scientific Translations, Jerusalem.

Washington, George, 1781. Letter to John Blair dated 17 October 1781 from Yorktown Virginia. Cited in Historical Notes, College of William and Mary, Volume 2: 243. Unpublished notes in the Colonial Williamsburg Library.

Watson, David, 1796. "Heads of Lectures on Natural Philosophy" by Bishop Madison, President of Wm & Mary College – Commenced on Friday 28th October, 1796. Unpublished notes in The College of William and Mary Archives, Williamsburg.

Williams, T.R., 1996. The development of astronomy in the southern United States, 1840-1914. *Journal for the History of Astronomy*, **27**:13-44.

Zech, Kristin A., 2001. "So Well Endowed": Economic Support of The College of William and Mary During the Colonial Period. Unpublished Thesis, The College of William and Mary.

Jeffrey Shy received an A.B. degree in 1971 from The College of William and Mary, and is currently employed in the software industry. His main astronomical interests are in observation and public education, and he is currently enrolled in a Masters degree in Astronomy at the University of Western Sydney, Australia, through their graduate internet programme.

Journal of astronomical history and Heritage 5(1):65-87 2002

Eise Eisinga and his planetarium

Jolanda Mulder de Ridder
AIM, University of Western Sydney, NSW, Australia
Address for correspondence: rojomulder@wanadoo.nl

Abstract
During the eighteenth century, the intellectual climate of the Dutch Republic was very much influenced by the Enlightenment and Newtonian principles, and the province of Friesland had quite a number of amateur astronomers. One of these was Eise Eisinga, who in his youth wrote four manuscripts on mathematics and astronomy and later in life constructed a remarkable mechanical model of the solar system on the ceiling of his living room in the city of Franeker. Professor Van Swinden visited this planetarium while it was still under construction and was so impressed that he published a thorough description of it. As a result, it became well known throughout Europe and attracted many visitors. The State officially purchased Eisinga's house and planetarium in 1825, guaranteeing its survival and long-term preservation. Today Eisinga's legacy is the oldest operational mechanical planetarium in the world, and its accuracy is such that adjustments hardly ever need to be made.

Keywords: *Eise Eisinga, planetarium, orrery, Netherlands*

1 INTRODUCTION

When William Herschel discovered the planet Uranus in 1781, a Dutch wool-comber named Eise Eisinga (1744-1828) had just completed a remarkable 'planetarium' in the Friesland town of Franeker (for localities mentioned in the text see Figure 1). This was not a planetarium in the sense that the term is used today, but a scale model of the solar system that Eisinga constructed between 1774 and 1781 in the living room of his seventeenth century canal-side home (Figure 2). To this day, Eisinga's planetarium is still operational, making it the oldest fully-functioning mechanical planetarium in the world, and as a result of King's book, *Geared to the Stars ...* (1978) and a number of recent more popular articles also written in English (see Allen-Wytzes, 1994; Rudd, 1999; Schilling, 1994) it is becoming widely known in the international astronomical community.

In this paper we provide biographical material on Eise Eisinga, and describe in detail his unique mechanical planetarium. But in order to provide a context for this study we begin by describing the intellectual climate in the Dutch Republic, and the cultivation of astronomy in the Dutch province of Friesland during the eighteenth century. Our account of Eisinga and his planetarium draws heavily on two particular books. One was first published by Van Swinden in 1780 and provides a detailed description of the planetarium (see Van Swinden, 1994), and the second is an account of the life of Eise Eisinga by Eekhoff published in 1851. All later books, brochures and articles written about Eisinga and his planetarium are based on these two books, but our description of the planetarium and its accuracy also draws on an account written by Eisinga as an instruction manual for his sons so that they could keep the planetarium operating successfully (see Noordmans, 1997). In this paper we also focus on the sale of the planetarium to the State, and largely base our account on primary sources, but particularly the letters, recommendations and decrees in the Algemeen Rijksarchief (General State Archive) in The Hague.

2 THE DUTCH SCIENTIFIC CLIMATE IN THE EIGHTEENTH CENTURY

2.1 A Short Historical Overview

The intellectual climate in Europe during the eighteenth century was very much influenced by the Enlightenment (see Grijzenhout, Mijnhardt, and Van Sas, 1987; Israel, 1995, 2001; Kloek, and Mijnhardt, 2001; Zwager, 1980). The increase of religious persecution in France reached its peak in 1685 when the Edict of Nantes was cancelled, and this lead to an enormous exodus of Huguenots who sought refuge in, among other places, the Dutch Republic. These immigrants debated on the role and meaning of the church, the State, and tolerance. But the majority of intellectuals in the Republic were hardly interested in these discussions, for in the Republic these kinds of problems had long been solved (Grijzenhout, Mijnhardt, and Van Sas, 1987). Tolerance, civilian protection by law, and a reasonable penalty were already established in the Republic. But of course scholars in the Republic were interested in the ideas of the early phase of the Enlightenment. The debate on the friction between ratio and religion was a very current one (ibid.).

Figure 1: Dutch localities mentioned in the text.

When the young lawyer Willem Jacob 's-Gravensande returned from England in 1717 and was appointed lecturer of mathematics and astronomy in Leiden, he brought Newton's ideas with him. The text books that 's-Gravensande wrote were based on the Newtonian approach, and spread the new method throughout the Republic. Of great significance was his book, *Physices Elementa Mathematica, Experimentis Confimata. Sive Introductio ad Philosophan Newtonianam (Mathematical Foundations of Physics, Tested by Experiments. With an Introduction to Newtonian Philosophy)*, which was reprinted and translated many times and quickly found its way across mainland Europe (see Zuidervaart, 1999). Together with Jan van Musschenbroek, 's-Gravensande also developed a set of instruments with which to demonstrate Newtonian physics, and by the time that Jan's brother, Petrus van Musschenbroek, returned to Leiden to lecture at Leiden University Newtonianism was well established (ibid.). But the Dutch philosophical climate was eclectic and pragmatic, and so the universities taught Aristotelian views as well as Cartesian and Newtonian ideas (Grijzenhout, Mijnhardt, and Van Sas, 1987). Outside the universities, through publications and lectures by Daniël Gabriël

Fahrenheit, John Theophilus Desaguliers, and others, more and more people became acquainted with the new investigational science. But these were mostly well-to-do people, and only a very small percentage of the overall population heard about the latest scientific developments (ibid.).

However, in the beginning of the eighteenth century books gradually began to appear in Dutch, and in the second half of the century it was quite normal to publish books and brochures in Dutch as well as in Latin. The version in Latin was usually intended for export to foreign countries, where books written in Latin were still widely read (Kloek, and Mijnhardt, 2001). But the use of Dutch as a scientific language was not common to all sciences. Theology, for instance, cherished the old ideal of science as a closed community of scholars, which could be maintained by the use of Latin. But in the natural sciences this concept was completely out of date. The barrier between scientists and laymen rapidly became smaller and smaller, and skilled craftsmen appeared in all kinds of scientific areas (ibid.). Science here was no longer a closed territory, and in the end the boundaries between scientist and layman slowly disappeared.

Figure 2. A view of Eisinga's house from the street (after *Eisinga Planetarium* ..., n.d.: facing 1).

2.2 Astronomy in Friesland

Friesland has been home to many amateur astronomers over the centuries. The oldest report on this topic dates back from the thirteenth century and concerns a certain Valerius Camga, who is said to have been an exceptional astronomer (Louwman, and Terpstra, 1994). Another report dates from 1374 and concerns the monk Hermanus, who taught metaphysics, philosophy, calculation, and mathematics at the Monastery of the Fratres Minores in Bolsward, and was also a gifted astronomer (ibid.).

In the seventeenth and eighteenth centuries the study of astronomy was strongly influenced by the Franeker High School (1585-1811) (ibid.). For more than 250 years, Franeker had an institution for higher education, first a University and later an Athenaeum (see Ekkart, n.d.), and because of this the town was able to play an important role in the Frisian, Dutch, and international scientific and cultural community. With the publication of astronomical books and the education of teachers, surveyors, and other professionals, large transfers of knowledge took place, and the study of astronomy among self-educated men also thrived (ibid.). Friesland had a large number of telescope-makers, and two-thirds of all reflecting telescopes in the Republic in the late eighteenth century were of Frisian manufacture (Zuidervaart, 1999). In addition, many Frisians computed eclipses, and a Franeker University professor, Cornelis Ekama, even stated that Frisians had a special innate talent for mathematics (Kloek, and Mijnhardt, 2001; Zuidervaart, 1999). This led to a 'scientific fiasco' in 1817 when King Willem I gave two self-taught Frisian telescope-makers, Arjen Roelofs and Sieds Johannes Rienks, an order for some large telescopes. Grinding a 550-mm parabolic mirror proved too difficult for them, although they did complete some smaller mirrors. But their finished telescopes, while beautiful works of art, were by no means suited for astronomical observation. The telescope they manufactured for the Leiden Observatory was used just once and was later, in 1850, sold as scrap, while the telescope intended for the Utrecht Observatory was displayed at an exhibition in Haarlem, where it stayed for fifteen years, and when it finally reached Utrecht it was never used. The Utrecht astronomers claimed there were inaccuracies in the mirror that could even be seen with the unaided eye, and shortly afterwards the telescope was abandoned (De Jager, Van Bueren, and Kuperus, 1993; Zuidervaart, 1999).

Even though a lot of amateur astronomers lived in Friesland, the majority of the population had outmoded and peculiar ideas about the orbits of celestial objects, so special celestial events were often cause for concern. Furthermore, religious conscientiousness only intensified people's fear of the horrible consequences that God would bring down in judging the sins of mankind. This would have been the case on 1774 May 8, when Jupiter, Mars, Venus, Mercury, and the Moon were together in Aries at the same time, and an author who called himself 'liefhebber der waarheid' (lover of the truth) wrote a small book with the long and sensational title, *Godgeleerde en Philosophische Bedenkingen over de Conjunctie van de Planeten Jupiter, Mars, Venus, Mercury en de Maan, op den Agsten May Staande te Gebeuren en wel over de Mogelijke en Waarschijnlijke Sterre- en Natuurkundige Gevolgen Deezer Conjunctie, waaruit Opgemaakt kan worden, dat die niet alleen Invloed kan hebben op Onzen Aardbol, maar ook op het Ganze Zonnestelsel, Waartoe Wij Behooren, en eene Voorbereiding of een Beginmaking van de Ontsloping of Vernieling van Hetzelfde, ten Deele of Geheel zou kunnen zijn*. This translates in English as: *Philosophical Considerations about the Conjunction of the Planets Jupiter, Mars, Venus Mercury and the Moon, to Take Place on the Eighth of May 1774, Especially about the Possible and Probable Astronomical and Physical Consequences of this Conjunction from which may be Deduced that they will not only Influence our Earth, but also the Complete Solar System to which We Belong and that they Might be a Preparation or a Commencement of the Demolishing or Destruction of the Same.* The author's real name was Eelco Alta and he was a preacher in Bozum. He stated that this conjunction could have a pernicious influence on not only the Earth but also on the whole solar system, to the point where this could be a preparation for the destruction of the universe (Eekhoff, 1851). He believed that this celestial spectacle most likely foreshadowed the approach of the Day of Judgement. As soon as this booklet was made public all kinds of prophecies were made, among them predictions that the Earth would certainly be destroyed on 1774 May 8. This was, of course, cause for major concern among the population, which was added to by local printers and by travelling bards who sang about the upcoming end of the world (ibid.). Eventually things got so out of hand that the Government had to interfere and confiscate the books and jail the bards. To reassure the population, the Government then had an expert prepare a notice for the provincial newspaper, the *Leeuwarder Courant*, stating that nothing untoward would happen on that day except for the sight before dawn (and only if the weather was clear) of the four planets and the Moon in the same region of the sky. Moreover, this astronomical event would have no effect whatsoever on happenings here on Earth (ibid.).

At this time Eise Eisinga was an amateur astronomer in Franeker, and he was so annoyed and concerned that this kind of superstitious nonsense could thrive among his countrymen that he decided to build a clock-driven planetarium that would clearly demonstrate that planetary conjunctions and close groupings have no supernatural significance but were merely the result of the physical structure of the solar system. This decision was to make him one of Friesland's most famous astronomers.

3 EISE EISINGA: A BRIEF BIOGRAPHY

The following account draws heavily of the book about Eisinga and his planetarium that was published by Eekhoff in 1851. Eise Eisinga (Figure 3) was born on 1744 February 21 in Dronrijp, a small village about 10 km west of Leeuwarden in the province of Friesland. He went to the Dronrijp primary school for a few years and was then educated in his father's

Figure 3. Portrait of Eise Eisinga, painted in 1827 by Willem Bartel van der Kooi (after *Eisinga Planetarium* ..., n.d.:7).

business. Eise's father was a wool-comber by profession, but he had a keen interest in mathematics and astronomy and a knowledge of mechanics, and practised these disciplines for a hobby. Among other things, he built sundials. From an early age Eise also showed an aptitude for mathematics and astronomy, and once a week he went to Franeker where he studied Euclid's first six books and the eleventh and twelfth books with a wool-dyer named Willem Wijtses. Together they also studied spherical trigonometry, the structure of the solar system, the use of astronomical tables, and the computation of eclipses. Apart from this schooling, which was far from flawless, Eise never received any form of higher education.

In the years 1759 and 1760 Eise compiled a 665-page manuscript on computation, even though he was not yet seventeen years of age when he finished it. This contained chapters on the fundamentals of calculation and on geometry, and of special interest was a chapter on decimal fractions, which were not very often used in those days. The manuscript also included many illustrations, including figures of barrels and towers, which were in Eisinga's hand. All this work was done in his spare time, because during the day Eisinga had to work in his father's business.

Then Eisinga met the famous Frisian mathematician, astronomer, and instrument-maker, Wytse Foppes Dongjuma (1707-1778) of Leeuwarden, who was to have an important influence on his further development. Foppes was the son of a humble carpenter, and he, too, had received little serious education, but he applied himself to mathematics and astronomy and became very accomplished at constructing mathematical instruments. In 1761 June there would be a transit of Venus and Foppes had constructed instruments with which he hoped to accurately observe and measure this event. He received permission to make his observations from the abandoned castle Camminghaburg near Leeuwarden, and Eisinga was allowed to be present at the time – which only served to increase his interest for astronomy even more.

Like his father, seventeen year old Eisinga kept devising and manufacturing sundials, and each year he also prepared monthly tables to help him find planets more easily during his observations. He did not know that professional astronomers in Europe did the very same thing in order to popularize astronomy. In 1762 Eisinga wrote two more manuscripts, *Gnomonica of Sonnewijsers alle door Passer en Lijnjaal afgepast Op De Noorder Breete van Dronrijp* (*Gnomonica or Sundials, all Measured out by Compass and Ruler on the North Latitude of Dronrijp*) and *Grondbeginselen der Astronomie of Starre-loopkunde op een Theoretische Wijze Verhandelt* (*Fundamentals of Astronomy Treated in a Theoretical Manner*). At the end of that same year he started working on a fourth manuscript that he finished in 1763. In this new manuscript he computed and drew every solar and lunar eclipse from 1762 to 1800 (*Eisinga Planetarium* ..., n.d.).

In 1768, at the age of 24, Eisinga married Pietje Jacobs, and they moved to Franeker, to the seventeenth century house called 'De Ooijevaar' (The Stork), where he started his own wool-combing business. Franeker was an important university town, but wool-combing then was the main trade and through hard work a lot of money could be made. Eisinga and his wife had their first child in 1773, but the little girl died within a month. The following year a boy, Jelte (1774-1809), was born, and ten years later, on 1784 March 7, another boy was born. His name was Jacobus (1784-1858), and he would later follow in his father's footsteps.

Eisinga led a relatively quiet life and was not involved in any business other than wool-combing, although he was appointed to a number of municipal posts. However, his main love was astronomy, and he devoted every spare moment to his planetarium, yet he made no attempt to contact others in Franeker who shared his astronomical interests. With the passage of time Eise Eisinga's name became well known throughout the Dutch Republic and by the time he died, on 1828 August 27 at the age of 84, he was quite a celebrity. He was buried in Dronrijp, in a family grave.

4 CONSTRUCTION AND USE OF THE PLANETARIUM

The book about Eisinga and his planetarium that was published by Eekhoff in 1851 also gives a lot of information about the construction and use of the planetarium. The following account, therefore, draws heavily on this book.

As the 1774 May 8 quadruple planetary conjunction approached and word on the street was that the world would come to an end panic broke out among Frisians. But Eisinga realized that there was nothing to fear, and he regretted the ignorance and superstition of the local people. He had already rejected Ptolemy's and Brahe's views and accepted the Copernican cosmovision, and was amazed that most people still believed the Earth to be the centre of the solar system with the Sun and the planets revolving around her. He wished to take away the fear among his fellow Frisians and decided to build an instrument that would show the true movement of the planets and the harmlessness of these conjunctions. But the instrument had to be simple, so that everyone could understand it, and he settled on a planetarium, a mechanical scale model of the solar system with the planets revolving around the Sun. At that time most planetariums were table-top models, but instead Eisinga opted for a large-scale moving model of the solar system attached to the ceiling of his living room!

The construction of the planetarium would take about seven years according to Eisinga's calculations, and after convincing his wife of his plan he started work. She insisted that the project should take no more than seven years, and that the drive-clock and all the wheelwork should be hidden from view. Eisinga had never seen a planetarium nor read any of the books about them, but he began making the necessary calculations and drawings (see Figure 4). His father made some shafts and wheels on his lathe and a clockmaker constructed four brass clockworks, based upon Eisinga's plans, but everything else, including the forging of ten thousand iron nails, Eisinga did himself.

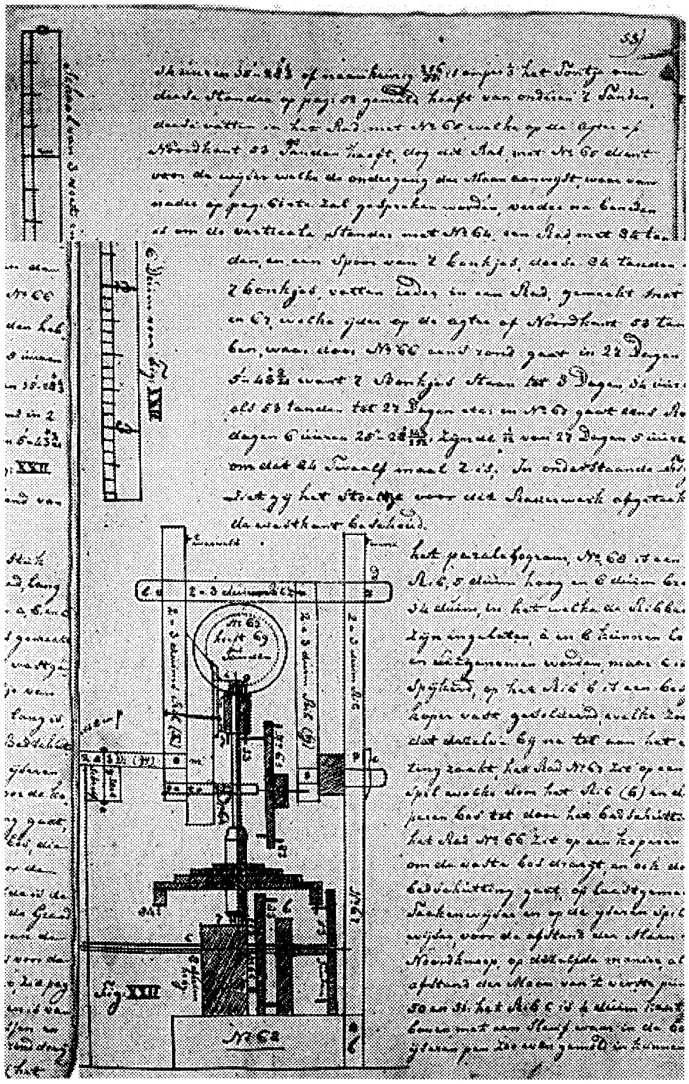


Figure 4. A page from Eisinga's design of the wheelwork, written for his sons (after *Eisinga Planetarium* ..., n.d.:8).

Construction of the planetarium took place entirely in Eisinga's spare time, and despite some unforeseen obstacles it first became operational in 1778. By 1780 February it was finished except for the paintwork, which Eisinga completed by 1781 May. Two months earlier William Herschel had detected a new planet, Uranus, but by the time this discovery was publicized in the Dutch Republic it was too late for this planet to be incorporated into Eisinga's planetarium (nor was his living room large enough to accommodate its orbit).

In 1780 February, before the planetarium was quite finished, Jan Hendrik van Swinden (1746-1823), a Professor of Philosophy at Franeker's University, together with two of his colleagues, visited Eisinga. They had heard of a 'small instrument' he had made and they wanted to see it. Van Swinden (1994) had seen planetariums before and had even made simple sketches of one, but he was touched by the beauty and scale of Eisinga's new instrument – or 'work of art' as he termed it – and examined it for two hours. Once home, he wrote a description of the most important features, read about other planetariums to convince himself of the value of Eisinga's planetarium, and compiled a list of thoughts and questions for further research. On March 13 he again visited Eisinga and brought along a number of professors and other highly-placed persons. After an inspection that lasted several hours, he discovered more qualities of the planetarium that he had missed on his first visit. His appreciation grew and he showed this by sending his brother, a lawyer in The Hague, a short description of the planetarium. He also sent copies to the Academy of Sciences in Brussels, the Prince of Gallitzin, the famous scientists Du Luc in London, Cotte in Montmorenci, and Baussen in Montpellier. Lack of time prevented him from sending copies to his correspondents in Paris, St. Petersburg, Germany, Switzerland, and Italy. As a scholar and fellow citizen, he felt obliged to proclaim the genius of Eise Eisinga. He believed the Frisians had every right to be as proud of Eisinga as the English were of John Harrison whose solution to the longitude problem was the famous marine timepiece H4, or James Ferguson, Britain's leading popularizer of astronomy. For this reason and to inform everybody who would like to visit the planetarium of its true value, but mostly to avoid disdain and misjudgement, he decided to write a detailed description. He did this in 1780, the same year of his visits, and before Eisinga had painted and gilded the planetarium.

Soon after the publication of Van Swinden's description of the planetarium, Eisinga's house was visited almost daily by people whose curiosity and interest had been aroused. Even though Eisinga enjoyed the attention, the planetarium was still not painted and gilded, and after a while he had to deny access to anyone other than a few friends and scholars. But when the planetarium was finally finished, in 1781 May, Eisinga opened his doors to the public and the run was enormous. From all over the country people came to visit, and special group outings to Franeker were organized in order to see this remarkable work of art.

But Eisinga did not consider the completion of the planetarium the end of his labour, and he continued working on improvements. It seemed, for instance, better to move the pointers of the Moon phases from the bottom of the pillars of the frame around the built-in bed up to the ceiling, where there was more space for an accurate representation. The wheels had to be relocated and rearranged, so this took a lot of time and effort.

In 1784 November Eisinga wrote a manuscript titled *Naaukeurege Afteekeningen en Beschrijving van de Uitwendege Vertoning en Inwendege Samenstelling van het Alom Geroemde Beweeglijk Franeker Planeetarium Hemelsplein Zon en Maanwijsers (Accurate Record and Description of the External View and Internal Composition of the Generally Renowned Moving Franeker Planetarium Hemisphaerium Sun and Moon Pointers)*. This consisted of ninety-two folio pages with twenty-seven illustrations, and was dedicated to his two sons, Jelte and Jacobus, so that they and their offspring could maintain the planetarium and keep it operating. Later in life he made an exact copy of the manuscript, probably as a spare if the original should be lost or to give each son a personal copy (see Figure 4).

From 1780 The Netherlands experienced political disputes and civil discord, and these conflicts reached their peak in 1787. Franeker then became the centre where armed discontented people, calling themselves patriots, fought the authority of Stadholder Willem V of Orange. Eisinga had been a member of the City Council and was, against his will, involved in these conflicts, but soon Prussian troops restored the authority of the Stadholder and Franeker was recaptured (*Eisinga Planetarium* ..., n.d.). Thousands of Frisians had to flee to safety, and Eisinga was among them. He had to leave his wife and children and his beloved planetarium behind and he escaped to Steinfurt and later from there to Gronau, both of which were just across the German border (Louwman, and Terpstra, 1994). It was there, a few months later, that he received the news of his wife's death, but he could not return home at this time. His house was then let and the furnishings were sold, the planetarium came to a standstill, and the upbringing of his children was left to relatives.

During his stay in Gronau Eisinga thought about the construction of a new, larger planetarium, an idea given to him years before by Professor Van Swinden. In letters to his family Eisinga even described ideas for the new instrument: it should be housed in a cylindrical building with a roof in the shape of a hemisphere, and the building had to be at least 8.5 m (28 ft) in diameter, or if possible even larger (Noordmans, 1997). Though Eisinga must have known about the discovery of the new planet, Uranus, by Sir William Herschel, he never mentioned it in his plans for this second planetarium. Nor did he fully develop the concept, although he did work out design details of the building and of the wheelwork, but lack of money prevented him from constructing it. If Eisinga had actually built this planetarium, it would have been even more accurate than the planetarium in his living room (ibid.).

In 1790 Eisinga took the risk of returning to the Frisian border and settled in Visvliet (in the province of Groningen), but a year later he was taken prisoner by Frisians who operated on behalf of the *Hof van Friesland* (Frisian Court) outside the borders and jurisdiction. He was transferred to *Het Blokhuis*, a prison in Leeuwarden, and after a year of imprisonment and an extensive tribunal in 1792, he was sentenced to five years exile outside the province of Friesland. He returned to Visvliet where he met Trijntje Sikkema, who became his second wife. Together they had three daughters, Eelke (1793-1795), Hittje (1796-1843) and Minke (1798-1870).

In 1795 a political revolution took place, the Stadholder fled to England, and the French revolutionary army occupied the Dutch Republic which became the Batavian Republic (see Israel, 1995). Eisinga was then able to return to Franeker, but his former home was still let and he had to find another place to live. However about a year later, he was able to return to his old dwelling, but it took almost nine years of repairs before his planetarium was operational again. Soon it was open to the public and attracting large numbers of visitors.

Eisinga spent all his spare time working on the planetarium and had aspirations to constantly improve it. He also worked on his plans for the construction of the second, larger, much improved planetarium again, but as his prestige in the community rose he was offered a number of administrative positions which took up more and more of his time. In 1797 he was appointed a Curator of the Franeker Academy, and in 1802 he once again became a member of the Council of Franeker, a post he held until his death in 1828 (Louwman, and Terpstra, 1994).

5 DESCRIPTION OF THE PLANETARIUM

The following account is based on the description Eisinga prepared for his two sons, as rewritten and edited by Noordmans (1997), plus a synthesis of the following sources: Eekhoff (1851); *Eisinga Planetarium* ... (n.d.); Havinga, Van Wijk and Dáumerie (1928), and Van Swinden (1994).

In the Dutch Republic, the prime use of planetariums as a means of demonstrating the movements of the planets around the Sun in accordance with the prevailing Copernican view began in the second decade of the eighteenth century (Dekker, 1985; King, 1978; Zuidervaart, 1999), but Eisinga was not familiar with these planetariums.

The key characteristic of his planetarium is the large overhead model of the Copernican solar system, constructed between 1774 and 1781. The model has a scale of roughly $1{:}10^{12}$, so one millimetre equals one million kilometres. It consists of a series of seven eccentric circular slots of which the seventh represents a zodiac/calendar scale. The first six slots represent the orbits of the planets Mercury to Saturn. Each planet is represented by a metal ball that is gilded on its sunward hemisphere. These balls are attached to short metal rods and orbit a painted Sun. Only the Earth has a revolving and rotating satellite; all the other moons shown – four for Jupiter and five for Saturn – are suspended by metal wires from their respective planets. Added to each planet's orbit is a painted zodiac scale and a somewhat eccentric circle with markings that refer to the planet's latitude, and the positions of its aphelion, perihelion, and nodes. Eisinga also constructed additional dials and clocks to show the times of sunrise, sunset, Moon rise and Moon set, lunar phases and distances, days of the week, and more. The impressive clockwork that drives this planetarium is mounted between a false wooden ceiling and the ceiling proper and consists of dozens of wooden disks and wheels and some ten thousand iron nails (e.g. see Figure 5). Everything is kept in motion by one weight-driven clock. The planetarium only works in real time, and cannot be sped up or slowed down. Visitors, therefore, will hardly see any signs of motion, but this planetarium has been kept operational for over two hundred and twenty years without interruption. This makes it the oldest, still functioning mechanical planetarium in the world, and during this interval nothing of importance has ever been replaced. The accuracy of this planetarium is such that to this day the current position of the stars and planets, and the current day, date and rising and setting of the Sun and Moon are given. Nor does this planetarium ever fail to recognize a solar or a lunar eclipse.

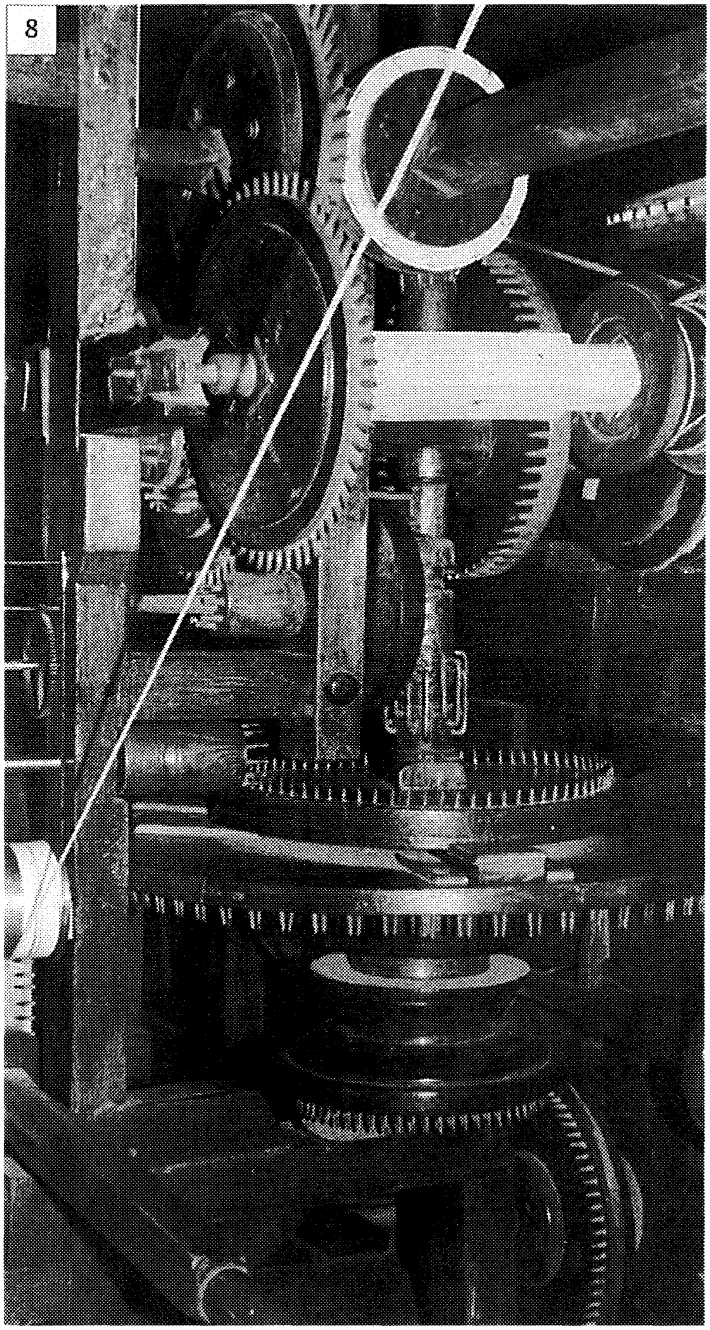


Figure 5. Some of the impressive wheelwork between the two ceilings (after *Eisinga Planetarium* ..., n.d.:6).

5.1 The Sun and the Ecliptic

In the centre of the living room ceiling a stationary Sun is painted (see Figure 6). In the centre of this Sun a gilded ball dangles from a string. Twenty-four sunbeams leave the painted Sun and every second sunbeam reaches to the outer circle of the planetarium, which represents the ecliptic. Because of these twelve sunbeams, twelve equal parts are identified on the ecliptic, and these carry the names of the signs of the zodiac.

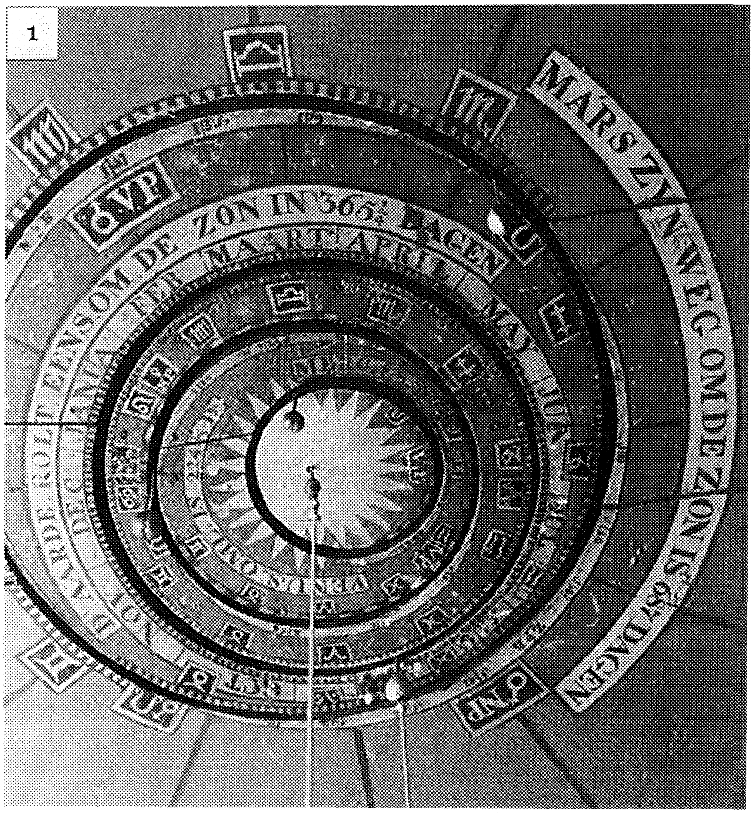


Figure 6. The four planets in orbit around the Sun on the ceiling of Eisinga's living room (after *Eisinga Planetarium* ..., n.d.:1).

5.2 Mercury and Venus

The first slot around the painted Sun is Mercury's orbit (Figure 6). The slot's diameter is 139.7 mm, and the ball representing Mercury moves round this slot in 88 days. It is half gilded and half black, the gilded side standing for day and the black side corresponding to night. Mercury moves in an orbit that does not have the Sun in its centre. The second circle from the Sun is for the orbit of Venus (Figure 6). The diameter of the slot in which this planet moves is 234.95 mm, and the ball representing the planet orbits once every 225 days.

5.3 The Earth and Moon

The third circle is for the Earth (Figure 6), and is divided in months and days. The diameter of the slot is 330.2 mm, and the ball representing the Earth circles once every 365 days. At a distance of 25 mm from the Earth there is a smaller ball symbolizing the Moon, which revolves around the Earth once every $27^{d}\ 7^{h}\ 43^{m}$. Together with the Earth, it orbits the Sun in 365 days. The ball representing the Moon is half gilded and half black, with the gilded side always turned towards the Sun. When observed from the Earth, this construction shows the phases of the Moon.

5.4 Determining the Geocentric Position of a Planet

The ball representing the Earth dangles on a string of the same length as the previously-mentioned rod from which the Sun hangs. At the end of this string there is a small gilded ball.

Both balls serve to keep the rod taut. This way it is possible with the aid of the two strings to determine the geocentric position of a planet. One picks a location in the room where the planet is behind the rod from which the Earth dangles, and then distinguishes what part of the ecliptic is behind the rod from which the Sun hangs. This is exactly the position of the planet as seen from Earth.

5.5 Mars, Jupiter and Saturn

The fourth slot from the Sun is the orbit of the planet Mars (Figure 6). The diameter of this slot is 456.2 mm, and the ball that represents Mars orbits the Sun in 687 days. The fifth slot is the planet Jupiter's orbit. The slot has a diameter of 1562.1 mm, and the ball representing the planet orbits the Sun in 4335 days. To the ball representing Jupiter four smaller balls are attached representing the four Galilean moons, Io, Europa, Ganymede, and Callisto. These four little balls do not move separately. The sixth slot is for the Saturn's orbit, and has a diameter of 2908.3 mm. Attached to the ball which represents Saturn is a flat ring and five smaller balls. The latter represent Saturn's moons, Thethys, Dione, Rhea, Titan, and Iapetus. Saturn needs 10760 days in order to complete an orbit around the Sun.

5.6 Sun and Date Pointer

The seventh slot (the slot outside Saturn's orbit) is the apparent route of the Sun in a year. This slot has a diameter of 3544.3 mm. The hand that goes through this slot takes 365 days for one orbit. On the inside of the slot, the hand points to the sign of the zodiac in which the Sun is in, and to the number of degrees in that sign. Each sign is divided into thirty degrees. On the other side of the slot the hand points to the month and the day of the year. In addition, the declination of the Sun is shown. From the circle representing the date, perpendicular lines are drawn to equal scale divisions on the baseboards of the ceiling. Every scale is divided into twice times 23½°, and gives the northern and southern declination of the Sun. The seventh slot is divided into 365 days. That is the time the hand needs for one orbit. In the case of a leap year, on February 29 the hand needs to be set back one day, so that it will point to the right day on March 1.

5.7 Pointers of the Day and Year

Along the southern side on the ceiling there are five dials, and the middle one (Figure 7) is divided into seven parts, the days of the week. Every day in its turn is divided into twenty-four hours. The hand goes around in one week and points towards the day and the hour according to solar time. A painted sign referring to the original name of the day accompanies each day. There is a rectangular opening in the ceiling between the centre of the dial and its periphery, which reveals the year. On December 31 at about 4pm the year sign starts moving. Slowly the new year appears, and it is completely visible by next morning. Every twenty-two years the board with the years painted on it has to be repainted with twenty-two new years.

5.8 The Pointers of the Moon

To the right of the pointers of the day and year there are two dials on the ceiling, the pointers of the Moon. On the first dial the position of the ascending node of the Moon's orbit is indicated in the signs of the zodiac. On the dial next to it the Moon's phases are shown. Beneath these two dials, on wooden boards above the built-in bed and the cupboards, there are another two dials. One indicates the time the Moon sets and the other the Moon's distance to the ascending node. The pointer on the ceiling that indicates the position of the ascending node in the zodiac therefore has the same rotation period. Because of the monthly revolution of the Moon around the Earth, the Earth will be in a node twice a month. The pointers of the dial in the pillars indicate the distance from the Moon to the ascending node. This distance is expressed in signs of the zodiac by the small pointer and in degrees by the large pointer. When both pointers indicate zero, the Moon is at the ascending node. When the small pointer indicates six and the large one zero, the Moon is exactly six zodiac signs away from the ascending node and is thus located at the descending node. If the Moon is located at one of the nodes at the moment the pointer of the phases of the Moon indicates New Moon, then there will be a solar eclipse visible from somewhere on Earth on that day. However, if the pointer indicates Full Moon, there will be a lunar eclipse.

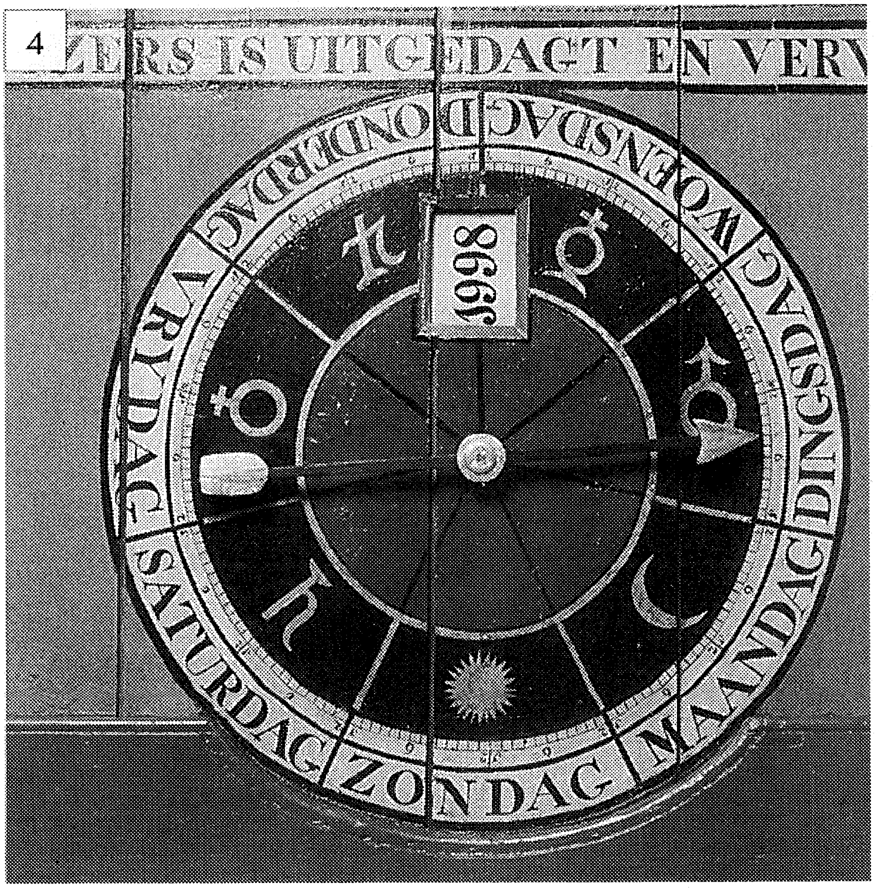


Figure 7. The day and year pointers, on the ceiling (after *Eisinga Planetarium* ..., n.d.:2).

To the left of the pointer of the day, there are also four Moon dials. One of these indicates the apogee of the Moon in the signs of the zodiac. The positions of the aphelion and perihelion of the Moon revolve in eight years and three hundred and eleven days, and this is also the time the pointer on the ceiling takes to rotate. The pointer of the dial on the pillar gives the distance from the Moon to the perihelion, just like the indication of the distance to the ascending node in signs of the zodiac and in degrees. On the ceiling is another pointer indicating the distance covered by the Moon on the ecliptic. It shows the location of the Moon in the zodiac sign and in degrees. Above the cupboard there is another dial that indicates the time of moonrise.

5.9 The Planisphere

Over the built-in bed there is a nearly circular opening of almost 500 mm radius in a panel. The border of the opening represents Franeker's horizon, and is divided into hours. Behind the opening is a planisphere of 700 mm radius which rotates in one day (see Figure 8). The part of the planisphere that is visible shows those stars and star signs that are actually visible at that moment above the horizon in Franeker. Furthermore, the equator, both tropics and the arctic circle are drawn on this planisphere. The ecliptic is represented by means of a slot cut through the planisphere. This slot is eccentric, and cuts the tropic of Cancer in the zodiac sign Cancer and the tropic of Capricorn in the zodiac sign of Capricorn. The planisphere rotates in twenty-four hours. The wheel has a pivot attached it which runs through a slot to a metal disc representing the Sun. So the Sun also rotates in twenty-four hours along with the wheel, and runs three minutes and fifty-six seconds behind on the rotation of the planisphere each day. The planisphere therefore shows the apparent rotation of the stars, the rising and setting of the Sun, and the lengthening and shortening of the days.

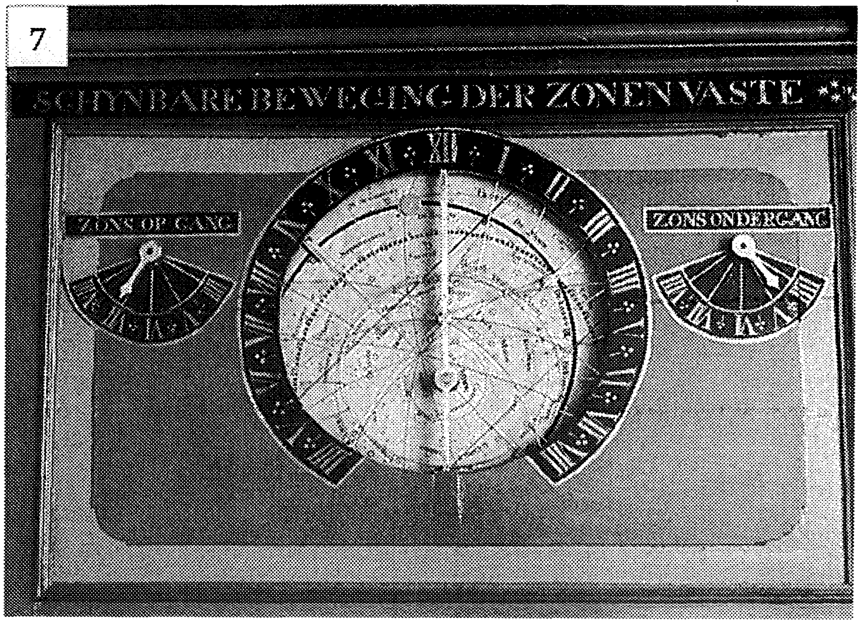


Figure 8. The planisphere, on the central wall panel above the built-in bed (after *Eisinga Planetarium* ..., n.d.:5).

5.10 The Wheelwork

The living room has a false ceiling, which supports the day, year, and various Moon pointers, and the orbits of the planets. These orbits divide the ceiling into seven separate discs, and these hang from the joists of the original ceiling and are connected by iron hooks. By unscrewing the nuts from the bolts it is possible to lower parts of the ceiling. Access to the wheelwork that is between the original and the false ceiling can be obtained by entering the attic and lifting hatches in the original ceiling. The cogwheels were made from oak wooden discs and hoops, with handmade iron pins that serve as cogs (see Figure 5). Only the central clock above the built-in bed has metal wheels. Eisinga had this clock manufactured by a clockmaker, and its sole function is to regulate the pace of the wheelwork.

The wheelwork is driven by eight weights that are located in the cupboards on either side of the built-in bed. Every main shaft has its own weight, in order to spread the driving force evenly over the whole wheelwork. The clockwork is also driven by a weight. Its pendulum swings eighty times per minute.

6 ACCURACY OF THE PLANETARIUM

In order for the planetarium to operate properly, with the passage of time various adjustments have to be made. These were documented by Eise Eisinga for his sons (see Noordmans, 1997), and are summarized below.

6.1 The Inner Planets Mercury and Venus

In Eisinga's planetarium the inner planet Mercury orbits the Sun in 88 days. The true orbital period however is $87^d\ 23^h\ 14^m\ 26^s$, so the planet moves a little too slowly. In 88 days this amounts to $45^m\ 34^s$. During this period, 44 cogs are moved, so only after 15 years is a correction of one cog necessary. Venus orbits the Sun in 225 days in the planetarium, and this, too, is a little slow as its true orbital period is $224^d\ 16^h\ 41^m\ 32^s$. In these 225 days Venus falls $7^h\ 18^m\ 28^s$ behind. The wheel for Venus has 60 cogs and one cog moves in $3^d\ 18^h$, so after $7^y\ 210^d\ 14^h$ a correction of one cog is needed.

6.2 Earth and Moon

At first the cogwheel belonging to the Earth moved around in 365 days. The Earth's average orbital period however is $365^d\ 5^h\ 48^m\ 45^s$. Because of this, the wheel went $5^h\ 48^m\ 45^s$ too fast every year and therefore caused a lead of almost one day in four years and needed a correction of one cog after twenty years. For this reason, in 1782 Eisinga decided to keep the Earth in motion by a separate shaft which would be connected to another shaft that went around in 365 days and was corrected by a day every leap year. This construction made the average orbital period of the Earth in the planetarium about the same as the planet's true orbital period. But the correction made the Moon revolve around the Earth in $29^d\ 12^h\ 21^m\ 49^s.09$, which is a little too fast (it should be $29^d\ 12^h\ 44^m\ 3^s$). However, it takes more than 19 years before a correction of one cog on the wheel has to be made.

6.3 The Outer Planets

In Eisinga's planetarium Mars orbits the Sun in $686^d\ 22^h\ 18^m$ and therefore moves $6^h\ 18^m$ too fast. The Martian wheel has 103 cogs. It takes $6^d\ 16^h$ to move one cog, thus it will take 47¾ years before a correction of one cog must be made. Jupiter has a wheel with 289 cogs and revolves round the Sun in 4335^d. Since its true orbital period is $4330^d.373611$, it moves $4^d\ 15^h\ 2^m$ too slowly. One cog of Jupiter's wheel moves in fifteen days and it therefore will take more than 38 years before the wheel needs a correction of one cog. Saturn orbits the Sun in 10760 days and its wheel has 538 cogs. Saturn's true orbital period is $10749^d.6347222$, so it will take more than 56 years before a correction of one cog is needed.

6.4 The Wheel Belonging to the Pointer of the Date

The wheel belonging to the pointer of the date, just outside Saturn's orbit, has 584 cogs plus one cog for the motion of the year pointer. This is the largest wheel of the planetarium. Once every four years, on February 29, the wheel has to be moved back one day, so that year it will be February 28 twice. But the next day the orbital period of the pointer of the day will exactly correspond to reality.

6.5 The Hemisphaerium

The hands for the Sun and the night revolve in twenty-four hours. The Sun moves around the ecliptic in 365 days, but its true speed should be $365^d.25$. The difference amounts to twenty-four hours in four years, which equals about one degree on the ecliptic. One cog represents $4^\circ.9$, so it will take about twenty years before a correction by one cog is required.

6.6 Sunrise and Sunset

The pointers for sunrise and sunset are set to motion by a wheel so accurate that the difference is only $1^m\ 51^s$ per year. The shaft has 31 cogs and only moves by one cog each twelve days. This is why it takes 9300 years before a correction of one cog is necessary.

6.7 Pointer for the Distance from the Aphelion to the Spring Equinox

This pointer revolves in $8^y\ 312^d$ but the true orbital period is $8^y\ 311^d\ 8^h\ 34^m\ 58^s$, so the pointer is $15^h\ 25^m\ 2^s$ too slow. The wheel has 101 cogs and moves by one cog every thirty-two days. Each cog represents $3^\circ\ 33'\ 52''$. Therefore it takes 441 years before the difference amounts to one cog.

6.8 Pointer for the Distance from the Ascending Node to the Spring Equinox

This pointer revolves in 6800 days but its true orbital period should be $6798^d\ 4^h\ 52^m\ 3^s$, so the pointer is $1^d\ 19^h\ 7^m\ 57^s$ too slow in one revolution. The wheel has 68 cogs and moves one cog every hundred days. Each cog represents $5^\circ\ 17'\ 39''$. It therefore takes 1035 years before the difference amounts to one cog.

6.9 The Eastern-aphelion Shaft

This shaft revolves in $27^d\ 13^h\ 18^m\ 36^s.97$, but the actual time the Moon needs to get to the same orbital position is on average $27^d\ 13^h\ 18^m\ 34^s$. The difference is almost three seconds, and it takes about 1678 years before a correction of one cog is required.

6.10 The Moon's Distance to the Aphelion

This pointer revolves in the same time as the above-mentioned eastern-aphelion shaft, in $27^d\ 13^h\ 18^m\ 36^s.97$. The sign pointer and the degree pointer have the same irregular speed as the eastern-aphelion shaft. The pointer for the degrees revolves twelve times while the pointer for the signs revolves once. The pointer has exactly the same small inaccuracy as the eastern-aphelion shaft.

6.11 The Moon on the Ecliptic
This pointer revolves in $27^d\ 7^h\ 43^m\ 4^s.06$, which is slightly faster than the sidereal month. However, it takes 841 years before a correction of one cog is necessary.

6.12 The Western-aphelion Shaft and the Node Wheels
The western- aphelion shaft revolves in the same time as the eastern-aphelion shaft, and so it takes about 1678 years before a correction of one cog is required.

6.13 The Node Wheels
The node wheels drive the pointers for 'Moon Rise' and 'Moon Set'. These wheels rotate in $27^d\ 5^h\ 5^m\ 43^s.1$, instead of $27^d\ 5^h\ 5^m\ 39^s$. Only after 642 years does this four second delay cause a difference of one cog.

6.14 The Pointer for the Distance from the Moon to the Ascending Node
This pointer revolves in exactly the time the Moon needs to regain the same position in relation to nodes, so no correction is required.

6.15 The Pointer for the Phases of the Moon
The pointer for the phases of the Moon revolves in an average $29^d\ 12^h\ 43^m\ 13^s.37$. This should be $29^d\ 12^h\ 44^m\ 3^s$, so the pointer is 50^s too fast. One cog moves in $1^d\ 5^h\ 31^m\ 50^s$ and the wheel has 24 cogs, so it takes almost 172 years before a correction of one cog must be made.

6.16 The Pointer for 'Moon Rise'
The pointer for 'Moon Rise' revolves in $14^d\ 18^h\ 22^m\ 0^s.51$. This is exactly the time the Moon requires in order to reach the same phase again. The time for the rising of the Moon indicated by the pointer is nearly the same as in reality, so no correction needs to be made.

6.17 The Pointer for 'Moon Set'
The pointer for the wheel 'Moon Set' revolves in $14^d\ 18^h\ 22^m\ 0^s.51$. This, too, barely differs from the real value, and again a correction is not required.

7 THE PURCHASE OF THE PLANETARIUM BY THE STATE
With the passing of the years, many visitors to Eisinga's house must have worried about what would eventually happen to the planetarium after his death, for there was the very real danger that the house would be sold and that the new owner, having little interest in astronomy, would remove this annoying obstacle.

This possibility is mentioned in the diary of Jacob van Lennep who visited Franeker and the planetarium on 1823 June 9. The son of a professor, Van Lennep was from Amsterdam, and during the summer he and a university friend from Leiden, Dirk van Hogendorp (also a member of a prominent and well-to-do family), travelled on foot through The Netherlands instead of taking the usual *Grand Tour* of Europe. From the diary account, it is clear that both students felt superior to Eisinga, who after all was a simple working man of modest descent, without a university education (Mak, and Mathijsen, 2000). Van Lennep even suggests that Eisinga did not seem to know all that much about his own creation, but it is more likely that the Frisian was so annoyed by the arrogance and behaviour of the two young men that he simply kept quiet (ibid.). Here is an English translation of Van Lennep's description of the visit:

> A few canals further on we entered the modest home of wool comber Eise Eisinga. He came to us wearing an apron and he lead us to a small room, in which we saw the entire solar system above our heads. All planets visualized here, really move as in nature and complete their orbits in the same time, just like their moons. Four other plates show the rise and set of the Sun and the Moon. On others one can see the apparent movement of the Sun, the phases of the

> Moon, the distance from Earth to the Sun, from the Moon to the North and South Poles, the days of the month, the week, the hour, the minutes and seconds, also the year, the north and south declination etc.. This all is put into motion by a clock. The wheels and pins are all made from wood and take no more place than there is in the attic, which is a foot and a half high, above the small room. The maker showed all this to me as if it were some sort of fairground attraction, seemingly lacking all knowledge about it. (see Mak, and Mathijsen, 2000:68-69).

Van Lennep (ibid.) continues his account with the observation that both he and Van Hogendorp did not exactly know what to appreciate more, the planetarium itself, which was constructed with such precision, or the incomprehensible simplicity of its maker! He ends with the important statement that it was really sad that this remarkable construction is not transportable and that it and the house are doomed to come to an end some day.

Concern about the survival of this unique planetarium was cause enough for some of Eisinga's contemporaries to be moved to action, and three individuals, in particular, were largely responsible for the fact the house and its work of art survived and can still be visited today. They were Idsert Aebinga van Humalda, Daniel Jacob van Ewijck, and King Willem I. Van Humalda (1754-1834) was born into nobility, and was a fellow villager and school friend of Eisinga. He completed his academic education in Franeker and throughout his life was very interested in the arts and the sciences, including astronomy. In 1813, the year the French were driven out of the country and the House of Orange was restored, King Willem I appointed him Governor of Friesland. Van Ewijck (1786-1858) was also interested in astronomy, and after being appointed to a post in the Ministry of the Interior became Administrator for Education, Arts and Sciences, a post that was to prove crucial to the survival of the planetarium.

In 1824, a second edition of Van Swinden description of Eisinga's planetarium was published. Actually, it was Eisinga who suggested this new volume, for the original was no longer available, and a new printing also allowed for some minor additions to the text. For example, three illustrations of the planetarium by Klaas Johannes Sannes (a friend and fellow citizen of Eisinga) were added so that readers of the book who could not come to Friesland to see the planetarium with their own eyes would still have a good idea of what it looked like. These illustrations showed the planetarium as it appeared in 1820. Eisinga provided some text to support the three illustrations, and he also indicated the changes and improvements that had been made since the publication of Van Swinden's original edition in 1780. The 1824 edition included a portrait of an ageing Eisinga, also drawn by Sannes, and Reverend Brouwer from Leeuwarden provided a caption in poetic form. Brouwer also wrote a Foreword for this edition, and in this he alludes to the possible loss of the planetarium for Friesland and the Netherlands, and hopes that the interest shown by King Willem I will guarantee its survival. Brouwer was undoubtedly referring to the fact that the King visited the planetarium in 1818 June.

Van Humalda made sure that a copy of Van Swinden's new edition was send to the King as soon as it was published, and in a covering letter (Van Humalda, 1824) he mentioned the King's visit in 1818 and the fact that he had earlier appointed Eisinga a 'Broeder van de Orde des Nederlandse Leeuw' (Brother of the Order of the Dutch Lion). For the benefit of this highly meritorious old man, the Governor dared to include a request which, if granted, would bring Eisinga enormous satisfaction and delight. Van Humalda stated that although he was not exactly poor, the wool-comber was in a difficult situation financially, and several times had mentioned his fear that the house and planetarium would be sold after his death. Van Humalda noted that the planetarium could not be transferred to another building (as the King himself had observed during his visit), and as a result it would probably end up being destroyed. Van Humalda pointed out that the future of the planetarium would be assured if the King approved the purchase of the house by the State. Furthermore, Van Humalda suggested that Eisinga's sole surviving son, who had been educated by his father for quite some time now, could live in the house and be responsible for the continued operation of the planetarium. In this way, the famous work of art would not only be preserved, but would also be immediately available for the education of young students. In concluding his letter, the Van Humalda urged the King to consider this proposition seriously

The King wanted to obtain extensive advice on this matter, so Van Humalda's letter was handed to Van Ewijck, and he in turn corresponded on the matter with the Governor. In his first letter, dated 1825 January, Van Ewijck asked how much money would be required for the purchase of the house and planetarium. Van Humalda (1825a) then had to estimate the financial value of the planetarium, and he found this to be a considerable challenge. He took into consideration the fact that Eisinga had spent seven years building the planetarium and that it had cost him a considerable sum of money. There had also been the expense of keeping the whole planetarium, including the clockwork, functioning for many years. On this basis, the Governor concluded that Eisinga should be paid an amount of ten thousand Dutch guilders (about US$4,800), but that this would only take into account the manual labour. If one were to note the ingenuity of the invention (despite the fact that Eisinga had no scientific education), and if one were also to note his domestic situation and his not very ample financial circumstances, then Van Humalda believed that the King should be advised to not only pay the calculated ten thousand Dutch guilders, but to raise this amount considerably – and the final amount should be considered a homage to the special merits of the this remarkable eighty-years old man. Van Humalda then repeated the suggestion he had earlier put directly to the King, namely that the State should let Eisinga's son Jacobus, continue to live in the house. Jacobus, who was 41 years old, also had no formal scientific education, but was already very familiar with the planetarium and had the competence to maintain it and keep it functioning. In return for doing this, he should be allowed to occupy the house free of rent, and he should also receive a considerable annual fee. The Governor ended with the assertion that through Van Swinden's book, Van Ewijck would realize that it is no overstatement to say that Eisinga's planetarium is truly one of a kind, and must be considered a national 'jewel'.

Shortly after receiving this letter, Van Ewijck presented Van Humalda with some more questions. Among other things he wanted to know whether it would be possible to pay the purchase price in instalments over four to five years. He also wanted to know what sort of annual fee Jacobus Eisinga should be paid. Van Humalda (1825b) rejected the idea of payment by instalments, and recommended a single payment. Meanwhile, he thought that Jacobus Eisinga should be given the use of the house rent free, that he should receive an annual fee of two hundred Dutch guilders, and that the maintenance of the planetarium should be carried out under the observation of a professor from the Athenaeum.

Van Ewijck (1825a) now had all the information he required, and in 1825 May he assembled his recommendations. He agreed with all of Governor Van Humalda's suggestions, with the exception of the payment of an extra amount on top of the purchase price of ten thousand Dutch guilders. But there was one problem: he could not identify funds from which the ten thousand Dutch guilders should be paid, as all funds that qualified for this in the budget were already being used. Despite this, the Minister of the Interior approved Van Ewijck's recommendations, and they were presented to the King. As far as they were concerned, it would be up to the King to designate the funds to be assigned for this expenditure, although the annual payment to Jacob Eisinga could come from the Ministry of Interior's budget.

After receiving Van Ewijck's recommendations, the King advised the Minister that because funding was not available the purchase of the planetarium could not go ahead. His suggestion was to see whether the State could still obtain the planetarium, but by making annual payments to Eisinga, which would then be transferred Jacobus after his death. The King asked Van Ewijck to prepare a new proposal along these lines.

Van Ewijck then put this scenario to Van Humalda, and the Governor found it very difficult to react to this new proposal, especially in that another total amount for the purchase of the planetarium had to determined before the annual payments could be computed. Van Humalda (1825c) subsequently suggested a minimum annual fee of one thousand Dutch guilders, with the proviso that after Jacobus Eisinga's death the State would become the new owner of the house and planetarium. Upon reflecting on this and taking account of Jacobus's age, Van Ewijck concluded that this was not a viable alternative as it would most likely cost the State three times as much money as the figure of ten thousand Dutch guilders originally mentioned by Van Humalda. Certainly, spending all this extra money would not have been the intention of the King!

Van Ewijck took all of these factors into consideration when preparing a new proposal for the King in 1825 December. In this document (Van Ewijck, 1825b), he suggested that it would be better to make the payment for the purchase of the house and planetarium in instalments, over a period of ten years. Meanwhile, the State would also agree to pay Eisinga the sun of one thousand Dutch guilders each year, and this arrangement should start on 1826 January 1 on which day the planetarium would become the property of the State. For the maintenance of the planetarium, Eisinga would also receive an annual fee of two hundred Dutch guilders, and upon his death this arrangement would be transferred to his son, Jacobus. Furthermore, father and son could occupy the house free of rent, so long as they fulfilled their obligation to maintain the planetarium. Finally, the Minister of the Interior should include this expenditure in his Departmental budget. The Minister approved this new proposal, and it was passed to the King for his consideration. This time the King agreed to the terms, and one year after Van Humalda had put forward his original proposal Willem I signed the document approving the purchase of the planetarium by the State (Koning Willem I, 1825). This actually occurred on December 20, and not on December 28 as some authors have erroneously written (e.g. see Eekhoff, 1851; *Eisinga Planetarium* ..., n.d.).

The Minister of the Interior was now responsible for the execution of the Royal Decree, and informed van Humalda of this excellent progress (see Van Humalda, 1826a). In order to officially formalize the arrangement a notary act for the purchase had to be drawn up which Eise Eisinga would then be required to sign, as would Governor Van Humalda acting on behalf of the Dutch State. Notary Kutsch in Leeuwarden received the assignment, but it was only on 1826 September 2 that the Minister of the Interior approved the final manuscript of the notary act and signing it in Friesland was possible. Finally, on October 4, in the *Heerenlogement* in Franeker, the purchase was made official and Eisinga transferred his possessions to the State. Witnesses to this transaction were Professor ll.m. Jan Willem Crane (a friend of Eisinga) and the Frisian nobleman and lawyer Carel Salomon van de Poll. In November the governor sent a copy of the signed notary act to Van Ewijck (Van Humalda, 1826b), and on the last day of 1826 he forwarded a copy to the King. Willem I approved the notary act on 1827 January 4 (Koning Willem I, 1827a), and although Eisinga had yet to receive a single Dutch guilder he must have been somewhat relieved.

Now that the King's signature was on the notary act, payments of the first thousand Dutch guilders for the purchase of the planetarium and the first two hundred Dutch guilders for its maintenance could commence, albeit retrospectively for the year 1826. Van Ewijck reported this welcome news to the newly-appointed Governor of Friesland, Van Zuylen van Nijevelt, who in turn advised Eise Eisinga (see Van Humalda, 1827). For his part, 83 year old Eisinga was pleased with this progress as he was still receiving tax forms as the official owner of the house. Later in the year Eisinga received his first payment, and at about the same time he was specially honoured when his old friend, Van Humalda, arranged for Willem Bartel van der Kooi to paint his portrait (see Figure 3). It was also the former Governor who, in the presence of Eise Eisinga, delivered the speech on 1827 November 13 when the painting was presented to the municipality of Franeker and was hung in the Council Chamber (Eekhoff, 1851).

In 1827 January Van Ewijck (1827a) found time to inform the Curators of the Franeker Athenaeum of the King's decision of 1825 December 20 and the allocation of two hundred Dutch guilders a year to Eisinga for the maintenance of his planetarium under the supervision of a professor from the Athenaeum. The Professor in question was J W Ermerins, and he was assigned the task of reporting each year to the Curators on the condition of the planetarium. The Curators would then incorporate this account into their annual report on the state of the Athenaeum, which would subsequently be presented to the Minister.

In March, Van Ewijck (1827b) wrote to the Curators of the Athenaeum about maintenance of the planetarium and possible repairs to Eisinga's house, noting that these should be paid for from the funds that the State provided to the Athenaeum. The following month, the Athenaeum's caretaker inspected Eisinga's house and estimated the budget for necessary maintenance and repairs. He noticed that the house was not in a good condition, and that it had not been renovated for quite some time. He reported that the living room floor had almost completely decayed and urgently needed to be replaced, and that it also would do no harm to paint the planetarium while Eisinga was still alive (Wijbrandus, 1827). In 1827 June the King agreed to add the sum of four hundred and fifty Dutch guilders annually to the Athenaeum's budget, specifically for the maintenance of the planetarium (see Koning Willem I, 1827b). As a result of these decisions, the planetarium was indeed painted in 1828, and in this same year Van

Humalda joined the board of Curators of the Franeker Athenaeum. This was a fitting reward for a man who had worked so long and so hard to ensure the survival and preservation of Eisinga's planetarium.

After Eise Eisinga died in 1828 Jacobus continued to maintain the planetarium, and the flow of visitors was undiminished. One of those who visited in 1841 was King Willem II (Eekhoff, 1851). Jacobus also lived to see a new edition of Van Swinden's book about the planetarium, which was published in 1851 (ibid.). This third edition began with an extensive history of the planetarium written by W Eekhoff, keeper of the archives of the city of Leeuwarden. He pointed out that although the Athenaeum had closed in 1843, many people still visited Franeker in order to see Eise Eisinga's planetarium with their own eyes. Given that the second edition was long out of print, this description alone should have been sufficient grounds to justify a reprinting. To round it off, this new edition also included a biography of Eisinga's life contributed by his son.

In 1859 February Willem III and the State handed the planetarium over to the municipality of Franeker, and Eisinga's descendants continued to live in the house until 1922, looking after the planetarium and serving as guides for the visitors (King, 1978). The municipality is now responsible for the care and maintenance of this facility, and to this day many people still find their way to Franeker so that they, too, can witness Eise Eisinga's remarkable creation.

8 DISCUSSION

When we think of a planetarium today, we think of a dome-shaped building with a special projector to simulate the night sky. In Eisinga's day the term 'planetarium', or orrery, was used for a mechanical model of the solar system. The English language makes a distinction between a planetarium, an instrument that represents the orbital motions of the planets but ignores the rotation of the Earth, and an orrery, in which the Earth has diurnal motion. In fact, there are further distinctions. When the orrery has the lunar portion absent it is called a tellurian and when present it is called a lunarium. Eisinga's construction is a planetarium in the true original sense of the word.

It was probably Desaguliers who boosted the success of the planetarium in the Dutch Republic by using his orrery as a demonstration model for lessons in astronomy. He had it specially constructed for his lectures just before he left for the Dutch Republic in 1731. Many people attended these lectures, and they were considered highly successful. But planetariums were not new to The Netherlands at this time for the first ones had been built soon after publication of Copernicus's *De Revolutionibus*. However, often they were not an accurate reflection of this new view of the solar system, being no more than simplistic arrangements of the Sun and the planets. This changed when Kepler disclosed the true elliptical orbits of the planets (Zuidervaart, 1999).

Although the first mechanical devices built in The Netherlands to demonstrate the motions of the planets were created in the seventeenth century, few have survived through to the present day. In fact only two are known, and both are on display at the *Museum Boerhaave* in Leiden. One is a planetarium designed by Christiaan Huygens and built by Johannes van Ceulen in 1682 (Dekker, 1985). The other is the *Leidsche Sphaera* (Sphere of Leiden), constructed by Steven Tracy, a clockmaker from Rotterdam (ibid.). This Copernican orrery has a pendulum clock, which indicates that it was not made before 1665 because that is the year in which Huygens was granted the patent on this invention. Furthermore, since the newly-discovered Jovian moons were not included on the *Sphaera*, it must have been constructed before 1672. This makes it the oldest Copernican orrery in The Netherlands.

The eighteenth century marked the heyday of the planetarium in The Netherlands, and many of the models that were built have survived through to the present day in both Dutch and foreign museums. One of the most famous planetary machines of the eighteenth century was built by Pieter Eijsenbroek of Haarlem (King, 1978; Zuidervaart, 1999). A spinner by profession, he probably was more interested in physics and astronomy, and he constructed his planetarium in 1738. It had the form of a grand orrery with a hemisphere and was supplied with an armillary hemisphere. This planetarium was improved by Jan Peres in 1793, and is now on display in the Adler Planetarium in Chicago (see Stephenson *et al.*, 2000:133). Eijsenbroek also fabricated a brass tellurian for educational purposes. Other machines were built by Jan van den

Dam of Amsterdam. Originally a cobbler and later a mathematician, this workman designed a planetarium that was similar to the one made by Tracy, only smaller, and it is still on display in *Het Scheepvaart Museum* in Amsterdam (King, 1978). Johannes Regter of Delft built a double cone planetarium that is now on display at the *Museum Boerhaave* in Leiden (King, 1978; Zuidervaart, 1999). In 1782-1788, a clockmaker named Joseph van den Eeckhout constructed a clock-driven planetarium with help from I F Robert. This planetarium was designed by Johan Adriaen van de Perre who also supervized the work, and after its completion kept the planetarium for his own personal use. After his death it was donated to the *Zeeuws Museum* in Middelburg, where it still forms part of the collection (Zuidervaart, 1999). Hartog von Laun was a member of a family of scientific instrument-makers in Amsterdam, and he constructed a number of demonstration planetariums that were originally designed by D Stoopendaal (King, 1978; Zuidervaart, 1999). Van Swinden, who documented Eisinga's planetarium, was also interested in von Laun's work, and in 1803 he wrote an illustrated description of a tellurian/lunarium/planetarium which served to increase public interest in these planetary devices (see King, 1978).

Most of the above planetariums were table instruments, but Eise Eisinga built one that could only just fit into his living room. Yet as we have seen, he planned to construct an even larger one, in a building specially designed for it, but this dream was never realised – and in The Netherlands it would take until the twentieth century before such a special building was constructed (and by then the word 'planetarium' had acquired a new meaning). Instead Eisinga turned to small instruments and in 1818 he designed a manual planetarium which was constructed by W Jans Jansen, a farmer from Dongjum. This small planetarium, known affectionately as 'The Appendix', is on display in Eisinga's house in Franeker (ibid.).

Unfortunately, little is known of other planetary machines that were built in the nineteenth century, but from those that have survived we may conclude that the momentum established in the previous century continued. Two nineteenth century devices that achieved fame regrettably were destroyed in a large fire at Enschede in 1862. One of them was a planetarium constructed by Lambertus Nieuwenhuis. Eisinga knew Nieuwenhuis well, and during the years of his exile stayed with him in Enschede for a while. Inspired by Eisinga's work, Nieuwenhuis also built a large planetarium, but it was completely destroyed in the great fire (Zuidervaart, 1999). The other device that was lost at this time was a tellurian/lunarium that was built by Coenraad ter Kuile in 1824 (see King, 1978; Zuidervaart, 1999).

Among other planetary devices constructed in the nineteenth century was the *Sneeker Planetarium*, which derived its name from the city of Sneek (in Friesland) where it remained in obscurity for over fifty years (Louwman, and Terpstra, 1994). A bailiff named Cornelis Jacobs van der Meulen completed this device in 1842, but it is not a planetarium in the strict sense of the word since it displays no other planets than the Earth. It is a type of elaborate astronomical clock carrying the names Tellurium, Lunarium, and Planisphaerium, and when constructed generated a lot of interest, but after Van der Meulen's death was quickly forgotten. However it has now been restored, and is on display in Eisinga's house in Franeker (*Eisinga Planetarium* ..., n.d.).

Petrus Verhaar built an electrically-operated planetarium, and before it was put on display in 1921 in The Hague it underwent some alterations by the Kipp firm from Delft (King, 1978). Soon though, the word 'planetarium' would acquire a completely new meaning. It saw its origin in Germany, and the world's first projection planetarium was invented by Walter Bauersfeld of the Carl Zeiss Optical Company in 1923. That same year it was demonstrated at the *Deutsches Museum* in Munich, and it was permanently installed there in 1925 (see Werner, 1957). The first projection planetarium in The Netherlands was the Zeiss Planetarium in The Hague (see Raimond, 1948), which was constructed in 1934 and was operational through until 1976 when it was damaged in a fire. Fortunately the Zeiss projector could be restored, and it is now on display at the *Omniversum* theatre in The Hague. During the second half of the twentieth century, more of these projection planetariums appeared in The Netherlands, and millions of people have enjoyed a planetarium show since these instruments first arrived in this country.

9 CONCLUSION

Eise Eisinga was an extraordinary man. A wool-comber by profession, between 1774 and 1781 he succeeded in constructing a unique scale model of the solar system in the living room of his home in the Dutch city of Franeker. Given that he had little formal education and hardly any knowledge of planetariums, the way in which he constructed this mechanical planetarium demands our respect.

Eisinga's planetarium has been kept in continuous operation for over two hundred and twenty years, making it the oldest functioning mechanical planetarium in the world, and during this period nothing of importance has been replaced. The precision of this planetarium is such that to this day the current day and date, the positions of stars and planets, and the rising and setting times of the Sun and Moon are accurately given. In addition, this planetarium never misses a solar or a lunar eclipse.

Although Eisinga constructed his planetarium in order to educate his superstitious and ignorant countrymen about the orbits of celestial objects, his legacy has been visited by people from all around the world. Planetariums may have changed dramatically in design since Eisinga's day, but their educational goal has not, and nor has the delight that people derive from observing the heavens.

10 ACKNOWLEDGEMENTS

This study formed part of the research requirements for the Topics in History of Astronomy double unit in the Astronomy Internet Masters (AIM) degree at the University of Western Sydney, and I am grateful to Dr Wayne Orchiston for his guidance and enthusiasm, and for helping me to revise this paper for publication.

I also wish to thank the staff at the Eisinga Planetarium in Franeker for their assistance, and for permission to publish Figures 2-8.

11 BIBLIOGRAPHY

The following abbreviations are used:

AS = Archiefnummer 2.02.01, Algemene Staatssecretarie en Kabinet des Konings, 1813-1840, Algemeen Rijksarchief, Den Haag (ARA)

BZ = Archiefnummer 2.04.01, Binnenlandse Zaken, 1813-1870, Algemeen Rijksarchief, Den Haag (ARA)

Allen-Wytzes, M., 1994. A wool-comber's guide to the planets. *New Scientist*, **141**(1913):30-34.

De Jager, C., Van Bueren, H.G., and Kuperus, M., 1993. *Bolwerk van de Sterren*. Uitgeverij Bekking, Amersfoort.

Dekker, E., 1985. *De Leidsche Sphaera*. Museum Boerhaave, Leiden.

Eekhoff, W., 1851. *Het Leven van Eise Eisinga en Beknopte Geschiedenis van het Planetarium*. S.E.van Nooten, Schoonhoven.

Eisinga Planetarium Franeker. Telenga's drukkerij b.v., Franeker (n.d.).

Eisinga, E., 1760. Untitled work on computation. Manuscript, Eisinga Museum, Franeker.

Eisinga, E., 1762a. *Gnomonica of Sonnewijsers alle door passer en lijnjaal afgepast Op De Noorder breete van Dronrijp*. Manuscript, Eisinga Museum, Franeker.

Eisinga, E., 1762b. *Grondbeginselen der Astronomie of Starre-loopkunde op een Theoretische wijze verhandelt*. Manuscript, Eisinga Museum, Franeker.

Eisinga, E., 1763. *Son en Maan Eclipsen van 1762 tot 1800* ... Manuscript, Eisinga Museum, Franeker.

Eisinga, E., 1784. *Naaukeurege Afteekeningen en Beschrijving van de Uitwendege Vertoning en Inwendege Samenstelling van het alom geroemde Beweeglijk Franeker Planeetarium Hemelsplein Zon en Maanwijsers*. Manuscript, Eisinga Planetarium, Franeker.

Ekkart, R.E.O., n.d. *Frieslands Hogeschool en het Rijks Athenaeum te Franeker*. T. Wever b.v., Franeker.

Grijzenhout, F., Mijnhardt, W.W. and Van Sas, N.C.F. (eds.), 1987. *Voor Vaderland en Vrijheid*. De Bataafsche Leeuw, Amsterdam.

Havinga, E., Van Wijk, W.E. and Dáumerie, J.F.M.G., 1928. *Planetariumboek Eise Eisinga*. N.V. Van Lochum Slaterus' Uitgevers-Maatschappij, Arnhem.

Israel, J. I., 1995. *The Dutch Republic*. Clarendon Press, Oxford.

Israel, J.L., 2001. *Radical Enlightenment*. Oxford University Press, Oxford.

King, H.C., 1978. *Geared to the Stars. The Evolution of Planetariums, Orreries and Astronomical Clocks*. University of Toronto Press, Toronto.

Kloek, J. and Mijnhardt, W., 2001. *1800 Blauwdrukken voor een Samenleving*. Sdu Uitgevers, Den Haag.

Koning Willem I, 1825. Koninklijk Besluit, signed December 20. In AS: 2382.

Koning Willem I, 1827a. Koninklijk Besluit, signed January 4. In AS: 2642.

Koning Willem I, 1827b. Koninklijk Besluit, signed June 8. Copy in BZ: 4340.

Louwman, P. and Terpstra, H., 1994. *De wereld rond Eise Eisinga*. Museum 't Coopmanshûs, Franeker.

Mak, G., and Mathijsen, M., 2000. *Lopen met Van Lennep*. Waanders Uitgevers, Zwolle.

Noordmans, H. (ed.), 1997. *Volledige beschrijving van het Planetarium te Franeker en van de plannen voor de bouw van een tweede "Hemisphaerium en Planetarium" door Eise Eisinga.* Eisinga Planetarium, Franeker.
Raimond, J.J., 1948. *Planetaria*. N.V. Uitgevers MIJ. Diligentia, Amsterdam.
Rudd, E., 1999. Eise Eisinga and his amazing planetarium. *Journal of the Antique Telescope Society*, **16**:4-7.
Schilling, G., 1994. Eise Eisinga's novel planetarium. *Sky & Telescope*, **87**(2):28-30.
Stephenson, B., Bolt, M. and Friedman, A.F., 2000. *The Universe Unveiled. Instruments and Images through History*. Adler Planetarium & Astronomy Museum, Chicago, and Cambridge University Press, Cambridge.
Van Ewijck, D.J., 1825a. Undated Report (but written in May). In AS: 2382.
Van Ewijck, D.J., 1825b. Report dated December 11. In AS: 2382.
Van Ewijck, D.J., 1827a. Letter to Curators, dated January 20. In BZ: 4317.
Van Ewijck, D.J., 1827b. Letter to Curators, dated March 22. In BZ: 4326.
Van Humalda, I.A., 1824. Letter to Koning Willem I, dated December 10. In AS: 2382.
Van Humalda, I.A., 1825a. Letter to D.J. van Ewijck, dated January 27. In BZ: 4237.
Van Humalda, I.A., 1825b. Letter to D.J. van Ewijck, dated April 28. In BZ: 4237.
Van Humalda, I.A., 1825c. Letter to D.J. van Ewijck, dated June 16. In BZ: 4263.
Van Humalda, I.A., 1826a. Letter to D.J. van Ewijck, dated March 24. In BZ: 4279.
Van Humalda, I.A., 1826b. Letter to the Minister van Binnenlandse Zaken, dated November 8. In BZ: 4313.
Van Humalda, I.A., 1827, Letter to D.J. van Ewijck, dated March 10. In BZ: 4326.
Van Swinden, J.H., 1994. *Beschrijving van het Eisinga-planetarium te Franeker*. Uitgeverij van Wijnen, Franeker (first published in 1780).
Werner, H., 1957. *From Aratus Globe to the Zeiss Planetarium*. Verlag Gustav Fischer, Stuttgart.
Wijbrandus, L., 1827. Letter to Curators, dated April 12. In BZ: 4338.
Zuidervaart, H.J., 1999. *Van 'Konstgenoten' en Hemelse Fenomenen*. Erasmus Publishing, Rotterdam.
Zwager, H.H., 1980. *Nederland en de Verlichting*. Unieboek b.v., Bussum.

Jolander Mulder de Ridder received a B.A. degree in History and English in 1991 from Hogeschool Gelderland, Nijmegen. Her main astronomical interests are in planetary sciences, and she is currently enrolled in a Masters degree in Astronomy at the University of Western Sydney, Australia, through their graduate internet programme.

Journal of Astronomical History and Heritage 5(1):89-98 2002

From Pythagoreans to Kepler: the dispute between the geocentric and the heliocentric systems

Theodossiou, E., Danezis, E., Manimanis, V.N. and Kalyva, E.-M.
Department of Astrophysics-Astronomy and Mechanics, School of Physics, University of Athens, Panepistimioupoli Zographou 157 84, Greece
E-mail: etheodos@cc.uoa.gr

Abstract
Some ancient Greek philosophers and thinkers questioned the geocentric system and proposed instead a heliocentric system. The main proponents of this view – which was seen as heretical at the time – are believed to have been the Pythagoreans Philolaos, Heraclides, Hicetas, and Ecphantos, but mainly Aristarchos of Samos, who placed the Sun in the position of the 'central fire' of the Pythagoreans.

The geocentric system, reworked by Claudius Ptolemaeus (Ptolemy), was the dominant one for centuries, and it was only during the sixteenth century that the Polish monk-astronomer, Copernicus, revisited the ancient Greek heliocentric views and became the new champion of the theory that we all accept today.

Key words: *Pythagoreans, Aristarchos the Samian, geocentric system, heliocentric system*

1 THE PYTHAGOREAN SCHOOL

The Pythagorean School considered the *number* as the essence of all beings; it was something that was abstract, unperceived by the senses, and only of the mind. Therefore, the nature of all beings was not material, nor accessible to the senses. Only through abstract thought, according to the Pythagoreans, could the essence be conceived. Thus, the philosophers of this School reduced infinity to a material element, which was beyond counting and definition. That is, they introduced the notion of 'matter' as an element that denied any definition, and was the source of ontological and ethical imperfection.

For the Pythagoreans, the world was created after the initial 'One' was formed. This entity, created in the very beginning, attracted the infinity and assigned to it the end. The Pythagoreans considered an initial single element as the beginning of Creation, which continuously expanded and included infinity. This corresponds, in a certain sense, to the cosmological hypothesis of the universe being a static sphere, continuously expanding, after starting from an initial point. The Pythagorean School stated that the universe evolved from an infinitesimal nucleus, which was expanding spherically upon the infinity. As we know from Aristotle *The Metaphysics* (Book XIV, iii. 12-15, 1091a 15), the Pythagoreans

> ... clearly state that when the One had been constituded – whether out of planets or seed or out of something that they cannot explain – immediately the nearest part of the Infinite began to be drawn in and limited by the Limit. (Aristotle, 1939).

2 THE HYPOTHESES OF PHILOLAOS OF CROTON

In the middle of fifth Century BC, the Pythagorean hypotheses about the very beginning were made more widely known by Philolaos of Croton (in South Italy), who was saved from the revolt against the Pythagoreans along with Archippos, Lysis, and others. Philolaos settled in Thebes, where he taught Pythagorean philosophy and wrote the books *Bacchae* and *On Nature (ABC)*. The following passages are found in the first book: "The world is one, and it was created beginning from the middle, i.e. from the central point which is equidistant from both the upper and the lower." (Fragmente 17. [B. 90] Stob. Ecl. I 15, 7 [p. 148, 4W.]) (Plutarch Chaeronensis Scripta Moralia), and "The initial one, consisting the beginning of the creation of the universe, is called Hestia." (Fragmente [B. 91] Stob. Ecl. I 21, 7 [p. 189, 17W.] (Philolaos of Croton, 1996).

At the beginning of second century AD the doxographer (this is, a writer who records the theories of older philosophers), Aetius (1879), wrote:

> Philolaos held the view that in the middle of the world approximately at the centre lies the fire which he calls the hearth of the universe, the Jupiter's abode, the mother of Gods, the Altar and Unity and Measure of Nature. There is also another fire in the upper part of the world which surrounds it. First comes by nature the centre around which ten divine bodies revolve the heavens, the sphere of fixed stars, the five planets, then the Sun under which the Moon, the Earth and the Counter-Earth (Antichthon) come in succession; at the very end comes the fire which is the focus around the centre. (Aetius II 7, 7).

And drawing his information from Theophrastus, Aetius (ibid.) writes:

> Philolaos the Pythagorean believed that the centre of the world was occupied by the fire (because this is the focus of the universe), then came the Counter-Earth (Antichthon) and thirdly the inhabited Earth which lies opposite the Counter-Earth and revolved around the centre along with the Counter-Earth; thus the inhabitants of the Counter-Earth are not visible to those who live on Earth ... [Aet. III 11, 3 (D. 377 aus Theophrast.)].

As mentioned by Diogenes Laertius, in the book *On Nature (A B C)* Philolaos writes that "Nature in the ordered Universe was composed of unlimited and limited elements, and so was the whole Universe and all that is therein." (Diog. VIII 85, chapter 7. [A1 I 398, 20]). (Diogenes Laertius, 1925:400).

Pythagoras laid the foundations of mathematical philosophy and mathematical physics by correlating the order and the harmony of sounds with the order and the harmony of the universe. We must not forget, of course, that this great thinker believed that the Earth was spherical, just as we do today. Aristotle informs us in his work *On the Heavens* (II, Chap. xiii, 293a, 293b) that the Pythagoreans also supported a pyrocentric theory of the World, according to which the Earth was revolving around a central fire, called 'Dios Phylake' (the Watch-tower of Zeus) (Aristotle, 1933). This theory, which must be attributed to Philolaos, did not place the Sun at the position of that central fire; this was only done in the third Century BC by Aristarchos the Samian, the astronomer and natural philosopher who must also be classified as a Pythagorean.

Therefore, the Pythagoreans as a whole were the ones who questioned for the first time the geocentric theory of the universe, and in so doing they opened the way for the (essentially Pythagorean) heliocentric theory, which was made widely known many centuries later by Copernicus.

Cicero reports the following in his *Academica Priora* (II, xxxix, 123):

> Hicetas Syracusius, ut ait Theophrastus (Phys. Opin. Fr. 18, D. 492), caelum lunam stellas, supera denique omnia stare censet neque praeter terram rem ullam in mundo moveri: quae cum circum axem se summa celeritate convertat et torquerat, eadem effici omnia quae si stante terra caelum moveretur (Vgl. Aet. III 13, 2 [s. Zeile 23]. Diog. VIII 85: 44 A1 [I 398, 12]) atque hoc etiam Platonem in Timaeo dicere quidam arbitrantur, sed paulo obscurius. (Cicero, 1933).

This translates as:

> The Syracusan Hicetas, as Theophrastus asserts, holds the view that the heaven, the Sun, the Moon, the stars, and in short all the things on high are stationery, and that nothing in the world is in motion except the Earth, which by revolving and twisting round its axis with extreme velocity produces all the same result as would be produced if the Earth were stationery and the heavens in motion; and this is also in some people's opinion the doctrine stated by Plato in Timaeaus (40B) but a little more obscurely.

3 ANAXIMANDER, ECPHANTOS, AND HERACLIDES OF PONTUS

According to Theon of Smyrna (1878) who lived in the time of Emperor Hadrian, in addition to the Pythagoreans, Anaximander considered the Earth to be a moving body, and the Sun to be a circle twenty-eight times the size of the Earth.

Meanwhile, Aetius (1879) informs us that

> Heraclides of Pontos and Ecphantos the Pythagorean think that the Earth moves not being displaced from its position in space, but rotationally, as the wheel rotates around its axis, from the west to the east around its centre. [Aet. III, 13, 3 (D. 378)].

According to Simplicius, Heraclides of Pontus, "... by supposing that the earth is in the centre and rotates literally ['moves in a circle'], while the heaven is at rest ... thought by this supposition to save the phenomena." (Simpl., on Arist. De Caelo, II, 13, 293 b 30; p 519, 9-11, Heib) (Heath, 1965, I:317).

So Heraclides, Ecphantos and other Pythagoreans accepted the notion that the Earth moved only rotationally, as a wheel, fixed to an axis, from the west to the east. But they believed that the stars and the planets Mercury and Venus were moving around the Sun. Sir William Cecil Dampier (1946:48) has written about this hypothesis:

> It was known that the Earth was a sphere, and some idea of its true size began to be formed. This growth in knowledge was not favourable to the ideas of the counter-earth or central fire imagined by Philolaus, and those parts of Pythagorean astronomy were thenceforward discredited. But the knowledge gained of the variations with the latitude in the length of day and night led Ecphantus, one of the latest of the Pythagoreans, to the simpler conception of the revolution of the Earth on its own axis at the centre of space. This was also taught about 350 by Heraclides of Pontos, who held that, while the Sun and major planets revolve round the Earth, Venus and Mercury revolve round the Sun as it moves.

Heraclides believed that the sphere of fixed stars was at rest, and he proposed a model where the Earth was at the centre of planetary motion but rotated on its axis daily. As far as the composition of the material of the universe is concerned, Heraclides conceded that it was made of small molecules of matter not connected with each other. It seems that he had modified the theory of Democritus, and he thought that the first elements that existed in the world were not atoms, but the molecules which these atoms constituted. Heath (1965, I:317) says that: "But there is no doubt of the originality of the other capital discovery made by Heraclides, namely that Venus and Mercury revolve, like satellites, round the Sun as a centre."

Heraclides (390-339 BC) was a student of Plato, but also studied with Aristotle and with Speusippus, who was Plato's successor as head of the Academy. Heraclides believed planets to be divine entities revolving around the Earth and that the Earth was rotating on its axis, a rather interesting idea due to the fact that the eigenorbit simplifies the celestial movements that must be defined. For example, the daily orbit of the Earth explains the daily movement of the celestial sphere, whereas in Eudoxus's model of homocentric spheres this movement was described from the outer sphere of the system. Heraclides accepted the fact that the Sun revolved around the Earth in one year, and assumed that Venus was at the same time in circular motion around the Sun. This orbit had a radius smaller than the distance between the Earth and the Sun, and had a period equal to the duration of the synodic period of Venus.

Dreyer (1953), who reconstructed the semi-heliocentric model of Heraclides, agrees with the above scenario, a view against which Neugebauer expressed some not very persuasive doubts. According to a translation by Neugebauer (1972:601), in a commentary by Chalcidius (fifth century AD) on Plato's famous Timaeus: "Heraclides Ponticus, when describing the circle (circulum) of Venus as well as that of the sun, and giving the two circles the same centre (unum punctum) and the same mean motion (unam medietatem), showed that Venus is sometimes ahead (superior), sometimes behind (inferior) the sun." A number of scholars have pointed out the significance of this passage: in saying that Venus was sometimes above and sometimes below the Sun, Heraclides must have believed that this planet was in orbit around the Sun. On the contrary, Neugebauer (ibid.) believes that the above passage simply means that Venus is sometimes ahead of the Sun, and sometimes behind it. This was a new interpretation of Heraclides's hypothesis.

In writing about Heraclides's hypothesis, Angus Armitage (1956:40) points out:

> The Greeks actually hit on the idea that the Sun might be the fixed centre about which the Earth and the planets moved in circles. This interesting development began in the fourth century B.C. with one Heraclides trying to account for the peculiar behavior of Venus and Mercury. These planets are never seen far from the Sun and they appear sometimes on one side of him and sometimes on the other. Heraclides suggested that perhaps they each described a circle about the Sun, while he revolved about the Earth.

4 ARISTARCHOS THE SAMIAN

Circa 280 BC Aristarchos the Samian (310-230 BC) assumed that the Sun was at rest and that the Earth revolved around the Sun in a circular orbit. Aristarchos's hypothesis is recorded by Archimedes in his work *Psammites* (Arenarius or The Sand-reckoner):

> Aristarchus uero Samius hypothesium quarundam descriptiones edidit, in quibus ex iis, quae supponuntur, adraret, mundum multiplicem esse, quam supra diximus. Supponit enim, stellas fixas solemque immobiles manere, terram uero circum solem in medio cursu positum secundum circuli ambitum circummolui. (Arenarius, I. 8-13) (Archimedes).

An English translation is:

> Aristarchos the Samian has published in outline certain hypotheses from which it follows that the universe is greater than formerly believed. He assumed that the fixed stars and the Sun are at rest, while the Earth revolves in an orbit the centre of which is occupied by the Sun. On the other hand, the sphere of fixed stars, having the same centre as the Sun, is so large that the circular orbit of the Earth around the Sun has the same ratio to the distance of the fixed stars, as that existing between the centre of the sphere and its surface.

This hypothesis is also verified by Plutarch, who states in his book *De Placitis Philosophorum*: "Aristarchos Solem fixis stellis adjungit, terram [al. lunam] autem moveri ait circum Solis orbem, et suis inclinationibus umbram disco inferre." (Liber Secundus, XXIV. De Solis defectu, 6), which translates as: "Aristarchos held the view that the Sun and the fixed stars are at rest while Earth is revolving around the solar circle; also that during the Earth's obliquely circular motion the Sun's disc is shadowed (causing a solar eclipse)." (Stamatis, 1973:31-34).

These references by the ancient writers show that Aristarchos is the father and founder of the heliocentric theory, and this is also confirmed by Claudius Ptolemaeus (Ptolemy) in his second century AD *Great Mathematical Syntaxis*. This important astronomer writes that Aristarchos suggested the heliocentric system, as also did Hicetas and Ecphantos. Furthermore, Aristarchos combined this with the rotation of the Earth on its own axis. He supported a model where the Earth had a double motion: it rotated on its axis daily and it revolved around the Sun annually.

Unfortunately, Aristarchus could not prove his hypothesis with the astronomical instruments of his time,. For many centuries humans had been happy to believe that the Earth was the centre of the universe, and views like those put forward by Aristarchos were, to say the least, disrespectful to the heavenly divine order. But more than this, they shocked the foundations of the geocentrically- and egocentrically-founded solar system.

Plutarch mentions that as a result of his radical views Aristarchos was accused of atheism, and it may have been for this reason the great philosopher of Samos did not develop his hypothesis mathematically. Nor did he create a system of planetary orbits in order to support it, as he did in the case of the geocentric system. Thus, one of his treatises, with the title 'Peri ton megethon kai apostematon Heliou kai Selenes' ('On the sizes and distances of the Sun and Moon'), is based on the geocentric system (see Heath, 1932).

However, it is an indisputable fact that Aristarchos proposed the heliocentric theory, and he was the first astronomer, who around 280 BC, dared to speak openly about the Earth's movement in a heliocentric system. Many later astronomers rightly give him this credit. In the original text of Copernicus's *De Revolutionibus Orbitum Celestium* (Lib. i, cap. x) was the sentence: "Similar reasons probably lead Philolaus to assume the Earth's rotation and movement, an opinion that among others, Aristarchos from Samos accepted.", but for some unknown reason this was deleted and was never published (although one can find it in the manuscript preserved at the University Library in Warsaw). Since Copernicus's day, many research papers and books have been touched on this topic (e.g. see Armitage, 1956, Dingle, 1953, Dreyer, 1953, Fraser, 1948, Gibbs, 1979, Gingerich, 1985, Heath, 1981, Neugebauer 1972, Stahl, 1945 and Wall, 1975), and the following comments are characteristic: "Aristarchos of Samos, proposed a heliocentric theory which was an anticipation of the Copernican theory of the solar system." (Fraser, 1948:49); "Aristarchos of Samos, who is best known for proposing, long before Copernicus, that the Sun was the center of the solar system." (Gibbs, 1979:47); and "If the Greeks had followed Aristarchos the latter achievement – i.e. the problem of celestial motions – might have been completed by the time of Ptolemy." (Dingle, 1953:116). And in referring to the theory of Aristarchos, Armitage (1956:41) wrote:

> Then it was realized that everything would look just the same if, instead of the Sun revolving round the Earth, the Earth went round the Sun, just as the five planets were being supposed to do. This step was taken in the 3rd century B.C. by a Greek astronomer called Aristarchos who came from the same island of Samos as did Pythagoras. He also accounted (as Heraclides too had done) for the daily rising and setting of the heavenly bodies by supposing the Earth to turn round once a day on its axis. He thus arrived at the complete Copernican theory of the solar system, and earned his title of the Copernicus of Antiquity.
>
> Aristarchos did not work out his theory in detail as Copernicus did.... So little more was heard of this sun-centred planetary system until 1800 years later, when Copernicus began to establish it as the accepted theory of modern times.

Finally, the title of Gingerich's 1985 article is characteristic: 'Did Copernicus owe a debt to Aristarchus?'

5 ARISTOTLE AND CLAUDIUS PTOLEMAEUS

In that period the geocentric system was the dominant one, since it served human vanity to have our little planet at the centre of the universe. Many astronomers supported the theory of the geocentric system, but it was under the weight of the great Aristotle that this system was maintained for many centuries in Western Europe.

According to Aristotle, the visible 'corporality' of the stars – of the divine bodies – was in a continuous circular motion. The fixed stars and the planets were mixed together in a series of hollow spheres, and moved in circles with various directions and velocities. According to this theory, there should be as many spheres as is needed to explain all celestial motions, and in his scenario Eudoxos required 55 spheres in order to attain this goal. Therefore, one should take into consideration 55 'stellar gods', consisting of a 'moving spirit' and a body in circular motion. Meanwhile, the Sun was moving around the Earth normally, but varied in distance, which explained summer and winter.

The geocentric system became widely known as the Ptolemaic system, due to the fact that Claudius Ptolemaeus or Ptolemy (second century AD) was the one who worked out the planetary orbits in detail and tried to explain them. In the first book of the *Great Mathematical Syntaxis* (more generally known as *The Almagest*) Ptolemy gives an account of his arguments in support of a motionless Earth in the centre of the universe. He argues that, if the Earth were moving, then certain phenomena should be observable as a result of its motion. For example, since all bodies tend to fall towards the centre of the universe, the Earth should be motionless in this centre. Otherwise, the falling bodies should not move towards the centre of the Earth as they do. Moreover, if the Earth were rotating on its axis once every 24 hours, an object thrown vertically should not fall in the same place, as in fact seemed to happen (Ptolemy, 1984).

6 THE PTOLEMAIC SYSTEM

Nevertheless, Hipparchus and older Greek astronomers knew of the irregularities observed in the motions of the planets, and this led them to introduce a system of deferents and epicycles in order to explain them. This system was not invented by Ptolemy, but by the great geometrist of antiquity, Apollonios of Perge (262-190 BC), and of special interest is his work on the determination of the points where a given planet appears to be motionless.

The ancient Greek astronomers considered the motions of the planets uniform and circular. Thus, the deferents were the larger circles having the Earth at their centre, while the epicycles were the smaller circles, the centres of which were moving on the circumferences of the deferents. The motions of the Sun, the Moon, and of the known planets were taking place on the circumferences of their own epicycles. On the moving eccentre there was only one circle, which had as its centre a point outside the Earth, and the planet was moving on the circumference of this circle. Although these two constructions were mathematically equivalent, it was impossible to explain all observed planetary phenomena.

Ptolemy expanded the conclusions of Hipparchus and, from references found in *The Almagest*, it seems that he was influenced considerably by the geometrical views of Apollonios.

Thus, he introduced one more concept: he supposed that the Earth was offset by a small distance from the centre of the deferent of each planet, and moreover that the centre of the deferent was moving with a uniform circular motion around a point which he called the 'equant'. This was a hypothetical point, and Ptolemy placed it on the diameter of the deferent in such a way that it was opposite the Earth in respect to the centre of the deferent. In other words, the centre of the deferent was always between the Earth and the hypothetical equant, and the distance between the Earth and the centre of the deferent was equal to the distance between the centre of the deferent and the equant. With all these conjectures, Ptolemy could at last satisfactorily explain many of the observed planetary phenomena.

In general, the plane of the ecliptic in the Ptolemaic geocentric system was the one followed by the Sun during its annual 'apparent' motion amidst the fixed stars. The planes of the planetary deferents were believed to intersect the plane of the ecliptic at a small angle, while the planes of the planetary epicycles intersected at the same angles the planes of the deferents. As a result, the planes of the epicycles were parallel to the ecliptic plane. For the planes of Mercury's and Venus's deferents, it was supposed that they were oscillating on both sides of the ecliptic plane, and that the planes of their epicycles were oscillating with respect to the planes of their deferents.

Ptolemy believed that the planets were much closer to the Earth than the fixed stars. However, he apparently believed in the existence of crystal spheres upon which the fixed stars were attached. Beyond the sphere of the immovable fixed stars there were other spheres and ultimately, as he proposed, the 'first cause of moving', the force which caused the motion of the other spheres in his perception for the universe. Possibly Ptolemaeus may have felt intuitively that the geocentric theory was incorrect, but he remained faithful to it and tried to avoid any theories that would shake this world-image. Thus, he spent a lot of time trying to prove that space could not have more than three dimensions!

Later on, the geocentric system was accepted by the Christian Church as a dogma, and in spite of its shortcomings it then became almost impossible to replace. It continued to withstand astronomers' criticisms until the sixteenth century, when more detailed observations of the planetary orbits and of other heavenly bodies complicated it to such a degree (for example, epicycles over epicycles had to be created in order to explain the observations) that its validity was seriously disputed.

7 THE EMPEROR JULIAN

In the meantime, we should not assume that support for the heliocentric system died off completely. The Emperor, Julian (336-363 AD), was deeply affected by his knowledge of, and respect and admiration for, ancient Greek civilization. Strongly influenced by the Neoplatonic philosophers, he believed in the right of the individual to carve a path towards the truth. Julian thought that it was an unalienable right of each person to search and to doubt, and at the same time he was afraid that this right could be lost forever because of the prevailing religious attitude which tended to characterize any doubter as a heretic. As a result, he became known as a 'parabate' and a 'renegade', high-handed terms that indicated that he never became a Christian and that he never reneged on anything; and history and the Church continued to brand him as such, even after his death. Nevertheless, Julian was a passionate idealist, and he envisioned the revival of the ancient Greek spirit and values, which he wrongly combined with the revival of the ancient Greek religion, a religion that had irrevocably declined. Thus, when Julian consulted the Oracle of Delphi, he was advised: "Tell the Emperor everything is destroyed, Apollo has no roof over his head, Pythia has no bay leaf, not even the mountain spring speaks, even the water has stopped its voice." (Julian, 1913).

Julian himself studied the ancient wisdom at the philosophical schools of Athens. Captured by the beauty of the ancient Greek spirit, he wished to revitalize it. He became interested in philosophy and astronomy, and he warmly supported the heliocentric system. In his treatise *Hymn to King Helios dedicated to Sallust* he states:

> For that the planets dance about him as their king, in certain intervals, fixed in relation to him, and revolve in a circle with the perfect accord, making certain halts, and pursuing to and fro their orbit [i.e. the stationary positions and the direct and retrograde movements of the planets],

> as those who are learned in the study of the spheres call their visible motion. (The Orations of Julian, IV. Vol. I., 31, 135 B, p. 366). (Julian, 1913).

This quote shows that in the fourth century AD the heliocentric theory of Aristarchos was not forgotten, and that it still had its supporters.

8 THE RE-EMERGENCE OF THE HELIOCENTRIC SYSTEM

The original 'Ptolemaic' geocentric system remained unaltered and largely undisputed for more than fourteen centuries, but at the same time the heliocentric system was still alive in the memories of astronomers and in the writings of the ancient Greek Pythagorean philosophers. However, the geocentric system had one major flaw: it could not explain the retrograde motions of the planets in their orbits.

Yet it was only during the sixteenth century, an era of intense scientific investigation, that the Polish astronomer Nicolaus Copernicus (1473-1543) reintroduced the heliocentric theory, and from that point on it began to be accepted by scientists. After carrying out a long and detailed study of the ideas and hypotheses of the Greek philosophers he concluded that some of the difficulties with the Ptolemaic system could be eliminated if the Sun rather than the Earth was placed at the centre of the planetary system. Thus, the retrograde motions of the planets could be explained without the need for epicycles, since the inferior planets were moving faster than the superior, which were much further away from the Sun.

In Copernicus's analysis, the hypotheses of Aristarchos and the faith of the Pythagoreans in the heliocentric theory, emerged as crucial. For example, in the Preface of his work *De Revolutionibus Orbium Coelestium Libri VI*, which was addressed to the Pope Paul III, Copernicus (1995) refers to both Hicetas and Ecphantos, in writing:

> For this reason I took the labor to search all the books of the philosophers I could find easily, in order to ascertain whether someone was of the opinion that the motions of the heavenly bodies are different from those being taught by the teachers of mathematics in the universities. And I found initially in Cicero that Nicetas believed that the Earth moves. Later I found in Plutarch that other philosophers too had the same opinion. From them I took the motive and begun to think myself about the motion of the Earth.

(It should be noted that Copernicus followed an altered writing of the manuscripts, and he therefore refers to Hicetas as 'Nicetas').

Copernicus was convinced that the heliocentric system was correct, but even though his detailed study was completed in 1515, he did not dare to publish it at this time because of his fear of the Inquisition. As the Earth was then considered the centre of the universe with everything revolving around it, anyone who questioned this belief – which was by now Christian dogma – was automatically placed in a very difficult position. Therefore, although Copernicus's Austrian disciple, Georg Joachim (more widely known as Rheticus), exhorted his teacher to publish his new theory, the eminent Polish astronomer only did so in 1543, shortly before his death. Because the immortal work, *De Revolutionibus Orbium Coelestium Libri VI*, was dedicated to the Pope and would be read by clerics, Andreas Osiander (who suoervised he printing) wrote a forward where he stressed that the Copernican system was only 'a model' and not necessarily the true representation of the planetary system!

According to C G Fraser (1948:73):

> In the following quotation Copernicus proposed the heliocentric theory of Aristarchus. He developed that hypothesis and showed its superiority over the more cumbersome Ptolemaic system. Now it is universally accepted by astronomers.
>
>> "Every observed change of position is due either to the motion of the observed body or of the observer or to the motions of both. Since the planets appear now nearer, now farther from the Earth, this shows necessarily that the center of the Earth is not in the center of their circular orbits."
>
> He still holds with Aristotle that the orbit must be a circle, the perfect curve.

Something that is not widely known is that Copernicus never did manage to remove the epicycles. Nor was he able to predict the positions of the planets with an accuracy that was greater than in the Ptolemaic system.

9 THE SYSTEM OF TYCHO BRAHE AND JOHANNES KEPLER

In 1583, a generation after Copernicus's death, the great Danish observer Tycho Brahe (1546-1601) proposed his own system to describe the planetary motions in the Solar System. Brahe's so-called 'Tychonic system' was a combination of the earlier Ptolemaic and Copernican systems. It adopted the Ptolemaic view that the Earth was the stable centre of the universe around which the Sun and the Moon revolved, but it also accepted that the remaining planets revolved around the Sun, in accordance with the new system of Copernicus.

Both the Ptolemaic and the Tychonic systems predicted the existence of an external sphere, the one with the fixed stars, executing a daily revolution around the Earth. Tycho's theory accounted for the observed changes in the phases of Venus, which were impossible to explain within the framework of the Ptolemaic system. In fact, a system analogous to the Tychonic one had been proposed – as has already been mentioned – by the Greek philosopher, Heraclides, who believed that at least Mercury and Venus revolved around the Sun.

Brahe's system became better known through the book *Astronomica Danica*, which was written in 1622 by his student, Christian Longomontanus. Meanwhile, Brahe greatly appreciated the astronomical insights of the German astronomer, Johannes Kepler (1571-1630), and in 1599 offered him a position as astronomical assistant in Prague. Kepler accepted, because he wanted to co-operate with the great Danish astronomer, who had accumulated an amazing quantity of data from many years of accurate observations. Unfortunately, each wanted to take maximum possible advantage of the other. Brahe wished to justify the Tychonic system by tapping Kepler's genius, while Kepler wanted to prove the validity of the Copernican system by using Brahe's accumulated observations. Kepler was an ardent supporter of Copernicus, having first heard of his theory in 1590 when studying at the University of Tubingen, and he hoped to improve it and thus make it more acceptable in astronomical circles.

Given these conflicting objectives, co-operation between the two men was difficult, and Brahe would not give Kepler access to his planetary data. This only became possible after Brahe's death in 1601, when Kepler inherited his teacher's records, and after many years of hard work he succeeded in identifying the precise imperfections of the Copernican system. Although Copernicus had correctly placed the Sun at the centre of the solar system, he had retained circular orbits for the planets. Moreover, he had supposed that each planet moved at a constant velocity, which had forced him to retain the epicycles in his system.

Kepler was the real founder of the new heliocentric system, and he then formulated his three laws of planetary motion which proved to be catalytic to the study of the solar system. In his first law he stated that the planets moved in elliptical rather than circular orbits, which was a heretic belief since from the beginning astronomers and philosophers had believed in the divine sanctity of circular orbits. He also realized that the planets did not move with a constant velocity, but instead, the line connecting the Sun with the respective planet described equal areas in equal intervals of times. Finally, in his third law, the harmonic law, he stated that the squares of the sidereal periods of any two planets are proportional to the cubes of their mean distances from the Sun. Kepler's third law was probably a decisive starting point for the law of universal gravitation that was subsequently formulated by Newton, a law that in fact was probably first discovered by the German astronomer but not analysed in detail. In any case, there is no doubt that Kepler's work paved the way for Newton.

Despite these advances, the widespread acceptance of the heliocentric system did not come automatically or easily. The case of the well-known French astronomer Jean-Baptiste Morin, who was Professor of Mathematics at the College de France, is typical. Morin was an exceptionally good astronomical observer, but in spite of his own high-quality observations he remained an ardent supporter of the geocentric theory. More than a century after Copernicus's death there were still astronomers who were trying to prove that the Earth was motionless at the centre of the solar system!

10 COMPLETE ACCEPTANCE AND JUSTIFICATION

The indisputable superiority of the heliocentric system lead finally to its full acceptance, at least by the astronomical community. However, the Vatican continued to include Copernicus's *De Revolutionibus Orbium Coelestium Libri VI* in its Index Librorium Prohibitorum until 1835, and it was only in 1999 June, when the Polish-born Pope John-Paul II visited Torun, the birthplace of Copernicus, that he delivered a speech at the city's University in which he restored and justified the work of the great Polish astronomer. The Pope stated that the discoveries and concepts of Copernicus strengthened our confidence in the wisdom of the Creator, and at the same time they exhibited the power of the human mind.

11 REFERENCES

Aetius, 1879. Aetii Placitorum Compositione (De Vestutis Placitis). In Diels, H., 1879. *Doxographi Graeci. Editio Quarta*. Walter De Gruyter et Socios, Berolini (reprinted 1965).

Archimedes. Psammites or Arenarius or The Sand-reckoner. In Heiberg, J.L. (ed.), 1972. *Opera Omnia. Volume II*. Bibliotheca Scriptorum Graecorum et Romanorum Teubneriana, Lipsiae.

Aristotle, 1933. *On the Heavens*. William Heinemann, London (The Loeb Classical Library; English translation by W.K.C. Guthrie, 1953).

Aristotle, 1939. *The Metaphysics*. William Heinemann, London (The Loeb Classical Library; English translation by Hugh Tredennick, 1958).

Armitage, A., 1956. *The World of Copernicus (Sun Stand Thou Still). Fifth Edition*. The New American Library, New York.

Cicero, 1933. *Academica Priora*. William Heinemann, London (English ranslation by H. Rackham, 1961).

Copernicus, Nicolaus, 1995. *On the Revolution of Heavenly Spheres*. Prometheus Books, Essex (English translation by C.C. Wallis).

Dampier, W.C., 1946. *A History of Science and its Relation with Philosophy and Religion. Third Edition*. Cambridge University Press, Cambridge.

Dingle, H., 1953. *The Scientific Adventure-Essays in the History and Philosophy of Science*. The Philosophical Library, New York.

Diogenes Laertius, 1925. *Lives of Eminent Philosophers. Volume II*. William Heinemann, London (English translation by R.D. Hicks, 1958).

Dreyer, J.L.E., 1953. *A History of Astronomy from Thales to Kepler. Second Edition*. Dover, New York.

Fraser, C.G., 1948. *Half-Hour with Great Scientists – The Story of Physics*. University of Toronto Press, Toronto.

Gibbs, S., 1979. The first scientific instruments. In K. Brecher and M. Feirtag (eds.), *Astronomy of the Ancients*. MIT Press, Cambridge (Mass.), pp. 47-59.

Gingerich, O., 1985. Did Copernicus owe a debt to Aristarchus? *Journal for the History of Astronomy*, **16**:37-42.

Heath, Th.L., 1932. *Greek Astronomy*. Dent, London.

Heath, Th.L., 1965. *A History of Greek Mathematics. Volumes I and II*. Clarendon Press, Oxford.

Heath, Th.L., 1981. *Aristarchus of Samos the Ancient Copernicus. Part II: Aristarchus of Samos: On the Sizes and Distances of the Sun and Moon*. Dover, New York.

Julian, 1913. *The Works of the Emperor Julian (The Orations of Julian, IV). Volume I. Hymn to King Helios Dedicated to Sallust*. William Heinemann, London (The Loeb Classical Library; English translation by Wilmer Cave Wright, 1954).

Neugebauer, O., 1972. On the allegedly heliocentric theory of Venus by Heraclides Ponticus. *American Journal of Philology*, **XCIII** (93):600-601.

Philolaos of Croton, 1996. Bacchae and Peri Physios (On Nature ABC). In W. Kranz (ed.), *Die Fragmente der Vorsokratiker von Hermann Diels*. Zweiter Band, Weidmann, Zurich.

Plutarch Chaeronensis Scripta Moralia. Graece et Latine. Tomus Secundus. De Placitis Philosophorum-Libri quinque. II. Firmin Didot, Paris (editored by Ambrosio Firmin Didot, 1841).

Ptolemaeus, Claudius, 1898-1903. *Great Mathematical Syntaxis (Almagest). Parts I and Part II.* Teubner, Lipsiae, (edited by J.L. Heiberg).

Ptolemy, 1984. *Almagest. Ptolemaeus Claudius*. Duckworth, British Library Cataloguing in Publication Data, (translated by G.J. Toomer).

Stahl, W.H., 1945. The Greek heliocentric theory and its abandonment. *Transactions and Proceedings of the American Philological Association*, **76**:321-332.

Stamatis, E.S., 1973. The heliocentric system of Greeks. *Contributions from the Research Center for Astronomy and Applied Mathematics. Academy of Athens. Series I (Astronomy)*, **32**(3):31-34.

Theon of Smyrna, 1878. *Theonis Smyrnaei Philos. Platonici Lipsiae*. Hiller, Lipsiae.

Wall, B.E., 1975. Anatomy of a precursor: the historiography of Aristarchus of Samos. *Studies in History and Philosophy of Science*, **6**:201-228.

Dr Efstratios Theodossiou and Dr Emmanuel Danezis are assistant Professors of Astrophysics at the University of Athens (School of Physics, Department of Astronomy-Astrophysics and Mechanics). Their scientific interests include observational astronomy and astrophysics, satellite spectrophotometry in UV of Be stars, variable stars and history and philosophy of astronomy. They have published in excess 40 scientific papers in international journals and proceedings of astronomical conferences, more than 150 scientific articles in Greek newspapers and journals, and eight books on his scientific subjects.

Mr Vassilios N Manimanis has an M.Sc. in Astrophysics, and is now doing his Ph.D. in our Department with a thesis on double and variable stars.

Miss Kalyva Euanthia-Maria is student of the School of Physics and she is doing her diploma dissertation on the "Cosmological ideas of Pythagoreans".

Foucault – the man who swung the pendulum

Suzanne Débarbat

Observatoire de Paris

One hundred and fifty years ago Foucault (1819-1868) successfully demonstrated using a pendulum the special effect of the influence of the rotation of Earth which henceforth became known as the experiment of Foucault's Pendulum. In January of 1851 Foucault conducted the first of his successful pendulum experiments in the house in which he lived with his widowed mother on the corner of the rue d'Assas and the rue de Vaugirard, Paris. His experimental pendulum was no more than two and a half metres long.

Told of the success, Arago (1786-1853) – then Acting Director of the Office of Longitudes since the death of Bouvard (1767-1843) – invited him to stage the experiment in the room on the second floor of the Paris Observatory which is nowadays known as the Salle Cassini. This second demonstration was held in the beginning of February 1851 with a pendulum which was ten or eleven metres long.

The Prince-president (1808-1873), who would become a little later Napoleon III (1852-1870), told in his turn of the success of the venture, invited Foucault to stage his pendulum in a place more suited to a large public demonstration. The Pantheon was chosen and all who went there in March of 1851 were the witnesses, through this third experience, of an Earth which, turning under their feet, gave the impression that the pendulum itself produced this rotation.

In 1902 Flammarion (1842-1925) restaged the operation, which *l'Astronomie* bears witness of in its February 1996 issue. In 1994, on the occasion of the Festival of Science at the Paris Observatory, which had as its theme the Rotation of the Earth, the experience of Foucault's pendulum was repeated in the Salle Cassini with the help of the Athanor Society of Montlucon (for the "ball" of the pendulum), the participation of the Conservatorium of Arts and Trades, in particular one of its engineers, and the carrying through of the project to completion by the staff of the Paris Observatory. The success of the operation was such that for the following festival, in 1995, the Conservatorium of Arts and Trades restaged the operation of the pendulum of sixty metres at the Pantheon.

There have been many demonstrations throughout the world of Foucault's pendulum since the first successful demonstration in 1851. To mark the occasion of the one hundred and fiftieth anniversary the "History of Astronomy" commission of the Astronomical Society of France launched a project to make an inventory of the pendulums of Foucault which have existed or exist throughout the world.

A search like this can be done in many ways: for example you can help by investigating a pendulum found during the course of a journey, or do research without even leaving your home or library, by consulting tourist guides or books, or by asking friends in any part of the world.

Please send any information you may collect to the Société Astronomique de France, 3 rue Beethoven, 75016 PARIS, clearly marked on the envelope to the attention of: Commission "Histoire de l'astronomie" – Opération Foucault. A first appraisal is already being made of the items received before the first cut-off date of 2001 December 31. Further material is eagerly awaited as – if the pursuit of the pendulum continues – we shall be able to look forward to an annual classification of the catch.

Reviews

Science in Theistic Contexts: Cognitive Dimensions, J.H. Brooke, M.J. Osler and J.M. van der Meer (eds), 2001, Osiris, **16**, second series, (University of Chicago Press: Chicago) 376 + xii pp., ISBN 0-226-07564-8, hard cover, price $39.00 and ISBN 0-226-07565-6, soft cover, price $25.00, 261 × 179 mm.

In response to Napoleon's question about the place of God in his cosmology, Laplace famously retorted that he had "no need of *that* hypothesis." Newton saw things rather differently: for him the "most beautiful System of the Sun, Planets, and Comets, could only proceed from the counsel and dominion of an intelligent and powerful being." Though writing in a very different astronomical and religious context, the fourteenth century Islamic astronomer and theologian al-Sharīf al-Jarjānī expressed similar sentiments: "the characteristics of the celestial orbs and the Earth, and of what they reveal of subtle wisdom and wondrous creation–things that overcome whoever apprehends them with awe, and facing him with the glory of their Creator, prompt him to say: "Our Lord, thou has not created this in vain."' The remarks of both Newton and al- Jarjānī seem to echo the Old Testament, where "the heavens declare the glory of God; And the firmament sheweth his handiwork" (Psalms 19:1).

Both science and religion traditionally purport to provide ways of understanding the world. Further, modern, western science developed during the Renaissance and Early Modern times in societies whose philosophy, culture, and world-view were dominated by Christianity. In these circumstances it is inevitable that religious ideas would influence scientific ones. The traditional narrative has an emergent science slowly but inexorably pushing back the boundaries of ignorance and superstition, whilst organized religion is reluctantly forced to yield ground. Hostilities were joined over astronomy, in particular Copernicanism, but in later centuries the battleground shifted to geology and biology. This triumphalist narrative derives from nineteenth century accounts, such as Draper's *History of the Conflict between Religion and Science* (1875) and White's *A History of the Warfare of Science with Theology in Christendom* (1896). Whilst there is certainly some truth in it: modern science constitutes a vastly more rigorous, powerful, self-consistent, and accurately predictive method of understanding the world than any previous system, the notion that these advances were gained in the face of opposition by organized religion oversimplifies a complex interaction. Simply recall, for example, that the Catholic Church has long been a patron of science. Further, such a notion is ahistorical: the boundaries of 'science' and 'religion' were not the same in previous centuries as today. Renaissance and Early Modern scholars did not partition their intellectual activities using modern categories. Indeed, the word 'scientist' was not coined until the nineteenth century. Further, the influences are not necessarily one-way and can take any number of forms:

> ...the variety of relationships is much richer and more complex than the notions of conflict and harmony can convey. For example, one cannot neglect such other possibilities as separation, dialogue, integration and subordination. Even within the concept of conflict, we should add the notion of (peaceful) competition to that of warfare, and within the notion of harmony it is extremely important to distinguish the direction of influence, whether from religion to science or from science to religion. And in any case there are several different kinds of influence: presupposition, sanction, motive, prescription, and substantive source (Finocchiaro, quoted from the volume under review, p. 115).

It is in the nature of religious convictions that, when deeply held, they will often underpin a person's approach to many aspects of life, and it is almost a commonplace that if a scholar adheres to such beliefs then they might affect his scientific work. Even in the absence of any conscious influence, the syllogism runs that his religious beliefs influence his standpoint on metaphysical questions, which, in turn, inform his approach to scientific issues.

The purpose of *Science in Theistic Contexts* is primarily to examine in detail instances in which religious beliefs have influenced scientific thought. It is the eponymous proceedings of a conference held in July 1998 at the Pascal Centre for Advanced Studies in Faith and Science, Redeemer College, Ancaster, Ontario and is published as a volume of *Osiris*, the annual companion to the journal *Isis*. Most of the contributors have a background in the history and philosophy of science. Geographically most hail from North America, but with a few from the UK and two from Israel. The volume is divided into two sections: an introduction and a series of case studies. The introduction comprises two essays on more general topics: 'Religious Belief and the Content of the Sciences' by Brooke and 'Religious Beliefs, Metaphysical Beliefs and Historiography of Science' by Wykstra. Manuscript versions of these essays were circulated before the conference to provide a context for the subsequent discussions. The case studies examine individual instances in which scholars' religious beliefs and attitudes have influenced their scientific work. There are fourteen case studies, of which six are on astronomical topics.

The case studies are arranged broadly chronologically, with most of the astronomical material occurring in earlier rather than later contributions. The first investigates the way in which Islam changed the Hellenistic astronomy adopted in the Arab world from the eighth century. The second discusses the reception of Copernicanism amongst Jewish scholars. These two contributions are the only ones which consider religions other than various forms of Christianity. Subsequent entries consider the religious influences on Kepler, Galileo, and Newton. Kepler, of course, is always an ambiguous figure, seemingly poised between mediaeval and modern modes of thought. Barker and Goldstein argue that his discoveries in planetary motion were informed and under-pinned by his religious convictions, particularly that God had constructed the world according to an intelligible plan, discernible by man. Finocchiaro reconsiders the trial of Galileo. Snobelen excavates evidence of Newton's heretical Unitarianism hidden in the General Scholium to the *Principia*. In the final astronomical case study Crowe provides four examples, two from the eighteenth century and two from the nineteenth, in which religious concerns influenced astronomical ideas about extraterrestrial life. Of the non-astronomical case studies, two concern Early Modern natural philosophy and the rest address nineteenth century topics, mostly related to the development and reception of the theory of evolution.

Science in Theistic Contexts is not an easy read. The contributions are detailed, careful, closely-argued disquisitions in the style of modern scholarship. However, they are uniformly stimulating and thought-provoking. Some provide fresh insight into familiar ground while others cover less well-known material. The volume has the usual problem of conference proceedings that it is a collection of disparate papers which will be of varying interest. On the one hand, this consideration is augmented by fewer than half the contributions being on astronomical topics, but, on the other, is mitigated by the very reasonable price. Anyone with a serious interest in the influence of religion on the history of astronomy should find much food for thought in the astronomical contributions and would need to be narrowly focussed indeed not to find something of interest in the non-astronomical ones. The volume is physically very well produced and the contributions are uniformly well-written, with few, if any, typographic errors. The authors, editors and publishers are all to be congratulated in these regards.

Clive Davenhall.

New Observations of Heavenly & Earthly Objects [Made] with the Aid of Optical Instruments Devised by Him and Brought to Perfection, by Francesco Fontana (Naples, 1646), translated from the Latin with annotations by Peter Fay and Sally Beaumont (privately printed, available from the authors at 18 Orchard Avenue, Sonning Common, Reading RG4 9LT, UK), 130 pp. + numerous plates, spiral bound, £12.00.

Novae Coelestium Terrestriumque Rerum Observationes, by Francesco Fontana (Naples, 1646), a transcription by Peter Fay and Sally Beaumont (privately printed, available from the authors at 18 Orchard Avenue, Sonning Common, Reading RG4 9LT, UK), 81 pp., spiral bound, £12.00.

Everyone with an active interest in the history of telescopic astronomy will have heard of Francesco Fontana. His blurred, spiky drawings of the crescent Venus accompanied by a big spherical satellite, or of Saturn surrounded by a narrow oblique ring terminating in a pair of large round objects, appear in a variety of histories of astronomy, as do his much better drawings of the Moon. Yet the book from which they came, Fontana's *Novae Coelestium Terrestriumque Rerum Observationes (New Observations of the Heavenly and Earthly Objects)* published in Naples in 1646, is not only extremely rare but has never, until now, been available outside its Latin original. It is for this reason, therefore, that Peter Fay's and Sally Beaumont's translation is so significant and deserves notice by the astronomical community. It is an indictment of the modern publishing industry, moreover, that neither academic nor commercial publishers were willing to take *New Observations* ..., making it necessary for the authors to issue their translation in spiral-bound, photocopied format, into which high resolution photographs of Fontana's original engravings have been individually glued in the appropriate places in the text.

One of Fontana's most memorable and unverified claims is that he not only developed telescopes before Galileo, in 1608, but that he was using the 'Keplerian' optical configuration (in which both object glass and eyepiece were convex lenses) several years before Kepler himself. Indeed, it is clear that Fontana was an accomplished lens-grinder, for one of the most important sections of his book is his description of how to grind and polish telescope lenses and conduct simple optical tests to ascertain their quality. What is clear, however, is that some of these instruments, such as the refractor containing no less than *eight* lenses in its tube, could produce severely aberrated images which no doubt generated the large satellites of Saturn and Venus, and the round spots that appeared in the middle of the bright image of Mars – engraved images of all of which are photographically reproduced in the text.

In spite of these now-recognized mistakes, Fontana's text is fascinating to read and is full of important asides on classical and contemporary astronomy. For instance, he describes the ancient technique of improving naked-eye images by looking at the stars through long, narrow tubes, which of course cut out stray light and improve the resolving power of the unaided eye. Fontana also reviews the optical writings of his older pre-telescopic contemporary, Giambatissta della Porta, and makes the prescient observation that the angular diameter of Mars varies in relation to the planet's position *vis-à-vis* the Earth and the Sun when viewed through a telescope.

Yet one cannot help noticing that, amidst his descriptions of the Moon, planets and stars, Fontana says nothing about sunspots, yet sunspots were the controversial bodies which Galileo had used as evidence both of the Sun's flawed surface and of its axial rotation. Both were contrary to the teachings of Aristotle, and Galileo pressed them into service as evidences for the Copernican theory. Fontana, however, kept well away from any discussions about Copernicanism. No doubt this was occasioned in part by the recent condemnation of Galileo, but more likely, I suspect, it derived from Fontana's close friendship with many figures in the Roman Catholic hierarchy within the Jesuit scientific community. For like the Jesuits, Fontana seems to have felt (quite rightly, considering the evidence available in 1646) that there were still no clear physical proofs of the Earth's motion, and that the Tychonian Theory (in which all the planets rotated around the Sun, but the Sun in turn rotated around a fixed Earth) still provided the most extensive and connected explanations of both celestial and terrestrial phenomena.

Fay and Beaumont present us with a fascinating book that is both accurately and elegantly translated from the Latin. It opens up an astronomical world scarcely touched upon in the existing accessible literature, which is primarily concerned with the radical impact of Galileo and largely ignores non-Copernican telescopic astronomers such a Fontana. And in order to support their translation and place the whole evidence before those whose interests in Fontana are academic as well as practical or astronomical, the authors also offer a transcription of the complete Latin text and engravings as a separate volume. Peter Fay and Sally Beaumont must be warmly congratulated for making this valuable text more readily available, and it deserves notice from all people who have a serious interest in the history of astronomy.

Allan Chapman

Agnes Mary Clerke and the Rise of Astrophysics by Mary Brück (Cambridge University Press 2002), x + 275 pp., 220 × 140 mm.

To the loss of the majority, probably rather few working astronomers now read Agnes Clerke's books, although historians of astronomy still find them valuable for reference. Of particular value is her best-known book, *A Popular History of Astronomy in the Nineteenth Century*, published in 1885 with a fourth edition appearing in 1902, only a few years before its author's death. Mary Brück's biography makes clear, however, that Agnes Clerke wrote much more than this one book. She was the author of three other astronomical books, many articles for periodicals, major articles for the *Encyclopaedia Britannica* and biographies of most of the major British astronomers for the then new *Dictionary of National Biography*. Much of her writing had some connection with astronomy, but she also wrote on other scientific topics and even occasionally tackled non-scientific subjects. The title of her best-known book should not mislead modern readers into thinking of Agnes Clerke as simply a popularizer. Her work was respected by many of the eminent astronomers of her day (not only British ones) who became her friends, and her opinions on astronomical matters, including possible future directions of research, won her further respect in those quarters. All this was achieved by a woman who, like many of her generation, received no formal schooling as a girl.

The Clerkes were an Irish family and Agnes, born in 1842, spent her childhood and adolescence in Ireland, first in a small town in the south, later in Dublin. She was the second of three children, having an elder sister, Ellen, and a younger brother, Aubrey. The brother received the schooling and university education that the girls were denied, and became a lawyer. None of the three married and they remained close until the last one, Aubrey, died in 1923. The girls' education at home seems to have been primarily the responsibility of the father and, to judge from the results, he was a first-class teacher. Ellen also became a prolific writer for periodicals and published a volume of her own poetry. The family moved to Dublin at about the time that Aubrey entered Trinity College in that city but, a few years later, they went to Italy for ten years, a sojourn that perhaps partly accounts for the two sisters' facility with languages. Finally, in 1877-8, the family moved to London, all living under one roof, where they remained for the rest of their lives. Agnes herself died in 1907.

It was in London, when they were each in their thirties that the two sisters embarked on their literary careers. Mary Brück follows both careers to some extent but the spotlight is, of course, on Agnes. Her first articles were for the *Edinburgh Review* and drew on her recent experiences in Italy, but she soon began to concentrate on astronomical or other scientific topics. Her articles were well researched and their success gave her the confidence to attempt her first book, the *Popular History*. Already, before that book was published, Agnes had been in correspondence with the American astronomer E S Holden. (One of the attractive features of this biography is the pleasanter side of the controversial first Director of the Lick Observatory that it reveals.) The success of her book was to bring her a much wider circle of astronomical friends: Campbell, Keeler, Hale, Newcomb, Gill, and Lockyer were all members of this circle, but the most significant friendship was with Margaret Huggins, the wife and colleague of Sir William Huggins. It was, no doubt, particularly the influence of William and Margaret Huggins, on the one hand, and the scientifically different influence of Lockyer, on the other, that brought Agnes to a realization of the importance of the new astrophysics. David Gill was also a strong influence, however: he actually persuaded Agnes to spend two months at the Cape, where she acquired her only significant observing experience under his direction.

As Agnes learned more and found that leading astronomers listened to her opinions, she ventured beyond the mere recording of history into summaries of current knowledge and suggestions for future research. Two later books: *The System of the Stars* (1890) and *Problems in Astrophysics* (1902) exhibit this trend. As Mary Brück points out, Agnes was sometimes rash in committing herself to an opinion, when more experienced observers tried to urge caution on her. This trait was particularly evident in her conviction that the spiral nebulae must be part of the one stellar system – there were no "island universes" for her. Even here, however, she was representative of a substantial body of the professional opinion of her time and the matter was not settled until decades after her death. The principal lesson we should draw from her misplaced confidence is not so much that she was mistaken, but that we might be just as mistaken about some matters of which we are just as sure. Inevitably, she got caught in the cross-currents of academic disputes: some criticized her friendship with Holden, while her closeness to William and Mary Huggins led to strains in her relations with supporters of Lockyer. She never lost the friendship of Lockyer himself, but the pages of *Nature*, to which she had once been a welcome contributor, were closed to her by his former pupil and successor, Richard Gregory, a severe critic of her books.

Mary Brück has established herself as a leader in chronicling the lives and work of nineteenth-century women astronomers and she is at pains to place Agnes Clerke in the context of the times. A chapter of the book is devoted to the status of women in late nineteenth-century British astronomy. Although there were then considerable obstacles to women's advancement, they seem to have arisen more from the general attitudes of contemporary society than from any animosity on the part the men who would have been colleagues. We learn that Agnes Clerke was among the first women to be offered a temporary post (all that was possible at the time) at the Royal Observatory. She declined for personal reasons. She did not live long enough to see women elected to Fellowship of the Royal Astronomical Society, but she was allowed to attend meetings and became one of the few women to be elected honorary members.

Reviewers are expected to make some criticisms, if only to show that they have actually read the book. Misprints are few, but the omission of one zero from the value of the velocity of light (page 40) is unfortunate (it will probably mortify the author more than anyone else). Less serious, is the reference to a 60-inch telescope at Yerkes Observatory in 1902 (page 154). Of more substance is the discussion of Agnes Clerke's view of novae on page 118. She had initially been attracted to the idea that novae were the result of a collision between two stars, but, correctly, she eventually abandoned the hypothesis. Neither she nor any of her contemporaries could have foreseen the connection we now make between the nova phenomenon and membership in a particular type of binary system. Mary Brück adds a brief explanation of the nova phenomenon as the expulsion of an outer shell from a star, but adds a categorical comment "No second star is involved.", which is misleading. Finally, the comparison between the relations of light-curves and velocity-curves of Cepheid and eclipsing variables (page 168) is rendered unclear by the implication that in the latter, light and velocity minima should coincide.

These are small blemishes, however. After all the focus of the book is on the life and work of Agnes Clerke, not on modern astronomy. Mary Brück has succeeded in painting an attractive portrait of a woman who was obviously not only highly intelligent but must also have been a pleasure to know. Perhaps the biography is successful because author and subject share so much in common: both are women working in astronomy, both are Irish and both practising Roman Catholics. The reader feels that the biographer is really in sympathy with her subject, but she does not descend to hagiography and is ready to offer criticism where it seems to her to be merited. Agnes Clerke was a significant figure and we should not have had to wait nearly a century after her death for an account of her life. Perhaps, however, Agnes' spirit thinks the wait worthwhile, since this biography is a model of what a scientific biography should be.

Alan H. Batten.

The Transit of Venus. The Quest to Find the True Distance of the Sun, by David Sellers (Maga Velda Press, Leeds, 2001), 222 pp., ISBN 0-954-1013-0-8, paperback, £12.95, 234 × 155 mm.

The upcoming 2004 and 2012 transits of Venus are eagerly awaited events and as such have attracted a number of recent books on these rare and historically-important events, so the appearance of yet another could be greeted with dismay. But *The Transit of Venus* is different. Although designed to appeal to astronomers, this book is also written for the general reader who might be intrigued to know how it is possible to measure something as intangible as the distance to the Sun.

David Sellers has done an excellent job, taking us through the mandatory introductory chapters on Greek and Roman astronomy and the ideas of Copernicus, Brahe, Galileo, Kepler, and other luminaries, before launching into the pioneering transit of Venus observations made by Horrocks and Crabtree in 1639. Next are chapters on "Predicting transits of Venus" and marine navigation, before we are introduced to the genesis of the idea that transits of Venus could be utilized to determine the solar parallax – hence the Astronomical Unit. Following this come those all-too-familiar sagas associated with the all-important 1761 and 1769 transits.

The next chapter, "Venus Abandoned", is the only weak point in the book in that Sellers is unduly dismissive of the 1874 and 1882 transit results. These transits, too, had their human dramas – just like the two eighteenth century transits – but Sellers does not share these with us, and while it is true that other methods were used to investigate the solar parallax, Dick *et al.* (1998), among others, have clearly demonstrated that the 1874 and 1882 transits did produce meaningful results. Having said that, Sellers' account of Gill's expedition to Ascension Island to observe the 1877 opposition of Mars is captivating!

The final two chapters drag us into the twentieth and twenty-first centuries. In "Venus Reclaimed" we read of how radar observations of Venus led the IAU in 1976 to adopt a value of 8.794148″ for the solar parallax, while Chapter 15 discusses the 2004 and 2012 transits.

Although the contents of *The Transit of Venus* is predictable, Sellers writes in an entertaining style, which makes this book enjoyable reading. For example: "The quest to find the Sun's distance—the so-called 'Astronomical Unit'—runs like a bright thread through the entire tapestry of astronomical history. Its story spans two millennia and reveals the extraordinary efforts which have been devoted to discovering the true place of our earthly home in the solar system" (page 14). Many other examples could be given, and in this regard I found shades of Sobel's *Longitude* in Sellers' book. I hope it, too, will reach and be appreciated by a wide lay audience, but I can also recommend it for historians of astronomy, especially those seeking an easy-going refresher course in preparation for 2004 and 2012.

Wayne Orchiston

Reference

Dick, S.J., Orchiston, W. and Love, T., 1998. Simon Newcomb, William Harkness and the nineteenth century American transit of Venus expeditions. *Journal for the History of Astronomy*, **29**:221-255.

New Commissions

The Inter-Union Commission for History of Astronomy

We are pleased to announce the formation of the Inter-Union Commission for History of Astronomy (ICHA) by the International Astronomical Union (IAU) and the Division of History of Science of the International Union for History and Philosophy of Science (DHS/IUHPS). The ICHA is an international body representing the interests of *all* professional historians of astronomy world-wide. It encourages research into the history of astronomy, facilitates communication between researchers, organizes scientific meetings, undertakes collaborative projects, and publishes a biannual newsletter. The ICHA will also prepare recommendations for the IAU and the IUHPS, and will liaise with other international organizations.

Membership is open to the entire history of astronomy community. Those who are IAU members become full members of the new Commission, while those who conduct their research through the IUHPS become associate members. New members (of either kind) are elected to the ICHA at the triennial General Assemblies of the IAU (and the next one is in Sydney, Australia, in July 2003).

The ICHA is governed by an Organising Committee (OC) of ten. The inaugural OC, which is based upon the current OC of IAU Commission 41, comprises:

President:	Professor Richard Stephenson (UK: f.r.stephenson@durham.ac.uk)
Vice-President:	Professor Alex Gurshtein (Russia: agurshtein@hotmail.com)
Secretary:	Dr Wayne Orchiston (Australia: wo@aaoepp.aao.gov.au)
Members:	Dr Steven Dick (USA: dick.steve@usno.navy.mil)
	Dr Wolfgang Dick (Germany: wdick@astrohist.org)
	Professor Rajesh Kochhar (India: rkochhar2000@yahoo.com)
	Dr Tsuko Nakamura (Japan: tsuko@cc.nao.ac.jp)
	Professor Il-Seong Nha (Korea: SLISNHA@chollian.net)
	Professor Woodruff Sullivan (USA: woody@astro.washington.edu)
	Professor Brian Warner (South Africa: Warner@physci.uct.ac.za)

Production of *ICHA Newsletters* is the responsibility of an Editorial Board comprising Dr Ileana Chinnici (Italy), Professors Gurshtein and Stephenson, and Dr Orchiston. Newsletters are scheduled to appear in June and December.

The official establishment of a genuine Inter-Union Commission by the two parent Unions is a major step forward for the history of astronomy community. IAU Commission 41 was founded in 1948, and for decades there has been close co-operation between colleagues from this Commission and those associated with the DHS/IUHPS. During the 1970s an attempt was made to have C41 formally recognized as a joint commission of the two Unions, but this initiative was unsuccessful.

However, in 1994 the idea somehow took hold that C41 had become "A joint IAU-IUHPS Commission" (*IAU Transactions XXIIB*, p. 207), even though its status was unchanged, and this notion was perpetuated through the 1994 *ICSU Yearbook* (see p. 104). Once this fiction of a "Joint Commission" or "Inter-Union Commission" was established, it was accepted without question until the true situation was discovered in late 2000.

The quest for a genuine Inter-Union Commission then became a priority of the C41 OC, and we are delighted to see so pleasing an outcome. Under the aegis of the ICHA, historians of astronomy world-wide can look forward to an era of unprecedented co-operation and harmonious collaboration.

Finally, on behalf of all members of the ICHA we should like to thank the General Secretaries of the IAU and the DHS/IUHPS for their unstinting support and encouragement.

F. RICHARD STEPHENSON (President, ICHA)
ALEXANDER GURSHTEIN (Vice-President, ICHA)
WAYNE ORCHISTON (Secretary, ICHA)
STEPHEN J. DICK (Immediate Past President, IAU C41)

International Commission for History of Ancient and Medieval Astronomy

The 21st International Congress of History of Science (ICHS) was held in Mexico, 2001 July 8–14. The Congress was sponsored by the International Union of History and Philosophy of Science (IUHPS), which in turn is adhered to UNESCO through the International Scientific Union (ICSU). ICHS is held every fourth year. The next Congress will be held in China in 2005. As a matter of fact, ICHS is organized with the help of a large number of symposia and meetings of its scientific sections. At the 21st Congress, 67 symposia were organized, 28 sectional meetings, and 4 special sessions. More than 1000 historian of science contributed in the Mexico Congress.

The international community of historians of science cannot become individually members of the IUHPS. Its constitution allows only countries (through national committees) and history of science associations/academies as members. At present, 49 countries adhere to it. For the individual historians of science, there are a number of historical commissions, that are a sort of working groups of specialized research fields, and the members of which interact among themselves. For instance, there were 11 historical commissions before the Mexico Congress. At the General Assembly (GA) of IUHPS (i.e. the business meetings of the Executive Council and General Body of IUHPS), which is held at each ICHS, the presidents of the *Historical Commissions* are also elected, besides the election of the Executive Council. Proposals of *new* commissions are also approved at GA. At the 21st ICHS in Mexico two *new* commissions were created, namely, *Commission for the History of Ancient and Medieval Astronomy* (President, S.M. Razaullah Ansari, Aligarh /India), *and Commission for the History of Science and Cultural Diversity* (President, Paulus Gerdes, Mozambique).

The proposal for the creation of the *Commission for the History of Ancient and Medieval Astronomy* (CHAMA) was moved by Prof. S.M.R. Ansari. He stated the rationale underlying the proposal of this commission as follows:

> "The main aim and objective of this Commission is to bring under its purview research in the *astronomical heritage of all cultural areas* of the world. This idea is in consonance with the theme of this 21st Congress, namely, *Science and Cultural Diversity*. As historians of science, we know that astronomy was the most significant science during the ancient and medieval period. The majority of the world historians of astronomy are expert not only of astronomy, but they are also scholars of *classical* languages: Chinese, Sanskrit, Greek, Latin, Hebrew, Arabic, and Persian etc., in the sources of which enormous amount of astronomical data is locked in. For these historians of astronomy particularly a *forum* is required, so that its members could interact among themselves, and acquaint themselves particularly with the work-in-progress of their colleagues. To achieve this end , this Commission is proposed."

The President wishes to organize under this Commission a Symposium at the 22nd ICHS (China), in 2005. Further, this Commission intends to publish a *Newsletter*, under the Editorship of Prof. Ansari, and Ms Anne Tihon, the Secretary of the Commission, who is a well-known historian of Greek astronomy.

It may be mentioned that Prof. S M R Ansari is a former Professor of Physics at Aligarh Muslim University (Aligarh / India). He has been very actively engaged in the field of History of Science for the last few decades. He has been President of the IUHPS Commission for Science & Technology in the Islamic Civilisation (1993-97), and also of the IAU Commission for History of Astronomy (1994–97). Under the auspices of the latter, he organized a Symposium on *"History of Oriental Astronomy"*, which was held in Kyoto (Japan), in 1997 August. He has edited the *Proceedings* of this Symposium,, which will be published by Kluwer Academic Publisher (Dordrecht/The Netherlands). It is expected in the summer of 2002. Further, in his capacity as the President of the IUHPS–IAU Inter–Union Commission for History of Astronomy (for the period 1997-2001), he organized at the Mexico Congress a Symposium: *"Astronomical Heritage of the Non-European Cultural Areas"*, which was held on 2001 July 11–12. The Symposium was chaired by Prof. Ansari, at which 22 historians of astronomy from all over the world presented their talks. The Proceedings of this Symposium is also intended for publication.

The Commission requests all historians of astronomy to register themselves and to send the President / Secretary information regarding their work–in–progress, publications and news item for the *Newsletter*. The contact addresses are:

President:
Prof. S M R Ansari
Roshan Villa
Muzammil Manzil Compound
Dodhpur
Aligarh 20002
INDIA

E-mail: Raza.Ansari@gmx.net or Raza.Ansari@vsnl.com
Telephone: +91 571 703952, facsimile: +91 400466,

Secretary:
Ms Anne Tihon
Université Catholique de Louvain
28 rue Ferme du Coq
Court-St-Etienne 1490
BELGIUM.

E-mail: ti[illegible].be

Journal of Astronomical History and Heritage

Volume 5 Number 1 2002 June

CONTENTS

Cover illustrations show a series of images of the η Carinae area beginning with a drawing by John Herschel published in 1847, a black and white photograph taken by Ben Gascoigne with the MSSSO 40-inch reflector at Siding Spring, a colour photograph taken by David Malin with the AAO 150-inch at Siding Spring, and a view taken with the Hubble Space Telescope, courtesy J Morse (U. CO), K Davidson (U. MN), and NASA.