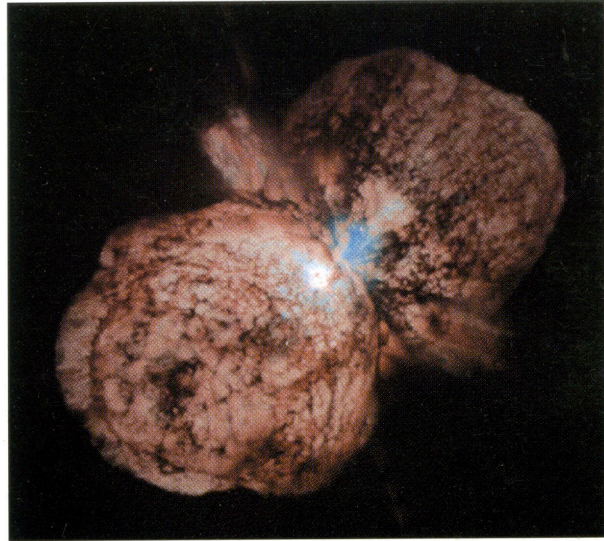


Journal of Astronomical History and Heritage



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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

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

ISSN 1440-2807

Journal of Astronomical History and Heritage

2001

Volume 4

Edited by
John Perdrix
and
Wayne Orchiston

Published by
ASTRAL PRESS
WESTERN AUSTRALIA
MMI

Visibility of the thin lunar crescent: the sociology of an astronomical problem (A case study)

Nidhal Guessoum

*American University of Sharjah, College of Arts and Sciences,
P.O. Box 26666, Sharjah, United Arab Emirates*

E-mail: guessoum@aus.ac.ae

Kiram Meziane

*University of New-Brunswick, Physics Department,
P.O. Box 4400, Fredericton, NB E3B 5A3, Canada*

E-mail: karim@unb.ca

ABSTRACT

In the Islamic calendar, a new month starts the day after the first naked-eye sighting of the thin crescent, shortly after a luni-solar conjunction. The crescent can be observed after sunset in the general western direction. As the visibility depends strongly on the atmospheric conditions, the beginning of the Islamic new month cannot be predicted very precisely. Three times a year, because of religious events, officials of Islamic countries decree the beginning of the month on the basis of reports from witnesses who volunteer to watch the thin crescent. In the present study, we confront the dates as decreed by the officials with the astronomical data and criteria of earliest visibility. The data collection consists of 115 dates corresponding to the religious occasions in Algeria between 1963 and 2000.

We have found those dates to be largely inconsistent with the astronomical data. The rate of impossible cases (where the crescent was not present at all in the sky, let alone be visible) is about 17.4%. In more than half the cases, one or more of the absolute limits or all-time records of visibility was/were violated. And according to most or all the prediction criteria of visibility, there were about 80 % cases in error. We have also found that the error rates versus time correlate well with the sociological changes that occurred in Algeria between 1963 and 2000. Finally, we should emphasize that comparatively to Algeria, the error rates are higher in the Middle-East.

These results suggest that the officials must reconsider their approach in the determination of the beginning of the Islamic months.

Keywords: *Crescent visibility; Lunar Date Line; Lunar calendar; Islamic calendar*

1 INTRODUCTION

In the Islamic religion, religious dates and occasions are determined on the basis of the lunar calendar, which comprises 354 or 355 days. The month of Ramadan (the month of fasting) corresponds to the ninth month of the lunar year, and starts on the day following the observation of a new crescent, soon after a conjunction. The same rule holds for the day of 'fast-breaking', called 'Eid-ul-Fitr', which occurs a month later, again soon after a conjunction. As to the 'Sacrifice Feast', called 'Eid-ul-Adha', which corresponds also to the period of Pilgrimage in Mecca, it begins on the tenth day of the last lunar month (Dhul-Hijja). In all cases, on the night preceding the event, people watch with high attention the local horizon after sunset in an attempt to catch the thin new crescent. If the latter is seen, Muslims begin the feast (e.g. fasting, if that corresponds to the month of Ramadan) on the very next day, if not it is postponed to the following day. That is the approach used until today in practically all Muslim countries.

It is obvious, however, that this approach carries several drawbacks. One cannot, for instance, know the dates of these religious occasions in advance; it follows thus that each year a controversy (not to say anarchy) takes place, as some countries announce that the crescent has indeed been observed, while others announce the contrary. That translates then into one-day and sometimes two-day differences in the periods of fasting and in feast celebrations, even between neighbouring countries, when of course none of that can be justified. Moreover, public debate takes place, in which the masses and the media echo widespread criticism of this controversy, while officials attempt to justify their decisions. The officials unfortunately do not

make astronomical facts and data an important part of their decisions, and in fact 'observations' of the lunar crescent are often announced before conjunction! Regrettably, experience – and the statistics of the present work – show that this occurs with an alarming frequency in the Islamic world. Consequently, there results a deep confusion in the minds of people, most of whom are unable to grasp the various aspects of the problem; they do not know whether to doubt the scientific input on the matter or rather criticize the officials who are in charge of adopting and announcing the dates of the religious occasions.

This situation is due to a number of factors that we have already discussed in detail in a book published in Arabic a few years ago (Guessoum *et al.*, 1997). In our view the most important of these factors, however, is the fact that both the officials and the jurisconsults (scholars of religious law), base their decisions on simple ideas that date back to the early Islamic era and ignore the huge development that has taken place in astronomy in general, and on the lunar crescent visibility problem in particular. Indeed, the classical Islamic jurisprudence states that if two trustworthy Muslim individuals (and in some schools, one is enough) bear-witness(es) that they(he) have(has) seen the lunar crescent, then the religious date (or month) is decreed. People and officials have thus come to accept the (obviously) doubtful testimony of a layman on the observation of the crescent and reject the calculations and explanations of professional astronomers. Most of the time, the testimony is accepted without any verification; all that is required of the witness is that he be 'trustworthy' (i.e. not a known liar or drunkard, or such), when it is a fact that optical illusions – and we know that in this problem they are more probable than one normally would think – can mislead even the very careful.

This kind of behaviour may come as a surprise to the reader and to a more rational audience, as in the West, where questions that fall in the prerogatives of science have for a long time been freed from outside interventions. But in the Islamic world, those factors are to be taken into account when attempting to resolve these kinds of problems, where astronomy intermingles with sociology and religious jurisprudence. Those factors have made it very difficult to devise a 'crescent' calendar, that is one based upon the observation of the new crescent. The crescent calendar obviously differs from the usual lunar calendar (based upon the conjunction), and is much more difficult to put together. The latter is rigorous, and today it poses no practical problems since the motion of the Moon is now known to a remarkable precision.

The problem of the visibility of the lunar crescent is very old, with the first systematic studies dating back to the early Islamic era (which began in the eighth century). Faced with the problem, the astronomers of that time developed several criteria for the detection of the new crescent, in order to allow the precise prediction of the start of the new month (Guessoum *et al.*, 1997). Based upon a purely geometrical approach, the criteria that were devised remained imprecise, mainly because they did not take into account the conditions of observation, which prove particularly important. We shall later present in some detail the modern works on the problem; however, we wish to emphasize that neither the works of the astronomers of the Islamic period nor those of the contemporary astronomers have been taken into account by the jurisconsults. Perhaps the reader will deem our remarks a little biased, as they mostly target the jurisconsults, but we believe they are justified, for two reasons: first the unquestionable conviction that this kind of problem can only be thoroughly solved using a scientific approach, and secondly the results of this study which show to what extent the present approach is flawed.

The aim of this study is to show what kind of aberrations the present method used by the officials and jurisconsults is actually producing. For that, we have gathered the dates of all the Islamic feasts and religious occasions as they were adopted and applied in Algeria between 1963 and 2000; then we set ourselves to compare them with basic astronomical data and/or the various crescent visibility criteria (which we shall define and explain in later sections). And in that light – and without any pretensions from our part – our wish is to lead the officials and jurisconsults to review their method and approach, in other words to adopt a more rational and objective attitude *vis-à-vis* this problem. We should have liked to extend the study to other Muslim countries, in order for the conclusions to be more general, but we unfortunately could not obtain the necessary historical data. However, our personal experiences lead us to state that the results of such a wider study must not be essentially different from the present ones. Similar studies on other Islamic countries should be done, so that more thorough conclusions may be drawn.

The present paper has been structured as follows. Section 2 deals with the historical as well as recent developments on the problem of the visibility of the lunar crescent. In sections 3 and 4, we present and discuss the results of our investigation based on the astronomical and historical data. Finally, a brief conclusion is given in Section 5.

2 MAIN SCIENTIFIC WORKS AND RESULTS ON THE PROBLEM

2.1 The Islamic Era

The problem of the detection of the lunar crescent was known before Islam. The most ancient observations that have come down to us date back to the Babylonian era (Bruin, 1977). However, rigorous studies of this problem go back only to the Islamic period (eight to fourteenth centuries), for in Islam the calendar is based upon the Moon, and therefore the astronomers were faced with this real-life, practical problem to solve. Research, both theoretical and observational, was undertaken during that period; computational methods were thus devised, and several first-visibility criteria for the new crescent were proposed. Many of the great, famous astronomers of that time worked seriously on this problem, among them: Ibn Tāriq (eighth century), al-Khwārizmī (d. 863), al-Battānī (859-929), Ibn Yūnus (eleventh century), al-Tabarī (eleventh century), al-Tūsī (1207-1274). In the following paragraphs we wish to present a brief review of the criteria they developed; for a more thorough and detailed discussion, we refer the reader to the literature (Bruin, 1977; Hogendijk, 1988; Kennedy and Janjanian, 1965; King, 1988; and others).

The most famous first-visibility criterion of that era is that of the 12 degrees. This criterion states that the crescent can be observed only if the Moon sets at least 48 minutes after the Sun (i.e. that the arc of separation of the two luminaries along the equator is larger than 12°). Al-Khwārizmī used this criterion mainly to construct his prediction tables (Kennedy and Janjanian, 1965).

Another criterion, no less important, used by al-Tabarī (Hogendijk, 1988) states that the crescent will be seen if, at the time of moonset, the Sun has a certain depression (height below the horizon). The value of $9^\circ.5$ was often adopted.

We shall note that in these last two criteria, the azimuth of the Moon relative to the Sun is not taken into account, and thus both criteria depend upon only one parameter (or only one condition). More complicated criteria, combining several conditions, have been put forward by other astronomers. Al-Battānī included in his model both the azimuth and the Earth-Moon distance, which varies (Bruin, 1977). Ibn Yūnus considered the thickness of the crescent as well as the orbital velocity of the Moon (King, 1988), and, for the first time, noted the importance of meteorological and physiological conditions (*ibid.*).

All these criteria remained unsatisfactory, as they were all almost purely geometrical. Their lack of precision was not due to their usage of the Ptolemaic model, which constituted the basis of the works of all the astronomers of the Islamic era, but rather because they neglected the atmospheric conditions, even though some realized their basic importance.

2.2 The Modern Era

The problem of the visibility of the lunar crescent did not see any significant development for many centuries after the Islamic era. One had to wait until the beginning of the twentieth century, more exactly the year 1910, to witness the appearance of an important work, that of Fotheringham, who presented a new first-visibility criterion. A year later, Maunder proposed a slightly modified criterion on the same problem. These two new criteria had an important common characteristic with those of the Islamic era: they were all based on purely astronomical considerations, that is on the relative geometrical positions of the Sun, the crescent, and the observer. These criteria all had the same kind of formulation: the new crescent would be seen if the position of the Moon relative to the Sun satisfied such-and-such geometrical condition (or criterion).

Moreover, we can state that all the criteria adopted since the Babylonian era and until 1977 were of an astronomical nature, that is geometrical. For example, one may adopt as an elementary criterion the angular distance between the Sun and the Moon (the phase angle, for

example, which corresponds to the angle between the two directions Earth-Moon and Earth-Sun) in any appropriate co-ordinate system. Ancient observations suggested that the crescent appears (or disappears) to the naked eye when the phase angle surpasses a value of some 173 degrees. Other observations indicated that the crescent becomes visible if about 1% of the surface of the lunar disk is lighted (in appearance); this translates to a phase angle of about 169 degrees. (Note that between these two values, there corresponds an average interval of time of about 7 to 8 hours – an indication of how various criteria gave quite different results.)

Another parameter that was often considered as a good predictor of the detection of the crescent is the interval of time Δt between sunset and moonset (called moonset-lag); this is the 'Babylonian' criterion (which in fact probably goes back to Indian observations), which states that the lunar crescent will only be seen if Δt is larger than 48 minutes. However, an analysis of a set of 201 observational data (Schaefer, 1988) stretching over more than 130 years (most of the observations having been made by Julius Schmidt in Athens during the nineteenth century), that analysis showed that the shortest interval ever recorded between sunset and moonset for an observed crescent is 22 minutes. The results also show, however, that the crescent is very difficult to observe when the Moon sets less than half an hour after the Sun.

A third parameter often taken as a predictor of the visibility of the crescent is the 'age' of the Moon (the elapsed time since the last conjunction). The ancient civilizations believed that one had to wait at least 24 hours after the conjunction to be able to see the new crescent, but an analysis of all recorded observations up to 1992 (Schaefer *et al.*, 1992) showed that the record of the youngest moon ever observed by a naked eye was then held by Julius Schmidt (1871): 15h 24min (this record was broken in 1990 by John Pierce: 15h exactly). For an observation made with binoculars, the record was broken in 1989: 13h 28 min; and for an observation made with a 20-cm telescope, the record was broken in 1996 by Jim Stamm: 12h 6 min. This criterion, called 'age criterion', is very useful for the acceptance (and especially the rejection) of a testimony, but it is very poor in predicting the start of the month.

The other criteria proposed and used until 1977 all rested on a generally simple astronomical rule related to the angular separation between the Sun and the Moon.

Fotheringham's (1910) criterion simply considered the difference in height (called 'arc of vision') between the two celestial objects, and stated that the crescent can be seen if that relative height is greater than 12 degrees. When the relative azimuth of the two objects is quite large, this limit of 12° is reduced (to 10° for instance, when the relative azimuth is 20°). This criterion was established empirically by Fotheringham, on the basis of 76 observations, gathered mostly by Julius Schmidt between 1859 and 1880.

In 1984 Ilyas proposed another criterion of the same kind (a critical condition between the height and the azimuth). However, Ilyas was not so much concerned with obtaining a condition for a local observation, but rather to globally determine the regions where the new month would begin (on a given date) and those where it would have to be postponed to the following night. For this purpose, he took the whole Earth map and, taking some 300 points one by one, he tried to determine for each latitude the point where the crescent would first be seen. He thus defined a line of first-visibility, which he called a Lunar Date Line; this he did with the help of computer programs which allow the computation of the Moon's position (in the astronomical and local sense) at the time of sunset, the precise moment of conjunction, etc.

We note that Doggett and Schaefer (1992) have shown that all of these geometrical criteria remained poor in precision, at least in the determination of the Lunar Date Line.

The astronomical approach adopted by the Muslim scholars as well as the western researchers at least until 1977 proved unable to solve the problem of the visibility of the lunar crescent in a definitive and satisfactory manner. The biggest flaw of this method was that each criterion thus proposed did not seem to be valid for very different regions of the world, as they were often empirically constructed from observational data gathered from a specific site (say Athens). Indeed, the observational conditions for Mecca during the winter, Karachi during the spring, Marrakech during autumn, and London during the summer time could hardly be the same. In fact, it is today accepted as a given fact that the visibility of the crescent depends crucially upon the local conditions. Most of the astronomers who worked on this problem were undoubtedly aware of this aspect, but they probably left it out of their models because of the great inherent difficulty in taking it into account.

The original model of Bruin (1977) tried to take these factors into account by pioneering a new approach to the problem. Bruin proposed to use the ratio of the brightness of the Moon and that of the sky at a given moment as perceived by an observer; this takes empirically into account the limits of visual detection, the effects of atmospheric transmission, as well as other secondary factors. Knowing the limit of detection of the human eye, it is possible to deduce if the Moon can or cannot be observed in each case and situation. So the problem is transformed simply into a calculation of the brightness of the Moon and the sky for the time and place of interest, then computing the apparent contrast between the two, and finally comparing this with the limit of visual detection.

It is obvious that the astrophysical model of Bruin is very different in its approach from the (rather simple) models or criteria proposed by the astronomers who dealt with the problem before him. However, we must note and emphasize the fact that this model was taking the observing conditions only globally and indirectly, and therefore was suffering of the same flaw and defect as the astronomical criteria. One still needed to find a way to introduce the absorption effects, corresponding to the observing conditions, for a given place and time. In the following years, some corrections were introduced on Bruin's astrophysical model, including the reflectivity of the lunar soil, the atmospheric transmission, the seasonal effects, the atmospheric observational conditions, and the human eye's capacity to detect a given contrast.

The most complete and sophisticated model of this kind to have been proposed and constructed to this day is that of Schaefer (1988, 1990). In this model, one computes a quantity denoted by R , the logarithmic ratio between the actual brightness of the Moon to the required brightness of the Moon for it to be observed in the specified conditions: $R = \log [R_{\text{calc}}/R_{\text{min}}(\text{vis})]$, which is in effect a logarithmic measure of the lunar visibility. The atmospheric, geographic, and physiological factors go into the latter quantity $R_{\text{min}}(\text{vis})$. We may consider R as a measure of the probability of seeing the crescent in given observing conditions.

There are several parameters and factors that go into this model; however, it appears that the most influential parameter in determining the probability of observing the crescent is the degree of pollution and humidity of the site. The relative humidity is an essential factor in this model, because it induces the atmospheric haze which absorbs the flux of light coming from the Moon. It is obvious that the thicker the haze, the more difficult the observation of the crescent will be; it was noted, for example, that in Los Angeles, where the smog (a layer of smoke and fog in the city sky) is substantial, very few people could see the young Moon, compared to the neighbouring regions. Similarly, stratospheric dusts constitute a major obstacle to the lunar visibility, the dust absorbing and diffusing non-negligible quantities of lunar photons. In desert regions, for example, sand storms carry large amounts of dust into the air and atmospheric layers, which translates into a relatively high extinction factor of the incident light flux.

2.3 Observational Data

As models were being produced with greater numbers and frequency and were now based upon astrophysical and atmospheric considerations, it was becoming more and more necessary to evaluate them on experimental bases; in other words, observational campaigns were becoming crucial. We note that the authors of this work had thought of performing such a task, by organizing observing campaigns in Algeria for the religious occasions mentioned earlier, such as the beginning of the month of Ramadan and the 'fast-breaking feast'; in fact, we had submitted to the local press calls for widespread group observations, but the social conditions unfortunately did not allow for such endeavours to succeed. We also intended to call on the Arab and Muslim religious institutions to supply us with information on the actual dates of religious occasions during the last 20 or 30 years, in the aim of confronting them with astronomical calculations and thus producing results and propositions as rigorous and precise as possible. The present work is thus a partial realization of those objectives, as we have been able to obtain that kind of historical data (the start of the months of Ramadan, Shawwal, and Dhul-Hijja) for Algeria since its independence (1962), and we here present the results of their confrontation with the astronomical calculations and the conclusions that we draw from that.

However, we were very pleasantly surprised to learn that just such campaigns had been thought of by Ilyas around 1989 and that a large network for the execution of the International

Islamic Calendar Programme had been progressively set up throughout the largest possible part of the Islamic world. (Details of the Programme and its progress so far can be found in Ilyas, 1997, and Ilyas and Kabeer, 2000.)

And we were even more surprised to learn that many such campaigns have been conducted in the same period in the United-States at the instigation of Schaefer. Five such vast campaigns were thus conducted (in 1987 April, 1988 July, 1989 April, 1989 May, and 1990) with the support of the American press and media (both general and scientific).

The results were truly impressive: no less than 2500 volunteers sent in reports on their observations, containing very useful information on the conditions and results of their observations, which immediately translated into an improvement of the list of observations made since 1859 from 201 to 251 independent observations. But much more important than that is the fact that these observation campaigns have been conducted and supervised by experts, which made the surveys much more precise and the information thus collected much more useful. Several aspects of the problem have thus been statistically treated for the first time: i) determination of successful observational percentages in the aim of comparing the various models; ii) filtering the principal factors from the secondary ones in the problem; iii) study of some aspects, such as the exact length of the crescent at the moment of observation, either by naked eye or by instruments (binoculars, telescopes, cameras, etc.); iv) precise measurement of the total time of actual observation, again either by naked eye or by instruments.

The results of these observation campaigns confirmed *experimentally* that, apart from the atmospheric visibility conditions, the probability of observing the crescent increases gradually as one goes west, a fact known for a long time (since it is simply due to the Moon's motion around the Earth). To make the point clearer – as it has direct consequences on the conclusions we shall draw later in this work – if at sunset in Saudi Arabia the crescent's age is 13 hours, it will be practically impossible to see (as the all-time record is 15h, as stated earlier), while in Morocco it will be 16 or 17 hours old, and its observation will thus be possible, though extremely difficult. If, on the other hand, the crescent is seen in Saudi Arabia, meaning its age is more than 15 hours, it will be over 18 hours old in Algeria and Morocco, and its observation, aside from weather conditions, should be even easier.

The observation campaigns resulted in several other important conclusions, concerning for instance the improvement that the usage of an instrument brings, and also the important light shed on the possibility of human error in the claim of observation itself.

Indeed the most important result to arise from the analysis of the observation data collected in those campaigns is, in our view, the scientific deduction that there is a probability P_0 that a person, otherwise objective and in good faith, claiming to have observed the new crescent cannot possibly be correct. In fact, we had already pointed out, in earlier articles, that such a probability must exist, for various reasons (illusions, ignorance, etc.), and we had even proposed to quantify it on statistical observational bases (Meziane and Guessoum, 1991, 1992). Doggett and Schaefer (1992) have in fact shown that there exist about 15% of 'positive errors', which are cases where the crescent cannot be observed and people claim to have seen it, and 2% of 'negative errors', that is cases where the crescent is trivial to see and people claim not to have seen it. Obviously it is the 15% value, corresponding to the definition of P_0 , which interests us; for that simply means that in order to have 2 people claiming (in error) that they have seen a crescent on a given night, all we need is to assemble a group of a dozen persons, even in small groups! This conclusion is obviously laden with consequences with regard to the Islamic jurisprudence criteria (which we mentioned in the introduction) concerning the adoption of testimonies and the proclamation of a religious date. We must, however, warn that this 15% value is very approximate, as it was deduced from a very small set of observers (only about 20) all in one site, and we need therefore to conduct other campaigns, especially in Muslim countries, in order to better estimate this error percentage, as we had proposed in the above-mentioned articles.

Another very important aspect of the problem, as we shall see later, resides in the knowledge of the length of the crescent at the moment of observation. We have known for almost 70 years (Danjon, 1932) that the young crescent, when seen with the naked eye, hardly ever extends on a 180° arc. In fact, Danjon showed that the smaller the phase angle (defined

earlier) the shorter the crescent arc, measuring 90° when the Moon-Sun separation is only 10° , and vanishing when the two objects are within 7° of each other. This is the famous Danjon limit, which has often been used as a crescent visibility criterion. We must first note that this limit applies only to human (naked-eye) observations; that is telescopes and cameras are subject to a similar limit, but not necessarily the same value (7°). Secondly, and more important still, we wish to note the important remark made by Ilyas with this regard, namely that this 7° value is very uncertain; Ilyas in fact suggested that a limit closer to $10^\circ.5$ be adopted (Ilyas, 1981, 1994). Why? Because the data upon which Danjon's analysis and deduced value rest contain very few points in the (critical) domain between 0° and 20° , and only one for angles less than 10° ; thus the extrapolation to small angles can be made in quite a different way, leading to a different limit than Danjon's. Ilyas showed that if that crucial one point below 10° were cancelled or thrown out, the limit would automatically be raised to $10^\circ.5$ (Ilyas, 1981).

This is not at all, as it might appear to the reader, a purely academic and useless debate between scientists, each claiming that his analysis is the correct one. For this 7° limit has been very largely adopted as a prediction criterion concerning the visibility of the lunar crescent. In fact, in 1978 a conference was held in Istanbul (one of the most important to have been organized in the Islamic world on this problem), a gathering of jurisconsults and astronomers in the aim of solving both the problem of predicting the dates of religious occasions (such as Ramadan and Eid) and the more general (and more important) problem of the Islamic calendar. A committee was set up to produce a set of 'recommendations', but these soon became cited more as 'decisions'. Unfortunately it appears that this committee poorly studied the problem and decided what follows: "the crescent will be considered as visible if the Moon is more than 8° from the Sun and higher than 5° with respect to the local horizon."

From where did these values – and this 'new' criterion – come? Ilyas, surprised as we were by this 'recommendation', wrote to the committee's chairman asking for clarification and referencing and received the following reply: "Concerning the 8° , the committee adopted Danjon's limit (7°) and decided to add 1° for 'safety'; as to the height of 5° , that was deduced from observational data collected and filed at the Kandili Observatory."

However, as noted by Ilyas, Danjon's limit is a necessary but not sufficient condition for crescent visibility, meaning that the Moon may be 12° or 15° away from the Sun and not be seen, not to mention the fact (explained above) that the 7° value itself is a disputed one! Secondly, the Kandili observations have been made at a site located at more than 40° of terrestrial latitude, so they can hardly be generalized. Finally, we must note that these two conditions have been casually juxtaposed, without the slightest consideration of any possible relation or correlation between the two. This example (or anecdote) is enough to show how a poor understanding of the problem can lead to erroneous and dangerous proclamations!

But one may ask: does such an erroneous criterion (like the one stated by the Istanbul conference) have an important consequence on the determination of the religious dates? In fact, the above Istanbul criterion translates into a more than seven-hour advance in the starting of a month, or put in another way, it leads to a lunar date line situated more than 100° east of the correct one! In practice thus, if the correct criteria declare the month to begin some day in all regions west of Algeria, then the Istanbul criterion wrongly makes the month also begin in the large region situated between Indonesia and Algeria! This is undoubtedly a good real-life example of how the problem has been misstudied and mishandled.

Lastly, we wish to remind ourselves and the reader that the thin new crescent always takes a concave orientation, meaning that the centre of its approximate semi-circle is always above the crescent, or stated in another way, that its two ends always point (partly or completely) upward. In fact, one may compute in advance the degree of orientation of the crescent to the East or to the West; we usually adopt the symbols of the watch to describe the orientation: for example, 2h-7h or 4h-9h. This allows us thus to also confront the observational data or reports, especially the doubtful ones, to the predicted orientation in order to filter out the wrong ones. This is one of the tests we had proposed in earlier articles for the acceptance or rejection of reports of observations (Meziane and Guessoum, 1991, 1992), and it is in fact one of the arguments used by Doggett and Schaefer (1992) to estimate the probability of positive errors (15%), and also by Schaefer *et al.* (1992) to reject the 'new records' of crescent observations

reported by Durrani (1990), according to whom two groups of observers established a new record when they "observed" the new crescent for the start of Ramadan in 1990 May.

2.4 Criteria for Accepting or Rejecting 'Positive' Observations

As is well known to astronomers (professionals as well as amateurs), the observation of the new crescent is not an easy task. Several astronomical and, more importantly, atmospheric conditions must be satisfied for the thin crescent to be visible. We have also often stressed the fact that it is very easy, even for experienced observers, to commit errors of appreciation when attempting to spot the crescent. But we astronomers have now obtained the necessary scientific tools that allow us to filter out reports of observation and thus put an end to the confusion presently prevailing between different Muslim countries and often even within the same country.

If the prediction of the crescent observation is not an easy thing, which explains the existence of various criteria for it, the rejection of an erroneous observation is in general not very difficult. That is because an incorrect observation cannot contain all the correct characteristics of the new crescent (position, timing, orientation, etc.) which one may compute and determine in advance. For instance, we know that the new crescent has to this day never been seen within less than 22 minutes of sunset, that no one has ever observed a moon younger than 15 hours (after conjunction), and that the Moon is practically impossible to see if it is less than 7° away from the Sun. These three conditions alone would be sufficient to eliminate a large part of erroneous claims of observations, especially when these are completely ridiculous, such as when they are claimed to have been made before conjunction or after moonset! A simple check suffices to throw away such a report. The aim of this paper is precisely to quantify the percentages of error made in Muslim countries such as Algeria merely because such simple rules are not followed.

3 THE HISTORICAL AND ASTRONOMICAL DATA

In order to perform our comparative study, we needed two kinds of data. The first collection of data, which we termed 'the historical data', consisted of the actual dates as adopted for the religious occasions we have been considering, namely the start and end of Ramadan, and the Sacrifice Feast (or, indirectly, the start of the month of Dhul-Hijjah), from 1963 to 2000 January. For each lunar year we therefore have 3 dates (or data). But since the lunar year consists of only 354 or 355 days, it may happen that we get 4 dates during one Julian year, as was the case, for instance, in 1968 and 1997. These historical data were obtained by consulting the archives of the Algerian press, mainly from the daily newspapers *El-Moudjahid*, *E-Chaab*, *El-Djournhouria*, and *Alger-Republicain*.

But in order to analyse these data, we needed the relevant astronomical information, which we computed for the city of Algiers, that is longitude $+3^\circ 2'$ and latitude $+36^\circ 42'$. (See the remark below.)

Lunar and solar ephemerides can be obtained by using many computer programs and software, which today are available to the amateur as well as the professional astronomer. For our work, we used the Interactive Computer Ephemeris (ICE), which is available from the Nautical Almanac Office (of the U.S. Naval Observatory). This program gives more than satisfactory results, with an adopted refraction of $34'$ at the horizon.

One last remark before presenting our analysis and results. It would have been interesting to know, for each date of the past religious occasions, where the crescent was 'observed', the precise location as well as the meteorological conditions then and there, in order for the comparative analysis to be more precise. Indeed the reader may object that an observation we may declare erroneous may actually be possible if it was made at an extreme western point of Algeria; however a quick calculation will show that such local considerations induce only slight differences between Algiers and others cities or regions of Algeria. Moreover, we could not find any such specifically-local information, for in Algeria the oral tradition still prevails in many aspects of social life (such as this one). Therefore we have used the astronomical data as computed for the city of Algiers.

4 RESULTS AND DISCUSSION

The results of this comparative study between the historical data and the astronomical predictions and criteria for the observation of the crescent are summarized in the histograms (Figures 1-5) shown below. However, in order to correctly understand the methods we have used in obtaining our results, and also in order to better appreciate their meaning and implication, we should like to provide the reader with a few explanations and remarks.

We have adopted two types of criteria in our comparative analysis: the first group consists of three 'rejection criteria', that is limits or records that are well established and accepted by the experts in the problem; the second group consists of two 'prediction criteria' for the observation (or visibility) of the crescent on a given evening of interest.

The three rejection criteria are the following:

- 1) The moon-age criterion, which states that the crescent has never been observed – in a scientifically verified and credible manner – when its age (i.e. the elapsed time between conjunction and the moment of observation) was less than 15h, a record broken by John Pierce in 1990 after it was held by Julius Schmidt since 1871, according to the analysis of Schaefer *et al.* (1994).
- 2) The moonset-lag criterion (the elapsed time Δt between sunset and moonset), which states that the crescent has never been observed – again in a scientifically verified and credible manner – when this elapsed time was less than 22 minutes (Ilyas, 1981). In fact, for median latitudes, such as Algeria's or most of the Muslim lands', this limit, according to Ilyas, is closer to 30 minutes. However, in order to be as strict and rigorous as possible in our results and conclusions, we preferred to adopt the absolute world limit of 22 minutes in our analysis.
- 3) Danjon's limit, which states that the crescent has never been observed – again in a scientifically verified and credible manner – when the angular distance between the Sun and the Moon (at the time of sunset) was less than 7° . We did explain above that some researchers, such as Ilyas, take a stronger limit (around 10°), but here also we have preferred to adopt the more conservative and largely accepted limit of 7° in an effort to insure a greater objectivity in our analysis.

As to the prediction criteria for the observation of the crescent, we have chosen the following two (for the reasons explained below) among the dozen or so that can be found in the literature:

- 1) Ibn Tāriq's criterion, an astronomer of the eighth century, first because we wished to show to what extent the religious occasions are wrongly determined today even by ancient Muslim standards; and we have chosen Ibn Tāriq's compared to Ibn Yūnus', Tabarī's, al-Khwārizmī's or others', because according to Doggett and Schaefer (1994), it is the most precise of all the criteria of the Islamic era. According to Ibn Tāriq, the new crescent is observable if, at the time of sunset, one of the two following conditions is satisfied:

$$\Delta t > 48 \text{ min} \quad \text{and} \quad \text{Ang. Sep.} > 11^\circ.25$$

or

$$\Delta t > 40 \text{ min} \quad \text{and} \quad \text{Ang. Sep.} > 15^\circ.$$

- 2) Ilyas's criterion, although it is not the most precise or the most sophisticated (Schaefer's is), simply because it is one of the most recent of the geometrical criteria (those based upon the angular relationship between the Sun, the Moon, and the observer at the time of sunset), and because it is, according to its author, the result of an attempt at unification between the geometrical approach and the astrophysical approach of Bruin (1977). It is also very simple and easy to apply.

We thus constructed a comparative table between the historical data and the astronomical data. Out of these comparisons we deduced our first important result: the number of cases where the beginning of the month was declared (i.e. some observation of the crescent was evidently accepted) while the conjunction had not yet taken place and/or the Moon had set before the Sun; in other words, that the observation of the crescent was strictly impossible. Out of 115 cases in all, we have counted 20 such impossibilities, a rate of 17.4%.

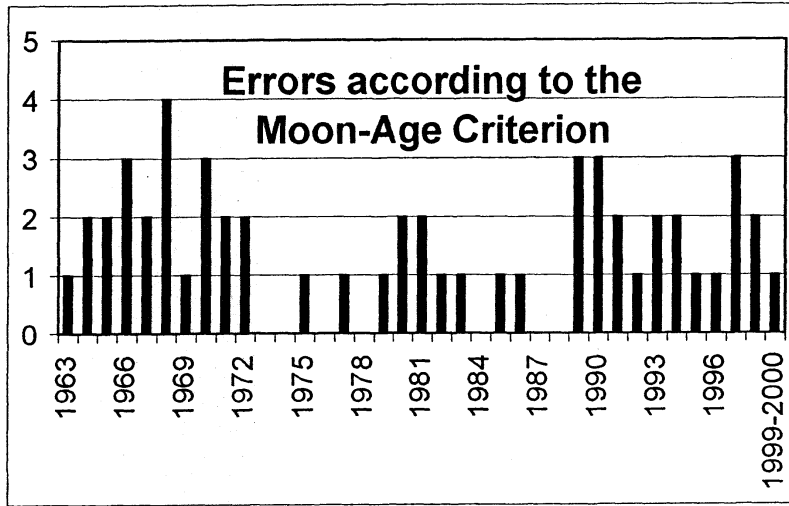


Figure 1. Number of error cases according to the Moon-age criterion, for each year from 1963 to 2000.

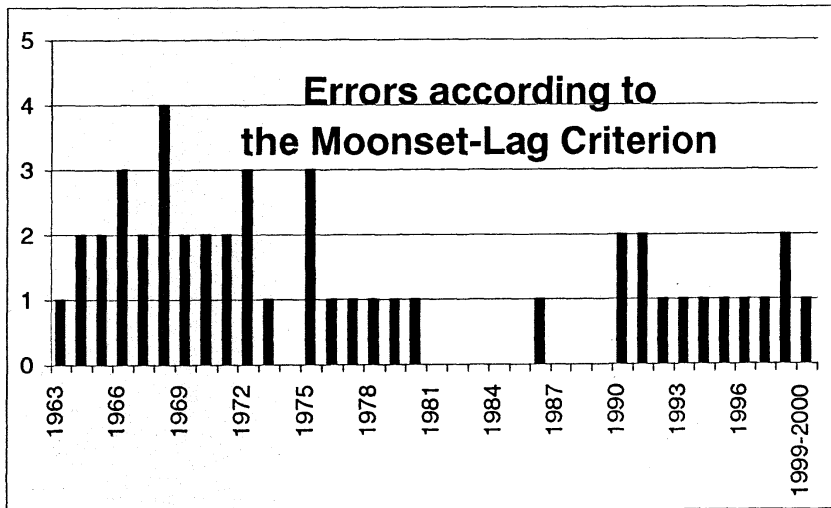


Figure 2. Number of error cases according to the Moonset-lag criterion, for each year from 1963 to 2000.

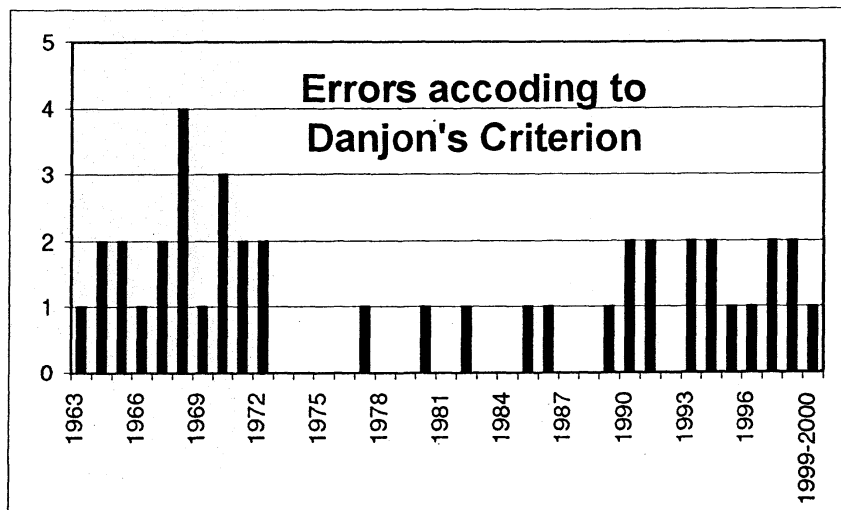


Figure 3. Number of error cases according to Danjon's criterion, for each year from 1963 to 2000.

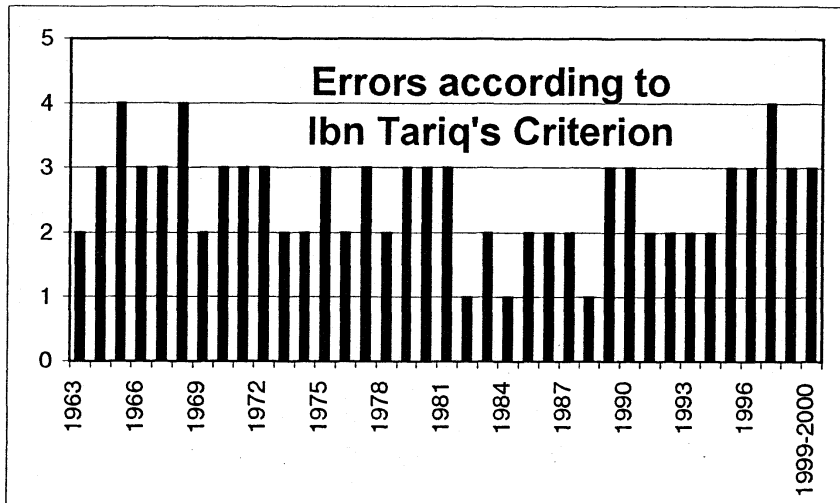


Figure 4. Number of error cases according to Ibn Tāriq's criterion, for each year from 1963 to 2000.

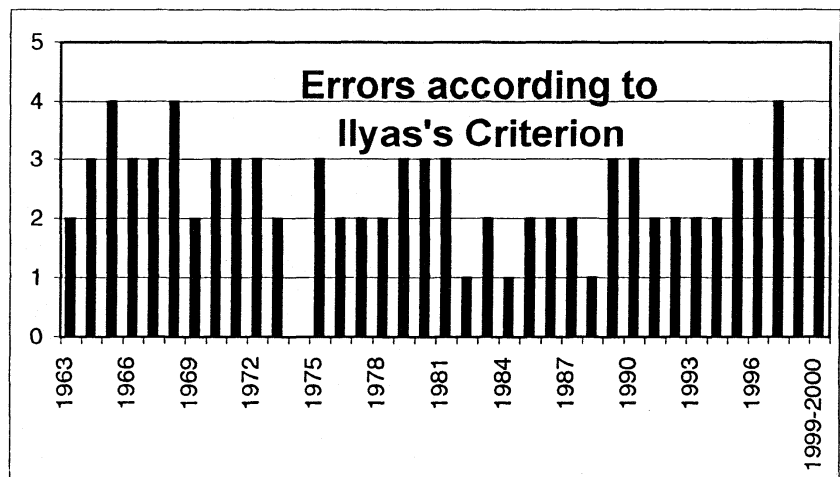


Figure 5. Number of error cases according to Ilyas's criterion, for each year from 1963 to 2000.

But the most important work of analysis was undertaken on the basis of the two groups of criteria described above, from which we have obtained several interesting results. First we have counted the cases where the crescent could not be seen according to each criterion; secondly, and with the aim of studying the progress made (or lack thereof) by Algeria with regard to this problem, we have computed the rates for two periods, 1963-1990 and 1991-2000. The results, which we shall discuss below, are given in Table 1.

These results speak for themselves: in almost half the cases, one or more of the absolute limits (or records) was/were violated, while according to the prediction criteria in 4 out of 5 instances the officials who decreed the start of the month were in error; moreover, these numbers do not take into account the atmospheric conditions which, if unfavourable, can force the postponing of the new month by one day, even though the astronomical conditions may allow for the observation of the crescent in principle, thereby raising the error count.

Moreover, when comparing the results for the three time periods of interest (1963-1990; 1990-2000; 1963-2000), we see clearly that the situation has got worse; indeed, the rates of error for the last decade, when astronomical studies and publications on the problem have increased manifold, are much higher than their counterparts in the earlier years. Most staggering is the doubling of the rate of impossible 'sightings' between the two periods 1963-1990 (when it was *only* 13.3%) and 1991-2000 (when it reached a very high 28.1%)!

Table 1: Numbers and percentages of error cases according to the 3 rejection and the prediction criteria, computed for the three time periods of interest: 1963-1990; 1991-2000; 1963-2000.

Criterion	Number and Percentage of Error Cases between 1963 and 1990	Number and Percentage of Error Cases between 1991 and 2000	Number and Percentage of Error Cases between 1963 and 2000
Moon Age	36/83 = 43.4%	18/32 = 56.3%	54/115 = 47.0%
Moon Lag	31/83 = 37.3%	13/32 = 40.6%	44/115 = 38.3%
Angular Separation	26/83 = 31.3%	15/32 = 46.9%	41/115 = 35.7%
Ibn Tariq	67/83 = 80.7%	27/32 = 84.4%	94/115 = 81.7%
Ilyas	64/83 = 77.1%	27/32 = 84.4%	91/115 = 79.1%

Moreover, when comparing the results for the three time periods of interest (1963-1990; 1990-2000; 1963-2000), we see clearly that the situation has got worse; indeed, the rates of error for the last decade, when astronomical studies and publications on the problem have increased manifold, are much higher than their counterparts in the earlier years. Most staggering is the doubling of the rate of impossible 'sightings' between the two periods 1963-1990 (when it was *only* 13.3%) and 1991-2000 (when it reached a very high 28.1%)!

Then, in order to better investigate this overall trend, we plotted histograms counting the number of errors for each year, for reasons that we explain below. As was stated earlier, in principle there are 3 religious occasions to determine each year (the beginning and end of Ramadan and the start of the month of Dhul-Hijjah), and thus a maximum error number of 3 each year. However, in 1965, 1968, and 1997 there were 4 occasions, because the lunar year is shorter by 10 or 11 days than the solar year. That is why on our histograms, one may find 4 errors in a given year instead of the maximal 3.

Our results can thus be read directly from the histograms. We shall simply note that the number of years where all three occasions were incorrectly decreed is truly alarming, especially if we base ourselves on the prediction criteria.

What is the value of these histograms? Their value is mainly sociological. We wanted to see whether the Muslim society (taking the Algerian society as a sample) is making progress in solving this problem or not. If the Muslim society had been progressing on this question, we would have seen on the histograms a gradual decrease in the number of errors made each year. (By error we particularly mean the violation of one of the three limits/records.) However, the histograms do not show that, or at least not clearly; they show that in Algeria the problem has gone through 3 periods: the first, between 1963 and 1972, when the number of errors was practically maximal each year (twenty or more out of 32 dates in all); the second, from 1973 to 1988, when the number of errors was rather limited (around ten out of 48 possible cases); and the third, from 1989 to 2000, when the number of cases suddenly jumped up very sharply (about 20 out of 35 possible cases). In fact, if one considers the prediction criteria (Ibn Tariq or Ilyas), the average error is found to be quasi-constant at about 2.5 per year.

We should like to suggest here a possible sociological explanation for these results. After independence (1962) in Algeria, the absence of experts (especially astronomers) on this problem probably made the officials adopt the dates decreed in the Middle-East, where, according to our personal experience, the cases of error are more numerous and flagrant than in the western part of the Muslim world. Then, in the seventies and with the beginning of a correct understanding

of the nature of the problem and of the methods needed to resolve the confusion, the Algerian institutions probably called on the experts to help them and propose credible calendars, which translated into a substantial decrease in the number of errors over a period of 15 years. Finally, toward the end of the eighties, and with the resurgence of fundamentalist religious stands and the insistence that the scientific computational methods be rejected in favour of the traditional laymen naked-eye observations (without even any verification or confrontation), a drastic increase in the number of error cases was immediately witnessed.

Two remarks before concluding. First, we wish to recall that the atmospheric conditions have not been taken into account in this study. Our analyses could have been more accurate if we had gone back to the meteorological archival reports and checked whether an 'observed' crescent could be rejected on such grounds (even if it does not violate any of the astronomical conditions). Schaefer did do such a work, in a different context, for two American locations and the following periods: 1930-31, 1935-36, and 1940-41; this allowed him to reject a certain number of 'positive' cases. Error percentages would then automatically have been higher.

The second remark we should like to emphasize is a more important one and concerns the rates error that would be found if a similar study were performed in the Middle-East; and here we do strongly recommend that it be conducted. Error rates in the East are necessarily higher than those obtained in this research (for Algeria) because, due to the Moon's rotation around the Earth, if the observation of the crescent turns out to be impossible in Algeria, then it is automatically impossible in all eastern lands, except for slight latitude effects. But in our personal experience we have never known a case where the month was decreed in the East after it had been declared in the West; most often it is the contrary – by a day or more! Therefore we expect the average number of errors each year to be close to 3 in the East! Furthermore, because of the distance and time-zone difference between Algeria and the East, there must be many more cases where the start of the month was decreed there while the conjunction had not yet occurred; therefore the percentage of totally erroneous cases (flagrant impossibilities) there must be much greater than the 17.4 % determined for Algeria!

5 CONCLUSION

Facing the total confusion that we see and live in the Muslim world today concerning the problem of correctly determining the dates of religious occasions, we decided to scientifically investigate the historical dates adopted in Algeria between 1963 and 2000. The results of this work show that the error rates obtained do not depend upon the visibility criterion being used, since both ancient prediction criteria (such as Ibn Tāriq's) and recent ones (such as Ilyas's) give practically the same result: around 80 % error cases. We also should like to note that the percentage of cases presenting an absolute impossibility was found to be as high as 17.4%. And, very importantly, we have explained that error rates in the Middle-East are necessarily larger (perhaps we might say much larger) than those obtained for Algeria.

These must, in our view, be urgently considered by the officials as a resounding no-confidence vote on the part of astronomy regarding the methods they (the officials) have been adopting. These results should also draw the attention of the jurisconsults that their approach contains a much-too-large intrinsic error probability, and must therefore be modified and improved. This paper was deliberately written in a simple non-technical style for it to be accessible to the largest educated public. It is our hope that officials and jurisconsults finally come to the understanding that there are questions in which science has a lot, if not all, to say, and that they cannot continue to ignore the tremendous development of human activity and science in such fields where they (the officials) continue to claim an exclusive control.

6 ACKNOWLEDGEMENTS

We should like to thank M al-Atbi for pertinent remarks on the original manuscript and B Schaefer for helpful comments and suggestions.

7 REFERENCES

- Bruin, F., 1977. The First Visibility of the Lunar Crescent. *Vistas in Astronomy*, **21**:331-358.
 Danjon, A., 1932. Jeunes et Vieilles Lunes. *L'Astronomie*, **46**:57-66.
 Doggett, L.E., and Schaefer, B. E., 1989. Results of the July Moonwatch. *Sky & Telescope*, **77**:373-375.

- Doggett, L.E. and Schaefer, B. E., 1994. Lunar Crescent Visibility. *Icarus*, **107**:388-403.
- Durrani, M.N., 1990. A Still Younger Moon. *Sky & Telescope*, **79**:582.
- Fotheringham, J.K., 1910. On the Smallest Visible Phase of the Moon. *Monthly Notices of the Royal Astronomical Society*, **70**:527-531.
- Guessoum, N., al-Atbi, M. and Meziane, K., 1997. *Ithbāt al-Shuhūr al-Hilāliyya wa Mushkilat at-Tawqīt al-Islāmī* (The Determinations of "Crescent" Months and the Islamic Calendar Problem). Dar al-Taliaa, Beirut.
- Hogendijk, J.P., 1988. Three Islamic Crescent Visibility Tables. *Journal for the History of Astronomy*, **19**:29-44.
- Ilyas, M., 1981. Lowest Limit of ω in the New Moon's First Visibility Criterion of Bruin and its Comparison with the Maunder Criterion. *Quarterly Journal of the Royal Astronomical Society*, **22**:154-160.
- Ilyas, M., 1984. *Islamic Calendar, Times, and Qibla*. Berita Publications, Kuala Lumpur.
- Ilyas, M., 1994. Lunar Crescent Visibility Criterion and Islamic Calendar. *Quarterly Journal of the Royal Astronomical Society*, **35**:425-461.
- Ilyas, M., 1997. *Astronomy of Islamic Calendar*. A.S. Noordeen, Kuala Lumpur.
- Ilyas, M. and Kabeer (Eds.), 2000. *Unified World Islamic Calendar: Sharia, Science and Globalization*. IICP/University of Science Malaysia, Penang.
- Kennedy, E.S. and Janjanian, M., 1965. The Crescent Visibility Table of al-Khwārizmī's Zij. *Centaurus*, **11**:73-78.
- King, D.A., 1988. Ibn Yūnus on the Lunar Crescent Visibility. *Journal for the History of Astronomy*, **19**:155-168.
- Meziane, K. and Guessoum, N., 1991. La Visibilité du Croissant Lunaire entre le Fiqh et la Science. *El-Moudjahid (Algeria)*:8029-8032.
- Meziane, K. and Guessoum, N., 1992. L'Observation du Croissant Lunaire. *L'Eveil (Algeria)*, March.
- Schaefer, B.E., 1988. An algorithm for Predicting the Visibility of the Lunar Crescent. In I. Ahmad (ed.), *Proceedings of the Lunar Calendar Conference*. II-1-12, IIT, Herndon.
- Schaefer, B.E., 1990. *Lunar Cal*. Western Research Company, Inc.
- Schaefer, B.E., 1991. Length of the Lunar Crescent. *Quarterly Journal of the Royal Astronomical Society*, **32**:265-277.
- Schaefer, B.E., 1996. Lunar Crescent Visibility. *Quarterly Journal of the Royal Astronomical Society*, **37**:759-768.
- Schaefer, B.E., Ahmad, I.A. and Doggett, L.E., 1992. Records for Young Moon Sightings. *Quarterly Journal of the Royal Astronomical Society*, **34**:53-56.



Nidhal Guessoum is an Algerian astrophysicist. He received his Ph.D. in 1988 from the University of California at San Diego, and spent two years as a research associate at the NASA/Goddard Space Flight Center; he continues to do research on gamma-rays and collaborate with colleagues in various centres. He lived and worked in Kuwait for several years, and currently he is an Assistant Professor of Physics at the American University of Sharjah, UAE. He has published dozens of papers and articles on astronomical and other science-related issues in Arabic, English, and French; on the topic of the visibility of the crescent and its importance for the Muslim world, he and Karim Meziane have published a book and several articles/papers in Arabic and French.

Karim Meziane received his doctorate in Astronomy in 1988 at the University of Toulouse, France. He worked for a few years as a research scientist at Algiers' Observatory. He also spent a few years working at the Space Sciences Laboratory in Berkeley, USA. He is now an Assistant Professor of Physics at the University of New-Brunswick, Canada. His main research interests are in particle acceleration by magnetohydrodynamic shocks.

Six stages in the history of the astronomical unit

David W Hughes

Department of Physics and Astronomy,

The University of Sheffield

Sheffield S3 7RH, UK

E-mail: d.hughes@sheffield.ac.uk

Abstract

Giovanni Antonio Rocca wrote "The problem of solar distance and parallax was one of the most important in astronomy, well worth a lifetimes work by any astronomer." (see Ricciolo, 1651:732). This paper briefly reviews the values obtained for the Earth-Sun distance throughout the history of astronomy, and divides the investigation of the astronomical unit into six stages. It is suggested that a similar six stages can be recognized in the history of many other fundamental parameters in our subject.

Key words: *astronomical unit*

1 INTRODUCTION

In a historical context, the fundamental parameters of astronomy fall into two categories: there are those quantities that our predecessors measured nearly correctly first time, and those that they did not. Staying firmly in the solar system, two examples of the first type of parameter are the radius of Earth and the distance between Earth and the Moon. Ever since Eratosthenes of Alexandria, around 235 BC, used his famous shadow-stick approach, at noon, near the summer solstice, and his near contemporaries timed the duration of the phases of a lunar eclipse, we (i.e. the enlightened non-flat-earthers) have known that Earth has a radius, r_e , of about 6400 km, and that the Moon is about $60 r_e$ from Earth. As far as these parameters are concerned, all that has happened since the time of the Ancient Greeks is the dotting of a few i's and the crossing of a few t's. I do not belittle this 'dotting and crossing' because, for example, it led French astronomers in the late seventeenth century to the realization that Earth was not strictly spherical, and Edmond Halley, a few years later, to the discovery that the Earth-Moon distance was slowly changing with time, but these topics are not germane to the main thrust of the present paper.

A typical parameter of the second type is the mean distance between Earth and the Sun, the so called astronomical unit. The Greeks got this wrong, and not just a little wrong: their value was too small by a factor of twenty. So the Greeks, knowing the angular diameter of the Sun, thought that the Sun was a mere 5.4 times bigger than Earth, whereas it is actually about 109 times bigger. As there is an inverse cube relationship between the astronomical unit and the mass of the Sun (as calculated by its gravitational influence on Earth), and an inverse relationship between the astronomical unit and the values of stellar parallaxes (these being expected in post-Copernican days), the influence and importance of the astronomical unit in the history of astronomy is clear. This fundamental datum was referred to by Sir George Airy as "... the noblest problem in astronomy." (see Agnes Clerk, 1885:269), and this was earlier underlined by Robert Grant (1852:211) when he wrote "The determination of the distance from the sun to any of the planets revolving around him, is one of the most important problems of astronomical science."

The history of a parameter of the second type can be divided into six stages, these being:

- (1) The Age of Ignorance
- (2) The First Measurements and their Acceptance
- (3) The Realization of Error
- (4) The Period of Confusion
- (5) The Diminution of the Standard Deviation about a Commonly-accepted Value
- (6) The Era of Growing Disinterest.

According to Charles A. Young (1895:375), "The problem of finding the true value of the astronomical unit is difficult, because of the great disproportion between the size of the earth and the distance of the sun. The relative smallness of the earth limits the length of our available "base line," which is less than $1/12000$ part of the distance that is to be determined by it."

Table 1 lists a selection of the measurements made of the astronomical unit throughout history, together with certain values used in key-note texts, the latter being produced by authors reviewing the data that were available at the time. Notice that the solar parallax, π , is defined as being the angle, in seconds of arc, subtended by the equatorial radius of Earth at the Sun's mean distance. Figure 1 shows the AD 900 to 1980 subset of astronomical unit values, whilst Figure 2 shows the last two centuries in more detail, taken from Table 1.

Let us start by trying to define the onset times and durations of each of the six stages mentioned above. These have clearly been affected by improvements of specific astronomical instruments, the introduction of new techniques, and the vagaries of the rate of advance of astronomical theory. The temporal changes of these factors will be stressed in what follows.

Table 1. Measurements and accepted values of the Earth-Sun distance throughout astronomical history. The first column of values is in units of the Earth's equatorial radius ($r_e = 6378.140$ km). The second column expresses the distance as a fraction of the value of the astronomical unit accepted at the present time (i.e. $1 \text{ au} = 149,597,870.61 \text{ km} = 23454.78 r_e$). Note that the mean Earth-Sun distance $= r_e \times [\tan(\text{solar parallax})]^{-1}$.

Source	r_e (km)	Value au
Aristarchus of Samos (280 BC)	1150	0.04903
Ptolemy/Hipparchus (135 BC)	1210	0.05159
Al-Battani (AD 900)	1108	0.04724
Tycho Brahe (1570)	1150	0.04903
Kepler (1604) ($\pi < 1'$)	> 3438	> 0.14657
Wendelin (1626) lunar dichotomy ($\pi < 1'$)	> 3438	> 0.14657
Wendelin (1630)	14000	0.59689
Wendelin (1635) planetary diameters ($\pi \approx 14''$)	≈ 14733	0.62815
Horrocks (1640) planetary diameters ($\pi = 14''$)	14733	0.62815
Langrenus (1650)	3420	0.14591
Riccioli (1651) lunar dichotomy	7300	0.31124
Huygens (1659) ($\pi = 8''.2$)	25154	1.07246
Hevelius (1662) ($\pi = 40''$)	5156	0.21985
Picard/Cassini (1669) ($\pi < 12''$)	> 17188	> 0.73285
Richer/Cassini, C.D. (1672) Mars parallax ($\pi = 9''.5$)	21712	0.92570 ± 7000
Flamsteed (1672) Mars parallax ($\pi = 10''$)	20626	0.87941
Picard (1672) Mars parallax ($\pi = 20''$)	10313	0.43971
Lahire (1672) Mars parallax ($\pi < 6''$)	34377	1.46569
Newton (1673) ($\pi > 20''$)	< 10300	0.43943
Flamsteed (1673) ($\pi < 10''$)	> 20626	0.87941
Halley (1678) Mercury transit ($\pi \approx 45''$)	≈ 4583	0.19543
Flamsteed (1681) ($\pi < 15''$)	> 13751	0.58628
Newton's <i>Principia</i> 1st edition (1687)	10000	0.42635
Whiston (1696) ($\pi \approx 15''$)	≈ 13751	0.58628
Whiston (1701) ($\pi \approx 10''$)	≈ 20626	0.87941
Maraldi (1704) Mars parallax ($\pi = 10''$)	20626	0.87941
Newton's <i>Principia</i> 2nd edition (1713)	20626	0.87941
Newton's <i>Optics</i> (1717) ($\pi = 12''$)	17188	0.73285
Pond & Bradley (1717) Mars parallax ($9'' < \pi < 12''$)	19600	0.83565
Newton's <i>Principia</i> 3rd edition (1726)	19600	0.83565
Maraldi (1719), Cassini (1736) Mars parallax ($11'' < \pi < 15''$)	16000	0.68216
de Lacaille (1751)	19800	0.84418
Delises (1760) Venus transit ($10'' < \pi < 14''$)	17000	0.72480
de Lacaille (1761)	21850	0.93158
de Lacaille (1769)	23940	1.02069
Delambre (1770) Venus transit review ($\pi = 8''.6$)	23984	1.02258
Henderson (1832) Mars parallax ($\pi = 9''.125$)	22604	0.96374
Hansen (1854) ($\pi = 8''.97$)	22995	0.98040

Table 1 (concluded).

Source	Value	
	r_e (km)	au
Foucault (1862) c + aberration ($\pi = 8''.86$)	23280	0.99257
Hansen (1863) parallactic inequality of the Moon ($\pi = 8''.92$)	23124	0.98589
<i>Nautical Almanac</i> (1866) adopts $\pi = 8''.90$	23176	0.98811
Newcomb (1867) Mars parallax ($\pi = 8''.848$)	23312	0.99391
Berlin Ephemeris adopts $\pi = 8''.85$	23307	0.99369
Leverrier (1872) parallactic inequity of the Moon ($\pi = 8''.95$)	23046	0.98259
Stone (1872) ($\pi = 8''.91$)	23150	0.98700
1873 observations of Flora ($\pi = 8''.875$)	23241	0.99089
Cornu (1874) c + aberration ($\pi = 8''.794$)	23455	1.00002
Stone, 1874 Venus transit ($\pi = 8''.88 \pm 0.04$)	23228	0.99033
Airy, 1874 Venus transit ($\pi = 8''.754$)	23562	1.00459
Puiseux (1875) Venus transit ($\pi = 8''.879$)	23231	0.99044
French micrometer (1875) Venus transit ($\pi = 9''.05$)	22791	0.97173
Todd (1875) Venus transit ($\pi = 8''.883 \pm 0.34$)	23220	0.99000
Lindsat & Gill (1877) Juno parallax ($\pi = 8''.815$)	23399	0.99763
Tupman, Venus transit ($\pi = 8''.813 \pm 0.033$)	23405	0.99763
Hall (1879) ($\pi = 8''.879 \pm 0.060$)	23231	0.99044
Downing (1880) ($\pi = 8''.788 \pm 0.018$)	23471	1.00070
Gill (1881) Mars parallax ($\pi = 8''.78 \pm 0.12$)	23493	1.00161
Todd (1880) c + aberration ($\pi = 8''.803$)	23431	0.99899
Todd (1881) Venus transit ($\pi = 8''.883 \pm 0.034$)	23220	0.99000
The consensus was that the 1874 Venus transits gave the au as $(148.9 \pm 2.6) \times 10^6$ km, i.e.		0.9953 ± 0.017
Values used by the USA's <i>Astronomical Almanac</i> :		
1834-1869 $\pi = 8''.5776$ (Encke, 1824)	24047	1.02525
1870-1889 $\pi = 8''.848$ (Newcomb, 1867)	23312	0.99391
after 1890 $\pi = 8''.80$ (Paris, 1896)	23439	0.99933
Faye (1881) c + aberration ($\pi = 8''.813$)	23405	0.99786
1882 transit of Venus ($\pi = 8''.911 \pm 0.084$)	23147	0.98689
Newcomb (1885) c + aberration ($\pi = 8''.805$)	23426	0.99877
Gill (1890) asteroid parallax ($\pi = 8''.802 \pm 0.005$)	23434	0.99911
Proctor (1892) <i>Astronomy Old and New</i> ($\pi = 8''.811$)	23410	0.99809
Hinks, Eros parallax visual (1901) ($\pi = 8''.806 \pm 0.004$)	23423	0.99865
Hinks, Eros parallax photographic (1901) ($\pi = 8''.807 \pm 0.0027$)	23421	0.99854
Hough, radial velocities of stars (1912) ($\pi = 8''.802 \pm 0.004$)	23434	0.99911
Noteboom, perturbations of Eros (1921) ($\pi = 8''.799 \pm 0.001$)	23442	0.99945
Jones & Halm, Mars parallax (1924) ($\pi = 8''.809 \pm 0.005$)	23415	0.99831
Jones (1924) paral. inequality of the Moon ($\pi = 8''.805 \pm 0.005$)	23426	0.99877
Russell Dugan Stewart (1926) ($\pi = 8''.803 \pm 0.001$)	23431	0.99899
Rabe (1950) ($\pi = 8''.79835 \pm 0.00039$)	23443.58	0.99952
IAU (1964) ($\pi = 8''.794$)	23455.17	1.00002
IAU (1976) ($\pi = 8''.794148 \pm 0.000007$)	23454.78	1.00000

2 THE FIRST TWO STAGES IN THE HISTORY OF THE ASTRONOMICAL UNIT

Stage 1, *The Age of Ignorance*, lasted from prehistory until about 280 BC. Before that time the Sun, Moon, planets and stars were 'a long way off', further away than the clouds, but there was little concept as to how far away they actually were. Pythagoras (circa 530 BC) and his school had the celestial bodies attached to equi-spaced crystalline spheres, and the ordering of these Earth-centred spheres in increasing radius (i.e. the Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, and the stars) was simply a function of their mean angular velocity with respect to the background sky. By about 235 BC Eratosthenes had found that the Earth was about 6000 km in radius, and the Moon was about $88 r_e$ away. Aristarchus of Samos reduced the later value to about $60 r_e$ this being within about 1% of what is presently accepted.

Aristarchus used the lunar dichotomy method to estimate the Earth-Sun distance (for a more detailed explanation see, for example, Rogers, 1960). Here the quarter Moon is watched carefully until the terminator exactly bisects the disc. At this 'half moon' instance, the astronomer measures the Moon-Earth-Sun angle (α). The Sun-Earth distance is then equal to the reciprocal of cosine α times the Earth-Moon distance. Aristarchus found that $\alpha = 87^\circ$, and thus the Sun-Earth distance = $1150 r_e$. This figure gained great authority, but unfortunately the

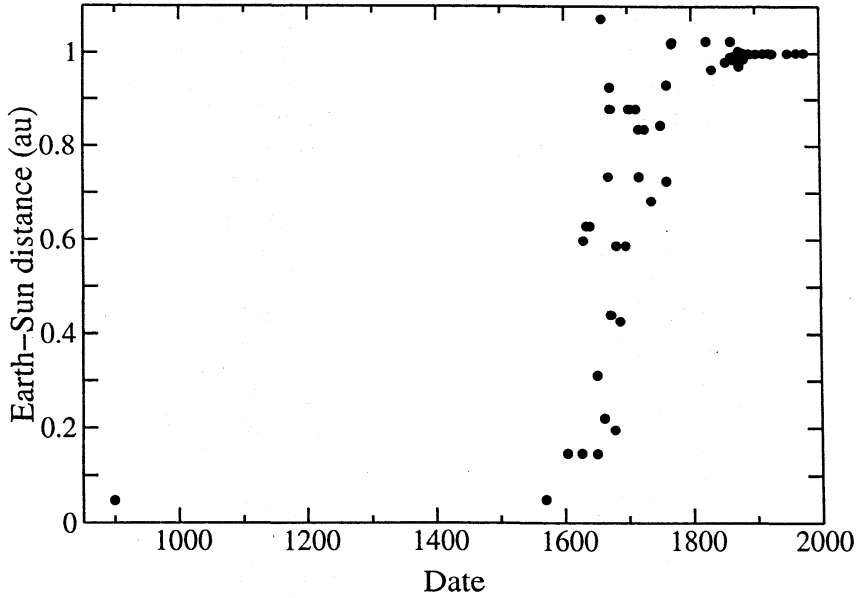


Figure 1. The measured, and accepted, values of the Earth-Sun distance for the period AD 900 to AD 2000. The ordinate is astronomical units, which are obtained by dividing the value (in km) given in each reference by 149,597,870.61 km. Notice how the investigations of the transits of Venus at the end of the eighteenth century led to a considerable decrease in the standard deviations.

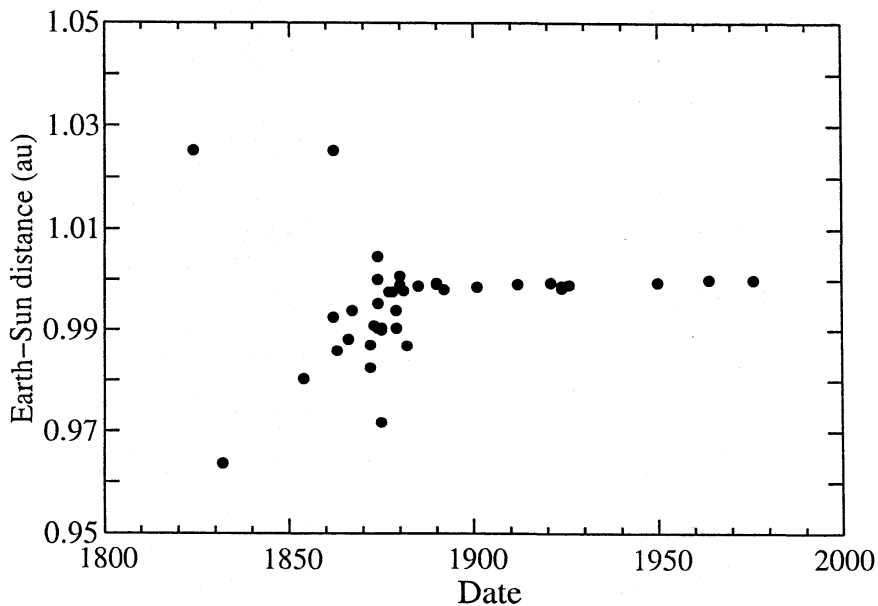


Figure 2. The measured, and accepted, values of the Earth-Sun distance between AD 1800 and 2000. Since 1885 the suggested value has never been more than 0.2% away from today's value. Notice that most results were under-estimates, and that it took about fifty years (between about 1885 and 1935) before the accumulation of many similar results seriously reduced interest in the astronomical unit.

method by which it was obtained is fatally flawed. First it is extremely difficult to estimate the time of dichotomy (a problem not helped by the fact that the mountainous nature of the Moon makes the terminator far from linear). The required angle, α , is also changing quickly as a function of the time. And further more, the fact that one is using a \cos^{-1} function in the calculation means that the difference between $\alpha = 87^\circ$ and $\alpha = 89^\circ.333$ (the latter being the correct value) introduces an error of a *factor* of eighteen.

Hipparchus used an approach that depended upon the timing of the phases of lunar eclipses, and these timings led to a value for the lunar horizontal parallax (i.e. Earth-Moon distance in terms of the Earth's radius). Combining this with the acceptance (from the work of Aristarchus) that the Sun was 19 times further away from Earth than the Moon (and thus that the solar parallax was $\frac{1}{19}$ the lunar parallax), led to the solar parallax being a little less than 3' (Dreyer, 1906:183, quotes 2' 54"), a figure that was accepted and publicized by Ptolemy. Hipparchus, however, realized that 2' 54" was probably an upper limit. He also noted that the correct value was not observationally obtainable at the time and might even be as low as zero.

Stage 2, *The First Measurements and their Acceptance*, lasted an amazing nineteen centuries, between the work of Aristarchus (and Hipparchus and Ptolemy) and Kepler's analysis of Tycho Brahe's observations of Mars. There was hardly any questioning in this interval; the distance of $1150 r_e$ was simply accepted.

3 STAGE THREE: THE REALIZATION OF ERROR, and STAGE FOUR: THE PERIOD OF CONFUSION

As in many planetary endeavours, Johannes Kepler was a key player in the early seventeenth century. He can be regarded as the initiator of Stage 3, *The Realization of Error*, not because he had been tackling the problem of the Earth-Sun distance directly, but because his Martian observations indicated that the solar parallax could not exceed 1 minute of arc. His estimated Earth-Sun distance of $< 3450 r_e$ was regarded as very much a lower limit, and Kepler encouraged his contemporaries to return to the lunar dichotomy method and try and do it more accurately. Stage 3 only lasted about twenty years. Other astronomers quickly followed Kepler in doubting the 'Greek' distance, and these astronomers started to re-examine the problem. Attempts were made to improve the lunar dichotomy approach.

To this end Gottfried Wendelin (1626:11-12), noted that the Moon was at most 1° from quadrature at the time of dichotomy, so the solar parallax must be less than 1 minute of arc. Giovanni Battista Riccioli (1651) was one of the last astronomers to apply the lunar dichotomy method carefully, getting $\pi = 28''$. He advised observers to concentrate on the centre of the lunar disc and to do the measurements only when the Moon was close to the ecliptic. By the mid-seventeenth century most astronomers were convinced that this dichotomy method just would not work and at best would provide only a lower limit.

Kepler instigated a new, typically seventeenth century, approach to the problem, and one that relied upon the measurement and (erroneous!) interpretation of planetary diameters. He was not only convinced that successive nestings of a cube, a tetrahedron, a dodecahedron, an icosahedron, and an octohedron, inside spheres of ever decreasing diameter, might give an important clue as to the scale and form of the solar system, but was also convinced that "... nothing is more in concord with nature than that the order of the sizes should be the same as the order of the spheres." (Kepler, 1617:878) By 'size' it was left open to the reader as to whether diameter, surface area, or volume should be used. In 1635 Wendelin argued that the planetary diameters were directly proportional to their distances from the Sun, and further more, that all planets, seen from the Sun, had an angular diameter of about $28''$, or at most $30''$. This gave a solar parallax of $\pi < 15''$. Kepler (Caspar, 1940) suggested (guessed!) that planetary volume was proportional to orbital period (i.e. surface area proportional to distance). Both of these propositions were rejected by Jeremiah Horrocks in around 1640. Pierre Gassendi had measured the apparent diameter of Mercury during the 1631 transit and Horrocks had found that Venus, in transit, subtended an angle of $1' 16''$ at Earth, in comparison with the $31' 30''$ subtended by the solar disc. Horrocks concluded (assumed?), like Wendelin, that the planetary diameters were proportional to their distances from the Sun, and that all planets subtended an angle of $28''$ at the Sun (see Whatton, 1859). If this were so, the solar parallax would be half this value, that is $14''$.

In the context of the Earth-Sun distance, Christiaan Huygens (1659) wrote that "... no tolerable method for measuring that distance has yet been found. For whether they try to discover it by means of eclipses or of the dichotomies of the Moon, it can easily be demonstrated that these efforts have been in vain." He therefore decided to follow the Keplerian approach. No direct observations were used, and the whole argument depended upon a 'feeling' for how big the Earth should be. Two things were known. From Kepler's harmonic

law one had the relative ratios of the semi-major axes of the planetary orbits, but no direct measurements of any specific orbit size. And from contemporary telescopic observation one had, with the exception of Earth, fairly reasonable estimates of the angles subtended by the discs of each known planet at Earth. Huygens then simply assumed that Earth, being a typical terrestrial planet, would have a size that was half way between the sizes of Mars and Venus, its two neighbours. Huygens had made extensive measurements of planetary sizes. In *Systema Saturnium* he wrote: "We have said that the diameter of Mars is $\frac{1}{166}$ the diameter of the Sun, and that the diameter of Venus is $\frac{1}{84}$. Taking, then, for the earth's diameter the mean of these two diameters, we find that it is $\frac{1}{111}$ of that of the Sun.... I grant that the calculations rest on a slippery basis..." (Huygens, 1659). Well, slippery, indeed, but Huygens' $\frac{1}{111}$ is fortuitously very close to today's accepted value of $\frac{1}{109.1}$. Taking the mean angular diameter of the Sun as 0.507° , Huygens then estimated that the Earth-Sun distance was $25086 r_e$.

The first sound steps towards a reasonable estimation of the astronomical unit were via Mars. If the distance between Earth and Mars could be measured accurately, then the astronomical unit could be calculated. The Earth-Mars distance could be most accurately measured when Mars was at opposition, at its closest to Earth, this happening about every 780 days.

The first serious measurements were made in 1672 by the French team of Giovanni Domenico Cassini, Ole Römer, Jean Richer, and Jean Picard (see Olmsted, 1942). They observed Mars at opposition (when it is about 0.38 au from Earth) from both Paris and Cayenne (in French Guiana, South America). Cassini analysed these observations and obtained a value of $9''.5$ for the solar parallax, and an Earth-Sun distance of $21600 r_e$. John Flamsteed, however got $\pi = 10''$, Jean Picard $\pi = 29''$ and Lahire $\pi < 6''$, so uncertainty continued on a gigantic scale (see Cassini, 1772). Flamsteed (1672) also observed Mars, in 1672 October, and obtained a Martian parallax of $25''$ and a solar parallax of $10''$.

Isaac Newton, for one, was very reluctant to accept the French values. He was not too happy with Flamsteed's either. The effect of atmospheric refraction was severe, and most astronomers regarded the similarity of the two solar parallax results as somewhat fortuitous (see Hufbauer, 1991). In fact the period between about 1626 and about 1704 was a Period of Confusion. During this interval a host of different figures for the Sun-Earth distance was used, more or less at random. Anything between $3000 r_e$ and $25000 r_e$ seemed to do! Young (1895:375) concluded that "Until nearly 1700 no even reasonably accurate knowledge of the sun's distance had been obtained."

Newton was somewhat confused about the whole problem and changed his mind several times. He used a value of $\pi = 20''$ in the 1687 first edition of the *Principia* (see Van Helden, 1985:147), but in the second edition (published in 1713) gave Cassini's and Flamsteed's value of $10''$. [This halving of the parallax led, among other things, to an increase in the accepted mass of the Sun by a factor of eight, no mean jump in 26 years!]. In the third edition of *Principia* (1726), Newton used $\pi = 11''$, $12''$, and $13''$ in different places; he also used $10''.5$, this being justified as the midpoint of the not less than $9''$ and not more than $12''$ found by James Pond and James Bradley in 1719 (see Rigaud, 1832). Meanwhile, in the second edition of *Optik's* (1717), he used $12''$.

In passing it is worth noting that the solar system, as discussed by Newton in the *Principia*, differed greatly from the one proposed by Nicolaus Copernicus in 1543. Four Jovian and five Saturnian moons had been added, and the scale of the system had been expanded by an order of magnitude. This had magnified the Sun so that it now truly deserved its central role. Knowledge of the angular diameters of the planets had led to a tremendous enlargement of the accepted physical dimensions of the outer planets. Coupled with these effects, attempts by Galileo, Newton, and Huygens to estimate the distance between the Sun and the bright stars had helped make the Universe itself almost inconceivably large. The new cosmic dimensions, learned by all educated men and women, were one of the wonders of the age.

Around 1550 the cosmos was very Ptolemaic, the *Almagest* being the supreme authority. The Sun was thought to be $1200 r_e$ away from Earth, 10.5 times bigger than Earth, and the naked-eye stars were at a distance of about $20,000 r_e$. By 1760 the Sun had become 110 times the size of Earth, and the bright star Sirius was estimated to be at a distance of around $7 \times 10^8 r_e$.

4 THE COMMONLY-ACCEPTED VALUE, AND THE ERA OF GROWING DISINTEREST

More careful work on the parallax of Mars, and especially Maraldi's measurement in 1704 seemed to convince contemporary astronomers that they were reasonably close to the correct value. Only the archaic accepted the Greek value for the solar parallax after that date. Astronomers agreed that the true Earth-Sun distance was somewhere in the range 16,000 to 24000 r_e . What was needed to further improve the situation was hard work, careful observations, accurate results and a reduction of systematic and experimental errors. Three completely new techniques helped greatly. These were: (i) the timing of the transits of Venus across the solar disc from many known positions on Earth, (ii) the use of ground-based measurements of the velocity of light together with the accurate assessment of the constant of aberration to measure the mean orbital velocity of Earth, and (iii) the quantification of the dynamic perturbation of the Martian, Cytherean and Earth-Moon systems by their neighbours.

The accuracy of the Mars parallax method was also improved greatly by doing it 'diurnally', that is looking at the way in which the position of Mars changed against the celestial background as a specific observatory was moved in space as Earth spun during the night (see later). By the late nineteenth century the Mars opposition parallax technique had also been applied to certain asteroids. The increased sensitivity and accuracy of astronomical spectrometers enabled the annual variation of Earth's orbital velocity to be measured directly, thus providing a fourth approach to the problem, with this bearing fruit in the early twentieth century. More recently, in the last few decades, pulse radar techniques have taken over and the distance has been measured directly.

Needless to say the two-station parallax method could also be applied to Venus as well as Mars, but the brightness of Venus, and the fact that the Cytherean atmosphere produced a somewhat indistinct limb, did not help. Gillis used a Santiago (Chile) to Washington (USA) arc in 1849/1852, but with limited success. The parallax method could also be applied directly to the Sun. The accuracy of the measurements of the solar apparent declination (as seen from observatories at different latitudes) were, however, greatly reduced due to the imprecise nature of the 'boiling' solar limb and the effects of solar heating on the adjustments of the viewing instruments.

Edmond Halley was a great advocate of the Venus transit method, this keenness being spawned by his observation of a transit of Mercury on 1677 October 28 from the South Atlantic island of St. Helena. Halley was extremely unimpressed by the plethora of values being used for the astronomical unit at the time, and published his famous 'advert' for the Venus transit method in 1716. Unfortunately the next transit, in 1761, was a long way off. In the interim, Halley (1716) suggested that the value of $\pi = 12''.5$ should be used, simply because this made Earth (which had a moon) bigger than Venus (which did not), and made Mercury bigger than the Moon.

In 1737 William Whiston was using 10" as the solar parallax but wrote "... the Sun's parallax ... is not yet accurately determined by astronomers; so that no exact number can be certainly pitch'd upon, till farther observations put an end to our doubts." (Whiston, 1737:34-35).

By 1760, on the eve of the Venus transit observations, Halley's Comet had already been seen to retreat 4 times further from the Sun than the Saturnian aphelion, and the 12" typical value accepted for the solar parallax made the Sun 17,000 r_e away from Earth and 150 times bigger (today it is given as being 109 times bigger).

An Earth-orbit baseline of some 40,000 r_e gave the more optimistic searchers of stellar parallax some hope. In 1669 Robert Hooke thought that he had succeeded with the star Gamma Draconis (see Hooke, 1674). Flamsteed tried unsuccessfully with the star Polaris (see Wallis, 1699).

Unfortunately the great effort expended on the observations of the transit of Venus did not produce a very satisfactory result (see, for example, Woolf, 1959 and Meadows, 1974). The 1761 June 6 transit was observed by 120 scientists at 62 different locations, and the resulting solar parallax values ranged from 8''.28 to 10''.60 (i.e. Earth-Sun distance from 24900 to 19500 r_e). Two factors were to blame for the magnitude of this parallax range. One was the inaccuracy of the timing of the Cytherean ingress and egress, due to the black-drop effect. Errors in estimating when Venus had left the solar limb, or reached it, could easily be between

10 and 15 seconds of time. The other was due to poor knowledge of the latitudes and longitudes of some of the observing sights (see Hufbauer, 1991).

The subsequent observations of the 1769 June 3 transit narrowed the parallax range to 8.43-8".80. These transit observations were at least providing genuine measurements of the solar parallax, which might not have been the case with either the early observations of the parallax of Mars (where the instrumental, systematic, and refraction-induced errors were thought by many to be of the same magnitude as the required angle) or with the lunar dichotomy estimations. Apart from the black-drop effect, and the need for the observers to travel to distant, and often unpleasant parts of the globe, there was a third serious defect in the transit approach and that was the rareness of its occurrence. Venus transited and transits the Sun on 1761 June 5; 1769 June 3; 1874 December 8; 1882 December 6; 2004 June 7; 2012 June 5; 2117 December 10 and 2125 December 8. All scientists like to repeat their observations in order to check the veracity of their results and improve their experimental performance. In this context, the period of 105.5 years between, say, the 1769 and 1874 transits was clearly impractical in both respects, and this alone favoured other approaches to the parallax problem.

There were three ways of collecting data for the transit method. Halley's method required observations from Earth's polar regions, plus a knowledge of the latitude of the observing sight, and measurements of the total time it took the planet to cross the disc (i.e. it had to be seen at both ingress and egress). Delisle's method utilized stations near the equator, plus accurate knowledge of their longitude and latitude, and measurements of either the time of ingress or the time of egress. The third method required continuous measurements of the exact position of the planet on the solar disc, as a function of time. Both photographic (mainly in 1874) and visual heliometric approaches were tried for the latter.

After all the rigours of the Venus transit observations of 1874, Harkness, (1879) still gave the parallax error as $\pm 1.7\%$. As a result, "Astronomers, accordingly, looked round for fresh means or more refined expedients for applying those already known. A new phase of exertion was entered upon... [to solve] the *quæstio vexata* of the sun's distance." (Clerke, 1885: 282).

Gravitational methods can be used to measure the Earth-Sun distance and one of these, the lunar parallactic inequality approach, was first suggested by Matthew Stewart in 1763. This method relies on the fact that the Sun is not an infinite number of times further away from Earth than the Moon, but only about 400. The Sun affects the Moon's orbit around Earth, the solar force accelerating the Moon when it is moving towards it and decelerating the Moon when it is moving away from it. As the Sun is not an infinite distance away, its disturbing force on the half of the Moon's orbit that is on the sunward side of Earth differs from the disturbing force on the opposite half, and the amount of difference is a function of the Earth-Sun distance. So, for example, the solar retarding force exerted on the Moon as it moves from being new to first quarter differs from the force exerted on the Moon as it moves from first quarter to full. Due to this, the Moon's position varies by as much as minus two minutes of arc and plus two minutes of arc with respect to the position it would have had if the Sun were an infinite distance away. Now two minutes of arc corresponds to four minutes of time, a quantity that can easily be accurately measured.

Unfortunately this accuracy is somewhat diminished by the fact that the lunar surface is uneven and that different lunar limbs have to be used for measuring the lunar position during the different quarters of the orbit. Laplace published a value for the solar parallax using this method (see Wallis, 1699).

A second gravitational approach depends upon measuring the perturbing forces that Earth exerts on the orbits of its neighbouring planets Mars and Venus. Using Kepler's Harmonic Law and Newton's second law we can write

$$M_{\text{O}} + M_{\text{E}} = 4 \pi^2 D^3 / G T^2, \text{ and}$$

$$g = G M_{\text{E}} / r_{\text{e}}^2,$$

where M_{O} and M_{E} are the masses of the Sun and Earth respectively, D is the Earth-Sun distance, G is Newton's constant of gravitation, T is the length of the year, g is the average acceleration of gravity at Earth's surface and r_{e} is the average radius of Earth. Combining these equations gives

$$D^3 = [(M_{\text{O}} / M_{\text{E}}) + 1] T^2 r_{\text{e}}^2 g / 4\pi^2$$

The quantity (M_O / M_E) can be obtained (with effort) from measurements of the rate at which the longitudes of the nodes and the position of the line of apsides of the orbits of Venus and Mars change with time. Leverrier developed this approach, and was so impressed with its potential that he would have nothing to do with the Venus transit observations of 1874. Spencer Jones (1924:109) also dismissed the transit approach, and wrote disparagingly: "Although this method is not capable of giving results of a high order of accuracy, it is of considerable interest historically ...".

A third gravitational approach assumed that the mass of the Moon was known, and had been calculated from, say, its tidal effects on Earth. As it is the centre of gravity of the Earth-Moon system, and not the centre of the Earth that moves on an elliptical orbit around the Sun, the Sun is displaced from where it is expected to be, throughout the month, by a maximum of 6".3 (a quantity known as the lunar equation). It can easily be shown that the solar parallax is given by

$$\pi = 6.3'' (r_e / EM) (M_E + M_C) / M_C,$$

where EM is the Earth-Moon distance and M_E and M_C are the masses of the Earth and Moon respectively. Unfortunately the lunar equation is a very small angle, which is extremely difficult to measure with accuracy.

A completely new approach to the quantification of the astronomical unit came via the combination of a knowledge of the velocity of light and the constant of aberration of starlight. The fact that light travelled at a finite velocity was discovered by Ole Römer in 1675, when he analysed the variations in the intervals between the eclipses of the Jovian satellites as a function of the Earth-Jupiter distance. For many years the velocity of light was given in terms of the "light-equation" (i.e. the time it takes light to travel an astronomical unit). Delambre obtained a value of 493.2 seconds in 1792, and Glasenapp, two years later, found 500.84 seconds. Both these produced velocities of light that depended upon contemporary knowledge of the Earth-Sun distance, so were useless in the present endeavour.

The first successful 'ground-based' experimental measurements of the velocity of light were made by Fizeau, who obtained $308 \times 10^8 \text{ m s}^{-1}$ and Foucault who obtained $298 \times 10^8 \text{ m s}^{-1}$. These velocities, when combined with the 'light-equation', immediately lead to a value for the astronomical unit (see Foucault, 1862).

James Bradley discovered the aberration of starlight in 1726. Here the velocity of light combines vectorially with Earth's orbital velocity to displace the position a star against the celestial background. A star that would be at the pole of the ecliptic if Earth were stationary is displaced by an angle of about 20".5. [Here we have an example of a parameter of the first type, i.e. one where the initial measurement produced a value that was very close to the 'correct' value that is obtained later on. Bradley first measured the constant of aberration to be 20".25, but "Upon further consideration he was induced to fix it at 20"." (Grant, 1852: 340). Delambre found 20".255. By 1844 Baily was quoting 20".4192, and later on M Struve made it 20".445. Nyrén suggested 20".492 in 1882. Notice that constants of aberration of 20.46, 20.48, 20.50, 20.52 and 20".54 correspond to solar parallaxes of 8.808, 8.799, 8.790, 8.782 and 8".773 respectively.]

It is clear that, by the early 1860s, when Fizeau and Foucault had measured the velocity of light accurately, the constant of aberration was known with an even greater precision, so the calculation of an accurate value for the solar parallax was a simple matter. Struve, for example found $\pi = 8".86$ (see Table 1).

The original Mars parallax method, first attempted by the French (see above), was seriously disadvantaged by the fact that it required two observers, working at a considerable latitudinal distance from each other. These observers were out of touch and were using different instruments. The method gave too large a value for the parallax and Young (1895) thought this might be due to the red colour of the planet affecting the astronomical refraction. A more satisfactory approach was to measure the diurnal parallax, a quantity that maximized for an observer near Earth's equator. A single observer using a single instrument (usually a heliometer) could measure the change in right ascension and declination of Mars produced by the approximate $2 r_e$ shift of the observer in the time interval between Mars' rising and setting on a single night (Mars, being near opposition at the time, transits the meridian at midnight, and is

thus in the sky throughout the night). This method was used by Gill during the 1877 opposition of Mars. Observing from the Ascension Islands, he obtained $\pi = 8''.783 \pm 0.015$.

The parallax method was also applied to asteroids, and especially those that pass close to Earth. The fact that asteroids appeared as star-like points, and not planetary discs, improved the accuracy. This approach was first suggested by Johanne G. Galle in 1873, and he used 8 Flora to obtain $\pi = 8''.87$. In 1886, Robert Ball wrote: "Let us hope that ere long the next transit of Venus approaches, the problem of the sun's distance will have been satisfactorily solved by the minor planets." (Ball, 1886:210). In 1888-1889 Gill observed asteroids 7 Iris, 12 Victoria and 80 Sappho, all of which came within 0.85 au of Earth, and found $\pi = 8''.802$.

The asteroid 433 Eros was discovered in 1897 and its close passage (0.27 au) in 1900-01 produced more precise values of $\pi = 8''.806 \pm 0.004$ (from visual observations using telescopes of long focal length) and $\pi = 8''.807 \pm 0.003$ (from photographic observations). At its opposition of 1930-01 Eros was only 0.17 au distant, and Spencer Jones (1941) obtained $\pi = 8''.790 \pm 0.001$ (cf. Atkinson, 1982). Thirty telescopes in fourteen different countries were used to produce 2847 photographic plates of this nearby object.

In 1912 Hough, using a high dispersion spectrograph at the Cape of Good Hope, measured the annual variation in the Doppler shift of the light from a set of seven bright near-ecliptic stars to measure the mean orbital velocity of Earth. The resulting value of the solar parallax was $8''.802 \pm 0.004$. Working with Arcturus alone gave $8''.805 \pm 0.007$.

Between about 1705 and 1880 the quoted standard deviation of the astronomical unit went from about 11 % to 1 % of its value. By 1931 it had been reduced further to around 0.01 %. The period between 1705 to 1931 saw *The Diminution of The Standard Deviation about a Commonly-Accepted Value* (i.e. Stage 5 in the evolution of this parameter). By 1931 the job of quantifying the astronomical unit had almost been done, and then followed the final stage, *The Era of Growing Disinterest*.

Rabe (1950:) obtained the solar parallax using a dynamic method in which he studied the perturbation of Earth on near-by objects, deriving $\pi = 8''.79835 \pm 0.00039$. (i.e. 1 au = 149,532,000 \pm 7,000 km). The post-WWII period was somewhat enlivened by the completely new technique of pulsed radar ranging. This has been applied to the Sun, nearby planets and asteroids since 1961 (see, for example, Ash *et al.*, 1967; Hey, 1973:122; and Shapiro, 1968). At the nearest approach of Venus in 1961 it took a radar pulse about 5 minutes to travel from Earth to Venus and back. The American, British and Soviet results led the International Astronomical Union to adopt a solar parallax of $8''.794$ and an astronomical unit of 149,600,000 km at its 1964 General Assembly. Further detailed work led the 1976 meeting of the IAU to adopt a solar parallax of $\pi = 8''.794148 \pm 0.000007$, corresponding to an astronomical unit of 149,597,870 \pm 120 km. Stix (1989:3) gives the astronomical unit as 149,597,870 \pm 2 km, while the Jet Propulsion Laboratory Planetary Ephemeris uses 149,597,870.61 km (see Lang, 1991:11).

5 CONCLUDING REMARKS

The measurement of the distance between Earth and the Sun has been approached in about seven sensible ways. Young (1895) went so far as to give each contemporary and historic method a mark out of a hundred, and his grading is listed in Table 2, in order of decreasing efficacy. More recent methods have been added to the top of this table.

In this paper we have suggested that the fundamental parameters of astronomy can be divided into two types, this division being dependent upon the history of their development and the accuracy of their quantification in any historical epoch.

Type one parameters have a very simple two-stage history. In the first stage, the parameter is not known. In the second it is known with reasonable accuracy. Here the first attempts to measure the parameter achieve very nearly the correct answer. Typical examples of 'type one' parameters, are the radius of the Earth, the distance to the Moon, the radius of the Moon, the length of the month and the year, the velocity of the Sun around the galactic centre, the Eddington Limit, Oort's constants, the Schönberg-Chandrasekhar limit, etc..

The history of a quantity of the 'type two' is more interesting. Instead of there being only two stages in their development, there are six. In this brief paper we have considered the history of the astronomical unit, but there are many other similar quantities in the field of astronomy. A

few examples are the age of the Earth, the temperature of the solar photosphere, the mass of the Sun, the solar luminosity, the cosmic hydrogen to helium ratio, the distance to nearby stars, the number of stars in the sky, the size of the Milky Way Galaxy, the number of galaxies in the Universe, the mass of the Universe, the Hubble Constant, the density parameter of the Universe, the Cosmological constant, and so on.

Table 2. Methods of measuring the astronomical unit, ordered according to the marking scheme suggested by Young (1895). Here 0 is bad and 100 is good.

Mark	Method
100	Modern Radar
100	Annual variation in radial velocity of ecliptic stars
100	Near Earth Asteroid diurnal parallax
95	Perturbation of the orbits of Mars and Venus
90	Mars diurnal Parallax (from a single observatory near the equator)
90	Constant of aberration + knowledge of c
80	Light equation + knowledge of c
75	Venus transit (measuring planet's position on solar disc, using a heliometer)
75	Venus transit (noting planet's position on solar disc, using photography)
75	Asteroid diurnal parallax (from a single near-equatorial observatory)
70	Lunar parallactic inequality
50	Venus transit (Delisle Method)
40	Venus transit (Halley Method)
40	Monthly perturbation of solar position (i.e. measuring the lunar equation)
25	Mars parallax (from two observatories, north and south)
20	Venus declination from many observatories
20	Asteroid parallax (north + south observatories)
0	Lunar dichotomy (Aristarchus)
0	Hipparchus method (timing lunar eclipses and assuming $1/19$ for ratio of Earth-Moon and Earth-Sun distances)
0	Parallax of Sun directly

We have divided the history of these 'type two' parameters into six different stages. The temporal start- and end-points of these stages provide interesting mileposts on any journey through astronomical history. Often they are associated with major advances in instrumentation or with key paradigmatic shifts in our approach to the subject. When it comes to the astronomical unit the Stage 1, *Age of Ignorance*, ended around 300 BC with the flourishing of Greek astronomy under the likes of Eratosthenes and Hipparchus. They introduced Stage 2, and *The First Measurements and their Acceptance* lasted until the work of Kepler around 1604. Nineteen centuries is a long time without change. Not only was there no specific reason during that time period to doubt the original value of the astronomical unit, but, more importantly, the one inadequate lunar dichotomy method of measurement was not superseded by something better.

Kepler's desire to quantify the sizes of planets and the scale of the heliocentric solar system led to the brief two decades or so (1604-1630) of Stage 3, *The Realization of Error*. By the 1630s quite a few astronomers harboured strong suspicions that the Greeks were wrong, and that in fact the Solar System and its central Sun were much larger than had been previously thought. From 1630 to around 1705 the situation was very confused, and many different values were produced for the solar parallax. Much of this confusion arose because the lunar dichotomy method was shown to be not only completely inadequate, but also not open to improvement. Results obtained by this method during the early seventeenth century therefore differed widely. The new, 1672, approach to the astronomical unit, via the measurement of the Earth-Mars distance at opposition, was also very imprecise when first attempted. Here astronomers were trying to measure the angular distance between Mars and nearby stars at specific times (i.e. the measurements made in Cayenne and Paris had to be co-temporal). Successful observations depended upon the use of the newly-invented eye-piece micrometers, as well as on the accuracy of the contemporary clocks. A further weakness of this new method was that the required angle (i.e. the parallax of Mars) was obtained by calculating the difference between two numbers, both of which were known imperfectly.

The telescopic eyepiece micrometer was invented around 1640 by the Yorkshireman William Gascoigne, and the next sixty years saw huge improvements in this device (see, for

example, King, 1955). This fact, coupled with important developments in telescope design and mountings during the late seventeenth and early eighteenth centuries, revolutionized the accuracy with which astronomical positions could be measured. This accuracy was vital when it came to measuring the position of Mars. Pledge (1939:291) plots a graph (which he attributes to H Mineur) showing the way in which the angular accuracy, β seconds of arc, of an astronomical positional measurement varied as a function of the epoch of the measurement. Typical values given in this graph are listed in Table 3. These follow a relationship of the form

$$\log \beta'' = (1.45 \pm 0.14) - (14 \pm 1) \times 10^{-3} (T - 1700), \quad [\text{AD } 1600 < T < \text{AD } 1900]$$

where T is the date of the observation. It can be seen from this relationship, and from Table 3, that the errors of the Cassini measurements in 1672 were probably comparable with the magnitude of the parallax ($\sim 28''$) that was being measured. It is also noticeable just how speedily the accuracy of astronomical angular measurement improved at this time.

The accuracy of time measurement has been reviewed by Howse (1980). Again the interval between AD 1650 and 1900 saw great improvements. If the best clocks of the period were gaining or losing about Δt seconds per day, the data in Howse (*ibid.*) indicate that

$$\log \Delta t = 0.76 - 0.0114 (T - 1700). \quad [\text{AD } 1650 < T < \text{AD } 1900]$$

Table 3. The accuracy of astronomical angular measurements ($\pm \beta$), taken from Pledge (1939).

Astronomer	Date (AD)	Accuracy ($\pm\beta$) (seconds of arc)
Tycho Brahe	1585	240
Flamsteed	1700	10
Piazzi	1800	1.5
Bessel	1845	0.3
Auwers	1880	0.1
Newcomb	1900	0.03

The *Period of Confusion* about the value of the astronomical unit was followed, round about AD 1705, by a general realization that the Sun was of the order of 150,000,000 km away from Earth (i.e. at a distance of about 24000 r_e). This was the start of Stage 5, the period of *The Diminution of the Standard Deviation about a Commonly-Accepted Value*. This stage in the history of the astronomical unit lasted from about 1705 to about 1935 and was enlivened by a host of new experimental approaches to the distance measurement, and a strengthening of the realization that the astronomical unit lay at the heart of astrophysics, in as much as all the important quantities such as stellar distance, size, mass, temperature, and luminosity depended upon it. Stage 5 saw considerable competition between the advocates of the different measurement techniques, many of which had similar precision. This competition added greatly to the excitement of the endeavour and to the pace of improvement.

At the start of Stage 5 much was expected of the method that relied upon the timing of the transits of Venus across the solar disc. Unfortunately many inherent problems and inconveniences led to disappointing results and a waning of interest by the time of the most recent transit, in 1882 (see Dick, Orchiston and Love, 1998). The Mars opposition parallax method was transformed both by the increase in measuring accuracy and by taking the measurements from a single site close to the equator during a single night, as opposed to using two sites in different hemispheres. In the late nineteenth century the diurnal parallax approach was extended to asteroids and then revolutionized by the discovery of certain asteroids that come much closer to the Earth than Mars does. The ground-based measurement of the velocity of light by laboratory physicists meant that this quantity could be combined with the constant of aberration to give an accurate value for the Earth-Sun distance. Also, the ever-increasing accuracy of astronomical telescope scales and time pieces meant that the varying solar gravitational effects on the motion of the Moon around Earth, and the effect of the Sun/Earth mass ratio and the Sun/Earth distance on the perturbation of the orbits of Venus and Mars, could also be measured, leading again to accurate estimates of the astronomical unit. Both of these methods were working well in the 1870s, and this furthered the growth of the disillusionment

with the transit of Venus method. Work on the annual variation in the radial velocity of certain stars, and observations taken during the close flyby of Earth by asteroid Eros meant that, by 1935, the problem of quantifying the astronomical unit was essentially solved.

Returning to the topic of the competition between different techniques, Russell, Dugan, Stewart (1926:188) wrote: "The mutual agreement of the values arrived at by very different methods (none differing from the mean by more than 1 in 1500) is very striking." Again referring to the competition, van Helden (1995) reported on the worrying way in which the raw data of the 1761 and 1769 Venus transits were analysed time and again in the hope that they would yield results that were more in agreement with other and more recent results.

The Sixth Stage, *The Era of Growing Disinterest*, has lasted from about 1935 to the present day. The disinterest is illustrated beautifully by the change in prominence given to the measurement of the astronomical unit in the university textbooks of the period. Young (1888, first edition, and 1895, second edition) devoted the whole of his chapter 16, some 18.3 pages, to the subject; Russell, Dugan, Stewart (1926) assign a mere 2.2 pages; Payne-Gaposchkin (1955) also 2 pages; Motz and Duveen (1966) just the one page; and the recent 1400-page classic by Carroll and Ostlie (1996) has only two lines. What is more, this Sixth Stage saw the introduction of a completely new technique, one relying upon the timing of reflected radar pulses. This technique did not 'compete' with previous techniques, it completely overwhelmed them. The 1926 accuracies of 1 part in 1500 were replaced, in the 1980s, by accuracies of better than 1 in 70,000,000. The job had been done.

6 ACKNOWLEDGEMENTS

In writing this paper I have referred extensively to van Helden (1985) and would like to thank him for all the encouragement he has (inadvertently) given.

7 REFERENCES

- Ash, M.E., Shapiro, I.I. and Smith, W.B., 1967. Astronomical constants and planetary ephemerides deduced from radar and optical observations. *Astronomical Journal*, **72**:338-350.
- Atkinson, R.d'E., 1982. The Eros parallax, 1930-31. *Journal for the History of Astronomy*, **13**:77-83.
- Ball, R.S., 1886. *The Story of the Heavens*. Cassell & Co., London.
- Carroll, B.W. and Ostlie, D.A., 1996. *An Introduction to Modern Astrophysics*. Addison-Wesley, Reading.
- Caspar, M. (ed.), 1940. *Johannes Kepler. Gesammelte Werke. Volume 6*. Beck, Munich.
- Cassini, J.D., 1772. *Histoire Abrégée de la Parallax du Soleil*. Paris.
- Clerke, Agnes, 1885. *A Popular History of Astronomy during the Nineteenth Century*. Black, Edinburgh.
- 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.
- Dreyer, J.L.E., 1906. *History of the Planetary Systems from Thales to Kepler*. Cambridge University Press, Cambridge.
- Encke, J. F., 1824. *Der Venusdurchgang von 1769*. Becker, Gotha.
- Flamsteed, J., 1672. An extract of Mr. Flamsteed's Letter ... concerning the Appulses ... of the Moon, and other Planets to Fixed Stars; together with an Observation of the Planet Mars, made by the same. *Philosophical Transactions of the Royal Society of London*, **7**:5118-5119.
- Foucault, J.B.L., 1862. A value for the solar parallax obtained using the velocity of light and the constant of aberration. *Comptes Rendus de l'Academie des Sciences*, **55**:502.
- Grant, Robert, 1852. *History of Physical Astronomy from the Earliest Ages to the Middle of the Nineteenth Century*. Baldwin, London.
- Halley, E., 1716. Methodus singularis qua Solis Parallaxis sive distantia a Terra, ope Veneris intra Solem conspiciendæ tuto determinari poterit. *Philosophical Transactions of the Royal Society of London*, **29**:454-464.
- Harkness, W., 1879. *American Journal of Science*, **20**:393.
- Hey, J.S., 1973. *The Evolution of Radio Astronomy*. Elek Science, London.
- Hooke, R., 1674. *An Attempt to Prove the Motion of the Earth by Observation*. London (see, also, Gunther, R.T., 1931. *Early Science in Oxford, Volume 8 (Cutler Lectures of Robert Hooke)*. Oxford University Press, Oxford, pp. 1-28, where it is reprinted).
- Howse, D., 1980. *Greenwich Time and the Discovery of Longitude*. Oxford University Press, Oxford.
- Hufbauer, K., 1991. *Exploring the Sun: Solar Science since Galileo*. Johns Hopkins University Press, Baltimore.

- Huygens, C., 1659. *Systemma Saturnium*. See *Oeuvres Complètes de Christiaan Huygens, Volume 15*. The Hague, Martinus Nijhoff, pp. 342-345.
- Jones, H.S., 1924. *General Astronomy*. Edward Arnold, London.
- Jones, H.S., 1941. The solar parallax and the mass of the Moon from observations of Eros at the opposition of 1931. *Memoirs of the Royal Astronomical Society*, **66**:11-66.
- Kepler, J., 1617. *Epitome Astronomiae Copernicanae*. Plank, Linz.
- King, H.C., 1955. *The History of the Telescope*. Charles Griffin & Co., London.
- Lang, K.R., 1991. *Astrophysical Data: Planets and Stars*. Springer-Verlag, New York.
- Meadows, A.J., 1974. The transits of Venus in 1874. *Nature*, **250**:749-752.
- Motz, L., & Duveen, A., 1966. *Essentials of Astronomy*. Columbia University Press, New York.
- Newcomb, S., 1867. Investigations of the distance of the Sun and the elements which depend on it. *Washington Observations for 1865*, Appendix II:1-29.
- Olmsted, J.W., 1942. The Scientific expedition of Jean Richer to Cayenne, (1672-1673). *Isis*, **34**:117-128.
- Paris, 1896. *Conference International des Etoiles Fondamentales*. Process-Vebaux, Paris.
- Payne-Gaposchkin, C., 1956. *Introduction to Astronomy*. Eyre & Spottiswoode, London.
- Pledge, H.T., 1939. *Science Since 1500: A Short History of Mathematics, Physics, Chemistry, Biology*. His Majesty's Stationery Office, London.
- Rabe, E., 1950. Derivation of fundamental astronomical constants from the observations of Eros during 1926-1945. *Astronomical Journal*, **55**:112-126.
- Riccioli, G.B., 1651. *Almagestum Novum, Volume 1*. Benati, Bologna.
- Rigaud, S.P. (ed.), 1832. *Miscellaneous Works and Correspondence of James Bradley*. Oxford University Press, Oxford.
- Rogers, E.M., 1960. *Physics for the Inquiring Mind; The Methods, Nature and Philosophy of Physical Sciences*. Princeton University Press, New Jersey.
- Russell, H.N., Dugan, R.S., & Stewart, J.Q., 1926. *Astronomy: A Revision of Young's Manual of Astronomy. Volume 1: The Solar System*. Ginn & Co., Boston.
- Shapiro, I.I., 1968. Spin and orbital motions of the planets. In J.V. Evans, & T. Hagfors (eds.). *Radar Astronomy*. McGraw-Hill, New York, pp.143-185.
- Stewart, M., 1763. *The Distance from the Sun to the Earth Determined by the Theory of Gravity*. Sands, Kincaid & Bell, Edinburgh.
- Stix, M., 1989. *The Sun: An Introduction*. Springer-Verlag, Berlin.
- van Helden, A., 1985. *Measuring the Universe: Cosmic Dimensions from Aristarchus to Halley*. University of Chicago Press, Chicago.
- van Helden, A., 1995. Measuring the solar parallax: the Venus transits of 1761 and 1769 and their nineteenth-century sequels. In R. Taton, R., & C. Wilson (eds.). *The General History of Astronomy. Volume 2. Planetary Astronomy from the Renaissance to the Rise of Astrophysics Part B: The Eighteenth and Nineteenth Centuries*. Cambridge University Press, Cambridge, pp. 153-168.
- Wallis, J., 1699. *Wallis Opera Mathematica. Volume 3*. Lichfield, Oxford.
- Wendelin, G., 1626. *Loxias, seu de Obliquitate Solis Diatriba. In qua Zodiaci ab aequatore ... tandem eruitur et in canonem suum refertur ...* Antwerp.
- Wendelin, G., 1635. Letter to Gassendi, dated May 1. See *Petri Gassendi Opera Omnia. Volume 6*. Lyons, pp.427-429 (1658).
- Whatton, A.B. (ed.), 1859. *Memoire of the Life and Labours of the Rev. Jeremiah Horrox ... To which is Appended a Translation of his Celebrated Discourse upon the Transit of Venus across the Sun*. London.
- Whiston, W., 1737. *A New Theory of the Earth. Second Edition*. Macintosh, London.
- Woolf, H., 1959. *The Transits of Venus: A Study of Eighteenth-Century Science*. Princeton, New Jersey.
- Young, C. A., 1895. *A Textbook of General Astronomy*. Ginn & Co, Boston.



David W Hughes is a Reader in Astronomy at the University of Sheffield, UK. He has spent his academic life researching the minor bodies of the solar system and specifically into cometary decay, asteroidal evolution, cosmogony and the relationships between comets and meteoroid streams. He is author of *The Star of Bethlehem: An Astronomer's Confirmation* (Walker & Co., 1979).

The English equatorial mounting and the history of the Fletcher Telescope

Wayne Orchiston

Anglo-Australian Observatory, PO Box 296, Epping, NSW 2121, Australia *

E-mail: wo@aoepp.aao.gov.au

Abstract

The first all-metal English equatorial Mounting of the 'Cross Axis' type was constructed in 1859 for a 9.5-in (24.1 cm) Cooke refractor owned by Isaac Fletcher of Carlisle, northern England. Over the next ten years Fletcher used this telescope for systematic observations of known double stars, and after his death it was acquired by S Chatwood of Manchester. In 1902 the telescope was purchased by J T Ward for the newly-formed Wanganui Astronomical Society in New Zealand. Ward used the telescope to discover new southern double stars, and it was also the mainstay of public viewing nights. This educational function has remained through to the present day, and during the 1980s and 90s O Warren reactivated a micrometric double star programme involving the re-measurement of the Ward and other southern double stars. After nearly 150 years, the 'Fletcher Telescope' remains New Zealand's largest operational refractor, and has been maintained in excellent mechanical and optical condition.

Keywords: *double stars, English Equatorial Mounting, I. Fletcher, J.F. Miller, Ward (Wanganui) Observatory*

1 INTRODUCTION

The English equatorial mounting has a long and distinguished history (see Gingerich, 1967; King, 1979). There are two principal varieties:

- the 'Through Axis' type, where the tube of the telescope "... passes between, and is pivoted from, two or more structural elements of the polar axis ..." Hingley (n.d.), and
- the 'Cross Axis' type, where the telescope "... is pivoted to one side of the single polar axis and thus needs a counterweight on the other side." (ibid.).

The Palomar 'Horseshoe Mounting' should be regarded as a special variant of the 'Through Axis' type that permits direct access to the celestial pole, and its origins have recently been traced back to nineteenth century Australia (Orchiston, 2000).

Hingley (op. cit.) discusses the history of both types of English equatorial mounting, and shows that an important advance took place when a cast-iron 'Cross Axis' mounting was manufactured for a 9.5-in (24.1 cm) f/15.2 Cooke refractor owned by Isaac Fletcher. This was the first time that metal (rather than wood) had been used in the overall construction of an English equatorial mounting. As such, Fletcher's telescope serves, in zoological parlance, as a *type specimen*, and it is of interest to trace its chain of ownership and use. After discussing its English affiliations, this paper focuses on the circumstances leading to the relocation of the telescope to New Zealand in 1902, and its subsequent use for research and for the popularization of astronomy.

2 THE ENGLISH HISTORY OF THE TELESCOPE

There is some confusion surrounding the early history of the 9.5-in refractor, and it is only possible to unravel the facts of the matter by critically examining various publications that specifically mention this telescope. At the root of the problem is King's claim (1979:251) that in about 1851 Thomas Cooke manufactured a 9.5-in refractor for a John Fletcher Miller (1816-1856), who lived at Whitehaven on the south-western shore of Solway Firth. One of Miller's astronomical contemporaries in far north-western England was Isaac Fletcher (1827-1879), who lived at Greysouthen, near Carlisle, and it is clear from their publications that the two men knew each other (e.g. see Miller, 1853). Miller died in 1856, and it is a reasonable assumption that

* Address for correspondence: 17 Russell Street, Greenacre, NSW 2190, Australia

the 9.5-in Cooke refractor then passed to Fletcher, as he is known to have been in possession of just such an instrument during the 1860s. This is a plausible story, but what is the truth of the matter?

Published papers by Fletcher (1853) and Miller (1852) indicate that Cooke did indeed make a refracting telescope for Miller, and in 1851, but the aperture was actually 4.14 inches (10.5 cm) not 9.5 inches, and it is clear from Miller's obituary that he never acquired a larger instrument (Obituary, 1857). Meanwhile, Fletcher had a refractor of identical aperture, which Cooke had made for him in 1847 (Fletcher, 1850), and the only difference between the two instruments was in their mountings: Fletcher's featured a wooden English equatorial and Miller's a German equatorial (Miller, 1853). Both men used their telescopes for micrometric observations of double stars and published their results in the *Monthly Notices* and the *Memoirs* of the Royal Astronomical Society. Where the same stars were involved, they included each other's measures in some of their publications (e.g. see Fletcher, 1853, 1855; Miller, 1852). Furthermore, both astronomers were elected to Fellowships of the Royal Astronomical Society in 1849, and each subsequently became an FRS (see Obituary, 1857; Obituary, 1880).

Miller died in 1856 at the youthful age of 40 (Obituary, 1857), and on April 24 in the following year Fletcher placed an order with Cooke for a 9-in refractor costing £400 (Orders ..., n.d.) in order to dramatically increase his available light grasp (see W.H. Smyth, 1860). The actual aperture of the completed telescope was 9.5 inches, and delivery took place towards the very end of 1859 (Jacob, 1860; W.H. Smyth, 1860; cf. Crossley, Gledhill and Wilson, 1879). Regardless of the precise date, this was a new telescope that was specifically made for Fletcher by Cooke, and it was in no way associated with Miller. The parallels between the two men in relation to their instruments, observations, publications and FRAS election, and the common 'Fletcher' element in both their names, may go some way towards explaining King's version of events. He may also have been misled by the statement that Miller's Cooke telescope was "... of the same size as Mr. Fletcher's instrument." (Crossley, Gledhill and Wilson, 1879:49). Crossley *et al.* were, of course, referring to Fletcher's smaller refractor.

Captain Jacob (Director of the Madras Observatory) provides an account of Fletcher's new acquisition in an 1860 issue of *Monthly Notices*:

The telescope in question is the property of our worthy Fellow, J. Fletcher, Esq., of Tarnbank, where it has been but recently erected by him; the optical portion by Cooke, of York; but the mounting, a long polar axis of cast-iron ... has been executed under Mr. Fletcher's direction at an engineering foundry at Whitehaven, belonging to one of his brothers....

The mounting seemed remarkably firm, and so smooth in its movement, that, with the telescope slightly under-counter-poised, a star could be well followed and kept pretty near the centre of the field by gentle pressure with the finger. On the whole, I should say it was creditable both to the designer and the maker, and that in such able hands it is likely to prove a most efficient instrument ... (Jacob, 1860: 248-249).

Accompanying the telescope were "... a double-image micrometer of varying powers, a wire micrometer with positive magnifiers to 1,000, and a battery of negative eye-pieces ranging from 25 to 1,500." (W.H. Smyth, 1860:304).

W H Smyth's son (see Brück and Brück, 1988) was a friend of Isaac Fletcher, and the Piazzzi Smyth Collection in the Royal Observatory Edinburgh (Brück, 1988) includes a diary documenting his visit to Greysouthen in 1860 April:

Isaac Fletcher describes his new equatorial. Object glass by Cooke, 9.5 sees 7 Satellites of Saturn and perhaps an 8th at least as much as Sir W. Herschel with a four foot reflector.

Polar axis of home make i.e. at his brother's foundry. of English form with telescope on one side; cast in iron in one piece – 15ft long ... (C.P. Smyth, 1860).

Of particular interest is the mounting, for this was the very first time that an all-metal English equatorial mounting had been used in telescope design and construction.¹ It was manufactured "... expressly at the Lowca Engine Works belonging to Messrs. Fletcher, Jennings, and Co. near Whitehaven. " (W.H. Smyth, 1860:302-305); as we have seen, Henry A Fletcher was Isaac Fletcher's brother. This innovative design, which was in part inspired by the smaller wooden mounting used by W H Smyth at his Hartwell Observatory (Smyth, 1860), is described in an 1865 issue of *Monthly Notices*:

The middle portion of the axis, which is pierced for the declination axis, is a tube of 17 inches, the metal being one inch thick. From the central cube to each extremity the axis is circular in section, and tapers from 16 inches diameter at the cube to 8 inches near the ends, where it spreads out as a moulded flange to give sufficient strength to carry the pivots. The thickness of the metal in the conical portions diminishes gradually from $\frac{3}{4}$ inch to $\frac{3}{8}$ inch. The cube is planed accurately, and the rest of the axis very carefully turned. The declination axis is of hammered iron, $4\frac{1}{2}$ inches diameter; it is carried *direct* by the polar axis without the intervention of either bushes or friction rollers; a boss is cast on the *inside* of the cube on the telescope side, of sufficient depth to give a bearing $4\frac{1}{2}$ inches long, and a similar boss is cast on the *outside* of the cube, on the counterpoise side, which gives a similar length of bearing. As there are no means of adjusting the declination axis, great pains were taken to bore out the bearings at right angles with the polar axis ... One end of the declination axis carries a strong cradle of cast-iron, to which the tube is fixed by means of four very strong clasps; the opposite end carries the counterpoise. The pivots of the polar axis are of wrought-iron, $2\frac{1}{2}$ inches diameter; they work in brass bearings without friction rollers, but have the necessary adjustments. The hour-circle is of gun metal, 42 inches diameter; the declination circle is cast from the same pattern, and reads off by opposite microscopes to single seconds...

The total weight of the *moveable* portion of the mounting is upwards of $1\frac{1}{2}$ tons, yet the instrument may be moved either in hour-angle or declination with a finger, and a clock-weight of 45 lbs. (acting on the clock of $22\frac{1}{2}$ lbs.) is sufficient to drive it with the greatest regularity. (Fletcher, 1865a: 242-243; c.f. W.H. Smyth, 1860: 303-304).

C P Smyth (1860) also includes a number of interesting sketches in his diary. Fletcher (1865a:243) was proud of this newfangled mounting, and was quick to proclaim that "In regard to *firmness*, I do not think this instrument is surpassed by any ..." It was this 1865 paper which led Harper (1992; see also Harper, Warren and Austin, 1990) to erroneously associate this date with the actual manufacture of the telescope.

Although we have stressed the unique nature of the mounting, the telescope itself was an achievement as it was "... one of the largest telescopes yet made in England ... and may serve to show that it is not now needful to go abroad in order to procure a first-rate instrument." (Jacob, 1860:247-248). Cooke only opened the Buckingham Works at Bishopshill in 1855, and the telescope was important for his burgeoning reputation (see King, 1979; McConnell, 1992; Smiles 1884). More specifically, an examination of the firm's first order book reveals that at the time it was made the Fletcher telescope ranked as Cooke's largest refractor, surpassing two 8-in (20.3 cm) instruments (for J Nasmyth and W Hartree) ordered in 1857 (Orders ..., n.d; cf. Smiles, 1884). Fletcher's telescope also rated highly on an international scale (see Table 1 below, after Crossley, Gledhill and Wilson, 1879; Howse, 1986; Krisciunas, 1988; Welther, 1984; Whitesell, 1998), the equal largest operational refractors in the world at that time being the 15-in Merz & Mahler instruments at the Pulkovo and Harvard College Observatories (see van Helden, 1984).

Table 1. Some operational refractors with apertures exceeding 9.5 inches in 1859.²

Aperture	Manufacturer	Observatory
15.5-in (39.4 cm)	Merz & Mahler	Harvard College
14.93-in (37.9 cm)	Merz & Mahler	Pulkovo
13.3-in (33.8 cm)	Cauchois	Colonel E.J. Cooper
12.8-in (32.5 cm)	Merz & Mahler	Royal, Greenwich
12-in (32.5 cm)	Merz & Mahler	Cincinnati
12-in (30.5 cm)	Fitz	Detroit
11.6-in (29.5 cm)	Cauchois	Cambridge University
11-in (27.9 cm)	Ross	Mr J.W. Grant
11-in (27.9 cm)	Amici	Royal, Florence
10-in (25.4 cm)	Merz & Mahler	Kazan University
9.75-in (24.8 cm)	Fitz	West Point
9.6-in (24.4 cm)	Fraunhofer	Dorpat
9.6-in (24.4 cm)	Merz & Mahler	U.S. Naval
9.6-in (24.4 cm)	Fraunhofer	Royal, Berlin

In order to house his new telescope Fletcher built a commodious new Tarn Bank Observatory (Figure 1), with an 18-ft (5.5 m) diameter dome that revolved on eight railway wheels of 12-in diameter (W.H. Smyth, 1860). C P Smyth's diary (1860) contains details and sketches of the dome, and a plan of the Observatory, which housed a number of other instruments including a transit telescope by Simms and an astronomical clock by Frodsham. Fletcher believed this facility was one of "... the best and most complete observatories in private hands in existence." (Mr. Fletcher's Observatory ..., 1866).

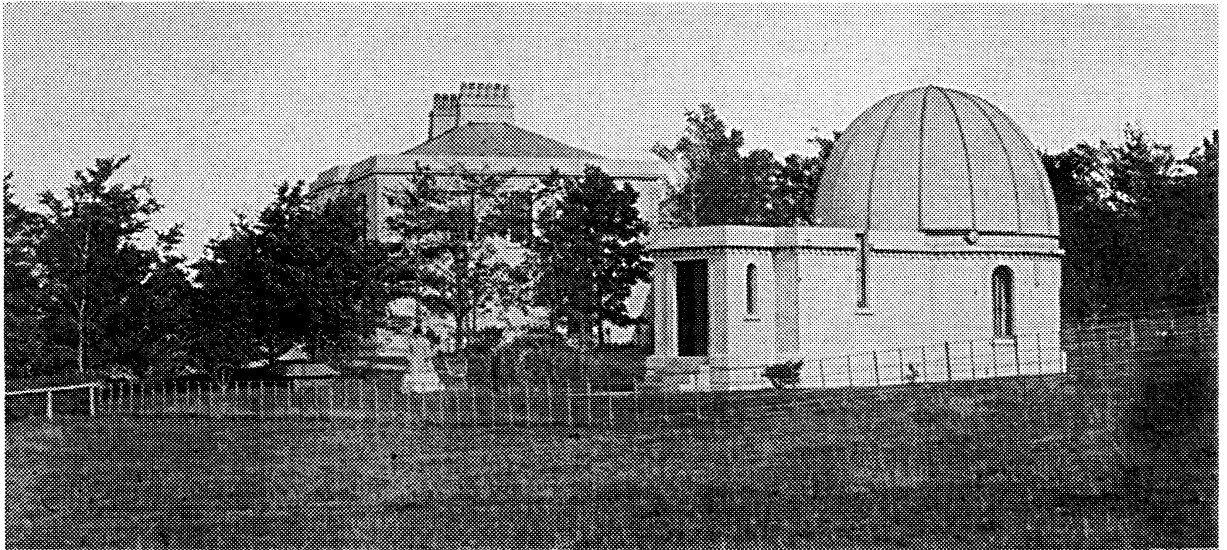


Figure 1. Fletcher's residence and his Tarn Bank Observatory (Courtesy: Royal Astronomical Society).

Initially, Fletcher used the Cooke telescope to examine the double star, ζ Herculis (Fletcher, 1865b), and his observations of solar granulation clarified the controversy over their true nature by reinforcing the views of Sir William Herschel and W R Dawes and conflicting with the explanation put forward by J Nasmyth (see Fletcher, 1865c, 1865d). But he had much grander plans for the Tarn Bank Observatory, which he believed boasted "... one of the finest telescopes in this country ..." (Fletcher, 1865d:25). He intended to re-observe the objects in Smyth's Bedford Catalogue, and

... when that is done, it is his intention to bring out a new edition of Admiral Smyth's *Cycle of Celestial Objects*, for which purpose the Admiral, some time ago, made over to him his entire interest in that work. (Mr. Fletcher's Observatory ..., 1866; cf. W H Smyth, 1860).

W H Smyth died in 1865, and Fletcher was left with what can only be described as a mammoth undertaking. After all, Smyth's two-volume book, published in 1844, ran to a little over 1100 pages of text, more than half of which comprised the remarkable 'Bedford Catalogue'. Chapman (1998:80) has written an excellent evaluation of this indispensable tool of the nineteenth century observational astronomer:

The *Cycle* provides a wealth of information about the equipping of observatories and an evaluation of instruments ... But it is in the second volume of the 1844 *Cycle*, known as the *Bedford Catalogue*, that we see the celestial 'harvest' of which Smyth spoke. Here is a detailed description and analysis, occupying some 543 pages, of hundreds of binary, variable, and coloured stars in 70 constellations. No one can read these pages without appreciating the thousands of hours of sheer hard observing, undertaken purely for the 'love' of astronomy, that lay behind Smyth's book.

Smyth based his 'Bedford Catalogue' upon observations carried out with a 5.9-in (15 cm) Tully refractor (see the diagram in Smyth, 1844, I:338), a much smaller instrument than Fletcher's 9.5-in Cooke, so different field sizes and limiting magnitudes were involved, particularly

important factors for nebulae and star clusters. Moreover, all of the double stars needed to be re-measured as their position angles and separations would, in most instances, have changed since Smyth's initial observations of the 1830s.

Fletcher responded to the challenge and for several years he "... systematically collected materials for the revision of the work." (Smyth and Chambers, 1881:vii, cf. Mr. Fletcher's Observatory, 1867), although one cannot help but wonder if he completely understood the magnitude of the task before him. As it turned out, a non-astronomical factor put paid to this ambitious project once and for all, for in 1868 Fletcher "... exchanged in great part his scientific career for a political one by becoming Member of Parliament for Cockermouth." (Smyth and Chambers, 1881:vii). One consequence of this was that no further papers in Fletcher's name were to appear in *Monthly Notices* or in the *Memoirs* of the Royal Astronomical Society.

Fletcher finally took his own life in 1879, at the age of 52 (Obituary, 1880), and by that time the 'Bedford Catalogue Project' had passed to George Chambers. The 'Revised, Condensed, and Greatly Enlarged' Second Edition emerged from the Clarendon Press at Oxford in 1881. As a single weighty tome of about 700 pages (see Smyth and Chambers, 1881), this was a worthy successor to Smyth's original Volume II.

After Fletcher's death, the 9.5-in Cooke refractor passed to Samuel Chatwood, the successful and "... well-known bankers' engineer ..." (Baker, 1902) who owned the Chatwood Lock and Safe Company (Beaumont, 1963b). Chatwood does not disclose whether he acquired the telescope from the estate immediately after Fletcher's death or at a later date, but we do know that he installed it in a new observatory adjacent to his home at Worsley, near Manchester (see Figures 2 and 3). If the singular lack of published papers in the *Journal of the British Astronomical Association*, *Monthly Notices of the Royal Astronomical Society* and *The Observatory* is anything to go by, we must assume that Chatwood made little if any attempt to use this excellent telescope for serious research before selling it, in 1902, to the Wanganui Astronomical Society in New Zealand.

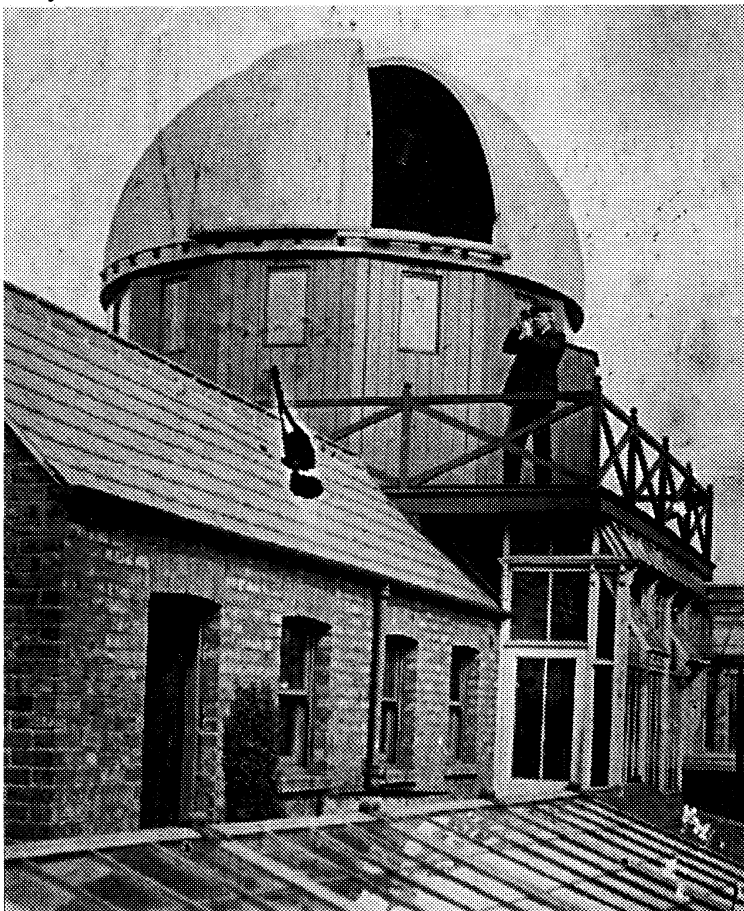


Figure 2. Mr Chatwood's Observatory; the man with the sextant is Dr Fison (Courtesy: Ward (Wanganui) Observatory Archives).

3 THE NEW ZEALAND HISTORY OF THE TELESCOPE

In this Section, we shall discuss separately the transfer of the telescope to New Zealand and its subsequent role and function.

3.1 Transfer to New Zealand

The transfer of the telescope to New Zealand was effected by Joseph Thomas Ward (see Figure 4), a prominent New Zealand amateur astronomer during the first three decades of the twentieth century and a member of the British Astronomical Association (see Beaumont, 1963a; Calder, 1978a; Orchiston, 1996b). Born in England on 1862 April 7, Ward migrated to New Zealand in about 1880 and in 1896 he and his wife settled in the North Island coastal town of Wanganui (which is about 150 km due north of the capital, Wellington). There he opened a bookshop and stationery business, and also taught the violin. From an early age he had been interested in astronomy, and in about 1899 he purchased a 4.5-in (11.4 cm) refracting telescope. When the Great Comet of 1901 (C/1901 G1) appeared, townsfolk flocked to view it through this instrument.

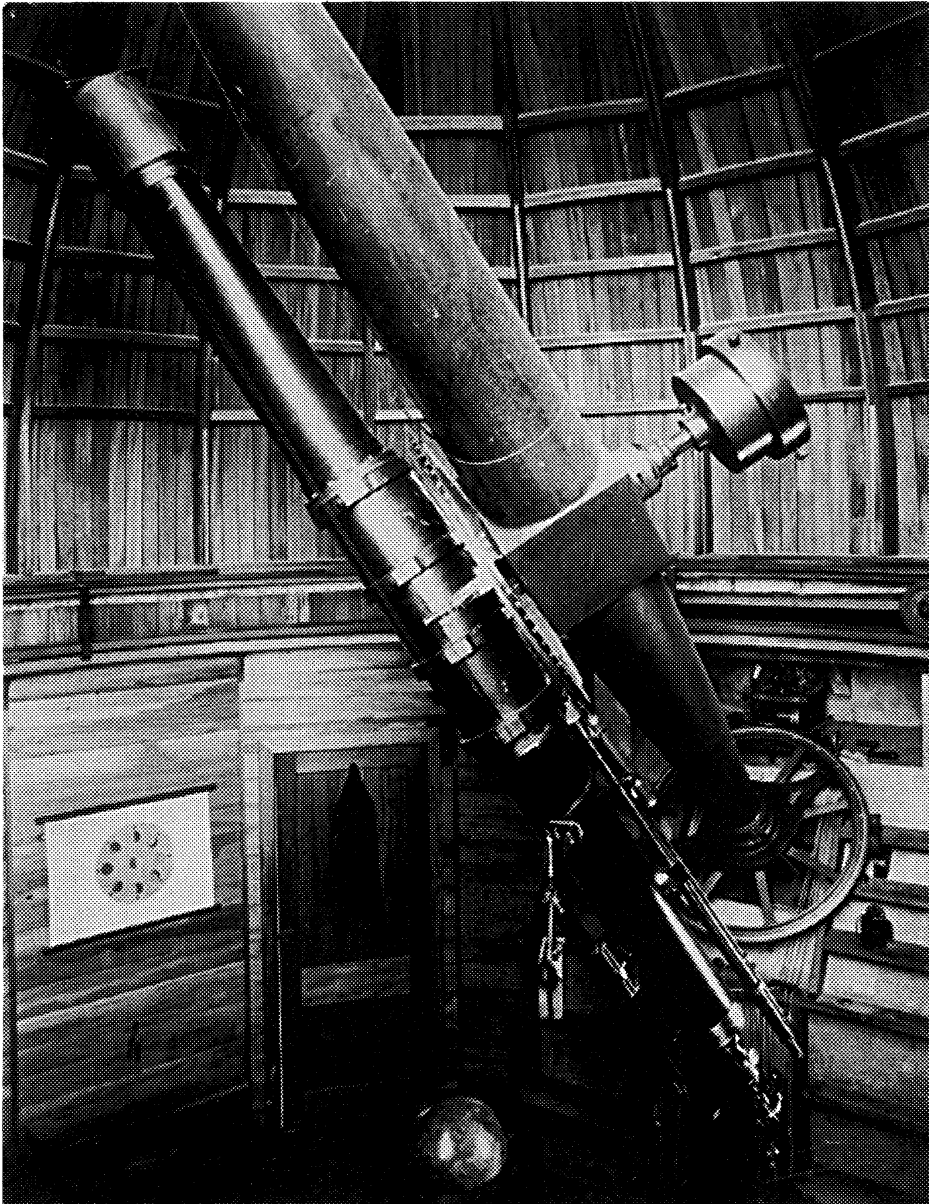


Figure 3. A view of the Cooke Telescope and mounting at Mr Chatwood's Observatory (Courtesy: Ward (Wanganui) Observatory Archives).

In this same year Professor R C Maclaurin from Wellington gave a public lecture on astronomy in Wanganui, and Ward used this as the catalyst to form the Wanganui Astronomical Society. As might be expected, Ward was elected to the Presidency, a post that he was to occupy until his death in 1927. One of the first decisions made by the new Society was to establish an observatory, and the committee set about fund-raising. They also obtained a suitable site in suburban Cook's Gardens from the Borough Council. Ward, meanwhile, was busy searching for "... a very large telescope capable of research as well as public observation ..." (Beaumont, 1963b:6).



Figure 4. Joseph Ward, 1862-1927
(Orchiston Collection).

Thrush (1963) recounts how Ward succeeded in tracking down three suitable instruments in England: 8-in (20.3 cm) Grubb and Clark refractors and a 20.5-in (52.1 cm) Calver reflector, and by 1901 October the Society had decided to purchase this last instrument. After part of the purchase price of £400 had been dispatched to the Bolton firm of Banks & Co., a cable arrived from a Mr Chatwood advising that the payment should be stopped as he was the owner of the reflector and Banks & Co. had not been authorized to sell it!

Fortuitously, Chatwood also owned the ex-Fletcher 9.5-in Cooke refractor with the prototype metal English equatorial mounting, and he decided to make that instrument available to the Society. Negotiations on his behalf were entered into by Charles Baker of London, and in a letter dated 1902 March 27 Baker stressed the telescope's optical quality:

I have had consultations with Mr. Maunder, and with Mr W.H. Maw, Treasurer of the B.A.A. who express themselves satisfied with the instrument; and Mr Chatwood informs me that Dr Fison, Mr Antoniadi and Sir Robert Ball, who have used his instrument, all say that the object glass in a beauty. (Baker, 1902).

As an added incentive, Baker offered an extremely attractive purchase price of just £400, but when the cost of constructing an observatory was added to this the Society was facing a

daunting task for a city with a population of just 6,000 since "The [total] amount needed would be at least the equivalent of two years salary for the average citizen." (Venimore, n.d.:12). In fact, the price soon proved to be even higher, for the Society agreed to pay an additional £50 to Mr Chatwood for some improvements he made to the telescope and for some extra equipment that he added to the consignment.

Yet the all-up cost did not deter Ward and his colleagues, and at their meeting on 1902 May 2 the Committee voted to accept Baker's offer. Mr Chatwood (1902) was quick to point out that the Society had got itself a bargain, for "Under other circumstances ... I would not have sold the instrument for less than £750. It could not be replaced [today] for less than £1250 ...". The instrument was then dismantled and packed ready for shipping on *S.S. Indravedi*. In 1902 December the vessel reached New Zealand, and the telescope was placed in storage pending the construction of an observatory.

The Society's 20-ft (6.1 m) diameter 16-sided wooden observatory was designed by a local architect named Atkins from drawings and a model provided by Ward, and its construction was completed in early 1903 May (Figure 5) at a cost of £277-12-6. The massive supports for the telescope mounting were a special feature, and weighed heavily on the mind of a 4-year old boy who 75 years later was to recall how he "... clearly remembers the day the heavy cast-iron pillar of the mounting was erected. His father provided the lifting gear the foundry used ... and a gang of willing helpers provided the manpower that lifted the pillar into place." (Calder, 1978b:4). This pillar and the 40 ton concrete foundation made to support the lower end of the polar axis are shown in Figure 6, along with the outline of the observatory building.

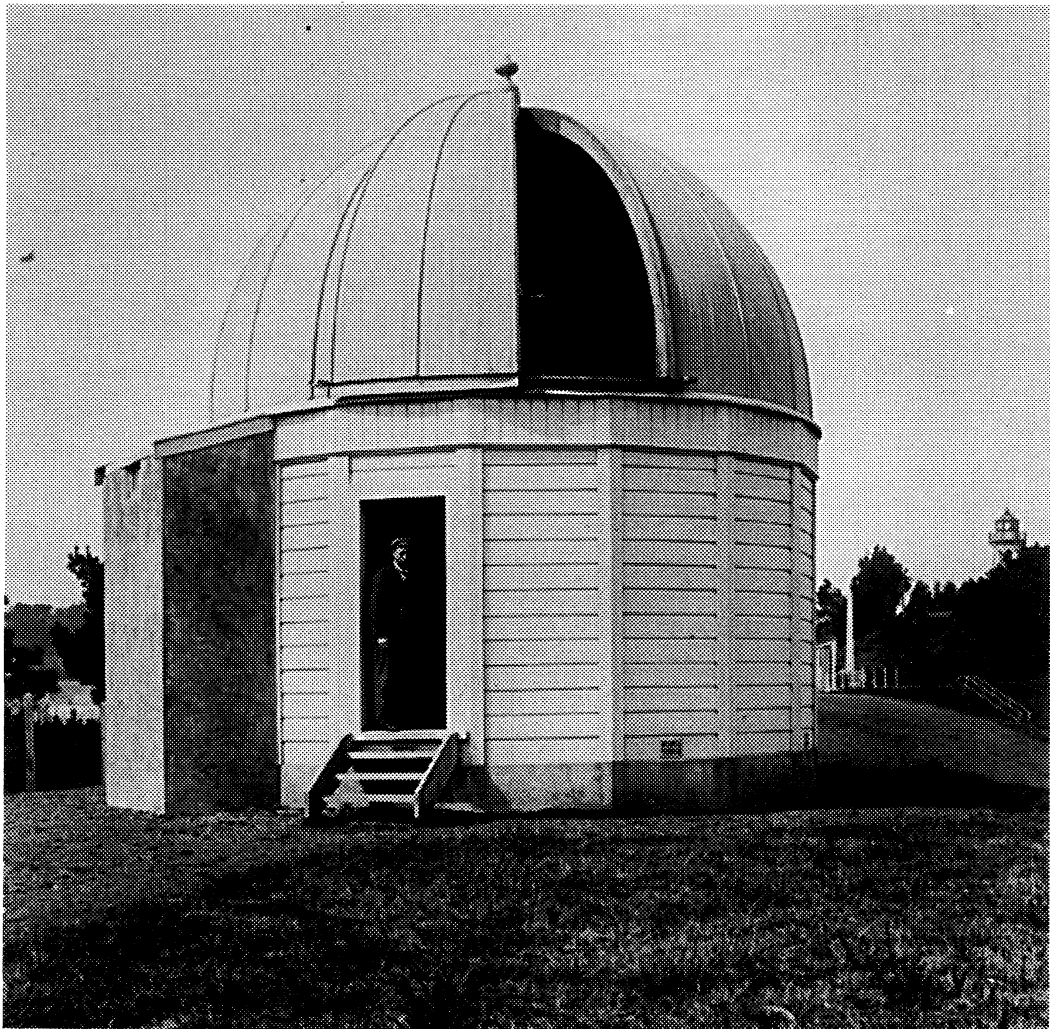


Figure 5. The completed Ward (Wanganui) Observatory
(Courtesy: Ward (Wanganui) Observatory Archives).

Now came the installation of the telescope and mounting, in good time for the official opening of the observatory by the Premier of New Zealand, the Right Honourable Richard Seddon, on 1903 May 25. Beaumont (1963b:7) describes what a perceptive Seddon would have seen:

The 9½-inch refractor has a 12-ft. focus and is equipped with a 2½-inch finder. There is a battery of eyepieces magnifying from 32 to 750 diameters; filar and position micrometer with divided heads in silver, position circle on silver, reading by opposite verniers; Cooke's two-movement adaptor for centring an object; solar and stellar diagonal eyepieces; Dawes eyepiece for observing the Sun; aluminium shutter to object glass. The telescope is mounted on what is known as the English form of equatorial. It is supported on a massive axis, weighing nearly two tons, which rests at one end on a large iron bracket, which is fastened to a cast-iron column 12 ft. high of architectural proportions. The lower support for the axis is [an] adjustable stopping-piece of brass resting on iron bearings, and moved by set screws in azimuth... A powerful driving clock is attached to the edge of the circle at the lower edge of the large axis, which is kept in motion by a weight attached to a steel cord, and working on the clock at a pressure of 22½ lbs. By this manner an object can be kept in the telescope in the centre of its field for purposes of photography, drawing or measurement.

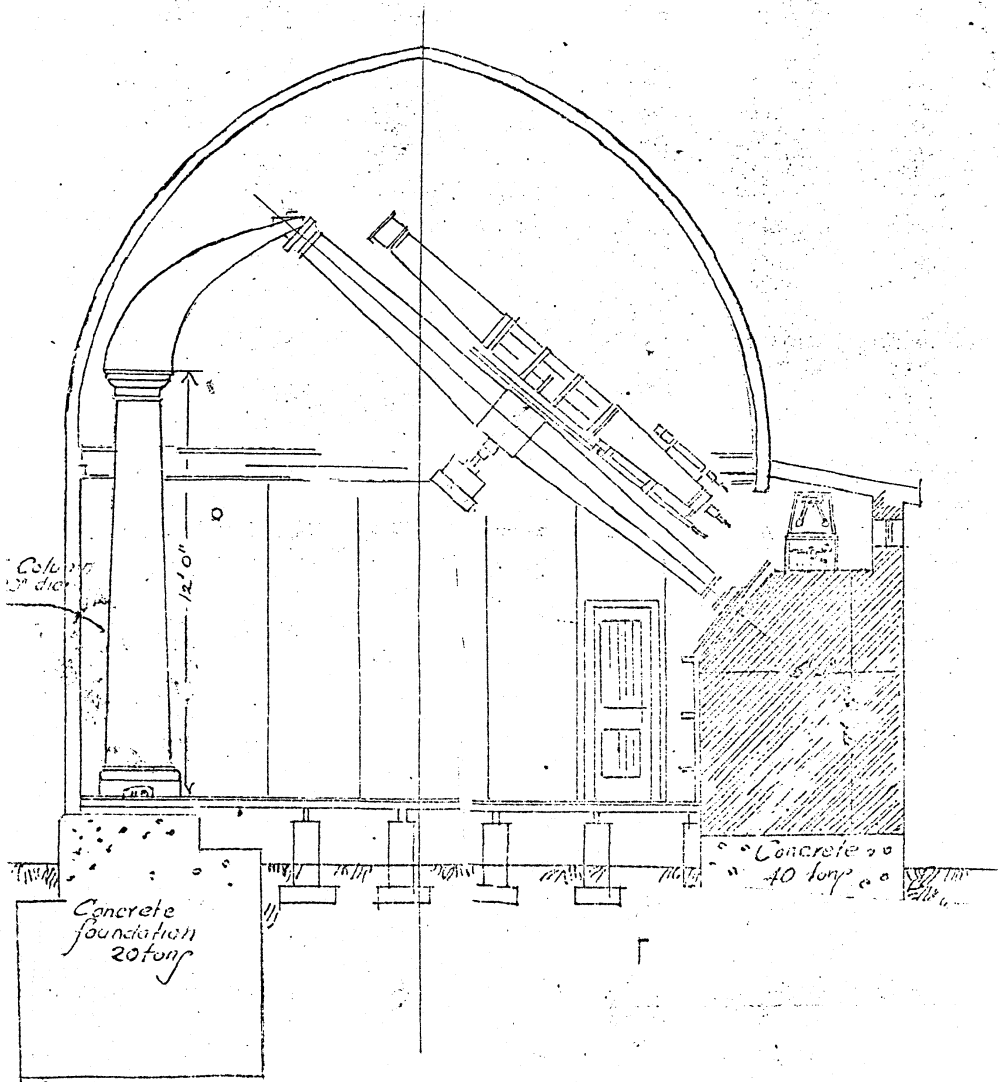


Figure 6 Section drawing showing the Ward (Wanganui) Observatory, telescope and mounting, and supports for the mounting (Courtesy: Ward (Wanganui) Observatory Archives).

Figure 7 shows a close-up view of the lower end of the polar axis, the oversized 42-in (1.07 m) diameter RA circle, and the eyepiece end of the main telescope tube and finder, complete with RA and declination clamps and slow motion controls.

Ward was appointed Honorary Director of the Observatory, a post that he was to retain until his sudden and unexpected death on 1927 January 4 at the age of 65. Nine months earlier, ownership of the Observatory had been transferred from the Astronomical Society to the Borough Council. One of Joseph Ward's sons who happened to inherit a passion for astronomy was prophetically named William Herschel Ward, and in 1927 the local Council arranged for him to succeed his father as Honorary Director of the Observatory, a role that he fulfilled with distinction until 1959 (W.S.T., 1975).

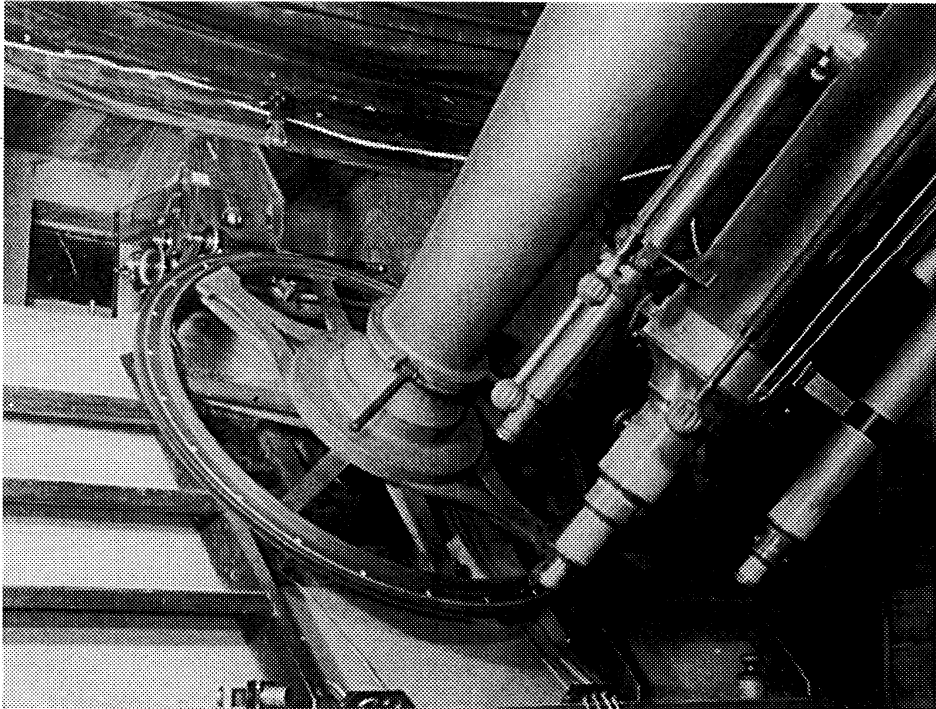


Figure 7. View of the lower end of the polar axis and main telescope tube (Orchiston Collection).

The Observatory is nowadays known officially as the 'Ward (Wanganui) Observatory' in honour of its founder (Beaumont, 1963b), and in spite of its antiquity the historic Cooke telescope remains the largest operational refractor in New Zealand marginally surpassing the better-known 23 cm Cooke at the National Observatory of New Zealand in Wellington (see Orchiston, n.d. (a), 1996a).

3.2 Role of the Telescope in Recreation and Research

Joseph Ward was quick to recognize the potential of what was then by far the largest refractor in New Zealand, and he was keen to find a suitable research programme for it. He began by canvassing the views of Australia's leading astronomer, John Tebbutt (Ward, 1903), and in 1904 he and his assistant, local lawyer Thomas Allison, commenced a search for new double stars in selected areas of the southern sky, mainly "... along the southernmost sections of the Milky Way among the constellations Triangulum Australe, Centaurus and Musca, between -50° and -80° south declination." (Harper, Warren and Austin, 1990:283). In the course of the next six years they made 212 discoveries (see Warren, 1991), although unbeknown to Ward many of these had previously been detected by others (Innes, 1911). Today, 88 of these stars are recognized as 'Ward doubles' (Harper, Warren and Austin, 1990) and appear with NZO (New Zealand Observatory) listings in international double star catalogues, thereby serving as a memorial to Ward's international contribution in this specialized field of astronomy.

In addition to double stars, Ward also observed sunspots (Venimore, 1988), and 15 drawings of Mars that he made in 1905 were forwarded to the British Astronomical Association

(see Antoniadi, 1910). He also used the Cooke refractor to carry out numerous observations of Comet 1P/Halley in 1910 (see Mackrell, 1985).

It should be mentioned that in addition to using telescopes Ward was one of that rare breed that also enjoys manufacturing them, and over the years he made many refractors and reflectors of modest aperture. Undoubtedly his crowning achievement was a 20.5-in (52.1 cm) equatorially-mounted Newtonian reflector completed in 1924 (Venimore, 1988), which for 40 years remained the largest reflecting telescope manufactured by a New Zealand amateur astronomer. Further information on Ward's pioneering efforts in telescope-making is provided in Orchiston (n.d. (b)).

Another of Ward's important contributions to New Zealand astronomy was in popularizing the wonders of the southern sky, and two evenings a week he ran 'public viewing nights' at the Wanganui Observatory (Venimore, 1988) where he used the old Cooke telescope to eagerly share his love and knowledge of astronomy with visitors. As one writer so aptly put it, "... he loved the telescope to read the open volume of the sky." (cited by Beaumont, 1963a:14). Meanwhile, through his monthly column, 'Astronomical Notes', which appeared in the *Wanganui Herald* newspaper for twenty-two consecutive years from 1904, he was able to bring astronomy to a much wider audience, and help raise the level of astronomical literacy in the general population.

Despite these various achievements, some have painted an even more glowing picture of Ward, suggesting that he proposed "... several theories concerning the movement and nature of heavenly bodies, which were accepted by leading authorities." (Beaumont, 1963a:13); that "In his time he was considered one of the world's foremost astronomers." (Beaumont, 1963b:7); and that "His writings were more widely known abroad than in New Zealand due to their publication in many British and French astronomical journals." (Rice, 1982:272). In reality, there is no basis for these exaggerated claims. Although Ward did indeed discover a number of new double stars (as, also, did other astronomers at about this time), he actually published nothing of substance in international journals (but see Venimore, 1988:156; Ward, 1906, 1910). He was not even destined to publish his own double star discoveries. In 1907 he sent a list of these to the British Astronomical Association but they decided not to publish this (Harper, Warren and Austin, 1990), and his catalogue was eventually published in South Africa by Innes in 1911 (although Ward did manage a half-page note about it in the *Journal of the British Astronomical Association* in 1908)! Yet these comments should not blind us to Ward's notable contribution to Wanganui and New Zealand astronomy.

What of the Ward (Wanganui) Observatory today? It is only fitting justice that the observing tradition begun by Fletcher in the 1860s and followed by Ward has in more recent times been perpetuated by Ormond Warren. During the 1980s and 1990s, he used the historic Cooke telescope and its original Cooke Type-A bifilar micrometer to carry out a re-examination of the 'Ward doubles' (e.g. see Warren, 1991, 1995) and to measure the position angles and separations of other southern double stars (e.g. Warren, 1992a, 1992b, 2000). Furthermore, the dedication to astronomical education espoused by Joseph Ward and his son (Thrush, 1963) also is a current priority with the Wanganui Astronomical Society (see Harper, 1992), and the Cooke refractor remains the focal point of their regular public viewing nights.

As to the telescope itself, a recent critical examination of the 9.5-in achromatic objective has confirmed the earlier evaluations of Ball and Antoniadi as to its performance. Nankivell (1994:9) found that in spite of the passage of the years it

... is in a very good state of preservation. The crown lens shows some slight incipient smearing of the front surface ... [but] There are very few scratches of any consequence. The flint lens is free of any obvious tarnish patches. There are one or two "lead spots" about 2-3 mm diameter. Some localised water stains were noted close to the edge...

With the provision of reasonable care, this objective should perform well for another 100 years.

The present appearance of the telescope is impressive, with the cast-iron polar axis painted an attractive shade of blue and the declination axis (plus counterweight) and tube of the main telescope a pale grey. The natural brass finish of the eyepiece assembly and of the finder has been retained.

4 CONCLUDING REMARKS

New Zealand's largest operational refractor is the 9.5-in f/15 Cooke telescope at the Ward (Wanganui) Observatory, which has some claim to fame as the first telescope in the world to be furnished with a cast-iron (as opposed to wooden) English equatorial mounting of the 'Cross Axis' type.

This instrument was manufactured in 1859 for I Fletcher of Carlisle, and was later owned by S Chatwood of Manchester before transferring to New Zealand and the observatory of the Wanganui Astronomical Society in 1902-03. Fletcher and Ward (at Wanganui) both used the telescope for serious positional astronomy (including the observation of known double stars and the search for new ones) and published a number of papers on their work, while at Wanganui the telescope also was the focal point of a popular 'public viewing' programme.

After a heritage of nearly 150 years this historic telescope is in remarkably fine condition, and it continues to contribute to serious observational astronomy and to the popularization of astronomy.

5 ACKNOWLEDGEMENTS

I should like to thank the following for their assistance: Ray Lee, the Reverend Colin Venimore, Ormond Warren and the late David Calder (all from the Ward (Wanganui) Observatory); Alison Brech (The Borthwick Institute of Historical Research, York) and Dr Richard Crossley (The University of York); Dr Mary Brück (Penicuik, Scotland); Dr Allan Chapman (Oxford University); Peter Hingley (Royal Astronomical Society Library); the late R F Joyce (Kaiapoi, New Zealand); Garry Nankivell (Wellington, New Zealand); Sandra Ricketts (Anglo-Australian Observatory Library); Jackie St. George (Sydney); and staff at the Public Library of New South Wales (Sydney).

Finally, I am grateful to the Donovan Astronomical Trust for helping fund my archival research in England, and to the Royal Astronomical Society and the Wanganui Astronomical Society for permission to publish Figures 1, 2, 3, 5, and 6.

6. NOTES

- 1 However, the Fletcher refractor was not the first astronomical instrument with a part-iron English equatorial mounting. In 1775 Bird made an equatorial sector for the Radcliffe Observatory, and this featured a plywood laminated single iron axis, 7½ feet long, 3 inches square in the middle and tapering to about 2 inches at the ends (Chapman, 1995). In 1993 the remains of this historic instrument were discovered by Allan Chapman and Tony Simcock in a 'store hole' at Oxford (A. Chapman, pers. comm., August 2000).
- 2 Compiling this table was a challenge as different authors sometimes give differing apertures for the same instrument, depending upon their sources of documentation, the effects of rounding (e.g. 9.6-in becomes 9.5-in and 14.93-in and 15.5-in both become 15-in), and whether total or clear apertures were involved. Where such variations occurred, I generally (but not always) opted for the dimensions given in Howse (1986).

7. REFERENCES

- Antoniadi, E.M., 1910. Section for the observation of Mars. Report of the Section, 1905. *Memoirs of the British Astronomical Association*, **17**(2):35-64.
- Baker, C., 1902. Letter to J.T. Ward, dated 27 March. Original in Ward (Wanganui) Observatory Archives.
- Beaumont, L.R.H., 1963a. J.T. Ward, founder of Wanganui's Observatory, made important contributions to science. *Journal of the Auckland Astronomical Society*, **21**(2):13-14.
- Beaumont, L.R.H., 1963b. Wanganui Observatory: the story of its foundation. *Journal of the Auckland Astronomical Society*, **21**(2):6-7 & 12.
- Brück, M.T., 1988. The Piazzzi Smyth collection of sketches, photographs and manuscripts at the Royal Observatory Edinburgh. *Vistas in Astronomy* **32**:371-408.
- Brück, H.A., and Brück, M.T., 1988. *The Peripatetic Astronomer: The Life of Charles Piazzzi Smyth*. Adam Hilger, Bristol.
- Calder, D., 1978a. Joseph Ward: pioneer astronomer and telescope maker. *Southern Stars*, **27**:104-108.
- Calder, D., 1978b. Seventy-five years of astronomy: Ward Observatory, 1903-1978. Lecture given to the Wanganui Astronomical Society, 24 May 1978.

- Chapman, A., 1995. Out of the meridian: John Bird's equatorial sector and the new technology of astronomical measurement. *Annals of Science*, **52**:431-463.
- Chapman, A., 1998. *The Victorian Amateur Astronomer. Independent Astronomical Research in Britain 1820-1920*. Wiley, Chichester.
- Chatwood, S., 1902. Letter to J. Ward, dated 16 August. Copy in Ward (Wanganui) Observatory Archives.
- Crossley, E., Gledhill, J. and Wilson, J.M., 1879. *A Handbook of Double Stars ...* Macmillan, London.
- Fletcher, I., 1850. Brief description of a small equatoreal and dome at Tarn Bank, near Cockermonth. *Monthly Notices of the Royal Astronomical Society*, **10**:137-139.
- Fletcher, I., 1853. Results of micrometrical measures of double stars made at Tarn Bank, Cumberland, from 1850.2 to 1853.4. *Monthly Notices of the Royal Astronomical Society*, **13**:256-259.
- Fletcher, I., 1855. Remarks on Mr. Powell's elements of the orbit of 70 Ophiuchi. *Monthly Notices of the Royal Astronomical Society*, **5**:161-162.
- Fletcher, I., 1865a. Description of an equatorial mounting. *Monthly Notices of the Royal Astronomical Society*, **25**:241-243.
- Fletcher, I., 1865b. Note on ζ Herculis. *Monthly Notices of the Royal Astronomical Society*, **25**:275.
- Fletcher, I., 1865c. On the photosphere of the Sun. *Monthly Notices of the Royal Astronomical Society*, **25**:231-233.
- Fletcher, I., 1865d. Some remarks on the solar photosphere. *Monthly Notices of the Royal Astronomical Society*, **26**:23-26.
- Gingerich, O., 1967. What is an English mounting? *Sky and Telescope*, **34**(4):293-295.
- Harper, C.T., 1992. Teaching astronomy in New Zealand: the Ward Observatory. In J.M. Pasachoff and J.R. Percy (eds.), *The Teaching of Astronomy*. Cambridge University Press, Cambridge, pp. 354-357.
- Harper, C.T., Warren, O. and Austin, R., 1990. J.T. Ward and the NZO double stars. *Southern Stars*, **33**:281-294.
- Hingley, P.D., n.d. The Shuckburghs of Shuckburgh, Isaac Fletcher, and the history of the English mounting. Unpublished manuscript.
- Howse, D., 1986. The Greenwich list of observatories: a world list of astronomical observatories, instruments and clocks, 1670-1850. *Journal for the History of Astronomy*, **17**.
- Innes, R.T.A., 1911. Observations of southern double stars. *Transvaal Observatory Circular*, **6**:61-72.
- Jacob, W.S., 1860. Account of the performance of Mr. Fletcher's new equatoreal. *Monthly Notices of the Royal Astronomical Society*, **20**:247-249.
- King, H.C., 1979. *The History of the Telescope*. Dover, New York.
- Krisciunas, K., 1988. *Astronomical Centers of the World*. Cambridge University Press, Cambridge.
- McConnell, A., 1992. *Instrument Makers to the World. A History of Cooke, Troughton & Simms*. William Sessions, York.
- Mackrell, B., 1985. *Halley's Comet Over New Zealand*. Reed Methuen, Auckland.
- Miller, J.F., 1852. Micrometrical measurements of the binary star ξ Ursae Majoris, and the double star Struve 1263, made at the Observatory, Whitehaven. *Monthly Notices of the Royal Astronomical Society*, **12**:170-172.
- Miller, J.F., 1853. Micrometrical measurements of double stars made at the Observatory, Whitehaven, in the years 1851, 1852 and 1853. *Memoirs of the Royal Astronomical Society*, **22**:187-188.
- Mr. Fletcher's Observatory. *Monthly Notices of the Royal Astronomical Society*, **27**:131 (1867).
- Mr. Fletcher's Observatory at Tarnbank. *Monthly Notices of the Royal Astronomical Society*, **26**:143-144 (1866).
- Nankivell, G.R., 1994. The 9.5 inch Cooke objective of the Wanganui Observatory. *Southern Stars*, **36**:1-9.
- Obituary: Isaac Fletcher. *Monthly Notices of the Royal Astronomical Society*, **40**:194 (1880).
- Obituary: John Fletcher Miller. *Monthly Notices of the Royal Astronomical Society*, **17**:99-100 (1857).
- Orchiston, W., n.d. (a). From Crossley to Carter: the life and times of an historic 22.9cm Cooke refractor. Submitted to *Journal of the Antique Telescope Society*.
- Orchiston, W., n.d. (b) Joseph Ward: pioneer New Zealand telescope-maker. Submitted to *Amateur Telescope Making Journal*.
- Orchiston, W., 1996a. The historic 23-cm refracting telescope at the Carter Observatory. In W. Orchiston and B. Carter (eds.), *Astronomical Handbook for 1997*. Carter Observatory, Wellington, pp. 59-69.
- Orchiston, W., 1996b. Ward, Joseph Thomas 1862-1927. In C. Orange (ed.), *The Dictionary of New Zealand Biography. Volume Three 1901-1920*. Auckland University Press and Department of Internal Affairs, Auckland, p. 555.
- Orchiston, W., 2000. Illuminating incidents in Antipodean astronomy: H.C. Russell and the origin of the Palomar-type mounting. *Journal of the Antique Telescope Society*, **19**:13-15.

- Orders. Astronomical & Mathematical Instruments. Order Book, Borthwick Institute, York (Cooke Archives).
- Rice, P., 1982. The story of Ward Observatory. *Southern Stars*, **29**:271-274.
- Smiles, S., 1884. *Men of Invention and Industry*. Murray, London.
- Smyth, C.P., 1860. Unpublished diary. Royal Edinburgh Observatory.
- Smyth, W.H., 1844. *A Cycle of Celestial Objects, for the Use of Naval, Military, and Private Astronomers*. Two Volumes. Parker, London.
- Smyth, W.H., 1860. *The Cycle of Celestial Objects Continued at the Hartwell Observatory to 1859 ...* Nichols and Sons, London.
- Smyth, W.H., and Chambers, G.F., 1881. *A Cycle of Celestial Objects*. Clarendon Press, Oxford.
- Thrush, W.S., 1963. Astronomy in Wanganui. *Southern Stars*, **20**:73-76.
- Van Helden, A., 1984. Telescope building, 1850-1900. In O. Gingerich (ed.), *The General History of Astronomy. Volume 4. Astrophysics and Twentieth-century Astronomy to 1950: Part A*. Cambridge University Press, Cambridge, pp. 40-58.
- Venimore, C., 1988. Good Viewing. (A History of the First Wanganui Astronomical Society and the Ward Observatory). Unpublished manuscript.
- Ward, J.T., 1903. Letter to John Tebbutt, dated 20 November. Original in *Letters to J. Tebbutt 1903*, Mitchell Library, Sydney (A 3715).
- Ward, J.T., 1906. The lunar eclipse of August 4. *Journal of the British Astronomical Association*, **17**:32-33.
- Ward, J.T., 1908. The Wanganui Observatory . Observations of two hundred and twelve new double stars. *Journal of the British Astronomical Association*, **18**:122.
- Ward, J.T., 1910. The total eclipse of the Moon, 1909, November 26. *Journal of the British Astronomical Association*, **20**:205-206.
- Warren, O.C.R., 1991. The NZO double stars. *The Web Society Quarterly Journal*, **85**:1-7.
- Warren, O.C.R., 1992a. Micrometrical measurements of visual double stars. *Southern Stars*, **35**:373-380.
- Warren, O.C.R., 1992b. Micrometrical observations of southern double stars. *Southern Stars*, **35**:12-14.
- Warren, O.C.R., 1995. Survey of NZO double star measures from 1989 to 1995. Paper presented at the Annual Conference of the Royal Astronomical Society of New Zealand.
- Warren, O.C.R., 2000. Micrometric measures of southern double stars. *Southern Stars*, **38**:217- 222.
- Welther, B.L., 1984. The world's largest telescopes, 1850-1950. In O. Gingerich (ed.), *The General History of Astronomy. Volume 4. Astrophysics and Twentieth-century Astronomy to 1950: Part A*. Cambridge University Press, Cambridge, pp. Ai-Avi.
- Whitesell, P.S., 1998. *A Creation of His Own: Tappan's Detroit Observatory*. University of Michigan, Ann Arbor.
- W.S.T., 1975. Obituary. William Herschel Ward (1900-73). *Southern Stars*, **26**: 93-94.



In 1999 Wayne Orchiston retired as Executive Director of the Carter Observatory (The National Observatory of New Zealand), and moved to Sydney, Australia, where he continues to research Cook voyage astronomy, Australian and New Zealand astronomical history, and early radio astronomy as a Research Associate of the Anglo-Australian Observatory. He is Secretary of IAU Commission 41 (History of Astronomy), and author of *Nautical Astronomy in New Zealand: The Voyages of James Cook* (Carter Observatory, 1998).

Spectroscopic observations of the 1874 transit of Venus: the Italian party at Muddapur, eastern India

Luisa Pigatto and Valeria Zanini

*Astronomical Observatory of Padova,
Vicolo dell'Osservatorio, 5 – 35122 Padova, Italy*
E-mail: pigatto@pd.astro.it; zanini@pd.astro.it

Abstract

The transit of Venus over the Sun expected on 1874 December 9, gave the opportunity to the Italian astronomers of organizing the second scientific mission of the new Kingdom of Italy born in 1861. Pietro Tacchini of the Astronomical Observatory of Palermo was designated to organizing the expedition for the Transit of 1874, and at the same time Giuseppe Lorenzoni of the Astronomical Observatory of Padova took care of getting all the necessary instruments ready and of shipping them to Bengal, eastern India. In this mission the Italians obtained a very important result: they observed, for the first time, details of the spectrum of Venus which confirmed the existence of its atmosphere. At the same time they demonstrated the validity of the spectroscopic observations to determine the exact instant of the contacts.

Keywords: *Transit of Venus, spectroscopic observations, Italian astronomers*

1 INTRODUCTION

The transits of Venus over the Sun of 1874 December 9 and 1882 December 6, mobilized astronomers all around the world to measure the parallax of the Sun. This predictable pair of events, separated by eight years, occurs every 113 and a half years, plus or minus 8 years, counting from the last of the two transits, so that the next two will occur on 2004 June 8 and 2012 June 5-6. This rare phenomenon did not find the international astronomical community unprepared: *The Nautical Almanac and Astronomical Ephemerides for the year 1874* gave the elements and the Greenwich Mean Time of the four contacts, and added an appendix with the names of 46 geographical places, together with their positions (latitudes and longitudes) and the local mean time of sunrise, sunset and the contacts—first external (I), first internal (II), middle of transit (M), last internal (III) and last external (IV)—visible in the listed places; the *Connaissance des Temps pour l'An 1872* gave Puisieux's computations for 20 places. *Nature* had started in 1874 June to give news concerning transit expeditions and, from 1874 December, reports of the expeditions themselves; so too did the 1875 issues of *Astronomische Nachrichten*. From 1871 a special Commission created by the US Congress planned the American transit expeditions (see Forbes, 1874; Janiczek and Houchins, 1974; Orchiston *et al.*, 2000). The telegraph, patented by Morse in 1840, played an important role in giving information in real time about the results of observations.

The rare phenomenon of the transit gave Italian astronomers the opportunity of organizing the second scientific mission of the new Kingdom of Italy, established in 1861; the unification of the Italian territory as a national state was completed after the annexation of the Venetian region in 1866 and of the Papal State in 1870. In December of that year, the first Italian scientific mission to Sicily, to observe the total eclipse of the Sun, was accomplished (Pigatto, 1998). This collaboration of Italian astronomers inspired Angelo Secchi¹ to found the Italian Spectroscopists Society in order to co-ordinate spectroscopic observations of the Sun, and the inaugural issue of the Society's *Memorie*, the first astrophysical journal in the world, was published in 1872.

In 1873 Pietro Tacchini² (Figure 1, left) from the Astronomical Observatory of Palermo began promoting the expedition to observe the transit and was subsequently charged with organizing it by the Minister of Education, who on Christmas Day granted him 50 000 lire (Tacchini, 1873c). Giuseppe Lorenzoni³ (Figure 1, right), from the Astronomical Observatory of Padova, was responsible for preparing all the necessary instruments and shipping them to western Bengal. The site for the expedition was chosen on the basis of Proctor's (1874) maps

(see Figure 2) and taking into account the cost of the journey and information received from the Italian Consul in Calcutta. The place selected was Muddapur (now Madhapur), about 300 kilometres north-west of Calcutta, at latitude $24^{\circ} 17' 0''.96 \pm 0''.34$ N, longitude $5^{\text{h}} 46^{\text{m}} 20^{\text{s}}.570$ E.



Figure 1. Pietro Tacchini (1838-1905) (left) and Giuseppe Lorenzoni (1843-1914) (right).

Because of the high cost of the mission, the Italian astronomers could not organize a second observing station necessary for determining the solar parallax; for this reason, they decided to address their efforts mainly to spectroscopic observations, in order to verify the best way of minimizing errors in measuring the exact instant of the contacts, and prepare for the transit of 1882.

The observers engaged for the expedition were: Tacchini, as chief of the mission; Angelo Secchi from the Roman College, who was prevented from leaving because of bad health; Alessandro Dorna⁴ from the Observatory of Torino; Antonio Abetti⁵ from the Observatory of Padova, together with Antonio Cagnato, a clever pupil from the workshop of the Observatory. Carlo Morso, an amateur astronomer from Palermo, "... well known for his aerostatic expeditions, as well as for his other travels ..." (*The Englishman*, 1874:2), joined the expedition at his own expense. Lastly the Jesuit, Eugène Lafont, director of the St. Xavier College in Calcutta and an expert in astronomy, joined the Italians at Muddapur (Tacchini, 1875a; Chinnici, 1995/96).

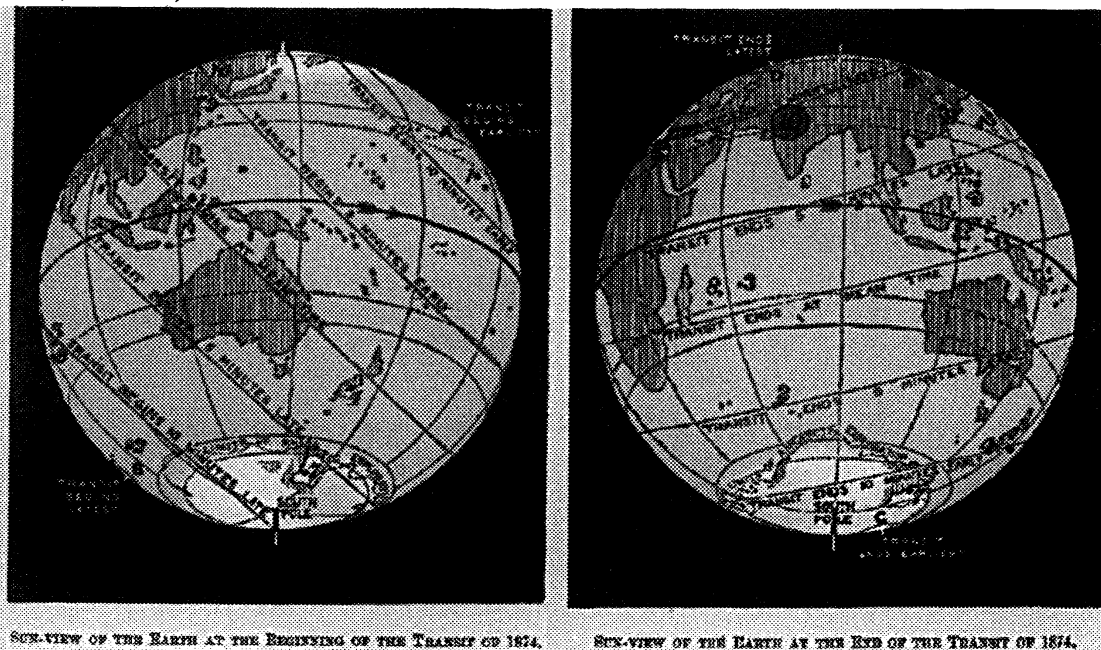


Figure 2. Proctor's maps used by Tacchini to choose the place from which to observe transit.

The instruments to be shipped to India, arranged and packed at the Observatory of Padova, were five refractors (Figure 3) – a Starke equatorial refractor from the Observatory of Padova (117 mm aperture, 1.65 m focal length), a Steinheil refractor from the Observatory of Bologna, with parallactic mounting⁶ modified at the Padova Observatory (162 mm aperture, 2.60 m focal length), a Fraunhofer refractor from the Observatory of Torino, with parallactic mounting modified at the Padova Observatory (117 mm aperture, 1.95 m focal length), a Starke altazimuth from the Observatory of Padova (117 mm aperture, 1.95 m focal length) and a 95-mm Dollond refractor from the Nautical College of Palermo – a Repsold transit instrument (Figure 4), three spectroscopes, chronometers, chronographs, thermometers, barometers, micrometers, other accessories and four pavilions to shelter the main instruments (Figures 5 and 6).

On 1874 November 25, *The Englishman* of Calcutta, informed its readers that "The Italian expedition of Astronomers which has come to India to observe the transit of Venus... [had] established their quarters at Madápur, on the chord line of the E.I. Railway, where the atmosphere is very clear in this time of the year, and where they have built *pakka* platforms." (p.2). On 1874 December 7, *The Daily Telegraph* of London gave a detailed review of the transit phenomenon, both from the historical and scientific points of view, and added information on "... British expeditions which have been provided by the nation." and private expeditions like that organized by Lord Lindsay. The paper stated that

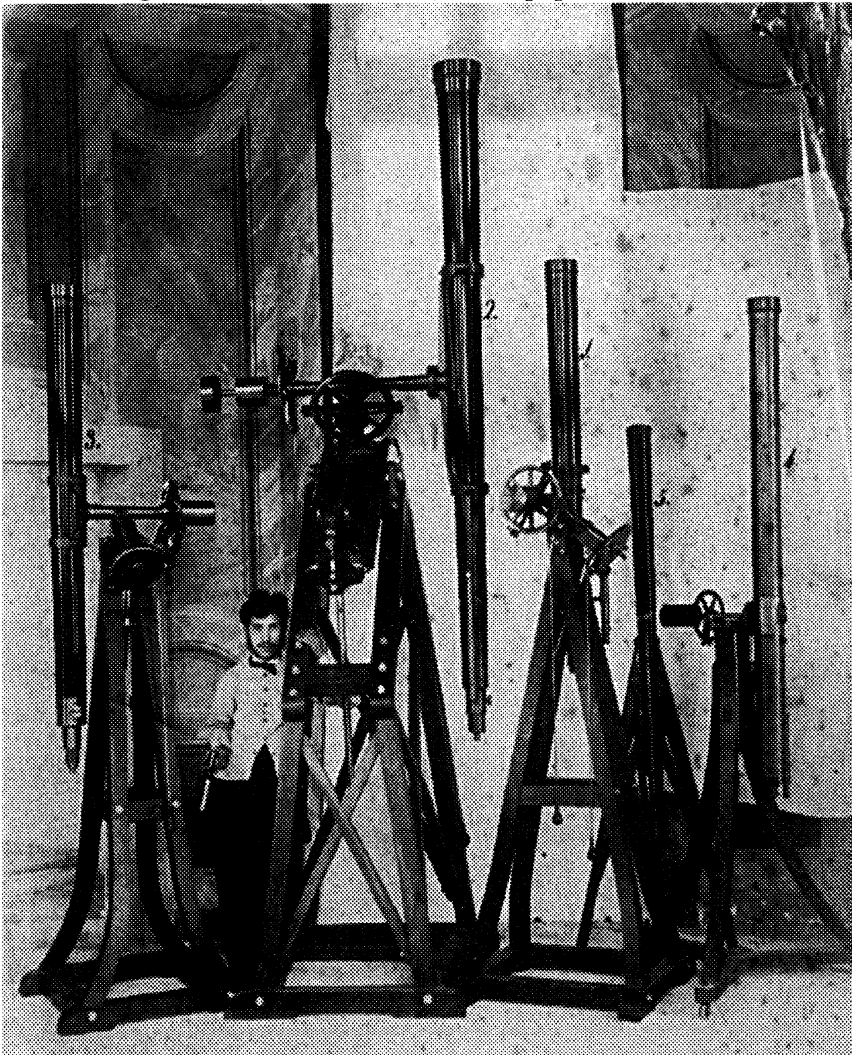


Figure 3. The five refractors photographed in the 'Sala delle figure' at the Observatory of Padova before shipping them to Muddapur (left to right): (3) the Fraunhofer refractor from Torino, (2) the Steinheil refractor from Bologna, (1) the Starke equatorial from Padova, (5) the Dollond refractor from Palermo, (4) the Starke Altazimuth from Padova. Near the Steinheil refractor is the young mechanic A. Cagnato (Photograph: Astronomical Observatory of Padova, Historical Archives).

The Americans took up the subject upon such a scale as might be expected of them. The dollars they voted amounted to double the sum granted by the British Government ... and Italy has been so quiet over her operation that their extent is not known. (see pp.5-6).

In fact, the silent protagonists of the only Italian expedition were two passionately-keen astronomers, whose close friendship helped get the expedition ready in just a few months, as is documented in the Lorenzoni-Tacchini correspondence (which is to be published shortly).

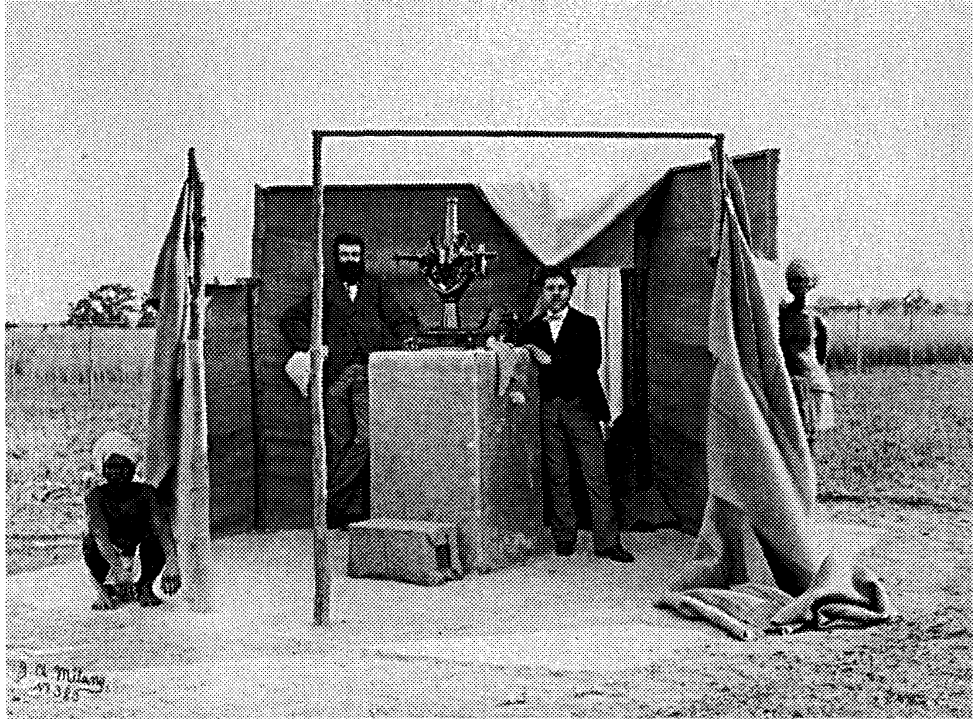


Figure 4. The Repsold transit instrument from the Observatory of Padova, used by Antonio Abetti to check the geographical latitude and longitude and the local time. Near the pillar are C. Morso (left) and A. Cagnato (right) (Photograph: Astronomical Observatory of Padova, Historical Archives).

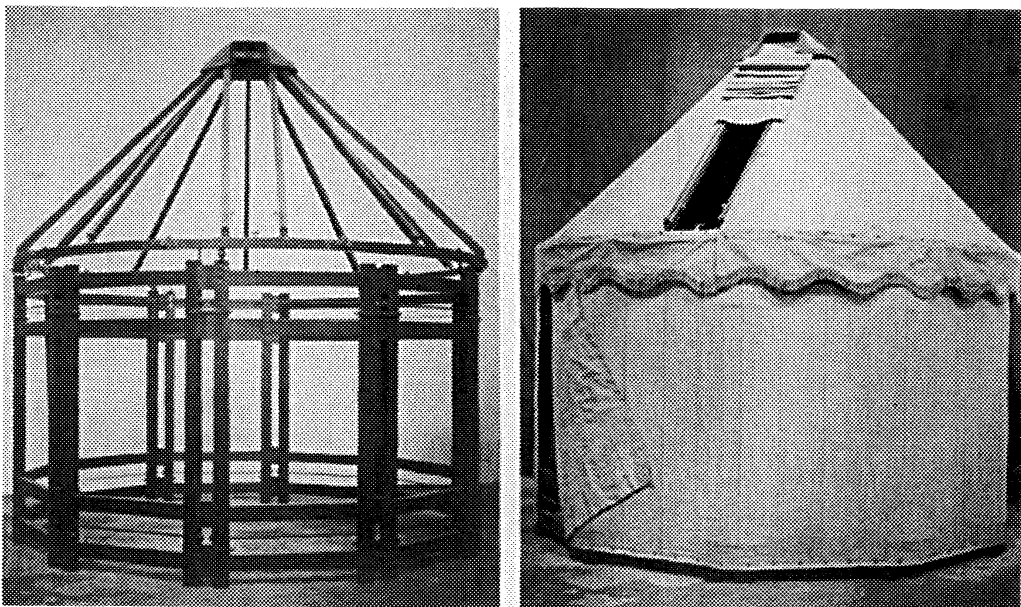


Figure 5. One of the four pavilions made to shelter the main instruments: the circular upper part of the wooden skeleton (left) could rotate like a little dome; the cover was made of sail-cloth (right) (Photograph: Astronomical Observatory of Padova, Historical Archives).



Figure 6. A panorama of the Transit station at Muddapur. From left to right: the pavilions for the Starke equatorial refractor, Starke Altazimuth, Fraunhofer refractor, the pillar for the Repsold transit instrument, and the pavilion for the Steinheil refractor. Background: the tent to shelter the astronomers (Photograph: Astronomical Observatory of Padova, Historical Archives).

2 THE SPECTROSCOPES

For the transit observations, the Italian astronomers used only two direct-vision spectroscopes, among the six carried with them. Figure 7 shows the scheme of a 19th-century spectroscope: SS' is the slit, C is the collimator, P the dispersing prisms, and FO the analyser telescope (Secchi, 1877b).

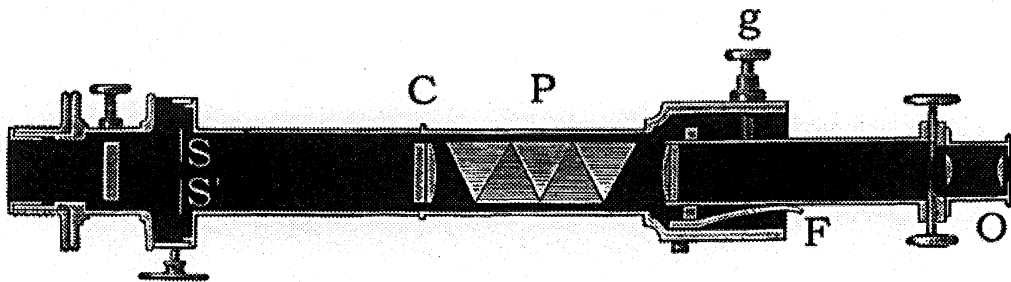


Figure 7. Cross-section of a direct-vision spectroscope.

The direct-vision spectroscope was invented in 1860 by the Italian optician Giovan Battista Amici (1786-1863) (Abetti, 1949; Abetti *et al.*, 1960; Monaco, 1994). It consisted of two crown-glass prisms alternating with a flint-glass one: by this arrangement it was possible to observe the spectrum of incident light without deviation from the line of sight. The French optician J G Hofmann improved this invention by inserting five alternating prisms to increase the dispersion. At that time, the term 'dispersion' meant the angle formed by the red and violet rays emerging from the analyser, which could be rotated to the left or right by the screw g , in order to look at different parts of the visible spectrum.

The Hofmann's spectroscope (Figure 8) used by Antonio Abetti during the transit was purchased in 1870 to observe the eclipse of the Sun in Sicily and was then acquired by the Astronomical Observatory of Padova (Pigatto, 1998). Originally, the instrument had a total dispersion of 10° and its telescope provided four magnifications (Lorenzoni, 1872), so that it was possible to resolve the sodium doublet. Subsequently, Lorenzoni modified the spectroscope in order to improve it and to make it more suitable for solar spectroscopy: he added a 20° graduated arc to measure the angular position of the spectral lines and inserted a slit in the focal plane of the analyser to reduce the spectral field (*ibid.*). Lastly, he increased the magnification of the analyser to 17 and replaced the collimator with one of 30 cm focal length; in this way, he was able to exploit the whole aperture of the prisms and of the objective of the

telescope to which the spectroscope was applied (Lorenzoni, 1873f). The telescope-spectroscope system was an organic whole, so Lorenzoni coined the word *telespectroscope* (Lorenzoni, 1873c), a term which was also used by Lockyer (1873) at this time.

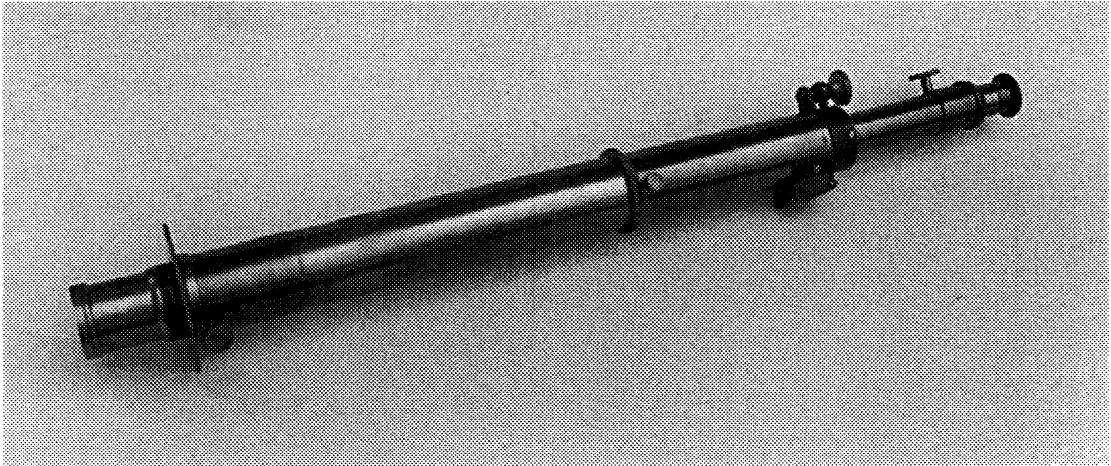


Figure 8. The Hofmann direct-vision spectroscope, modified by Lorenzoni (Museo *La Specola*, Astronomical Observatory of Padova).

The spectroscope used by Pietro Tacchini (Figure 9), purchased by the Astronomical Observatory of Palermo in 1870, was made in Tauber's workshop in Lipsia following a project of the German astronomer Johann Karl Friedrich Zöllner (1834-1882); it was composed of a double prism system (Foderà-Serio & Chinnici, 1997), with a collimator of 70 mm focal length (Tacchini, 1873a). In 1873 Tacchini asked Lorenzoni to provide his spectroscope with a new collimator: the lens was made in Venice, whereas the spectroscope tube was modified in the workshop of the Padova Observatory (Tacchini, 1873b; Lorenzoni, 1873d; Lorenzoni, 1874c).

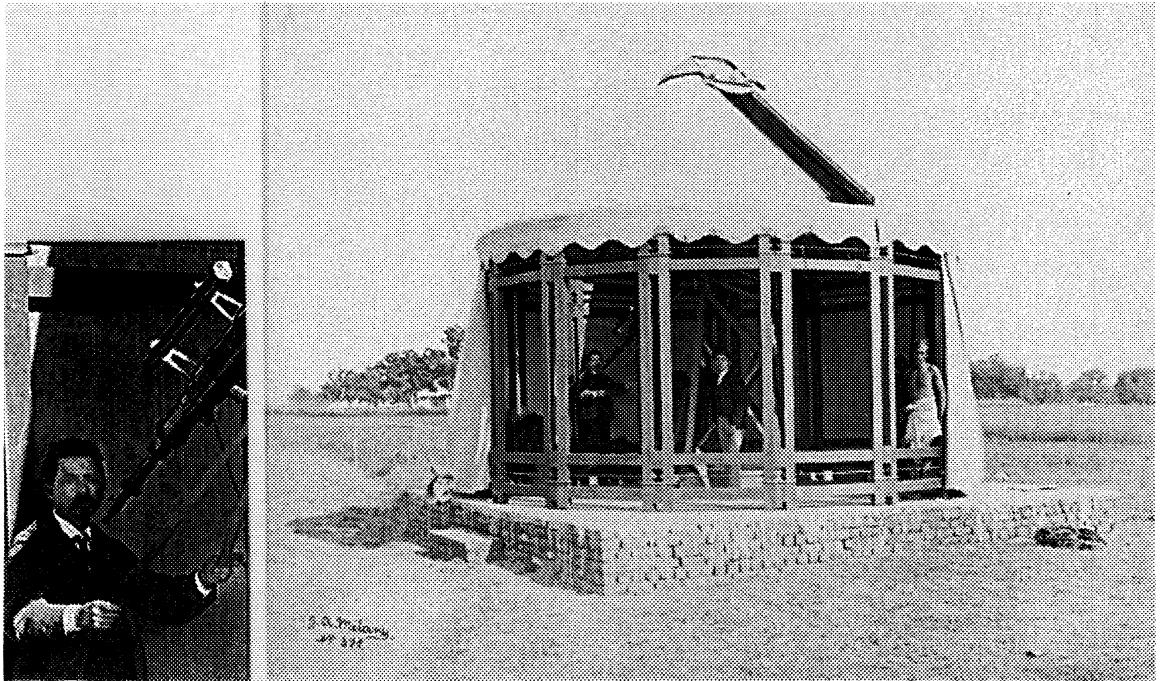


Figure 9. Tacchini at work, with his Tauber spectroscope (detail on the left) attached to the Steinheil refractor, in the pavilion with A. Cagnato (Photograph: Astronomical Observatory of Padova, Historical Archives).

3 METHODS OF OBSERVATION

Since the foundation of the Spectroscopists Society, Italian astronomers were engaged in a vivid debate about the best method to make spectroscopic observations of the Sun (Secchi, 1872a, 1874; Lorenzoni, 1872, 1873a, 1873b, 1873e, 1873f, 1874a, 1874b; Tacchini, 1874a). The

spectroscopic observation of the transit was based upon the possibility of highlighting the chromosphere in emission, and observing the planet's presence on it before contact with the solar photosphere. In this way, it was possible to determine exactly contacts I and IV in addition to II and III. With traditional observations, contacts I and IV were observable, because of light diffusion, only when the planet had already entered the solar disc, or was still on it before exit.

Two methods of observation were used, one with the 'narrow slit', and one with the 'large slit'. The former consisted of putting the slit tangential to the Sun's limb, so that it was possible to observe a solar spectrum, on which the red chromospheric emission dominated, precisely in the line C ($H\alpha$) range (Figure 10, left). Once the planet entered the slit, the contact of Venus with the Sun produced a break in the spectrum and the appearance of a transversal strip, first very thin and then thicker and thicker, proportional to the fraction of the incoming planet. The exit of the planet from the slit produced a similar effect, but in opposite sequence. Therefore, the gradual appearance and disappearance of the strip gave the four contacts in succession, during the ingress and egress of Venus respectively.

The second method worked with the large slit, so that the whole part of the included chromosphere could be seen on line C (Figure 10, right). If a small portion of the solar disc were also included, it would be possible to observe the absorbed black arc of the photosphere surrounded by the bright red chromosphere. In this case, Venus appeared like a small dark disc coming over the chromosphere: the touch of the planet with the limb of the Sun gave the first contact; the second was given by the complete recomposition of the chromosphere. Also in this case, the transversal strip was present along the spectrum, but the contacts were independent of its appearance or disappearance.

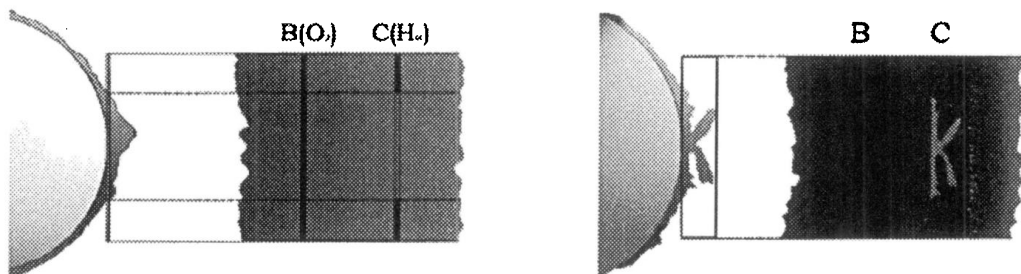


Figure 10. Drawings of the two methods of observing the solar limb in the spectral range of $H\alpha$, with narrow (left) and wide (right) slits (after Figures 152 and 158 in Secchi, 1877a).

4 THE OBSERVATIONS BY TACCHINI AND ABETTI

On 1874 December 9, clouds prevented Tacchini and Abetti from observing the first contact with the spectroscopes, but, with the narrow slit, it was presumed to be seen as in drawing 3 of Figure 11. In the original drawing, because of printing error, line C is black instead of red. After a short time, Tacchini (1875a:81) saw "... a wonderful strip of a crazy black; and it seemed almost dark tobacco colour ..." (drawing 2); a few minutes later "... this strip occupied about the third part of the slit." (drawing 1). In these conditions, Tacchini (1875a:82) decided to observe the phenomenon also with the large slit: "Actually, with the large slit, before the second contact Venus was visible over the chromosphere as in Figures 5 and 6 of table VI ..." (drawings 5 and 6 on the right of Figure 11). He concluded (*ibid.*) that "Also with the large slit it was possible to see the instant of the recomposition of the chromosphere, like in Figure 4." (drawing 4). Unfortunately, again because of clouds, the second contact also was invisible and was lost by both Tacchini and Abetti; the latter observed the transit with the large slit, as he had learned from his teacher Lorenzoni. The two astronomers were luckier at the third and fourth contacts: the weather cleared and Tacchini could observe the appearance, growth, and disappearance of the transversal strip over the solar spectrum, with the sequence of drawings 3, 2 and 1 (and back) shown in Figure 11; Abetti, instead, observed the phenomenon with the sequence of drawings 2 and 1 shown in Figure 12.

The other members of the expedition could see all of the four contacts, although they were disturbed by clouds. The observations were recorded in the *Diario* (Figure 13) with

MUDDAPUR - 9 Dicembre 1874.

Tav. VI

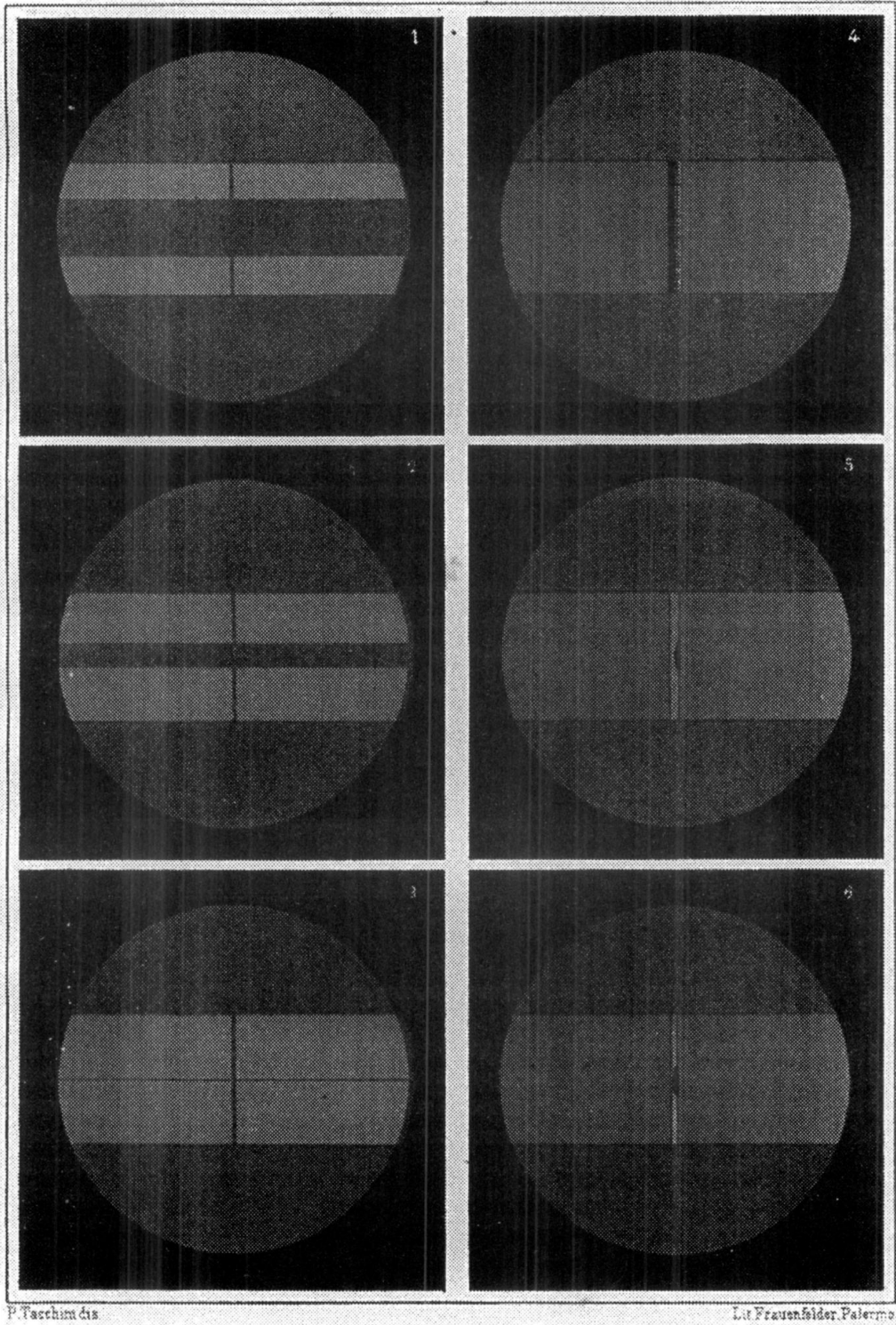


Figure 11. Reproduction of Table VI (Tacchini, 1875a) described in the text. In this Table, the drawings are numbered from 1 to 6, starting from the upper left corner; the circle represents the telescope field.

the Starke Altazimuth, viewed the phenomenon with direct visual observations, while Morso, with the Dollond refractor placed under the covering of the transit instrument, used projection, with a method perfected by Tacchini (Tacchini, 1875b). The results of the Italian observations are shown in Table 1.

Table 1. Time of the four contacts recorded by the observers at Muddapur*

Contacts	Abetti	Dorna	Lafont	Morso	Tacchini
I	-	19 ^h 38 ^m 36 ^s .55	19 ^h 37 ^m 40 ^s .78	19 ^h 41 ^m 35 ^s .06	-
II	-	20 ^h 05 ^m 52 ^s .56	20 ^h 05 ^m 25 ^s .01	20 ^h 06 ^m 41 ^s .04	-
III	23 ^h 48 ^m 52 ^s .97	23 ^h 51 ^m 03 ^s .63	23 ^h 51 ^m 06 ^s .73	23 ^h 51 ^m 09 ^s .93	23 ^h 48 ^m 57 ^s .48
IV	0 ^h 17 ^m 36 ^s .90	0 ^h 18 ^m 46 ^s .63	0 ^h 18 ^m 42 ^s .56	0 ^h 19 ^m 12 ^s .92	0 ^h 18 ^m 06 ^s .41

* Contacts are in Muddapur Local Mean Time, 1874 December 8-9. In those days the mean time or astronomical time, started at noon⁷.

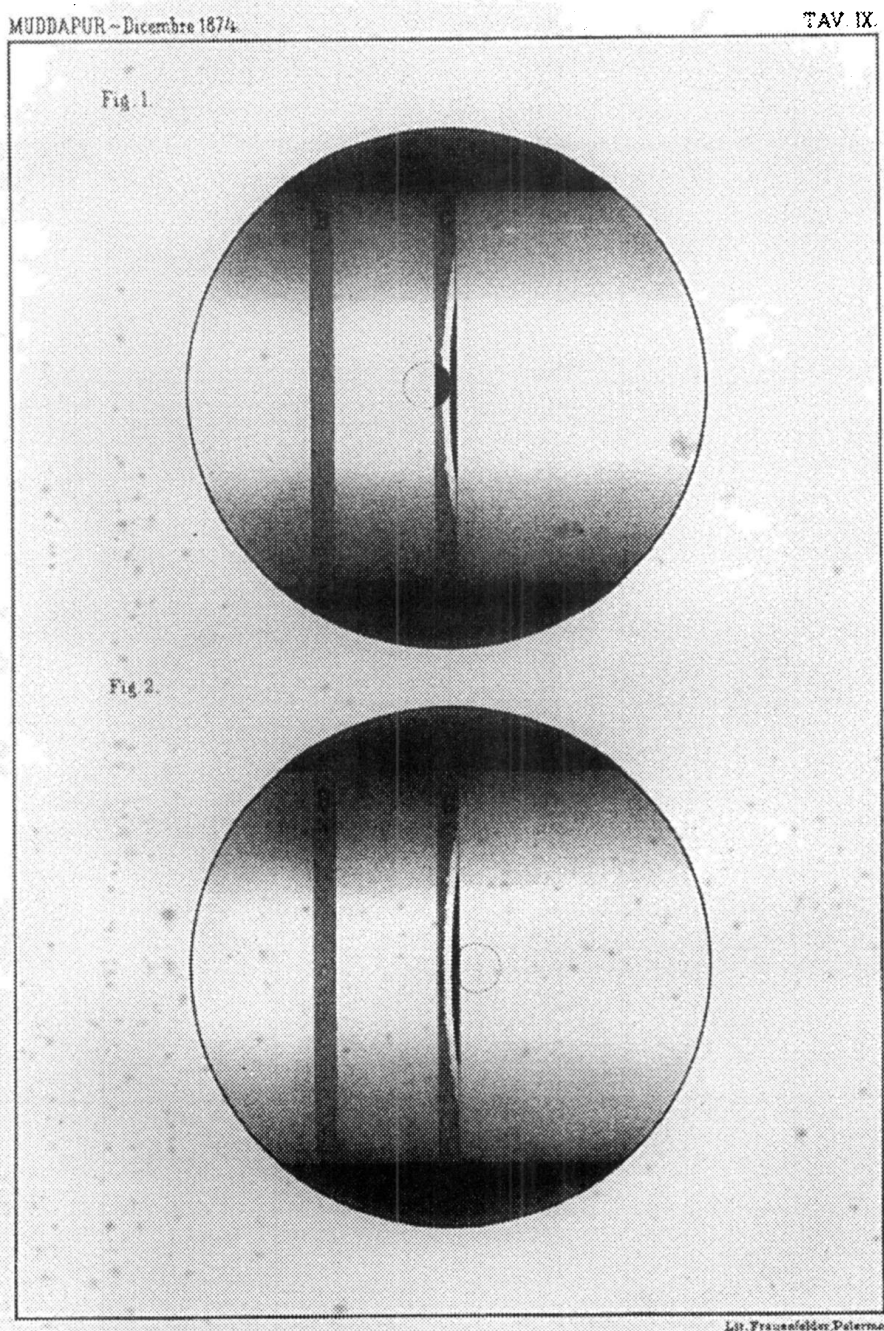


Figure 12. Reproduction of Table IX (Tacchini, 1875a), showing the solar limb observed by Abetti with the Hofmann spectroscope attached to the Starke equatorial.

As we can see from these data, contacts III and IV observed with the spectroscope took place earlier than the telescopic ones, so Tacchini (1875a:99) concluded that "... at the spectroscope the solar diameter is smaller than that observed in an ordinary telescope." In previous works on spectroscopic observations, Secchi (1872b) and Lorenzoni (1873a, 1873b) had reached the same conclusion, and Secchi (1874:13) had suggested that "... the spectroscope deprives the solar disc of that halo formed naturally by the chromosphere mixed with vapours of other metals." (translated from Italian).

The path of Venus during the transit was inclined by $57^{\circ}.75$ with respect to the vertical solar radius, and Tacchini calculated a difference of $4''.33$ between the spectroscopic and ordinary diameters, but emphasized that this value was scarcely significant. In fact, comparing the meridian transit times of the Sun published in *The Nautical Almanac* with those of Washington, he noted differences both among observations made by the same observer in subsequent times, and among contemporaneous ones made by different observers (Tacchini, 1875a).

In the days after the transit, the Italians made new observations of the telescopic and spectroscopic solar diameter, and although the latter always furnished lower values, the differences between the two diameters varied between $2''.82$ and $4''$ (Tacchini, 1875a). Tacchini (ibid.) concluded that although the spectroscopic diameter was systematically smaller than the telescopic one, diameters derived from transit timings showed great differences, for reasons that were unknown.

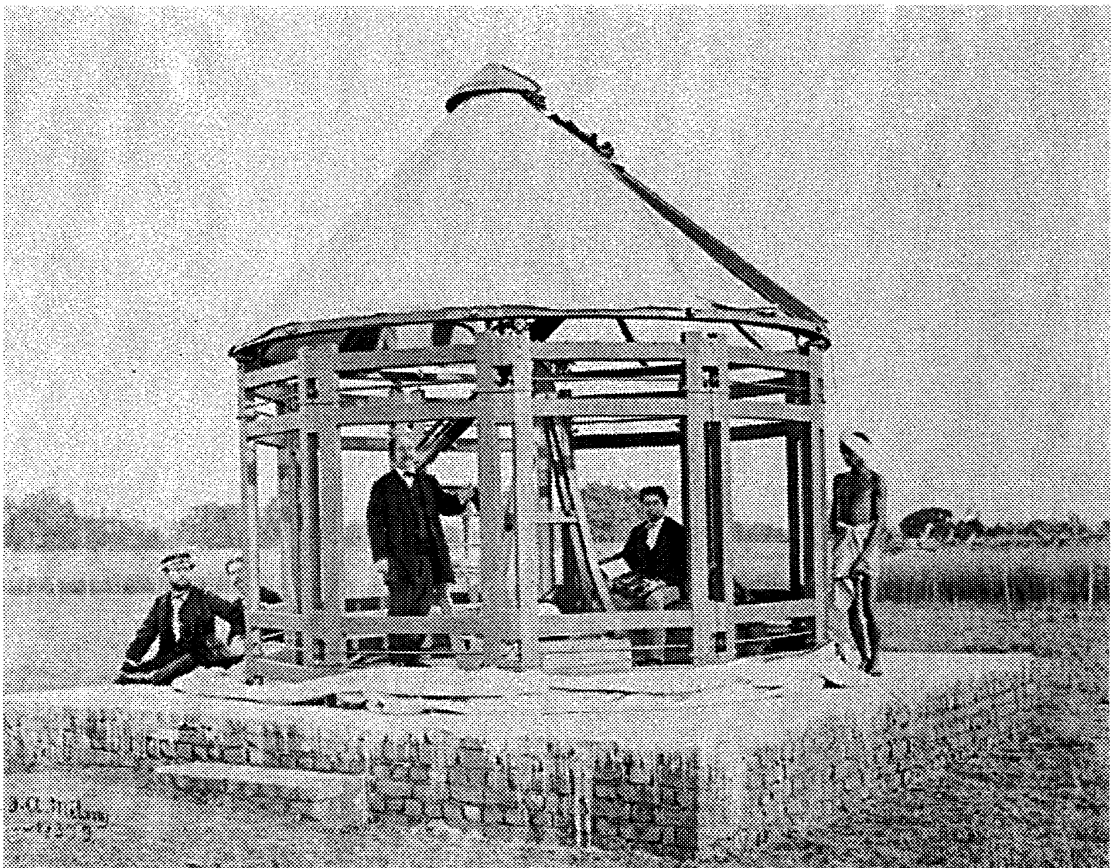


Figure 13. A. Dorna (standing) and A. Cagnato (seated) in the pavilion of the Fraunhofer refractor of the Observatory of Torino (Photograph: Astronomical Observatory of Padova, Historical Archives).

Recent works (e.g. see Delache, 1988; Stephenson, 1981; Toulmonde, 1997; Wittman, 1977, and Wittman and Débarbat, 1990) confirm that the best method of observing the solar diameter (and its supposed secular and periodic variability) is still open to debate, but these reports do indicate that the transit diameter is larger than that obtained using other methods.

Moreover, it is necessary to distinguish solar diameter with or without irradiation, but this distinction was not taken into account in 1874—it only came into use after 1890 (Stephenson, 1981). Lastly, it should be recalled that the Italian spectroscopic observations were made in H α light, a wavelength absorbed by the photosphere, so that the measurements refer to the inner edge of the chromosphere rather than the diameter of the photosphere.

5 THE ATMOSPHERE OF VENUS

On 1874 December 9 through the Calcutta consul, Tacchini sent a telegram to the Italian Minister of Education: "First observations disturbed by small clouds – Good results spectroscopic and ordinary – Spectrum of Venus observed, details probably related to its atmosphere." [in English in the original] (Tacchini, 1875a:35). At the same time, he sent a telegram to Lorenzoni: "Osservazioni passaggio Venere riescite felicemente / Veduta atmosfera pianeta." (Tacchini, 1874b).

After the loss of the first two contacts, Tacchini had ample time to observe the planet while it was crossing the Sun's photosphere, placing the slit of the spectroscope normal to the path of Venus:

Then I observed the solar spectrum through a narrow slit, making the planet transit across; and before the disc of Venus entered the slit or immediately after its exit, I seemed to see some modifications: I repeated the same observation many times, and I actually saw the spectrum always grow dark around the C line [H α at 6563 Å] and near the B line [O $_2$ at 6867 Å], that is, in the well-known place of the telluric lines [translated from the Italian] (Tacchini, 1875a:82).

He repeated the experience in the spectral range around the D lines of sodium, but did not see any change in the spectrum. Abetti also observed and confirmed the phenomenon; lastly, Tacchini concluded that he had observed the atmosphere of Venus spectroscopically and that it was similar to the terrestrial one: "I believe that the phenomenon is due to the planet's atmosphere which has the same elements as the Earth, i.e., a large quantity of water vapour ..." (Tacchini, 1875a:83).

At that time, knowledge of the solar spectrum was greatly improved following Fraunhofer's discovery. The fundamental work of Kirchhoff, Janssen, Brewster, Van der Willigen, Draper (who introduced the first diffraction photographic spectrum) and Ångström (who introduced the wavelength unit), was well-known among astronomers (see Secchi, 1875). Within this framework, the possibility of finding a terrestrial or similar atmosphere associated with other planets and in consequence some kind of life similar to that on Earth encouraged astronomers to search for them. Tacchini, too, was involved in this fascinating problem, so that it was not at random that he observed the spectral range where telluric lines of oxygen and water vapour are in large numbers. In the field of his telescope he could observe both lines B and C. In this spectral range, water vapour lines are very near H α ; in addition, a luminous portion of the continuum is clearly visible for about 265 Å (Rowland, 1896; Moore *et al.*, 1966). Perhaps Tacchini was able to perceive the instantaneous darkening, quoted above, because of the contrast with the near luminous continuum (see Figure 14). This fact may explain why he did not perceive any change around the sodium doublet, where water vapour lines are crowded, leaving little space for the continuum. This is the spectral range that was known as the 'rainband' in the nineteenth century, and because its variability was linked with meteorological events it was thought that by observing it through the spectroscope one could forecast rain and storms (Capron, 1882).⁸

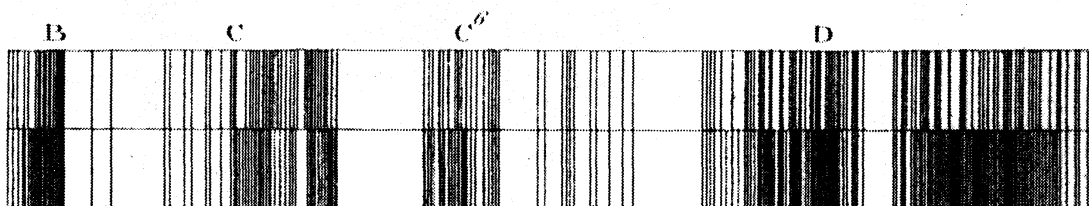


Figure 14. Solar spectra taken by Janssen, with the Sun in two different positions above the horizon. The top spectrum represents a higher solar position. The variable intensity of telluric absorption lines is evident (after Secchi, 1875a).

Today, the existence of water vapour, oxygen, and many other elements in the atmosphere of Venus (see Hunten, 1998 for a review) has been confirmed by many spacecraft experiments—and particularly those associated with the Soviet Venera 15 (Moroz *et al.*, 1990) and US Pioneer Venus Orbiter (Koukouli *et al.*, 2000)—but all observations relate to the near infrared. For this reason, it seems interesting to quote two papers which, although widely separated in time, concern observations of the visual spectrum of Venus from the Earth. Both are based upon observations of the Doppler effect on the atmospheric lines of Venus, because of the relative velocities of the two planets. In 1921, using the Snow telescope and the Littrow grating-spectrograph, St. John and Nicholson (1922) observed the water vapour lines near 5900 and oxygen bands α and B, but concluded that "No trace of any line due to the planet's atmosphere was observed." whereas in 1999 Slander *et al.* (2000) used the Keck 1 telescope and the HIRES echelle spectrometer to observe the 5577 Å oxygen green line in the atmosphere of Venus.

So what did Tacchini see with his spectroscope back in 1874? Perhaps he observed some absorption because of the peculiar condition of the transit: since Venus was at inferior conjunction at the time, the path-length of sunlight through the Venesian atmosphere was greater than at other phases. The planet was never again observed spectroscopically under these conditions, even when the 1882 transit gave astronomers the opportunity. For this reason, it will be very interesting to repeat Tacchini's observations during the 2004 and 2012 transits, using the original instruments *and* modern spectroscopes, in order to determine whether the two Italian astronomers saw a genuine effect or not.

6 CONCLUSIONS

The Italians (see Figure 15) were the only ones who made spectroscopic observations during the transit. In 1874 December, *Nature* reproduced most of an article which had appeared in the *Times* on December 9. Speaking about the scientific results of English, American and German astronomers, the article stated:

The German observations made this morning in the South seas will be the most important obtained by all the expeditions. With regard to Italy, also, there are the same signs of scientific enterprise. The spectroscope, which forms no part of the equipment of the English expeditions, was intended by her men of science to be their chief weapon of attack, and as in no country is there such a skilled body of spectroscopists as in Italy, this determination was probably not arrived at on insufficient grounds. (*Nature*, XI:103)



Figure 15. The Italian Transit party at Muddapur. Seated (left to right): E. Lafont, P. Tacchini, the consul F. Lamouroux, A. Dorna, C. Morso. Standing (left to right): the Muddapur station-master Witley, A. Abetti, the mechanic A. Cagnato (Photograph: Astronomical Observatory of Padova, Historical Archives).

Meanwhile, Flammarion (1877:167) was enthusiastic, and defined as "capital" the spectroscopic observation of the atmosphere of Venus by the Italian astronomer Tacchini.

The results of the Italian observations were published in 1875 (Tacchini, 1875a). Unfortunately, because of financial difficulties, but mainly due to the scientific myopia of the Ministers of Education of the new Government, the Italian astronomers could not organize the expedition for the 1882 transit, and could not even take part in the Paris meeting of 1881 organized by France to prepare the new expeditions (*Passaggio di Venere del 1882*). They were thus prevented from entering into a constructive debate with the international scientific community, and this missed opportunity had negative repercussions on the development of the modern astrophysics in Italy.

7 NOTES

- 1 Angelo (Pietro) Secchi (*b.* Reggio Emilia, 18 June 1818; *d.* Rome, 26 February, 1878). Instructor in mathematics and physics at the Jesuit colleges, in 1849 he took up an appointment as director of the Observatory of the Collegio Romano, and remained there until his death. His scientific activity was mainly devoted to spectroscopy and astrophysics and in particular he turned his attention to the Sun, its chromosphere and its corona. In his studies of stellar spectra, Secchi was able to identify five types, and this classification (which still bears his name) was soon adopted almost universally. Most of his work was published in the *Memorie della Società degli spettroscopisti italiani* (Abetti, 1975)
- 2 Pietro Tacchini (*b.* Modena, 21 March 1838; *d.* Spilamberto [Modena], 24 March 1905), received a degree in engineering from the *Archiginnasio* of Modena, and studied astronomy at the Observatory of Padova, under Giovanni Santini. In 1863 he was appointed adjunct astronomer to the Observatory of Palermo, where he began research on solar physics using the spectroscope. In 1879 he succeeded Angelo Secchi as director of the Observatory at the Collegio Romano and became director of the Central Meteorological Office. Tacchini's scientific activity was thus mainly devoted to astrophysics and meteorology. Most of his publications are in the *Memorie della Società degli spettroscopisti italiani* (Abetti, 1976).
- 3 Giuseppe Lorenzoni (*b.* Rolle di Cison [Treviso], 10 July 1843; *d.* Padova, 7 July 1914), received a degree in engineering from the University of Padova in 1863, and became assistant to the director of the Observatory of Padova, Giovanni Santini, in the same year. In 1872 he was appointed professor of astronomy at the University of Padova, and in 1878 became the director of the Observatory. He also held the professorship of geodesy from 1869 to 1885. Lorenzoni's scientific activity was devoted to classical astronomy, astrophysics and spectroscopy, and also to geodesy. His research is published in various issues of *Memorie della Società degli spettroscopisti italiani* and *Atti dell'Istituto Veneto di Scienze Lettere ed Arti* (Abetti, 1973).
- 4 Alessandro Dorna (*b.* Asti, 13 February 1825; *d.* Borgo S. Pietro – Moncalieri [Torino], 19 August 1886), received a degree in engineering from the University of Torino in 1848, and in 1850 was appointed professor of rational mechanics at the military academy, professor of astronomy at the University of Torino, and director of the Observatory of the same city. As director, he promoted and developed the Observatory and its instruments. Dorna's scientific activity was devoted essentially to positional astronomy (Monaco, 1992).
- 5 Antonio Abetti (*b.* S. Pietro di Gorizia, 19 June 1846; *d.* Arcetri [Florence], 20 February 1928), received a degree in civil engineering from the University of Padova in 1867 and was astronomer of the Observatory of Padova from 1868 until 1893. In 1894 he became director of the Astronomical Observatory of Arcetri and professor of astronomy at the University of Florence, and remained there until 1921. Abetti's scientific activity was devoted essentially to positional astronomy. His research was published in various issues of *Memoirs and Observations of the Observatory of Arcetri* (Abetti, 1970).
- 6 The terms 'parallactic mounting' and 'parallactic machine' (= equatorial telescope) were used by Italian, French and German astronomers and telescope-makers during the eighteenth and nineteenth centuries, but never by English ones. This term was invented by Cassini II (1677-1756) in 1721. In his *Astronomie*, La Lande (1797-1807: 622) writes: "The parallactic machine, also called parallactic telescope, is used to follow the parallel of a star, or its diurnal motion from east to west, describing the same parallel."

- 7 The unification of the civil and astronomical day started to be accepted by astronomers only in 1925. In 1928 the IAU recommended that Universal Time (UT) should be used internationally in almanacs (Howse, 1997).
- 8 The water vapour lines of the terrestrial atmosphere are subject to continuous variation due to observational circumstances such as height above the horizon, season and other meteorological phenomena (Salet, 1909; Secchi, 1875). The Astronomer Royal of Scotland, Charles Piazzi Smyth (1819-1900), was the first to suggest using the rainband to forecast rain and storms (Smyth, 1875). He developed this idea in 1872 during a visit to Palermo to observe the zodiacal light, on which occasion he was able to see the rainband using his pocket spectroscope both before and after a sirocco (Capron, 1882). It was in Palermo that Piazzi Smyth met Tacchini, to whom he must have mentioned the phenomenon. Tacchini (1872) speaks of this meeting in a letter to Lorenzoni that was delivered in person by the Scottish astronomer during his visit to Padova.

8 REFERENCES

The following abbreviation is used:

CL = *Correspondence Lorenzoni-Tacchini*

PAO = Padova Astronomical Observatory, Historical Archives.

Abetti, Giorgio, 1949. *Storia dell'Astronomia*. Vallecchi, Firenze; and Abetti, Giorgio, 1952. *The History of Astronomy*. Abelard-Schuman, London (English edition).

Abetti, Giorgio, 1970. Abetti, Antonio. In *Dictionary of Scientific Biography. Volume I*. Charles Coulston Gillispie, New York. P.19.

Abetti, Giorgio, 1973. Lorenzoni, Giuseppe. In *Dictionary of Scientific Biography. Volume VIII*. Charles Coulston Gillispie, New York. Pp.503-504.

Abetti, Giorgio, 1975. Secchi, (Pietro) Angelo. In *Dictionary of Scientific Biography. Volume XII*. Charles Coulston Gillispie, New York. Pp.266-270.

Abetti, Giorgio, 1976. Tacchini, Pietro. In *Dictionary of Scientific Biography. Volume XIII*. Charles Coulston Gillispie, New York. Pp.232-233.

Abetti, Giorgio, Ronchi, Vasco and Lusina, G., 1960. Amici, Giovanni Battista. In *Dizionario Biografico degli Italiani. Volume 2*. Istituto della Enciclopedia Italiana, Roma. Pp.780-784.

Astronomische Nachrichten, **85** (2019):45-48; (2020):63-64; (2021):69-70, 77-78; (2027):165-170, 173-176 (1875).

Capron, Rand J., 1882. A plea for the rainband. *The Observatory*, **5**:42-47, 71-77.

Chinnici, Ileana, 1995/96. An "Italian" Observatory in India: The History of the Calcutta Observatory. *Studies in History of Medicine and Science*, **14**:91-115.

Connaissance des Temps pour l'An 1872. Bureau Connaissance des Temps, Paris (1871).

Delache, Philippe, 1988. Variability of the solar diameter. *Advances in Space Research*, **8**:119-128.

Flammarion, Camille, 1877. *Études et Lectures sur l'Astronomie. Le Passage de Vénus de 1874. Volume VIII*. Gauthier-Villars, Paris. Pp.165-177.

Foderà-Serio, Giorgia and Chinnici, Ileana, 1997. *L'Osservatorio Astronomico di Palermo*. Flaccovio Editore, Palermo.

Forbes, George, 1874. *The Transit of Venus*. MacMillan and Co., London.

Howse, Derek, 1997. *Greenwich Time and the Longitude*. Philip Wilson, London.

Hunten, Donald M., 1998. Venus: Atmosphere. In Paul R. Weissman, Lucy-Ann McFadden and Torrence V. Johnson (eds.), *Encyclopedia of the Solar System*. Academic Press, San Diego. Pp.147-159.

Janiczek, P.M. and Houchins, Lee, 1974. Transit of Venus and the American Expedition of 1874. *Sky and Telescope*, **48**:366-371.

Koukoulis, M.E., Irwin, P.J.G. and Taylor, F.W., 2000. Cloud top vapour abundance on Venus. *Bulletin of the American Astronomical Society*, **32**:1121.

La Lande Jérôme (Le Français) de, 1797. *Astronomie, Troisième édition, Revue et Augmentée*. P. Didot l'aîné, Paris.

Libro d'Informazioni ad uso dei Passeggeri e Caricatori coi piroscafi postali della Compagnia Inglese di Navigazione a Vapore 'Peninsular and Oriental'. Tipografia Emiliana, Venezia (1874).

Lockyer, J. Norman, 1873. *The Spectroscope and its Applications*. MacMillan and Co., London.

Lorenzoni, Giuseppe, 1872. Osservazioni spettroscopiche del bordo solare fatte nel R. Osservatorio di Padova durante l'anno 1871. *Memorie della Società degli Spettroscopisti Italiani*, **I**:7-16.

Lorenzoni, Giuseppe, 1873a. Delle eclissi parziali di Sole e sulla maniera di osservare i contatti collo spettroscopio. *Memorie della Società degli Spettroscopisti Italiani*. **II**:137-141.

- Lorenzoni, Giuseppe, 1873b. Discussione delle osservazioni eseguite in Roma ed in Padova sull'eclisse parziale di sole del 26 maggio 1873. *Memorie della Società degli Spettroscopisti Italiani*, **II**:145-158.
- Lorenzoni, Giuseppe, 1873c. Letter to P. Tacchini, undated [but 1873]. Copy in CL, PAO.
- Lorenzoni, Giuseppe, 1873d. Letter to Tacchini, dated November 28. Copy in CL, PAO.
- Lorenzoni, Giuseppe, 1873e. Osservazione dell'eclisse parziale di sole del 26 maggio 1873 fatte nel R. Osservatorio di Padova. *Memorie della Società degli Spettroscopisti Italiani*, **II**:73-74.
- Lorenzoni, Giuseppe, 1873f. Osservazioni sulle righe lucide f e b dello spettro cromosferico solare, e riflessioni sulla visibilità spettroscopica delle immagini monocromatiche quando queste appariscono proiettate sopra uno spettro continuo. *Memorie della Società degli Spettroscopisti Italiani*, **II**:20-37.
- Lorenzoni, Giuseppe, 1874a. Aggiunta alla Nota del Vol. II di queste Memorie che ha per titolo "Discussione delle osservazioni eseguite in Roma ed in Padova sull'eclisse parziale di sole del 26 maggio 1873". *Memorie della Società degli Spettroscopisti Italiani*, **III**:61-64.
- Lorenzoni, Giuseppe, 1874b. Di un mezzo atto a rendere visibile tutta in una volta una immagine monocromatica completa della cromosfera e delle protuberanze solari. *Memorie della Società degli Spettroscopisti Italiani*, **III**:45-61.
- Lorenzoni, Giuseppe, 1874c. Letter to Tacchini, Padova, dated January 3. Copy in CL, PAO.
- Monaco, Giuseppe, 1992. Dorna, Alessandro. In *Dizionario Biografico degli Italiani. Volume 41*. Istituto della Enciclopedia Italiana, Roma. Pp.494-496.
- Monaco, Giuseppe, 1994. I primi contributi italiani alla spettroscopia astronomica. *Giornale di Astronomia*, **I**:24-31.
- Moore, Charlotte E., Minnaert, M.J.G. and Houtgast, J., 1966. *The Solar Spectrum 2935 Å to 8770 Å. Second Revision of Rowland's Preliminary Table of Solar Spectrum Wavelength*. National Bureau of Standards, Washington (Monograph No. 61).
- Moroz, V.I., Spaenkuch, D., Titov, D.V., Doehler, W., Zasova, L.V., Schaefer, K., D'Iachkov, A.V., Oertel, D., Linkin, V.M. and Nopirakowski, J., 1990. Water vapor and sulfur dioxide in the Venus' atmosphere from the Venera-15 data. In *Middle Atmosphere of Venus*. Berlin Akademie-Verlag, Berlin. Pp.205-216.
- Nature*, **X**:11, 27, 33, 49, 66, 73, 86, 114, 151, 158, 172, 190, 426, 449 (1874).
- Nature*, **XI**:16, 36, 93, 102, 112, 121, 130, 134, 153, 171, 177, 194, 214, 234, 254, 306, 313, 332, 354, 365, 371, 387, 394, 417, 455 (1874-1875).
- Orchiston, Wayne, Love, Tom and Dick, Steven J., 2000. Refining the astronomical unit: Queenstown and the 1874 transit of Venus. *Journal of Astronomical History and Heritage*, **3**(1):23-44.
- Passaggio di Venere del 1882*. Manuscript, PAO (XXI, 12).
- Pigatto, Luisa, 1998. L'eclisse totale di Sole del 22 dicembre 1870. La prima spedizione scientifica del nuovo Regno d'Italia. *Coelum*, **10**:31-36; **11**:32-34.
- Proctor, Richard A., 1874. *Transit of Venus. A Popular Account of Past and Coming Transits*. Longmans, Green, London.
- Rowland, Henry A., 1895-1896. Preliminary Table of Solar Spectrum Wave-lengths. *The Astrophysical Journal*, **2**:360-369; **3**:356-373.
- Salet, P., 1909. *Spectroscopie Astronomique*. Octave Doin et Fils, Paris.
- Secchi, Angelo, 1872a. Osservazione del passaggio di Venere sul Sole col mezzo dello spettroscopio. *Memorie della Società degli Spettroscopisti Italiani*, **I**:105-109.
- Secchi, Angelo, 1872b. Sulle variazioni del diametro solare. Studi fatti all'Osservatorio del Collegio Romano. *Memorie della Società degli Spettroscopisti Italiani*, **I**: 97-103.
- Secchi, Angelo, 1874. Alcune considerazioni spettroscopiche. *Memorie della Società degli Spettroscopisti Italiani*, **III**:12-16.
- Secchi, Angelo, 1875. *Le Soleil*. Gauthier-Villars, Paris.
- Secchi, Angelo, 1877. *Le Stelle. Saggio di Astronomia Siderale*. Dumolard, Milano.
- Slanger, T.G., Huestis, D.L., Cosby, P.C. and Bida, T.A., 2000. First Observation of the 5577 Å Oxygen Green Line in the Night Airglow of Venus. *Bulletin of the American Astronomical Society*, **32**:1120.
- Smyth, Charles Piazzi, 1875. Spectroscopic *prevision* of Rain with a High Barometer. *Nature*, **12**:231-232.
- St. John, Charles E. and Nicholson, Seth B., 1922. The Absence of Oxygen and Water-vapor Lines in the Spectrum of Venus. *The Astrophysical Journal*, **56**:380-399.
- Stephenson, F. Richard, 1981. The Solar 'Constant' and the Sun's Diameter. *Journal of the British Astronomical Association*, **91**:345-356.
- Tacchini, Pietro, 1872. Letter to G. Lorenzoni, dated April 6. In CL, PAO.
- Tacchini, Pietro, 1873a. Letter to G. Lorenzoni, dated March 13. In CL, PAO.
- Tacchini, Pietro, 1873b. Letter to G. Lorenzoni, dated November 13. In CL, PAO.
- Tacchini, Pietro, 1873c. Telegram to G. Lorenzoni, dated December 25. In PAO.
- Tacchini, Pietro, 1874a. Alcune considerazioni spettroscopiche. *Memorie della Società degli Spettroscopisti Italiani*, **III**:20-28.

- Tacchini, Pietro, 1874b. Telegram to Lorenzoni, dated December 9. In PAO.
- Tacchini, Pietro, 1875a. *Il Passaggio di Venere sul Sole dell'8-9 Dicembre 1874 Osservato a Muddapur nel Bengala*. Stabilimento Tipografico Lao, Palermo.
- Tacchini, Pietro, 1875b. Sulla misura degli angoli di posizione delle macchie e delle facole per proiezione. *Memorie della Società degli Spettroscopisti Italiani*, IV:53.
- The Daily Telegraph* (London), 7 December 1874.
- The Englishman* (Calcutta), 25 November 1874.
- The Nautical Almanac and Astronomical Ephemerides for the year 1874*. Her Majesty's Stationery Office, London (1870).
- Toulmonde, M., 1997. The diameter of the Sun over the past three centuries. *Astronomy and Astrophysics*, **325**:1174-1178.
- Wittman, Axel, 1977. The Diameter of the Sun. *Astronomy and Astrophysics*, **61**:225-227.
- Wittman, Axel and Débarbat, Suzanne, 1990. Le diamètre du Soleil est-il variable? *L'Astronomie*, **104**:8-13.



Luisa Pigatto is a researcher astronomer at the Astronomical Observatory of Padova, Italy, and head of the *Specola* Museum (which she founded in 1994). She teaches historical astronomy at the University of Padova, and is editor of *Giuseppe Toaldo e il suo tempo, Nel bicentenario della morte, Scienza e Lumi tra Veneto ed Europa, Atti del Convegno, Padova 10-13 novembre 1997* (2000).

Valeria Zanini received a degree in astronomy from the University of Padova in 1999. She has completed a catalogue of the astronomical instruments of the *Specola* Museum, and is now researching the history of the Astronomical Observatory of Padova during the 17th, 18th and 19th centuries.

Little known aspects of the history of Georgian astronomy

Irakli Simonia

*Vazha-Pshavela av; 14-4, 380060, Tbilisi,
Republic of Georgia.*

Abstract

The present paper reviews the fundamental achievements of ancient Georgian astronomy and the dynamics of the process by which the Georgian astronomical world view developed in the period from the sixteenth century BC to the eighteenth century AD. It is during this period that the Georgian astronomical world view both formed and became fully developed. The author of the present paper divides this extended period into three shorter periods: an archaeological period, a transitional period, and a period of systematics. The characteristics of these three periods are cited. The paper also presents various facts and other information that illuminate the life and work of Georgian astronomers as well as the functioning of ancient Georgian astronomical and other scientific institutions. Several Georgian astronomical manuscripts are mentioned and described in brief, and a number of other questions are also discussed.

Keywords: *Georgian astronomy, cosmograms, David Gareja complex, Gelati Observatory, Narikala Observatory, The Star Book, Vakhtang IV Bagrationi*

1 INTRODUCTION

The aspect introduced here is quite complicated and an arduous Georgian history makes this task even more difficult. Information and materials, sources and facts have to be gathered piece by piece as precious stones on the beach of an impetuous history. This study is merely a first step in documenting a history of Georgian astronomy, and in this paper we try to reflect the dynamic process by which astronomy developed in Georgia over a protracted period of time. We subdivide this period into shorter periods: an archaeological period, a transitional period, and a period of systematics.

Georgian astronomical and astrological manuscripts, that until now have been unknown to Western researchers, are deserving of study. Approximately 300 such manuscripts are preserved in the various institutes and archives of Georgia. These manuscripts form a huge monolith of astronomical data that bring information of a relict character. These manuscripts did not disappear in the fire of social and natural cataclysms, did not sink into oblivion in the depths of ancient centuries. They were preserved through the self-sacrificing work of Georgian authors, translators, and copyists. It is possible that there are many unknown, unstudied sources of historical-astronomical information in the world – in particular in those countries that are only now re-establishing themselves as independent states. Therefore it seems expedient to propose the creation of an international institute of 'unstudied' historical-astronomical materials or, for that matter, of 'unstudied' historical-scientific materials in general. Such an institute would study the previously-unknown materials and would publish the study results in special bulletins in order to bring the 'new-old' information to the attention of the international scientific community.

The ruins of old observatories, fragments and remains of instruments, numerous manuscripts and books, unclaimed discoveries, and forgotten names – this is the world of ancient Georgian astronomy, which until now has been little known outside of Georgia.

The state of Georgia (see Figure 1) is located in the Caucasus on the very border between Europe and Asia. The Black Sea, Caucasus Mountains, and thick forests together create a unique, beautiful landscape and healthy, temperate climate. This territory was already populated by Georgian tribes in ancient times, and a Georgian state has existed for more than twenty-five centuries. Over these long, difficult centuries the Georgian people created their own language, culture, and world view. Numerous monuments of literature, art, and architecture bear witness to the original culture of these people.

Fire worship and other religions were widespread in Georgia until the fourth century AD. Christianity began to spread across Georgia in the first half of the fourth century, and within 100

years it had acquired the status of the state religion. This process was brought about by the strong political and cultural influence emanating from the eastern provinces of the Roman Empire, with which Georgia had close relations. Poti, on the Black Sea near the ancient city of Phazis, was both one of the first cities and one of the first cultural centres. Later Kutaisi and Mtskheta became major cities and cultural centres. At the present time Georgia's most important city and cultural centre is Tbilisi, which is also the capital of the Republic of Georgia. This city was founded in the fifth century AD by the Georgian king and military leader Vakhtang Gorgasali.



Figure 1. Location map of places mentioned in the text.

Celestial phenomena interested Georgians from ancient times. This is confirmed by real proofs. Oral folk art has brought down to us ancient Georgian sayings and legends that mention individual celestial bodies, various celestial phenomena, and so on. The principal thought or moral of such legends was the 'supremacy of celestial laws' and the 'inevitability of punishment by powerful celestial forces'. The ancient Georgians attached a mystical character to the sky and to celestial phenomena, thereby acknowledging their full grandeur. Ancient material objects of brass, bronze, silver, and gold have also come down to us. When we examine these ornaments, implements of labour, weapons, and household wares, we see images of the Sun, Moon, and stars presented in various shapes and sizes. The fact that ancient Georgians depicted celestial bodies on material objects shows that celestial phenomena interested them.

2 THE ARCHAEOLOGICAL PERIOD

What are the most ancient material objects containing images of an astronomical character? In the 1940s Georgian archaeologists (Gambashidze *et al.*, 1986) discovered bronze plates dating from the sixteenth to the fourteenth centuries BC. In all about thirty plates were discovered – primarily in the graves of women – at various burial sites including the large burial ground known as 'Zadengora'. The plates are massive and measure several tens of centimetres in diameter. Their surfaces are covered by numerous convex, circular apertures, Figure 2. Until now Georgian scientific literature has examined these plates only from the archaeological point of view. In the present article we shall examine them from the astronomical point of view for the first time.



Figure 2. Georgian bronze plate, circa fifteen century BC.

Georgian tribes that populated the eastern regions of Georgia in the sixteenth to fourteenth centuries BC supported themselves mainly through agriculture and by raising cattle. These tribes practised fire worship. Worship of the cults of fire, heat, and light played an important role in the lives of the Georgian tribes. Giving tribute to the Sun as the principal source of light and heat and also seeing its large dimensions, the ancient masters and artists depicted it in the centre of the bronze plates in the form of a circular aperture.

The Moon served as another important source of light for the ancients. It was precisely the Moon that supplied them with bright light at night. Phenomena such as changes in the phases of the Moon provoked their special interest and had overtones of mysticism. As a result, the Moon was depicted on the bronze plates in the form of a sickle-shaped aperture.

The ancients also saw other celestial objects in the sky and noticed that they differed from each other in form, brightness, and colour. Trying to reflect these differences, the ancient Georgian masters gave varying outlines to the spherically-shaped protuberances on the surfaces of the plates. Thus the ancient bronze plates reflect what the Georgian tribes saw in the sky. The religious views of the tribes also played an important role in the distribution of images of celestial bodies on the ancient bronze plates.

The character of the pictures on these bronze plates is clearly systematic. Perhaps the artisans of these plates have put their cosmological understanding in them? Therefore it is suggested to call these ancient Georgian bronze plates 'cosmograms' (Simonia, 2000). It seems to us that these Georgian cosmograms are the earliest known material objects in Georgia to include astronomical images. At the present time the cosmograms are preserved in various Georgian museums and institutes. It would be interesting to conduct a comparison between the Georgian cosmograms and analogous objects that can be found in other parts of the world.

The most ancient Georgian states were formed in the sixth century BC. The western Georgian state was known as Kolkheti, and the eastern Georgian state was called Kartli. (Some literary sources call Kolkheti by the name Egrisi and Kartli by the name Iveria.) New societies and institutions characteristic of that time began to take form in these two Georgian states. Agriculture and cattle-raising continued to develop, but artisanal professions and trade with neighbouring and distant states also arose. In the third century BC the Georgian king Parnavaz united the western and eastern Georgian states into a single state. At that time the religion of Fire-Worship was widespread.

The principal Georgian god was the Moon, which was seen as the symbol for a male warrior. The Moon's sacred animal was the bull, and thus bulls were frequently given as sacrifice. The shape of the bull's horns reminded the ancient Georgians of the Moon. Various depictions of the bull and his horns were widespread on the walls of religious buildings and in the homes of the ancient Georgians. Statues and statuettes of bulls (see Figure 3) and other sacred animals likewise spread widely. Such animals as the lion, boar, donkey, and deer were worshiped by the ancient people and this is the reason for their sacred representation of these animals. Relief images of sacred animals and geometrically complex Georgian ornamental design compositions were cut into the surfaces of such metal objects as containers, women's jewellery, shields, and so on. Among the various compositions and graphical fragments, the diverse symbols and signs of a clearly astral character are of special interest (Figure 4). Symbols showing spatial relationships and symbols of motion are especially widespread.

King Parnavaz played an important role in the development of Georgian language and culture. In the third century BC he invented the first Georgian alphabet. In doing so he became the founder of the written Georgian language, the history of which has been studied by the French orientalist Mary Brosset and the Georgian historian Simon Kauhchishvili (Brosset, 1849-1858). The creation of writing served as a turning point in the development of Georgian culture. The first written inscriptions appeared on material objects, and the process of developing a literature began. We believe that the development of the early Georgian astronomical concepts culminated simultaneously with the creation of a written language. This early period encompasses the sixteenth through the third centuries BC. We propose that this early period be called the archaeological period. In the course of this period the following two processes developed: a) acquisition of the simplest primary knowledge of the sky and celestial objects by the ancient Georgians and b) representation of this acquired knowledge in culture, in oral works, and in the applied arts.



Figure 3. Statuette of bull.

The acquisition of knowledge during the archaeological period, and likewise the invention and spread of a written language transformed and expanded the world view of the ancient Georgians. A new class of citizens appeared in society – a class whose principal activities included the writing of chronicles, the development of grammar and arithmetic, and so on. From this class we must take note of those (generally people close to the king) who were charged with making regular observations of celestial bodies insofar as these were seen to be higher powers upon which earthly life depended. The observers of that time undoubtedly would have noted that many climatic phenomena (e.g., river flooding, cooling and warming trends) were preceded by various celestial phenomena, such as the appearance of certain stars, and the disappearance of others. Having noted this type of regularity, the ancients would have tried to use it for their practical aims such as agriculture. Purely earthly concerns such as fertility and crop yield would have caused the ancients to study deeply and in detail the regularities in the

disposition and motion of celestial bodies. In this way the prerequisites for the appearance of astronomy as a science were created – in particular the prerequisites for those important parts of astronomy concerned with chronology and the calendar.



Figure 4. Relief images of sacred animals on Georgian silver cup, third century BC.

Georgian historical manuscripts and notes that form a historiography called *The life of Kartli* (Kaukhishvili, 1959) tell us that in the second century BC Georgia used a lunar calendar, and we know that this lunar calendar continued to be used until the end of the third century AD. These chronicles have provided us with the ancient Georgian names of the known planets: Mercury–Djimagi, Venus–Mtiebi, Mars–Tarkhoni, Jupiter–Obi, and Saturn–Morige. These names were used in Georgia until the end of the third century AD. In the fundamental work of Ivane Dzhavahishvili, *The History of the Georgian Nation* (1949), it is shown that Mtiebi is an ancient Georgian word meaning 'the star of sunrise', that is, Venus. The word Morige in the ancient Georgian language meant the name of the highest God of the 'seventh sky'. In some parts of Georgia it was believed that Morige was a god of order. Dzhavahishvili compares Morige with Chronos. He also mentions that the word Obi (or Vobi) meant the name of the God of thunderstorm in ancient Georgia. He therefore compares Obi with Dios. In the same work it is also mentioned that the word Djimagi named the God of Wednesday, which corresponds to Hermes or Mercury, while the word Tarkhoni means the God of War, which corresponds to Mars. Dzhavahishvili stresses that all the above names were widely spread in both Eastern and Western Georgia. The history of these names themselves goes back as far as the times of fire-worship and heathenism. When working on this part of the paper it was thought that it would be a good idea to create a dictionary of ancient astronomical terms and names. Such a dictionary could comprise Arabic, Greek, and Georgian terms and names. Analysis and comparison of these names could lighten up many interesting questions of the history of astronomy. We only have to find co-authors from the East and West.

The existence of a calendar and of Georgian names for the planets tells us that in the period between the second century BC and the third century AD, the Georgians had some degree of knowledge of celestial phenomena and that they used this knowledge in practical life. Naturally, at that time this knowledge could only have a limited character.

3 TRANSITIONAL PERIOD

The period from the second century BC to the third century AD was a transitional period in the development of the Georgian astronomical world view. This transitional period was characterized by simple astronomical observations and likewise the creation and use of the first calendars. It was the priests who observed the sky and who played an important role in the organization of regular knowledge, and during this period many generations of priests succeeded each other. Unfortunately, the Georgian chronicles do not give us their names.

The spread of Christianity in Georgia in the fourth century AD gave an impulse to the development of new elements in Georgian culture. New, progressive – in the context of that time – ideas and views as well as knowledge of man and the world penetrated into Georgia. A feudal society began to form. The first schools and educational institutions began to spring up. The process of systematically translating foreign books into the Georgian language began, and new knowledge enriched the Georgian astronomical world view.

4 PERIOD OF SYSTEMATICS

In the second half of the fourth century AD the Julian calendar came into use in Georgia, and from this moment a new period in the development of the Georgian astronomical world view begins. This period can be called the period of systematics. Fragmentary evidence from various sources shows that in the fifth and sixth centuries AD the teachings of the Greek astronomer Claudius Ptolemy began to spread in Georgia. Ptolemy was a popularizer of the geocentric theory. The educated sections of the population (i.e., the priests and the king's courtiers) evidently were well acquainted with the geocentric system. In the Georgian language there exists the word 'Dedamitsa', which literally translates as 'mother Earth'. Here the word 'mother' signifies beginnings, the start of existence. Thus the question arises, did this word not appear at that time when the ideas of geocentrism first penetrated into Georgia? Additional study will be required to answer this question.

In the sixth century AD the priest Father David and his students founded the David Gareja complex in the rocky mountains of Gareji near Tbilisi (Dzhavakhishvili, 1949; Gubinashvili, 1948). The monasteries in this complex were hollowed directly out of the rocks. In various historical periods the number of monasteries grew to as many as twelve. In the seventh through the ninth centuries AD, David Gareja became a major religious and educational centre, and regular observations of the celestial bodies were conducted there. The works of foreign authors were translated into Georgian. At David Gareja a large library of philosophical works was collected. In our view David Gareja could be, in fact, the first Georgian astronomical centre. This complex continued to function through several more centuries, surviving periods both of flourishing activity and of decline. Fragments and ruins of this complex have been preserved until the present time (see Figure 5). Unfortunately, the sources of the above information do not give any details of the scientific research that was carried out in David Gareja.

The earliest manuscript containing astronomical information to survive to the present day dates from the tenth century AD (Kevanishvili, 1951). This manuscript is 263 pages in length, is written using letters from the first Georgian alphabet, and has both religious and astronomical content. The manuscript illuminates questions of chronology, and it describes and gives tables for computing solar days and months (see Figure 6). It discusses the regularities in the day-night cycle and gives other information as well. Evidently the manuscript's religious portion is not itself an original work but is, rather, a translation into Georgian. This manuscript is the first historical document bearing witness to the development of astronomy in Georgia.

In addition to the above we have to say that the name of the author of the manuscript or the name of the copyist who completed his work in year 974, is unknown. The catalogue of Georgian astronomical manuscripts by Galaction Kevanishvili states, though with no proof, that this manuscript is a copy. This at least means that the original manuscript was of an earlier date. We cannot confirm nor disprove the hypothesis that this manuscript has been copied. The manuscript deserves a special study.

Chronicles and other historical materials give evidence that at the end of the first millennium an astronomical observatory was functioning in Tbilisi, in the region called Narikala. The available materials do not allow us to establish the precise date of this observatory's founding, but these same materials do show that it was active in the tenth century. Staff at the observatory carried out various predictive computations and practical observations, and compiled tables and calendars. They also translated the works of Greek and Arab astronomers. There is evidence that Arab astronomers worked at the observatory for an extended period, and thus we cannot exclude the possibility that information about the Narikala observatory could be found in Arab sources. The observatory continued to function until the fourteenth century.

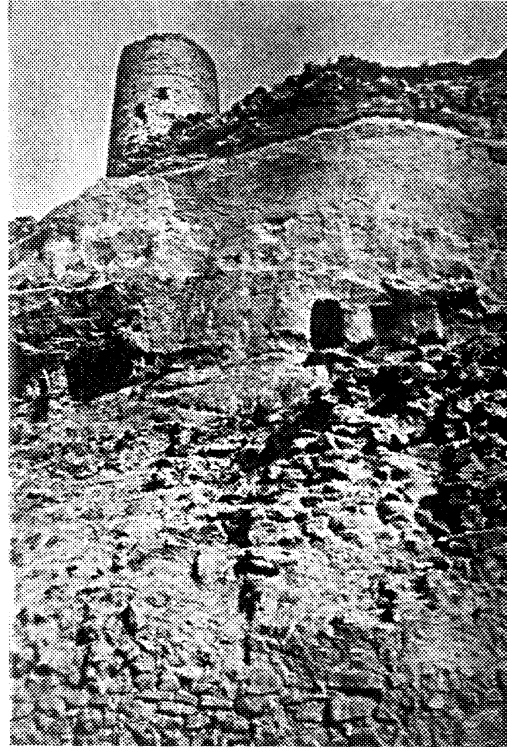


Figure 5. Ruins of part of the David Gareja centre from sixth century AD.

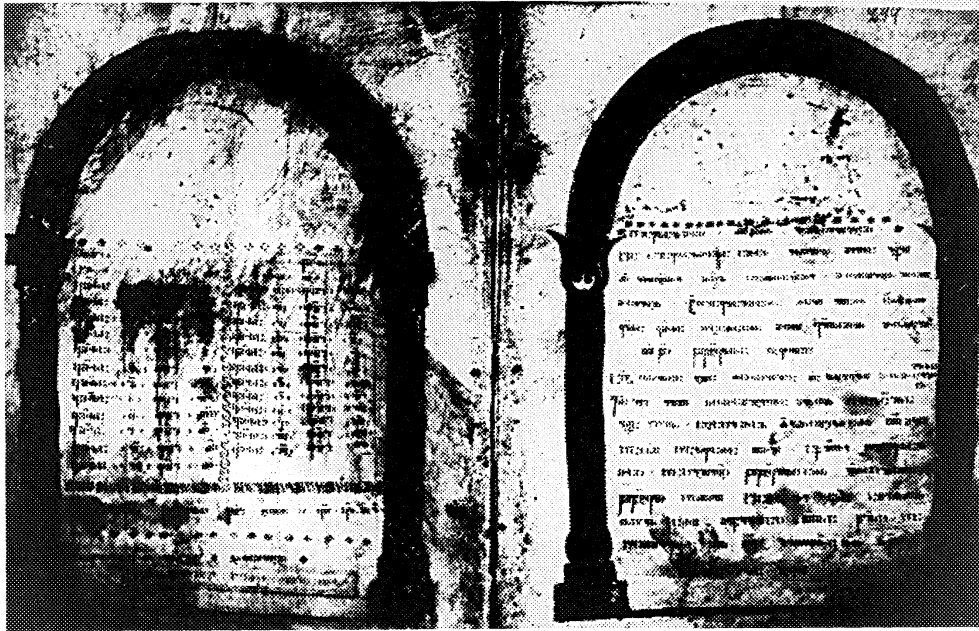


Figure 6. Page from Georgian manuscript, tenth century AD.

In the thirteenth century the Georgian and Eastern astronomer Khlatali (or Ikhlati) worked at the Narikala observatory (Kharadze and Cochlashvili, 1958; Kharadze, 1975). Using simple instruments for making angular measurements, he conducted observations from which he compiled tables, calendars, and so forth. Ikhlati was also a good computer. The well-known Eastern astronomer Nasireddin at-Tusi took note of Ikhlati's scientific abilities and invited him to work at his observatory at Maraga, where Ikhlati adopted the name Fakhredin Ikhlati. As shown in Matvievskaia and Rozenfel'd (1983), Ikhlati was an Eastern astronomer, and one of the closest co-workers of Nesireddin at-Tusi. The authors call the astronomer Fakhr Ad-Din Al-Maragi. We do not know the years when he worked in Georgia. A fair question arises here:

what was the actual name of this astronomer – Ikhlati, Fakhr Ad-Din or Khlатели? In our opinion, he can be called by any of these names, as he contributed to Eastern and Georgian astronomy.

In 1106 the Georgian King David IV Bagrationi founded the scientific and cultural academy Gelati in the western part of Georgia, not far from the city of Kutaisi (Gamsakhurdia, 1975; Kaukhchishvili, 1948). David IV (1073-1125) played a special role in the history of the Georgian state. Having only a small army, he nevertheless succeeded in liberating Georgian territory from foreign invaders. He also succeeded in uniting the fragmented parts of Georgia into a single state. David IV created state institutes and structures that were progressive for their day. In addition, he devoted a significant amount of time to scientific and cultural activities of various kinds. David IV has gone into Georgian history as David the Builder. He is buried in the grounds of Gelati.

Several of Gelati's buildings and structures have survived to the present day. Some sources (e.g. Kareeva, 1894 and Khakhanov, 1898) note that the Georgian philosophers Arsen Iqaltoeli and Ioanne Petritsi were invited to work at Gelati, where they conducted active scientific, pedagogical, and translating work. These same sources indicate that geometry, arithmetic, music, philosophy, rhetoric, grammar, and astronomy (or, as it was called at that time, astrology) were all taught at Gelati.

Gelati had an astronomical observatory (Figure 7) where a variety of observations were carried out using astrolabes and other instruments. David the Builder in his own works writes that he devoted many nights to the stars, studying their positions in the sky and their effect on the fates of man and the state.

The Georgian astronomer Abuserisdze Thbeli (1190-1240) made an appreciable contribution to the development of the Georgian astronomical world view. Working in the ancient Georgian language, he wrote a fundamental treatise on calendars and chronology, the title of which can be translated approximately as *The Complete Time Keeper* (Dzhavakhishvili, 1945; Lordkinamidze, 1977). This treatise contains information related to calendars, descriptions of different systems for maintaining chronology, dates of church holidays, tables of moonrise and moonset, information on special cycles, and so on.

Abuserisdze Thbeli did not conduct astronomical observations himself, nor did he work in any astronomical laboratory. His treatise has a theoretical character and is connected to a large degree with his mathematical investigations. *The Complete Time Keeper* is, in fact, the first astronomical work of a theoretical nature produced in Georgia, and this elevates Abuserisdze Thbeli to a special place in Georgian astronomy.

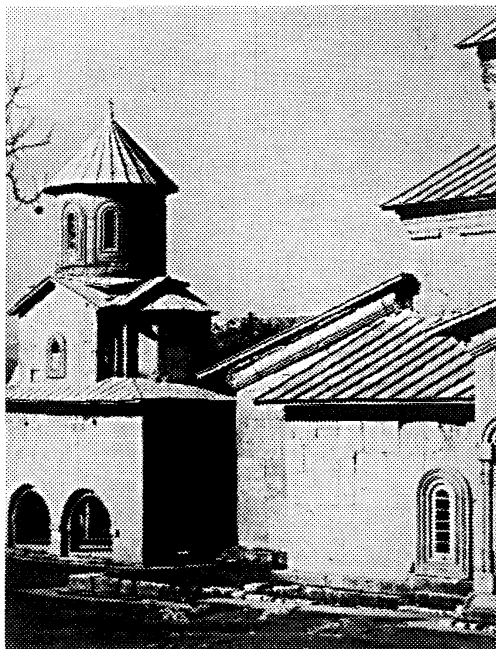


Figure 7. The astronomical observatory at Gelati.

Analysis of manuscripts, books, and material objects shows that the basis for the Georgian astronomical world view in the tenth through the thirteenth centuries remained Ptolemy's geocentric system, a description of which can be found in almost every astronomical manuscript from that period. There are some variations in the description from one manuscript to another, and there are differences in detail. Nevertheless, one can find mention of the Ptolemaic system even in non-scientific manuscripts. These facts show that the geocentric idea had complete control of the minds of Georgian astronomers and philosophers at that time.

The scientific work of Georgian observatories in the tenth through the thirteenth centuries expressed itself primarily in the study of star positions. The following peculiarity is noteworthy: as a rule those manuscripts containing the fundamentals of theory are translations of foreign authors into Georgian, whereas the manuscripts and books of a calendar-chronology character belong to the pens of Georgian authors. This fact implies that fundamental theoretical ideas penetrated into Georgia from outside. The Georgian astronomers and philosophers concerned themselves with developing the more practical, applied areas of astronomy that were necessary to both the people and the state. In particular, they concerned themselves with those practical areas that were needed for the construction of precise calendars, for the determination of time periods, for the prediction of dates for church and civil holidays, and for commercial, military, and other purposes. This was natural, of course. One cannot imagine the normal development of a state without knowledge of precise time, or without the possibility of predicting climatic phenomena connected with the different seasons of the year. We could give the name 'scientific systematics' to these practical works by Georgian astronomers.

Such systematics have both positive and negative aspects. On the negative side, extreme practical aims pushed aside the important necessity of perfecting basic theoretical ideas. On the positive side, the deepening of practical knowledge and habits must have stimulated the development of related disciplines. In particular, constant improvements in the calendar system in Georgia gave a powerful stimulus to the development of Georgian mathematics.

Of course, early scientific systematics were not unique to Georgia. Other countries with analogous social and economic structures and with analogous world views also passed through this phase. An interesting peculiarity of that time is that along with astronomical information and descriptions, the majority of written materials also contained astrological information. As a rule, the astrological information encompasses those questions concerned with predicting, forecasting, or otherwise determining people's fates in accordance with the disposition of the stars and so forth.

Society at that time continued to be under the influence of various types of mystical ideas and concepts. We can conjecture that there was something like a state-supported institute of astrologers in Georgia and that Georgian kings had court astrologers who were responsible for predicting the fate of the king, the state, and even individuals. Astrologers wrote their works, compiled tables and graphs, and distributed all of this among the appropriate layers of society. It is interesting to note that manuscript materials always exhibit a sharp, definite dividing line between their astronomical and astrological parts. It was usual that certain paragraphs in these manuscripts would be devoted to astronomy, while other parts would be concerned with astrology. Astrological predictions in Georgian manuscripts may be characterized by descriptions of life and health of a man in various periods of time (months, weeks, days). These facts demonstrate that in Georgia in the tenth through thirteenth centuries the distinction between astronomy and astrology was already understood. Figure 8 shows the use of symbols for the zodiacal constellations in a Georgian manuscript (Kevanishvili, 1951).

We should like once again to turn to the catalogue of Georgian astronomical manuscripts by Galaction Kevanishvili (1951). It states that the above manuscript contains 209 pages. It was copied (into ancient Georgian language) in 1210, by someone named Isaim. The pictures of zodiacs and Moon phases are done in gold. The manuscript contains descriptions of calendar systems, zodiacs, and Moon phases. Unfortunately, we do not have any reference to the name Isaim.

The most complicated period in Georgian history began with the start of the Tatar-Mongol invasion in the middle of the thirteenth century. This invasion involved numerous battles and resulted in widespread death among the population, and the destruction of cities and cultural centres. The Tatar-Mongols attempted to seize the territory of Georgia. However, loyal

Georgian armies and strong opposition among the populace became an insurmountable barrier in the path of the newcomers. Although at a great cost, the Georgian government was preserved, and relative peace was restored. But Georgia to all intents and purposes lost its freedom through external political action, being forced to pay large tributes and to supply soldiers for the Tatar-Mongol armies on a regular basis.



Figure 8. The zodiacal constellation of Libra depicted by symbols in an ancient Georgian manuscript.

Georgian King Georgi V (reigned 1313-1346) used flexible politics to strengthen the Georgian state. As a result Georgia was able finally to free itself from the Tatar-Mongols by the middle of the fourteenth century. This period of calm turned out to be short, however, with Tamerlane's (Timour, 1335-1405) invasion beginning at the end of the fourteenth century. Georgian soldiers and people resisted fiercely, but the forces proved too unequal. Nevertheless, resistance continued. One of the most notable resistance figures was Georgian King Georgi VII (reigned 1393-1407). With the death of Tamerlane, Georgia once again secured its liberation.

The events of the thirteenth through the fifteenth centuries had a negative effect upon the development of Georgian culture and science. The invading hordes destroyed the academies and observatories and burnt the libraries, and the Georgian people had to start over again from the beginning. The process of restoring the Georgian state began at the start of the sixteenth century. Cities and cultural centres were resurrected, schools were opened, and the people gradually returned to their accustomed style of life.

The resurrection of scientific thought accompanied the general restoration of the state. Special interest was paid to the science of the sky – in particular to its practical applications. In the sixteenth and seventeenth centuries no fewer than nineteen astronomical works were translated into Georgian – most of them dealing with calendars and chronology. Georgian authors, translators, and book copiers all realized the importance of restoring astronomical knowledge, which to all intents and purposes had been lost in the period from the thirteenth through fifteenth centuries. The writing and translating of astronomical manuscripts continued even into the eighteenth century.

Let us take a closer look at one of these manuscripts entitled *The Star Book*, which dates from the beginning of the eighteenth century (the original is preserved in the Georgian Manuscript Institute in Tbilisi under catalogue No. Q 867). The manuscript, whose author is unknown, consists of 250 pages and is divided into 31 chapters, each of which is devoted to a specific topic of an astronomical or astrological character.

On page 7, chapter 1, of *The Star Book*, we find the following statement: "Zokhar has a single star in the sky." Zokhar is Venus, and the reference to a star "in the sky" is a way of indicating that Venus has a satellite. On page 8 we also find: "Marekhi has a single star in the sky." Marekhi is Mars, and the reference to a star here is also a way of indicating the presence of a satellite. In both cases the manuscript gives a measure of the satellite's orbit. It is difficult to explain these two statements. At that time there were no optical instruments capable of revealing the satellites of Mars, and of course Venus has no satellites at all.

Chapter 8 of *The Star Book* concerns the Moon. Page 42 states: "First we must know that God created the Sun and Moon and ordered that the Moon should receive its light from the Sun. The Moon itself is blank. The Moon illuminates us after receiving its light from the Sun." These quoted sentences, translated from Georgian, show unambiguously that the manuscript's author understood the fact that the Moon shines by reflected light. Page 42 also includes the statement: "Many philosophers, first of all Alexander, say that Galileo built a ten metre tube and, after using it, asserted that the visible dark spots on the Moon's surface are in fact mountains, seas, and rivers." The description of a 10-metre telescope is confusing but we have given the exact meaning of this part of the manuscript. Nevertheless, this citation shows that the author was acquainted with seventeenth and eighteenth century European literature and knew of some of the achievements of European astronomers. The author of the manuscript does not give any information about Alexander, but we have done a wide search of the sources (Metreveli, 1979), and among a long list of names we found Alexander Bagrationi (1674-1711), the son of Georgian King Archil II Bagrationi. Apparently Alexander Bagrationi was doing a lot of things, including translating and copying of the manuscripts. Our careful guess is that this is the same Alexander.

Chapter 12 deals with eclipses of the Sun and Moon. Page 59 states: "Belorano was a scientist who for wisdom has no equal in our times. If he had lived at the time of Aristotle, then the latter would have paled before him. This scientist greatly simplified astronomy. He could determine in which year, in which month, in which week, on what day, and at what time eclipses of the Sun and Moon would take place." In translating these lines from the Georgian language we have tried our utmost to preserve the author's style. It is apparent that the manuscript's author was familiar with the scientific works of the European astronomer Belorano. Figure 9 shows page 59 of the manuscript together with an original drawing. On page 60 we find a detailed description of the conditions for both total and partial solar and lunar eclipses. Unfortunately, all our attempts to determine who Belorano was have failed. We hope that our colleagues will be interested in this question and we will be able to solve it together.

Chapter 14 concerns planetary motion, and page 72 contains a drawing that reflects the author's cosmological world view. From the centre to the edge we find regions that are labelled as follows: "Earth water," "air," "fire," "sky Mtvare" (the Moon), "sky Otavid" (Mercury), "sky Zokhar" (Venus), "sky Mze" (the Sun), "sky Marekhi" (Mars), "sky Mushtar" (Jupiter), "sky Zokhal" (Saturn), "the fixed sky," "the second movable sky", and "the first movable sky." From this we can see that the author had a geocentric world view.

Chapter 15 is devoted to the motion of the celestial spheres. Page 77 states: "The sky itself moves and rotates, but the stars are fixed to their places. Hence we speak of the 'fixed sky'." Page 78 states furthermore that "its width is 250,230,000 agadji." (The agadji was an ancient Georgian unit of measure that is equal to approximately 4-5 km.) On page 78 we find the following: "The ninth sky – the second movable sky – is like crystal." Chapter 15 contains information on the dimensions, motion, and periods of the different spheres and on the dimensions of the stars, and it also gives information of a religious character. Indeed, chapter 15 is the author's attempt to describe the universe as a whole, and the quoted fragments tell us something about his world view.

The manuscript's subsequent chapters contain information on the 12 zodiacal constellations, on the number of stars in the constellations, on star brightness, on the annual motion of the Sun through the constellations of the zodiac, on the motion of the Moon, on the calendar, on the changes of seasons, on several types of climactic phenomena, and on crop yields to be expected in coming years. The manuscript also contains extensive information of an astrological character.

This general review of *The Star Book* shows that it contains diverse types of information. On the one hand the manuscript contains information that was modern for its time, for example,

information on telescopic observations by Galileo, on the sizes and shapes of the planets, and on the daily and annual motion of celestial bodies. On the other hand the manuscript also includes detailed descriptions of Ptolemy's outmoded geocentric system. It is our view that the manuscript's author attempted to create something of an encyclopaedia – astronomical handbook – containing various types of information that would reflect contradictory world views and ideas. The author evidently relied on various sources and used the achievements and works of various astronomical schools. *The Star Book* is an important historical-astronomical document that reflects the level of the Georgian world view at that moment in its scientific development. (It would be useful to translate and publish *The Star Book* to make it available to researchers.)

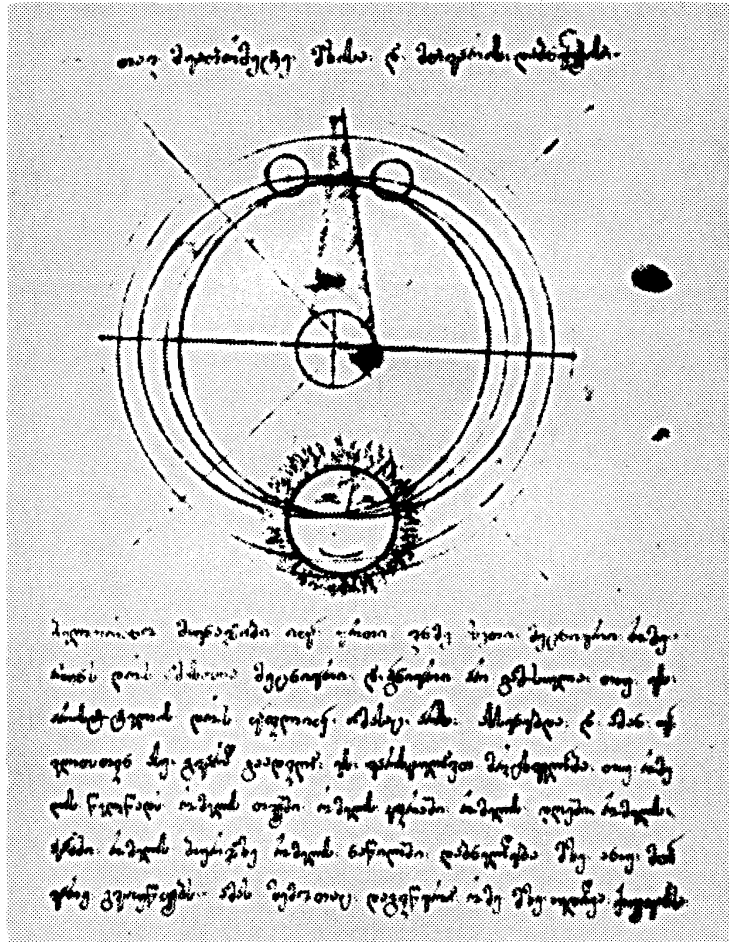


Figure 9. Page 59 of the Georgian manuscript, *The Star Book*.

The first quarter of the eighteenth century was marked by the scientific and educational activity of Georgian King Vakhtang VI Bagrationi (reigned 1703-1723) and his associates. Vakhtang VI was not just a statesman. He was also a scientist. Astronomy, which he studied using ancient Georgian and eastern manuscripts and books, was one of those disciplines that held special interest for him. In his first period of scientific work, Vakhtang VI translated fundamental astronomical works from among the classics of Eastern astronomy into Georgian. Vakhtang VI translated the works of Ulugh Bek, Naseredina Tusi, and Ali Kushchi. In 1721 Vakhtang VI established a printing house in Tbilisi. That same year the printing house issued several hundred copies (according to various sources between 200 and 300) of an astronomical treatise by Ali Kushchi in a translation by Vakhtang VI. Several copies of this book have been preserved to the present day, and one copy is in the rare book division of the Georgian National Library in Tbilisi. Figure 10 shows pages from this book in which we can see a figure representing the geocentric system. King Vakhtang VI also produced his own astronomical works that for the most part were descriptive in nature and as a rule were devoted to descriptions of the geocentric system.



Figure 10. Georgian text and drawing of an astronomical treatise which was translated and printed by King Vakhtang VI Bagrationi.

In his second period Vakhtang VI conducted scientific work that was more practical in character. Persian masters built an astrolabe using plans drawn by the king himself. Vakhtang VI conducted regular observations with the astrolabe and used the results to construct special tables and other materials. Vakhtang VI's astrolabe (Figure 11) is preserved in the Georgian History Museum in Tbilisi.

King Vakhtang VI established scientific contacts with scientists from Georgia and from various countries. One of his main local associates – in both the political and scientific fields – was the Georgian philosopher, writer, and educator Slukhan-Saba Orbeliani (1658-1725), who compiled an explanatory dictionary of the Georgian language under the title *Bouquet of Words*. This dictionary includes several hundred astronomical terms of both Georgian and foreign origin. Some of the terms first entered the Georgian language from Greek, Arab, or other languages and were then transformed to Georgian lexical forms and began to be used widely in scientific speech. By analysing the astronomical terms in the dictionary of Slukhan-Saba Orbeliani, we can study the process by which Eastern and Western astronomical ideas and views influenced Georgian astronomy (Simonia & Simonia, 1994; Georgobiani, 1986; Gavriushin, 1983).

The period of systematics in the development of Georgian astronomical world view can be characterized by the following processes:

- a) formation of fundamental knowledge about celestial objects;
- b) creation of a Georgian scientific astronomical literature in the form of a set of manuscripts;
- c) practical and theoretical work by Georgian astronomers; and
- d) the operation of Georgian astronomical observatories.



Figure 11. The astrolabe of king Vakhtang VI Bagrationi.

The idea of a heliocentric model began to spread through Georgia in the mid-eighteenth century, and by the end of that century the new astronomical world view based upon the heliocentric system of Nicolaus Copernicus had firmly taken possession of the minds of Georgian astronomers and philosophers. During this period the arrival of scientific and educational literature from various countries – including Germany, France, and Russia – acquired an intensive and regular character. Some of the books and scientific publications that arrived from these countries are preserved in the Georgian National Library and in various Georgian museums and archives. These preserved books and publications bear witness to the increased Georgian exposure to Western scientific literature in the eighteenth century.

With the arrival of the nineteenth century we come to the end of our survey.

5 CONCLUDING REMARKS

Of course, it would be unthinkable difficult in the bounds of a single paper to illuminate all details concerning the development of astronomy in Georgia for a period of more than 2500 years. To do so would require a whole series of diverse and complementary studies. We have not touched upon questions connected with the study of ancient Georgian astronomical inscriptions on the walls of such structures as monasteries and churches. We also have not discussed the instrumental aspects of measuring time in ancient days, although in Georgia the tradition of preparing and using solar clocks was well developed. Of course, these as well as many other topics and questions should be analysed in subsequent studies.

What we have tried to do here is describe the principal events, achievements, problems, and ideas of Georgian astronomy, information that was, until now, previously unknown outside of Georgia. We hope that we have been at least partially successful in bringing little known aspects of Georgian astronomical history to an international audience.

6 ACKNOWLEDGEMENTS

The author thanks Dr Robert McCutcheon for his English translation and valuable comments, together with Mrs Olga Hedge for translating the referee's adjustments. The author also thanks Professor Gene Milone, Dr Wayne Orchiston and John Perdrix for their important and valuable comments.

7 REFERENCES

- Brosset, M., 1849-1858. *Histoire de la Georgie depuis l'antiquité jusqu'au XIX siècle*, V. 1-7. Saint Petersburg.
- Dzhavakhishvili, I., 1945. *Historical Literature of Ancient Georgia* [in Russian]. University Publishing House, Tbilisi.
- Dzhavakhishvili, I., 1949. *The History of the Georgian People, Vols. I-VIII*, [in Russian]. Nauka, Tbilisi.
- Gambashidze, O., Kvizhinadze, K. and Gambashidze, I., 1986. Principal Results of an Expedition to Meskheti and Djavakheti [in Russian]. *Journal of Archaeological Field Investigations*, 1986, pp. 27-35.
- Gamsakhurdia, S., 1975. *Education in Ancient Georgia* [in Russian]. Nauka, Tbilisi.
- Gavriushin, K., 1983. Byzantine Cosmology in the 11th Century [in Russian]. *Historical-Astronomical Investigations* 16. Nauka, Moscow.
- Georgobiani, G.G., 1986. Halley's Comet in an Inscription on the Wall of the Cathedral at Lykhni [in Russian]. *Historical-Astronomical Investigations* 18, Nauka, Moscow, 1986.
- Gubinashvili, G.N., 1948. *The Cave Monasteries of David Gareja* [in Russian]. University Publishing House, Tbilisi.
- Kareeva, N., 1894. Ikalto Monastery. In F.A. Brokgauz and I.A. Efron (eds.), *Encyclopaedic Dictionary*, [in Russian]. Vol. 24:897. Saint Petersburg.
- Khakhanov, A., 1898. Ioanne Petritsi. In F.A. Brokgauz and I.A. Efron (eds.), *Encyclopaedic Dictionary*, [in Russian]. Vol. 45:453-454. Saint Petersburg.
- Kaukhchishvili, S., 1948. *The Gelati Academy*. Nauka, Tbilisi [in Georgian].
- Kaukhishvili, Simon (ed.), 1959 *"The Life of Kartli," Chronicle*, Vol. 1. Nauka, Tbilisi [in Georgian].
- Kevanishvili, G., 1951. *Catalogue of Georgian Astronomical Manuscripts* [CGAM]. The CGAM was compiled in 1951 and is housed in the Department of Astronomy at the Tbilisi University.
- Kharadze, E., 1975. Astronomy, article in *Georgian Encyclopaedia*, Vol. 1, pp. 648-651, Tbilisi.
- Kharadze E. and Cochlashvili, T., 1958. On the Study of the History of the Development of Astronomical Knowledge in Georgia [in Russian]. *Historical-Astronomical Investigations* 4, Nauka, Moscow.
- Lordkinamidze, M., 1977. Abuserisdze Thbeli, article in *Georgian Encyclopaedia*, Vol. 1, p. 47. Tbilisi.
- Matvievskaja, G.P. and Rozenfel'd, B.A., 1983. *Mathematicians and Astronomers of the Moslem Middle Ages (VIII-XVII centuries) and their Works, Vols. 1, 2, & 3* [in Russian]. Nauka, Moscow.
- Metreveli, R., 1979. *The History of Georgia – A Dictionary* [in Russian]. Publishing House Obrazovanie, Tbilisi.
- Simonia, I., 2000. Ancient Georgian Cosmograms [in Russian]. *Circular of the Shamakhy Astrophysical Observatory*, N 99, pp.13-15, Baku.
- Simonia I. and Simonia, Ts., 1994. The East and The West and Astronomy in Georgia. *Time and Astronomy at the Meeting of Two Worlds*. Proceedings of the International Symposium held April 27 - May 2, 1992, in Frombork, Poland. Organized by the Department of Historical Anthropology, Institute of Archaeology, Warsaw University, Warsaw.



Dr Irakli Simonia (born 1961) is an astrophysicist, inventor, and lecturer involved in studying the physics of solar system bodies, both large and small. His interest in archaeoastronomy is directed mainly towards the history of Georgian astronomy. He is the author of 37 articles and papers, and among his society memberships is the Society for Astronomy in Culture and President of International Association Astroarchaeocauca.

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- Agar, Jon. *Science and spectacle: the work of Jodrell Bank in post-war British culture*. Amsterdam, Harwood Academic Publishers, 1998. xx, 260 p. illus. (Studies in the history of science, technology and medicine, v. 5)
- Ancient astronomy and celestial divination. Edited by N. M. Swerdlow. Cambridge, Mass., MIT Press, 1999. 378 p. illus. (Dibner Institute studies in the history of science and technology)
 Contents: Swerdlow, N. M. Introduction.—1. Reiner, E. Babylonian celestial divination.—2. Rochberg, F. Babylonian horoscopy: the texts and their relations.—3. Walker, C. B. F. Babylonian observations of Saturn during the reign of Kandalanu.—4. Hunger, H. Non-mathematical astronomical texts and their relationships.—5. Grasshoff, G. Normal star observations in late Babylonian astronomical diaries.—6. Brack-Bernsen, L. Goal-year tablets: lunar data and predictions.—7. Aaboe, A. A new mathematical text from the astronomical archive in Babylon: BM 36849.—8. Britton, J. P. Lunar anomaly in Babylonian astronomy.—9. Swerdlow, N. M. The derivation of the parameters of Babylonian planetary theory with time as the principal independent variable.—10. Jones, A. A classification of astronomical tables on papyrus.—11. Goldstein, B. R., and A. C. Bowen. The role of observations in Ptolemy's lunar theories.—12. Tihon, A. Theon of Alexandria and Ptolemy's *Handy Tables*.
- The Art of time. [Greenwich, Conn., Bruce Museum of Arts and Science, 1999?] 44 p. illus. (part col.)
 Exhibition checklist and errata slip laid in.
 Contents: Sturges, H. Acknowledgments.—Smith, M. The art of time.—Snellenburg, J. Measuring time.—Ehlinger, C. Connecticut clocks.—Bartky, I. R. Nineteenth-century American timekeeping.—Adams, G. Time in art.
- Astronomical amusements. Papers in honor of Jean Meeus. Edited by Fabrizio Bònoli, Salvo De Meis, Antonio Panaino. Roma, ISIAO; Milano, Mimesis, 2000. 158 p. illus., port.
 Contents: Bònoli, F., S. De Meis, and A. Panaino. [Foreword]—Bezza, G. Le tavole del primum mobile nel medioevo.—Casanovas, J. A new approach to spherical astronomy.—Chapront-Touzé, M., and J. Chapront. Analytical ephemerides of the moon in the 20th century.—De Meis, S., and A. Vitagliano. Some unusual Meeus portraits.—Denoyelle, J. My joint venture with Jean Meeus.—Goffin, E. Orbit determination without Gauss.—Huber, P. J. Modeling the length of day and extrapolating the rotation of the earth.—Magni, T. L'integrazione numerica di alta precisione per i non professionisti.—Marsden, B. G. Astronomical collisions.—Mucke, H. Zu der Entwicklung der Planetariums-Hauptprojektoren neueste Modelle von Zeiss nützen Daten von J. Meeus.—Panaino, A. An "Avestan" planetary order?—Romano, G. Matematica maya: ipotesi sulle operazioni aritmetiche.—Sinnott, R. W. A line of planets.
- Bartky, Ian R. *Selling the true time: nineteenth-century timekeeping in America*. Stanford, Calif., Stanford University Press, 2000. xvi, 310 p. illus., facsim., group port., maps.
- Besomi, Ottavio, and Michele Camerota. *Galileo e il Parnaso Tychonico. Un capitolo inedito del dibattito sulle comete tra finzione letteraria a trattazione scientifica*. Firenze, L. S. Olschki, 2000. 274 p. facsim. (Biblioteca di Nuncius. Studi e testi, 41)
 Contents: pt. 1. Camerota, M. Galileo e il Parnaso Tychonico. 1. "Gran portento di foco." 2. "Un assemblea fatta in Parnaso avanti Apollo." 3. Parnaso Tychonico. 4. Assemblea celeste. 5. Academico Danico. 6. Esopo in Parnaso.—pt. 2. Testi. Edizione critica e note a cura di Ottavio Besomi. 1. Assemblea celeste. 2. Abbozzi di Mario Guiducci in risposta all'*Assemblea celeste* (Firenze, Biblioteca Nazionale Centrale, Ms. Conv. Soppr. A.5. 1443).—Appendice. Discorso sopra il gran Cometa che si vede dal principio di Novembre di quest'anno 1618. Glossario dell'*Assemblea Celeste*.
- Borel, Pierre. *Discours nouveau prouvant la pluralité des mondes*. Ristampa anastatica dell'edizione Genève 1657 a cura di Antonella Del Prete. Lecce, Conte editore, 1998. xxiii, 80 p. (Aurifodina philosophica)
- Brunier, Serge, and Jean P. Luminet. *Glorious eclipses: their past, present, and future*. Translated by Storm Dunlop. Paris, Bordas; Cambridge, New York, Cambridge University Press, 2000. 192 p. illus. (part col.), facsim. (part col.), maps (part col.)
 First published as *Éclipses, les rendez-vous célestes* in 1999.
 Contents: Brunier, S. Journeys of an eclipse chaser.—Luminet, J. P. The story of eclipses, the story of people.—Luminet, J. P. The dance of the Sun and Moon.—Brunier, S. The great cosmic clockwork.—Luminet, J. P. By the light of eclipses.—Bruner, S. 11 August 1999: the last eclipse of the millennium.—Atlas of eclipses of the Sun and Moon.
 Includes information on occultations and transits.
- Buffo, Alberto. *Ouranos theorem*. Cambridge, Mass., Bovo Press, 2000. 338 p. illus.
 "A Dialogue on the subject of how the distances to the farthest reaches of the Universe have

- been measured and on the many attempts since Antiquity to understand the architecture of the Cosmos, with a digression or two on a few related matters."
- Carvalho, Rómulo de. *Colectânea de estudos históricos (1953–1994); cultura e actividades científicas em Portugal*. Évora, Universidade de Évora, 1997. xxi, 538 p. illus., facsim., ports.
- Partial contents: I. Temas e personalidades de ciência: actividade e pensamento científico em Portugal. Portugal nas "Philosophical Transactions," nos séculos XVII e XVIII (1956). Posição histórica da invenção de nónio de Pedro Nunes (1960). Relações científicas do astrónomo francês Joseph-Nicolas de l'Isle com Portugal (1965). Os nomes portugueses na carta da Lua (1967). A doutrina heliocêntrica de Copérnico e a sua aceitação em Portugal (1973). A aceitação, em Portugal, da filosofia newtoniana (1991).
- Casati, Roberto. *La scoperta dell'ombra; da Platone a Galileo, la storia di un enigma che ha affascinato le grandi menti dell'umanità*. Milano, Mondadori, 2000. 278 p. illus., facsim.
- "Eppure le ombre sono state la chiave per risolvere alcuni grandi problemi scientifici: il perché delle eclissi, le distanze tra terra, luna e sole, la forma e la dimensione della terra, la struttura del sistema solare. Contemplando le ombre si è riusciti, tra l'altro, a determinare la latitudine di un luogo, si è visto che la luna è costellata di valli e montagne, si è capito che Saturno è circondato da straordinari anelli e che la luce viaggia a velocità finita."
- Chabás, José, and Bernard R. Goldstein. *Astronomy in the Iberian Peninsula: Abraham Zacut and the transition from manuscript to print*. Philadelphia, American Philosophical Society, 2000. 196 p. facsim. (American Philosophical Society, Philadelphia. Transactions, v. 90, pt. 2)
- Contents: Preface.—Introduction.—1. Abraham Zacut: supplementary notes for a biography.—2. Setting the scenes.—3. The *Hibbur*.—4. The *Almanach Perpetuum*.—5. The influence of Zacut's astronomical works.—Appendix 1. Zacut's *Judgments of the astrologer*.
- Coles, Peter. *Einstein and the total eclipse*. Duxford, Cambridge, Icon Books; New York, Totem Books, 1999. 71 p. illus. (Postmodern encounters)
- Constructions of time in the late Middle Ages. Edited by Carol Poster and Richard Utz. Evanston, Ill., Northwestern University Press, 1997. 206 p. illus. (Disputatio, an international transdisciplinary journal of the late Middle Ages, v. 2)
- Partial contents: Travis, P. W. Chaucer's *Chronographiae*, the confounded reader, and fourteenth-century measurements of time.—Laird, E. S. Astrolabes and the construction of time in the late Middle Ages.—Cárdenas, A. J. A learned king enthralls himself: escapement and the clock mechanisms in Alfonso X's *Libro del saber de astrologia*.—Vilhjalmsson, T. Time and travel in Old Norse society.—Akkach, S. Ibn 'Arabi's cosmogony and the Sufi concept of space and time.
- Conti, Giovan Stefano. *Lettere a Ruggiero Giuseppe Boscovich*. A cura di Edoardo Proverbio. Roma, Accademia nazionale delle scienze detta dei XL, 1996–98. 2 v. facsim. (Scritti e documenti, 18, 22) (Documenti boscovichiani, 4–5)
- Contents: v. 1. 1760–1771.—v. 2. 1771–1784.
- Couteau, Paul. *Le ciel est mon jardin*. Paris, Flammarion, 2000. 225 p.
- Des astres et des hommes. Sous la direction de Pierre Erny. Paris, L'Harmattan, 1996. 205 p. illus. (Collection Culture et cosmologie)
- Contents: Erny, P. Liminaire.—1. Erny, P. De l'ethnoastronomie.—2. Navet, E. Quelques réflexions sur l'idée d' "ethnoastronomie" et les "ethno ... quelque chose" à partir de la cosmologie des Indiens Ojibwé (Amérique du Nord).—3. Navet, E., and N. Mohia. Le proche et la lointain: éléments d'ethnoastronomie émerillon (Guyane Française).—4. Zahan, D. La lune "sale." Un thème cosmologique en Afrique méridionale et orientale.—5. Köhler, U. Le cycle lunaire et sa signification chez les Indiens mexicains.—6. Molet, L. Durée et temps à Madagascar.—7. Verdier, P. Les calendriers indo-européens.—8. Maillard, C. Dans le procès de l'astrologie, le rationalisme est-il tout à fait rationnel?—9. Viret, J. Musique et astronomie au Moyen Age: le cryptogramme "solaire" des notes de la gamme et la "musique céleste."—10. Triomphe, R. Le communisme et la lune. Contribution à une étude de la relance cosmique de l'idéologie soviétique.
- Seven of these papers first appeared in the *Série Astronomie et sciences humaines*, published by the Observatoire astronomique de Strasbourg.
- DeVorkin, David H. Henry Norris Russell, dean of American astronomers. Princeton, Princeton University Press, 2000. xix, 499 p., [8] p. of plates.
- Dick, Steven J. *Extraterrestrial life and our world view at the turn of the millennium*. Dibner Library Lecture, Smithsonian Institution Libraries, May 2, 2000. [Washington, Smithsonian Institution, 2000] 47 p. illus. (part col.), facsim., col. port.
- Drake, Stillman. *Essays on Galileo and the history and philosophy of science*. Selected and introduced by N. M. Swerdlow and T. H. Levere. Toronto, Buffalo, University of Toronto Press, 1999. 3 v. illus., facsim., plates, ports.
- Contents: v. 1. Preface. Acknowledgments. Introduction. Prologue. Drake's speech on receiving the international Galileo Prize for History of Italian Science. pt. 1. Galileo: biographical and general. pt. 2. Galileo: bibliographical and textual studies. pt. 3. Galileo: scientific method and philosophy of science. pt. 4. Galileo: astronomy.—v. 2. pt. 5. Galileo: *Dialogue*

- Concerning the Two Chief World Systems.* pt. 6. Galileo: motion and mechanics, including the *Discourses on Two New Sciences.*—v. 3. pt. 7. Galileo: instruments. pt. 8. History of science: ancient, medieval, Renaissance, Seventeenth Century. pt. 9. Philosophy of science and language. A bibliography of the writings of Stillman Drake. Index.
- Drevniaia astronomiia: nebo i chelovek. Tezisy dokladov mezhdunarodnoi nauchno-metodicheskoi konferentsii (19–24 noiabria 1997 goda); programma konferentsii. Moskva, Komissiiia po paleoastronomii EAAS, 1997. 68 p.
- Drössler, Rudolf. 2000 Jahre Weltuntergang; Himmelserscheinungen und Weltbilder in apokalyptischer Deutung. Würzburg, Echter, 1999. 184 p. illus. (part col.), facsims. (part col.)
Contents: Das Jahr 2000 und der Weltuntergang.—Der lichte Tag wird zur Nacht.—Der Mond schwimmt in seinem Blut.—Kometen verkünden Unheil.—Planeten machen Geschichte.
- Ducrocq, Albert. L'éclipse. Monaco, Éditions du Rocher, 1999. 259 p., [8] p. of plates. illus. (part col.), facsims. (part col.), port. + 1 éclipsographe.
Contents: 1. Quand une vague d'obscurité déferle.—2. Chaldéens et chinois observent longuement.—3. Une architecture conforme de l'univers: l'astronomie.—4. Le mouvement de la Lune fait le désespoir des astronomes.—5. Pourquoi une éclipse totale de Soleil est un phénomène critique.—6. Les ressources de l'informatique et de la règle à éclipse.—7. L'Éclipse la plus courte: beaucoup de grains de Baily.—8. La fantastique couronne du Soleil.—9. Planètes et étoiles d'un ciel étrange.—10. Les éclipses d'Einstein.—11. Quand finira le temps des éclipses.—12. Si la Lune n'avait pas existé.
- Elst, Koenraad. Update on the Aryan invasion debate. New Delhi, Aditya Prakashan, 1999. 342 p.
Partial contents: 2. Astronomical data and the Aryan question. 2.1. Dating the Rg-Veda. 2.2. Ancient Hindu astronomy. 2.2.1. Astronomical tables. 2.2.2. Ancient observation, modern confirmation. 2.2.3. The start of Kali-Yuga. 2.3. The precession of the equinox. 2.3.1. The slowest hand on the clock. 2.3.2. Some difficulties. 2.3.3. Regulus at summer solstice. 2.3.4. One Veda can hide another. 2.4. Additional astronomical indications. 2.4.1. The Saptarshi cycle. 2.4.2. A remarkable eclipse. 2.4.3. Cosmic data in Vedic ritual. 2.4.4. The Zodiac. 2.4.5. India as the metropolis. 2.5. Conclusion.
- Encyclopedia of the scientific revolution: from Copernicus to Newton. Editor, Wilbur Applebaum. New York, Garland Pub., 2000. xxxv, 758 p. illus., facsims., ports. (Garland reference library of the humanities, v. 1800)
- al-Farghānī. Astronomicheskie traktaty. Perevod s arabskogo, vvodnaia stat'ia i kommentarii B. A. Rozenfel'da, I. G. Dobrovol'skogo, N. D. Sergeevoi; pri uchastii P. G. Bulgakova; pod nauchnoi redaktsiei B. A. Rosenfel'da. Otv. redaktor A. Akhmedov. Tashkent, Glav. red. Izdatel'sko-poligraficheskogo kontšerna "Shark," 1998. 232 p. illus.
- 1543 and all that; image and word, change and continuity in the proto-scientific revolution. Edited by Guy Freeland, Anthony Coronas. Dordrecht, Boston, Kluwer Academic Publishers, 2000. xv, 404 p. illus., facsims., plan, ports. (Australasian studies in history and philosophy of science, v. 13)
Partial contents: Kemp, M. Vision and visualisation in the illustration of anatomy and astronomy from Leonardo to Galileo.—Freeland, G. The lamp in the temple: Copernicus and the demise of a medieval ecclesiastical cosmology.—Coronas, A. Copernicus, printing and the politics of knowledge.—Thomason, N. 1543—the year that Copernicus didn't predict the phases of Venus.—Brundell, B. Bellarmine to Foscarini on Copernicanism: a theologian's response.
- Gaspani, Adriano. La cultura di Golasecca; cielo luna e stelle dei primi Celti d'Italia. Aosta, Keltia editrice, 1999. 239 p. illus., maps, plans. (Le Antiche querce, v. 13)
Contents: Introduzione.—1. L'astronomia dei Celti.—2. Gli eventi astronomici straordinari.—3. L'astronomia e i luoghi sacri.—4. I tumuli del X secolo a.C.—5. I recinti tombali.—6. Le necropoli.—7. Gli insediamenti.—Conclusione.
- Gassendi, Pierre. Institution astronomique. Suivi du Discours inaugural tenu dans le Collège royal de Paris. Traduit pour la première fois du latin en français, avec un avertissement et des notes par Jean Peyroux. Bordeaux, J. Peyroux; Paris, Diff. A. Blanchard, 1997. 163 p. illus.
Translation of t. 4. of Gassendi's *Œuvres complètes* (1658).
- Gee, Emma. Ovid, Aratus and Augustus: astronomy in Ovid's *Fasti*. Cambridge, New York, Cambridge University Press, 2000. 226 p. illus.
- Die Geschichte der Astronomie in Berlin. Hrsg.: Dieter B. Herrmann, Karl-Friedrich Hoffmann. Berlin, Archenhold-Sternwarte und Wilhelm-Foerster-Sternwarte Berlin [1998?] 159 p. illus., facsims., ports.
Contents: Johann Carion und der Beginn der Astronomie in Berlin.—Kalendermacher und der Beginn der akademischen Astronomie.—Johann Elert Bode.—Die Akademiesternwarte unter dem Direktorat von Encke.—Wilhelm Julius Foerster—Forschungsorganisation und Wissenschaftspopularisierung.—Arthur von Auwers und "Die Geschichte des Fixsternhimmels."—Astrophysik—ein neues Forschungsgebiet an der Akademie der Wissenschaften und der Berliner Sternwarte.—Die astronomische Forschung nach dem II. Weltkrieg unter dem Dach der Akademie der Wissenschaften.—Universitäre Astronomie im geteilten Berlin.—Hundert Jahre populärwissenschaftliche Arbeit in der Astronomie.

Gingras, Yves, Peter Keating, and Camille Limoges. *Du scribe au savant; les porteurs du savoir de l'Antiquité à la révolution industrielle*. Paris, Presses universitaires de France, 2000. 361 p. illus., facsim., maps. (Science, histoire et société)

The first three chapters, on the ancient Near East, Greece, and Rome, include brief sections relating to the history of astronomy. See particularly chapters 7 and 8, "La révolution astronomique: de l'humaniste au savant" (p. 211–244) and "De la philosophie mécaniste à l'univers mathématique" (p. 245–287).

Giorgetti, Renzo. *Gli orologi da torre nella provincia di Lucca*. Lucca, Maria Pacini Fazzi Editore, 2000. 205 p. illus.

Giovanni Schiaparelli: storico della astronomia e uomo di cultura. Atti del Seminario di studi organizzato dall'Istituto italiano per l'Africa e l'Oriente e dall'Istituto di fisica generale applicata dell'Università degli studi di Milano. Milano, 12–13 maggio 1997, Osservatorio astronomico di Brera. A cura di Antonio Panaino e Guido Pellegrini. Milano, Mimesis—IsIAO, 1999. 193 p. illus., facsim. (Collana Mimesis)

Contents: Panaino, A., and G. Pellegrini. Prefazione.—Simili, R. Giovanni Schiaparelli astronomo e uomo di scienza.—Casaburi, M. Giovanni V. Schiaparelli e l'astronomia antico-testamentaria.—De Meis, S. Il *Planetarium Babylonicum* di G. V. Schiaparelli: problematiche astronomiche.—Hunger, H. Schiaparelli's notebook of Babylonian star names.—Mandrino, A. Giovanni Virginio Schiaparelli archivist and l'archivio della Specola di Brera.—Panaino, A. Giovanni V. Schiaparelli e la storia dei più antichi calendari iranici. Con tre inediti di G. V. Schiaparelli ed una Nota di S. De Meis.—Pellegrini, G. Il *Thema Mundi* nell'Oriente e nell'Occidente. Presentazione.—Pellegrini, G. Le configurazioni planetarie e la nascita di Rāma: una comunicazione di G. V. Schiaparelli ad A. Weber.—Bezza, G. Sulla tradizione del *Thema Mundi*.—Raffaelli, E. G. Il tema del mondo e il tema del *Gayōmard* nel *Bundahišn*.

The papers by Casaburi, De Meis, and Panaino, and the first paper by Pellegrini, are accompanied by short summaries in English.

Giuseppe Toaldo e il suo tempo, nel bicentenario della morte. Scienze e lumi tra Veneto e Europa. Atti del convegno, Padova, 10–13 novembre 1997. A cura di Luisa Pigatto; presentazione di Paolo Casini. Cittadella, Bertinello Artigrafiche, 2000. xix, 1033 p. illus., facsim., maps, plans, ports. (Contributi alla storia dell'Università di Padova, 33)

Partial contents: Sessione 1. Maestri, amici, corrispondenti di Giuseppe Toaldo. Baldini, U. La formazione scientifica di Toaldo. Ferrighi, A. Toaldo, Cerato e la fabbrica della Specola astronomica di Padova: un sodalizio eemplare tra astronomo e architetto.—Sessione 3. L'astronomia e i suoi strumenti, le discipline correlate (geodesia, geografia ecc.) e gli osservatori pubblici nel Settecento. Bònoli, F. L'evoluzione degli strumenti d'osservazione astronomici nel Settecento. Tucci, P. Brera astronomers' contributions to Celestial Mechanics from 1776 to 1821. Triarico, C. La Specola di Leonardo Ximenes a Firenze e la catalogazione dei suoi strumenti. Casanovas, J. L'insegnamento dell'astronomia nei Collegi dei Gesuiti nel Settecento. Calisi, M. Le Specole romane nel Settecento. Contardi, S. Concezioni museali e collezionismo scientifico nella Toscana settecentesca: l'Imperiale e Regio Museo di fisica e storia naturale di Firenze. Pagliari, M. La longitudine: una conquista del XVIII secolo attesa a lungo.—Sessione 6. La meteorologia e le sue relazioni con le scienze della natura (agricoltura, botanica, medicina, fenomeni della natura). Casati, S. La meteorologia lunare di Toaldo.

Gotteland, Andrée, and Georges Camus. *Cadrans solaires de Paris*. Nouv. éd. rev. et corr. Paris, CNRS Éditions, 1997. 223 p. illus. (part col.), facsim., maps.

Hail, Raven. *The Cherokee sacred calendar; a handbook of the ancient Native American tradition*. Rochester, Vt., Destiny Books, 1999. 141 p. illus.

Hamou, Philippe. *La mutation du visible; essai sur la portée épistémologique des instruments d'optique au XVII^e siècle*. v. 1. *Du Sidereus Nuncius de Galilée à la Dioptrique cartésienne*. Villeneuve d'Ascq, Presses universitaires du Septentrion, 1999. 317 p., [8] p. of plates. illus., facsim. (Histoire des sciences)

Contents: Introduction. 1. ptie. La révélation galiléenne. ch. 1. Un message des étoiles. ch. 2. Vision télescopique et certitude sensible. ch. 3. L'optique de fortune. ch. 4. Le manifeste empiriste. ch. 5. L'expérience télescopique après Galilée — Gassendi, Hevelius, Huygens. — 2. ptie. La lunette dans l'ordre des raisons: Kepler et Descartes. Avant-propos: "À la honte de nos sciences." ch. 6. "Fait et cause": la discussion képlerienne du message télescopique. ch. 7. Le "panégyrique géométrique" de l'instrument: Kepler, la *Dioptrice* de 1611. ch. 8. L'invention méthodique de la lunette: Descartes, la *Dioptrique* de 1637.

A History of science in the Netherlands: survey, themes and reference. Edited by Klaas van Berkel, Albert Van Helden, Lodewijk Palm. Leiden, Boston, Brill, 1999. xxvii, 659 p. illus., facsim., ports.

The history of astronomy is not separately treated, and there is no subject index. However, the section of biographies includes sketches of Isaac Beeckman, Willem Janszoon Blaeu, Ejnar Hertzsprung, Johannes Hudde, Christiaan Huygens, Frederik Kaiser, Jacobus Cornelius Kapteyn, Marcel Gilles Jozef Minnaert, Jan Hendrik Oort, Antonie Pannekoek, Willem de Sitter, Willibrord Snel, Jan Hendrick van Swinden, and Pieter Zeeman.

Holmberg, Gustav. Reaching for the stars: studies in the history of Swedish stellar and nebular astronomy, 1860–1940. Lund, Lund University, 1999. 243 p. illus. (Ugglan, Lund studies in the history of science and ideas, 13)

Contents: From classical astronomy to astrophysics: an introduction.— New technologies, new astronomy.— Charlier and stellar statistics.— Lundmark and the Lund Observatory.— From Uppsala and Stockholm to the stars.— The many cultures of astronomy.

Homet, Jean M. Cadrans solaires en Queyras. Photographies de Franck Rozet. Aix-en-Provence, Édisud, 2000. 117 p. col. illus., col. map.

IAU Colloquium, 178th, Cagliari, 1999. Polar motion: historical and scientific problems. Edited by Steven Dick, Dennis McCarthy, and Brian Luzum. Historical sessions. San Francisco, Astronomical Society of the Pacific, 2000. (Astronomical Society of the Pacific conference series, v. 208) p. 1–219. illus., facsim., maps, ports.

Contents: Dick, S. J. Polar motion: a historical overview on the occasion of the centennial of the International Latitude Service.— pt. 1. History of early polar motion research. Abalakin, V. K. On Leonhard Euler's contribution to the theory of precession and nutation. Melchior, P. J. Theories of polar motion from Tisserand to Poincaré (1890–1910). Verdun, A., and G. Beutler. Early observational evidence of polar motion. Débarbat, S. V. Latitude observations at Paris Observatory prior to the ILS. Stavinschi, M. Romanian contribution to the study of polar motion. Šíma, Z. The observations of latitude changes measured in Prague. Brosche, P. Küstner's observations of 1884–85: the turning point in the empirical establishment of polar motion. Carter, M. S., and W. E. Carter. Seth Carlo Chandler Jr.: the discovery of variation of latitude.— pt. 2. History of the International Latitude Service, Bureau international de l'heure, International Earth Rotation Service and polar motion applications. Proverbio, E. The period of organization of the International Latitude Service: 1889–1899. Höpfner, J. On the contribution of the Geodetic Institute Potsdam to the International Latitude Service. Ehgamberdiev, S. A., S. K. Eshonkulov, and E. A. Litvinenko. Kitab as one of the five stations of the ILS: history and present. Uras, S., A. Poma, and P. Calleda. Browsing through the observing books of Carloforte. Guinot, B. History of the Bureau international de l'heure. Korsuñ, A. O. E. P. Fedorov as president of Commission 19 of the IAU during the period of the reorganization of ILS. Wilkins, G. A. Project MERIT and the formation of the International Earth Rotation Service. Mueller, I. I. The first decade of the IERS. Muller, P. M. Time and polar motion in early NASA spacecraft navigation.

Instrument—Experiment; historische Studien. Im Auftrag des Vorstandes der Deutschen Gesellschaft für Geschichte der Medizin, Naturwissenschaft und Technik hrsg. von Christoph Meinel. Berlin, Diepholz, Verlag für Geschichte der Naturwissenschaften und der Technik, 2000. 423 p. illus., facsim.

Partial contents: Staley, R. Michelson's interferometer: experiment or instrument?— Keil, I. Aus den Augsburgs optischen Werkstätten des 17. Jahrhunderts.— Oestmann, G. Uhren- und Instrumentenbau in Norddeutschland: die Dynastie der Hager in Braunschweig- Wolfenbüttel.— Voskuhl, A. Schein und Strahlung: die Anfänge der Messung von Sonnenstrahlung im 19. Jahrhundert und ihre Replikation.

International Congress on the History of Sciences, 20th, Liège, 1997. Proceedings of the XXth International Congress of History of Science (Liège, 20–26 July 1997). v. 5. The spread of the scientific revolution in the European periphery, Latin America and East Asia. Edited by Celine A. Lértora Mendoza, Efthymios Nicolaidis and Jan Vandersmissen. pt. 3. East Asia. Turnhout, Brepols, 2000. (De diversis artibus, t. 45) p. 145–192. facsim.

Includes lists of the Chinese characters representing romanized terms used in the respective papers.

Contents: Fung, K.-W. Christopher Clavius and Li Zhizao.— Hashimoto, K. The earliest evidence of the introduction of Kepler's laws into China as is observed in the *Lifa wenda*.— Lu, D. Guimao yuan calendar (1732–1911) and Isaac Newton's theory of the moon's motion.— Cervera Jiménez, J. A. Dominican contributions to science in the 16th and 17th centuries. The example of Fray Juan Cobo in East Asia.

Istoriia astronomii v Rossii i SSSR. Pod red. V. V. Soboleva. Moskva, "ĪAnus-K," 1999. 589 p., [16] p. of plates. illus., ports.

Contents: Predislovie.— 1. Sobolev, V. V. Obshchii obzor.— 2. Gul'faev, A. P., and M. S. Zverev. Astrometriia.— 3. Khol'shevnikov, K. V. Nebesnaia mekhanika.— 4. Gurshtein, A. A., and I. N. Minin. Fizika solnechno sistema.— 5. Gel'freikh, G. B., and E. V. Kononovich. Fizika solntsa.— 6. Gorbatskiĭ, V. G. Fizika zvezd.— 7. Voshchinnikov, N. V., and L. P. Osipkov. Galakticheskaia astronomiia.— 8. Hagen-Thorn, V. A., and A. D. Chernin. Vnegalakticheskaia astronomiia.— 9. Gul'faev, A. P., and A. K. Kolesov. Astronomiia v universitetakh.— 10. Hagen-Thorn, V. A., and A. K. Kolesov. Nauchnye uchrezhdeniia.

Jachím, František. Tycho Brahe: hvězdářova odyssea z Dánska do Čech. Praha, Eminent, 2000. 214 p., [32] p. of plates. illus., facsim., ports.

Jackson, Myles W. Spectrum of belief: Joseph von Fraunhofer and the craft of precision optics. Cambridge, Mass., MIT Press, 2000. 284 p. illus., facsim., ports.

Jaki, Stanley L. *The limits of a limitless science, and other essays*. Wilmington, Del., ISI Books, 2000. 246 p.

Partial contents: 2. Extraterrestrials, or better be moonstruck?—4. The Biblical basis of Western science.—5. The inspiration and counter-inspiration of astronomical phenomena.—8. The reality of the universe.—9. A telltale meteor [ALH 84001]—10. Cosmology: an empirical science?

Jordanus, *Nemorarius*. *Il planisfero di Giordano Nemorario*. [A cura di] Rocco Sinisgalli, Salvatore Vastola. Fiesole, Edizioni Cadmo, 2000. 95 p. illus. (Domus perspectivae, 6)

Latin and Italian in parallel columns.

Jungnickel, Christa, and Russell McCormmach. *Cavendish: the experimental life*. Rev. ed. Lewisburg, Pa., Bucknell, 1999. xvi, 814 p. illus., facsims., geneal. tables, maps, ports.

In the third part, "Henry Cavendish," see particularly chapter 6; "Earth," with sections entitled "Philosophical Tours in Britain," "Entire Globe," "Weighing the World," and "The Cavendish Experiment."

Although the index contains no heading for astronomy, among the relevant topics treated or touched on are the Greenwich-Paris triangulation, the 1761 and 1769 transits of Venus, the Hindu calendar, stars, double stars, comets, marine chronometers, and telescopes.

This revision includes, as part four, "Henry Cavendish's Scientific Letters" (p. 515–731).

Among his correspondents, listed on p. 527, were Nevil Maskelyne, William Herschel, Charles Blagden, and John Michell.

Karl Friedrich Zöllner and the historical dimension of astronomical photometry. A collection of papers on the history of photometry. C. Sterken, K. B. Staubermann [eds.] Brussels, VUB Press, 2000. 186 p. illus., facsims., map, ports.

Contents: Sterken, C., and K. B. Staubermann. Preface.—I. Instruments of Zoellner's era. 1. Hearnshaw, J. B. Nineteenth century visual photometers and their achievements. 2. Geyer, E. H. The reversion spectrometer of Karl Friedrich Zöllner. 3. Geyer, E. H. Friedrich Magnus Schward (1792–1871) and his double-beam photometer. 4. Bartha, L. Zöllner and Zöllner-type photometers in Hungary. 5. Staubermann, K. B., and others. The replication of an original Zöllner-photometer. 6. Staubermann, K. B. Lessons from replicating Zöllner's photometer.—II. Zoellner's photometric data. 7. Sterken, C. Astrophysical insights based on archeo-photometry. 8. Sterken, C. The data content of Zöllner's catalogue. 9. Sterken, C., and K. B. Staubermann. Visual magnitudes based on Zöllner's catalogue.—III. Zoellner's personality. 10. Dick, W. R. Friedrich Zöllner's personal papers. 11. Dick, W. R., and G. Münzel. Friedrich Zöllner's correspondence with Wilhelm Foerster. 12. Münzel, G. Friedrich Zöllner's relation to the staff of Leipzig observatory.—IV. Studies on K.-F. Zoellner. 13. Herrmann, D. B. Zöllner studies at Archenhold Observatory 1974–1994. 14. Hamel, J. Bibliography of publications by K.-F. Zöllner 1834–1882.

Kertz, Walter. *Geschichte der Geophysik*. Hrsg. von Ruth Kertz und Karl-Heinz Glassmeier. Hildesheim, G. Olms, 1999. 376 p. illus., facsims., maps, ports. (Zur Geschichte der Wissenschaften, Bd. 3)

Covers the period 1600–1939.

See particularly sections 6, "Streit um die Figur der Erde" (p. 69–81); 9, "Kurzzeitige Variationen des Magnetfeldes und Polarlichter" (p. 116–129); 10, "Das Gravitationsgesetz bewährt sich auf der Erde" (p. 130–138); 16, "Licht von der Sonne und aus den Polgebieten der Erde" (p. 225–245); and 17, "Lord Kelvin und das Alter der Erde" (p. 246–255).

Kirch, Gottfried. *Astronomie um 1700*. Kommentierte Edition des Briefes von Gottfried Kirch an Olaus Römer vom 25. Oktober 1703. Von Klaus Dieter Herbst. Thun, Verlag H. Deutsch, 1999. 143 p. facsims., ports. (Acta historica astronomiae, v. 4)

Kochhar, Rajesh K., and Jayant V. Narlikar. *Astronomy in India, past, present and future*. Pune, Inter-University Centre for Astronomy & Astrophysics; Bangalore, Indian Institute of Astrophysics, 1993. 121 p., [12] p. of plates. illus. (part col.), facsims., ports. (part col.)

Contents: Preface.—1. Historical perspective.—2. Observational facilities.—3. The university sector.—4. Research in astronomy and astrophysics.—5. Professional societies.—6. Amateur and popular astronomy.—Directory of addresses. Kraemer, Robert S. *Beyond the moon: a golden age of planetary exploration, 1971–1978*. Washington, Smithsonian Institution Press, 2000. xxix, 270 p., [8] p. of plates. illus. (part col.), group ports. (Smithsonian history of aviation and spaceflight series)

Langermann, Y. Tzvi. *The Jews and the sciences in the Middle Ages*. Aldershot, Hants, Brookfield, Vt., Ashgate Variorum, 1999. [318], 19 p. illus., facsims. (Variorum collected studies series, CS624)

Partial contents: 1. Science in the Jewish communities of the Iberian peninsula: an interim report (first publication).—2. Sa'adya and the sciences (first publication).—3. Some astrological themes in the thought of Abraham ibn Ezra (1993).—4. Maimonides and astronomy: some further reflections (first publication).—6. Gersonides on the magnet and the heat of the sun (1992).—7. The astronomy of Rabbi Moses Isserles (1991).—9. The scientific writings of Mordekhai Finzi (1988).—10. The Hebrew astronomical codex Ms. Sassoon 823 (with Karl A. F. Fischer and Paul Kunitzsch, 1989).

The Legacy of J. C. Kapteyn; studies on Kapteyn and the development of modern astronomy. [Edited] by P. C. van der Kruit and K. van Berkel. Dordrecht, Boston, Kluwer Academic Publishers, 2000. xvii, 382 p. illus., facsim., ports. (Astrophysics and space science library, v. 246)

Contents: Kruit, P. C. van der, and K. van Berkel. Preface.—1. Blaauw, A. Meeting Kapteyn in the Kapteyn Room.—2. Heijden, P. van der. The 'lost letters' of J. C. Kapteyn.—3. Krul, W. E. Kapteyn and Groningen: a portrait.—4. Sitter, W. R. de. Kapteyn and de Sitter; a rare and special teacher-student and coach-player relationship.—5. Feast, M. W. Kapteyn and South Africa.—6. DeVorkin, D. H. Internationalism, Kapteyn and the Dutch pipeline.—7. Berkel, K. van. Growing astronomers for export: Dutch astronomers in the United States before World War II.—8. Smith, R. W. Kapteyn and cosmology.—9. Gingerich, O. Kapteyn, Shapley, and their universes.—10. Kinman, T. D. Kapteyn and the selected areas: a personal perspective.—11. Sullivan, W. T. Kapteyn's influence on the style and content of twentieth century Dutch astronomy.—12. Gilmore, G. F. Surveys and star counts: the Kapteyn legacy.—13. Perryman, M. A. C. Modern astrometry.—14. Kruit, P. C. van der. The Milky Way compared to external galaxies.—15. Schmidt, M. Kapteyn's (m, log r) table and cosmology.—16. Woltjer, L. Kapteyn's unfortunate universe.—Appendix: A. J. H. Oort's public lecture of 1926: "Non-Light-Emitting Matter in the Stellar System", introduced and translated by P. C. van der Kruit.—Appendix: B. Berkel, K. van, and P. C. van der Kruit. Note on E. R. Paul's translation of H. Hertzsprung-Kapteyn's biography of J. C. Kapteyn.

Lippincott, Kristen. The story of time. With Umberto Eco, E. H. Gombrich, and others. London, Merrell Holberton in association with National Maritime Museum, 1999. 304 p. illus. (part col.), facsim. (part col.), ports. (part col.)

Contents: Acknowledgements. Forewords. Preface.—Eco, U. Times.—1. The creation of time.—2. The measurement of time. North, J. D. From observation to record: astronomy in prehistory and the early civilizations. The movement of the sun and moon. Time in India. Ackermann, S. The principles and uses of calendars; political and social implications. Aveni, A. F. Mesoamerican and Andean timekeeping and calendars. King, D. A. Time and space in Islam. Loewe, M. Cyclical and linear concepts of time in China. Hendry, J. Cycles, seasons and stages of life; time in a Japanese context. MacDonald, J. Inuit time. Dekker, E. Of spheres and shadows. Mechanical timekeeping in Europe: the early stages. Betts, J. The growth of modern timekeeping; from pendulums to atoms.—3. The depiction of time. Gaskell, I. The image of vanitas; efflorescence and evanescence. Campbell, L. Time and the portrait. House, J. Seasons and moments; time and nineteenth-century art. Pointon, M. "These fragments I have shored against my ruins." Ades, D. Art and time in the twentieth century.—4. The experience of time. Fenlon, I. Music and time. Arnold, K. Does time heal? Time in the history of medicine. Gombrich, E. H. The history of anniversaries: time, number and sign. Fernández-Armesto, F. Time and history. Rudwick, M. Geologists' time: a brief history. Morphy, H. Australian aboriginal concepts of time. Spalinger, A. Egyptian time.—5. The end of time. Rees, Sir M. J. Understanding the beginning and the end.

The essays are interspersed with catalog descriptions of 312 items displayed at the exhibition held Dec. 1, 1999–Sept. 24, 2000, at the Queen's House, National Maritime Museum.

Littlewood, Kevin, and Beverley Butler. Of ships and stars; maritime heritage and the founding of the National Maritime Museum, Greenwich. London, New Brunswick, NJ, Athlone Press and the National Maritime Museum, 1998. xxiii, 275 p., [41] p. of plates. illus., facsim., plan, ports.

McGlone, Bill, Phil Leonard, and Ted Barker. Archaeoastronomy of southeast Colorado and the Oklahoma Panhandle. Kamas, UT, Mithras, 1999. 156 p., [32] p. of plates. illus. (part col.)

Mathesis. Festschrift zum siebzigsten Geburtstag von Matthias Schramm. Rüdiger Thiele (Hrg.). Berlin, Diepholz, Verlag für Geschichte der Naturwissenschaften und der Technik, 2000. 348 p. illus., facsim., port.

Partial contents: Mathematik. Knobloch, E. Archimedes, Kepler, and Guldin: the role of proof and analogy.—Astronomie. Maeyama, Y. Zur geozentrischen Planetenbewegung; Methoden zum Studien der Astronomiegeschichte. Oestmann, G. Das Chronometer des Bremer Uhrmachers Johann Georg Thiele (1714–1784). Hamel, J. Die erste deutsche Übersetzung des Hauptwerkes von Nicolaus Copernicus um 1586.

Mazzucotelli, Mauro. Cultura scientifica e tecnica del monachesimo in Italia. Seregno, Abbazia San Benedetto, 1999. 2 v. (338 p., [8] leaves of plates) facsim. (Orizzonti monastici, 22)

Partial contents: IV. Astronomia. 1. Studi astronomici nei monasteri prima di Galileo. 2. Astronomia monastica nel XVII secolo. 3. I monaci della cerchia di Galileo. 4. Giovanni Alberto Colombo insegnante di astronomia e meteorologia.—V. Astronomia applicata. 1. Scienze nautiche. 2. Costruzione di strumenti ottici. 3. Trattatisti di gnomonica e costruttori di orologi solari. 4. Monaci e riforme del calendario. Cronologia.—X. Astrologia e alchimia. 1. Placido Titi: "l'Astrologia è vero scienza." 2. Benedetto Mazzotta astrologo e alchimista.

Relevant illustrations appear on plates 1, 2, and 4 in v. 1.

Mijangos Díaz, Eduardo N. Felipe Rivera. Astrónomo michoacano [1852–1920] In Sánchez Díaz, Gerardo, and Eduardo N. Mijangos Díaz. Las contribuciones michoacanas a la ciencia mexicana del

siglo XIX. Morelia, Michoacán, Instituto de Investigaciones Históricas, Universidad Michoacana de San Nicolás de Hidalgo, Morevallado Editores, 1996. p. 113–120. ports.

Four articles by Rivera are reprinted, with illustrations, on p. 191–208. These are:

"Uranografía" (1901); "La fotografía como auxiliar del estudio de la astronomía" (1906); "El eclipse total del 28 de mayo de 1900. Descripción del gran fenómeno" (1900); and "Reseña histórica de los principales eclipses totales de Sol en el siglo XIX" (1905).

Milbrath, Susan. *Star gods of the Maya: astronomy in art, folklore, and calendars*. Austin, University of Texas Press, 1999. 348 p., [23] p. of plates. illus., map. (The Linda Schele series in Maya and pre-Columbian studies)

Contents: Introduction. — 1. Contemporary Maya images of the heavens. — 2. Naked-eye astronomy. — 3. Precolumbian and Colonial period Maya solar images. — 4. Precolumbian and Colonial period lunar images and deities. — 5. Venus and Mercury: the body doubles. — 6. The celestial wanderers. — 7. Stars, the Milky Way, comets, and meteors. — Appendix 1. Guide to astronomical identities. — Appendix 2. Table of Classic period dates, monuments, and associated astronomical events. — Appendix 3. Table for calculating the Tzolkin intervals. — Glossary.

Millburn, John R. *Adams of Fleet Street, instrument makers to King George III*. With the kind support of the Scientific Instrument Society, London. Aldershot, Hants, Burlington, VT, Ashgate, 2000. xix, 420 p. illus., facsim., geneal. tables, map.

The instruments made by George Adams Sr. and his two sons include armillary spheres, celestial globes, quadrants, sextants, octants, orreries, and telescopes.

Montgomery, Scott L. *Science in translation: movements of knowledge through cultures and time*. Chicago, University of Chicago Press, 2000. 325 p. facsim.

Contents: Introduction. Transfers of learning, questions of influence. — pt. 1. The heavens through time and space; a history of translating astronomy in the West. 1. The era of Roman translation; from Greek science to medieval manuscript. 2. Astronomy in the East; the Syriac and Persian-Indian conversions. 3. The formation of Arabic science, eighth through tenth centuries; translation and the creation of intellectual traditions. 4. Era of translation into Latin; transformations of the medieval world. — pt. 2. Science in the non-Western world; levels of adaptation. 5. Record of recent matters; translation and the origins of modern Japanese science. 6. Japanese science in the making; of texts and translators. 7. Issues and examples for the study of scientific translation today. 8. Conclusion; gained in translation.

Mosello, Rosario. *Orologi solari nell'arco alpino: le meridiane della Val d'Ossola*. Domodossola, Edizioni Grossi, 1999. 260 p., [16] p. of plates. illus. (part col.), facsim., maps.

Summary in English: p. 229–237.

Nautical Almanac Office Sesquicentennial Symposium, *Washington, D.C., 1999*. Proceedings, Nautical Almanac Office Sesquicentennial Symposium, U.S. Naval Observatory, March 3–4, 1999. Edited by Alan D. Fiala and Steven J. Dick. [History] Washington, D.C., U.S. Naval Observatory, 1999. p. 9–177. illus., ports.

Contents: Fiala, A. D. Dedication of the history session to Leroy E. Doggett, 1941–1996. — Dick, S. J. History of the American Nautical Almanac Office. — Wilkins, G. A. The history of H.M. Nautical Almanac Office. — Waff, C. B. Navigation vs. astronomy: defining a role for an American nautical almanac. — Moyer, A. E. Simon Newcomb at the Nautical Almanac Office. — Gutzwiller, M. C. Wallace Eckert, computers, and the Nautical Almanac Office. — Carter, M. S., P. Cook, and B. J. Luzum. The contributions of women to the Nautical Almanac Office, the first 150 years.

Navarro Brotóns, Víctor, and Enrique Rodríguez Galdeano. *Matemáticas, cosmología y humanismo en la España del siglo XVI. Los Comentaríos al segundo libro de la Historia Natural de Plinio de Jerónimo Muñoz*. Valencia, Instituto de Estudios Documentales e Históricos sobre la Ciencia, Universitat de València-C.S.I.C., 1998. 664 p. (Cuadernos valencianos de historia de la medicina y de la ciencia, ser. A, 54)

The edition of the *Comentaríos* (p. 254–659) is presented in Latin with Spanish translation on facing pages.

Le Nuove stelle. Il dialogo tra scienza e letteratura nella cultura moderna. Atti del convegno di S. Giovanni in Persiceto, 22 novembre 1997. A cura di Bruno Capaci. San Giovanni in Persiceto, Comune di San Giovanni in Persiceto, 1998. 95 p. illus., port.

Supplement to *Strada maestra*, n. 43, 2. semestre 1997.

Contents: Marulli, F., and G. Nicoli. Presentazione. — Capaci, B. Prefazione. — Battistini, A. Introduzione: Le ragioni di un dialogo. — Celli, G. Van Gogh e le stelle. — Battistini, A. Galileo e il telescopio nell'immaginario barocco. — Barbieri, C. Il telescopio nazionale Galileo. — Baffetti, G. Tradizione gesuitica e nuova astronomia: la ricezione del "Sidereus Nuncius" presso il Collegio Romano. — Braccesi, A. Galileo, Torricelli, Cartesio e Pascal: antefatti e discussioni sul pieno, il vuoto, il peso dell'aria e l'esperienza barometrica. — Capaci, B. Da Conti a Rezzonico. La poesia del cielo nel Settecento. — Dragoni, G. Isaac Newton (1642–1727): uno scienziato ai confini del pensiero. — Ferrarini, M. L'astrofilo in biblioteca: le riviste divulgative della Biblioteca del Dipartimento di Astronomia date in deposito alla Biblioteca "G. C. Croce" di San Giovanni in Persiceto.

- Panaino, Antonio. *Tištrya*. Roma, Istituto italiano per il Medio ed Estremo Oriente, 1990–95. 2 v. illus. (Serie orientale Roma, 68)
 Contents: pt. 1. The Avestan hymn to Sirius. — pt. 2. The Iranian myth of the star Sirius.
- Paschos, Emmanuel A., and P. Sotiroidis. *The schemata of the stars; Byzantine astronomy from A.D. 1300*. Singapore, River Edge, N.J., World Scientific, 1998. xiv, 213 p. illus. (part col.), facsimis.
 Provides Greek text, with English translation on facing pages, of *Περὶ τῶν σχημάτων τῶν ἀστέρων*, ascribed to Gregory Chioniadēs.
- Peebles, Curtis. *Asteroids; a history*. Washington, Smithsonian Institution Press, 2000. 280 p., [8] p. of plates. illus., port.
- Perspectives arabes et médiévales sur la tradition scientifique et philosophique grecque. Actes du colloque de la SIHSPAI (Société internationale d'histoire des sciences et de la philosophie arabes et islamiques), Paris, 31 mars–3 avril 1993. Édité par Ahmad Hasnawi, Abdelali Elamrani-Jamal et Maroun Aouad. Préf. de Roshdi Rashed. Leuven, Peeters; Paris, Institut du monde arabe, 1997. xiv, 665 p. illus. (Orientalia lovaniensia analecta, 79)
 Partial contents: Morelon, R. *Le Livre des hypothèses* de Claude Ptolémée et la lecture de cet auteur en langue arabe. — Saliba, G. A redeployment of mathematics in a sixteenth-century Arabic critique of Ptolemaic astronomy. — Pingree, D. *Māshā'-allāh*: Greek, Pahlavī, Arabic and Latin astrology. — Lemay, R. Acquis de la tradition scientifique grecque confrontés aux réalités des civilisations médiévales: cas particulier de l'astrologie-cosmologie. — Federici Vescovini, G. Perspectives médiévales sur l'astronomie ancienne: l'astronomie arabe du IX^e au XII^e siècle et le témoignage de Pierre de Padoue (*le Lucidator dubitabilium astronomiæ*, 1303–1310).
- Poirier, Jean P. *Ces pierres qui tombent du ciel*. Paris, Editions Le Pommier, 1999. 159 p. (Leçons de choses)
 "Les météorites, du prodige à la science."
- Principio di secol novo; saggi su Galileo. A cura di L. A. Radicati di Brozolo. Pisa, Cassa di risparmio, 1999. xxi, 374 p. illus. (part col.), facsimis. (part col.), ports. (part col.)
 Partial contents: Garin, E. Galileo filosofo. — Radicati di Brozolo, L. A. Il libro della natura. — Maccagni, C. La cosmologia di Galileo. — Brandmüller, W. Galileo e la chiesa alla luce della storia di pensiero. — Howald-Haller, M. Le meraviglie del cielo nel cannocchiale di Galileo. — Maffei, L., and A. Fiorentini. Galileo al telescopio: che cosa il suo cervello disse al suo occhio. — Baldo-Ceolin, M. Galileo e il telescopio.
- Riccobono, Nanni. *Tunguska: un'avventura nella taiga siberiana per risolvere il mistero dei corpi celesti che minacciano la Terra*. Milano, Rizzoli, 2000. 239 p., [8] p. of plates. illus. (part col.), maps.
 On the 1999 Italian expedition led by Giuseppe Longo.
- Sacro Bosco, Joannes de. *Il Trattato de la spera*. Volgarizzato da Zuccherò Bencivenni. Edizione critica a cura di Gabriella Ronchi. Firenze, Presso l'Accademia della Crusca, 1999. 212 p. (Quaderni degli "Studi di filologia italiana," 15)
- Sakai, Masato. *Reyes, estrellas y cerros en Chimor; el proceso de cambio de la organización espacial y temporal en Chan Chan*. Lima, Perú, Editorial Horizonte, 1998. 139 p. illus. (part col.) (Arqueología e historia, 11)
- Sanchez, Jean C. *Le Pic du Midi de Bigorre et son observatoire; histoire scientifique, culturelle et humaine d'une montagne et d'un observatoire scientifique*. Pau, éditions Cairn, 1999. 334 p. illus., maps. (Lieux de mémoire pyrénéens)
 Contents: Coupinot, G. Préface. — Introduction. — 1. Légende et découverte géographique d'un pic des Pyrénées centrales. — 2. Les savants à la conquête du Pic du Midi. — 3. Le projet d'Observatoire: les hommes et les sciences du XIX^e siècle à la conquête du Pic du Midi. — 4. La fondation de l'Observatoire, 1867–1882. — 5. L'époque héroïque, 1892–1920. — 6. Un très actif établissement scientifique, 1920–1937. — 7. Espoirs et rêves dans une période troublée, 1937–1947. — 8. Les "Trente Glorieuses." — 9. Les menaces de fermeture. — En guise de conclusion, ou à la recherche d'un observatoire perdu. — Chronologie de l'Observatoire du Pic du Midi de Bigorre. — Annexes. — Sources et bibliographie.
- Sartori, Eric. *Histoire des grands scientifiques français, d'Ambroise Paré à Pierre et Marie Curie*. Préf. de Pierre-Gilles de Gennes. Paris, Plon, 1999. 425 p., [16] p. of plates. illus., ports.
 Partial contents: Pierre-Simon de Laplace (1749–1827). L'intelligence du monde. — François-Dominique Arago (1786–1853). La jeunesse de la science.
- Schiaparelli, Giovanni V. *La vita sul pianeta Marte*. Tre scritti di Schiaparelli su Marte e i "marziani." A cura di Pasquale Tucci, Agnese Mandrino e Antonella Testa. Milano, Mimesis, 1998. 116 p. illus. (part col.), facsimis. (part col.)
 Contents: Tucci, P. Premessa. — Elenco e didascalie delle tavole. — Tucci, P. Fu solo illusione? I canali di Marte tra il 1877 e il 1910. — Mandrino, A. G. V. Schiaparelli, memoria storica dell'Osservatorio di Brera: breve nota. — Testa, A. Il telescopio rifrattore Merz da 218 mm (8.05 pollici francesi): scheda. — Nota editoriale. — Schiaparelli, G. V. Il pianeta Marte (1893). — Schiaparelli, G. V. La vita sul pianeta Marte (1895). — Schiaparelli, G. V. Il pianeta Marte (1909).
- Schuetz, Melvin H. *A Chesley Bonestell space art chronology*. Parkland, Fla., Universal Publishers, 1999. xxxiii, 221 p.

- Science antique, science médiévale (autour d'Avranches 235). Actes du colloque international (Mont-Saint-Michel, 4–7 septembre 1998). Édités par Louis Callebat et Olivier Desbordes. Hildesheim, New York, Olms-Weidmann, 2000. 469, [15] p., [39] p. of plates. illus., facsim. (part col.)
 Partial contents: Holtz, L. Ms. Avranches, B.M. 235; étude codicologique. — Burnett, C. S. F. Avranches, B.M. 235 et Oxford, Corpus Christi College, 283. — Pingree, D. Avranches 235 dans la tradition manuscrite du *Preceptum Canonis Ptolomei* [in English] — Puigvert i Planagumà, G. Textes communs au manuscrit ACA Ripoll 225 et au manuscrit Avranches 235 [in Spanish] — Abry, J. Martianus Capella: la diffusion du livre 8 du *De nvptiis* dans les florilèges astronomiques. — Hübner, W. Une glose à la *Massa compoti* d'Alexandre de Villedieu contenant des vers sur le zodiaque. — Kunitzsch, P. La table des climats dans le corpus des plus anciens textes latins sur l'astrolabe. — Poulle, E. *Astrolabivm, astrolapsvs, horologivm*: enquête sur un vocabulaire.
- Sciences exactes et sciences appliquées à Alexandrie. Textes réunis et édités par Gilbert Argoud et Jean-Yves Guillaumin. Astronomie. Saint-Étienne, 1998. (Centre Jean-Palerne. Mémoires, 16) p. 289–395. illus.
 Contents: Bakhouché, B. L'héritage alexandrin (III^e a.c.–I^{er} p.c.) dans les textes latins d'astronomie. — Abry, J. H. *Les anaphorai* des signes du zodiaque dans les écrits astrologiques. — Hübner, W. Astrologie et mythologie dans la Tétrabible de Ptolémée d'Alexandrie. — Feraboli, S. *Astrotesie celesti in antichi cataloghi stellari*. — Santini, C. *Sulle tracce dei catasterismi di Eratostene a Roma*. — Delattre, J. Théon de Smyrne: modèles mécaniques en astronomie.
- Standage, Tom. *The Neptune file; a story of astronomical rivalry and the pioneers of planet hunting*. New York, Walker, 2000. 240 p. illus., facsim., ports.
- La Stazione astronomica di Carloforte; immagini e strumentazione storica. A cura di Pino Calleda e Edoardo Proverbio. Cagliari, Cooperativa Universitaria Editrice Cagliariitana, 2000. 158 p. illus. (part col.), facsim. (part col.), col. map, ports.
- Steele, John M. *Observations and predictions of eclipse times by early astronomers*. Dordrecht, Boston, Kluwer Academic Publishers, 2000. 321 p. illus., facsim., map. (Archimedes, v. 4)
- Stephenson, Bruce, Marvin Bolt, and Anna F. Friedman. *The universe unveiled: instruments and images through history*. Cambridge, New York, Cambridge University Press; Chicago, Adler Planetarium & Astronomy Museum, 2000. 152 p. illus. (part col.), facsim. (part col.), maps (part col.)
 Contents: Acknowledgments. — Introduction. — Discovering space. — Discovering time. — Understanding the Earth. — Understanding the heavens. — Glossary. — Astronomical appendix. — Further reading. — List of illustrations.
- Sweetnam, George K. *The command of light: Rowland's school of physics and the spectrum*. Philadelphia, American Philosophical Society, 2000. xxv, 233 p. illus., ports. (American Philosophical Society, Philadelphia. Memoirs, v. 238)
- Taton, René. *Études d'histoire des sciences*. Recueillies pour son 85^e anniversaire par Danielle Fauque, Myriana Ilic et Robert Halleux. Turnhout, Brepols, 2000. 544 p. illus., facsim., port. (De diversis artibus, t. 47)
 Reprints of articles that were first published in periodicals, proceedings, and other collections.
 Partial contents: *Les origines et les débuts de l'Observatoire de Paris* (1976). — Picard et la *Mesure de la Terre* (1987). — L'expédition géodésique de Laponie (avril 1736–août 1737) (1988). — Madame du Châtelet, traductrice de Newton (1969). — Sur une pièce nouvelle concernant les recherches de Clairaut sur la théorie de la Lune (1982). — Clairaut et le retour de la Comète de Halley (1980).
- Thorel, Jean C. Robert Jonckheere, 1888–1974. Un Roubaisien, astronome à Hem, l'Observatoire de Hem, puis de Lille; ou, une passion pour les étoiles doubles. Hem, 1999. 60, 29, [1] p. illus. (part col.), map, ports.
- Tomilin, Anatolii. TŠaritsa neba. Moskva, "Sovremennik," 1998. 303 p. illus., facsim., ports. (Pod sen'iu družnykh muz)
 Contents: 1. ch. Nebo nevooruzhennym glazom. — 2. ch. Teleskopy shturmuiut nebo. — 3. ch. Planety v vek radioteleskopov i raket. — 4. ch. Mir zvezd.
- Torno, Armando. *La truffa del tempo; scienziati, santi e filosofi all'eterna ricerca di un orologio universale*. Milano, Mondadori, 1999. 115 p. (Saggi)
- Voelkel, James R. *Johannes Kepler and the new astronomy*. New York, Oxford University Press, 1999. 141 p. illus., facsim., ports. (Oxford portraits in science)
- Whelan, Richard. *The sun, the moon and the stars*. Designed by Arnold Skolnick. Cobb, Calif., First Glance Books, 1998. 176 p. illus. (part col.), facsim. (part col.)
 Subtitle on book jacket: "Art, literature, science & mythology."
 The 185 illustrations, more than 150 of them in color, derive from many cultures and historical periods. The author's text is interspersed with quotations from Blake, Dickinson, Dryden, Emerson, Milton, Shakespeare, Shelley, Thoreau, Whitman, and others.
- Wilk, Stephen R. *Medusa: solving the mystery of the Gorgon*. Oxford, New York, Oxford University Press, 2000. 277 p. illus.
 See particularly chapters 6 and 7, "Mira and Algol" and "The Surrounding Sky" for the

author's explanation of his belief that "the constellations and variable stars explain much about the myths of Perseus and Medusa, as well as Andromeda, Hesione, and Bellerophon and the Chimera." Zichichi, Antonino. *L'irresistibile fascino del tempo: dalla resurrezione di Cristo all'universo subnucleare*. Milano, il Saggiatore, 2000. 299 p. illus., ports. (Nuovi saggi)

Zimmerman, Brett. *Herman Melville: stargazer*. Montreal, McGill-Queen's University Press, 1998. xiv, 142 p. facsim.

Contents: Introduction.—1. The Uranic muse: Melville's knowledge of astronomy.—2. The cosmic drama of *Mardi*.—3. Stars and spiritual navigation in *Clarel*.—4. Astronomical imagery and symbolic antitheses in *Billy Budd*.—Appendix 1. Catalogue of references to astronomical subjects in Melville's writings.—Appendix 2. More maps and drawings from Hiram Mattison's *Atlas Designed to Illustrate Burritt's Geography of the Heavens*.

Articles, Including Essays in Books and Papers in Proceedings

- Abgrall, Philippe. La géométrie de l'astrolabe au X^e siècle. *Arabic sciences and philosophy*, v. 10, Mar. 2000: 7–77. illus.
- Adelman, Saul J., and Michael M. Dworetsky. Dorothy N. Davis Locanthi. *Physics today*, v. 53, Apr. 2000: 88.
- Aghjayan, George. William Stephen Mesrobian, 1943–1988 [i.e., 1998] *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1680. port.
- Andersen, Johannes. In memoriam: Claudio Anguita. *In International Astronomical Union. Information bulletin*, 87, June 2000: 2.
- Angerer, Martin. Die Museen der Stadt Regensburg. Einem Genie gewidmet—das Kepler-Gedächtnishaus. *In Geschichte der Stadt Regensburg. Bd. 2. Hrsg. von Peter Schmid in Zusammenarbeit mit der Stadt Regensburg. Regensburg, Verlag F. Pustet, 2000. p. 961–963. illus.* See also, on p. 1182–1184 of Hermann Reidel's "Die Architektur der Dalbergzeit 1802/03–1810," a paragraph on, and an illustration of, an early 19th-century memorial honoring Kepler.
- Anton, Ted. How much fun this is! Saul Perlmutter and the Supernova Cosmology Project. *In his Bold science: seven scientists who are changing our world*. New York, W. H. Freeman, 2000. p. 103–122.
- Anton, Ted. Worlds in profusion: Geoffrey Marcy's planetary astronomy. *In his Bold science: seven scientists who are changing our world*. New York, W. H. Freeman, 2000. p. 55–77.
- Armstrong, Thomas P., Stephen J. Shawl, Michael K. Bird, and Irene M. Engle. David B. Beard, 1922–1998. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1655–1656. port.
- Ashmore, Patrick J. Archaeology and astronomy: a view from Scotland. *Archaeoastronomy*, v. 14, no. 2, 1999: 3–32. illus.
- Ashwick, Brian, and Christopher Tucker. Gareth Hubert Stanley Jones, 1924–1997. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1672. port.
- Athanassakis, Apostolos N. The *Pelêades* of Alcman's *Partheneion* and modern Greek *Pouliá*. *Ancient world*, v. 31, no. 1, 2000: 5–14.
- Aveni, Anthony F. Solving the mystery of the Nasca lines. *Archaeology*, v. 53, May/June 2000: 26–35. illus. (part col.), col. maps.
"Forget about runways for ancient astronauts. These famous geoglyphs were paths meant to be walked in rituals related to the acquisition of water."
Includes two boxes, "A Stupendous Feat of Engineering?" (p. 31) and "The Desert Zoo Parade" (p. 32–33).
- Aveni, Anthony F., and Giuliano Romano. Temple orientations in Magna Graecia and Sicily. *In Archaeoastronomy. no. 25; 2000. Cambridge, Science History Publications. p. S51–S57. illus.*
- Bahcall, John N., and Raymond Davis. The evolution of neutrino astronomy. *In Astronomical Society of the Pacific. Publications*, v. 112, Apr. 2000: 429–433. group port. (Millennium essay)
- Balthasar, Horst, and Helmut Artus. 75 Jahre Einsteinturm. *Sterne und Weltraum*, 39. Jahrg., Nr. 8, 2000: 634–639. col. illus.
- Barker, Peter. The role of religion in the Lutheran response to Copernicus. *In Rethinking the scientific revolution*. Edited by Margaret J. Osler. Cambridge, New York, Cambridge University Press, 2000. p. 60–88. facsim.
- Barnbaum, Cecilia S. Our and astronomy's loss. *Mercury*, v. 29, July/Aug. 2000: 7. port.
On the death at age 92 of Philip C. Keenan, on Apr. 20, 2000
- Bartky, Ian R. Chicago's Dearborn Observatory: a study in survival. *Journal of astronomical history and heritage*, v. 3, Dec. 2000: 93–114. illus., facsim., ports.
- Bastakoty, Khila N. Ancient Nepalese astro-science. *In Revisiting Indus-Sarasvati age and ancient India*. Editors, Bhu Dev Sharma and Nabarun Ghose. Atlanta, GA, World Association for Vedic Studies, USA, 1998. p. 311–316.
- Beebe, Herbert A. James Cuffey, 1911–1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1658–1659. port.
- Beech, Martin, and David W. Hughes. Seeing the impossible: meteors in the Moon. *Journal of astronomical history and heritage*, v. 3, June 2000: 13–22.

- Bennett, J. A. Instruments and illustrations in eighteenth-century astronomy. *In Science and the visual image in the Enlightenment*. Edited by William R. Shea. Canton, MA, Science History Publications/USA, 2000. (European studies in science history and the arts, 4) p. 137–154. facsim.
- Bònoli, Fabrizio. Coronelli astronomo e i globi celesti. *In Un Intellettuale europeo e il suo universo: Vincenzo Coronelli (1650–1718)*. A cura di Maria Gioia Tavoni. Bologna, Costa Editore, 1999. p. 139–161. illus. (part col.), facsim.
- English summary: p. 260–261.
- Additional illustrations relating to celestial globes appear on p. 69, 136, 138, and 198.
- Brown, Laurel. The astronomy of the Kerkennah Islands. *Mercury*, v. 30, Jan./Feb. 2001: 34–35. illus., map.
- "Fishermen from isolated Mediterranean islands have developed their own unique brand of astronomy."
- Brück, Hermann A. Recollections of life as a student and a young astronomer in Germany in the 1920s. *Journal of astronomical history and heritage*, v. 3, Dec. 2000: 115–129. illus., ports.
- With an introduction by Mary T. Brück, who notes that the paper "is an edited extract from reminiscences which he wrote for his family."
- Burns, Jack O., Harvey Moseley, and Ryszard Pisarski. Richard Allen White, 1946–1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1693–1694. port.
- Burns, William E. "The terriblest eclipse that hath been seen in our days": Black Monday and the debate on astrology during the Interregnum. *In Rethinking the scientific revolution*. Edited by Margaret J. Osler. Cambridge, New York, Cambridge University Press, 2000. p. 137–152.
- "This essay is an attempt to read the English reception of a particular incident—the 'Black Monday' solar eclipse of March 29, 1652—not as an episode in the Scientific Revolution (although such a reading is possible), but as the clash of a variety of positions on natural phenomena and their meaning for humanity."
- Burton, W. Butler. Gijsbert van Herk, 1907–1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1689–1690. port.
- Campbell, Donald B., Herbert Carlson, Alexander Muslimov, Mohammed Noori, and Hugh M. Van Horn. Valentin Boriakoff, 1938–1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1656–1657. port.
- Catani, Remo. The polemics on astrology 1489–1524. *Culture and cosmos*, v. 3, autumn/winter 1999: 16–30.
- Clark, George W. Bruno Benedetto Rossi. 13 April 1905–21 November 1993. *In American Philosophical Society, Philadelphia. Proceedings*, v. 144, Sept. 2000: 329–341. port.
- An abridgment of the obituary published in the *Biographical Memoirs of the National Academy of Sciences*, v. 75 (1998).
- Cuesta Domingo, Mariano. Los libros de náutica en tiempos de Carlos V. *In Jornadas Nacionales de Historia Militar, 9th, Seville, 1999*. El Emperador Carlos y su tiempo. Actas, IX Jornadas Nacionales de Historia Militar, Sevilla, 24–28 de mayo de 1999. V. Descubrimientos. Madrid, Editorial Deimos, 2000. p. 657–681. facsim.
- Cunningham, Clifford J. The first asteroid. *Mercury*, v. 30, Jan./Feb. 2001: 13. illus.
- "The dawn of the new millennium also marks the bicentennial of one of astronomy's great discoveries."
- Curry, Patrick. Astrology. *In Encyclopedia of historians and historical writing*. v. 1. A–L. Editor, Kelly Boyd. London, Chicago, Fitzroy Dearborn, 1999. p. 55–57.
- Reprinted as "Historical Approaches to Cosmology" in *Culture and Cosmos*, v. 4, spring/summer 2000, p. 3–9.
- Cutri, Roc M. Robert M. Light, 1959–1998. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1676–1677. port.
- Dambis, Andrei K., and Iurii N. Efremov. Dating Ptolemy's star catalogue through proper motions: the Hipparchan epoch. *Journal for the history of astronomy*, v. 31, May 2000: 115–134. illus.
- Dedication: Walter J. Wild (1954–1999). *In Adaptive optics systems and technology*, 21–22 July 1999, Denver, Colorado. Robert K. Tyson, Robert Q. Fugate, chairs/editors. Bellingham, Wash., SPIE, 1999. (Proceedings of SPIE, v. 3762) p. xi. port.
- Despoix, Philippe. Mesure du monde et représentation européenne au XVIII^e siècle: le programme britannique de détermination de la longitude en mer. *Revue d'histoire des sciences*, t. 53, avril/juin 2000: 205–233.
- Summary in English.
- DeVorkin, David H. Boris Garfinkel, 1904–1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1666–1667. port.
- DeVorkin, David H. Gerhard Herzberg, 1904–1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1669–1670. port.
- Dick, Steven J., and Wayne Orchiston. History of astronomy at the 2000 General Assembly of the International Astronomical Union. *Journal of astronomical history and heritage*, v. 3, Dec. 2000: 165–168.

- Dumont, Simone. Henri Mineur, 7 March 1899, Lille–7 May 1954, Paris. In IAP Meeting, 15th, 1999. XVth IAP Meeting, dynamics of galaxies: from the early universe to the present. Proceedings of the IAP Meeting held at Institut d'Astrophysique de Paris, IAP in Paris, France, 9–13 July 1999. Edited by F. Combes, G. A. Mamon, and V. Charmandaris. San Francisco, Astronomical Society of the Pacific, 2000. (Astronomical Society of the Pacific conference series, v. 197) p. xxi–xxii. port.
"Compiled by Simone DUMONT from texts by Henri MINEUR himself, as well as his IAP colleagues Daniel BARBIER and Daniel CHALONGE, as well as Jean DUFAY and Jacques LEVY."
Includes a list of books by Mineur.
- Dunn, Richard B., George W. Simon, Raymond N. Smartt, and Jack B. Zirker. John Wainwright Evans, 1909–1999. In American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1663–1665. port.
- Dworetzky, Michael M., and Ian D. Howarth. Keith Colin Smith, 1965–2000. Astronomy & geophysics, v. 41, Aug. 2000: 38. col. port.
"Fellow of the RAS, stellar spectroscopist and dedicated teacher."
- Edmondson, Frank K. Daniel Kirkwood—"dean of American astronomers." Mercury, v. 29, May/June 2000: 26–33. illus., ports.
- Espenak, Fred. Kenneth W. Willcox, 1943–1999. In American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1695–1696. port.
- Esteban Piñero, Mariano. El Emperador y la astronomía. El *Astrónomo real* del matemático sevillano Alonso de Santa Cruz. In Jornadas Nacionales de Historia Militar, 9th, Seville, 1999. El Emperador Carlos y su tiempo. Actas, IX Jornadas Nacionales de Historia Militar, Sevilla, 24–28 de mayo de 1999. V. Descubrimientos. Madrid, Editorial Deimos, 2000. p. 689–700. facsims.
- Faidit, Jean M. Nouveaux éclairages sur l'œuvre de Marcel Moye. L'Astronomie, v. 114, janv. 2000: 19–23. illus., ports. (Histoire)
- Fermor, John, and John M. Steele. The design of Babylonian waterclocks: astronomical and experimental evidence. Centaurus, v. 42, no. 3, 2000: 210–222. illus.
- Fernie, J. Donald. Eclipse vicissitudes: Thomas Edison and the chickens. American scientist, v. 88, Mar./Apr. 2000: 120–123. illus., facsims. (Marginalia)
On an occurrence at Rawlins, Wyoming Territory, during the eclipse of July 29, 1878.
- Fernie, J. Donald. In search of better skies: Harvard in Peru. I. American scientist, v. 88, Sept./Oct. 2000: 396–399. illus. (Marginalia)
- Fideler, David R. Astronomy, contemplation, and the objects of celestial desire: notes from a cosmological journal. In Alexandria. 3. Edited by David Fideler. Grand Rapids, Mich., Phanes Press, 1995. p. 380–445. illus., facsims.
"This essay is an attempt to revive the ancient dialogue between the act of observing the heavens and the act of philosophical speculation. Out of this discussion, astronomy emerges as an ideal metaphor that can literally 'carry us across' (*metapherein*) to deeper ways of seeing and reflecting."
- Flórez Miguel, Cirilo. La reforma del calendario eclesiástico. In Estudios históricos salmantinos. Homenaje al P. Benigno Hernández Montes. José Antonio Bonilla y José Barrientos, coordinadores. Salamanca, Universidad de Salamanca, 1999. p. 443–463. facsims.
On the work leading to the Gregorian reform of 1582.
- Forcada, Miquel. L'expression du cycle lunaire dans l'ethnoastronomie arabe. Arabica, t. 47, janv. 2000: 37–77.
- Freeman, Kenneth C. In memory of Olin Eggen. In The Formation of galactic bulges. Edited by C. M. Carollo, H. C. Ferguson, R. F. G. Wyse. Cambridge, New York, Cambridge University Press, 1999. (Cambridge contemporary astrophysics) p. xiv–xv.
- Freeman, Kenneth C., Albert E. Whitford, Jesse L. Greenstein, Katherine Kron, Gerald E. Kron, and Virginia Trimble. Olin Jeuck Eggen, 1919–1998. In American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1661–1662. port.
- Frercks, Jan. Creativity and technology in experimentation: Fizeau's terrestrial determination of the speed of light. Centaurus, v. 42, no. 4, 2000: 249–287. illus.
- Fugate, Robert Q. Walter James Wild, 1954–1999. In American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1694–1695. port.
- García Rosselló, Jaume, Joan Fornés Bisquerra, and Michael A. Hoskin. Orientations of the talayotic sanctuaries of Mallorca. In Archaeoastronomy. no. 25; 2000. Cambridge, Science History Publications. p. S58–S64. illus., map.
- Gaspani, Adriano. Pianvalle un tempio proto-celtico. L'Astronomia, anno 22, giugno 2000: 36–45. illus. (part col.), col. map. (Archeoastronomia)
Includes three boxes: "Cicli lunari di levata e tramonto" (p. 38–39), "Lunistizi: un'importanza rituale?" (p. 40), and "Le stelle nella Cultura di Golasecca" (p. 42–43).
- Gingerich, Owen. Plotting the pyramids. Nature, v. 408, Nov. 16, 2000: 297–298. col. illus. (News and views)
Comments on the findings of Kate Spence, detailed in a paper cited below.
Another color illustration appears on the outside front cover of the issue.
- Görgemanns, Herwig. Sonnenfinsternisse in der altgriechischen Wissenschaft. Sterne und Weltraum, 39. Jahrg., Nr. 1, 2000: 30–36. ports. (part col.)

- "Wer hat als erster die Ursache von Sonnen- und Mondfinsternissen erkannt? Dass es ein Grieche des 5. Jahrhunderts v. Chr. gewesen ist, steht fest. Aber wem unter den Denkern dieser Zeit die Priorität gehört, ist nicht sicher auszumachen. Interessanter ist es jedoch, die Voraussetzungen, die Denkweise und die Argumente zu verfolgen, die hinter dieser Entdeckung standen."
- Gómez Ruiz, Adriano, and Michael A. Hoskin. Orientations of megalithic tombs of Huelva. *In* *Archaeoastronomy*, no. 25; 2000. Cambridge, Science History Publications. p. S41–S50. illus., plans. (Studies in Iberian archaeoastronomy, 7)
- Goody, Richard M. An early view of Earth and planetary atmospheres. *Planetary and space science*, v. 48, Apr. 2000: 351–356. (Planetary pioneers)
- Grafton, Anthony. Geniture collections, origins and uses of a genre. *In* *Books and the sciences in history*. Edited by Marina Frasca-Spada and Nick Jardine. Cambridge, New York, Cambridge University Press, 2000. p. 49–68. facsim.
- Gundrum, Darrell S. Fabric of time. *Archaeology*, v. 53, Mar./Apr. 2000: 46–51. col. illus., col. map. "A 2,000-year-old Peruvian textile offers evidence of early Andean calendrical systems."
- Gursky, Herbert. Herbert Friedman, 1916–2000. *In* *American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1665–1666. port.
- Gursky, Herbert. Technology and the emergence of X-ray astronomy. *Journal of astronomical history and heritage*, v. 3, June 2000: 1–12. illus.
- Gurzadyan, V. G. Astronomy and the fall of Babylon. *Sky & telescope*, v. 100, July 2000: 40–45. illus. (part col.), col. map, ports. (part col.) "Pottery, lunar eclipses, and state-of-the-art analytical techniques solve a 3,500-year-old mystery." Includes a box, "Babylonian Chronologies" (p. 42–43), by James A. Armstrong. Gurzadyan establishes the date of the fall of Babylon at 1499 B.C. See also the letters from John P. Britton and Peter J. Huber, with Gurzadyan's response, published in the Nov. 2000 issue, p. 16 and 18, under the heading "Dating of Babylon's Fall Disputed."
- Hall, Douglas S. John Hibbett DeWitt, Jr., 1906–1999. *In* *American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1659–1660. port.
- Hallyn, Fernand. L' "Absurdum \$ " d e Copernic. *Bibliothèque d'humanisme et renaissance*, t. 62, no 1, 2000: 7–24.
- Happer, William, P. J. E. Peebles, and David T. Wilkinson. Robert Henry Dicke, May 6, 1916–March 4, 1997. *In* *National Academy of Sciences. Biographical memoirs*. v. 77. Washington, D.C., National Academy Press, 1999. p. 78–94. port.
- Harrington, Spencer P. M. Vintage Altar of Heaven. *Archaeology*, v. 53, Mar./Apr. 2000: 19. col. illus. Describes an altar dating from the Sui Dynasty that was "unearthed, then reburied, this past summer in the city of Xian by the Chinese Academy of Social Sciences." The reburial was necessary since funds were lacking to put it on public display. An Hayao, the archaeologist who published the site report, is quoted as stating, "We hope the altar will one day be open to the public."
- Harrison, Mark. From medical astrology to medical astronomy: sol-lunar and planetary theories of disease in British medicine, c. 1700–1850. *British journal for the history of science*, v. 33, Mar. 2000: 25–48.
- Hartmann, William K. Painting the contours of space. *Astronomy*, v. 28, Aug. 2000: 52–57. col. illus. On the work of Ludek Pesek.
- Harwit, Martin. Instrumentation and astrophysics: how did we get to be so lucky? *In* *Imaging the universe in three dimensions: astrophysics with advanced multi-wavelength imaging devices*. Proceedings of an international conference held under the auspices of the Lawrence Livermore National Laboratory in Walnut Creek, California, USA, 29 March–1 April 1999. Edited by W. van Breugel and J. Bland-Hawthorn. San Francisco, Astronomical Society of the Pacific, 2000. (Astronomical Society of the Pacific conference series, v. 195) p. 3–10. "To see where the future might take us, I thought I might review how we got to where we are now ..."
- Hearnshaw, John B. Astrophysics in the 1890s—the dawn of a new age in astronomy. *In* *IAU Colloquium, 176th, Budapest, 1999*. The impact of large-scale surveys on pulsating star research. IAU Colloquium 176. Proceedings of a meeting held in Budapest, Hungary, 8–12 August 1999. Edited by L. Szabados and D. W. Kurtz. San Francisco, Astronomical Society of the Pacific, 2000. (Astronomical Society of the Pacific conference series, v. 203) p. 1–6. port.
- Henbest, Nigel, and Heather Couper. James Stanley Hey, 1909–2000. *Astronomy & geophysics*, v. 41, June 2000: 38. col. port. "Fellow and Eddington Medallist of the RAS, Fellow of the Royal Society, MBE, pioneer in radar and radio astronomy."
- Heuvel, Edward P. J. van den. Jan A. van Paradijs, 1946–1999. *In* *American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1690–1691. port.
- Heuvel, Edward P. J. van den. Jan van Paradijs. *Physics today*, v. 53, Apr. 2000: 87–88. port.
- Hidayat, Bambang. Under a tropical sky: a history of astronomy in Indonesia. *Journal of astronomical history and heritage*, v. 3, June 2000: 45–58. illus.
- Hingley, Peter D. Public understanding of science, naval style. *Astronomy & geophysics*, v. 41, Aug. 2000: 6. facsim. (From the RAS archives) Reproduces and discusses a sketch from *Punch*, Sept. 5, 1874, in which a sailor with a small refractor

provides the public with a view of the moon, as well as an exact figure for its distance (24 million miles, measured to the inch).

Hockey, Thomas A. Recognizing Jupiter's Great Red Spot. *Mercury*, v. 29, Sept./Oct. 2000: 19–25. illus. Examines reports of observations made during the years 1878–83, when the spot was particularly prominent, and shows how they were used to determine more precisely the planet's rotation period—an effort which resulted in the conclusion that Jupiter's surface was not solid and, like the sun, exhibited differential rotation.

See also the reproduction, in color, of Creti's 1711 painting on the front cover of the issue.

Hoffleit, Dorrit. Astronomy in Australia—a brief historical survey. *In American Association of Variable Star Observers. Journal*, v. 28, no. 1, 2000: 47–66. illus., maps, ports.

Hoffleit, Dorrit. In memory of Helen Meriwether Lewis Thomas, August 21, 1905–August 6, 1997. *In American Association of Variable Star Observers. Journal*, v. 28, no. 1, 2000: 40–46. port.

"A shorter version of this paper first appeared in *Isis: Journal of the History of Science Society*, March, 1998."

Huber, Peter J. Babylonian short-time measurements: lunar sixes. *Centaurus*, v. 42, no. 3, 2000: 223–234. illus.

Hunger, Hermann. Planetenstellungen bei der Geburt. *In Munuscula Mesopotamica. Festschrift für Johannes Renger. Hrsg. von Barbara Böck, Eva Cancik-Kirschbaum, Thomas Richter. Münster, Ugarit-Verlag, 1999. (Alter Orient und Altes Testament, Bd. 267) p. 229–239. illus.*

Includes illustration and transcription of text on a cuneiform tablet, with transliteration, German translation, and commentary.

Impey, Chris D. Reacting to the size and the shape of the universe. *Mercury*, v. 30, Jan./Feb. 2001: 36–39. illus., ports.

"As astronomers changed humanity's perception of the universe, the great writers and poets have risen to the challenge."

To be concluded in the Mar./Apr. issue.

Introductory session. *In Optical and infrared spectroscopy of circumstellar matter. Proceedings of a workshop held in honor of the 65th birthday of Josef Solf at the Thüringer Landessternwarte Tautenburg, Tautenburg, Germany, 10–12 March 1999. Edited by Eike W. Guenther, Bringfried Stecklum, and Sylvio Klose. San Francisco, Astronomical Society of the Pacific, 1999. (Astronomical Society of the Pacific conference series, v. 188) p. 1–22. illus., ports.*

Contents: Sedlmayr, E. Laudatio: Josef Solf.—Elsässer, H. Thirty years of partnership—laudatio.—Böhm, K. H., and S. Matt. Spectroscopic insight and the physics of circumstellar matter: Josef Solf's contribution to astrophysics.

Israel, Werner. Black hole 2000: the astrophysical era. *In Astronomical Society of the Pacific. Publications*, v. 112, May 2000: 583–585. (Millennium essay)

Jaki, Stanley L. The origin of the Earth-Moon system and the rise of scientific intelligence. *In Plenary session on the origin and early evolution of life. pt. 1. Vatican City, Pontificia Academia Scientiarum, 1997. (Commentarii, v. 4, n. 3) p. 321–331.*

Jan van Paradijs (1946–1999). *Zenit*, 26. jaarg., dec. 1999: 495.

Jardine, Nicholas, and Alain P. Segonds. Kepler as reader and translator of Aristotle. *In Philosophy in the sixteenth and seventeenth centuries: conversations with Aristotle. Edited by Constance Blackwell and Sachiko Kusukawa. Aldershot, Hants, Brookfield, Vt., Ashgate, 1999. p. 206–233.*

Jardine, Nicholas. Koyré's Kepler/Kepler's Koyré. *History of science*, v. 38, Dec. 2000: 363–376.

Jardine, Nicholas. The place of astronomy in early-modern European culture. *In Science and power: the historical foundations of research policies in Europe. A conference organized by the Istituto e Museo di Storia della Scienza (Firenze, Italy). Edited by Luca Guzzetti. 1. From patronage to the management of science. Luxembourg, Office for Official Publications of the European Communities, 2000. (Euroscientia conferences) p. 13–23.*

"A different version of this article has been published in *Journal for the History of Astronomy*, vol. 29, 1998, pp. 49–62."

Jones, Alexander. A likely source of an observation report in Ptolemy's *Almagest*. *Archive for history of exact sciences*, v. 54, no. 3, 1999: 255–258.

Jones, Alexander. Studies in the astronomy of the Roman period. 4. Solar tables based on a non-Hipparchan model. *Centaurus*, v. 42, no. 2, 2000: 77–88. illus.

Kastner, Joel. Sidney O. Kastner, 1926–1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1672–1673. group port.

Keil, Inge. III. Optische Instrumente. 3. Fernrohre. *In her Augustanus Opticus: Johann Wiesel (1583–1662) und 200 Jahre optisches Handwerk in Augsburg. Berlin, Akademie Verlag, 2000. (Colloquia Augustana, Bd. 12) p. 267–307. illus.*

King, Ivan R., James W. Liebert, and Imke de Pater. Observations of Hyron Spinrad. *In The Hy- redshift universe: galaxy formation and evolution at high redshift. Proceedings of a conference held at the University of California, Berkeley, California, USA to celebrate the research interests of Hyron Spinrad on his 65th birthday, 21–24 June 1999. Edited by Andrew J. Bunker and Wil J. M. van Breugel. San Francisco, Astronomical Society of the Pacific, 1999. (Astronomical Society of the Pacific conference series, v. 193) p. 1–8.*

- "The artwork on the [book's] front cover is a pastel sketch of Hyron Spinrad by his wife, Bette Spinrad, entitled *'The Great Observer'*, circa 1965."—p. xxiii.
- Krebs, Robert E. Astrology, astronomy, and cosmology. *In his Scientific development and misconceptions through the ages, a reference guide.* Westport, Conn., Greenwood Press, 1999. p. 163–212. illus.
- Krupp, Edwin C. Managing expectations. *Sky & telescope*, v. 100, Aug. 2000: 83–85. col. illus., col. port.
Explains why it took so long to realize that the object discovered by William Herschel in 1781 was actually a planet.
- Krupp, Edwin C. Negotiating the highwire of heaven: the Milky Way and the itinerary of the soul. *In Alexandria*. 5. Edited by David Fideler. Grand Rapids, Mich., Phanes Press, 2000. p. 74–102. illus.
- Laird, Edgar S. Heaven and the *Sphaera Mundi* in the Middle Ages. *Culture and cosmos*, v. 4, spring/summer 2000: 10–35. facsimis.
- Landolt, Arlo U. Raymond T. Grenchik, 1922–2000. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1668. port.
- Launius, Roger D. Project Apollo in American memory and myth. *In International Conference and Exposition on Engineering, Construction, Operations, and Business in Space, 7th, Albuquerque, N.M., 2000. Space 2000. Proceedings of Space 2000: the seventh International Conference and Exposition on Engineering, Construction, Operations, and Business in Space.* Edited by Stewart W. Johnson, Koon Meng Chua, Rodney Galloway, Phil Richter. Reston, Va., American Society of Civil Engineers, 2000. p. 1–13.
- Lawson, Peggy M., and Peter Shull. Harrison Shepler Mendenhall, 1903–2000. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1679–1680. port.
- Levitt, Theresa. Editing out caloric: Fresnel, Arago and the meaning of light. *British journal for the history of science*, v. 33, Mar. 2000: 49–65. illus.
- Liller, William. Freeman D. Miller (1909–1999). *International comet quarterly*, v. 22, Oct. 2000: 105.
- Lim, Choong-Shin. The Egyptian pyramids and the sun. *In Russian-Korean International Symposium on Science and Technology, 3d, Novosibirsk, 1999. Proceedings, the Third Russian-Korean International Symposium on Science and Technology, KORUS '99. June 22–25, 1999, Novosibirsk State Technical University, Novosibirsk, Russia.* v. 1. Novosibirsk, KORUS'99 Organization Committee; Piscataway, NJ, IEEE, 1999. p. 101–105. illus.
- Liu, Dun. The recent archaeological discoveries and their use in teaching the history of science in China. *In Methods and materials for teaching the history of science. I. Papers of the Istanbul-Symposium of the Commission on Teaching the History of Science and Technology of the International Union of the History and Philosophy of Science, 17–21 July 1995.* pt. 1. Editors: Alistair M. Duncan, Jaroslav Folta, Feza Günergun, Horst Remane. Halle/Saale, Martin-Luther-Universität Halle-Wittenberg, 1995. (Manuskripte zur Chemiegeschichte, Heft 6) p. 42–50. illus.
Discusses examples relating to astronomy, mathematics, and the technology of papermaking.
- Lüthen, Hartwig, Ignacio Ferrín, Daniel W. E. Green, and John E. Bortle. Max Beyer (1894–1982): a master of comet observing. *International comet quarterly*, v. 22, Oct. 2000: 105–114. illus., ports.
- McConnell, Anita, and Alison Brech. Nathaniel and Edward Pigott, itinerant astronomers. *In Royal Society of London. Notes and records*, v. 53, Sept. 1999: 305–318.
- McKitterick, Rosamond. Books and sciences before print. *In Books and the sciences in history.* Edited by Marina Frasca-Spada and Nick Jardine. Cambridge, New York, Cambridge University Press, 2000. p. 13–34. illus., facsimis.
Includes discussion of surviving texts on geometry, astronomy, arithmetic, cosmology, and medicine.
- Marvin, Ursula B., John A. Wood, and Bruce A. Campbell. Patricia Grizzaffi Rogers Campbell, 1963–2000. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1657–1658. port.
- Maul, Stefan M. Gottesdienst im Sonnenheiligtum zu Sippar. *In Munuscula Mesopotamica. Festschrift für Johannes Renger.* Hrsg. von Barbara Böck, Eva Cancik-Kirschbaum, Thomas Richter. Münster, Ugarit-Verlag, 1999. (Alter Orient und Altes Testament, Bd. 267) p. 285–316. illus., plan.
Includes illustration and transcription of text on a cuneiform tablet, with transliteration, German translation, and commentary.
- Maul, Stefan M. Sonnenfinsternisse in Assyrien: eine Bedrohung der Weltordnung. *Sterne und Weltraum*, 39. Jahrg., Nr. 9, 2000: 742–750. illus. (part col.)
- Mendis, D. A. Of comets, rings and other things: a random walk in cosmic physics. *Planetary and space science*, v. 48, Feb./Mar. 2000: 251–270. (Planetary pioneers)
- Methuen, Charlotte. The teaching of Aristotle in late sixteenth-century Tübingen. *In Philosophy in the sixteenth and seventeenth centuries: conversations with Aristotle.* Edited by Constance Blackwell and Sachiko Kusukawa. Aldershot, Hants. Brookfield, Vt., Ashgate, 1999. p. 189–205.
- Michel-Nozières, C. Second millennium Babylonian water clocks: a physical study. *Centaurus*, v. 42, no. 3, 2000: 180–209. illus.
- Mitchell, Grace. Cures from the *Lapidario*. *In Alfonso X el Sabio Institute, University of Kentucky, 1990. Estudios alfonsinos y otros escritos; en homenaje a John Esten Keller y a Aníbal A. Biglieri.* Edición y prólogo de Nicolás Toscano Liria. New York, National Endowment for the Humanities;

- National Hispanic Foundation for the Humanities, 1991. p. 156–164.
 "The *Lapidario* reflects the characteristic preoccupation with astrology and enumerates both the beneficial and the damaging qualities that selected stones acquire through the influence of the signs of the zodiac, the planets, the constellations, and the position of the stars."
- Mosley, Adam. Astronomical books and courtly communication. *In* Books and the sciences in history. Edited by Marina Frasca-Spada and Nick Jardine. Cambridge, New York, Cambridge University Press, 2000. p. 114–131. illus., facsimis.
- Narlikar, Jayant V. Concept of time in science. *In* Science, spirituality and the future; a vision for the twenty-first century. Essays in honour of His Holiness the fourteenth Dala Lama, Tenzin Gyatso. Edited by L. L. Mehrotra. New Delhi, Mudrit, 1999. p. 103–112.
- Navarro Brotóns, Víctor. *La Libra astronómica y filosófica* de Sigüenza y Góngora: la polémica sobre el cometa de 1680. *Cronos, cuadernos valencianos de historia de la medicina y de la ciencia*, v. 2, jul. 1999: 100–144. illus.
 Summary in English.
- Nietupski, Nancy. Hypatia of Alexandria: mathematician, astronomer, and philosopher. *In* Alexandria. 2. Edited by David Fideler. Grand Rapids, Mich., Phanes Press, 1993. p. 45–56.
- Norris, Raymond P., Michael M. De Robertis, and Sun Kwok. Charlene Anne Heisler, 1961–1999. *In* American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1668–1669. port.
- Ogilvie, Marilyn B. Obligatory amateurs: Annie Maunder (1868–1947) and British women astronomers at the dawn of professional astronomy. *British journal for the history of science*, v. 33, Mar. 2000: 67–84.
- Orchiston, Wayne, Tom Love, and Steven J. Dick. Refining the astronomical unit: Queenstown and the 1874 transit of Venus. *Journal of astronomical history and heritage*, v. 3, June 2000: 23–44. illus., maps, plan, ports.
- Orchiston, Wayne. Role of the large refracting telescope in Australian amateur astronomy: an historical perspective. *Australian journal of astronomy*, v. 7, Nov. 1997: 89–114. illus., map, ports.
- Orchiston, Wayne. The 'tyranny of distance' and Antipodean cometary astronomy. *Australian journal of astronomy*, v. 7, Nov. 1997: 115–126. illus., ports.
- Osterbrock, Donald E. Dorothy N. Davis Locanthi, 1913–1999. *In* American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1677–1678. port.
- Osterbrock, Donald E. Kandarpa Narahari Rao, 1921–2000. *In* American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1684–1685. port.
- Osterbrock, Donald E. A view of the future as seen from the past. *In* Astronomical Society of the Pacific. Publications, v. 112, July 2000: 869–872. (Millennium essay)
- Peale, Stanton J., Marc A. Murison, Harlan Lebo, and Stuart Wolpert. William Mason Kaula, 1926–2000. *In* American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1673–1674. port.
- Peccatte, Patrick. Les origines du zodiaque et la démarcation de l'astrologie antique. *In his* La consistance rationnelle; critique de la raison démarcative. Saint-Étienne, Aubin Éditeur, 1996. (Collection Philosophie: essais) p. 173–188.
 Contents: 1. La croyance en l'influence des astres et son "explication" analogique.—2. Les origines du zodiaque et la quadripartition du cosmos.—3. Le zodiaque astrologique.—4. La démarcation inattendue de l'astrologie antique.
- Peña, José H. Obituary. Rosario Peniche García, 1944–2000. *Revista mexicana de astronomía y astrofísica*, v. 36, abr. 2000: 77–78. port.
- Peperoni, Laura, and Marina Zuccoli. Urania: un volto di donna nell'iconografia astronomica. *Giornale di astronomia*, v. 25, dic. 1999: 29–41. facsimis.
 An enlargement of one of the illustrations is reproduced on the outside front cover of the issue.
- Pereira, Michela. Heavens on earth: from the Tabula Smaragdina to the alchemical fifth essence. *Early science and medicine*, v. 5, no. 2, 2000: 131–144.
- Pesic, Peter. Kepler at the bridge. *In his* Labyrinth; a search for the hidden meaning of science. Cambridge, Mass., MIT Press, 2000. p. 87–112. facsimis.
- Pfundstein, James M. *Per astra ad aspera: Aeneid 6.725*. *In* Vergilius. v. 43; 1997. [n.p.] Vergilian Society. p. 22–30.
 Argues that "Titania astra" signifies the zodiac.
- Pöss, Ondrej. Matematicko-fyzikálne vedy na Slovensku v medzivojnovom období a ich hlavné reprezentanti. *In* Priekopníci vedy a techniky na Slovensku. 3. Zostavili: Ján Tibenský, Ondrej Pöss. Bratislava AEP, 1999. p. 181–216. illus., ports.
 Includes discussion of astronomical activities in Slovakia during the period between the first and second world wars, and biographical sketches of three astronomers: Milan Rastislav Štefánik (1880–1919), by Ondrej Pöss (p. 205–208); Bohumil Šternberk (1897–1983), by Zdeněk Horský (p. 209–212), and Antonín Bečvář (1901–1965), by Zdeněk Horský (p. 212–216).
- Pogge, Richard W., and Gordon Newsom. Arne Slettebak, 1925–1999. *In* American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1686–1687. port.
- Portolano, Marlana. John Quincy Adams's rhetorical crusade for astronomy. *Isis*, v. 91, Sept. 2000: 480–503. illus., port.

- Preston, George W. What are extremely metal poor stars good for anyway? *In* Astronomical Society of the Pacific. Publications, v. 112, Feb. 2000: 141–143. (Millennium essay)
- Professor Hermann Alexander Brück 1905–1999. *Irish astronomical journal*, v. 27, July 2000: 114. port.
A portrait of Prof. Brück and his wife appears on the outside front cover of the issue.
- Rao, P. Venugopala. Astronomy in ancient India: observations and speculations. *In* Revisiting Indus-Sarasvati age and ancient India. Editors, Bhu Dev Sharma and Nabarun Ghose. Atlanta, GA, World Association for Vedic Studies, USA, 1998. p. 305–310.
- Rao, S. Balachandra, and Padmaja Venugopal. Astronomy in Sanskrit texts. *In* Sanskrit: a source of science. (A collection of research articles presented in a seminar.) Edited by G. N. Bhat. Mangalore, Centre for Inter-Disciplinary Studies and Research in Sanskrit, Canara College; Canara High School Association, 1997. p. 10–24. illus.
- Rees, Sir Martin J. Dennis Sciama, 1926–1999. *Astronomy & geophysics*, v. 41, June 2000: 37.
"Fellow of the RAS, Fellow of the Royal Society, inspiring cosmologist and leader."
- Reflections of V. A. Ambartsumian. *In* International Astronomical Union. Symposium, 194th, *Byurakan, 1998*. Active galactic nuclei and related phenomena. Proceedings of the 194th Symposium of the International Astronomical Union held in Byurakan, Armenia, 17–22 August 1998. Edited by Yervant Terzian, Daniel Weedman and Edward Khachikian. San Francisco, Astronomical Society of the Pacific, 1999. p. 463–477. illus., group port.
Contents: Boiarchuk, A. A. Influence of V. A. Ambartsumian on the development of astronomy.— Arp, H. C. Ambartsumian's greatest insight—the origin of galaxies.
See also the biographical note, "Victor Amazasp Ambartsumian (1908–1996)," on p. xiii of the volume, with a portrait on the facing page.
- Rieke, George. Carol Jane Anger Rieke, 1908–1999. *In* American Astronomical Society. *Bulletin*, v. 32, no. 4, 2000: 1685–1686. port.
- Rihll, T. E. IV. Astronomy. *In her* Greek science. Oxford, New York, Published for the Classical Association, Oxford University Press, 1999. (Greece & Rome. New surveys in the classics, no. 29) p. 62–81. illus.
- Rochberg, Francesca. Continuity and change in omen literature. *In* *Munuscula Mesopotamica*. Festschrift für Johannes Renger. Hrsg. von Barbara Böck, Eva Cancik-Kirschbaum, Thomas Richter. Münster, Ugarit-Verlag, 1999. (Alter Orient und Altes Testament, Bd. 267) p. 415–425.
- Rochberg, Francesca. Empiricism in Babylonian omen texts and the classification of Mesopotamian divination as science. *In* American Oriental Society. *Journal*, v. 119, Oct./Dec. 1999: 559–569.
- Roger Bonnet at 60. *In* Space science and the long-term future of space in Europe. Proceedings of a colloquium to celebrate R. M. Bonnet's 60th birthday, Paris, 7/8 January 1998. Noordwijk, The Netherlands, European Space Agency, 1998. (SP-431) p. 1–23. col. illus.
Contents: Huber, M. C. E. Introduction.—Pecker, J. C. Roger Bonnet, the early years.—Manno, V. Roger M. Bonnet—the man behind Horizon 2000.
A portrait of Bonnet appears on p. 106.
- Rood, Robert T., David E. Hogg, and Anthony R. Kerr. Samuel J. Goldstein, 1925–2000. *In* American Astronomical Society. *Bulletin*, v. 32, no. 4, 2000: 1667–1668. port.
- Ros, Rosa M. Astronomical photography and Galileo's observations. *In* Methods and materials for teaching the history of science. II. Papers of the Istanbul-Symposium of the Commission on Teaching the History of Science and Technology of the International Union of the History and Philosophy of Science, Division of the History of Science, 17–21 July 1995. pt. 2. Editors: Alistair M. Duncan, Jaroslav Folta, Feza Günergün, Horst Remane. Halle-Saale, Martin-Luther-Universität Halle-Wittenberg, 1996. (Manuskripte zur Chemiegeschichte, Heft 7) p. 7–38. illus.
Describes experiments intended to introduce the history of astronomy in a mathematics class at the high school level.
- Ros, Rosa M., and Ederlinda Vinaules. Graeco-Alexandrian astronomy today. *In* Strategies for maintaining the teaching of the history of science. Selected papers of the symposium 57 of the XIXth International Congress of History of Science. Zaragoza (Spain): 22.–29. August 1993. Commission on Teaching the History of Science of the International Union of the History and Philosophy of Science, Division of the History of Science. Editors: Alistair Duncan, Jaroslav Folta, Horst Remane. Halle-Saale, Martin-Luther-Universität Halle-Wittenberg, 1994. (Manuskripte zur Chemiegeschichte, Heft 5) p. 49–58. illus.
- Rosen, David M., and Victoria P. Rosen. New myths and meanings in Jewish new moon rituals. *Ethnology*, v. 39, summer 2000: 263–277.
"In recent years new rituals linking women to the traditional festival of the new moon, *Rosh Chodesh*, have become an important part of Jewish life. A central element of these rituals is the recasting of traditional Jewish origin myths about the moon. An examination of this process reveals a tension between gendered and nongendered readings and versions of these myths. Despite this, all new versions attempt to root new myths in the authentic soil of Jewish tradition."
- Rousseau, Claudia. An astrological prognostication to Duke Cosimo I de' Medici of Florence. *Culture and cosmos*, v. 3, autumn/winter 1999: 31–59. illus., facsimils.
Includes transcription and English translation of the prognostication.

- Rubin, Vera C. One hundred years of rotating galaxies. *In* Astronomical Society of the Pacific. Publications, v. 112, June 2000: 747–750. (Millennium essay)
- Rubincam, David P., and Paul D. Lowman. John Aloysius O'Keefe, 1917–2000. *In* American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1683–1684. port.
- Ruggles, Clive L. N. Ancient astronomies—ancient worlds. *In* Archaeoastronomy. no. 25; 2000. Cambridge, Science History Publications. p. S65–S76.
Adapted from the inaugural lecture delivered at Leicester University, Jan. 25, 2000.
- Ruggles, Clive L. N. Astronomy, oral literature, and landscape in ancient Hawai'i. *Archaeoastronomy*, v. 14, no. 2, 1999: 33–86. illus., maps.
- Ruggles, Clive L. N., and Gordon Barclay. Cosmology, calendars and society in Neolithic Orkney: a rejoinder to Euan MacKie. *Antiquity*, v. 74, Mar. 2000: 62–74. map.
- Rupen, Michael P., and David E. Hogg. Robert Michael Hjellming, 198–2000. *In* American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1670–1671. port.
- Salmon, Wesley C. Quasars, causality, and geometry. A controversy that should have happened but didn't. *In* Scientific controversies: philosophical and historical perspectives. Edited by Peter Machamer, Marcello Pera, Aristides Baltas. New York, Oxford University Press, 2000. p. 254–270. illus.
- Sandage, Allan R. Episodes in the discovery of variations in the chemical composition of stars and galaxies. *In* Astronomical Society of the Pacific. Publications, v. 112, Mar. 2000: 293–296. (Millennium essay)
- Sarma, K. V. Astronomical activity in Kerala during mediaeval times. *In* Facets of Indian culture. Ed. by P. C. Muraleemadhavan. Delhi, New Bharatiya Book Corp., 2000. p. 316–320.
- Sauzade, Gérard. Orientations of the Provençal dolmens. *In* Archaeoastronomy. no. 25; 2000. Cambridge, Science History Publications. p. S1–S10. illus., map, plans.
- Schaefer, Bradley E. The heliacal rise of Sirius and ancient Egyptian astrology. *Journal for the history of astronomy*, v. 31, May 2000: 149–155.
- Schaefer, Bradley E. The most mysterious astronomical manuscript. *Sky & telescope*, v. 100, Nov. 2000: 40–43. col. illus.
"The Voynich Manuscript has defied codebreakers for centuries. Can you help crack its cipher?"
- Sheehan, William, and Donald E. Osterbrock. Hale's "little elf": the mental breakdowns of George Ellery Hale. *Journal for the history of astronomy*, v. 31, May 2000: 93–114. ports.
- Sheehan, William. The moon illusion. *Mercury*, v. 30, Jan./Feb. 2001: 12. illus.
"Why does the Moon appear larger when it's near the horizon?"
- Shi, Yunli. Eclipse observations made by Jesuit astronomers in China: a reconsideration. *Journal for the history of astronomy*, v. 31, May 2000: 135–147.
- Shostak, G. Seth. Jean Heidmann. *Physics today*, v. 53, Dec. 2000: 85. port.
- Shrimplin, Valerie. Michelangelo and Copernicus: a note on the Sistine *Last Judgment*. *Journal for the history of astronomy*, v. 31, May 2000: 156–160. illus.
- Spaeth, Ove von. Dating the oldest Egyptian star map. *Centaurus*, v. 42, no. 3, 2000: 159–179. illus.
- Spence, Kate. Ancient Egyptian chronology and the astronomical orientation of pyramids. *Nature*, v. 408, Nov. 16, 2000: 320–324. illus.
Uses "trends in the orientation of Old Kingdom pyramids to demonstrate that the Egyptians aligned them to north by using the simultaneous transit of two circumpolar stars. Modelling the precession of these stars yields a date for the start of construction of the Great Pyramid that is accurate to $\dot{A}5$ yr, thereby providing an anchor for the Old Kingdom chronologies."
- Spissinger, Jessica. In memory of Joseph Weber (1919–2000). *Mercury*, v. 30, Jan./Feb. 2001: 6.
- Sprajc, Ivan. Astronomical alignments at the Templo Mayor of Tenochtitlan, Mexico. *In* Archaeoastronomy. no. 25; 2000. Cambridge, Science History Publications. p. S11–S40. illus., plan.
- Steele, John M. A re-analysis of the eclipse observations in Ptolemy's *Almagest*. *Centaurus*, v. 42, no. 2, 2000: 89–108.
- Stierlin, Henri. The Caracol or observatory of Chichén Itzá. *In his* The Maya: palaces and pyramids of the rainforest. Photographs: Anne and Henri Stierlin. Köln, New York, Taschen, 1997. (Taschen's world architecture) p. 175–180. col. illus., col. plans.
Includes a box, "Divinatory Astronomy" (p. 180).
- Strauss, Michael A., Stéphane Courteau, Vahé Petrosian, and Roger W. Romani. Jeffrey Alan Willick, 1960–2000. *In* American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1696–1697. port.
- Sundareswaran, N. K. A trinity of Kerala astronomers. *In* Facets of Indian culture. Ed. by P. C. Muraleemadhavan. Delhi, New Bharatiya Book Corp., 2000. p. 356–359.
- Tempesti, Piero. Spigolando fra i calendari: il cielo periodico dell'anno liturgico. *Giornale di astronomia*, v. 25, dic. 1999: 42–44. col. facsims.
- Teske, Richard G. Freeman Devold Miller, 1909–2000. *In* American Astronomical Society. Bulletin, v. 32, no. 4, 2000: 1680–1682. port.
- Thompson, Richard. Anomalous textual artifacts in archeo-astronomy. *In* Revisiting Indus-Sarasvati age and ancient India. Editors, Bhu Dev Sharma and Nabarun Ghose. Atlanta, GA, World Association

- for Vedic Studies, USA, 1998. p. 317–334. illus.
- Thornton, Christopher J. Kepler on Mars. *In his Truth from trash: how learning makes sense.* Cambridge, Mass., MIT Press, 2000. p. 31–42. illus., facsim., ports.
- Tonietti, Tito M. Newton credeva nella musica delle sfere? *In La Scienza e i vortici del dubbio.* A cura di Lino Conti e Marco Mamone Capria. Napoli, Edizioni scientifici italiane, 1999. (Università degli studi di Perugia. Ricerche filosofiche. Sezione epistemologia e storia della scienza, 7) p. 127–135.
"We read the 'Classical *Scholium*' to the *Propositio* VIII of the Third Book of the *Principia*, in which Newton stated the law of the inverse square in the distance for gravitational attraction between the bodies. In that *scholium*, already published by P. Casini, he constructed a musical model for the attraction considering sounding strings. We point out a mistake in the argument and discuss why Newton tried to justify his law in such a way."
- Tonietti, Tito M. Verso la matematica nelle scienze: armonia e matematica nei modelli del cosmo tra Seicento e Settecento. *In La Costruzione dell'immagine scientifica del mondo: mutamenti nella concezione dell'uomo e del cosmo dalla scoperta dell'America alla meccanica quantistica.* A cura di Marco Mamone Capria. Napoli, La Città del sole, 1999. (Istituto italiano per gli studi filosofici. Il pensiero e la storia, 56) p. 155–219. illus.
Contents: 1. *Exercitium arithmeticae occultum.*—2. Galileo o del cielo.—3. Keplero o dell'armonia.—4. Cartesio o della luce.—5. Newton o dell'infinito.—6. Leibniz o del infinitesimo.—7. Musica e morte.
- Topper, David. "I know that what I am saying is rather obscure ...": on clarifying a passage in Galileo's *Dialogue*. *Centaurus*, v. 42, no. 4, 2000: 288–296. illus.
On Galileo's argument that the motion of sunspots is evidence in support of heliocentricity.
- Trefil, James S. Putting stars in their place. *Astronomy*, v. 28, Nov. 2000: 62–67. illus. (part col.), ports.
"The creation of the Hertzsprung-Russell diagram was a landmark advance in our understanding of the stars."
Includes discussion of the role of the Harvard women in classifying stellar spectra.
- Trefil, James S. Rounding the earth. *Astronomy*, v. 28, Aug. 2000: 40–44. col. illus., facsim.
"Universal belief in a flat earth in Columbus's day is a myth."
- Tribute to Nüzhet Gökdoğan. *In International Astronomical Union. Symposium, 177th, Antalya, Turkey, 1996.* The carbon star phenomenon. *Proceedings of the 177th Symposium of the International Astronomical Union, held in Antalya, Turkey, May 27–31, 1996.* Edited by Robert F. Wing. Dordrecht, Boston, Kluwer Academic Publishers, 2000. p. xxvi–xxvii. group port.
- Trimble, Virginia. The first explosions. *In October Astrophysics Conference, 10th, College Park, Md., 1999.* Cosmic explosions. Editors: Stephen S. Holt, William W. Zhang. Melville, N.Y., American Institute of Physics, 2000. (AIP conference proceedings, 522) p. 3–21.
"Events that can be (at least broadly) described as explosions have joined the astrophysical inventory in many different ways. Some were predicted and then discovered. Some were predicted, often as a tentative explanation for some specific sort of event, and have not yet been seen. Others were seen and understood quite promptly, or very slowly. And a good many had been in the inventory for years to millenia before their explosive nature was recognized."
Events are discussed in descending order of the total amount of energy released, beginning with the Big Bang.
- Trimble, Virginia. Joseph Weber, 1919–2000. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1691–1693. port.
- Troche-Boggino, Alexis E. Buenaventura Suárez SJ: the pioneer astronomer of Paraguay. *Journal of astronomical history and heritage*, v. 3, Dec. 2000: 159–164. illus., facsim., map.
- Ueberschlag, Josette. Janssen et la démon de la précision. *L'Astronomie*, v. 114, févr. 2000: 58–61. illus., port. (Histoire)
- Ulansey, David. Mithras, the hypercosmic sun, and the rockbirth. *In Alexandria*. 5. Edited by David Fideler. Grand Rapids, Mich., Phanes Press, 2000. p. 160–173.
- Venugopal, Padmaja, and S. Balachandra Rao. Eclipses in the *siddhantas*. *In Sanskrit: a source of science.* (A collection of research articles presented in a seminar.) Edited by G. N. Bhat. Mangalore, Centre for Inter-Disciplinary Studies and Research in Sanskrit, Canara College; Canara High School Association, 1997. p. 25–39. illus.
- Verbunt, Frank. Van 5 Cephei tot GRO980425: de sterrenkunde van Jan van Paradijs. *Zenit*, jaarg. 27, feb. 2000: 111–115. illus., col. group port.
- Voigt, Hans H. Astronomie. Goethes Besuch auf der alten Sternwarte. *In "Der gute Kopf leuchtet überall hervor": Goethe, Göttingen und die Wissenschaft.* Hrsg. von Elmar Mittler, Elke Purpus und Georg Schwedt. Göttingen, Wallstein, 1999. p. 165–168. illus., col. port.
The portrait (of Gauss) appears on p.129.
The book seems to have been issued in connection with an exhibition, but the date and location thereof were not stated.
- Wainwright, Geoffrey J. The Stonehenge we deserve. *Antiquity*, v. 74, June 2000: 334–342. map.
"After years of discussion and argument, the fate of Stonehenge and its landscape have been decided. As Professor Geoffrey Wainwright (former head of Archaeology at English Heritage) describes, there

- is at last political will to ensure a better future for the monument."
- Wallace, William A. Dialectics, experiments, and mathematics in Galileo. *In Scientific controversies: philosophical and historical perspectives*. Edited by Peter Machamer, Marcello Pera, Aristides Baltas. New York, Oxford University Press, 2000. p. 100-124. illus.
- Walt, Martin. Billy Murray McCormac, 1920-1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1678-1679. port.
- Waterfield, Robin. The evidence for astrology in classical Greece. *Culture and cosmos*, v. 3, autumn/winter 1999: 3-15.
- Waters, D. W. Derek Howse (1919-98). *British journal for the history of science*, v. 33, June 2000: 223-225. port.
- Welther, Barbara L. Douglas Duke, 1923-1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1660. port.
- Welther, Barbara L. Hendrik Christoffel van de Hulst, 1918-2000. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1688-1689. port.
- Westerhout, Gart. Frank John Kerr, 1918-2000. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1674-1676. port.
- Whitesell, Patricia S. Nineteenth-century longitude determinations in the Great Lakes region: government-university collaborations. *Journal of astronomical history and heritage*, v. 3, Dec. 2000: 131-157. illus., facsim., maps, ports.
- Whitlock, Greg. Teaching archaeoastronomy. *In Alexandria*. 5. Edited by David Fidler. Grand Rapids, Mich., Phanes Press, 2000. p. 393-397.
- Whyte, Nicholas. The Irish astronomical tradition: rise and decline. *In his Science, colonialism and Ireland*. Cork, Cork University Press, 1999. p. 26-41.
"Much of this section has been published in *Irish Review* 17/18 (Winter 1995), 127-41, as "Lords of Ether and of Light": the Irish Astronomical Tradition of the Nineteenth Century."
- Williams, Thomas R. Henry W. Spreitzer, 1914-1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1687-1688. port.
- Williams, Thomas R. Oscar E. Mönig, 1902-1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1682-1683. port.
- Wilson, Robert E., and Haywood C. Smith. Heinrich Karl Eichhorn, 1927-1999. *In American Astronomical Society. Bulletin*, v. 32, no. 4, 2000: 1662-1663. port.
- Witt, Volker. Der Grosse Refraktor des Astrophysikalischen Observatoriums Potsdam. *Sterne und Weltraum*, 39. Jahrg., Nr. 9, 2000: 796-798. illus. (part col.)
- Witt, Volker. Das Observatorio Fabra in Barcelona. *Sterne und Weltraum*, 39. Jahrg., Nr. 7, 2000: 586-589. col. illus. (SuW Besuch)
- Wolfschmidt, Gudrun. Deutsch-ungarische Beziehungen in der Astronomie und Astrophysik. *In Deutsch-ungarische Beziehungen in Naturwissenschaft und Technik nach dem Zweiten Weltkrieg*. Hrsg. von Holger Fischer. München, R. Oldenbourg, 1999. (Südosteuropäische Arbeiten, 103) p. 337-373. illus.
Contents: 1. Einleitung.—2. Orientierung an der deutschen Astrophysik.—3. Die ungarische Nationalsternwarte in Budapest.—4. Periode der Isolierung 1945-1956/59.—5. Entwicklung ab den 60er Jahren.—6. Zusammenfassung.
- Wright, David. The astronomy in Pepys' diary. *Astronomy & geophysics*, v. 41, Aug. 2000: 23-27. facsim., col. port.



Ruth Freitag
Library of Congress
February 2001

Reviews

Worlds Without End: The Historic Search for Extraterrestrial Life, by R. A. S. Hennessey (Tempus Publishing, Stroud, Gloucestershire, UK, 1999), 160 pp., ISBN 0-7524-1450-X, £18.99, US\$29.99, hardback.

Does life exist elsewhere in the universe? This is a question frequently posed over the years in the mass media, because of the huge public interest. Despite this, serious discussion of the search for extraterrestrial intelligence, through such techniques as radio spectrum interrogation, was frowned upon by many 'serious' scientists until quite recently. NASA was banned from spending any US government funds on such work. Disparaging remarks were made about exobiology being "the only discipline with nothing to study", or similar.

Suddenly, though, the search for extraterrestrial life is in vogue. In 1996 pronouncements were made concerning the possible identification of microfossils in a meteorite known to have come from Mars. NASA has promoted the Europa Orbiter in its outer solar system mission sequence, largely because it is believed that Europa (one of the large moons of Jupiter) may have an ocean under an icy crust, and that could mean life. Around the world thousands of enthusiasts leave their home computers running to crunch data from radio searches for signs of intelligent life. Substantial slabs of observing time at major optical observatories are allocated to projects in which searches are made for planets orbiting nearby stars. On our own planet microbial life has been found thriving in environments where respected scientists had previously opined that it was 'impossible', and now there is even a journal dedicated to research on extremophiles. NASA has established a dispersed Astrobiology Institute, and frequent international conferences are held to discuss progress.

The cynic, of course, might comment that there has been none, because no definitive evidence for extraterrestrial life has been revealed. That's not the point, though. Even by considering such questions, we move ahead. And this book by Roger Hennessey describes just how long the question of the possible plurality of worlds has been a subject of philosophical debate. Very recent history, then, is misleading: this is not a newly invented discipline that has arisen only in the past few decades.

Some parts of the tale that Hennessey tells will be well known, starting from Plato's musings in the fourth century BC, through Giordano Bruno's many worlds in the sixteenth century, Thomas Wright of Durham in the eighteenth, and on to the present with such questions as the Fermi Paradox and suggested reasons why we have not (yet) found proof of life elsewhere. Along the way we are told of the absurdities that have been spawned, such as William Herschel's inhabitable Sun and the 'Martian canals' debacle.

All these will be familiar to most readers, but in addition Hennessey has rooted out a host of other ideas that have been mooted over the centuries. For most he provides good copies of original illustrations (all in black and white), coming close to bringing their ages to life. It is easier to sympathize with the authors of these schemes – many of them, in retrospect, seeming bizarre – if we can see the actual scenarios they were imagining.

For a brief introduction to the long-term historical development of the multifarious notions of extraterrestrial life, this book is highly recommended. You would want your library to have a copy. For specialists in the area, it is unlikely that you will learn much new, but it would still be a handy book to possess for the illustrations alone.

Duncan Steel

Treasure-Hunting in Astronomical Plate Archives, Proceedings of the International Workshop held at Sonneberg Observatory during 4-6 March 1999, edited by P Kroll, C la Dous, and H J Bräuer Acta Historica Astronomiae, 6 (Verlag Harri Deutsch: Thun and Frankfurt am Main, 1999), 266 pp., ISBN 3-8171-1599-7, soft cover, DM 38.00 (about £20), 147 × 208 mm.

Photography was adopted gradually by astronomers during the nineteenth century. Briefly, it became common during the 1880s, though the take-up was drawn-out and varied between institutions. The photographic era ended about a hundred years later, around 1980, after which photography largely gave way to electronic detectors such as Charge-Couple Devices (CCDs), though again the change-over was piecemeal and protracted. Indeed, some major photographic surveys are still in progress. In the intervening century the photographic plate was the pre-eminent imaging detector used in astronomy, and considerable archives of photographic plates survive from this era. Plates were used to record both direct images of the sky and spectra of various sorts. Most observatories which operated during the period had a 'plate store' where the exposed plates were carefully catalogued and stored for future use.

Treasure-Hunting in Astronomical Plate Archives is the proceedings of a workshop held at the Sonneberg Observatory during March 1999. The workshop was about preserving archives of

astronomical plates and exploiting the wealth of information that they contain. It was not principally about the history of astronomical photography per se, though the preservation and use of the plates cannot be divorced from the circumstances in which they were taken. In the context of the present journal the volume falls more into the area of astronomical heritage rather than astronomical history. Indeed, in terms of observational material the photographic archives are probably the major heritage bequeathed by twentieth century astronomy. The workshop was attended by forty-odd people, mostly from institutions in Europe, but with a handful coming from each of the US, the UK and the rest of the world. The proceedings are dedicated to Barry Lasker, who died tragically shortly before the meeting was held. It is a tribute which is both well-deserved and which, I suspect, he would have appreciated.

The workshop largely concentrated on direct photographs rather than spectra. Though some of the plates were taken for individual research projects the majority were part of systematic programmes. Such systematic programmes usually fall into two categories: sky surveys and sky patrols. In a sky survey typically the entire sky, or at least a substantial fraction of it, is photographed once in order to map the position and brightness of the objects visible. A number of major survey programmes are extremely well-known. The first was the ambitious (indeed, perhaps over-ambitious for its time) Carte du Ciel which started in the late nineteenth century. Since the 1950s optical sky surveys have been dominated by the large Palomar, UK, and ESO Schmidt telescopes, and the atlases made from the surveys conducted by these telescopes are well-known and indispensable tools of astronomy. The sky patrols are perhaps less well-known. Here selected areas of sky are repeatedly photographed over an extended period of time, principally to detect and monitor variable stars. Extensive sky patrols have been carried out at Harvard and latterly Sonneberg and Tautenberg. The number of plates in archives around the world is estimated to be in excess of two million (corresponding to a total area of glass of more than 10^9 cm²). Many of the older plates have a relatively bright limiting magnitude of perhaps 12 – 15 visual magnitude, though modern Schmidt plates go much deeper.

The uses of archival plates, like archival data generally in astronomy, derive from the circumstance that the 'fixed stars' are neither fixed nor of constant brightness. Comparison of the positions of stars on old plates with modern observations gives a long baseline for the determination of proper motions. Comparison of the brightness of an object at different epochs allows any variations in its brightness to be monitored. Incorporating measurements from archival plates currently allows substantial improvements to the accuracy of proper motion determinations, though future astrometric satellites, such as GAIA, will make measurements which are sufficiently accurate that incorporating the archival data will add little additional precision. The situation is rather different for variability studies: many objects show secular or long-term changes and the historical data are irreproducible and hence irreplaceable.

There are, however, a number of problems with using archival plates. Plates are held in numerous archives scattered around the world. Sometimes the archives are difficult to access and their contents are not always properly catalogued. Once a plate has been retrieved from an archive many observatories now only have limited measuring facilities. Further, the expertise in handling photographic data is dwindling as the staff who were familiar with them retire. Finally, photography is an analogue medium. It is practical to measure only a small fraction of the information on a plate using manual methods. If all the information is to be extracted then the plates must be scanned digitally and the resulting digital images analysed using computers. Also, it is difficult to compare photographic data with more modern digital images unless the former are converted to a digital form. Though there have been a number of major digitization programs, mostly of the Schmidt surveys and using specially-designed and highly-accurate scanners, most plates have not been digitized.

Treasure-Hunting in Astronomical Plate Archives considers the problems and possibilities of using plate archives. It is divided into six sections: Scientific Introduction, Technical Concepts and Solutions, Astrophysics, Astrometry, Data Reduction, and Databases. Each section starts with a useful introduction (all except the first by Kroll) followed by a number of papers of varying length. The 'Scientific Introduction' includes a survey by Hudec of the various large plate archives, which is a useful introduction to the data that are available. The papers in the 'Technical Concepts and Solutions' section are mostly split between descriptions of individual digitizing scanners or descriptions of individual plate archives, in both cases largely from European institutions. There is also a paper by Tsvetkov and his colleagues about their 'Wide Field Plate Database'. This database is a major undertaking to produce a comprehensive compilation of wide-field photographic plates. It can be searched remotely via the Internet and is an extremely useful tool for finding plates that might be suitable for a given project. A typical query might be to find a list of plates which have observed a particular region of sky.

Most of the papers in the 'Astrophysics' section describe investigations of variable objects; not just variable stars, but also supernovae, active galaxies, quasars and searches for the optical counterparts of Gamma-Ray Bursts. The 'Astrometry' section largely reports proper motion studies, though there is a paper by Boattini describing searches for Near-Earth Objects (NEOs), which is another important application for archival plates: 'pre-discovery' images identified and measured on

archival plates will usually lead to substantial improvements in the orbital elements of newly-discovered NEOs and other asteroids. The 'Data Reduction' section has papers on various aspects of the reduction procedure for photographic data. The final section on 'Databases' describes the use of database software not just for the traditional application of manipulating the final catalogues of objects detected on the plates, but also for managing the data reduction pipeline. Some ambitious and sophisticated projects are described.

The volume has the usual problem of conference proceedings that it is a collection of disparate papers which will be of varying interest, though here this is mitigated by the very reasonable price. It is likely to be useful to anyone working with photographic archives in astronomy, and, indeed, perhaps to anyone with a more general interest in astronomical archives. All the papers are in English, though it is obviously not the first language of most of the authors, and the text is enlivened by the occasional idiosyncrasy. Finally, these proceedings are not the only report of the workshop; Argyle (1999) published a summary shortly after the meeting was held. The efforts to digitize photographic archives have continued apace since the meeting and the recent report by Griffin (2001) summarizing these developments, and giving a number of useful references, might also be of interest.

Clive Davenhall

References

- Argyle, R., 1999. Treasure Hunting in Astronomical Plate Archives. *The Observatory*, **119** (no. 1152):269-271.
Griffin, R.E.M., 2001. The Problematic Past. *Astronomy & Geophysics*, **42**(2):25-26

East Asian Archaeoastronomy: Historical Records of Astronomical Observations of China, Japan, and Korea, by Zhentao Xu, David W. Pankenier and Yaotiao Jiang (Gordon and Breach Science Publishers, 2000), ix + 430 pp., ISBN 90-5699-302-X, cloth, £76, 255 × 178 mm.

The materials presented in this book do not reflect the broad field as implied by the book title. The oracle bones is the sole topic that is described more substantially. What astronomical events that are found in the oracle-bone inscriptions, namely solar and lunar eclipses, comets, guest stars, sunspots, auroras borealis, and planets, were chosen as the main topics. Each subject matter is described in a chapter and supplemented with the observed astronomical events in the historical written records of the Far East. This arrangement confines the book to the eight major topics, which only cover a part of the East Asian archaeoastronomy and the astronomical works in the recorded histories of China, Japan, and Korea.

The listings of the observations of solar eclipses, lunar eclipses, sunspots, planets, comets, meteors, and aurora are excellent. These are printed on 217 pages, while the original texts in Chinese characters are given in 133 pages of Appendix I. Yet most of the recorded events had been compiled and published in *Zhongguo gudai tianxiang jilu zongji* (1988) and *Nisshoku gesshoku hoten* (Canon of Solar and Lunar Eclipses) (1979) as mentioned in the book. The materials of the solar and lunar eclipses have been used for the studies of Earth's rotation (also mentioned in the book), and the regression of nodes of the Moon. The book, in Chinese, by Xu Zhentao and Jiang Yaotiao on the study of sunspots is given in the References on p.12, *The Ancient Study of Sunspot in China and Its Modern Application* (1990), and then on p. 152 it is given as *Zhongguo gudai taiyan heizi yanjiu yu xiandai yingyong* (1990).

The lack of a comprehensive bibliography is disturbing. In the References only one work on Japan is given: *Examination of Celestial Records in Japanese Literature* (1986); and one book on Korea: *The History of Korea* (1970). In this reviewed book, it says, "Korean history is subdivided into four distinct periods: the Three Kingdoms, Koryo, and the Yi Dynasty." without mentioning the fourth period. In the text, however, a number of Japanese and Korean works are referred to: *Dai Nihon shi*, *Nihon temmon shiryō*, *Samguk sagi*, *Koyo sa*, *Yijo sillok*, and *Chungbo munhon pigo*.

A glossary of the original Chinese characters for their romanizations in the text is conspicuously missing. This is a handicap for the interested readers who are not familiar with the Chinese language. The usefulness of the "Finding List of Stars and Asterisms" in Appendix II is doubtful, since the only mention of star maps is *The Chinese Sky During the Han: Constellating Stars and Society* (1997). One might find, however, the translated meanings of the Chinese names are of interest.

The authors have brought the comprehensive astronomical events observed in the East Asia, since the early days of recorded histories, in one English-version volume. This is most convenient for those workers in the field of history of sciences, who have no easy accession to other resources on the subject matters, to use. It would also be interesting to persons who like to know some aspects of the historical astronomy in the Far East.

Kwan-Yu Chen



Journal of Astronomical History and Heritage

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- 1 *Nidhal Guessoun and Karim Meziane*: Visibility of the thin lunar crescent: the sociology of an astronomical problem (A case study)
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