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

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In 2012 *JAHH* will become an electronic journal that can be downloaded free of charge from the SAO/NASA Astrophysics Data System (ADS) web site (http://www.adsabs.harvard.edu) and its 12 mirror sites around the world. Consequently, from 2012 there will be no annual subscription to this journal, except for those whose would like to continue receiving paper copies. The electronic version of the journal will continue to be produced three times a year (in March, July and November) and posted on the ADS web site, but the hard copy of Volume 15 (2012) will only be produced as a single bound publication at *the end* of the 2012 calendar year and will then be mailed out to those who have subscribed to it. Associate Editor, Professor Hilmar Duerbeck, will oversee the production of these hard copies, and a subscription rate of €50 (about US$75), including postage and shipping, will apply both to individuals and institutions and must be paid directly to him (i.e. subscriptions will no longer be available through subscription agencies). If you would like to arrange a hard-copy subscription for 2012 please email Professor Duerbeck (hilmar@uni-muenster.de) prior to 1 July 2012 to make the necessary arrangements.

COVER PHOTOGRAPH

This shows a painting of Sir John Herschel (1792–1871) by Edward Alfred Chalon. By the time Herschel wrote his *Treatise on Astronomy* in 1833 sufficient evidence had accumulated to indicate that the Sun could not be "… the most magnificent habitable globe" that his father, Sir William Herschel, had described in 1801. Nevertheless, John was happy to endorse his father's belief that the Sun had a large solid nucleus, which was visible through the openings (sunspots) in its exterior layer or 'luminous ocean'. John also believed that a layer of clouds separated this 'luminous ocean' from the solid interior. For more about the views of the two Herschels and other noted astronomers on the prospect of life on the Sun, see the paper by Professor Emeritus Michael J. Crowe on pages 169-179 in this issue of the journal.

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THE SURPRISING HISTORY OF CLAIMS FOR LIFE ON THE SUN

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Abstract: Because astronomers are now convinced that it is impossible for life, especially intelligent life, to exist on the Sun and stars, it might be assumed that astronomers have always held this view. This paper shows that throughout most of the history of astronomy, some intellectuals, including a number of well-known astronomers, have advocated the existence of intelligent life on our Sun and thereby on stars. Among the more prominent figures discussed are Nicolas of Cusa, Giordano Bruno, William Whiston, Johann Bode, Roger Boscovich, William Herschel, Auguste Comte, Carl Gauss, Thomas Dick, John Herschel, and François Arago. One point in preparing this paper is to show differences between the astronomy of the past and that of the present.

Keywords: Sun, stars, extraterrestrial life, W. Herschel, J. Herschel

1 INTRODUCTION

This paper discusses one aspect of the history of the extraterrestrial life debate, in particular, the history of claims for life on the Sun and stars. So far as I know, no one has previously put together a systematic survey of this topic.

First, some background. Earlier in my career, I spent over a decade researching the history of ideas of extraterrestrial life in the period from antiquity to 1915. This project culminated in 1986 when Cambridge University Press published my 700-page book, *The Extraterrestrial Life Debate 1750–1900: The Idea of a Plurality of Worlds from Kant to Lowell*. In the course of this research, I was able to show that this debate, rather than being confined to the twentieth century, began in Greek antiquity and has continued to the present. This book also provides evidence that already by 1915, over one hundred and forty books, not counting works of science fiction, had been published on the issue of extraterrestrial life (Crowe, 1986: 646-657).

One of the most fascinating aspects of this history concerns claims for life on the Sun. What is especially striking about the history of claims for solarians is that it can serve as an indicator of the level of enthusiasm for extraterrestrials among earlier authors. It takes a particularly robust passion for populating celestial bodies to claim that intelligent beings live on our Sun. I have located about fifty authors who, before 1900, supported life on the Sun. Another surprising research result concerns the prominence of some of these authors arguing for solarians. A number of these authors can, of course, only be described as cranks or as intellectuals venturing far from their areas of competence, but other authors were among the most prominent scientists or intellectuals at the time when they championed life on the Sun. And many of these individuals showed great ingenuity in finding ways to claim life on the Sun even when they were aware of some of the many convincing reasons that we now have for believing that the Sun is not a location favorable for highly-complex organic beings.

2 THE MEDIEVAL PERIOD

Would authors from the Medieval Period be shocked to hear us discuss extraterrestrial life? In fact, many Medieval authors explored the question of 'a plurality of worlds', as the issue of extraterrestrial life was then called. One of the most important Christian authors, Albertus Magnus (d. 1280), remarked: "Since one of the most wondrous and noble questions about Nature is whether there is one world or many ... it seems desirable for us to inquire about it." (as translated by Dick in 1982: 23). And inquire he did, as did his leading pupil, Thomas Aquinas (ca. 1224–1274), both of whom argued against extraterrestrials. But not all Medieval Christian authors opposed extraterrestrials. In 1440, the philosopher, theologian and mathematician Nicholas of Cusa (Figure 1) published his famous work *Of Learned Ignorance* in which he not only advocated extraterrestrials, but also stated regarding the Sun:

Figure 1: Nicholas of Cusa, 1401–1464 (Master of the Life of the Virgin, ca. 1480 (after https://commons.wikimedia/org/wiki/File:Nicholas_of_Cusa.jpg).

> It may be conjectured that in the area of the sun there exist solar beings, bright and enlightened intellectual denizens, and by nature more spiritual than such as may inhabit the moon—who are possibly lunatics—whilst those on earth are more gross and material. It may be supposed that those solar intelligences are highly actualized and little in potency, while the earth-denizens are much in potency and little in act, and the moon-dwellers betwixt and between. (Nicholas of Cusa, 1954: 116).

Persons learning about Cusa's advocacy of extraterrestrials and knowing that in 1600 the Catholic Inquisition burned Giordano Bruno at the stake may wonder what fate befell Cusa. What happened is that eight years after the publication of his book, he was made a Cardinal. This should not be taken to imply that Cusa's advocacy of extraterrestrials secured him this recognition. Nor is there solid evidence that Bruno's punishment was because he advocated extraterrestrials. It seems far more probable that his harsh sentence was because he argued for various heresies, such as denying the divinity of Christ.

3 THE PERIOD FROM 1500 TO 1725

Cusa, by the way, was a major influence on Giordano Bruno (Figure 2), when in the last two decades of the sixteenth century Bruno championed extraterrestrials. In fact, Bruno was the first author to claim that stars were suns surrounded by inhabited planets. Moreover, his enthusiasm for extraterrestrials was such that in his cosmology, not only planets were inhabited but also the Sun and stars (Bruno, 1950: 306).

Figure 2: Statue of Giordano Bruno, 1548–1600, by Ettore Ferrari (1845–1929), after en.wikpedia. org/wiki/File/Giordano_Bruno_Campo_del_Fiori).

Let us jump ahead more than a century and a half to Isaac Newton (1642–1727), who in 1687 published his masterpiece, the *Mathematical Principles of Natural Philosophy*. Newton did not advocate solarians; in fact, in his book he presented information that one might suspect would have killed off any claims for solar inhabitants. Using his theory of gravitation, Newton showed that the weight of any terrestrial object would increase by more than a factor of 23 by being transported to the Sun. He also showed that although the Sun is vastly more massive than the Earth, its density is four times lower than Earth's, making further problems for any beings living on its surface (Newton, 1999: 811-815).

Of course, not everyone read Newton's *Principia*, containing such distressing news regarding extraterrestrials, but surely Newton's successor in the Lucasian Professorship at Cambridge University must have known of these passages. This was William Whiston (1667–1752), who repeatedly advocated extraterrestrials. As early as his *New Theory of the Earth* (1696), Whiston urged that other planets and planetary systems have inhabitants subject to moral trials (Jaki, 1978: 94). Two decades later, in his *Astronomical Principles of Religion*, Whiston extended his extraterrestrials by proposing denizens dwelling in the interiors of the Sun, planets and comets. Moreover, Whiston (1717: 92) posited "not wholly Incorporeal, but Invisible Beings …" living in planetary atmospheres. Whiston made provision for his solarians by supposing that the Sun has cavities beneath its surface where the solarians could live, shielded from the intense heat of the Sun's exterior surface. Whiston was anxious that all parts of creation be put to use, so he suggested that the planets, including the Earth, have inhabited cavities beneath their surface. In support of this suggestion, he was able to cite similar claims made by another famous Newtonian, Edmond Halley (Whiston, 1717: 94).

4 THE PERIOD FROM 1725 TO 1800

Let us move ahead now to the period between 1725 and 1760, during which four prominent intellectuals wrote in support of solarians. In 1748, Gowin Knight (1713–1772), an English scientist and the first Principal Librarian at the British Museum, published *An Attempt to Demonstrate, That All the Phenomena of Nature May Be Explained by Two Simple Active Principles, Attraction and Repulsion.* In that volume, Knight suggests that the Sun and stars may be sufficiently cool to accommodate life. In fact, he states:

> Their globes [i.e. those of the Sun and stars] are no longer frightful Gulphs of Fire, but inhabitable Worlds: Those Philosophers who thought them too hot for the Habitation of Salamanders, and those sublime Genii, who thought them to be Hells, will now perhaps be in Pain, lest the inhabitants should freeze with Cold. (Knight, 1748: 58).

Moving on to 1752 and German authors, we find that Johann Jakob Bodmer (1698–1783), a prominent German poet, published his epic poem *Der Noah*, an account of the deluge modeled to some extent on John Milton's *Paradise Lost*. Astronomy enters that poem not only through his adoption of Whiston's idea that a comet caused the deluge, but also through a telescope, which Bodmer bestows on one of Noah's fellow patriarchs. From that instrument and from the angel Raphael's revelations to Noah comes information that inhabited planets orbit stars, that the Sun itself is inhabited, and that at least one planet has been spared the ravages of sin. Bodmer describes his solarians in these verses (Schatzberg, 1973: 164):

> Not of human form, and not of terrestrial dust;
> But with their own beauty adorned from the stuff of light,
> Worthy of inexhaustible skill, with finer limbs,
> In accord with their location, to endure the sun's heat.

The year 1752 saw the publication of *Sources of Incredulity with Regard to Religion*, written by Duncan Forbes (1685–1747), Lord President of Scotland's Court of Session. In this book, Forbes questions the idea of a plurality of worlds. Nonetheless, moved by the question of what purpose the heavenly bodies would serve if they are uninhabited, Forbes (1752: 2) suggests that

> … we cannot deem it impossible, that beings may have been made, fit to reside, to act, and to think, in the very centre, as well as on the surface of the sun.

The author with the most impressive scientific credentials who supported solarians in the 1750s was the famous Jesuit physicist Roger Boscovich (1711–1787), who in 1758 published his magnum opus, his *Philosophiae naturalis theoria*. In his explanation of fire as a fermentation in which a sulphurous substance must be present, he suggests that

> … in the sun itself, & in the stars ... there may exist bodies altogether lacking in such a [sulphurous] substance; & these may grow & live without the slightest injury of any kind to their organic structure. (Boscovich, 1966: 166).

Remarkable as his claim for life on the Sun and stars may be, Boscovich went even further in a suggestion based on his doctrine that matter ultimately consists not of hard, massy atoms but rather of point centers of force, which at certain distances exert repulsive and at other distances attractive forces. Drawing upon this hypothesis, Boscovich speculates about the interpenetrability of matter and proposes even that

> … there might be a large number of material & sensible universes existing in the same space, separated one from the other in such a way that one was perfectly independent of the other, & the one could never acquire any indication of the existence of the other. (Boscovich, 1966: 184).

By the 1770s, extraterrestrials had attained a level of acceptance, even among eminent astronomers, that probably exceeds what they now have. Among late eighteenth-century astronomers, few were more distinguished than Johann Elert Bode (1747–1826), who for over fifty years edited a leading German astronomical journal (*Astronomisches Jahrbuch*), and who, in 1786, became Director of the Berlin Observatory. Moreover, few authors from any nation advocated extraterrestrials with more frequency, fervor, or influence than Bode. His enthusiasm is evident in the fact that in 1776 he published a model of the Sun suitable for intelligent life. After attributing a protective layer to the Sun and inhabitants to its supposedly cool core, Bode described the Sun as

> … a dark planetary body which as our earth consists of land and water and exhibiting on its surface all the unevenness of mountains and valleys and also surrounded up to a certain height by a thick atmosphere. (Bode, 1776: 233).

Concerning solarians, he asks:

> Who would doubt their existence? The most wise author of the world assigns an insect lodging on a grain of sand and will certainly not permit ... the great ball of the sun to be empty of creatures and still less of rational inhabitants who are ready gratefully to praise the author of their life.
>
> Its fortunate inhabitants, say I, are illuminated by an unceasing light, the blinding brightness of which they view without injury and which, in accordance with the most wise design of the all-Good, communicates to them the necessary warmth by means of its thick atmosphere. (Bode, 1776: 246).

Next we come to Edward King (1735?–1807), who championed extraterrestrials in various books, including including his *Morsels of Criticism Tending to View Some Few Passages in the Holy Scriptures, upon Philosophical Principles and an Enlarged View of Things* (King, 1800), which was a work of scriptural exegesis. King argues that the Septuagint translation of the Old Testament contains anticipations of some modern ideas, including the idea of a plurality of worlds. He presents this "Enlarged View of Things" in such a way as to have each star be the heaven for the resurrected inhabitants of its system of planets. After arguing that the solar rays are not themselves hot but produce heat only in interaction with material bodies, King urges his readers to join him in viewing

> … our sun, and all the other fixed stars, merely as so many mansions, and habitations of residence; merely as so many Islands (as it were) of Bliss, placed in the vast ocean of space. (King, 1800: 108).

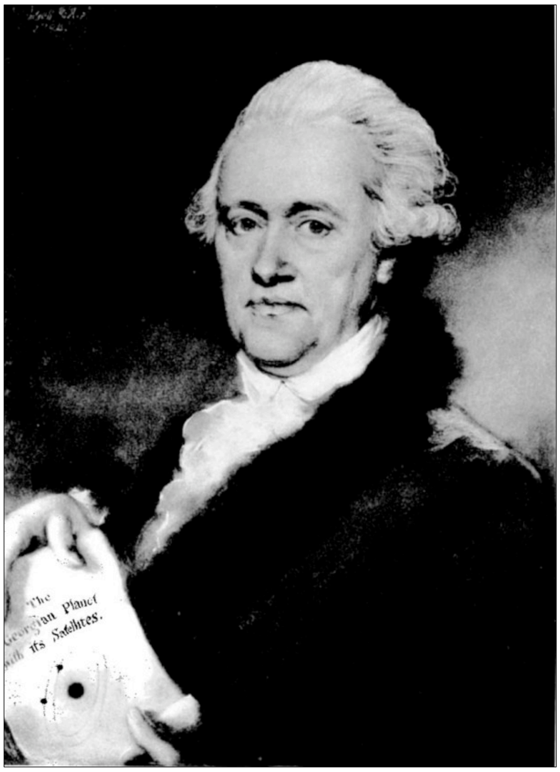

Figure 3: Sir William Herschel, 1738–1822 (after Dreyer, 1912, 1*:* frontispiece; courtesy: University of Notre Dame Library).

4.1 William Herschel

Many historians of astronomy view William Herschel (Figure 3) as the most important astronomer of the eighteenth and nineteenth centuries. Not only did he discover the planet Uranus, he also—and more importantly—was the pioneer of stellar and galactic astronomy. When he took up astronomy, only about one hundred nebulous objects were known. Using the giant telescopes he constructed, he discovered 2500 more, and made in addition numerous other discoveries. And his contributions to telescopic design and construction were legendary. He was also very interested in extraterrestrials. I have shown in my book that manuscripts from early in Herschel's career record his sighting a lunar forest (Crowe, 1986: 62–66). I have also suggested that a major reason why Herschel built some of his extraordinary telescopes may have been his determination to confirm his sighting of a forest and other evidences of lunar life.

Before discussing Herschel's view regarding life on the Sun, let us examine an incident reported in the 1787 issue of the *Gentleman's Magazine.* A certain Dr John Elliot was brought to trial in London for having come up behind a Miss Boydell and set fire to her cloak by firing a pair of pistols near it. Insanity was the plea made for Elliot, in support of which a Dr. Simmons recounted examples of Elliot's bizarre behavior, especially his having prepared a paper for submission to the Royal Society in which he maintained that the Sun is inhabited (see Manning, 1993).

This incident leads one to wonder what may have been the reaction among readers of the Royal Society's *Philosophical Transactions* when in 1795 and 1801 they encountered papers in which Herschel theorized that the Sun consists of a cool, solid, dark, spherical interior above which floats an opaque layer of clouds. In 1795, Herschel suggested that heat and light are carried by separate rays and that heat rays generate a rise in temperature only when in contact with special material (Herschel, 1795). In 1801, Herschel expanded the theory by proposing two exterior layers, the upper of which consists of the glowing matter, the lower being a reflecting shield that keeps the inner surface cool (Figure 4). As Herschel (1795: 63) states:

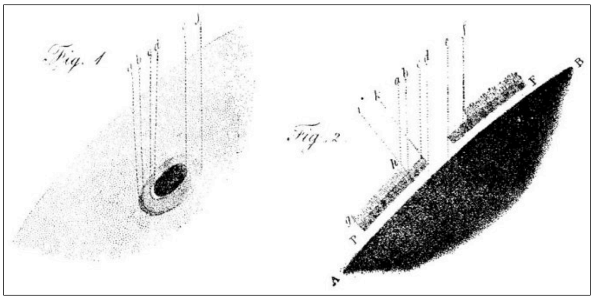

Figure 4: Diagram by William Herschel of his theory of the nature of sunspots (Herschel, 1801: Plate XVIII; courtesy: University of Notre Dame Library).

> The sun ... appears to be nothing else than a very eminent, large, and lucid planet, evidently the first, or in strictness of speaking, the only primary one of our system ... Its similarities to the other globes of the solar system ... leads us to suppose that it is most probably ... inhabited ... by beings whose organs are adapted to the peculiar circumstances of that vast globe.

Herschel contrasts his theory with that of "… fanciful poets …" who portray the Sun "… as a fit place for the punishment of the wicked …", urging that his claim rests "… upon astronomical principles." (ibid.). Herschel argues for his solarians by suggesting that terrestrial life flourishes in a variety of situation and by suggesting that terrestrials who deny life to the Sun have no more logic on their side than inhabitants of a planetary satellite who deny life to the primary around which they revolve. Such arguments seem to support E.S. Holden's statement (1881: 149) that Herschel's views on solar and lunar life "… rest more on a metaphysical than a scientific basis ..."

Holden's conclusion needs, however, to be qualified in one important way, which helps explain why the premier astronomer of that period adopted such a strange theory. Although as early as 1780 Herschel had considered a form of this solar model (Herschel, 1780: 2), he had between then and 1795 accumulated astronomical evidence that, when viewed in terms of his strong belief in the plurality of worlds doctrine, substantially increased the attractiveness of that model. In particular, during this period Herschel's stellar researches had led him to observe what he describes in his 1795 solar paper as "… very compressed clusters of stars." He goes on to argue that stars in such clusters will be too tightly packed to accommodate inhabited planets. This did not lead Herschel to abandon the region as a home for extraterrestrials; rather it led him to conclude that the stars themselves must be "… very capital, lucid, primary planets …" so structured as to allow habitation (Herschel, 1795: 69). Thus, Herschel had found a way to save these stars from being "… mere useless brilliant points." (ibid.: 71). That his solar theory was no passing fancy in his thought is shown by his having elaborated it further in his 1801 paper in which he refers to the Sun as "… a most magnificent habitable globe." (Herschel, 1801: 265) and by his 1814 description of stars as "… so many opaque, habitable, planetary globes." (Herschel, 1814: 263). However bizarre Herschel's solar theory may seem to us, there is good evidence that it persisted as the preferred theory of the Sun until the 1850s (Meadows, 1970: 6).

4.2 Other Eighteenth-Century Advocates of Solarians

Two scientists who immediately adopted it were Robert Harrington, M.D., and Thomas Thomson. In 1796, Harrington (1751–1837) published his *New System of Fire and Planetary Life. Shewing that the Sun and Planets Are Inhabited. and That They Enjoy the Same Temperament as Our Earth*, in which he claims that the two chief entities in nature are fire particles (which are mutually repulsive) and earth particles (which attract both air and fire particles). On the basis of this theory, he concludes that the Sun and planets

> … all enjoy the identical same fire, or light, or heat; the same temperature, and, I make no doubt, the same men, animals, vegetables, and minerals; the same atmosphere and water; in short, every thing the same. (Harrington, 1796: 50).

Harrington was on the fringe of British science, but Thomas Thomson, M.D. (1773–1852) was a leading Scottish chemist whose *System of Chemistry* contains in its 1804 edition an important exposition of Dalton's atomic theory. In that volume, Thomson also advocates Herschel's theory of the Sun without, however, mentioning solarians. In particular, Thomson (1804: 412) states that Herschel's observations indicate that

> … the sun is a solid opaque globe, similar to the earth and other planets, and surrounded by an atmosphere of great density and extent [in which] float two regions of clouds ...

Not only were some eighteenth-century scientists attracted to solarians, but so were a number of prominent poets, including the German, Friedrich Klopstock (1724–1803), and the American, Philip Freneau (1752–1832), who is known as the 'poet of the [American] Revolution.' Klopstock was widely regarded as one of the most gifted of eighteenth-century German poets, and no poet of such classic stature has devoted a larger portion of his poetry to extraterrestrial life themes. This is especially true of his most famous poem, *Der Messias* (1748–1773), in which he portrays the suffering, death, and resurrection of Christ within a Universe abounding with extraterrestrials. For example, he portrays the Patriarchs as living on the Sun. Also, late in his life, Klopstock (1962: 171) published his poem "Die unbekannten Seelen" ("The Unknown Souls"), in which he makes a favorable reference to William Herschel's ideas about life on the Sun and stars.

Philip Freneau also published two essays in the *Monmouth Almanac* for 1795 supporting extraterrestrials. In one of these he not only attributes life to the Sun but also suggests that the Sun is "… peopled with beings of nature infinitely superior to any of those on the neighbouring planets." (Freneau, 1795: 7).

5 THE NINETEENTH CENTURY

A good way to begin the discussion of the nineteenth century is by mentioning the French poet Paul Gudin de la Brenellerie (1738–1812). In 1801 Gudin published a long didactic poem, *L'astronomie*, and in 1810 expanded it for a new edition, to which he appended a discourse on the doctrine of a plurality of worlds. Gudin (1810: 193) describes this doctrine as having

> … become so much the fashion that there is at present no person who, were he to arrive at the moon or Saturn, would feel less at home than in arriving at China or Mexico.

However, Gudin (ibid.) separates himself from this sentiment by stating his belief that

> … all the globes are populated, even suns and comets, but ... by beings very different from us; some [are] far above us, others much below our weak intelligence.

Gudin's volume was partly in the tradition of natural theology, which saw in nature a source for contemplating the power and beneficence of God.

Far more clearly in that tradition was a quite popular volume, *Harmonies de la nature*, published in 1815 by Jacques Henri Bernardin de Saint-Pierre (1737–1814). The ninth and final book of *Harmonies*, that devoted to astronomy, contains an enthusiastic endorsement, based on analogy and teleology, of life not only on all the planets, but also on the Moon, the Sun, and on comets. Regarding the planets, Bernardin de Saint-Pierre (1815, 3: 256) asserts that they ought to be inhabited because

> Nature has made nothing in vain, and what would be the use of desert globes? There must be vegetable products in them, because there is heat; there must be eyes, because there is light; and there must be intelligent beings, because intelligence is displayed in their formation.

This former Director of the Jardin des Plantes was not scientifically uninformed; he draws heavily on Herschel's writings, for example, in support of life on the Sun. But his approach frequently leads him beyond the boundaries of science, as in his suggestion that the Sun "… should be the receptacle of the earth's inhabitants in a future stage of existence ..." (ibid.: 234). The extravagant character of some of his techniques for salvaging the habitability of planets is illustrated by his bestowal upon Uranus of "… an immense atmosphere …" (ibid.: 307), and

> … an animal of the reindeer kind, feeding on moss and combining in itself the advantages of the fleece of sheep, the milk of the cow, the strength of the horse, and the lightness of the stag. (ibid.: 310).

As this suggests, ideas of extraterrestrials were frequently linked with religion. A striking example of this is the multivolume commentary on the Bible published by a leading Methodist theologian, Adam Clarke (1762?–1832). The magnitude of this publication is suggested by the fact that it weighs 35 pounds, whereas the extent of its attention to astronomy is indicated by the fact that before reaching Genesis 1:2, we find an elaborate table of data on the planets and satellites. By Genesis 1:16 Clarke (1837, 1: 34) informs us that

> Dr. Herschel's discoveries, by means of his immensely magnifying telescopes, have, by the general consent of philosophers, added a new habitable world to our system, which is the SUN.

5.1 Thomas Dick

The Scottish astronomer and religious writer Thomas Dick (Figure 5), whose observatory was at Dundee, was one of the most enthusiastic advocates of extraterrestrials during the first half of the nineteenth century. The boldest of his presentations appeared in his 1837

Figure 5: Thomas Dick, 1774–1857 (engraving from Hogg, 1850; courtesy: en.wikipedia.org/ wiki/ File:Dick_Thomas_portrait %2Bsignature.jpg).

book, *Celestial Scenery*. In this volume, Dick provides a population table (see Table 1 here) for all known objects in our Solar System except the Sun (Dick, 1838: 305). The way Dick arrived at this table was to determine that the average population per square mile in England was 280 people. Then Dick, for purposes of calculation, assumed that no oceans occurred on these bodies. Then he multiplied the surface area in square miles of each body by 280 to derive the object's population. In this way he determined that every planet and asteroid in the Solar System, except Vesta, had a greater population than the Earth. Even the rings of Saturn had larger populations. What about the Sun? Dick's omission of a population figure for the Sun does not indicate that he doubted solarians; in fact, after citing William Herschel on their behalf, he warned:

> … it would be presumptuous in man to affirm that the Creator has not placed innumerable orders of sentient and intelligent beings ... throughout the expansive regions of the sun. (Dick, 1838: 242).

Table 1: Thomas Dick's population table for our Solar System (after Dick, 1838: 105).

	Square Miles.	Population.	Solid Contents.
Mercury	32,000,000	8,960,000,000	17,157,324,800
Venus..............	191,134,944	53,500,000,000	248,475,427,200
Mars	55,417,824	15,500,000,000	38,792,000.000
Vesta	229,000	64,000,000	10,035,000
Juno	6,380,000	1,786,000,000	1,515,250,000
Ceres	8,285,580	2,319,962,400	2,242,630,320
Pallas..............	14,000,000	4,000,000,000	4,900,000,000
Jupiter	24,884,000,000	6,967,520,000,000	368,283,200,000,000
Saturn	19,600,000.000	5,488,000,000,000	261,326,800,000,000
Outer ring of Saturn.	9,058,803,600	} 8,141,963,826,080	1,442,518,261,800
Inner ring..........	19,791,561,636		
Edges of the rings ..	228,077,000		
Uranus	3,848,460,000	1,077,568,800,000	22,437,804,620,000
The Moon..........	15,000,000	4,200,000,000	5,455,000,000
Satellites of Jupiter .	95,000,000	26,673,000.000	45,693,970,126
Satellites of Saturn..	197,920,800	55,417,824,000	98,960,400,000
Satellites of Uranus .	169,646,400	47,500 992,000	84,823,200,000
Amount........	78,195,916,784	21,894,974,404,480	654,038,348,119,246

Moreover, Dick all but carried out the calculation by noting that the surface area of the Sun was thirty-one times the combined surface area of all other Solar System objects.

5.2 John Herschel

William Herschel had one offspring, his son John (Figure 6), who graduated with many honors from Cambridge University and who during the decade after his father's death in 1822 emerged as the leading British astronomer, in fact, as arguably the leading scientist in Britain. In 1833, John Herschel published his *Treatise on Astronomy*, which his contemporaries viewed as the most authoritative presentation of astronomy published in English. In 1849, John published a far longer and even more highly-regarded presentation, his *Outlines of Astronomy*. By 1833, when John published his *Treatise*, William Herschel's claims concerning the Sun and its inhabitants had become increasingly problematic, as his son no doubt realized. It is true that John was well aware of the problems raised by physics and chemistry for the Sun. In his *Treatise and Outlines*, he laments, regarding the Sun, that

Figure 6: Sir John Herschel, 1792–1871 (by Edward Alfred Chalon, after http://en.wikipedia.org/wiki/File:John_Herschel100.jpg).

> … the great mystery … [is] to conceive how so enormous a conflagration (if such it be) can be kept up. Every discovery in chemical science here leaves us completely at a loss, or rather, seems to remove farther the prospect of probable explanation. If conjecture might be hazarded, we should look rather to the known possibility of the generation of heat by friction, or its excitement by the electric charge … for the origin of solar radiation. (Herschel, 1833: #337; 1850: #400).

Such puzzlement, however, did not prevent him, in both his *Treatise* and *Outlines*, from endorsing his father's doctrine that the Sun has a large solid nucleus, which becomes visible through the 'openings' (sunspots) in its exterior layer or 'luminous ocean'. John also champions a layer of clouds separating this 'luminous ocean' from the solid interior, finding evidence for it in the appearances at the edges of sunspots. Although admitting the extraordinarily high temperature of the Sun's exterior and also that

> … the most intensely ignited solids appear only as black spots on the disk of the sun when held between it and the eye … [and] it follows, that the body of the sun, however dark it may appear when seen through its spots, may, nevertheless, be in a state of most intense

> ignition. It does not, however, follow of necessity that it must be so. The contrary is at least physically possible. A perfectly reflective canopy would effectually defend it from the radiation of the luminous regions above its atmosphere, and no heat would be conducted downwards through a gaseous medium increasing rapidly in density. That the penumbral clouds are highly reflective, the fact of their visibility in such a situation can leave no doubt. (Herschel, 1833: #334; 1850: #396).

John Herschel does not directly discuss solar inhabitants in his *Treatise* and *Outlines*, being content with having supplied these provisions for their existence, of which David Brewster and others availed themselves later in the century.

That the source of this passage lay not only in filial fondness for his father's ideas, some of which John did not accept, but also in his own solicitude for solarians is suggested by John Herschel's theory of James Nasmyth's solar 'willow-leaves'. To see this matter in context, it is important to understand that in general Herschel was known for the soberness of his thought. Nonetheless, he did have his speculative moments; in fact, in a lecture delivered in late 1861 and subsequently twice published, he puts forth a solar speculation that went beyond even those of his father. Around 1860, James Nasmyth, a respected astronomer with one of the best telescopes of the period, reported that he had observed the surface of the Sun to be covered with numerous objects shaped like willow leaves. These were intensely luminous objects of immense size and in constant motion. In his 1861 lecture, Herschel not only accepts this observation, which by the mid-1860s had been shown to be erroneous, but goes beyond it to argue for the solidity of the willow leaves and to state that they are "… evidently the immediate sources of the solar light and heat ..." Then he adds the remarkable claim that

> … we cannot refuse to regard them as organisms of some peculiar and amazing kind; and though it would be too daring to speak of such organization as partaking of the nature of life, yet we do know that vital action is competent to develop both heat, light, and electricity. (Herschel, 1871: 84).

Two considerations help explain how the premier British astronomer of that period could make such a fantastic assertion. The first, which is supported by the materials presented above, is that the younger Herschel had inherited not only his father's instruments and abilities, but also his father's fondness for extraterrestrials. The second factor is the openness of Herschel's astronomical contemporaries to pluralist claims. An excellent example of this is Admiral William H. Smyth (1788–1865), whose *Cycle of Celestial Objects* (1844) won a gold medal from the Royal Astronomical Society. In that book Smyth (1844: 92), without directly advocating William Herschel's theory of life on the Sun, responds to Thomas Young's objection that solarians could not overcome the Sun's gravitation by:

> … the mysterious WORD which formed the Laplander and the Negro, the condor and the whale, the mosquito and the elephant, for the several portions of one and a small globe, is surely not to be limited to the fashioning of creatures of our constitution or conception. The inhabitants of every world will be formed of the material suited to that world, and also for that world; and it matters little whether they are six inches high, as in Lilliput, or as tall as [Voltaire's] inhabitants of Sirius ... whether they crawl like beetles, or leap fifty yards high.

5.3 Carl Friedrich Gauss

It is of course true that solarians were championed by some authors who knew essentially no astronomy or mathematics. Such a claim cannot, however, be made against Carl Friedrich Gauss (Figure 7), who is ranked as the most brilliant mathematician of the nineteenth century and possibly of all time. Moreover, Gauss by profession was Professor of Astronomy at the University of Göttingen and Director of its Observatory. We know Gauss' views regarding extraterrestrials partly from his writings, but also from other sources, for example, records kept by his Göttingen colleague, Rudolf Wagner (1805–1864), of conversations with the great mathematician. Wagner's records show that Gauss had adopted the doctrine that after death our souls take on new material forms on other cosmic bodies, including even the Sun. That Gauss held such an extreme idea is also evidenced in the biography of Gauss written immediately after his death by Baron Wolfgang Sartorius von Waltershausen (1809–1876). This intimate friend revealed that Gauss

Figure 7: Carl Friedrich Gauss, 1777–1855 (1887 oil painting by G. Biermann copied from an 1840 painting by Christian Albrecht Jensen; courtesy: https://commons.wikimedia.org/wiki/File:Carl_Friedrich_Gauss.jpg).

> … held order and conscious life on the Sun and planets to be very probable and occasionally called attention to the action of gravity on the surface of heavenly bodies as bearing preeminently on this question. Considering the universal nature of matter, there could exist on the sun with its 28-fold greater gravity only very tiny creatures ... whereas our bodies would be crushed ... (Sartorius, 1966: 73).

5.4 Auguste Comte

The degree to which various intellectuals uncritically accepted life on the Sun, despite the availability of scientific information that went against such belief, suggests that what was needed was an author who would stress the importance of empirical information, of a scientific approach, and would set aside from such discussions philosophical and religious issues. The French philosopher Auguste Comte (Figure 8), known as the founder of positivism, might seem the ideal person for this task. And, indeed, we do find Comte in a number of his writings stressing the importance of a scientific, positivistic methodology and simultaneously criticizing a religious approach. Moreover, we find him

Figure 8: Auguste Comte, 1798–1857 (after Comte, 1858: Frontispiece; scan courtesy: Eric Chaim Kline Bookseller).

Figure 9: Sir David Brewster, 1781–1868 (engraved by W. Holl from a painting by Sir H. Raeburn, R.A.; U.S. National Library of Medicine).

discussing the Sun in a book he published in 1851. In that volume, Comte (1968: 24) excoriates those who see astronomy as allied with religion,

> … as if the famous verse 'The Heavens declare the glory of God' had preserved its meaning. It is however certain that all true science is in radical and necessary opposition to all theology …

Moreover, he adds that for those familiar with the true philosophy of astronomy,

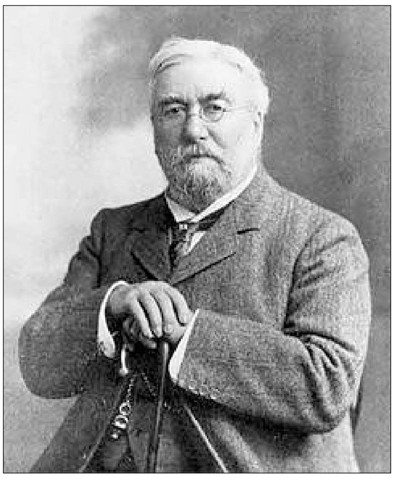

Figure 10: J. Norman Lockyer, 1836–1920 (after *Proceedings of the Royal Society,* 1909).

> … the heavens declare no other glory than that of Hipparchus, of Kepler, of Newton, and of all those who have cooperated in the establishment of laws. (ibid.).

In particular, Comte maintains that what shows the unacceptability of theology is the realization that the Earth, rather than being the center of the Universe, is only a secondary body circling the Sun,

> … of which the inhabitants have entirely as much reason to claim a monopoly of the solar system which is itself almost imperceptible in the universe. (Comte, 1968: 130).

What this, and Comte's repeated unqualified endorsements of extraterrestrials, indicates is that the programs advocated by some philosophers may not be an indication of their practice.

5.5 Second Half of the Nineteenth Century

The debate over life on the Sun continued into the second half of the nineteenth century. The slowness with which ideas change is dramatically indicated by the fact that life on the Sun was championed in the late 1850s and in the 1860s by a number of American, Belgian, British, French, and German authors. Some supporters of solarians came from the fringes of science (Schimko, 1856: 30-32; Read, 1860: 155), but in other cases prominent scientists advocated this idea.

For example, in 1854, the prolific Scottish physicist, Sir David Brewster (Figure 9), responded to an attack on extraterrestrials by publishing his *More Worlds Than One; The Creed of the Philosopher and the Hope of the Christian*, in which he endorses life on the Sun; in fact, he populates it with "… the highest orders of intelligence." (Brewster, 1870: 102). Moreover, in 1867 the English chemist Dr Thomas Lamb Phipson (1833–1908) asserted that the Sun "… must indeed be a region of eternal life and perfect happiness …" (Phipson, 1867: 3, 65). Shortly thereafter, the English astrophysicist and founder of the journal *Nature*, J. Norman Lockyer (Figure 10), in his *Elements of Astronomy* presented solar life as a possibility (Lockyer, 1870: 69). Also in the 1860s, Mungo Ponton (1802–1880), a pioneer of photography and a founder of the Bank of Scotland, championed both William Herschel's theory of a cool, habitable core for the Sun and John Herschel's view that Nasmyth's 'willow-leaves' consist of giant organisms (Ponton, 1866, 243, 262-266). In an 1859 address to the Belgian Academy, Jean Baptiste Joseph Liagre (Figure 11), an astronomer and mathematician, concluded his discussion of the Sun by stating that it ought no longer be seen

> … as a devouring furnace and destroyer, but as the most imposing of the planetary globes … [as a] majestic abode where the perfection of organized beings ought to be ... in harmony with the magnificence of the habitation. (Liagre, 1859: 413).

In France, the Director of the Paris Observatory was François Arago (Figure 12), who for twenty-three years delighted the population of Paris with his astronomical lectures. These were published shortly after his death as his *Astronomie populaire*, and included a section that focused on the question: "Is the Sun inhabited?" He answers:

> ... I know nothing. But if one asked me whether the sun can be inhabited by beings organized in a manner analogous to those which populate our globe, I would not hesitate to make an affirmative response. The existence

in the sun of a central dark nucleus enveloped in an opaque atmosphere, far from the luminous atmosphere, offers nothing in opposition to such a conception. (Arago, 1854-1857, 2: 181).

Arago then describes William Herschel's model of the Sun, mentioning as an aside Dr Elliot, whose already-tarnished reputation was further darkened by Arago erroneously reporting that Elliot had killed Miss Boydell. Arago (1854-1857, 2: 182) dryly adds: "The conceptions of a madman are today almost generally adopted." In 1862, Camille Flammarion (Figure 13), an immensely widely read astronomical author, published the first of the perhaps fifty editions of his *Pluralité des mondes habités*, in which he endorses life on the Sun (Flammarion, 1862: 81-85). Most energetic on behalf of solarians was Fernand Coyteux (1800 –?), who in 1866 published a massive book arguing for life on the Sun, thereby creating a controversy in a learned society in Poitiers, France (Crowe, 1986: 369).

In 1858, astronomers acquired a new tool, which helped them immensely, but probably had a bad effect on solarians. This was spectroscopy, which allowed astronomers eventually to determine the chemical composition and temperatures of various heavenly bodies (e.g. see Hearnshaw, 2010). Moreover, various critiques of claims for life on the Moon and planets began to carry more weight, until by century's end, extraterrestrials had been banished from most planets, with the exception of Mars, on which in 1877 sightings of canals had been reported. Claims for life on the Sun had by this time diminished, although a few hearty souls continued to champion solarians. For example, in 1894, Sir Edwin Arnold (1832–1904), a journalist, published an essay attacking astronomers for rashly and foolishly denying life to the Moon and planets and for failing to see that "… there may be creatures on the sun which thrive upon incandescent hydrogen ..." (Arnold, 1894: 407-408). Advocacy of solarians continued in Germany; for example, in 1880 William Preyer (1841–1897) published a book in which he claims that the Sun itself may be a

… glowing organism whose breath may perhaps be shining iron vapor, whose blood may be flowing metal, and whose food may perhaps be meteorites. (Preyer, 1880: 60).

And Carl Goetze (1896) published an entire book arguing for life on the Sun.

6 CONCLUSION

Solarians are gone. Moreover, their departure was far more than a local event. When our Sun lost its inhabitants, so did every star in the Universe. This raises a question that I fear I can answer only partially. The question is: "When and by whom were the solarians slaughtered?" I can answer a parallel question: "When and by whom were the Martians destroyed?" They were dispatched as the result of a successful campaign carried out against the Martians and their canals by various astronomers in the period from 1877 to 1915. Regarding the solarians, on the other hand, I know of no comparable campaign launched against them. Nor was their departure caused by a direct attack. It is true that Newton, as we have seen, made serious problems for them. Moreover, Thomas Young (1845: 399) in the first decade of the nineteenth century reminded his fellow scientists of these problems, as did François

Figure 11: Jean Baptiste Joseph Liagre, 1815–1891 (http://wiki.arts.kuleuven.be/wiki.images/1/11/Liagre.jpg).

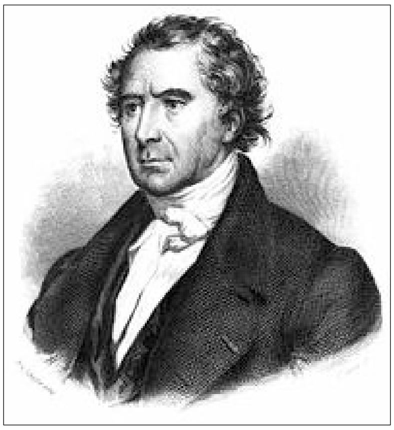

Figure 12: Francois Arago, 1786–1853 (en.wikipedia.org/wiki/Francois_Arago).

Figure 13: Camille Flammarion, 1842–1925 (en.wikipedia.org/wiki/Camille_Flam-marion).

Plisson in 1847 (Crowe, 1986: 168, 248-249). But what above all drove the solarians from the Sun was the progress of physical astronomy and physics. As more and more was learned about the Sun and stars, it became not just difficult, but impossible, to assume the existence of solarians. Although in the early decades of the nineteenth century, many saw solar life as plausible, by the last decades of the nineteenth century, it seemed impossible. For example, in 1870 the British astronomer and populariser, Richard Proctor, published his *Other Worlds than Ours*. In this volume, although Proctor supported life on the planets, he labeled life on the Sun as "… too bizarre [for] consideration." (Proctor, 1870: 20). Some castles crumble as a result of rapid and direct attack; others fall vacant and over decades become uninhabitable. The latter fate befell the Sun and stars.

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SIRIUS IN ANCIENT GREEK AND ROMAN LITERATURE: FROM THE ORPHIC *ARGONAUTICS* TO THE *ASTRONOMICAL TABLES* OF GEORGIOS CHRYSOCOCCA

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Abstract: The brightest star of the night sky, is Sirius, Alpha Canis Majoris (α CMa). Due to its intense brightness, Sirius had one of the dominant positions in ancient mythology, legends and traditions. In this paper the references of the many ancient classical Greek and Roman authors and poets who wrote about Sirius are examined, and the problem of its 'red' color reported in some of these references is discussed.

Keywords: Seirios, Sirius, Dog Star, Canis Major, scorching star, Maira

1 INTRODUCTION

Sirius, Alpha Canis Majoris (α CMa), is the brightest star in the night sky. It is visible throughout Greece on clear winter nights, and for this reason occupies a significant place in ancient mythology, legends and traditions. The original Greek name, 'Seirios', meant 'sparking', 'shining', 'fiery' or 'burning'.

In this work, ancient Greek and Roman and some Byzantine references to Sirius will be considered, which led to the popularization of its name in the Greco-Roman literature. The same is true for the myths and classical traditions associated with it; the classical folklore associated with Sirius became known and was enriched through the work of the main Latin authors. In this way, both the name and the myths were long established in Western culture and thus survived. We will also examine and discuss the problem of the 'red' color of Sirius, which arises from references of some ancient authors.

2 SIRIUS IN THE CONSTELLATION CANIS MAJOR

Canis Major is an average-sized southern constellation with 95 stars visible to the naked eye. Its brightest star, Sirius, is almost four times brighter than any other star visible from the latitude of Athens (38°, central Greece). One must go further south than 37° N, to Rhodes or Crete, in order to observe the next brightest star, Canopus, which is half as bright as Sirius (Canopus is the brightest star of the constellation Carina, and is Alpha Carinae).

We now know that Sirius is one of the closest stars to the Earth at a distance of just 2.64 parsecs (8.60 light years), and it has an apparent magnitude $m = -1.46$. This is 20 times brighter than our Sun would be at the same distance. Canopus is at a much greater distance of 96 pc (313 l.y.) and shines with an apparent magnitude of -0.72.

Of all visible celestial objects, only the Sun, the Moon, Venus, Jupiter and Mars appear brighter than Sirius; actually, Mars is brighter than Sirius only when it is close to opposition, approximately once every two years.

Sirius (α CMa), Procyon (α CMi, the brightest star in the constellation Canis Minor) and Betelgeuse (α Ori, the brightest star in the constellation Orion) form a large triangle in the January-to-March sky, the so-called, 'Winter Triangle', which is almost equilateral. Today, Sirius first appears in the dawn skies several weeks later than it did in ancient times (10 August versus near the summer solstice). This is because of the precession of the equinoxes due to the 26,000-year wobble of the Earth's axis.

Sirius is in fact a triple star system. The companion star, Sirius B, is a white dwarf about the size of the Earth; most of its mass is compressed so much that a cubic cm of this material would weigh on Earth a few tons (and hundreds of tons on the surface of the white dwarf). Sirius B shines eighty times fainter than the naked-eye theoretical limit, but even if it reached that limit the intense glow from the adjacent Sirius A would render its companion invisible. This is the reason that Sirius B was only indirectly detected in 1844 from the perturbations it caused in the position of Sirius. The discovery was made by the German astronomer Friedrich Wilhelm Bessel. It was first optically observed in 1862 by the American astronomer and telescope-maker Alvan G. Clark during the testing of a refracting telescope of exquisite quality. In 1994 Daniel Benest and Jean-Louis Duvent (1995) from the O.C.A. Observatoire de Nice in France suggested the existence of a second companion to Sirius, Sirius C.

Because of its great brightness, Sirius occupied a prominent position in mythology, legends and traditions of most people, and especially of the ancient Greeks. Its very name, *Seirios*, in Greek means 'sparking', 'fiery' or 'burning', 'flamboyant', 'scorching star' or 'scorcher' (Table 1); this epithet dates from at least the sixth century BC, as it was recorded in the Orphic *Argonautics* (Demetrakos, 1964: Volume 13).

Claudius Ptolemaeus (= Ptolemy, second century AD) mentions Sirius as "… the one in the mouth [of the dog], most bright, is called Dog and *hypokirros*." (Ptolemy, 1903: 142).[1] In a small differentiation, Johann Bayer in his *Uranometria* places the bright star on the greater dog's snout (see Bayer, 1603: Leaf 38).

Sirius can be seen from every inhabited region of the Earth's surface. The best time of the year to view it in our epoch is around 1 January, when it reaches the meridian at true midnight. In 500 BC this happened around 11 December.

3 SIRIUS IN GREEK AND ROMAN MYTHOLOGY

Canis Major probably depicts the faithful dog of Orion the Hunter, Laelaps. Orion is a nearby constellation. Indeed, Sirius can be located on the celestial sphere if we extend the line formed by the three stars of 'Orion's Belt' to the east.

In a tale of Greek mythology, Orion was in love with the goddess Artemis—the Greek equivalent of Diana. However, Apollo, in order to cancel the union of mortal Orion with his twin sister, sent a huge scorpion—represented now by the constellation Scorpius—that killed the unlucky hunter. After Orion's death, his beloved Artemis donated his exquisite hound to Procris, daughter of Erechtheus and one of Artemis' following nymphs. Procris later gave Laelaps to her husband Cephalus, who also was a famous hunter.

> In early classical days it was simple Canis, represented the dog Laelaps, the hound of Actaeon, or that of Diana's nymph Procris, or the one given to Cephalus by Aurora and famed for the speed that so gratified Jove as to cause its transfer to the sky. (Allen, 1963: 117).

Table 1: Greek names for Sirius.

Greek Name	Translit-eration	Latin spelling	Translation
Σείριος	Seirios	Sirius	Sparking
Αστροκύων	Astrokyon	Aster Cyon	The Dog Star

According to Eratosthenes' *Catasterismoi* (1997; cf. Eratosthenis, 1897), Laelaps is the dog given as a gift by Zeus to Europa. Their son, Minos, King of Crete, gave it later on to Procris because she healed him of some illness. Procris again donated it to her husband Cephalus. After Cephalus accidentally killed Procris, Zeus placed his dog in the homonymous constellation.

Less known versions refer to Sirius in connection with Cerberus, the wild three-headed dog that guarded the gates of the underworld (Hades), or with one of the hunting dogs of Actaeon, a renowned hunter and hero from Thebes, who, had the misfortune of wandering onto Artemis' bathing site. After this dog saw Artemis naked, she turned him into a deer and made his own dogs kill him.

Seirios was variously identified in myth. Some say that it was Maira, a daughter of the Titan Atlas, or that, according to the Roman poet Ovid (43 BC–AD 17), it was Maira, the faithful dog of King Ikarios—represented by Boötes.

Sirius may also have been associated with Orthros (= the morning twilight), hound of Geryon,[2] the giant of the West. The dog-star was probably also associated with the dog-goddess Hecate, daughter of the Titans Perses and Asteria.

It was also considered to represent Orion's hunting dog, pursuing Lepus the Hare or helping Orion fight Taurus the Bull; and is referred to in this way by Aratus, Homer and Hesiod (Theodossiou and Danezis, 1990: 114).

The ancient Greeks refer only to one dog, but by Roman times, Canis Minor appears as Orion's second hound (Allen, 1963: 132). According to Richard H. Allen (1963: 118), in Rome two additional names of Canis Major were

> Custos Europae [which] is in allusion to the story of the Bull who, notwithstanding the Dog's watchfulness, carried off that maiden; and Janitor Lethaeus, the Keeper of Hell, [who] makes him a southern Cerberus the watch-dog of the lower heavens, which in early mythology were regarded as the abode of demons.

4 SIRIUS IN ANCIENT GREEK AND ROMAN LITERATURE

4.1 The Ancient Greek References

In the Orphic *Argonautica*, in the scene where Zeus mates with Alcmene (Hercules' mother) it states: "… when the Sun was losing his Sirius-like triple lumenescence in his course and the black night was spreading from everywhere …" (Apollonius Rhodius, 1962: verse 121); or: "… just when for three consecutive days lost its light the flamboyant Sun ('Seirios Sun') …" (Petrides, 2005: 49).

Homer mentions Sirius in the *Iliad* (1924, V: 1-5, XXI: 25-32) and *Odyssey* (1919: v 4) as 'oporinós', the star of autumn, and as Orion's dog:

> Then Athena gave power and courage to Diomedes, so that excellently amidst the Greek multitudes he would be glorified and take shining fame everywhere. From his helmet and shield a flame was visible, which pours light without sleeping, as the autumn star, bathed in the Ocean, shines with its full light. (Homer, 1924, V: 1-5).

The 'autumn star' is actually Sirius, and appears every year, for the geographical latitude of Greece, in the predawn sky in late July or early August. This is mentioned also by Allen, who writes:

> Homer alluded to it in the *Iliad* as *Οπωρινός,* the Star of Autumn; but the season intended was the last days of July, all August, and part of September—the latter part of summer. The Greeks had no word exactly to our "autumn" until the 5th century before Christ, when it appeared in writings ascribed to Hippocrates. Lord Derby translated this celebrated passage: "A fiery light. There flash'd, like autumn's star, that brightest shines. When newly risen from his ocean bath …" (Allen, 1963: 120).

In *Iliad's* rhapsody XXII both Orion and Sirius are mentioned. The brightest star, Sirius, is referred to as Orion's dog. Homer presents Sirius as an ominous sign in the sky, as every summer it is connected with the so-called 'dog burnings':

> … like the star that comes to us in autumn, outshining all its fellows in the evening sky – they call it Orion's dog, and though it is the brightest of all stars it bodes no good bringing much fever, as it does, to us poor mortals. (Homer, 1924: Ch. 22, v 25-31ff).

At about the same time, or slightly later, Hesiod (1914), in his famous book *Works and Days*, discusses all the stars and constellations mentioned by Homer, with a special reference to Sirius. Indeed, he mentions Sirius in three different passages. In the first of these he gives some advice to his brother Perses about grape-gathering:

> But when Orion and Sirius are come into mid-heaven, and rosy-fingered Εος [Dawn] sees Arcturus, then cut

> off all the grape-clusters, Perses,[3] and bring them home. (Hesiod, 1914: v 609ff).

In the other two passages he speaks about the dog burnings: "For then the star Sirius passes over the heads of men, who are born to misery, only a little while by day and takes greater share of night …" (ibid.: 417) and "… for Sirius dries the head and the knees and the body is dry from the heat." (ibid.: 587).

Another work by Hesiod, *Aspis Irakleous* (*The Shield of Hercules*), is to a certain extent an imitation of *Aspis Achilleos* (*The Shield of Achilles*) as it is described in the *Iliad* (Homer, 1924). In this work, too, Hesiod mentions Sirius twice:

> Their souls passed beneath the earth and went down into the house of Hades; but their bones, when the skin is rotted about them, crumble away on the dark earth under parching Sirius. (Hesiod, 1914: v 139ff).

> And when the dark-winged whirring grasshopper, perched on a green shoot, begins to sing of summer to men—his food and drink is the dainty dew—and all day long from dawn pours forth his voice in the deadliest heat, when Sirius scorches the flesh, then the beard grows upon the millet which men sow in summer. (ibid.: v 391).

The ancient Greek lyric poet Alcaeus (seventh-sixth century BC) states the following about Sirius:

> Wet your lungs with wine: the dog star, Seirios, is coming round, the season is harsh, everything is thirsty under the heat, the cicada sings sweetly from the leaves ... the artichoke is in flower; now are women most pestilential, but men are feeble, since Seirios parches their heads and knees. (Alcaeus, 1982, 1993; cf. Alcaeus, 1922; Alcée, 1999).

Theognis (570–480 BC), a significant elegy poet from Megara, wrote several symposium poems, distinguished for their dignity and their respect for the gods. He even gave a rule for wine drinking, adding some information for the period around the rise of Sirius, calling it 'astrokyon' in Greek (Table 1): "Witless are those men, and foolish, who don't drink wine even when the Dog Star is beginning …" (Wender, 1984: 1039-1040).

The tragic poet Aeschylus (525–456 BC), in his tragedy *Agamemnon* (Aeschylus, 1955: v 966-968), also mentions Sirius, as 'seirios dog', while Euripides (480–406 BC) in both his tragedies *Hecuba* (2008) and *Iphigenia at Aulis* (1999; 2003; 2004) mentions it by its name, Seirios proper. Here are the relevant verses in their English translations:

> For while the stock is firm the foliage climbs, Spreading a shade, what time the Dog-star (seirios kynos) glows; And thou, returning to thine hearth and home, Art as a genial warmth in winter hours. (Aeschylus, 1955: v 967).

> Where Orion and Sirius dart from their eyes a flash as of fire … (Euripides, 2008: v 1104).

> Sirius, still shooting o'er the zenith on his way near the Pleiads' sevenfold track … (Euripides, 2004: 1A8).

The poet Lycophron of the Alexandrine 'Pleias'[4] (third century BC), in his only surviving poem, wrote of Cassandra's prophecy for the fall of Troy in which he referred to a 'Seirian ray', meaning more probably a solar ray (Scheer, 1958: Frag. 397).

The renowned Greek astronomical poem, *Phaenomena*, written by Aratus of Soloi in the Court of Antigonos Gonatas, the King of Macedonia (270 BC), refers to Seirios calling it 'Star of the Dog', 'Poikilos' (most probably meaning 'changing in color') and 'Seirios':

> A star that keenest of all blazes with a searing flame and him men call Seirios. When he rises with Helios (the Sun), no longer do the trees deceive him by the feeble freshness of their leaves. For easily with his keen glance he pierces their ranks, and to some he gives strength but of others he blights the bark utterly. Of him too at his setting are we aware. (Aratus of Soloi, 1921: 326-340).

Aratus also appended an adjective to the name, calling Sirius μέγας (= big, great); according to Allen. With this adjective he wanted only to characterize the brilliancy of the star, and not to distinguish it from the Lesser Dog. The Greeks did not know of the two Dogs at that time, nor did the comparison appear until the latter days of Vitruvius (Allen, 1963: 117). However, Allen does not mention the use of the same adjective (big, great) for Sirius by Eratosthenes.

Eratosthenes (276–194 BC) in his work *Astrothesiai* or *Catasterismoi* (Eratosthenes, 1997a; 2001) writes about the Dog, which he calls both *Isis* and *Seirios*, describing it as "… great and bright." However, he also uses the word *seirios* as an adjective, writing for example: "Such stars are called 'seirioi' by astronomers due to the quivering motions of their light." ('Seirioi' is the plural of 'seirios').

Apollonius of Rhodes (third century BC) in his *Argonautica*, a major epic poem that remolds in poetic form the mythical expedition of the Argonauts from Thessaly to Colchis on the Black Sea, also mentions Sirius in connection to the unbearable summer heat:

> But when from heaven Sirius scorched the Minoan Isles, and for long there was no respite for the inhabitants … (Apollonius Rhodius, 1962, Book II: 517).

Also, in another passage:

> But soon he appeared to her longing eyes, striding along loftily, like Sirius coming from ocean's depths, which rises fair and clear to see, but brings unspeakable mischief to flocks … (Apollonius Rhodius, 1962, Book III: 956-958).

Diodorus Siculus (ca. 80–20 BC), a Greek historian of Agyrium in Sicily, wrote forty books on world history, called *Library of History*, in three parts: mythical history of peoples (both non-Greek and Greek) up to the Trojan War; history up to Alexander's death (323 BC); and history up to 54 BC. From his writings we have complete Books I-V (Egyptians, Assyrians, Ethiopians, Greeks) and Books XI-XX (Greek history 480-302 BC); and fragments of the rest. He was an uncritical compiler, but used good sources and reproduced them faithfully. He is valuable for details that are not recorded elsewhere, and as evidence for works now lost, especially the writings of Ephorus, Apollodorus, Agatharchides, Philistus and Timaeus. Diodorus Siculus writes in *The Library of History*:

> A plague [i.e. a pestilence arising in a time of drought] prevailed throughout Greece … [and] the sacrifice he offered there was on behalf of all the Greeks. And since the sacrifice was made at the time of the rising of the star Seirios, which is the period when the Etesian winds customarily blow, the pestilential diseases, we are told, came to an end. Now the man who ponders upon this event may reasonably marvel at the strange

turn which fortune took; for the same man [Aristaios] who saw his son [Aktaion] done to death by the dogs likewise put an end to the influence of the star which, of all the stars of heaven, bears the same name [i.e. Seirios, which was known as the dog-star] and is thought to bring destruction upon mankind, and by so doing was responsible for saving the lives of the rest. (Diodorus Siculus, 1939, IV: 81.1).

Satirical author Lucian of Samosata (AD 120–190) mentions Sirius in his fantasy novel *Trips to the Moon* (original title: *A True Story*), where he narrates the imaginary war between earthlings with the dog-faced inhabitants of Sirius, who are called Cynobalani:

Near them were placed the Cynobalani [88b] about five thousand, who were sent by the inhabitants of Sirius; these were men with dog's heads, and mounted upon winged acorns: some of their forces did not arrive in time; amongst whom there were to have been some slingers from the Milky Way, together with the Nephelocentauri; [88c] they indeed came when the first battle was over, and I wish [88d] they had never come at all: the slingers did not appear, which, they say, so enraged Phaëton that he set their city on fire. (Lucian, 2010).

Apart from this work, which probably could be considered as the first science fiction novel, Lucian mentions Sirius in other works, as 'the Dog of Orion': "For this reason the poet, in order to praise the Dog of Orion, called it lion-tamer." (Lucian, 1911: Volume 6).

In *The Almagest*, Ptolemy (1903: Books VII and VIII) called Sirius *Αστροκύων* (*Astrokyon* = Dog star; see Table 1), writing that it was a red star like Antares (Alpha Scorpionis) and Aldebaran (Alpha Tauri). Ptolemy

… and his countrymen knew it by Homer's title, and often as *Αστροκύων*, although it seems singular that the former never used the word *Σείριος*. (Allen 1963: 118).

Ptolemy used Astrokyon as the location for the celestial globe's central meridian.

In the same century, Plutarch writes in his work *De Iside et Osiride* that the constellation of the Dog was dedicated to goddess Athena-Isis:

And the ship that Greeks call 'Argo' was built in the form of the ship of Osiris; it was enlisted among the constellations as an honor and it moves not far from the constellations of Orion and of the Dog, from which the former is dedicated by the Egyptians to Horus, while the latter is dedicated to Isis. (Plutarch, 1932: 354c-359f).

According to Allen (1963: 120),

Plutarch called i*t Προόπτης*, the Leader, which well agrees with its character and is an almost exact translation of its Euphratean, Persian, Phoenician, and Vedic titles; but *Κύων, Κύων σείριος, Κύων αστήρ, Σείριος αστήρ, Σείριον άστρον, or simply το άστρον*, were its names in early Greek astronomy and poetry.

According to the architect and author Nikolaos V. Litsas (2008: 40):

Plutarch in his opus *'De Iside et Osiride'* (354c and 366a) writes that Isis, which he identifies with Athena, is Sirius, the well-known star of the Dog. This is why Parthenon, the temple of Athena in the Acropolis of Athens is oriented in such a way that once per year, on July 2 [modern date], when the Sun passes above Sirius, the rays of the rising Sun penetrate in the sacrosanct of the sanctuary.

Quintus Smyrnaeus was a Greek epic poet who flourished in Smyrna in the late fourth century AD. His only surviving work is a fourteen-book epic entitled the *Fall of Tro*y (or *Posthomerica*). This poem covers the period of the Trojan War from the end of Homer's *Iliad* to the final destruction of Troy. Quintus is believed to have drawn heavily from works of the poets of the Epic Cycle, including such now-lost works as the *Aethiopis* and the *Little Iliad*:

From the ocean's verge upsprings Helios (the Sun) in glory, flashing fire far over earth - fire, when besides his radiant chariot-team races the red star Seirios, scatterer of woefullest diseases over men. (Quintus Smyrnaeus, 1913, 8: 30ff).

In the same period (fourth century AD) we have Anonymous*,* perhaps Pamprepius of Panopolis, referring to Seirios, as the dog-star (*kynos astraios*):

The snow-white brightness of blazing Phaethon [the Sun] is quenched by the liquid streams of rain clouds, and the fiery … [lacuna]... of the dog-star [(kynos astraios)] is extinguished by the watery snowstorms. (Anonymous, 1950: No. 140).

Nonnus, a Greek epic poet of the fifth century AD from the Egyptian city of Panopolis, writes in his *Dionysiaka* twice about the dog burnings of Sirius:

He sent an opposite puff of winds to cut off the hot fever of Sirius. (Nonnus, 1940, 5: 275ff).

He [Aristaios] had not yet migrated to the island formerly called Meropis [Kos]: he had not yet brought there the life breathing wind of Zeus the Defender [the Etesian Winds], and checked the fiery vapour of the parched season; he had not stood steel clad to receive the glare of Seirios, and all night long repelled and clamed the star's fiery heat—and even now the winds cool him with light puffs, as he lances his hot parching fire through the air from glowing throat. (ibid*.* 13: 253 ff*)*.

4.2 The Ancient Latin and Byzantine References

According to Allen (1963), the Romans adopted their Canis from the Greeks and kept that name forever, sometimes in its even diminutive form *Canicula* (with the adjective *candens*, meaning 'shining'). There are also the names 'Erigonaeus' and 'Icarius' from the fable of the dog 'Maera'—which by itself means 'Shining'. In the fable, the dog's mistress, Erigone, is transformed into Virgo, her master, Icarius, is transformed into Boötes, and Maera becomes Sirius. According to Allen (1963: 118), Ovid alluded to this in his *Icarii stella proterva canis* [*Amor*. II.16.4]; and Statius mentioned the *Icarium astrum*, although Hyginus [*Fab*. 130] had ascribed this to the Lesser Dog.

From the Latin authors and poets, Virgil in his *Georgics*, tragic poet Seneca (2003) in his *Oedipus*, epic poet Valerius Flaccus in his *Argonautica* (1934) and poet Statius in his *Silvae* (2003), all refer to Sirius mostly as the 'star of the dog'.

Virgil (first century BC) writes:

The time when the sultry Dog Star [Canis] splits the fields that gape with thirst … (Virgil, 1916: *Georgics* 2, 353 ff).

And now Sirius (the Dog Star), fiercely parching the thirsty Indians, was ablaze in heaven, and the fiery Sun had consumed half his course; the grass was withering and the hollow streams, in their parched throats, were scorched and baked by the rays down to the slime. (ibid. 2: 425 ff).

Virgil also writes in *Aeneid's* Books III and X about Sirius:

> Just as when comets glow, blood-red and ominous in the clear night, or when fiery Sirius, bringer of drought and plague to frail mortals, rises and saddens the sky with sinister light. (Virgil, 2002: Book X: v 271-273).

> They relinquished sweet life, or dragged their sick limbs around: then Sirius blazed over barren fields: the grass withered, and the sickly harvest denied its fruits (Virgil, 2002: Book III: v 140-142).

Seneca writes in his Roman tragedy *Oedipus* (first century BC):

> [Thebes was plagued by drought and] … No soft breeze with its cool breath relieves our breasts that pant with heat, no gentle Zephyrus blows; but Titan [Helios, the Sun] augments the scorching dog-star's [Seirios'] fires, close-pressing upon the Nemean Lion's [i.e. Leo, zodiac of mid-summer] back. Water has fled the streams, and from the herbage verdure. Dirce[5] is dry, scant flows Ismenus' stream, and with its meagre wave scarce wets the naked sands. (Seneca, 2004: *Oedipus*, 37 ff).

The Roman Valerius Flaccus writes in his epic *Argonautica* (first century BC):

> When Sirius in autumn sharpens yet more his fires, and his angry gold gleams in the shining tresses of night, the Arcadian [planet Mercury] and great Jupiter [the planet] grow dim; fain are the fields that he would not blaze so fiercely in heaven, fain too the already heated waters of the streams. (Valerius Flaccus, 1934, 5: 370 ff).

Horace (Quintus Horatius Flaccus) mentions Sirius in his *Satires* (Horace, 1870: V). Finally, Statius in *Silvae* (Roman poetry, first century AD) refers to Sirius:

> T'was the season when the vault of heaven bends its most scorching heat upon the earth, and Sirius the Dog-star smitten by Hyperion's [the Sun's] full might pitilessly burns the panting fields. (Statius, 2003: 3, 1, 5).

According to Allen (1963: 118), Sirion and Syrius occasionally appeared with the best Latin authors; and the *Alfonsine Tables* of 1521 had Canis Syrius.

Arab astronomers, influenced by Ptolemy and the other Greek astronomers, called Sirius 'Al Shiʿrã', which means 'the shining one', because of its extreme brightness (Allen, 1963: 121).

The scholar and Byzantine Princess, Anna Comnena (Komnene), in her large work *Alexias* (1148) mentions the 'star of the Dog':

> … even though it was summer and the sun had passed through Cancer and was about to enter Leo – a season in which, as they say, the star of the Dog rises … (Anna Comnena, 1928, 1969: I, Book 3, XII.4).

Finally, the Byzantine scholar, medical doctor and astronomer Georgios Chrysococca (fourteenth century) mentions Sirius as *Siaèr Jamanè* in his astronomical work *Synopsis tabularum persiacarum ex syntaxi Persarum Georgii medici Chrysococcae* (Chrysococca, 1645: 1347). Allen refers to this work as 'Chrysococca's *Tables*'. It was published by Ismael Bullialdus in Paris in 1645.

As a general observation, it can be noted that the ancient Greeks and Romans generally did not distinguish the constellation Canis Major from the star Sirius by name, but often called both simply 'Dog' (Ceragioli, 1996: 121).

5 MAIRA

Sirius in the annual period from its heliacal rising to 22 August was also called 'Maira', a word coming from the ancient Greek verb *marmairo*, which means 'to shine' (*Palatine or Greek Anthology*, 1917, 9: 55). As a name, Maira (or Maera) therefore became the star-goddess of the scorching dog-star Seirios, whose rising in conjunction with the Sun brought on the scorching heat of midsummer. Like the Pleiades and Hyades, Maira was a starry daughter of the Titan Atlas. She married a mortal King, the Arcadian Tegeates, the son of King Lycaon and the eponymous founder of the Arcadian town of Tegea. The precise location of her tomb was not known, and both Tegea and Mantineia laid claim to it. Pausanias (1935, VIII: 12, §4; 48, §4; 53, §1) thinks that Maira was the same as the Maira whom Odysseus saw in Hades (Pausanias: "[Odysseus sees the ghosts of heroines in the Underworld:] I saw Maira too." (Homer, 1919: 11, 326 ff).

In his *Description of Greece*, the Greek traveller Pausanias (second century AD) writes about the story of the nymph Maira, and reports all the mythical and historical information associated with her:

> There are also tombs [in Tegea, Arcadia] of Tegeates, the son of Lykaon, and of Maira, the wife of Tegeates. They say Maira was a daughter of Atlas, and Homer makes mention of her in the passage where Odysseus tells to Alkinous his journey to Hades, and of those whose ghosts he beheld there. (Pausanias, 1935: 8.48.6).

> The ruins of a village called Maira, with the grave of Maira … For probably the Tegeans, and not the Mantineans, are right when they say that Maira, the daughter of Atlas, was buried in their land. (ibid.: 8.12.7).

> Apollon and Artemis, they say, throughout every land visited with punishment all the men of that time who, when Leto was with child and in the course of her wanderings, took no heed of her when she came to their land [Tegea in Arcadia]. So when the divinities came to the land of Tegea, Skephros, they say, the son of Tegeates, came to Apollon and had a private conversation with him. And Leimon [= water-rich meadow], who also was a son of Tegeates, suspecting that the conversation of Skephros contained a charge against him, rushed on his brother and killed him. Immediate punishment for the murder overtook Leimon, for he was shot by Artemis. At the time Tegeates and Maira sacrificed to Apollon and Artemis, but afterwards a severe famine fell on the land, and an oracle of Delphi ordered mourning for Skephros (ibid.: 8.53.2).

5.1 Maira/Maera as a Dog in Greek and Roman Mythology

Maera was the faithful hound of Icarius, an Athenian King, and follower of the wine-god Dionysus. Icarius was the father of the maiden Erigone.

This is the whole story, according to the Roman mythographer Hyginus (second century AD): Dionysus had taught Icarius how to make wine. One day, Icarius was travelling on the road in a wagon, when he met some shepherds. Icarius shared his wineskin. The shepherds fell into a drunken stupor and when they woke up they thought Icarius had tried to poison them, so they killed him and buried him under a tree.

Concerned for her father's whereabouts, Erigone set off with Maera to find him, and Maera led the maiden to the grave. The hound howled in its grief, before leaping off the cliff to its death. Erigone was also distraught over her father's death, and hanged herself from the tree above her father's grave.

Taking pity on his followers and the hound, Dionysus placed them in the sky as the constellations Boötes (Icarius), Virgo (Erigone), and Maera as the constellation with the star Sirius. So, Maira was closely identified with the *Kyon Ikarion*, the dog of Icarius, which along with her star formed the constellation Canis Major. Others say the constellation Canis Major or Canis Minor was Maera.

Dionysus did not let the shepherds escape for murdering Icarius. Dionysus caused madness in Athens, where all the maidens hanged themselves. The Athenians found out from the oracle what had caused this phenomenon so they captured the murderers and hanged them. From that time onwards, the Athenians held an annual festival in honour of Icarius and his daughter during the grape harvest, where the girls swung on trees in swings. In a different version, the shepherds found refuge in the land of the Keans (i.e. on the island of Kea).

5.2 Maira as the Star Seirios

Callimachus, the Hellenistic poet of the third century BC, writes:

> The [Kean] priests of Zeus Aristaios Ikmaios (the Lord of Moisture): priests whose duty is upon the mountaintops to assuage stern Maira [Seirios] when she rises. (Callimachus, 1958: *Aetia Fragment* 3. 1).

The Greeks believed that the constellation Canis Minor and the Dog Star (Sirius) heralded the coming of a drought.

In the words of Hyginus:

> Jupiter [Zeus], pitying their misfortune, represented their forms among the stars … The dog, however, from its own name and likeness, they have called Canicula. It is called Procyon by the Greeks, because it rises before the greater Dog. Others say these were pictured among the stars by Father Liber [Dionysus].
>
> [The constellation] … Canicula rising with its heat, scorched the land of the Keans, and robbed their fields of produce, and caused the inhabitants, since they had welcomed the killers to be plagued by sickness, and to pay the penalty to Icarus with suffering. Their king, Aristaeus, son of Apollo and Cyrene, and father of Actaeon, asked his father by what means he could free the state from affliction. The god bade them expiate the death of Icarus with many victims, and asked from Jove that when Canicula rises he should send wind for forty days to temper the heat of Canicula. This command Aristaeus carried out, and obtained from Jove [Zeus] the favour that the Etesian winds should blow … (Pseudo-Hyginus, 1960).

It should be noted that the brightest star in the constellation of Canis Minor, Alpha Canis Minoris, is called Procyon (from the Greek words *pro* = before and *kyon* = dog) because it rises just before Sirius (the Great Dog).

The epic poet Nonnus of Panopolis (previously mentioned in Section 3.1) also calls Sirius 'Maira's star' in his *Dionysiaka* (Nonnus, 1940, Book 5: v. 220-222).

6 'DOG BURNINGS' AND 'DOG DAYS'

In antiquity the heliacal rise of Sirius had been connected with a period of the year of extremely hot weather, *κυνικά καύματα* (kynica kavmata, canine burnings). This period corresponded to late July, August and early September in the Mediterranean region. The Romans also knew these days as *dies caniculariae*, the hottest days of the whole year, associated with the constellation of the Great Dog. Ancient Greeks theorized the extra heat was due to the addition of the radiation of bright Sirius to the Sun's radiation.

In ancient Greek folklore, people referred to the summer days after the heliacal rise of Sirius as 'dog burnings'. The term has no relation to the Dog-star or the constellation, but rather to dogs in general, thinking that only dogs were crazy enough to go outside when it was so hot. This idea persisted through the centuries and can be found in modern Greek folklore as the belief that during the hot days of July and August, and especially between 24 July and 6 August, dog bites are infectious (Theodossiou and Danezis, 1990: 115).

According to an ancient myth, the inhabitants of the island Kea were dying from a famine caused by a drought brought on by the dog burnings around 1600 BC. Then, the god Apollo made a prophesy that Phthia[6] Aristaeus, the god's son, could be summoned to help them. Upon arriving on Kea, Aristaeus performed rituals, cleansings and sacrifices to Zeus Ikmaeus, the lord of the rains and the skies, and to Apollo the Dog.

Both gods listened to his pleas and they sent the Etesian Winds, northern winds that have blown ever since across the Aegean Sea during mid-summer, so that people could survive the unbearable heat. After that, the people of Kea, incited by Aristaeus, made sacrifices to the constellation of Canis Major and to Sirius; in order to remember his beneficence, they honored Aristaeus as 'Aristaeus Apollo' and pictured his head on the one side of their coins, while on the other side they depicted Sirius crowned with rays (Wendel, 1935: 168.8-12). Indeed, ancient coins retrieved from the island and dating to the third century BC feature dogs or stars with emanating rays, highlighting Sirius' importance (Holberg, 2005). From then on, the islanders of Kea used to predict from the first appearance of Sirius (its heliacal rising) whether the following year would be healthy or not: if it rose clear, it would portend good fortune; if it was misty or faint then it foretold (or emanated) pestilence.

According to Allen (1963: 126), even the 'father of Medicine', Hippocrates, writing *circa* 460 BC, stressed in his *Epidemics* and *Aphorisms* the influence of Sirius on the weather and on the physical aspect of humans; the same he believed for Arcturus. Some minor doctors in antiquity were arguing that the 'dog star' played some role in the appearance of cases of rabies (Ideler, 1841).

In ancient poetry Sirius is mentioned as a star with a particularly negative influence, a belief that is evident in the Homeric verse "… the most bright one, yet it bodes no good to us poor mortals." (Homer, 1924: XXII: 25-31).

Socrates appears to swear to Apollo, the Dog, in his *Apology* (and not to curse, as some have argued): "…

and, by the Dog, oh men of Athens – for I must tell you the truth." (Plato, 2002: 22a-22b). Similarly, Plato (*Platonis opera*, 1900-1907) in *Gorgias* swears to the god Kyna (Dog) that what he writes is true: "By the Dog, Gorgias, a lengthy conversation is needed about how these things are, so that we can analyze them in extent." [461b].

It should be noted that Kynas (Sirius) is one of the numerous appellations of Apollo, the god of solar and spiritual light, and of music.

Professor Pericles Theochares (1995) writes about the Kea island myth:

> This myth alludes to the relation of Sirius with the Earth. The sacrifices were made to Zeus Meilichius,[7] a god of the weather, of the sun and rain, and to Sirius, who causes the dog burnings on Earth; they believed that not only the Sun is responsible for the great heat of the summer, but also Sirius when standing next to the Sun. This was probably the belief of the builders of the Argolis pyramids, orienting their entrance corridors towards the azimuth of Sirius.

Also, for Manilius (1977: 5.208) the Dog-star is, in effect, a fiery mad dog that "… raves with its own fire."

On the influence of Sirius on 'dog burnings' Geminus (1898: 17.26) writes in *Isagoge*:

> For everyone assumes that the star has a peculiar power and is the cause of the intensification of summertime heat, when it rises with the sun.

7 THE RED COLOR OF SIRIUS

It is an interesting fact that the star's color is mentioned by most ancient authors as red, while today, we know it is a star of spectral type A1 V, and is white.

In essence, there is a series of ancient references about Sirius from different civilizations that describe it as a red star (Allen 1963: 128). In the fourth century AD epic poet Quintus Smyrnaeus (1913: 8. 30ff) mentions the 'red star' Sirius in the *Fall of Troy*.

From the Roman literary figures, Horace (1870) refers to Sirius as a red star (*rubra*), while Seneca (2004) writes (ca. AD 35) that: "… when the air is clear, then Sirius appears more red than planet Mars." (Whittet, 1999: 335).

In 1927, T.J.J. See reported on references to the color of Sirius from the second century AD to the tenth century AD:

> Many classical literature artists – Cicero, Horatius and Seneca to name a few – mention Sirius as a red star. Ptolemy goes even further in his description and claims that Sirius is fire-red in color. On the other hand, the Arabian Astronomer Abd-al Rahman Al-Sufi contradicts them and classifies Sirius as a white star in his catalogue dating around 925 BC, 850 years after Ptolemy. Also in *Carmina Burana*, based on the pastoral songs of the 13th century, the whiteness of Sirius is compared to that of ivory. Geoffrey Chaucer, in 1391, relates that the Arabians call Sirius Al-Habur, the beautiful white star. Chinese Astronomer and Historian Simaquian (91 BC), Roman artists Hyginus, Manilius and Avienus, (360 BC), and Archbishop Saint Isidore of Seville all support the opinion that Sirius is a white star.

According to Holberg (2007: 157),

> One of the most contentious and long-running mysteries regarding Sirius originated in the 2nd century AD with what appears to be a casual comment made by the Alexandrine astronomer/astrologer Claudius Ptolemy (Chapter 3). Books VII and VIII of Ptolemy's *Almagest* contain one of the earliest and most famous of the ancient star catalogues, in which Ptolemy lists the positions and brightness of some 1022 stars. He comments on the color of only six of these stars – Betelgeuse, Aldebaran, Pollux, Arcturus, Antares, and Sirius – and assigns the color red to each. In particular, for Sirius in the constellation Canis Major, he states its location, on the dog's mouth, as well as its relative brightness and color: bright and red.

Besides the references already mentioned, Horace (first century BC), Seneca (first century AD) and Aratus (third century BC) also described Sirius as being red in color. Various early translations of their works, including those by Cicero and Germanicus, drew no concern from anyone about Sirius' redness. In fact, it was not until 1760 (after a translation by Samuel Johnson) that anyone voiced skepticism about the observations.

There is a quote from Hephaestion of Thebes (Ceragioli, 1996) describing how the star's color upon rising was inspected as an omen. Curiously, he mentions that the star is 'white' (*lefkòs*). This agrees with Hyginus' description of Sirius as being remarkable for its 'candor', which is usually—from the context—interpreted as 'brightness', but almost certainly implies a white color. Add to these Manilius and Avienus, who explicitly describe the star Sirius as blue or perhaps blue-white.

Since we can see that there was an awareness and assumed meaning in the color of Sirius, perhaps Ptolemy's (1903) characterization of the star as 'hypokirros' is a guess at the star's 'actual' color, since we do not know if he shared an assumption with Seneca that celestial bodies have no inherent color. There is very little context to make a guess, although several astronomers (most notably See) took up the task and piled up dubious citations leading ultimately to the conclusion that the ancients saw Sirius as a 'fiery red' star all the time. So probably the correct question to ask here is not really 'Was Sirius red in antiquity?', but rather 'Did Sirius sometimes appear to be red, or was it sometimes described as red (or other colors) in antiquity, and if so what did this mean?'.

The certain thing is that the impression Sirius currently gives to a visual observer is of a 'cold white' star (i.e. with a lightly bluish tint) when it is high enough above the horizon, an impression which agrees with its modern spectral classification as an A1 star.

Another explanation involves the modern finding that Sirius is part of a binary star system. The fainter star of the pair (the companion), Sirius B, is a white dwarf. This means that it started with the larger mass of the two stars of the system, as it evolved faster and became a stellar remnant after it first passed from the evolutionary stage of the red giant. In that stage the fiery red light of Sirius B would dominate over the cold white light of Sirius A, thus causing all the ancient color descriptions mentioned in the previous paragraphs. Of course, the main weakness of this explanation scheme is that the time needed for a star to pass from the stage of a bright red giant to that of a clear white dwarf is, according to theoretical astrophysics, much longer than a few thousand years, so this can not be the reason for the ancient 'red color' of Sirius.

A more plausible explanation is that perhaps some interstellar cloud in the space between the Solar System and Sirius was absorbing the shorter wavelengths of the Sirian light, thus causing its ancient red appearance. This is not so probable, though, due to the relatively small distance of Sirius, only 2.64 parsecs. A much more feasible explanation is that the ancient tradition was created by the color of Sirius when it was very low in the sky, near the horizon. In this position Sirius—like other stars—appeared to twinkle, to move rapidly around a mean position and to change its color in tenths of a second, exhibiting a variety of very intense nuances more intense than its true color. All three phenomena are caused by the Earth's atmosphere. Moreover, Sirius is only a few times fainter than Venus in the terrestrial sky, and it is known that Rayleigh scattering of Venus' light—which is a function of the light's wavelength—reddens it considerably when the planet is near the horizon (the phenomenon of course is much better known and is more impressive in the case of the Sun and the Moon). Now Sirius, as we saw earlier, was intensely observed by the ancient Greeks when it first appeared in its heliacal rising, that is, when it was just above the eastern horizon during the last hour of the night. So, unlike today, the most frequently-observed image of Sirius in antiquity was when it was very close to the horizon. Hence, this explanation is by far the most probable.

8 CONCLUSIONS

In this paper we have only studied ancient Greek, Roman and Byzantine references to Sirius.

The name *seirios*, which means sparking, fiery or burning, flamboyant, scorching star or scorcher, turned out to be very ancient in the form of an adjective, as it occurred in the Orphic *Argonautics*, even though it did not relate to a specific star. Homer, also, did not use *seirios* for the star, preferring to call it the 'autumnal star' and 'Orion's Dog'. Hesiod, writing at about the same time (circa 800 BC) in two different works, calls this particular bright star *Seirios*, which is a most important turning point in the star's lore. Additional references to Sirius and its various names were in the works of Aratus and Eratosthenes.

After the two great epic poets (Homer and Hesiod), the Greek lyrical poet Alcaeus (seventh to sixth centuries BC) also mentioned the star as *Seirios* and the 'Dog's star'. Theognis of Megara (570–480 BC) refers to it in a single-word form (*Astrokyon*).

Next came the tragic poets Aeschylus and Euripides; the former with his 'seirios dog', while the latter used just Seirios as a proper name.

Lykophron of Alexandria (third century BC), a well-known poet of that period, wrote of a 'seirian ray' (most probably meaning sunray). Eratosthenes (third century BC) in his famous *Catasterismoi*, calls the star both *Isis* and *Seirios*, still using, however, the word *seirios* as an adjective; the use of the word as a name for the specific star had nevertheless been widespread by then, as is evident by the *Argonautics* of Apollonius of Rhodes during the same years (two different passages), and by Diodorus Siculus in *The Library of History*.

Passing to the AD years, Lucian of Samosata mentioned Sirius by that name in his *True Story* or *Trips to the Moon*. The leading astronomer of the time, Ptolemy, followed the older tradition by calling the star *Astrokyon*. Plutarch called it *Προόπτης*, the Leader; but *Κύων*, *Κύων σείριος*, *Κύων αστήρ*, *Σείριος αστήρ*, *Σείριον άστρον*, or simply *το άστρον* ('the star') were its names in early Greek astronomy and poetry.

Also considered were works from the fourth century AD, of epic poet Quintus Smyrnaeus and Pamprepius of Panopolis. One century later, epic poet Nonnus of Panopolis, in his main work *Dionysiaka*, wrote twice about Sirius and the 'dog burnings'.

The Latin authors and poets who mentioned the star are Virgil in his *Georgics* and the *Aeneid* (Books III and X), Seneca in his *Oedipus*, and Valerius Flaccus in his *Argonautica*, and the poet Statius in his *Silvae* (3.1.5).

According to Allen (1963: 118): "*Sirion* and *Syrius* occasionally appeared with the best Latin authors; and the *Alfonsine Tables* of 1521 had *Canis Syrius*."

In the mid-twelfth century, Byzantine Princess Anna Comnena (Komnene) in her opus *The Alexiad* (1148) also mentioned Sirius as the 'Dog's star'. Finally, the Byzantine scholar, medical doctor and astronomer Georgios Chrysococca, two centuries later, in his astronomical work *Synopsis tabularum* …, mentioned Sirius as *Siaèr Jamanè*.

An important additional element is that Sirius from its heliacal rising up to 22 August bore the special appellation Maira, both a Greek word stemming from the verb *marmairo*, which means 'to shine', and the name of a dog from Greco-Roman mythology. The name Maira appears for Sirius in poems by Callimachus in the third century BC and Nonnus (as 'Maira's star') eight centuries(!) later.

Mythology associated with the star and its constellation is also plentiful, a fact that indicates their significance. Thus, according to Eratosthenes, Sirius is Laelaps, the faithful dog of Orion the Hunter. Another legend puts in its place Cerberus, the horrid three-headed dog that guarded the World of the Dead, or with one of the hunting dogs of Actaeon, a renowned hunter and hero from Thebes.

The myths about Sirius also involve Orthrus (the dog of Geryon the giant), Maira (the faithful dog of Icarius, placed in the sky by the god Dionysus according to Ovid and Hyginus), and Hecate, the goddess protecting dogs, who was the daughter of the Titans Perses and Asteria.

A Roman myth refers to Canis Major as Custos Europae, the dog guarding Europa; and as Janitor Lethaeus, the watch-dog of the 'lower heavens', i.e. the Keeper of Hell.

The significance of the brightest star in the sky which emerges from all of these references is evident. As for the traditional ancient characterization of Sirius as 'red', this most likely arose from the custom of watching the star on the nights of its heliacal rising, when it was very low in the sky.

10 NOTES

1. All translations into English in this paper were made by the authors.
2. Geryon, son of Chrysaor and Callirrhoe and grand-

son of Medusa, was a giant on the island of Erytheia (Hesiod, 1914: 979 ff) in the far west of the Mediterranean. According to Hesiod (1914: 287 ff), Geryon had one body and three heads, whereas the tradition followed by Aeschylus (1955: 869 ff) gave him three bodies. He owned a herd of magnificent red cattle, guarded by a two-headed hound named Orthrus, which was the brother of Cerberus. In the *Bibliotheke* of Pseudo-Apollodorus (1913: 2. 5. 10) the tenth labour of Heracles was to obtain the Cattle of Geryon.
3. Perses was the brother of Hesiod. He is mentioned several times in the *Works and Days*.
4. Pleias is a 'group of seven stars' and refers to the seven tragic poets who wrote at Alexandria under Ptolemy Philadelphus in the third century BC: Alexander Aetolus, Philiscus, Sositheus, Homerus, Aeantides, Sosiphanes and Lycophron.
5. In Greek Mythology, Dirce was the wife of the Theban King, Lycus. She was devoted to the god Dionysus, who caused a spring to flow where she died, near Thebes (Tripp, 1970: стр. 213).
6. Phthia (Greek: Φθία or Φθίη; transliterations: Fthii (modern), Phthíē (ancient)) in ancient Greece was the southernmost region of ancient Thessaly, on both sides of the Othrys Mountain. It was the homeland of the Myrmidones tribe, who took part in the Trojan War under Achilles (Hornblower, 2004).
7. Meilichius is the surname of Zeus, the protector of those who honored him with propitiatory sacrifices.

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RADIO ASTRONOMY AND THE *JOURNAL OF ASTRONOMICAL HISTORY AND HERITAGE*

While the *Journal of Astronomical History and Heritage* publishes papers, IAU reports, and book reviews on a range of topics, the history of radio astronomy is of special interest. Papers published to date are:

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Unsolicited papers and book reviews are always welcome, but first please email the Editor (Wayne.Orchiston@jcu.edu.au) for further information and for a 'Guide to Authors'.

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THE COUDÉ EQUATORIALS

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Abstract: Between 1884 and 1892, no fewer than seven coudé equatorials were installed in France, Algeria and Austria. Invented by Maurice Lœwy, these equatorials allowed the observer to sit comfortably in a closed room, with all the controls and readings at hand. However they were expensive, they required two flat mirrors, which were a source of concern because of their thermal distortion, and their mechanics was complex and delicate, so that they did not succeed in replacing the conventional equatorials in spite of their advantages. Only two are preserved, in Lyons and in Algiers. We describe in detail these instruments, their history and their use.

Keywords: coudé equatorial, Lœwy, Paris Observatory, Algiers Observatory, Besançon Observatory, Lyons Observatory, Nice Observatory, Vienna Observatory, refraction, aberration.

1 INTRODUCTION

In 1824, Joseph von Fraunhofer (1787–1826) delivered to the Dorpat Observatory (now located at Tartu, in Estonia) a 23-cm aperture equatorial telescope which was considered as practically perfect.[1] It was taken as the model for most of the great equatorials built during the nineteenth century and the first half of the twentieth century (Lequeux, 2009b). Still, these instruments required large domes, and the observer had to stand or sit in the open air on clumsy movable stairs which could sometimes be dangerous. Several solutions were proposed in order to make observation more comfortable.

A first possibility was to build the equatorial mounting so that the head of the observer was located at the crossing of the right ascension and declination axes, so that he did not have to move when observing in different directions. This was realized in the *comet finder*, which was invented independently around 1859 by the Austrian-French instrument-maker Johann Josef Brunner (1804–1862) and the French astronomer and mathematician Antoine Yvon-Villarceau (1813–1883). This instrument is described by Yvon-Villarceau (1868). One was built for the Marseilles Observatory.[2] Another survives at the Strasbourg Observatory. A considerably larger instrument with the same properties was installed in 1896 in Berlin-Treptow by Steinheil und Söhne for the optics and Hoppe for the mechanics. With its 68-cm diameter and 21-m focal length, this was a real monster which remained unique.[3]

Siderostats and cœlostats offer another possibility. These instruments consist of one or two flat mirrors, driven by a clockwork or an electric motor, which reflect the light from the observed portion of the sky to a horizontal, fixed direction. This light feeds a fixed telescope so that the observer can be in a comfortable position in a heated room, and heavy instruments can be mounted at the focus. The best siderostats (with a single mirror) are due to Léon Foucault (1819–1868): see Tobin (1993: 266-267 and 274-276). A monster Foucault siderostat, 2-m in diameter, feeding a 58-m length, 125-cm diameter horizontal refractor, was built for the 1900 Universal Exhibition on Paris but was too impractical for real use (Launay, 2007; also see the image in Lequeux, 2009b: 10). Siderostats are unfortunately delicate and expensive, and their present use is essentially limited to solar telescopes.

The third solution is the coudé equatorial, which was invented by Maurice Lœwy (1833–1907) and is the subject of this paper. Previous papers on the coudé equatorials are by Weimer (1982) and Lequeux (2010b).

2 LŒWY'S INVENTION

Moritz Löwy (or Maurice Lœwy; see Figure 1) was born in Vienna on 15 April 1833 (Anonymous, 1907; Dyson, 1908). He started an astronomical career at the Vienna University Observatory, observing comets and asteroids and calculating their orbits. However, being a Jew, he had no chance of obtaining a permanent position in anti-Semitic Austria. Urbain Le Verrier (1811–1877), the Director of the Paris Observatory, knew about his researches thanks to the recommendation of the Director of the Vienna Observatory, Karl Ludwig von Littrow (1811–1877), and invited him to come to France. He arrived on 15 August 1860. By this time he had already published about ten papers on cometary and planetary orbits in *Astronomische Nachrichten*. The following year, he was appointed *Astronome adjoint*. In 1869 he changed his name to Maurice Lœwy and obtained French citizenship. The remainder of his career was at the Paris Observatory, where he was appreciated for his professional and human qualities.

Figure 1: Maurice Lœwy (1833–1907), at the start of the twentieth century (© Bibliothèque de l'Observatoire de Paris).

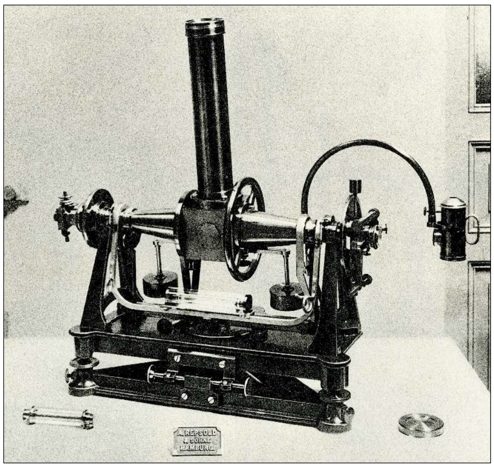

Figure 2: A coudé transit telescope by Repsold and Söhne, 1874 (after Repsold, 1914; © Bibliothèque de l'Observatoire de Paris).

He served as the Director from 1896 until his death on 15 October 1907, which occurred during a meeting of the *Conseil des Observatoires.*

Lœwy was very competent in astronomical instrumentation, especially for positional astronomy, and was a skilful observer. He was also familiar with surveying instruments, since geodesy was to some extent amongst the tasks of the observatories. Some meridian instruments and a large fraction of the theodolites built in Germany, in particular by Repsold in Hamburg, were of coudé type (see Figure 2): a 45° flat mirror or total reflection prism at the crossing of the axes reflected light along the horizontal hollow arm for the conven-ience of the observer.[4] This gave Lœwy the idea of his new instrument, and the report of the Paris Observatory for 1882 says (Mouchez, 1883: 7; all English translations are by the author):

> M. Lœwy had the idea to apply to his instrument the system of the coudé refractor used by the Germans for the small meridian instruments, allowing the observer to be stationary in front of an eyepiece which never changes position.

This instrument was officially proposed in October 1871 in a Note to the Académie des Sciences (Lœwy, 1871). It was a little later christened as the 'équatorial à deux miroirs', then as the 'équatorial coudé'. After discussing the inconvenience of the usual equatorials, of the comet finder and of the siderostat, Lœwy (ibid.) presents his new equatorial as follows:

> The polar axle is supported at its two ends by two pillars and, as for a transit instrument, the telescope rotates between the two bearings of the axle. This telescope is folded at right angle and, with a prism or a mirror, it sends the light through one of the hollow pivots of the polar axle, where the micrometer is installed for observation. At this stage, the astronomer sees the equatorial stars pass in front of his eye. Let us add now, in front of the objective, a flat mirror inclined at 45 degrees, attached to the declination circle. When rotating around the axis of the refractor, this mirror brings to the focal plane the images of the stars located on a great circle perpendicular to this axis.
>
> One can easily see that this set-up allows the observer to explore the whole sky without leaving his seat …
>
> The Director of the Observatory has been kind enough to agree to the construction of an equatorial according to this principle, with 3.55 m focal length and 9 pouces [24.4 cm] aperture.

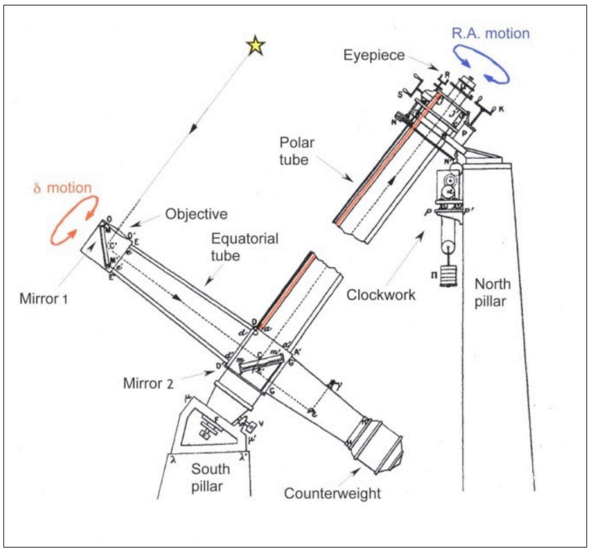

Figure 3: Principle of the coudé equatorials. The instrument schematized here is the 'Grand Coudé' of the Paris Observatory, adapted from Puiseux (1895: D.2). The other coudés are very similar. The crank K controls the fast motion in right ascension. The control of the slow motion is not represented. The tracking is driven by the clockwork which acts on the large toothed wheel NN'. The motion in declination is controlled by the cranks S (fast) and R (slow) which drive an axle (shown in red) located inside the polar tube. This axle drives the tube dd' ee' inside the equatorial tube by conical pinions. The cube which contains the objective and the 45° flat mirror #1 is attached to this tube dd' ee'. The axle drawn in red also controls the rotation of the tube aa' jj' concentric to the polar tube, which itself drives the graduated circle jj' on which declination is read. Initially, the Petit Coudé had its objective located behind mirror #1, but this was changed later to the disposition represented here in which the objective is in front of the mirror and closes the side of the cube.

Figure 3 shows the principle of the coudé equatorials, and Figure 4 shows the focal environment of one of the coudés.

It took eleven years before the first coudé equatorial was completed. Charles Delaunay (1816–1872), who headed the Observatory after the dismissal of Le Verrier in 1870, allocated 10,000 francs (equivalent to about 30,000 € or US$42,000 today) for the project, but the war and the accidental death of Delaunay on 5 August 1872 stopped the work. Le Verrier was reinstalled the following year as Director. In the minutes of the meeting of the Observatory Council on 7 January 1874 one reads:

> M. Bischofsheim [sic. for Bischoffsheim] offers 20 000 francs for construction of the two-mirror refractor of M. Lœwy.

Raphaël Bischoffsheim (Figure 5), a prosperous banker, was enthusiastic about astronomy. He also financed a large observatory in Nice, which will be discussed later. The Paris Observatory Council must have been surprised by this generous offer, and we can presume that Lœwy visited Bischoffsheim privately and interested him in the project. At the next Council meeting, on 15 January 1874,

> M. Lœwy presents to the Council and describes a model[5] of his equatorial instrument with two mirrors, whose purpose is to lessen the observer's fatigue by allowing him to stay motionless.

Several members had objections to the principle of the instrument. In particular, the famous physician Hippolyte Fizeau (1819–1896) feared, not without reason, that the thermal deformations of the mirrors would degrade the images; but he said that he would nevertheless vote in favour of the project because it was difficult to resist such a generous offer! The instrument was presented as able to measure large angular distances, and there was a need for "… a special instrument which would allow one to study regions on both sides of the meridian …" (Rapport …, 1874: liasse AA) avoiding in this way the necessity to wait for meridian crossing to measure the coordinates of a celestial object. Thus the Council agreed that a coudé equatorial should be built, but with an aperture of 8 pouces (22 cm) instead of 9 pouces. The German telescope-maker, Friedrich Wilhelm Eichens (1818–1884), provided an estimate of 20,000 francs without the objective, which was probably expected to be taken from the Observatory's reserves (hence the change in diameter of the objective), plus 18,000 francs for the 'cabane' (rolling shelter) and for installation. The cost of the building was not estimated. In any case, this looked too expensive, and as the Council was not unanimously in favour of the project it was abandoned. Bischoffsheim's gift, now raised to 26,000 francs (happy times!), would finance a meridian circle instead. This instrument (see Figure 6) was indeed completed, in 1877.

After replacing Le Verrier as the Director of the Observatory, Admiral Ernest Mouchez (1821–1892) managed to convince Bischoffsheim to give 25,000 francs to complete the coudé equatorial (including a new objective which finally reached an aperture of 10 pouces = 27 cm, and a focal length of 4.22 m). The building and the cabane were paid for by the Observatory with a special grant of 140,000 francs from the Ministry. The instrument (Figure 7) was completed in 1882, and was later called the 'Petit Coudé' (the 'Little Coudé'), because a larger coudé equatorial was installed at the Observatory in 1891, as we will see later. The optics of all later coudé equatorials were built by the brothers Paul (1848–1905) and Prosper (1849–1903) Henry, excellent opticians attached to the Paris Observatory, while the mechanics were all due to Paul Gautier (1842–1909), Eichens' successor (Figure 8). This included, for tracking, a clockwork with a centrifugal fan governor built according to Foucault's principles, but which was improved on by Antoine Yvon-Villarceau.

The instrument, its advantages and the first successsful tests were proudly presented by Lœwy during the 19 March 1883 meeting of the Académie des Sciences (Lœwy, 1883). The following year, Lœwy described the first results and discussed another advantage of the design: the possibility of a long focal ratio, which would be very expensive to reach with a conventional equatorial because an enormous dome would be needed. Lengthening the focal length would decrease the residual chromatic aberration (Lœwy, 1884a). Lœwy also cited enthusiastic reports by David Gill (1843–1914) and Sir Norman Lockyer (1836–1920), who both had the opportunity to observe with the equatorial. Lockyer (see Loewy, 1884a: 775) even said that "… this is one of the instruments of the future." There are several popular accounts of the coudé equatorial (e.g. see Hément, 1883) and Gérigny, 1884: 220-225).

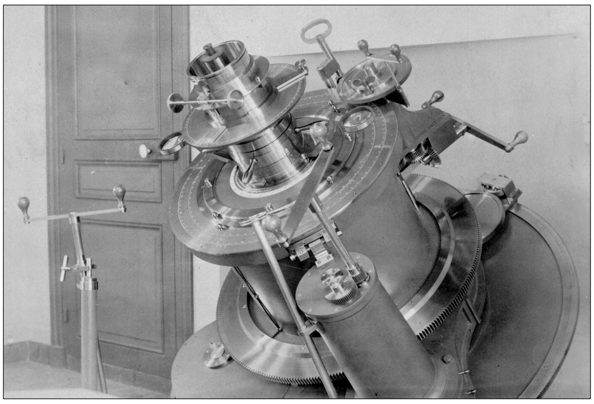

Figure 4: The focal environment of the Grand Equatorial Coudé. All the coudés are very similar in this respect. All the controls and readings are concentrated here. The crank in front drives the fast motion in right ascension and the long rod to its left drives the slow motion. The separate crank at the extreme left lifts the weight of the clockwork which insures the tracking. The cranks for driving the declination are at the back, at the top right of the image. Right ascension and declination are read on the two concentric large graduations. The smaller circular graduation on the top gives the orientation of the micrometer. For more details, see Puiseux, 1895 (© Bibliothèque de l'Observatoire de Paris).

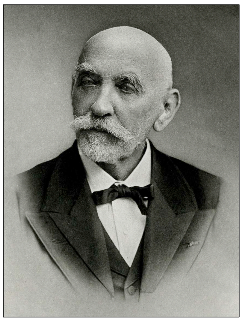

Figure 5 (right): Raphaël Louis Bischoffsheim (1823–1906), at the beginning of the twentieth century (© Bibliothèque de l'Observatoire de Paris).

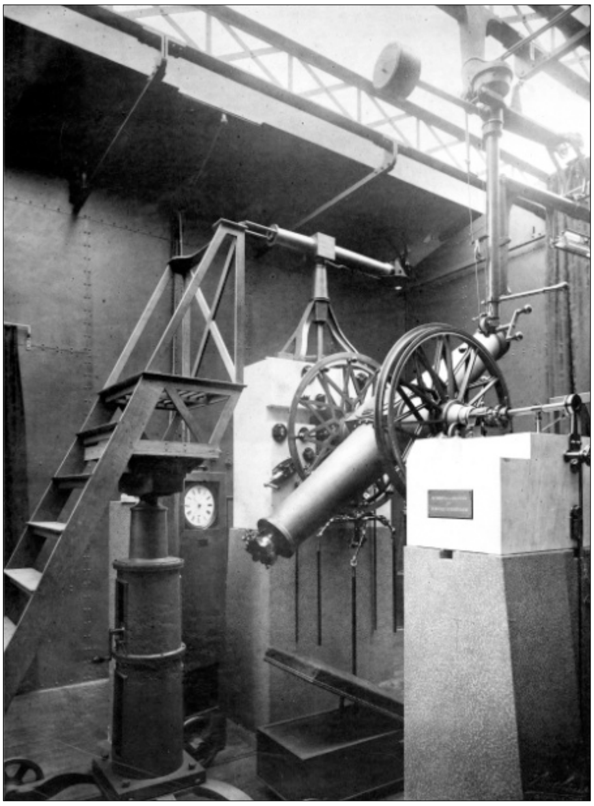

Figure 6: The Bischoffsheim meridian circle of the Paris Observatory (1877), contemporary photograph. The instrument has been in use for a century and can still be seen at the Observatory, but in a new shelter (© Bibliothèque de l'Observatoire de Paris).

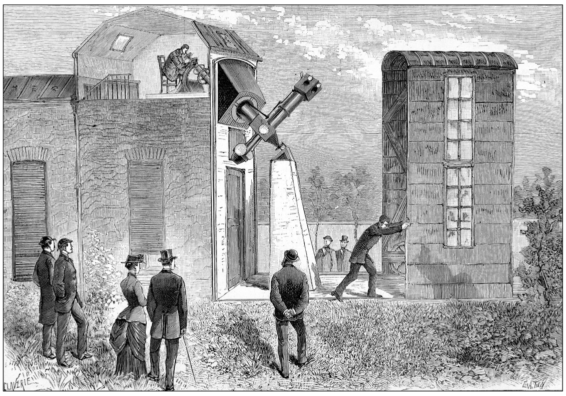

Figure 7: A somewhat schematic and inaccurate representation of the Petit Coudé at the Paris Observatory. A beautiful, accurate engraving can be seen in Lequeux (2010a: Figure 6), and on the cover of the November 2010 issue of this journal (© Bibliothèque de l'Observatoire de Paris).

In 1899, the Henry brothers installed a new objecttive with the focal length increased from 4.22 m to 5.25 m. As for all later coudés, the objective was now placed in front of the first 45° mirror, on one side of the rotating cube, and closed the tube of the instrument. Thermal insulation was applied to the tube. The cabane had been insulated the preceding year.

Given the success of his coudé refractor, Lœwy proposed two possible designs for a coudé reflecting telescope, of which he gave a complete theory (see Lœwy, 1884b). They are shown in Figure 9. However no instrument was constructed according to these principles.

3 SCIENCE WITH THE PETIT EQUATORIAL COUDE IN PARIS

The first observations made with the Petit Coudé were of minor planets (Lœwy, 1884a). These were position measurements with respect to nearby standard stars, made with a micrometer. Contrary to initial promises, the coudé equatorial was never used for measuring absolute positions as transit instruments do. Probably the flexions and the backlashes in the gears were judged too large for this. More differential observations were performed on minor planets, comets and nebulae. For the latter, one wanted to detect possible proper motions in order to obtain an estimate of their distance which was then completely unknown. The main observers were Pierre Puiseux (1855–1928) and Charles Le Morvan (1865–1933), from 1882 to 1886 (Anonymous, 1894) and from 1891 to 1893 (Anonymous, 1910; Anonymous, 1911). There were also a few observations of occultations of stars by the Moon, of the libration of the Moon, of eclipses of Jupiter's satellites, and of photometry of these satellites with a photometer using polarizers built by Alfred Cornu (1841–1902).

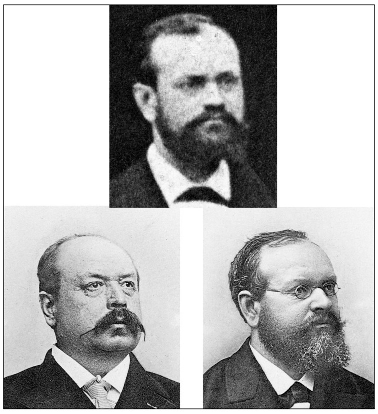

Figure 8: The builders of the seven coudé equatorials: Paul Henry (bottom left), Prosper Henry (bottom right), and Paul Gautier (top) (© Bibliothèque de l'Observatoire de Paris).

The apparent gap in the observations from 1886 to 1891 corresponds to another, original use of the Petit Coudé: an attempt to measure atmospheric refraction and a new determination of the constant of aberration. The latter determination is the realisation of Le Verrier's wish to check a new estimate of the parallax of the Sun he obtained in 1858 as a by-product of his theory of the motions of the planets of the Solar system (see Tobin, 1993: 278). Le Verrier found 8″.95 whilst the best previous determination made in 1824 by Johann Franz Encke (1791–1865) from observations of the 1761 and 1769 transits of Venus gave 8″.57. For his check, Le Verrier proposed to use the aberration constant, which, when expressed in radians, is the ratio of the mean orbital velocity of the Earth to the velocity of light: from an accurate measurement of both the velocity of light and the constant of aberration, one would obtain the orbital velocity of the Earth, hence the length of its orbit and its semi-major axis (this semi-major axis is inversely proportional to the solar parallax).

This is the reason why Le Verrier asked Foucault to make his famous accurate measurement of the velocity of light in 1862: using a rotating mirror, Foucault obtained 298,000 km/s. Combining this velocity with the value of 20″.445 given in 1843 for the aberration constant by Wilhelm Struve (1793–1864), a value which was then considered as the best available, one obtained 8″.86 for the solar parallax, a value closer to Le Verrier's than Encke's one, which pleased Le Verrier very much. Later, Alfred Cornu, who had no confidence in Foucault's method, measured again the velocity of light, this time with a toothed wheel, and obtained 300,400 km/s, which was in agreement with Foucault's determination (Tobin, 1993: 280-282). It remained to measure the constant of aberration. This should have been the task of Yvon-Villarceau, but he was reluctant to undertake it (Lequeux, 2009a: 372). Lœwy was the one who performed this work, but quite a bit later.

Lœwy had the clever idea to put in front of the coudé objective two mirrors making an angle of 45°, in order to be able to see simultaneously two fields 90° apart (Figures 10 and 11). These mirrors were silvered faces of a glass prism, making their angle very stable. Lœwy first attempted to apply this principle to a measurement of atmospheric refraction, by following for several hours a couple of stars chosen such that they were initially at the same elevation, until one of them came close to the horizon. The variation of their angular distance projected on a vertical would give a measurement of refraction (Lœwy, 1886). It seems that these measurements were not made systematically, as I have not been able to find any published result. Lœwy was still considering the problem in 1905 (Lœwy, 1905), probably with the intention of making new measurements, but his death in 1907 definitively ended the project.

Aberration produces an apparent annual motion of a star such that it describes an ellipse with its major axis parallel to the ecliptic. Its semi major-axis is equal to the constant of aberration; the length of the minor axis is proportional to sin λ, where λ is the ecliptic latitude. Consequently, the angular distance between two stars varies in general during the year. In order to measure the constant of aberration, a couple of stars at 90° from each other with ecliptic latitudes as different as possible must be observed during a large fraction of the year, at times when they are at the same elevation in order to get rid of refraction. As the angle of the prism may vary with temperature, another couple of stars taken such that their angular distance is unaffected by aberration must be observed at about the same times in order to provide the corresponding correction. One can also chose the second pair of stars so that their angular distance varies with aberration (see Lœwy, 1887a, for a complete discussion). Lœwy went to great pains to find suitable pairs of stars. He even had a 1-metre diameter celestial sphere built by Gautier, where all the stars brighter than the 6th magnitude were accurately plotted: with a curved ruler, angular distances could be measured to within 2 arc minutes (Mouchez, 1888: 11-12). The observations were made by Lœwy and Puiseux in 1890 and 1891 using four pairs of stars (Lœwy and Puiseux, 1891). In order to avoid obstruction they had to lower the roof of the building and to lengthen the tube of the instrument by 50 cm by inserting a diverging lens in the optical path. This set-up was probably not very satisfactory, hence the construction of a new objective with a larger focal length in 1899.

The value found for the constant of aberration was 20″.447 ± 0″.047, in excellent agreement with Struve's value. Combined with Foucault's velocity of light, it yielded an unchanged value of 8″.86 for the solar parallax. If we combine it instead with Cornu's speed of light, 300,400 km/s, we obtain 8″.80.

Lœwy's method for measuring large angles on the celestial sphere was novel and promising: it probably inspired Pierre Lacroute (1906–1993) when in 1968 he proposed the HIPPARCOS astrometry satellite, which measured stellar angular distances close to 58° by using two mirrors at 29° angle cut in a single solid block (see Kovalevsky, 1986: 584-585). However, the result of Lœwy and Puiseux remained relatively unnoticed, because one was soon to obtain a supposedly more precise value for the solar parallax through a campaign of measurements involving the asteroid 433 Eros.

Discovered in 1898, Eros came as close as 18 million kilometres from the Earth in 1901. Lœwy himself was very involved in the organisation of this international campaign, and apart from being busy with many other tasks this is why he could not continue his observations with the Petit Coudé. Observations of Eros produced a parallax of about 8″.81, independent of the velocity of light and aberration constant. The modern values of the constant of aberration and of the solar parallax are respectively 20″.4955 and 8″.79414, with very small errors, while the velocity of light is fixed by international convention at 299,792.458 km/s.

After the parallax measurements, the Petit Coudé equatorial was again used during a few years for measuring positions of comets and asteroids and for double star studies. In 1897, Maurice Hamy (1861–1936) undertook measurements of the diameters of Jupiter's satellites with an interferometric method invented by Fizeau in 1867 and applied for the first time by Édouard Stephan (1837–1923) using the 80-cm Foucault reflector in Marseilles (Stephan, 1873); observing the object with two slits placed on the objective, interference fringes modulate the image. When the separation of these slits is sufficiently increased, these fringes disappear; then the angular diameter of the object is close to the ratio of the wavelength to this separation. This is the very method used by Albert A. Michelson (1852–1931) and Francis G. Pease (1881–1938) in their famous 1920 observation of the diameter of Betelgeuse with the Mount Wilson 2.5-m telescope, although in their case the two light beams came from small mirrors located at some distance from the reflector. With the 80-cm telescope, Stephan could not see the disappearance of the fringes because the diameters of the stars were too small. But this was pos-

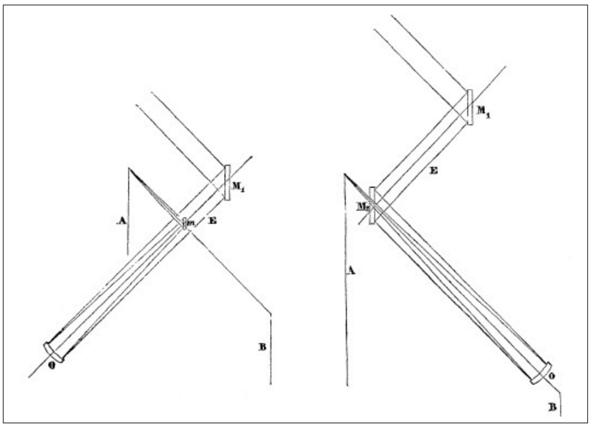

Figure 9: Two possible designs for a coudé reflecting telescope, according to Lœwy (1884b). The polar axis is AB and the observer sits in A. In the design at the right, the flat mirror M2 is pierced (© Bibliothèque de l'Observatoire de Paris).

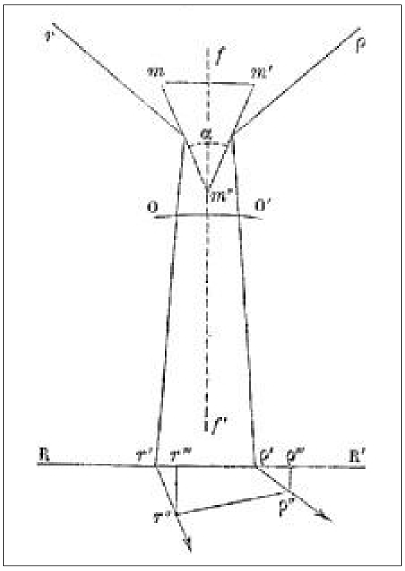

Figure 10: Principle of the measurement of the variations of the angular distance of two stars 90° apart. The faces of the prism with angle $\alpha \approx 45°$ reflect into the objective OO' of the telescope the light from two fields 90° apart. The images of two stars r and ρ separated by $90° + \varepsilon$ are distant by the small angle $90° + \alpha - 2\varepsilon$ when seen in the eyepiece (after Lœwy 1886: 77; © Bibliothèque de l'Observatoire de Paris).

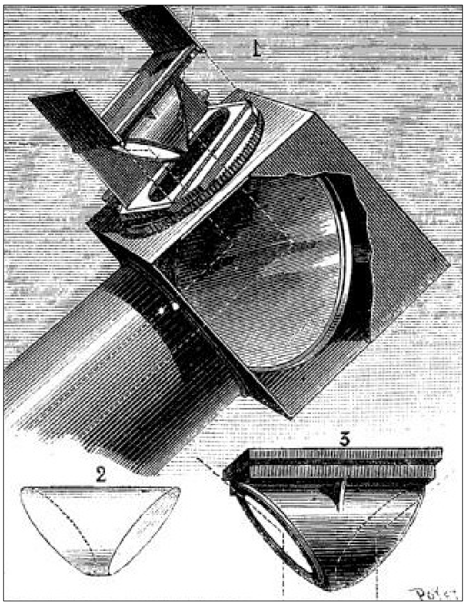

Figure 11: The device to measure the variations of the angular distance of two stars 90° apart (see scheme on Figure 10). The angle of the prism as drawn here is too large: the real angle is 45°. The device could rotate around the optical axis as a function of position of the target stars (after Lœwy, 1887b: 16; © Bibliothèque de l'Observatoire de Paris).

sible with Jupiter's satellites, whose angular sizes were measured in 1891 by Michelson with this method (Michelson, 1891). Tests were performed by Hamy with the Petit Coudé, but he decided afterwards to use the 38-cm refractor and the Grand Coudé—which will be described in the next section (Hamy, 1899). Neither Michelson nor Hamy supplied errors with their results, but Table 1 gives an indication of these errors. As can be seen from the discussion in Michelson (1891: 277), they are no better than those obtained using micrometers.

In 1901, it was decided that the Petit Coudé would be used for solar spectroscopy, and the following year a grating was ordered for a spectrograph which was installed in 1906. I could not find any published result from this set-up. Then Charles Nordmann (1881–1940) and collaborators used the Petit Coudé for multicolour photometry of stars, from 1908 on; for details, see Lequeux (2011). In 1939, the objective of the telescope was taken down owing to the threatening war. The coudé was reinstalled after WWII, and was used after 1951 for tests of the electronic camera of André Lallemand (1904–1978). It was finally dismantled in 1973. Nothing remains of this instrument, with the possible exception of the two objectives, which might exist among the large collection of old objectives in the reserves of the Paris Observatory.

4 THE GRAND EQUATORIAL COUDE

4.1 The 75-cm Equatorial: An Aborted Project

While the Petit Coudé was under construction, Admiral Mouchez was trying to revive an old project for which Le Verrier had obtained financing as early as 1865: that of a large equatorial with an objective 75 cm in diameter. The crown and flint disks for this objective were purchased from Chance Brothers even earlier, in 1856. Foucault worked for some time on testing these disks, but did not have time to make an objective from them because of his illness and death in 1868. Then the turmoil in the Observatory was such than nothing happened for several years. Work on the mechanics resumed in 1874, and by 1877, when Le Verrier died, Eichens had built a large part of the mount. Gustave Eiffel (1832–1923), the famous engineer who built the Eiffel Tower in 1889, was to be in charge of the dome. But when soundings were made at the place where the dome was to be built, in the garden of the Observatory, the numerous underground cavities they revealed prevented the erection of this instrument.

In 1883 Mouchez tried to create a subsidiary of the Observatory in the neighbourhood of Paris, where the refractor would be placed, but he did not succeed. Moreover, while the available money (187,257 francs) was sufficient for the equatorial itself, the dome would have cost between 500,000 and 600,000 francs, an enormous sum, which was simply not available. Algeria, then a colony of France, could have housed the telescope at the Bouzareah Observatory near Algiers, but the Parisian astronomers wanted it in Paris and did not accept the offer. Eventually the project was abandoned, and the parts that had already been built were given to Jules Janssen (1824–1907) for his Observatoire d'Astronomie Physique at Meudon. Some components are included in the mechanics of the large Meudon double equatorial of 1896, and it may be that one or two of the five 75-cm glass disks cast for the refractor served to build the photographic objective of the Meudon equatorial, which is 62-cm in diameter. A 75-cm crown disk still exists at the Paris Observatory.

4.2 The Grand Équatorial Coudé Replaces the Aborted Equatorial

Mouchez was so impressed by the Petit Coudé that he was able to convince the Minister of Public Education to devote what remained of the money intended for the 75-cm refractor to the construction of a 'Grand Équatorial Coudé'. He must have obtained more, as the total cost of the instrument, including the building and accessories, was around 400,000 francs, equivalent to some 1.2 million Euros today (Fraissinet, 1891). The coudé had two interchangeable objectives, each 60 cm in diameter, one for photography and the other for visual observations. Figure 3 shows a schematic cutaway section of the instrument; Figure 4 shows its focal environment, and Figure 12 is a complete image (for another photograph see de la Noë and Soubiran, 2011: 448). The photographic objective had a remarkably large field of 1° 30′. The focal length was 18 m, and the 45° flat mirrors had respective diameters of 86 cm and 73 cm. As for all coudés, the Henry brothers built the objectives and Gautier the mechanics. It was completed in 1891. The design was similar to that of the 'Petit Coudé', except that the objective was now placed in front of the first 45° mirror, closing the tube in this way and avoiding fast degradation of the silver layer on the mirrors. A 4-horsepower Otto gas machine driving a dynamo was placed in the basement, in order to charge the 39 accumulators which provided lighting to the coudé buildings with filament bulbs (the rest of the Observatory being lit with coal-gas). For short descriptions, see Fraissinet (1891) and Lœwy (1894), while Puiseux (1895) gives a detailed description, with drawings of the very complex mechanics of the equatorial.

Table 1: Diameters of Jovian satellites and of Vesta, as measured by Michelson and by Hamy.

	I: Io	II: Europe	III: Ganymede	IV: Callisto	Vesta
Michelson, 1891	3850 km	3550 km	5170 km	4940 km	-
Hamy, 1899	3550 km	3150 km	4640 km	5100 km	392 km
Modern value	3630 km	3138 km	5268 km	4800 km	576 km (aspherical)

Many difficulties were encountered during the period of tests with the visual objective, which lasted for two years. In particular, deformations of the flat mirrors were present, as foreseen by Fizeau, requiring replacement of supports and thermal insulation of the cabane and of the tube. When the photographic objective replaced the visual one in 1893, new difficulties arose, in particular with the motion of the 12 tons of the instrument. Small movements were almost impossible, so that the fine pointing and corrections of the tracking were done with the eyepiece holder rather than by moving the whole telescope.

4.3 The Photographic Atlas of the Moon

During the tests, it was noticed that the instrument gave impressive images of the Moon, and Lœwy decided to use it to make a photographic atlas of our satellite. The program started in 1894 and lasted until 1900, with a few supplementary observations until 1909. In order to track the Moon accurately, the plate was moved slowly at the focus during the exposure according to calculations of the Moon's motion. About 6,000 photographs were taken during some 500 nights. The beautiful photographs of the Moon during its different phases, 18 cm in diameter (Figure 13), were enlarged for heliographic publication in the Atlas: the size of each plate is 50 × 60 cm. The Belgian astronomical society also published a reduced-scale atlas with 20 × 24 cm plates, with the photographs reproduced at the original scale (Lœwy and Puiseux, 1898a; 1899). For exhibitions, the lunar images were enlargeed to a diameter of 80 cm, on special plates supplied for free by the Lumière brothers. The atlas (Lœwy and Puiseux, 1896-1910) was still found to be useful when choosing the landing sites for the Apollo project.

In a lengthy series of papers (Puiseux, 1896; Lœwy and Puiseux, 1897, 1898b, 1902a, 1902b, 1906), Lœwy and Puiseux attempted to use their photographs to understand the origin of the lunar features and the evolution of the Moon. They acknowledged that the maria were not liquid, but solid, formed by ground collapse according to them. They believed that the craters were of volcanic origin. In general, they tried to understand the Moon by comparison with the Earth, assuming that the primitive Moon had properties similar to those of the Earth. The Moon was supposed to have cooled from a fluid state (hence its volcanism), and to have later possessed some water, a windy atomsphere, etc. Not much remains of their conclusions, which were already received with some scepticism by their contemporaries: in Lœwy's obituary one reads:

> I do not think that one should subscribe to all their conclusions, and many of them certainly will have to be modified; but they were certainly allowed to be adventurous, like the first geologists who, albeit closer to the objects of their studies, sometimes proposed hazardous hypotheses which were not necessarily useless to their successors. (Anonymous, 1907: 393).

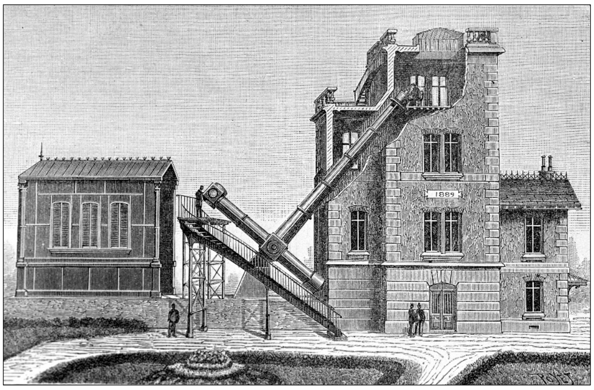

Figure 12: The Grand Équatorial Coudé of the Paris Observatory. North is to the right of the picture. The building and 'cabane' (rolling shelter on the left) are still visible in the garden of the Observatory, but are now in very poor condition (© Bibliothèque de l'Observatoire de Paris).

4.4 Stellar Spectroscopy with the Grand Coudé

Apart from photographing the Moon, the Grand Coudé was used occasionally for various observations of the positions of minor planets and comets; for lunar eclipses; for photography of planets, stars and clusters; and for the measurements of the diameters of Jupiter's satellites, as mentioned in the preceding section. When the program of lunar photographs neared completion, in 1906, Hamy installed a relatively high-resolution prism spectrograph at the focus. This was built by Gautier and mounted on a rotating support so that it could be substituted for the photographic equipment (see Figure 14). This instrument is described by Hamy (1925). It was used to obtain radial velocities of bright stars, but this resulted in few publications. Pierre Salet and Gaston Millochau also used it in an attempt to detect the displacement of some iron lines due to the Stark Effect in the solar chromosphere (Salet and Millochau, 1914), then for a study of line displacement in stellar spectra (Salet, 1921). Later Salet (1934) used this

Figure 13: Photograph of the Moon obtained with the Grand Coudé (© Bibliothèque de l'Observatoire de Paris).

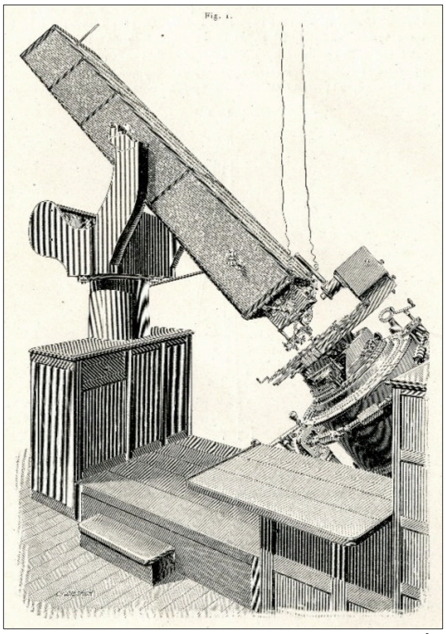

Figure 14: The stellar spectrograph of the Grand Équatorial Coudé (© Bibliothèque de l'Observatoire de Paris).

spectrograph to measure the velocity of light coming from various stars close to the ecliptic, by observing the Doppler shifts of their lines at two epochs, when the Earth approached or receded from them. He found that the velocity of light seemed to vary with spectral type, but he certainly underestimated the errors. Surprisingly, this result raised no comment from him. Clearly, Special Relativity was not yet universally accepted at that time.

The spectrograph and the Grand Coudé were partly dismantled during WWI. When it was a question of re-installing the Coudé , in 1920, the Director of the

Figure 15: The equatorial coudé of the Besançon Observatory, before 1934 (© Jérôme Mongreville, Région Franche-Comté, Inventaire du patrimoine ADAGP).

Paris Observatory, Benjamin Baillaud (1848–1934), proposed to send it to the Pic du Midi Observatory. But there was no money for this, and the instrument was re-installed in Paris in 1922, now with the spectrograph in a fixed position. Stellar spectroscopy was then resumed. In 1927, Henri Deslandres (1853–1948), who succeeded Baillaud in 1926, wanted to dismantle the instrument in order to use some elements for a fixed refractor in Meudon which would serve to observe the displacements of the Pole using photography. But nothing happened. The Grand Coudé was used from time to time until WWII, first for radial velocities, then for photography of star clusters. The objective was taken down in 1939, and it is presently in storage at the Paris Observatory. As to the visual objective, which was used very little, in 1943 it was sent to the Pic du Midi Observatory, where Bernard Lyot (1897–1952) used it to take very high-quality photographs of the Moon and planets on orthochromatic plates through a yellow filter. In 1981 the mounting was dismantled and transferred to the new Museum of Arts and Techniques at La Villette. It should have been installed in the park, but this was not done, and the tubes are presently rusting on the Observatory grounds in Meudon. As to the building and cabane, they are slowly decaying at the Paris Observatory—a sad end for a prestigious instrument which deserves better preservation.

5 THE OTHER FRENCH COUDÉS

On 11 March 1878, new public astronomical observatories in Besançon, Bordeaux and Lyons were created by decree. They added to the existing ones in Paris, Algiers (then a part of France), Toulouse and Marseilles (for details, see de la Noë and Soubiran, 2011). The new observatories had to be equipped, and the older ones required some new instrumentation. Given the success of the coudé equatorial in Paris, Besançon and Lyons received similar instruments. Algiers succeeded in obtaining a coudé as well for its observatory in Bouzareah (now the Centre de Recherches en Astronomie, Astrophysique et Géophysique—CRAAG). The three new coudés were all built by Gautier, with optics by the Henry brothers. They are slightly different from each other, with larger focal lengths than the Parisian Petit Coudé (Table 2). While the Lyons coudé had a rolling cabane similar to that in Paris, the coudés in Besançon (Figure 15; for other pictures see de la Noë and Soubiran, 2011: 176 and 190) and in Algiers (see an old photograph as Figure 16 in Lequeux 2010b) had very similar buildings and a different moving shelter in which a slit parallel to the celestial equator opened for observations. This saved room, but apparently the observers in Algiers found this device unsatisfactory

Table 2: Characteristics of the seven coudé equatorials.

Observatory	Diameter	Focal length	Operational	End of operations	Status
Paris (Petit Coudé)	27 cm	4.22, then 5.25 m	1884	1952	destroyed
Algiers	32 cm	6.78 m	1888	1934	good
Lyons	35 cm	7.80 m	1888	1949	good
Besançon	33 cm	6.40 m	1890	1934	dismantled
Vienna	38 cm	9.25 m	1890	1925	destroyed
Paris (Grand Coudé)	60 cm	18 m	1891	1939	dismantled
Nice	40 cm	10 m	1892	(1935)	renovated

Consequently, the Algiers coudé is presently housed in a rolling cabane (Figure 16; for other photographs see de la Noë and Soubiran, 2011: 248 and 249).

In 1879, Raphaël Bischoffsheim financed entirely a new observatory in Nice, which he later bequeathed to the University of Paris. As Bischoffsheim had already paid for the Parisian coudé, it is not surprising that he included a coudé equatorial amongst the instruments at the Nice Observatory, along with a large 76-cm diameter equatorial, a smaller 38-cm equatorial and meridian instruments, all built by Gautier and the Henry brothers. The Nice coudé (Figure 17; for another photograph see de la Noë and Soubiran, 2011: 273) is housed in a beautiful building and cabane built by Charles Garnier (1825–1898), the architect of the Paris Opera house, who designed all the Observatory buildings, together with Gustave Eiffel, who built the metallic structures.

Three of these instruments are still extant: those at Algiers, Lyons and Nice. The Algiers coudé has been restored recently. The Lyons coudé, located in the observatory at Saint-Genis-Laval near the great city, is preserved in its original state (Figures 18 and 19; for other photographs see de la Noë and Soubiran, 2011: 207 and 436) and is used for public demonstrations. The Nice coudé was modified in 1971-1972 for solar observations (Aime et al. 1974): in particular, the two flat mirrors—weak parts of the instrument—were replaced by low thermal expansion ceramic (Cervit) ones in order to minimize thermal deformations. This coudé served until 1975 or so—when the Nice astronomers gained access to the better facilities at Sacramento Peak—and it is presently used by amateur astronomers.

The four non-Parisian equatorials in their original form were used rather intensively, but in less imaginative ways than their Parisian brothers. The vast majority of the measurements were of positions of comets and asteroids, and there was no spectroscopy at all. Presumably the provincial observatories were supposeed to do the 'grunt work' of astronomy while the Parisian ones had more freedom. Figure 20 displays the cumulative number of publications of each of the four provincial observatories as a function of year.

Figure 20 needs some comments. Until 1917, the results were published in the *Comptes Rendus hebdomadaires de l'Académie des Sciences*, in the Parisian *Bulletin Astronomique*, in observatory publications (for Nice) and in *Astronomische Nachrichten*. The last-named journal offered a fast and convenient way of disseminating information on positions of comets and newly-discovered asteroids. It is remarkable that papers and telegrams were still sent to this German publication at times when the relations between France and Germany were very bad. The last papers with coudé observations were published in the October 1914 issue of *Astronomische Nachrichten*, after war was declared between the two countries. In 1917, a new journal, the *Journal des Observateurs*, was created by the Marseilles Observatory in order to publish observations made in France, and most of the coudé results went to this journal; however, the Besançon observer, Chofardet, published thirteen papers in the *Astronomical Journal* between 1918 and 1929, and only started publishing in the *Journal des Observateurs* in 1922.

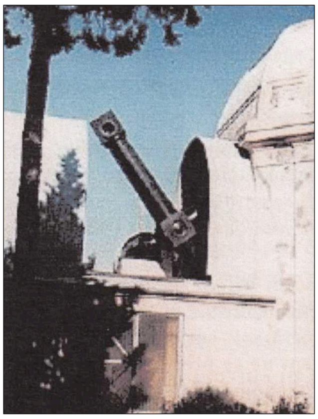

Figure 16: The equatorial coudé at the Bouzareah Observatory near Algiers, photographed in the 1990s (courtesy: http://www.saao.ac.za/~wgssa/as2/sadat.html).

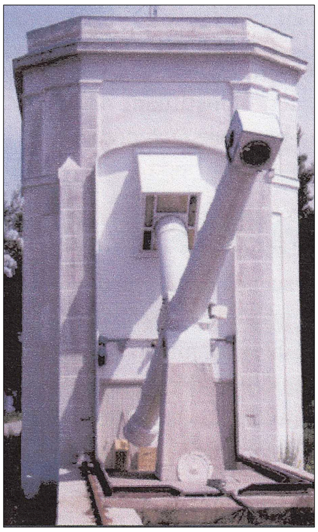

Figure 17: The current state of the Nice Observatory equatorial coudé (© Région Provence-Alpes-Côte d'Azur, Inventaire Général - Marc Heller (1996)).

Figure 18: The equatorial coudé of the Lyons Observatory (© Jean-Marie Refflé, DRAC Rhône-Alpes, 2004).

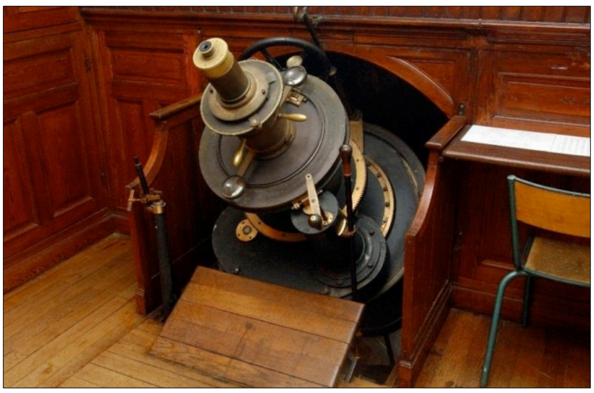

Figure 19: The focal environment of the Lyons coudé. Compare with Figure 9 (© Jean-Marie Refflé, DRAC Rhône-Alpes, 2004).

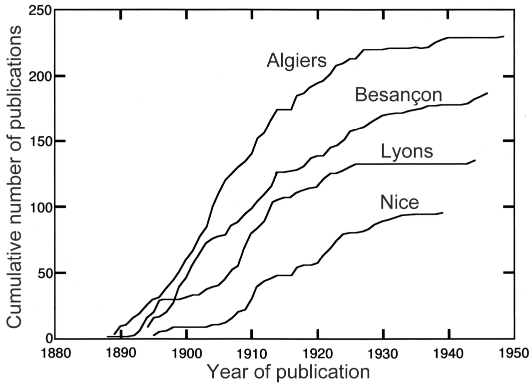

Figure 20: Cumulative number of publications of the Besançon, Lyons, Algiers and Nice Observatories based on observations with their coudé equatorials as a function of publication year.

The most active users of the provincial coudés were the ones in Algiers, partly due to a better climate and partly because there were several very motivated observers there. Besançon comes next, with essentially a single observer.

In Lyons, there was more variety in the observations than in the three other observatories: there was some specialization on the satellites of Jupiter and their mutual phenomena; after 1907, most observations in Lyons were of visual photometry of variable stars, performed by a specialized observer, Michel Luizet (1866–1918). But observations stopped in 1926, earlier than in the other observatories, although three papers were still published in 1944 in the *Journal des Observateurs*, reporting double star observations made in 1941-1942.

In Nice, the observations were centred on asteroids —a speciality of this observatory. Figure 16 gives a biased impression of the activity of the Nice coudé, because some of the relevant articles contain more observations than the papers from the other coudés.

6 THE VIENNA COUDÉ EQUATORIAL

In their famous book, *Lunettes et Télescopes*, André Danjon and André Couder (1979) mention a 43-cm coudé equatorial at the La Plata Observatory in Argentina. As noted by Weimer (1982: 117) this instrument never existed, and was confused with a classical Gautier equatorial of this diameter installed in 1894. Still, this mention deceived many historians, including myself (see Lequeux, 2009b).

Figure 21: The coudé equatorial of the Vienna Observatory (© Archive of the Institute for Astronomy, University of Vienna).

However, there was a real coudé equatorial outside France, at the Vienna Observatory. This instrument (Weimer 1982: 117; Schnell, 2009) resulted from a gift of 10,000 Gulden made by Baron Albert von Rothschild (1844–1911), banker and amateur astronomer, as a tribute to his compatriot Lœwy. Like the other coudés, it was built by Gautier, with optics by the Henry brothers (Figure 21). The shelter had an oblique slit aperture like the coudés in Besançon and Algiers. Anneliese Schnell (2009) writes that the idea of the shelter came from Johann Palisa (1848–1925), an Austrian astronomer who was a friend of Rothschild. The Vienna building was completed in 1885, while that of Besançon dates from 1884 (but the instrument was only installed in 1888), and that of Algiers was finished in 1886: it is thus possible that the Vienna instrument inspired those of Besançon and Algiers. In Vienna, observations of asteroids and comets started in 1890, until the most valuable metallic elements of the instrument were stolen in 1903. Renovation was decided upon in 1909, and Adolf Hnatek (1876–1960) was put in full charge of the equatorial. He carefully tested the objective and the attached Askania spectrograph, and studied the effects of temperature on image quality (Hnatek, 1911; 1913). The coudé was used for measurements of the radial velocities of stars, resulting in four publications in *Astronomische Nachrichten*. In 1920, a photometer was added and used for visual photometry of the Pleiades (Hnatek, 1922). But one of the pillars started to collapse, and observations ceased in 1925. Five years later, the instrument was considered completely unusable and was decommissioned. The only remaining part is the objective, which was reworked by Zeiss in 1952 and installed in one of the solar towers of the Kanzelhöhe Observatory of the University of Graz.

7 CONCLUDING REMARKS

There are two reasons for the decommissioning of all the seven coudé equatorials near the middle of the last century. One is the growing disinterest of astronomers in their main use, the measurement of the positions of comets and asteroids. The other reason is that these instruments were sensitive to temperature, complicated, difficult to point and in general less handy than the ordinary equatorials. Failures were numerous, and maintenance was costly. One reads in the report for 1909 of the Lyons Observatory:

> The instrument is somewhat old and, every year, shows some new weakness. Mounting peculiarities have been accumulated by the builder as for the fun of the thing, probably in order to require his costly intervention.

Surprisingly, this bad impression was not confirmed by Maurice Duruy (1894–1984), the astronomer who used the Lyons coudé during WWII and declared:

> The comfort of the observer is very remarkable. It allows one to use completely the data from the instrument whatever its direction. (Duruy, 1944: 1).

Nevertheless he said that the image quality was better with the 27.5-cm conventional Lyons equatorial! It seems indeed that, in spite of the lack of comfort of the classical domes, the astronomers preferred to use ordinary equatorials or reflecting telescopes when they had the choice. This appears to have been foreseen by the planners of the new observatories, as one or several conventional equatorials were always installed in parallel to the coudés. In spite of their initial enthusiasm, which perhaps was only on the surface, foreign astronomers did not adopt the system, mainly because they would have been forced to have the coudé equatorials built in France by Gautier, who was the only experienced constructor. The Vienna coudé is an exception because it was offered to the Observatory.

However, the principle is interesting, and during the second half of the twentieth century Zeiss built two small coudés. One was for the Radebeul Popular Observatory near Dresden and the other one, with the same optical dimensions, was for the Ankara Observatory in Turkey (Figure 22). Another 25-cm coudé equatorial built by Nikon is at the Kastushika City Museum in Tokyo.

Figure 22: The coudé equatorial of the Ankara Observatory. This instrument has a 15 cm aperture and 2.25 m focal length. It is used for observations of the Sun. The observer stands in a fixed position at the bottom of the polar tube, not as the top as for the Gautier equatorials. The light from the objective is sent to the polar tube by two flat 45° mirrors located on each side of the very short equatorial tube (© Ankara University Observatory).

8 NOTES

1. Recently restored, the Fraunhofer equatorial can still be seen in Tartu.
2. The Marseilles instrument has disappeared, but see a photograph in Lequeux (2009a: 102).
3. See images in Lequeux, 2009b: 55, and in http://en. Wikipedia.org.wiki/Archenhold_Observatory
4. Many such instruments are depicted in Repsold (1914).
5. There is in the collections of the Musée des Arts et Métiers/CNAM in Paris a beautiful model of the coudé equatorial built by J. Digeon (inv. 10848-0000), but it is said to date from 1882 to 1886 and was probably intended for presentation in an exhibition. The model presented to the Council by Lœwy in 1874 was certainly simpler.

9 ACKNOWLEDGEMENTS

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EARLY ASTRONOMICAL SEQUENTIAL PHOTOGRAPHY, 1873-1923

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Abstract: In 1873 Jules Janssen conceived the first automatic sequential photographic apparatus to observe the eagerly anticipated 1874 transit of Venus. This device, the 'photographic revolver', is commonly considered today as the earliest cinema precursor. In the following years, in order to study the variability or the motion of celestial objects, several instruments, either manually or automatically actuated, were devised to obtain as many photographs as possible of astronomical events in a short time interval. In this paper we strive to identify from the available documents the attempts made between 1873 and 1923, and discuss the motivations behind them and the results obtained. During the time period studied astronomical sequential photography was employed to determine the time of the instants of contact in transits and occultations, and to study total solar eclipses. The technique was seldom used but apparently the modern film camera invention played no role on this situation. Astronomical sequential photographs were obtained both before and after 1895. We conclude that the development of astronomical sequential photography was constrained by the reduced number of subjects to which the technique could be applied.

Keywords: Sequential astronomical photography, astronomical chronophotography

1 INTRODUCTION

The histories of astronomy and photography are inextricably linked by the public presentation of the daguerreotype by the astronomer François Arago (1786–1853), on 19 August 1839 (Levitt, 2003). At the time, as it is well known, Arago correctly predicted the future use of photography in the astronomical fields of selenography, photometry and spectroscopy. Photographs of the Moon and the solar spectra were obtained in 1840 and 1843, respectively, while correctly exposed daguerreotypes of solar features were secured in the 1840s. Following these early achievements the number of astronomical applications of the new technique increased throughout the nineteenth century in tandem with the development of new photographic emulsions and instruments (Bajac and Saint-Cyr, 2000; de Vaucouleurs, 1961; Lankford, 1984).

As early as 1847, John Herschel (1792–1871) pointed out the advantages of applying sequential photography to the study of the solar surface variability (Herschel, 1847). He championed this idea in the following years, which ultimately led to the daily solar photography program started at Kew Observatory in the late 1850's and later elsewhere (Bonifácio, et al., 2007, and references therein). In this paper we will focus on sequences of photographs made to study either the motion or the variability of celestial objects on time scales of at most a few minutes. Sequential photographs actuated individually or automatically will be considered but only if made with instruments specifically built for the observation. Time-lapse photography, i.e. long-period sequences like, for example, daily solar photography programs, will not be considered. Equally beyond the scope of this paper is the quick succession of plates an observer could, for example, shoot during a total solar eclipse, by changing them manually in a standard photographic device. Sequential photographs obtained on celluloid strips via cinematographic apparatus (i.e. 'moving pictures'), will also not be discussed here.

The remainder of this paper is divided into three parts. In Section 2 we discuss single-plate and multiple-plate sequential photographs. Due to the readily-available literature (Launay and Hingley, 2005 and references therein) we start by briefly summarizing the main characteristics of Janssen's 'photographic revolver' and results obtained with it. We proceed with the description and analysis of other rotating-drum instruments. Next we discuss David Peck Todd's (1855–1939) automatic mechanisms developed to photograph total solar eclipses. We end this Section with an analysis of Harvard College Observatory's photographic program on Jovian satellites and lunar occultations of stars. In Section 3 we deal with data recorded on a continuously-moving photographic plate. We decided to include these records because they take sequential photography towards its conceptual limit of a null-time difference between consecutive photographs. In practice there is always a degree of integration and each point of the photograph is an average of the image moving on the plate. This technique was used, for example, to record the variability of solar spectra. Finally, in Section 4, we discuss our findings and present our conclusions.

2 SINGLE-PLATE AND MULTIPLE-PLATE SEQUENTIAL PHOTOGRAPHY

2.1 Janssen's 'Photographic Revolver'

On 10 February 1873 Jules Janssen (1824–1907) presented at the *Académie des Sciences de Paris* his plan to construct a new instrument to sequentially photograph the instants of contact between Venus and the Sun in the eagerly-anticipated 1874 transit (Janssen, 1873; cf. Janssen, 1876). His 'photographic revolver' was the first instrument that automatically took a series of photographs. It recorded 48 images in 72 seconds, via a clockwork mechanism, on daguerreotype circular plates (Braun, 1997: 151; Launay and Hingley, 2005).

At least nine photographic revolvers designed by either Janssen or Warren De la Rue (1815–1889) were used in the observation of the 1874 transit of

Venus (Janssen, 1883), but the results obtained were a disappointment (see Launay and Hingley, 2005; Mourão, 2005). Following the failure to improve on the value of the astronomical unit by using photography, in general, and the 'revolver', in particular, visual observations of the 1882 transit of Venus were preferred by many, including the official British and French parties that had previously used the 'photographic revolver' (Canales, 2002). Meanwhile, Janssen (1883) opted to perform astrophysical rather than astrometric observations in 1882 (see Launay, 2008: 160).

After the 1874 transit observation the 'revolvers' had almost no use. In fact, we are aware of only two other occasions where the 'revolvers' were employed. Launay and Hingley (2005) discovered that in 1875 an instrument of British design was deployed to the Nicobar Islands (Indian Ocean) to record—in combination with a spectroscope—the coronal spectrum during the total solar eclipse of 5 April, but the observations were hampered by bad weather. In the course of this research we came across an 1882 communication by Janssen to the Parisian Academy of Sciences, which claimed that a 'revolver' was in use at the Meudon Observatory to capture the motion of granulation in the solar photosphere (also see Launay, 2008: 118). However, we did not find any later reference to this work.

Janssen's 1879 suggestion that the 'revolver' could be used to register solar eclipse phases and solar meridian transits, and in the search for intramercurial planets, was apparently never put into practice (see Launay and Hingley, 2005). Despite this outcome, Janssen's 'photographic revolver' was an important step on the road towards the invention of cinema (Tosi, 2007a; 2007b).

2.2 The Toulouse University 1900 Solar Eclipse Expedition

Henry Bourget (1864–1921), Astronomer at the Toulouse Observatory, was in charge of the 1900 Toulouse University expedition to Elche (Spain). In order to obtain photographs of the solar corona during the 28 May eclipse the Observatory's technician, Mr. Carrère, built a "… revolver photographique [sic.] …" (Bourget, 1902: 472) allowing the use of eight photographic plates of 6.5 by 9 cm without loss of time (Figure 1). The system was moved by hand. During totality four different Lumière plates were exposed from 1 to 8 seconds. In his eclipse report, Bourget (1902) described the different solar features photographed, commented upon the plate and exposure combinations used and concluded that no unexpected celestial body was detected around the Sun.

2.3 Grubb's 1900 Eclipse 'Kinematograph'

A different approach was employed by the Royal Irish Academy and the Royal Dublin Society on their joint expedition to Plasencia (Spain) to observe the total solar eclipse of 28 May 1900 (Plummer, 1923). According to Arthur Alcock Rambaut (1859–1923),

> The object of the spectroscopic observations undertaken by us was to obtain two series of spectra, at second and third contacts, with the idea of determining the order in which various lines appeared in, and faded out of, the flash and chromospheric spectra (Rambaut, 1903: 77).

During a total solar eclipse, near to the time of the 2nd and 3rd contacts one can detect a chromospheric emission spectrum. This 'flash spectrum', as it was then known, was first observed by Charles Augustus Young (1834–1908) during the solar eclipse of 22 December 1870 and was photographed by William Shackleton (1871–1921) in 1896 (Anonymous, 1911; D.B., 1922; Langley, 1871). Studying the 'flash spectrum' was a popular research topic during the late nineteenth and early twentieth centuries. For example, in 1900 the Irish planned an eclipse expedition to test

> … whether the change from the absorption spectrum to the 'flash' spectrum took place simultaneously for all the lines, or whether some became reversed earlier than others, as might be expected to occur if the absorption of different lines took place at different depths in a reversing layer (Rambaut, 1903: 77).

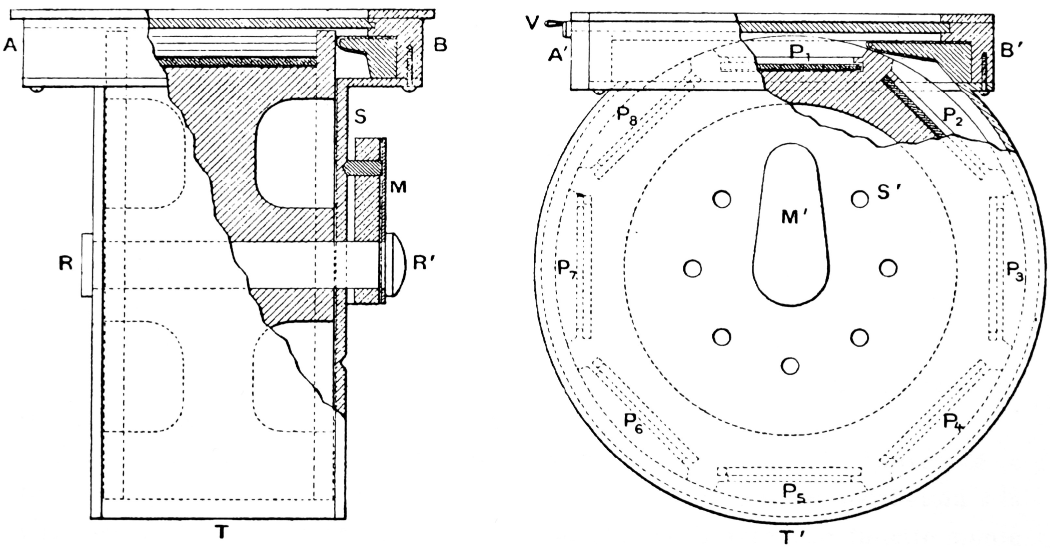


Figure 1: Side (left) and rear (right) diagrams of the Toulouse University 'revolver photographique'. The eight plates are numbered P1 to P8 and the system revolves around the R-R' axis. Motion is imparted by the handle M, M'. On the right hand image, plate P1 is in the correct position to be exposed. Note that the telescope is not represented (after Bourget, 1902: 473).

To attain this goal it was initially planned "… to project a very narrow spectrum upon a uniformly moving plate." (Rambaut, 1903: 77). This method was first used by Norman Lockyer (1836–1920) in 1896 (see Section 3). Due to Rambaut's late decision to join the expedition this plan was discarded in favour of "… a less complicated instrument, which could be more rapidly constructed …" (ibid.). According to Howard Grubb (1844–1931),

> It was required that some twelve photographic plates should be exposed to the image of the spectrum during about the same number of seconds, and that there should be absolutely no interval between the successive exposures, so that if any flash lines made their appearance, even for a moment, during those 12 secs., their images should certainly be impressed on some one of the plates. (Grubb, 1903: 73).

The instrument used two separate rotating hexagonal drums, each of which carried six photographic plates. A system of mirrors sent the light alternatively to each drum. To obtain a continuous registration for a while both plates, one on each drum, were simultaneously exposed. The system was activated by hand. Twelve spectra were obtained during second contact (Figure 2), giving an "… uninterrupted record of the changes in the chromospheric spectrum during the 17 or 18 seconds over which they extend …" (Rambaut, 1903: 81). The plate exposures varied from 1 to >2 seconds as the eclipse progressed. At third contact only five spectra were obtained, due to a drum malfunction and an over-exposed plate.

In his eclipse report Rambaut identified the spectral lines photographed, described their time evolution and estimated their visual intensity using an arbitrary scale (Rambaut, 1903).

2.4 More Rotating Drums

Heinrich Alfred Wolfer (1854–1931) had to observe alone during the total solar eclipse of 30 August 1905, and in order to obtain the largest possible number of coronal images he placed twelve 91 × 91 mm photographic plates upon a rotating drum and mounted this on a telescope. The photographs were shot at 15s intervals with exposures varying between 0.1 seconds and 3.0 seconds. Two different plate types were used. The system was apparently set in motion manually via a handle. The account of the expedition (see Wolf and Wolfer, 1906) describes a few of the images, while the discussion focuses on photographic rather than astronomical issues.

At Kalaa-es-Senam in Tunisia, Professor Ludwig Wilhelm Emil Ernst Becker (1860–1947) from Glasgow University observed the same eclipse equipped with a mechanism of his own design that allowed 10 exposures to be automatically made on a single plate. The shutter was rotated by spring-driven clockwork that was controlled by a pendulum clock. Half the plates were exposed for 1 second while the other five had exposures of 3, 9, 20, 46 and 89 seconds. Becker's plan was to study variations in coronal light intensity as a function of solar distance. Although the mechanism did not work flawlessly, two series of nine photographs were obtained. In a preliminary report Becker (1906) claimed to have measured the plates but, to our knowledge, no results were ever presented.

2.5 David Todd's Automatic Mechanisms

Following his 29 July 1878 solar eclipse observation D.P. Todd (1855–1939) realized that the number of photographs obtained was "… exceedingly meagre for an occasion when ... the money value of a single second is often hundreds of dollars …" (Todd, 1897: 318). As a consequence, over the following years he strove to increase the number of photographs taken during an eclipse by using various automatic apparatuses. In Todd's approach, at the beginning of an eclipse a single observer could automatically start up a 'compact' assortment of photographic equipment. The characteristics of the photographs to be obtained were already pre-defined.

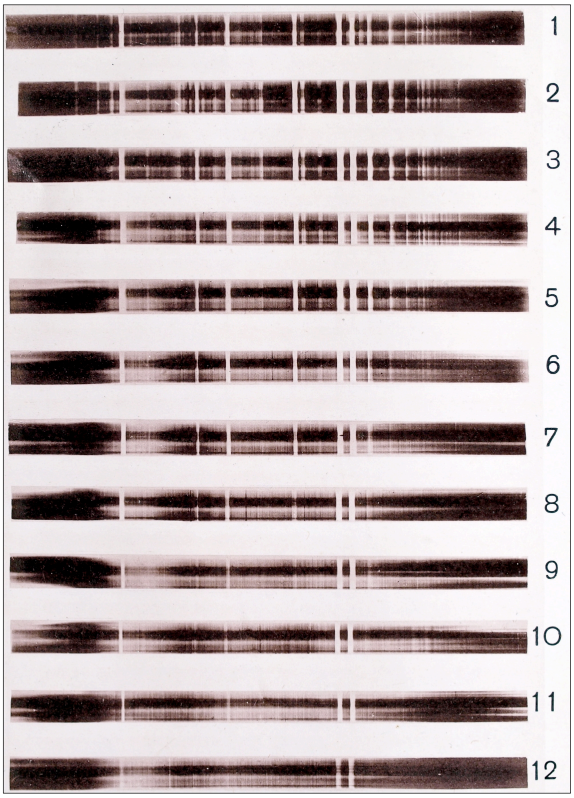


Figure 2: Twelve sequential spectra obtained at second contact by Grubb's 'kinematograph' during the 28 May 1900 total solar eclipse. The prominent pair of lines visible in all plates correspond to the chromospheric K and H calcium lines (after Rambaut, 1903: Figure 1, Plate VIII).

Upon returning from failed observations of the 19 August 1887 eclipse in Japan (Todd, 1888: 7), where a mechanical system was used to control the heliostat from a distance, Todd (1894: 178) again asked the question: "Why should it [i.e. changing plates and controlling the instruments] not all be done automatically?"

In 1889 Todd went to the west coast of Africa in today's Angola to observe the total solar eclipse of 22 December. Following "… much experimentation with different electric and pneumatic devices …" he selected a pneumatic valve system to control the photographic apparatus (Figure 3) (Todd, 1890: 382). A perforated paper ribbon moving along the mechanism fed the instructions to the machine in a process similar to the 'old' computer punch cards (Figure 4). When a perforation was opposite the corresponding pipe hole of the pneumatic system the air would flow

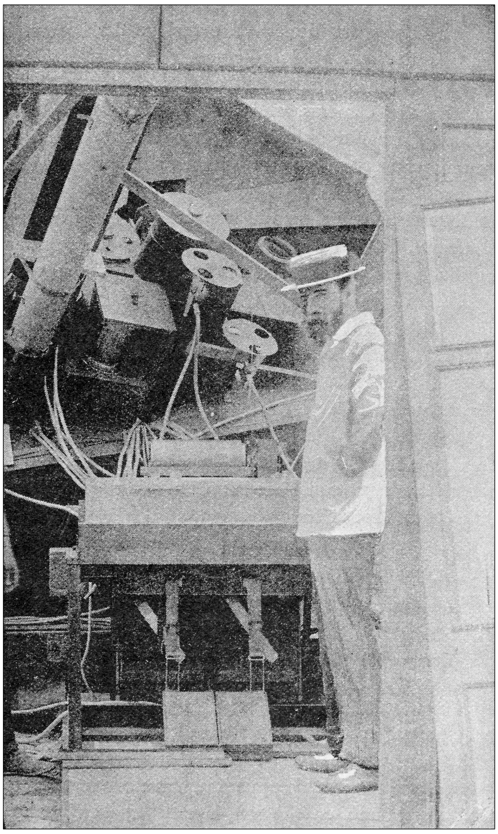
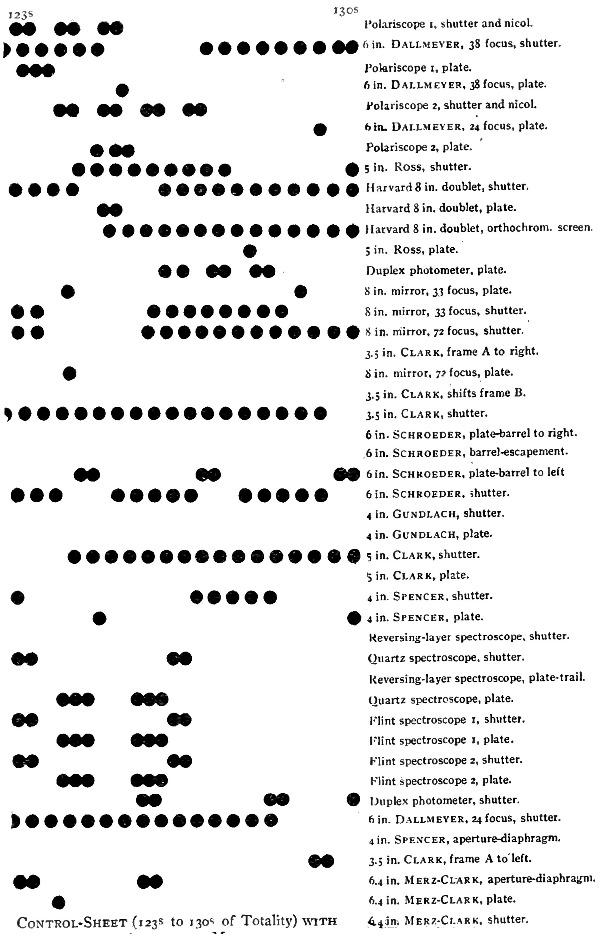


Figure 3: Partial view of the pneumatic commutator and photographic instruments (after Todd, 1894: 186).



CONTROL-SHEET (123s to 130s of Totality) WITH KEY TO AUTOMATIC MOVEMENTS

Figure 4: Partial control-sheet (123s to 130s of totality) with key to automatic movements (after Todd, 1894: 188).

and the photographic apparatus would be activated.

Figure 4 shows that in a seven second interval several photographs were planned for, at least, some instruments.

Despite the fact that bad weather prevented the photographs of the corona being obtained, more than one hundred exposures were made during the 190 seconds of totality. Consequently, Todd (1894) was upbeat about the future performances of his 'automatic' approach.

For his next attempt Todd returned to Japan to observe the total solar eclipse of 9 August 1896. On this occasion an electric commutator controlled the "… necessary instruments, about 500 in all." (Todd and Lynn, 1899: 363). Once more, unfavourable weather conditions impeded the observation of the eclipse.

In 1900, Todd went to Tripoli (Libya) to observe the 28 May eclipse. Upon his arrival he developed *in situ* a "… crude and provisional …" mechanical system that used "… gravity as a motive power for the mechanical operation of shutters and plate-holders." (Todd, 1900b: 674). Ironically, this time the skies were clear and over 100 photographs of the corona were obtained during the 51.5 seconds of totality. However, he did not enjoy this same good fortune the following year when he went to Singkep (Indonesia) to observe the solar eclipse of 18 May 1901 with a "… new type of mechanical commutator ..." (Todd, 1901: 364).

On 30 August 1905 Todd was again in Tripoli where a

> … three-and-one-half-inch Goerz doublet of thirty-three and one half inches focus, attached to one of the automatic movements used on my previous expeditions of 1896, 1900 and 1901, secured 63 fine pictures of the corona during the 186 seconds of totality. Some of these show the coronal streamers to exceptional length. (Todd, 1906: 458).

Unfortunately, while Todd published detailed accounts of his eclipse expeditions he never, as far as we know, analyzed his 1900 and 1905 photographic results.

2.6 Harvard College Observatory's Photographic Occultations

Becker's 1905 eclipse effort was not the first time that astronomical single-plate sequential photography had been attempted. Systematic observations of the eclipses of Jupiter's satellites were performed at Harvard College Observatory from 1878, and eventually a decision was taken "… to make photographic observations …" of all eclipses visible at the Observatory, using the 11-inch Draper photographic telescope (Gerrish, 1895: 146). In a novel approach, in order to determine the eclipse times the telescope and/or the photographic plate were moved during the exposure in such a way that a discrete series of images of Jupiter and its satellites was recorded in a single plate. In principle, from the photometric analysis of the plate one could determine the disappearance and reappearance times of the satellites. The first measurable plate was photographed on 24 July 1888, and initially the slow motion in declination was moved by hand at intervals of ten seconds, the time being taken from a chronometer (King, 1917). The motion was of sufficient rapidity to ensure distinct, detached images of the satellites without the use of an exposing shutter, and was gauged to produce a displacement of the image on the plate of about 0.8 mm. This amount was doubled on the sixtieth second of each minute, thus dividing the chain of images into groups of six, each group representing one minute of time (Gerrish, 1895).

In the 1890s the process was automated, ten seconds being the typical exposure time. Observations started eight minutes before the computed eclipse time and continued for a few minutes afterwards (Figure 5) (Gerrish, 1895; King, 1917). The occultation times corresponding to half brightness, and the last photographic image were determined from the plates, but the photometric analysis proved difficult. In particular, the light reflected from the back of the photographic plates made the satellites appear on a background of varying density.

In 1917 Edward S. King (1861–1931) published the results of 122 eclipses and concluded that although "… discrepancies between the photographic and visual observations occur … [the method] may be useful in the solution of the general problem of the eclipses of Jupiter's Satellites." (King, 1917: 190).

On 25 February 1898 King recorded photographically the first lunar occultations of stars with a variation of the previously-described apparatus (Pickering, 1898). Once more the aim was to precisely time the occultation. The results would be used to test the contemporary precision of the lunar tables in order to improve them and to increase the accuracy of future predictions (King, 1912). The results of thirty-eight such events photographed between 1898 and 1908 were published in 1912. One immersion and one emersion of Saturn were also observed (King, 1912).

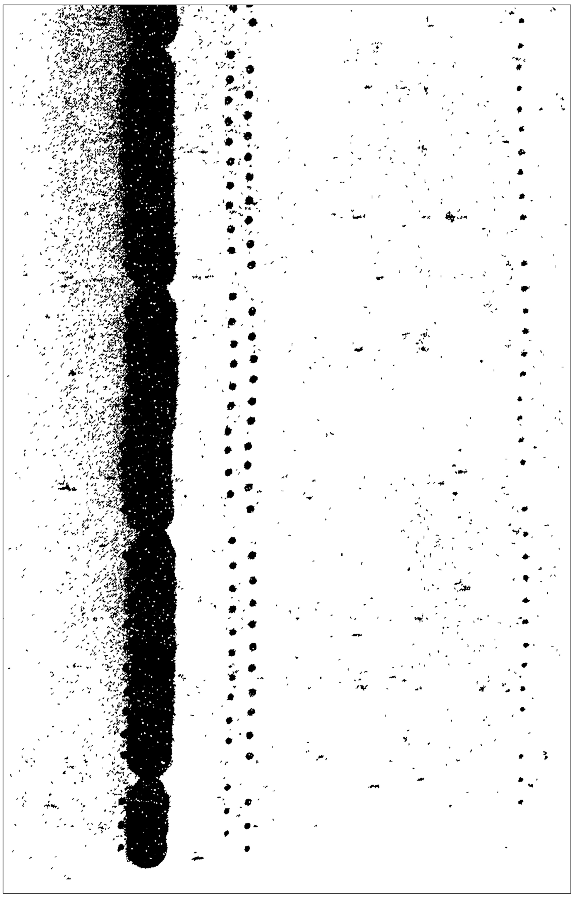


Figure 5: Photographic record of Io's disappearance on 14 April 1900 (after King, 1917: Figure 3, Plate I).

3 CONTINUOUSLY-MOVING PLATES

In the meantime and in order to investigate the possible effect of a lunar atmosphere on the measurement of the occultation times, King, devised an apparatus in which the photographic plate rotated at a constant rate. After one revolution, and to avoid superpositions, the centre of motion was carried near the point occupied by the star image. As a consequence a star traced a series of concentric arcs approaching the centre of the plate as time went on (Figure 6). The first emersion of a star recorded on this manner happened on 28 December 1904. King concluded that no appreciable atmosphere existed at a height of 1 mile above the lunar surface. If an atmosphere existed it would have a depth below the highest lunar mountains (King, 1912).

This was not, however, the first astronomical use of a continuously moving plate. For his observation of the 9 August 1896 total solar eclipse Norman Lockyer devised a 9-inch aperture prismatic camera with a 'dropping' plate. The plate was

> … to be exposed as near as possible ten seconds before the end of totality, and carried through until fifteen seconds after, the plate being moved slowly in the direction at right angles to the length of the spectrum. The object of this motion is to obtain an unbroken record of the changes in the spectrum during this interval of time.

In this manner "… an unbroken record of the changes in the spectrum …" during that time interval would be obtained. The use of the camera was prevented by the poor weather at Kiö Island (Norway) on the day of the eclipse (Lockyer, 1897: 81).

Apparently William Wallace Campbell (1862–1938) was simultaneously working upon a similar idea but only had the chance to try it out at the 22 January 1898 total solar eclipse (Bingham, 1923; Campbell, 1898). A schematic of Campbell's apparatus is presented in Figure 7.

While the method unavoidably represented some degree of integration Campbell believed his approach provided a better description of the "… rapidly changing [flash] spectrum …" than a series of photographs

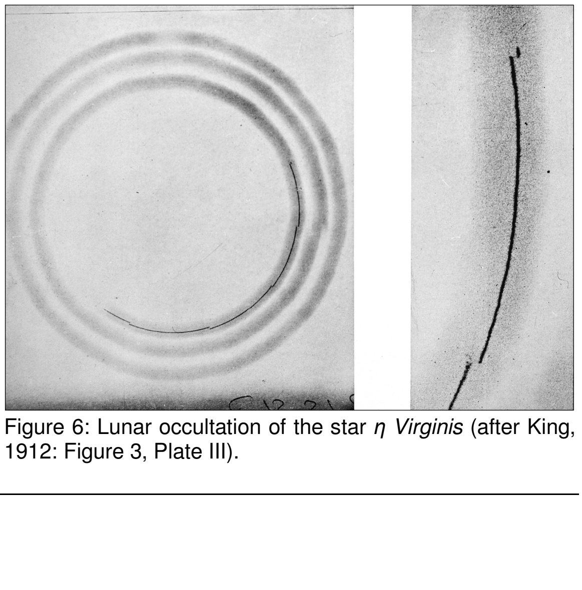


Figure 6: Lunar occultation of the star *η Virginis* (after King, 1912: Figure 3, Plate III).

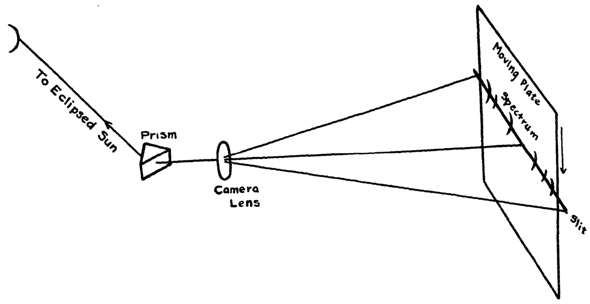


Figure 7: Diagram of the Moving-Plate Flash-Spectrum Camera (after Menzel, 1930: 3).

(Campbell, 1930: i). During the 30 August 1905 solar eclipse observation "... the plate-holder was moved by a hydraulic piston actuated by a weight ..." (Campbell and Perrine, 1906: 27). Between 1898 and 1908 five successful plates were obtained on four different occasions by Campbell's Lick Observatory eclipse expeditions. Of those one was classified as poor, three as good and one as excellent (Table 1). The quality of the plates was highly dependent on obtaining accurate focus, which was very difficult to determine. The plate speed was determined by the required exposure. Speeds of the order of 1/16 inch per second corresponding to an exposure on any part of the plate of about half a second were typically used (Carpenter, 1927).

At the fourth conference of the International Union for Co-operation in Solar Research held at Mount Wilson in 1910 Campbell described his technique and presented at least the 1905 plate (Figure 8) (Anonymous, 1911). In the following years "... pressure of administrative and other duties ..." prevented him from carrying out a full analysis of these plates (Campbell, 1930: vi).

Edwin Francis Carpenter (1898–1963) published some preliminary results in 1927, while a detailed analysis by Donald Howard Menzel (1901–1976) appeared in 1930-1931. In a work now recognized as a milestone in solar chromospheric studies (Osterbrock, et al., 1988: 170-172), Menzel (1930; 1931) emphasized the importance of turbulence and the high hydrogen abundance of the outer solar atmosphere (cf. Carpenter, 1927).

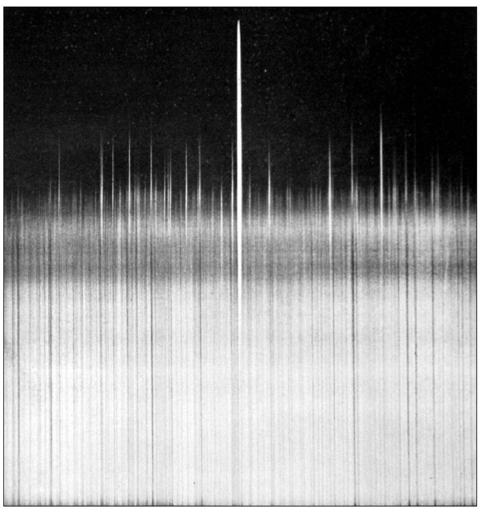


Figure 8: Enlarged section of the flash spectrum from the plate of 1905 (Spain). The most intense line is Hγ (after Carpenter, 1927: Plate IX).

Later Lick Observatory expeditions to the 21 August 1914 and 23 September 1923 solar eclipses were thwarted by poor weather conditions. On both occasions, amongst the instrumental apparatus transported to Brovary (Russia) in 1914 and Goldendale (Washingon state, USA) in 1923 there was a 'Moving Plate Spectrograph' for observations of the 'flash' spectrum. Due to the outbreak of WWI, the instruments of the Russia expedition were left behind and were unavailable for the 6 June 1918 total solar eclipse (Wright, 1923; Campbell and Curtis, 1914). This was unfortunate since on this occasion the weather allowed successful eclipse observations (Campbell, 1918). No reference to the moving plate spectrograph was found either in Campbell's papers about the 20 August 1922 solar eclipse observed from Wallal, Australia, nor in the 1927 and 1930 papers which analysed the plate spectra (Carpenter, 1927; Menzel, 1930). One may suspect that no such data were obtained, possibly because at the time Campbell's prime scientific objective was to confirm Einstein's predicted deflection of star light during a total solar eclipse. This approach was successful when photographs taken during the 1922 eclipse supported Einstein's theory (Burman and Jeffery, 1990; Crelinstein, 2006; Pearson, 2009; Pearson and Orchiston, 2008).

4 DISCUSSION AND CONCLUSION

The majority of celestial events occur on time-scales longer than a few minutes and as a consequence there are not, in practice, many astronomical applications open to sequential photography or cinematography. Notable exceptions are total solar eclipses, transits and occultations. In these latter events a series of photographs taken at very short regular intervals allows, in principle, precise determination of the contact times. In the former, sequential photography was valuable both for technical and scientific reasons. On the one hand, due to the short duration of total solar eclipses one could use different exposures and/or photographic plates in an attempt to better capture the phenomena. For instance the wide variation in the brightness of the solar corona made it impossible to correctly expose its inner and outer parts in a single photograph. On the other hand, a quick succession of images could capture the variability of solar phenomena. Obviously, in principle, a sufficiently large number of observers each furnished with their own equipment could obtain as many photographs as necessary, but this approach not only implied a higher cost—for instance in travel expenses—but its practicability was questionable since the 'human mechanism' needed to remain

> ... unperturbed under the strain and tension of totality; but sad experience shows its frailty, as attested by numerous and unfortunate instances of slips in the execution of a perfectly arranged programme, no matter how constantly rehearsed. (Todd, 1897: 318).

It is therefore not surprising that this paper describes a small number of observations of total solar eclipses, transits and occultations. One should point out that apparently the development of cinematography did not play a role in this outcome, for two reasons. Firstly, cinematography itself was rarely used in this time period and secondly, photography, in general, and sequential photography, in particular,

Table 1: Summary of Lick Observatory's 'moving-plate' spectrograph eclipse observations.

Date	Location	Plate	Spectral Region (Å)
1898 January 22	India	Good	5150–5500
1900 May 28	Georgia	Good	3930–5180
1905 August 30	Spain	Poor	3200–5200
1905 August 30	Spain	Excellent	3800–5200
1908 January 3	Flint Island, Pacific Ocean	Good	3800–5100

allowed the use of larger plates, i.e. larger magnifications (Bonifácio, et al., 2010). It is also interesting to note that despite Todd's support for his 'automatic' mechanisms until at least 1914, he was aware, as early as 1900, of the 28 May 1900 eclipse film (Jacoby, 1907; Todd, 1900a; 1915). Furthermore, at the Seventieth Meeting of the British Association for the Advancement of Science, held at Bradford in September 1900, he presented a communication titled "On the Adaptation of the Principle of the Wedge Photometer to the Biograph Camera in photographing Total Eclipses." The idea was to compensate for the wide variation in brightness that occurs during a solar eclipse by using a wedge photometer (Todd, 1900a). To our knowledge, this proposal was not implemented.

Upon analyzing the attempts to use sequential photography in astronomy outlined here, one quickly realizes that several of them produced no results whatsoever, while in the case of those that did (e.g. the Harvard College occultations program and the Lick Observatory flash spectrum study) several years elapsed between the observations and the publication of the results.

We conclude that the lack of convenient objects explains the relatively small number of attempts that were made to apply sequential photography in astronomy. This technique could only be employed in very specific niche fields of research.

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THE ASTRONOMICAL SIGNIFICANCE OF 'NILURALLU', THE MEGALITHIC STONE ALIGNMENT AT MURARDODDI IN ANDHRA PRADESH, INDIA

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Abstract: The stone alignment 'Nilurallu' at Murardoddi is a megalithic monument containing standing stones of 12 to 16 feet high that are arranged somewhat in a squarish pattern. This is one of the stone alignments listed by Allchin (1956) as a non-sepulchal array that might have some astronomical connotations. This impressive stone alignment seems to be similar to that at Vibhuthihalli, that was studied earlier, but constructed with much larger stones. The observations conducted by us show that the rows of stones are aligned to the directions of sunrise (and sunset) on calendrically-important events, like equinoxes and solstices. In contrast to Vibhuthihalli, the shadows of stones provide a means of measuring shorter intervals of time.

Key words: Observational astronomy, megalithic astronomy, stone alignments, equinoxes, solstices, sunrises

1 INTRODUCTION

On the day of the spring equinox (e.g. 21 March 2010) people from Mudumala and Murardoddi in India visit 'Nilurallu' (which means 'standing stones' in Telugu), a stone alignment located between these two villages, offer their prayers and celebrate the occasion by having a feast. Nilurallu is a megalithic alignment of standing and fallen stones that are 12-16 feet (3.7-4.9 meters) high (Figure 1) in the Mahbubnagar district of Andhra Pradesh. The celebration (Figure 2) in a way demonstrates a continuing tradition commemorating an astronomical event and its connection with this alignment. This is one of the megalithic alignments listed by Allchin (1956) as non-sepulchral stone arrays with possible orientations towards cardinal points, similar to Vibhuthihalli. We have surveyed about 17

Figure 1: The overall view of the Niluralllu alignment as seen from the western side.

Table 1: Status of the megalithic sites visited.

S1 No.	Site and Location	Type of Megalith	Comments
1.	Vibhuthihalli, 16°.665 N, 76°.858 E; Shahput Taluk, Yadgir, Karnataka	Stone Alignment	Preserved
2.	Bheemarayanagudi, 16°.727 N, 76°.798 E; Shahput Taluk, Yadgir, Karnataka	Stone Alignment	Disturbed
3.	Ijeri,Shahput Taluk, Yadgir, Karnataka	Stone Alignment	Does not exist
4.	Rajan Kollur, 16°.39 N, 76°.455 E	Stone Alignment	Does not exist
	Shorapur Taluk, Yadgir, Karnataka	Dolmens	Exists
5.	Hanamsagar, 15°.883 N, 76°.072 E; Shorapur Taluk, Yadgir, Karnataka	Stone Alignment	Disturbed
6.	Managodanahalli, Devanahalli Taluk, Bangalore, Karnataka	Menhirs, Cists	Does not exist
7.	Koiera,	Menhirs, Cists	Does not exist
	Shorapur Taluk, Yadgir, Karnataka	Dolmens	Exists
8.	Mudumala 16°.379 N, 77°.41 E; MakhtalTaluk, Mahabubnagar, Andhra Pradesh	Stone Alignment	Exists to some extent
9.	Murardoddi, 16°.378 N, 77°.406 E; Makhtal Taluk, Mahabubnagar, Andhra Pradesh	Stone Alignment	Exists
10.	Panjanur (Pundununnur), 16°.386 N; Makhtal Taluk, Mahabubnagar, Andhra Pradesh	Habitation	Disturbed
11.	Gudabellur, 16°.42 N, 77°.383 E; Makhatal Taluk, Mahabubnagar, Andhra Pradesh	Stone Alignment	Does not exist
12.	Kotakunda-Koilkunda, Makhatal Taluk, Mahabubnagar, Andhra Pradesh	Stone Alignment	Does not exist
13.	Madhawavaram, Makhatal Taluk, Mahabubnagar, Andhra Pradesh	Stone Alignment	Does not exist
14.	Gopalpur, Makhatal Taluk, Mahabubnagar, Andhra Pradesh	Stone Alignment	Does not exist
15.	Devakadra,16°.616 N, 77°.833 E; Makhatal Taluk, Mahabubnagar, Andhra Pradesh	Stone Alignment	Does not exist
16.	Kundanpur-Sanganunpalli, Makhatal Taluk, Mahabubnagar, Andhra Pradesh	Stone Alignment	Does not exist
17.	Jamshed I - IV, 16 Raichur, Karnataka	Stone Alignments	Do not exist
18.	Krishna Bridge, Raichur, Karnataka	Stone Alignment	Does not exist

of the sites listed by Allchin (Table 1) out of which only the Vibhuthihalli and Murardoddi alignments are relatively undisturbed. The remainder have either disappeared completely, or have very few stones left. General properties of the sites have been described by Allchin. The plan consists of stones arranged in parallel rows with equal spacing. The stone arrangements are either square-like, a checker board, or a square with a diagonal arrangement consisting of one more stone in the centre of a mini-square formed from a set of four stones. The effect is to stress the diagonals.

In an earlier paper (Kameswara Rao and Thakur, 2010; hereafter Paper I) we showed that the Vibhuthihalli stone alignment, in all likelihood, was used as a calendarical device by megalithic people from the Karnataka region. In the present paper we explore the possible astronomical significance of the Nilurallu alignment by monitoring sunrises and sunsets during calendrically-important occasions, such as the equinoxes and the solstices. Most of the alignments listed by Allchin have stones of 4-6 feet (1.2-1.8 meters) and 2-4 feet (0.6-1.2 meters) in diameter. Thus, the Nilurallu alignment is special as it consists of huge stones, two to three times the usual size. It might have had a special purpose as well.

Figure 2: A celebration at the Nilurallu stone alignment site on equinox day.

2 THE SITE

The Nilurallu alignment is located at latitude 16° 22' 44" N and longitude 77° 24' 40" E, southeast of Murardoddi village and southwest of Mudumala village. The Krishna River is about a 0.5 km away to the south (Figure 3). The alignment is in an area containing artifacts of different cultures, ranging in age from the Middle Paleolithic and Mesolithic to the Megalithic Period. In the course of our field work we found stone circles and avenues of smaller (i.e. normal sized) stones in the area to the east of Nilurallu (also see Krishna Sastry, 1983). Areas to the west of Nilurallu have some historical hero tablets, sculptures, iron slags, bruisings and even small rock pits used for sharpening stone tools (ibid.). To the south there are arrays of 0.5 to 3 feet (0.15 to 0.9 meter) high stones (ibid.). Meanwhile, Middle Palaeolithic tools (choppers, and different types of scrappers, borers, and flake tools) have been recovered from the site of the Nilurallu alignment (ibid). The site and its surroundings are filled with pebbles. The Nilurallu site occupies a prominent place on slightly elevated ground that dominates the surrounding terrain.

Figure 3: Google map of the area with the stone alignment. The Krishna River is about half a kilometer away to the south.

The earliest account of the site is by Krishna Murthy (1941: 86), who describes it as follows:

> … there is an almost square area studied with rough-hewn stone pillars. These pillars are arranged in parallel rows in a north-south direction. The pillars are 14′-16′ long and 6′-11′ in girth. There are 31 pillars still standing and many have fallen down. The square measures about 200′ × 200′ with apparently 6 pillars in each row.

Krishna Murthy (1941) also provides a photograph (which, unfortunately, we could not obtain). He adds: "… the pillars are locally known as 'Nilu Ralloo' meaning standing stones." (ibid.). Krishna Murthy (1941) also provides a local legend for the origin of Nilurallu alignment. Apparently a disappointed old beggar woman, who was deceived by the local farmers while harvesting grain, cursed them and they became stones. The standing pillars represent the men who were working and the fallen ones are those people who were lying down. The large group of short stunted pillars to the southwest of this alignment are supposed to be petrified cattle, and the sand around the stones was supposedly the grain they were harvesting. Krishna Murthy (1941) also seems to have picked up a piece of a stone axe at the site. Allchin (1956) quotes Krishna Murthy's description in his report. To our knowledge, these are the only reports about this site that have been published.

However, recently, two abstracts of conference papers by K. Pulla Rao (2007; 2009) appeared that provide some description of his observations of the site. According to him there are "… more than 800 menhirs arranged in different formations and rows. The rows are oriented in different directions." (Pulla Rao, 2009). He also mentions that observations on

> … summer and winter solstice reveals that one particular row aligns with the Sun in the morning and another row in the evening ... [and] The central area of the complex has a concentration of about 80 tall (up to 14 feet) menhirs which are arranged in rows forming alignments and avenues. The rows are oriented in different directions. (ibid.).

These bigger menhirs are the ones Krishna Murthy (1941) described earlier, mentioning that they were arranged in parallel rows but were not oriented in specific directions. In one of the abstracts, Pulla Rao (2007) mentions that "The central area with the bigger menhirs also has a formation of stones arranged in concentric circles with standing menhirs interspersed with horizontal blocks. It has been observed that two of the taller menhirs of the circle align with the Sun in both morning and evening." However, he does not mention on which days this alignment occurs. Presently no such structure of "concentric circles" of bigger menhirs exists, nor does Krishna Murthy (1941) mention any such formation.

Pulla Rao (2007) also found a stone in the south-western part of the complex which has 30 cup marks on its surface. He claims that these cup marks depict the constellation Ursa Major. We have located this rock (Figure 4) in the southwest periphery. The rock surface contains about fifty cup marks, not just seven. A comparison with sky charts (e.g. in Norton's Star Atlas—see Ridpath, 2004) of the naked eye stars shows that any resemblance to the Great Bear constellation is imaginary. There is no indication that these marks are even depictions of stars. They could even represent the layout of the stone arrays! At this same site we also found another stone with several cup marks on it, as well as a stone with a solitary cup mark. Stones with cup marks are found at other megalithic sites (see Peddayya, 1976).

Figure 4: It has been claimed that this bruising (the cup marks) depict the constellation of Great Bear (Ursa Major).

2.1 Recent Observations

The Nilurallu site is on private land and the owners plant crops when they desire, so astronomical observations have to be conducted when the fields are empty. Figure 5 illustrates the comparative size of some of the stones relative to people standing next to them. As of July 2009, there were 29 standing stones and 46 fallen ones, whereas a little over a year earlier—in April 2008—there were 31 to 32 standing stones. Thus, two or three standing stones disappeared during this interval. Some of the fallen stones have been heaped on the eastern side of the site between standing stones s27 and s28. All of the standing stones present in July 2009 and most of the fallen ones that are lying in open areas (and not heaped up) are plotted in Figures 6 and 7. A scaled map was generated from our measurements of the spacing between the different stones. This map is also consistent with the appearance of an enlarged Google Earth map of the region, except for some fallen stones in the eastern part of the site that were not measured by us.

The height of the standing stones varied from 3.0 meters to 4.7 meters. The stones were mostly granite, and they taper towards the top. They are of different shapes. In most cases their thickness is smaller than their width, thus showing a slab-like appearance (e.g.

Figure 5: Some of the stones are shown with people around them to illustrate the height and size of the stones.

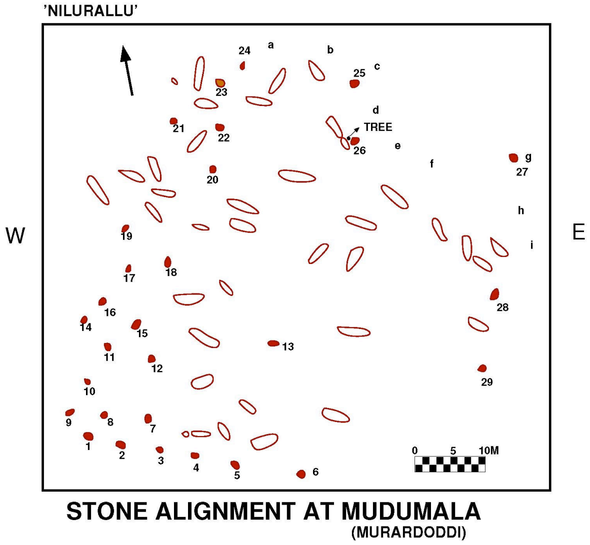

Figure 6: Scaled map of the Niluralllu site layout as measured by us. The filled spots that are numbered represent the standing stones and the open contours refer to the fallen stones. The numbers were arbitrarily given by us for the purposes of this study.

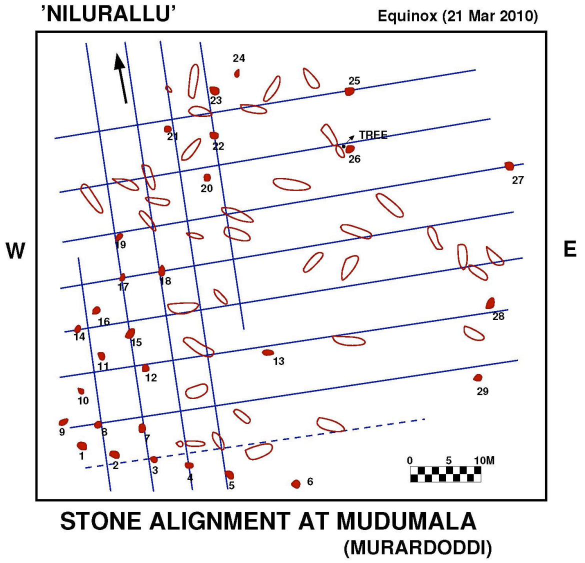

Figure 7: A map of the Niluralllu layout with the directions of sunrise and sunset at the time of the equinoxes shown by the near-horizontal lines. The near-vertical lines indicate the north-south direction.

Figure 8: A row of stones in a north-south direction. The stones numbered 19, 17, 15 and 12 (centre of the figure) can be seen to lie in a straight line. See Figures 6 and 7 for the numbering. This photograph was taken on 21 June 2010 at 5:17 pm (IST).

s22, s18, s15, s11 etc.), although some are like cylinders (e.g. s25). The stone numbers referred to are shown in Figures 6 and 7 and are internal to this study. We have marked these numbers on the stones too, for future reference during this study. Several of the stones are tilted from the vertical (the figures show the base positions) and give an impression that the tilt is inwards if looked at from afar (e.g. see Figure 1).

2.2 The Archaeological Setting

Because the site is in a slightly elevated area, the horizon in all directions is quite clear, and sunrises and sunsets are readily visible—except when there are crops on the site. The present extent of the site seems to be the same as that mentioned by Krishna Murthy (1941), i.e. about 200 ft × 200 ft. The layout as mapped gives the impression of a diagonal alignment. The separation of rows of stones seems to be uniform more or less (but defining them is not always easy and depends mostly on the presently-standing stones). The average separation of any two stones in a row (centre to centre) is 5.8 ± 0.9 meters.

2.2.1 North-South Direction

We determined the north-south line, as in Vibhuthihalli, by using a stick as a gnomon to measure the direction of the shadow of the stick. The meridian direction was established by marking on the ground the direction of the shortest shadow (i.e. when the Sun was on the meridian).

As far as possible, we tried to adopt methods which were simple and could have been accomplished with tools that were available in prehistoric times. Figure 7 shows the direction and the rows of stones which are parallel to north-south. A specific example, illustrated in Figure 8, is the row with stones s19, s17, s15, s12, s7 and s3 that lie in a north-south direction.

3 CALENDRICAL EVENTS

One of the important aspects regarding the astronomical relevance of the monument is to observe whether preferred alignments exists for calendrically-important events like sunrises and sunsets on equinox and solstice days. Were the rows of stones aligned in these preferred directions? We tried to monitor sunrises and sunsets on a few days around the dates of the equinoxes and solstices, weather permitting, and visual observations were made along the rows of standing stones pointing towards the directions of sunrise and sunset. Since the tops of the stones are tilted in random directions (in some cases), the positions of the bases of the stones, which were less disturbed, were used to define the directions.

3.1 Equinox Sunrises and Sunsets

Observations were made at the times of the September 2009 and March 2010 equinoxes. However, the September observations were mostly hindered by clouds. The equinox occurred on 20 March 2010 at 23:30 (IST), and our observations extended from 19 to 22 March. The sunrises and sunsets along the rows are marked in Figure 7. Examples of the direction of sunrise along various rows are illustrated in Figures 9, 10 and 11. Since the view directly along a row would be blocked by the stone in front, views from slightly to

Figure 9: Equinoxial sunrise as seen over the stone row containing stones numbered s9, s8, s7 and s29. The Sun's calculated azimuth is 89.39° and altitude is 2.52°.

Figure 10: Equinoxial sunrise as seen over the stone row containing stones numbered s12, s13 and s28. The Sun's calculated azimuth is 89.5° and altitude is 2.32°.

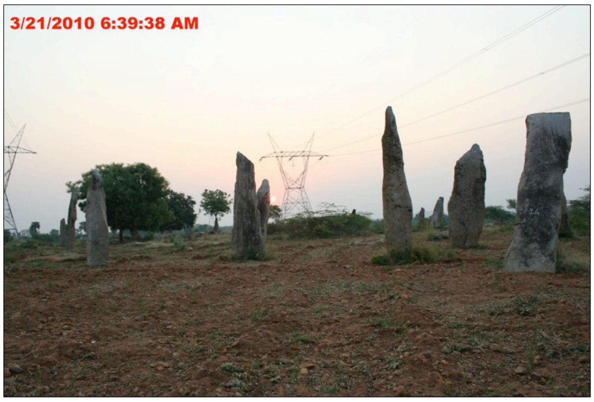

Figure 11: Equinoxial sunrise as seen over the stone row containing stones numbered s17 and s18. The Sun's calculated azimuth is 89.30° and altitude is 2.8°.

the right or the left of the stone in front are illustrated. The accuracy of the stated direction for each row is ~1° (i.e. two solar diameters). Since the rows point to the equinoxial sunrise (in the east) and sunset (in the west) they are parallel to each other and are shown as horizontal lines in Figure 7. As an example the row of stones, s9, s8, s7 and s29 points to the equinox sunrise (s29 is hidden in the Figure 9); as does the row with s12, s13 and s28 and the row with s17, s18. The rows as drawn in Figure 7 from the directions of sunrise and sunset provide roughly equal spacing between them and are perpendicular to the north-south rows. Equinoxial sunsets along the rows of stones are illustrated in Figures 12, 13 and 14. The calculated azimuth and altitude of the Sun are also given in the Figure captions.

Figure 12: Equinoxial sunset over stones s26 and s20. The Sun's calculated azimuth is 270.8° and altitude is 4.4°.

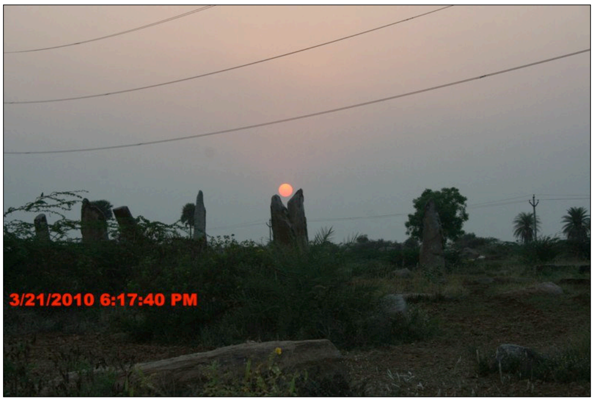

Figure 13: Equinoxial sunset over stones s18 and s17. The Sun's calculated azimuth is 270.4° and altitude is 2.5°.

Figure 14: Equinoxial sunset over stones s28, s13 and s12. The Sun's calculated azimuth is 270.36° and altitude is 2.36°.

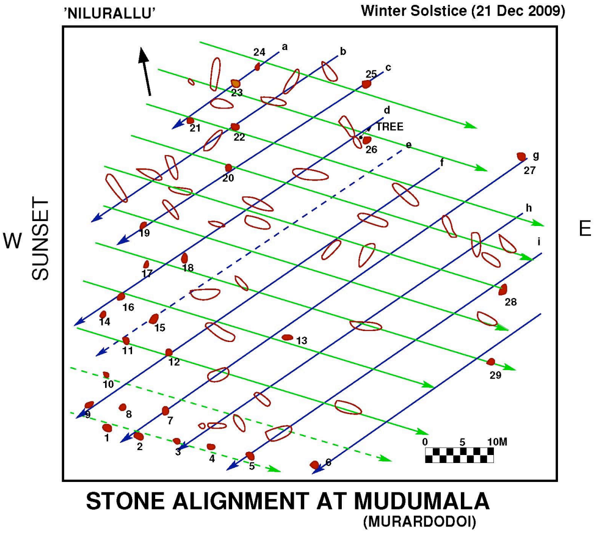

Figure 15: Sunrise (green lines) and sunset (blue lines) directions during the winter solstice are shown on the Niluralllu site layout. The diagonal stone rows showing the direction of sunset are denoted by the letters a, b, c, etc.

3.2 Solstice Sunrises and Sunsets

The solstice observations were obtained in December 2009 and June 2010. The summer solstice sunrise and sunset observations were affected by clouds. Winter solstice occurred on 21 December 2009, and we obtained observations from 19 to 22 December. The sunrise and sunset directions along the stones are marked in Figure 15. The stones seem to be well laid out in these directions and show a parallel outlay as expected. The images of sunsets along various diagonal rows are illustrated in Figures 16 to 19. Figure 17 shows the row with stones s25, s20 and, and s19 pointing to the sunset direction. Similarly, the sunrise direction is illustrated by s17 and s29 in Figure 18. There seem to be about ten diagonal and parallel rows present in the layout, as shown in Figure 15 suggesting a separation of about 20' between the rows (i.e. 6.0 meters). Even the parallel rows aligned with equinoxial sunrise and sunset might number the same, with similar spacing, as seen in Figure 7.

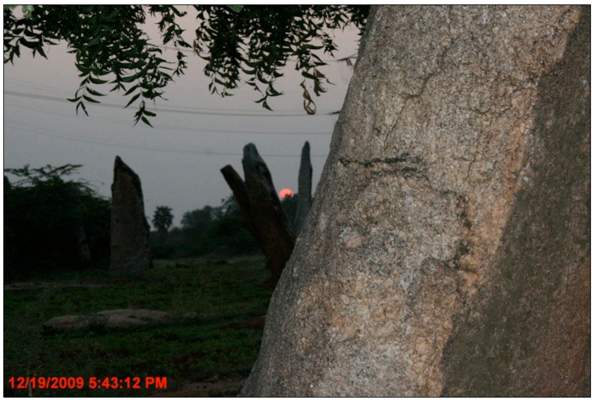

Figure 16: Winter solstice sunset over the row containing stones s26, s18, s16 and s14. The Sun's calculated azimuth is 245.16° and altitude is 1.1°.

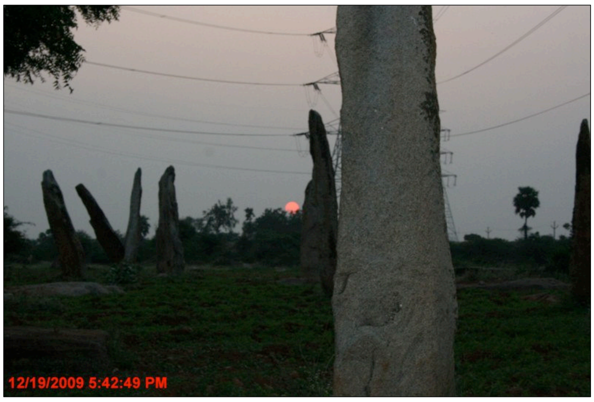

Figure 17: Winter solstice sunset over row c, containing stones s25, s20, and s19. The Sun's calculated azimuth is 245.14° and altitude is 1.18°.

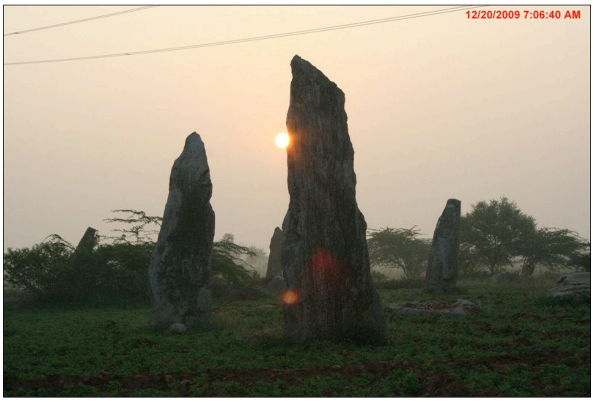

Figure 18: Winter solstice sunrise over stones s17 and s29. The Sun's calculated azimuth is 244.06° and altitude is 4.24°.

3.3 Shadows

Another major aspect of the Niluralllu alignment, that is not present at Vibhuthihalli, is the shadows of the stones. In particular, the shadows cast (by sunlight) on each other by high and broad neighbouring stones form a pattern that is so distinct and prominent that it enables the time during the day, as well as the day (like latter-day sundials), to be determined. Some examples are shown in Figures 20 to 23.

The stones are of sufficient height to cast prominent shadows not only on the neighbouring stones but also on the dry reddish soil underneath. The length and direction of the shadows change with time and day. At mid-day, when the Sun is on the meridian, a north-south row of stones would cast shadows which would be in a line (e.g. the stones s19, s17, s15, s12, etc.). On the winter solstice day the shadows at mid-day would be about half of the separation of stones (so a 12-foot high stone would have a shadow of about 10 feet in length).

Figure 19: Winter solstice sunrise over stones s11 and s12. The Sun's calculated azimuth is 244.92° and altitude is 1.8°.

Figure 21 illustrates the change in shadow direction in the evening from summer solstice to equinox to winter solstice. At summer solstice the stone s11 casts its shadow such that it falls on s12 (Figure 21a). At the equinox, s11's shadow falls midway between stones s15 and s12 (see Figure 21b). At winter solstice the shadow of s11 falls on the edge of s15. The altitude of the Sun on these three occasions is in the range of 21-28°, and does not differ much from one date to another.

Thus shadow length and direction could provide the time of the day. Distinct markers could be made when a stone cast its shadow and fully covered a nearby stone, another marker when it reached its base, etc., to reckon the time.

4 THE ANATOMY OF THE NILURALLU STONE ALIGNMENT

It is very clear from the earlier discussion that the stone rows are distinctly aligned to sunrises and sunsets during both the equinoxes and the solstices. Several issues regarding the squarish plan—a general feature of all of the stone alignments in Karnataka, Andhra Pradesh region, listed by Allchin (1956)—have been discussed in Paper I (Kameswara Rao and Thakur, 2010), but they do apply to Nilurallu. Although the present site lacks the sharp-edged demarcations as seen at Vibhuthihalli, it does look to be a square.

4.1 The Plan

As was discussed in Paper I, the squarish plan is well suited to point to the directions of the solstices at Nilurallu. At the latitude range of 16-17° the azimuthal travel of the Sun (plus the size of the Sun's disk) on the horizon was slightly over 50° in 1500 BC (i.e. ~25° on each side of the equinox sunrise—or sunset—direction). This angle is the same as the angle measured from a centre of a side to the opposite corners of a square within the error of two solar diameters. The Nilurallu alignment is also consistent with this picture. The diagonal lines are drawn parallel to the solstice directions. In this picture, a preferred position would be the centre of either eastern or western side. But as the rows are parallel to each other the view of sunrise and sunset could be monitored from any row.

Why would one need to have so many stone rows to mark the major calendrical events? As discussed in Paper I, the Sun's motion on the horizon is not uniform. It accelerates as it approaches the equinoxes and slows down as it nears the solstices. To monitor this motion and to be able to predict the day (or how many days before or after the equinox or the solstice) more stone markers were required. Smaller increments of motion per day would need to be measured near the solstices and larger ones near the equinoxes.

4.2 Comparison of the Nilurallu and Vibhuthihalli Stone Alignments

Obviously the Nilurallu site has much bigger stones, about three times higher than those used at Vibhuthihalli. The extent of the site is also less by 3.5 times (720 feet, or 219.5 meters for Vibhuthihalli as compared to 200 feet or 61 meters for Nilurallu). The spacing between the stones at Nilurallu is half that at Vibhuthihalli (about 20 feet or 6.1 meters as compared to 38 ± 3 feet or 11.6 meters at Vibhuthihalli). The Nil-

Figure 20: Shadows of stones on each other at the time of the equinox. The shadow of s18 on s17 is shown. The Sun's calculated azimuth is 83.88° and altitude is 20.41°.

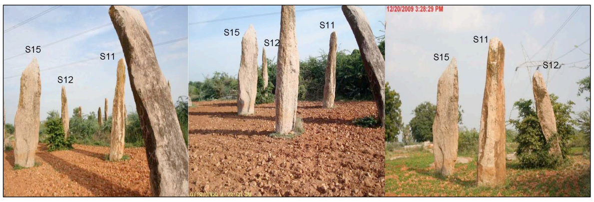

Figure 21: Evening shadows of stone s11 on s15 and s12 during (a) the summer solstice (note that the shadow of s11 is at the base of s12); (b) the equinox (the shadow of s11 is between s12 and s15); and (c) the winter solstice (the shadow of s11 is at the base of s15). The azimuths and altitudes of the Sun were calculated as 289.39° and 20.74° in (a); 264.05° and 26.3° in (b); and 230.72° and 28.67° in (c), respectively.

Figure 22: The shadow of stone s21 on s22 during the evening at the summer solstice. The Sun's calculated azimuth is 289.38° and altitude is 20.83°.

Figure 23: Stone s25 casts a shadow at the base stone s20 (slightly to the left), and s20, in turn, casts its own shadow slightly to the left of the base of s19, forming a long continuous dark path on the evening of 30 November 2009 (20 days before the winter solstice). The azimuth and altitude of Sun as calculated are 243.34° and altitude is 10.85°.

Figure 24: The shadow of the tall menhir s19 falling on a stone in one of the smaller stone arrays that surrounds Niluralu at sunrise on the day of the equinox (21 March 2011), illustrating that the small stones are also arranged along east-west lines. Note that the extension of the north-south line defined by the tall stones also passes through the small stones.

urallu alignment is more compact but is much more impressive because of the use of tall and massive stones. Although the main reasons for using such large stones is not known, one of the primary purposes could be to utilize the shadows of the stones as markers of time. The reason for reducing the spacing between the stones and increasing their height might be to enable the shadows to cover the adjacent stones. Many of the stones chosen are broad (more like slabs), thereby providing a flat surface upon which to see the shadow of the stone in front. Perhaps tapering of the stones towards their tops may have kept the shadows sharp and pointed so as to serve as markers. Another advantage of using tall stones is that they could be used as screens to directly view the Sun (at average human height). Even if shadows were not present one could still estimate the position of the Sun as it came out from behind the screen.

Figure 25: The base of a fallen stone is shown. Note the flat bottom and the shaping of the stone. Considerable effort might have been put into shaping the stone, probably by beating with smaller stones.

Observations of sunrises and sunsets would provide a count of the day of the year (or from the equinox or solstice), whereas the shadows of the stones would indicate the specific time of day. Unlike at Vibhuthihalli, all of the natural horizon is clearly visible from the Nilurallu stone alignment.

4.3 Uniqueness of the Nilurallu Stone Alignment

The Nilurallu alignment is unique and is surrounded by smaller stone arrays (particularly to the south). The spacing of the stones in the array seems to be consistent with the standard measurement of 37 ± 3 feet (11.28 meters) (see Paper I) noted at Vibhuthihalli and other Indian stone alignment sites.

The smaller stones immediately surrounding the Nilurallu site are also aligned with the large menhirs at Nilurallu that point in the directions of E-W and N-S. This is illustrated, for example, on the equinox day when the rising Sun casts the shadows of stones s19 and s17 on the small stones on the periphery of the Nilurallu complex (see Figure 24). It looks as though a grid of small stones pointing to the east and west and to the north and south was prepared before the large heavy stones were erected in the proper directions. Thus, Nilurallu became an integral part of its astronomical surroundings.

Measurements at Nilurallu must have evolved for a profound purpose from the earlier period. There do not seem to be any other stone alignment sites with such tall stones listed in Allchin's survey, although individual menhirs as long as 25 feet (or 7.6 meters) are mentioned.

Answers to the questions of where the stones come from, how they were shaped and transported, and how they were erected are not clear. Our survey of the terrain immediately surrounding the site did not reveal any stone quarries, which indicates that the stones originated from somewhere else. However, there are prominent rock outcrops in the general area (i.e. within a kilometre of the site) that could have provided stones up to 18 feet in length. Some of these were near the banks of the Krishna River. The question then arises as to how the stone slabs were extracted from the outcrop. In a few places there are indications that wooden(?) pegs may have been used to increase cracks in the rock and cause it to fracture.

As can be seen in Figure 25 (a fallen stone), the base of the stone is flat and also seems to have been shaped, maybe by pounding with hammer stones. Magli (2009: 14) mentions a method of shaping stone during the megalithic period:

> … so, the quarrying and shaping of the stones was done with tools made of stone. If the quarried stone was relatively soft, like limestone, one could easily use tools made of harder stone. However, for stones like granite or andesite (which is similar to granite, and found in the Andes), one has to use "percussors," which were

chunks of the same material worked roughly into spheres and violently thrown against the area to be removed.

We found what look to be 'percussors' at Niluralllu (see Figure 26), but whether they were used as suggested by Magli is not known. A granite stone 4 meters in height and 1.2 meters in radius would weigh ~48 tons, so it is a major challenge to determine how such stones could have been transported to the megalithic site and erected. Pebbles on the ground might have offered help when dragging the big stones. The subject of moving large stones in ancient times has been discussed by Magli (2009), but the specific method that was used at Niluralllu is not clear. We did not find any evidence that iron tools were ever used.

4.4 The Age of the Niluralllu Stone Alignment

The site provides evidence for the existence of cultures of different eras. In Paper I we discuss various factors that suggested that the Vibhuthihalli stone alignment site dated to period between 1400 and 1800 BC. The Niluralllu site must date to a later period for various reasons mentioned previously. The requirement for more precise time measurements may have been a driving force at Niluralllu. The technology for handling large stones and erecting them in fairly accurate arrays also suggests a later date. The considerable planning, labour and devotion involved in building the monument suggest a major and very important purpose. Since there is no evidence that iron tools were used (at least not in any major way) the alignment could have been constructed sometime between 1400 and 1000 BC (before the emergence of the Iron Age in India), but of course this is only an estimate, and it is based upon very limited 'hard' evidence. The location and the dominance of the monument over its surroundings suggest a great and sacred purpose and a society that was technically more proficient than the one found earlier at Vibhuthihalli.

5 CONCLUDING REMARKS

The Niluralllu stone alignment is a remarkable monument, and we conclude that its primary (if not sole) purpose was to serve as a calendrical device. Sunrise and sunset observations and the patterns of the shadows of stones were used to measure time, days and fractions of a day. The regular need for a good calendar (for agricultural and other purposes) may have been the driving force behind the erection of this monument, but there could also have been ritualistic and other purposes involved as well. Considerable knowledge of engineering and astronomy was required for the successful construction of this megalithic structure.

A serious archaeological study is required to accurately determine the date of this monument, and methods like archaeomagnetism might be helpful in this regard.

Whether night time astronomy was ever pursued at Niluralllu is not clear. The claim that a figure of the Great Bear is depicted on a nearby rock cannot be taken seriously as the numerous cup marks on the rock surface show no resemblance whatsoever to the constellation that we see in the night sky.

5.1 Preservation of the Site

Whatever the purposes of the Niluralllu stone alignment site—and we strongly suggest that astronomy was one of them—it is a remarkable monument that demonstrates the technological advancement and the skill of the megalithic people in this region. It is a pity that such an impressive structure is slowly being destroyed: stones are being removed, and because the land is under cultivation the stability of the stones is threatened. During the two years or so that our study was carried out several stones were removed from the site, and its long-term survival is under threat. The area is at present privately owned, but we would urge relevant Government and other agencies to now make every effort to preserve this unique heritage site.

Figure 26: A small spherical stone ('percussor'?) sitting on a tall fallen stone. The spherical stone might have been used as a hammer-stone in shaping the larger stones

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THE ROLE OF ASTRONOMICAL ALIGNMENTS IN THE RITUALS OF THE PEAK SANCTUARY AT KOKINO, MACEDONIA

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Abstract: The archaeological locality 'Taticev Kamen' (Tatic Rock) is located in the north-eastern part of Macedonia, near the village of Kokino. During the Bronze Age, it was used as a mountain sanctuary by the people living in the region. The large number of excavated artefacts have confirmed the practise of several different cults. The site also has many characteristics of a megalithic observatory. The detailed archaeoastronomical analysis of the locality indicates that the periodic movements of the Sun and other celestial objects were observed from three different platforms, and their positions on particular dates were marked by notches on the nearby stone blocks. From the first platform, a marker for the midsummer sunrise was carved for the purpose of performing the ritual that has solar characteristics. The second platform is a central site from which the Sun was observed throughout the year, and the extreme sunrise positions on the days of the solstices and the equinoxes were marked. The newly-discovered third platform contains evidence of ritual activities similar to those at the Minoan peak sanctuaries on Crete. Using this platform as an observational site, we found four markers that pointed to the rising of Aldebaran over an interval of several centuries (from 1900 BC to 1500 BC). The heliacal rising of this star before summer and its rising in the evening sky in early autumn were probably connected with vegetative cycles and the organization of agricultural activities.

Keywords: Megalithic astronomy, stone carvings, solstices, equinoxes, heliacal rising

1 INTRODUCTION

The interest of ancient peoples in different objects in the sky was deeply influenced by their religious beliefs, social structure and the need to produce more food and gain more wealth. The never-ending cycles of the Sun, the Moon and the stars provided a feeling of security, and their continuous reappearance in the same positions in the sky promised the renewal of birth and death cycles in nature (Belmonte, 2010). A union of Earth and the heavens was reflected in the influence of the celestial bodies on the events in terrestrial and divine worlds. The coincidence of the menstrual cycle of women and the monthly lunar cycle has led to the thinking of a direct connection between human destiny and celestial bodies. The stars played an essential role in following vegetational cycles and in the organization of agricultural activities. In searching for cosmic order, the ancient 'astronomer-priests' observed the positions of the bright stars over several centuries. Eventually, they divided the sky into regions and made the first maps containing constellations. The periodic motion of the Sun and the Moon made possible the creation of simple calendars based on the solstice and equinox points and changes in the phases of the Moon. Although these calendars were initially made for religious/social/agricultural purposes, eventually they led to the development of astronomy and navigation (see Ruggles, 2005).

A lot of research has been conducted on the astronomical importance of megalithic structures in the Bronze Age. During this period, the population in Britain used a calendar that had 16 'months' consisting of 22 to 24 days each. It was made by dividing the year by the solstices and equinoxes, and then each of these four into two, then into two again (Ruggles and Hoskin, 1999: 2). The work of Hawkins (1963) on one of the greatest monuments of this period, Stonehenge, revealed several alignments pointing towards the extreme rising and setting positions of the Sun and the Moon. In addition, a method was suggested for using the Aubrey holes to predict lunar eclipses by moving markers from hole to hole (Hawkins, 1964). Although Hawkins' results, and the later surveys by Alexander Thom at this site (e.g. see Thom et al., 1974; 1975) and other megalithic sites in Britain (Thom, 1969; Thom and Thom, 1978), attracted some controversy (e.g. see Atkinson, 1966; 1975; Ruggles and Hoskin, 1999), they undoubtedly proved the significant role of celestial objects in the religious and social life of Bronze Age people. The findings from Stonehenge also encouraged the search for similar megalith structures all over Europe.

It is possible that during the Bronze Age, Minoan people on the Mediterranean island of Crete built their palaces, sanctuaries and even graves according to astronomical alignments. As many researchers agree, the central courts of the main palaces were oriented toward the rising Sun on major calendar events, equinoxes or solstices. It has been suggested that some of the orientations in the palace at Knossos provided a simple method for regulating a lunisolar calendar and determining the beginning of the Minoan year, which coincided with the appearance of a specific phase of the Moon, most probably the new crescent moon following the autumn equinox. The method included the use of reflection which occurred at the precise moment of sunrise at the equinoxes and during the eleven days before the spring equinox and after the autumn equinox (Blomberg and Henriksson, 2001; Henriksson and Blomberg, 2011). Minoans oriented most of their graves towards the east and the rising Sun on solstices and equinoxes (Papathanassiou et al., 1992).

There is a significant possibility that the peak sanctuaries on the tops of the sacred mountains were also built according to astronomical alignments. For ex-

Figure 1: Sherds of a vessel that contains representations of the Sun (courtesy: National Museum, Kumanovo, Macedonia).

ample, it has been suggested that the axis of the main room in a small structure constructed around 2000 BCat the peak sanctuary of Petsophas was oriented towards the sunrise on the summer solstice at that time. The placement of the sanctuary was presumably with respect to the top of the conical-shaped mountain Modi, behind which the sunset at the autumn equinox occurred, and the remains of two walls are oriented toward the heliacal rising and setting of the bright star Arcturus (Blomberg and Henriksson, 2001). The heliacal rising of Arcturus also coincided with the festival of the grape harvest in early September (West, 1999), which was preceded by the sowing of the land around the autumn equinox.

Figure 2: The archaeological locality 'Taticev Kamen', near the village of Kokino.

Figure 3: Stone seats (thrones) on the first platform.

The characteristics of a Bronze Age mountain (peak) sanctuary, located in the centre of the Balkan Peninsula, on the top of the hill 'Taticev Kamen' (Tatic Rock), near the small village Kokino, will be presented in this paper. At the beginning of the second millennium BC it was the religious centre for the population in the surrounding region which had just abandoned a nomadic life style and adopted agriculture and stock-breeding. Since its discovery in 2001 (Stankovski, 2002), evidence of two Bronze Age religious cults has been identified, one of which has solar characteristics (Stankovski, 2007). Strong confirmation that some of the rituals in Kokino were related to Sun worship is revealed by the discovery of sherds of a vessel decorated with wavy lines combined with representations of the Sun (see Figure 1). These ornamental wavy lines are found in the early Bronze Age throughout the wider Balkans region, as well as in North-West Asia Minor, but never in combination with representation of the Sun (Blegen et al., 1950). Archaeological research on the recently-discovered ritual platform on the northern terrace at the Kokino sanctuary proves that a third religious cult was associated with it. In this paper we present an archaeoastronomical analysis of the locality and then discuss the possibility that it was used as a megalithic observatory. By measuring the celestial coordinates of several prominent markers that were artificially carved into stone blocks, we will consider whether they were made to point toward the rising positions of the Sun or other bright objects in the sky on particular dates.

2 THE PEAK SANCTUARY AT KOKINO

The peak sanctuary near the village of Kokino is located in the north-eastern part of the Republic of Macedonia, on the top of a large volcanic rock. With an altitude of 1013m it dominates the surrounding landscape (Figure 2). The excavated archaeological material dates from all phases of the Bronze Age, and was deposited during religious rituals that were performed over a period of around one millennium. In addition to the archaeological evidence, many topographical and archaeological characteristics of the site confirm its use as a sacred mountain. The position of the path leading to the top of the hill is on the south-eastern side, the side lit by the Sun. The large radius of visibility from the top of the mountain and the absence of nearby Bronze Age settlements that can be related to the material from that period found at the mountain-top site also confirm the prehistoric use of the locality as a huge extra-urban sanctuary for the people in this region.

Since Neolithic times, the people in the Mediterranean and Black Sea areas conceptualized the rocky mountain tops as places for communication with the gods, and even before the appearance of the first mountain cults, their stones were considered as sacred places inhabited by the gods. With the establishment of mountain cults, they acquired solar-chthonic characteristics, and researchers agree that most of them were related to the fertility cult of the Great Mother Goddess (Rutkowski, 1994). Hence, one of the rituals intensively performed at the Kokino sanctuary from the twentieth until the ninth century BC was probably related to this cult. Offerings, such as entire or fragmented vessels, ceramic weights, stone tools, moulds for casting bronze objects, and whorls were deposited in the natural fissures in the rocks on the highest part of the mountain. Once deposited, the structures were enclosed with earth and small stones and delimited with flat stones, thus creating ritual pits. The very same rituals appeared in the Early Minoan II period (between 2800 and 2400 BC) on the peak sanctuaries in Crete (Nowicki, 1994).

The preliminary archaeoastronomical analysis of the Kokino sanctuary suggested that during the second millennium BC, and especially in its first centuries, the locality was used as an astronomical site where the motions of the Sun and the Moon were observed, and it is for this reason that it has been called ‘megalithic observatory’ Kokino (Cenev, 2006). Geological analysis of the locality indicates the presence of andezite rock, which was formed from indurated volcanic lava and has a natural predisposition to crack vertically and horizontally. This enabled ancient peoples to relatively easily carve out the religious platforms and stone markers that are the subject of our research.

3 THE FIRST AND THE SECOND PLATFORMS

The first platform is located on the west side of the mountain, with a latitude of $\varphi = 42\ \ 15' 47''$ and a longitude of $\lambda = 21\ \ 57' 9''$. The platform was also a ritual site arranged for the purpose of performing the second Kokino cult. The andezite rocks were flattened and a few large stone seats (thrones) were carved into the stone blocks (Figure 3). The thrones are aligned in a north-south direction, so that the people sitting on them look at the eastern horizon and towards a vertical rock that is about 20m higher than the platform.

A stone marker is carved into this rock, forming an aperture which was probably covered in the past. Using modern geodetic instruments, we measured its horizontal coordinates from the thrones’ position and calculated its declination using the following formula:

$$\sin\delta = \cos A \cos\varphi \cos h + \sin\varphi \sin h \qquad (1)$$

where A is the azimuth measured from the north horizontal point, h is the altitude over the horizon and φ is the observer’s geographical latitude. The horizontal coordinates of the stone marker were: $A = 76\ \ 05' 10''$ and $h = 12\ \ 01' 40''$. When a small correction ($\rho = 4.6'$) due to atmospheric refraction is taken into account, the calculated declination of the object filling the aperture of the stone marker is $\delta = 18.26$. At present this coincides with the declination of the Sun in mid-May and at the end of July (31 July or sometimes 30 July). Due to precession, at the beginning of the second millennium BC the Sun rose through the marker a few days later, i.e. at the beginning of August on the second date.

Archaeological analysis confirmed that the second date coincided with the last days of the harvest in this region. This was the most likely time of the year when a ritual that had solar characteristics would be arranged on the throne’s platform (Stankovski, 2007). The end of the harvest had a special meaning for the Bronze Age agricultural peoples living in the surrounding valley. At the beginning of August the rising morning Sun passed through the aperture in the notch on the highest point of the site and along the right edge of an artificially-cut trench, creating the effect of a sunray (Figure 4 and Figure 5). This ray fell on the lower throne platform, illuminating just one seat (the second

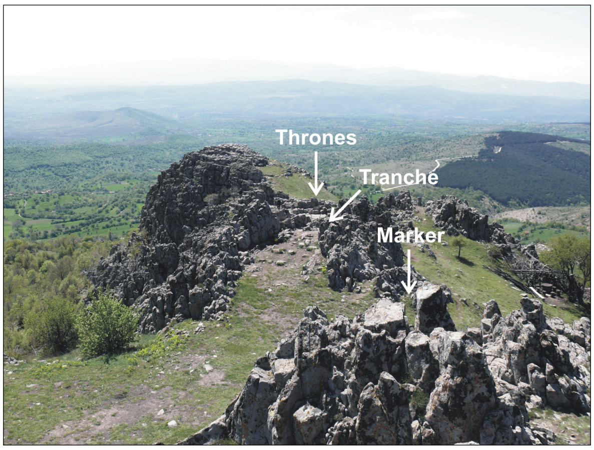

Figure 4: Ritual marker viewed from the highest, eastern part of the locality.

from the left), upon which the person who had a principal role in the execution of the ritual probably sat. This could have been the tribal leader, in the role of the chief priest, and it may be that we are dealing with an explicit illustration of ‘hieros gamos’, a concept of a sacred union of the celestial divinity, the Sun with the Great Goddess Mother, a union that would provide a rich harvest and a cyclic renewal of nature. There is also evidence of ‘hieros gamos’ on Crete, and it has been suggested that it took place during the celebrations around the autumn equinox (Koehl, 2001).

The second platform, which consists of a flattened stone block (Figure 6), is located near the platform with the thrones. No archaeological artefacts have been found on it, which leads us to conclude that it was not used for ritual activities. However, several


Figure 5: Rising Sun in the ritual marker at the end of July.

Figure 6: The observing position on the second platform.

prominent notches can easily be recognized on the nearby vertical rocks that represent the eastern horizon (skyline) for the observer standing on this platform. We measured their horizontal coordinates and calculateed their declination using equation (1). The results showed that the declinations of the two markers coincide almost exactly with the declination of the Sun

Figure 7: Sun markers observed from the central position (the second platform). S1 (left) = Sun summer solstice, S2 = Sun spring and autumn equinox; S3 (right) = Sun winter solstice.

Table 1: Declinations of the Sun markers measured from the second platform, compared with the theoretical values of the Sun declinations at summer and winter solstice and vernal and autumn equinox for the year 2000 B.C.

	Theoretical Declination ( )	Measured Declination ( )
Sun summer solstice	23.9	24.1
Sun winter solstice	–23.9	–23.9
Sun vernal and autumn equinox	–0.11	–0.19

Figure 8: Rising Sun on the day of summer solstice.

on the days of the summer and winter solstices, and the declination value of the third matches the Sun's declination on the days of the spring and autumn equinoxes (Figure 7). In Table 1 the declinations of the three markers are compared with theoretical values of the Sun's declinations at the solstices and equinoxes for the year 2000 BC. In Figure 8, the Sun is seen to rise in the notch that marks the summer solstice.

These findings indicate that the second platform was probably not used for cult activities, but was a central position from which the sunrise was observed throughout the year. Only one man could stand on the platform, and he would communicate with another person who would carve the notches on the nearby stone blocks that marked the three special positions of the rising Sun on the solstices and equinoxes, according to instructions provided by the observer on the platform. Undoubtedly, as with other similar ancient observatories, the purpose of this observational platform was not to provide scientific knowledge. In ancient times interest in objects in the sky usually had a religious dimension, and the sky-watchers were the local priests who in such a way determined the timing of the seasons and the natural cycles that depended on them. The Kokino priests probably found a connection between the periodic movement of the Sun and the vegetative cycles, and by marking its position at certain times of the year they were able to determine the 'right moments' for organizing agricultural work and performing related religious rituals. In the religious system of the Bronze Age people, the Sun God had a significant role in the periodic changes of the vegetative cycles, and its movement was carefully followed by the local priests. The returning of the sunrise point from its extreme positions in summer and winter guaranteed the renewal of nature, and the equinox points marked the change of the summer and winter seasons.

4 THE THIRD PLATFORM

The third recently-discovered ritual platform is located on the northern terrace, where circular stone constructions resembling tumuli were discovered (Figure 9). They are marked by large stones and have diameters of between 0.9m and 2.0m. Ceramic fragments, several vessels and stone tools covered with earth and fragments of stone were found inside. Some of the stone constructions cover the ritual pits that were formed around natural fissures. The fact that in both structures (the ritual pits and circular stone constructions) chronologically and typologically similar archaeological material has been found allows us to conclude that for a long period both types of structures coexisted. Some of the fragmented ceramic material had traces of burning, and this fact and the remains of two fireplaces indicates the use of fire during ritual activities. A funnel-like vessel was also found, which was probably used for pouring out fluids. The numerous stone hand mills, as well as fragments of movable ovens (puranoi) lead us to conclude that ritual food was prepared.

Although the meaning of such rituals could not be precisely determined from the archaeological findings, there are some obvious similarities to the construction and cult practices of early Minoan mountain sanctuaries on Crete (originating from the period 2200-1900 BC), where in a restricted circular area, animal and human figurines, pottery and scattered pebbles were discovered (Rutkowski, 1988). Most of these were identified as landmarks because of their location on the landscape. The shape and height of the rocks at the Kokino site, as well as their volcanic origin, makes them unique and they are very conspicuous from the surrounding valleys.

In that context, an important finding that relates the Kokino sanctuary to those of the early Minoans is the discovery of three ceramic figurines on the recently-excavated northern terrace: a female torso, an animal figurine and a lower part of a human leg with a foot. They are almost identical to the figurines from the peak sanctuary at Traostaloss in Crete (Faure, 1963). The Cretian figurines (which are no bigger than 20 cm in size) are shaped like animals or parts of the human body, and their main function was to provide fertility and good health. Since the beginning of the Minoan mountain religious practices they have usually been burnt and then stored in the sanctuaries (Nowicki, 1994). As for the use of peak sanctuaries as astronomical observatories, it has been suggested that some of the terracotta figurines and body parts found could be explained as representations of different constellations or their component parts (Blomberg, 2009).

The preliminary examination of the Kokino site indicated that the rocky hill in front of the third platform on the northern terrace contained artificially-made notches. Around 16m higher, its stone blocks cover the southeast horizon of the observer who is standing on the third platform. Therefore, we performed detailed astronomical analysis in order to find out whether the notches mark the position of some celestial objects. Precise measurements of the positions of several noticeable notches were made. The central position, which was assumed to be the observing site of the ancient skywatcher, is the ritual site on the third platform (Figure 10), with the following values of the latitude and longitude, respectively: $\varphi = 42\quad 15' \, 48''$ and $\lambda = 21\quad 57' \, 10''$. In the process of performing the measurements and drawing conclusions from the results, we were aware of the significance of choosing particular stone markers for investigation. Since some cracks in the rocks were made naturally, we paid attention to markers with signs of human intervention, as well as to those which were undoubtedly noticeable on the night (or day) horizon. From the horizontal coordinates of the selected stone markers (Figure 11), we calculated the declinations of astronomical objects from equation (1). The horizontal coordinates of the markers and their declination values, along with the corrections due to the astronomical refraction, are presented in Table 2. It can be seen that the calculated values of the declination of the object appearing at these markers in the past, show a remarkable coincidence with the declinations of the star Aldebaran in the constellation Taurus, taken from the 5000-year star catalogue of Hawkins and Rosenthal (1967: 147), in hundred-year intervals. This coincidence remains for the period from 1900 BC until 1500 BC, which is from the beginnings of the usage of the site as a sanctuary and as an observatory, and through the Middle Bronze Age. The positions of stars on the celestial sphere vary slowly in the course of the centuries, and the possibility of ‘placing’ another star with similar brightness as Aldebaran in all four markers in this time period is practically negligible.

Figure 9: Circular stone constructions at the north part of the locality.

According to the archaeological evidence found at the locality and on the northern terrace, the Aldebaran markers were made in a period of intensive religious practise, and in one of the cults that was arranged on the throne’s platform the periodic motion of the Sun played a crucial role. Unfortunately, no written records were found on the site dating from the Bronze Age, so we can only speculate on the exact time of the year when the appearance of the main star in Taurus was observed, as well as its connection to the cult. Aldebaran is one of the brightest stars at these latitudes with a magnitude of 0.89, and it rises in the

Figure 10: The central observing position on the third platform.

Figure 11: Stone notches that mark the position of Aldebaran and the ‘doubled’ marker for the Sun’s spring and autumn equinoxes (dashed lines).

Table 2: Horizontal azimuth and altitude, astronomical refraction corrections and declinations of the four markers observed from the third platform on the northern terrace. The markers' declinations are compared with the declinations of the star Aldebaran for the years 1900, 1700, 1600 and 1500 B.C., taken from the 5000-year star catalogue (Hawkins and Rosenthal, 1967: 147).

Marker Number	Azimuth	Altitude	Refraction correction (′)	Declination ( )	Catalogue declination ( )	Year (BC)
1	105 15′44″	17 40′13″	3.02	1.03	1.03	1900
2	103 40′44″	17 32′46″	3.02	2.02	2.10	1700
3	101 06′17″	15 51′49″	3.32	2.64	2.62	1600
4	99 23′31″	14 56′14″	3.43	3.21	3.15	1500

at dawn before summer, or after sunset in autumn and winter. Hence, one should not be surprised that its position in the sky was marked by the megalithic people in Kokino. A question arises about the role of Aldebaran in their religious beliefs and in the organization of their everyday life and agricultural activities. Was it simply a prominent celestial object whose rising at particular times of the year coincided with the land cultivation processes, on which the survival of the community depended? Or was it a part of a more complex picture of the sky that the Kokino priests developed, as around 2000 B.C. the constellation of Taurus and its principal star were positioned very close to the vernal equinox point?

Supporting the latter possibility is the discovery of another noticeable marker near those that point to Aldebaran, and this is shown by dashed lines in Figure 11. It is the most prominent of all those observed from the third platform as it is 'doubled', consisting of two parallel markers of identical shape, carved one in front of the other on two different stone blocks. According to the measured values of its azimuth, $A = 106\ \ 58'\ 14''$ and altitude $h = 18\ \ 02'\ 42''$, and taking into account the refraction corrections ($\rho = 2.7'$), we calculated the declination of the celestial object rising in the past through this marker. It is $\delta = 0.14$ and coincides well with the declination values of the Sun on the days of the spring and autumn equinoxes. The existence of identical notches on two blocks creating an effect of a sunray, as in the ritual marker on the first platform, also confirms the idea that the 'doubled' marker was most probably pointing to the sunrise on these particular calendar dates.

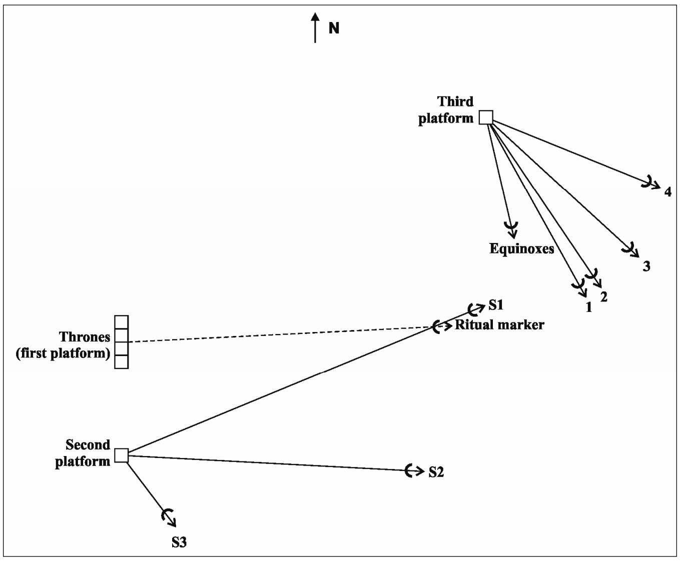

Figure 12: Map of the locality with the three platforms and markers' alignments. S1 = Sun summer solstice, S2 = Sun spring and autumn equinox; S3 = Sun winter solstice; 1,2,3,4 = Aldebaran's markers.

The position of the third platform and the alignments of its markers relative to the other two platforms are shown on Figure 12.

5 DISCUSSION

The brightest star in the constellation of Taurus and the prominent open star cluster close to it, the Pleiades, are considered to be among the first objects in the sky observed by man (Rappengluck, 1999). The seven brightest stars in the Pleiades, followed by Aldebaran ('aldebaran' means 'follower' in Arabic), were important to many ancient cultures (Worthen, 1995). Their rising after sunset or before sunrise marked the beginning of new seasons and was used in the creation of the first calendars (Ruggles, 2005: 45, 177-178, 183, 267-269, 322). There is strong evidence that prominent star patterns were recognized by hunter-gatherers in the Palaeolithic era (from 33,000 to 10,000 BC). On a panel in the cave La-Tête-du-Lion, and on a similar one in the cave Lascaux, there is a painting of a female bovine looking toward the east. It represents the constellation Taurus, where the eye of the bovine marks the red Aldebaran, and two clusters of dots on the face and above the animal relate to the Hyades and Pleiades open clusters respectively (Rappenglück, 1999). For Palaeolithic man these star patterns were used for orientation in space- and time-reckoning, and they played a significant role in his spiritual life (Belmonte, 2010). In Indian astronomy, the fourth of the 27 Nakshatras (asterisms) in the lunar path is Rohini (Aldebaran), or 'the rising one'. Her other name was Suravi, meaning 'the celestial cow'. From around 2300 BC, the ancient Chinese people celebrated the full moon passing the Pleiades around the autumnal equinox (Kistemaker and Xiaochun, 1997). In ancient Egypt the constellation Taurus and its main red star were related to Hathor, the cow goddess, connected with the inundation of the Nile and the abundance of the grape harvest (Muller, 2004). In Bronze Age Europe, the rising of Taurus and its prominent stars above the eastern horizon during October-November coincided with the period of ploughing and sowing the land in the Mediterranean area.

From approximately 4000 BC to 2000 BC, the vernal equinox point was located within the boundaries of the zodiacal constellation Taurus and near to its main star. There is strong evidence that the twelve constellations surrounding the ecliptic were formulated over the period of several millennia (Rogers, 1998) and named not according to their outward appearance, but as memory markers of areas in the celestial sphere which include four special positions of the Sun on its annual motion along the ecliptic: the spring and autumnal equinoxes and the summer and winter solstices (Gurshtein, 1993). The period of the year when the Sun was in the vernal equinox was the starting point of creating many ancient calendars. As a symbol of male fertility, the bull had been an important animal of worship for many Indo-European cults since the seventh millennium BC, influencing various aspects of ancient Egyptian religion, as well as the famous legend of the Minotaur on Crete. Around 2000 BC., precession shifted the sunrise at the spring equinox inside the boundaries of the constellation Aries. Our research shows that the Aldebaran markers in Kokino were made within this 'transition period'.

By no means are we suggesting that the constructors of Kokino were familiar with the phenomenon of precession. However, the markers found on the second astronomical platform and the newly-discovered equinox marker on the third prove that they observed the annual motion of the Sun and empirically determined its extreme rising positions at the solstices and equinoxes. Having small altitudes above the equator, i.e. very small declination values (around 1 arc degree at 1900 BC), Aldebaran was close to its intersection with the ecliptic—the equinox point. However, at the spring equinox Aldebaran rose in the east after the Sun and it was not possible to observe it on this exact date. We guess that the equinox marker was probably made according to observations from the second platform, which was used strictly for this purpose and not for rituals. The markers pointing to Aldebaran could determine another very important event—its heliacal rising in the weeks following the spring equinox.

The heliacal rising of a celestial object defines the period of the year when it first becomes visible above the eastern horizon, just before sunrise, after a period of time when it had not been visible. The heliacal rising of certain bright stars marked the beginning of time and agricultural cycles in many ancient civilisations. The most famous example is the heliacal rise of Sirius that occurred just before the annual flooding of the Nile, during the period of the Middle Kingdom (e.g. see Dodd, 2005; Schaefer, 2000). The ancient Egyptians based their calendar on this event and devised a method of telling time during the night according to the rising of 36 different stars (Parker, 1974). The peak sanctuaries of Petophas and Traostalos on the island of Crete were oriented towards the heliacal rising of the bright star Arcturus (Blomberg and Henriksson, 2001). According to some scholars, the civil New Year in the agricultural regions of the Indus Valley in the fourth millennium BC started with the autumnal equinox (Abhyankar, 1998), but there are some opinions that it was in connection with the heliacal rising of Aldebaran after the spring equinox (McIntosh, 2008; Subhash, 2010). The heliacal rising of Aldebaran also marked the forthcoming wet season, and it was later replaced by the Pleiades.

According to computer simulations of sky maps with the latitudes of the Kokino sanctuary, the heliacal rising of Aldebaran in the Early Bronze Age occurred between the spring equinox and the summer solstice. Using *Redshift 4* software, we determined the variation of the altitude of Aldebaran above the astronomical horizon at sunrise, starting from the day of the spring equinox for the year 1900 BC, which is approximately when the first marker was made (Figure 13). *Redshift 4* uses the Julian calendar for 1900 BC, so the spring equinox does not occur on 21 March, but near 7 April. On this day, the Sun was near the Pleiades in Taurus, but in front of Aldebaran, so that the star could not be seen on the sky. As the weeks progressed, the Sun moved at an average rate of 0.99 per day along the ecliptic to Gemini and then towards Cancer. According to Figure 13, about 35 days from vernal equinox, Aldebaran rose at the eastern astronomical horizon for a brief moment before sunrise, but it could not be seen by the observer at the third platform because it was hidden behind the stone blocks. The 'real' heliacal rising occurred some 67 days after the equinox, when it first appeared in the stone marker at dawn. For the observer standing on the third platform, the rock hill with the markers on top was his apparent eastern horizon and Aldebaran's passage through the marker determined its actual heliacal rising for this observer. The dividing day between the two situations, when the star cannot be seen at dawn and when it clearly appears in the stone marker some short time before sunrise, is the day of its heliacal rising. The eastern sky at dawn on the day of heliacal rising of Aldebaran in the epoch 1900 BC as seen from the third platform is shown in Figure 14. Aldebaran is precisely in the position of the stone marker. Very similar results were obtained for the periods of making the other markers. Bearing in mind the impact of atmospheric refraction and absorption, we can conclude that Aldebaran's heliacal rising above Kokino in the first centuries of the second millennium BC was some 67 ± 3 days after the vernal equinox.

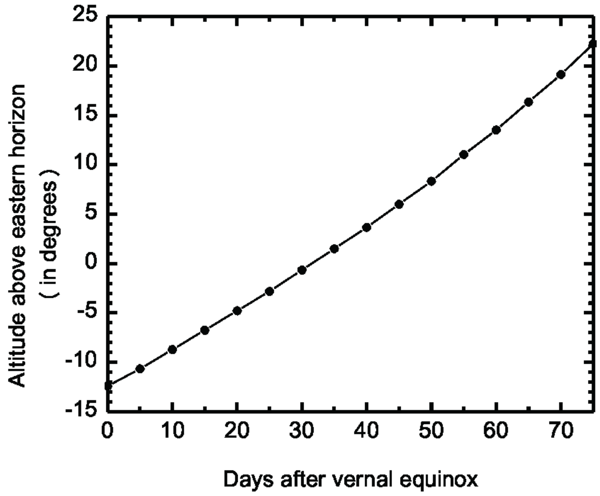

Figure 13: Altitude of Aldebaran above the eastern horizon during sunrise as a function of days after the vernal equinox.

It was a unique event that happened just once a year during the ripening of the crops. Hence it is quite possible that the star's morning appearance was a part of the annual cycle of agricultural activities with which the religious practice was related. Due to precession and proper motion, changes in the positions of stars in the sky were only noticeable over long periods. The Kokino sanctuary was active for more than one millennium (from around 2000 BC until 800 BC) and so it is not surprising that more than one marker for Aldebaran was made. As the star moved over the centuries it shifted more and more from the old marker (and from the equinox point), and the differences between the current observations of the Kokino priests and those performed by their predecessors would have be-

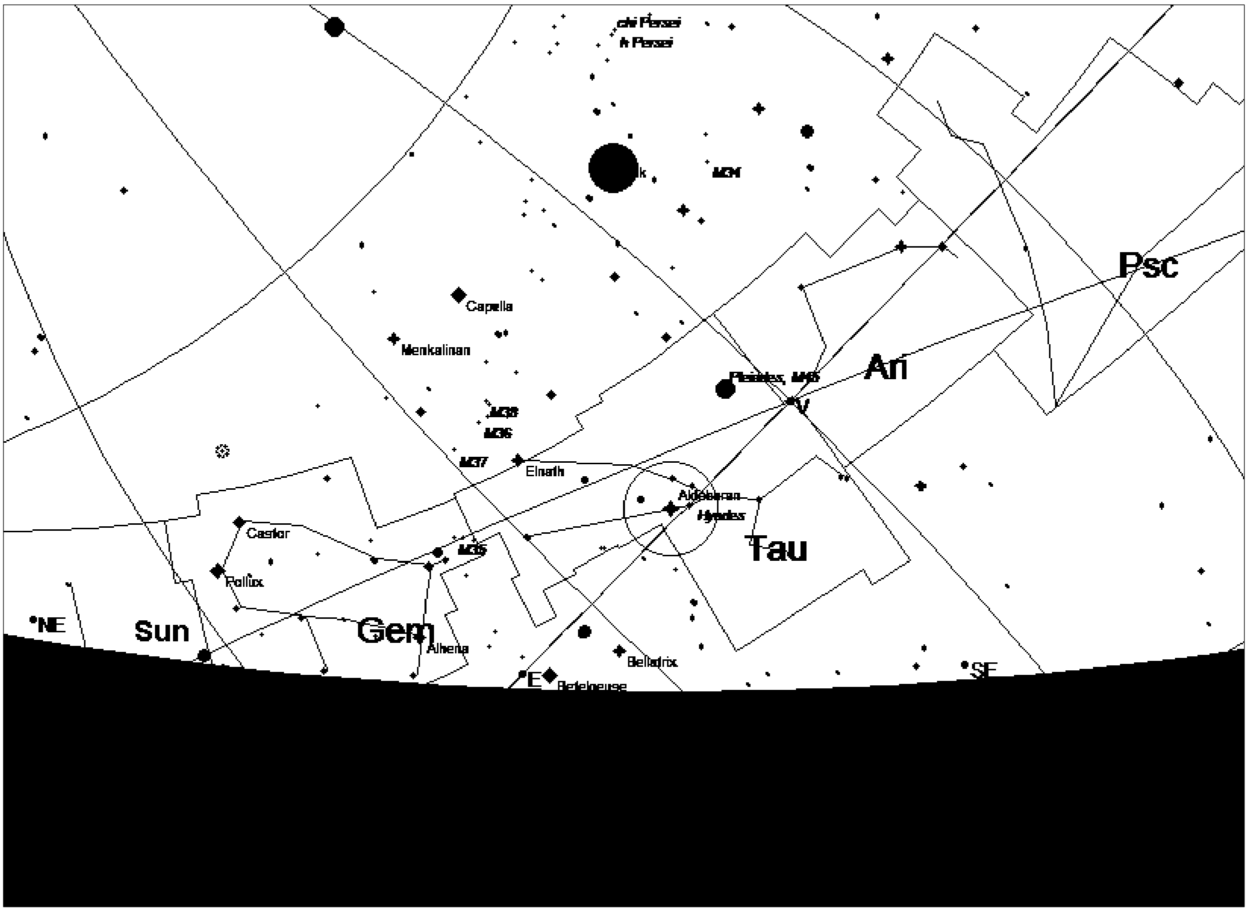

Figure 14: The eastern sky at the time of sunrise 67 days after the vernal equinox in 1900 B.C., as observed from the third platform. Aldebaran can be seen in the centre of the circle as it heliacally rises in the marker position. The image has been generated using *Redshift4* software.

come increasingly obvious, despite their not knowing the source, the limitations of the primitive observational techniques and the constancy of tradition. These differences were probably attributed to the will of the gods, and eventually would lead to the carving of a new marker, as the old one was no longer useful. If Aldebaran was related to the equinox point, then its displacement in time from this special position of the Solar God could be the reason that no markers were found that dated after 1500 BC. The absence of newer markers could also have been connected to the fact that, eventually, the locality lost its importance as an astronomical observatory.

It is also possible that Aldebaran was observed in early autumn. It was one of the brightest stars dominating the eastern evening sky around the days of the autumn equinox. At this time of the year, it rose above the eastern horizon soon after sunset, and appeared from behind the stone blocks and in the markers some time later, with the Pleiades above it. As previously mentioned, this was the period of the year for sowing and ploughing of the land in the Mediterranean area, and for the grape harvest. The appearance of such a bright star could signify that the priests had to perform rituals at the sanctuary and light fires that would be used as indicators by the farmers in the surrounding area to start particular agricultural activities.

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WHO INVENTED THE WORD ASTEROID: WILLIAM HERSCHEL OR STEPHEN WESTON?

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Abstract: William Herschel made the first serious study of 1 Ceres and 2 Pallas in the year 1802. He was moved by their dissimilarities to the other planets to coin a new term to distinguish them. For this purpose he enlisted the aid of his good friends William Watson and Sir Joseph Banks. Watson gave him a long list of possible names, which Herschel rejected. With a lifetime of experience classifying and naming newly found objects in nature, Banks became the man both Erasmus Darwin (in 1781) and William Herschel (in 1802) turned to for sage advice in developing a new descriptive language. In the case of Ceres and Pallas, Banks turned the task over to his friend, the noted philologist Stephen Weston, FRS. It has recently been stated by a noted British historian that it was Weston—not Herschel—who coined the term 'asteroid' to collectively describe Ceres and Pallas. This claim is investigated, and parallels are drawn in the use of neologism in astronomy and botany.

Key words: Ceres, Pallas, Herschel, asteroids, minor planets, planets, botany

Figure 1: Sir William Herschel, 1738–1822 (after Holden, 1881).

Figure 2: 1794 etching of Stephen Weston, 1747–1820, by Harding, from a picture painted in Rome in 1775 (courtesy: Devon Libraries. Westcountry Studies Library).

1 INTRODUCTION\

Employing his 20-foot telescope with a mirror 18.7 inches in diameter, William Herschel (Figure 1) made the first scientific study of Ceres and Pallas in 1802 (Cunningham, 1984). Ceres had been discovered on 1 January 1801 by Giuseppe Piazzi at Palermo Observatory in Sicily (Piazzi, 1802a), and Pallas had been found on 28 March 1802 by Wilhelm Olbers in Bremen, Germany (Zach, 1802). Herschel's first night of observation of Ceres was 7 February 1802, and for Pallas 21 April 1802. In a paper describing his observations, Herschel was inspired to look at the 'bigger picture', trying to put the new discoveries into context (Herschel, 1802a). How did they fit into the age-old categories defined by planets and comets? In his estimation they did not fit, and thus a new category was required. He called the new category 'asteroid'. Or did he? In a recent popular book, *The Age of Wonder*, British historian Richard Holmes (2008) refers to a 10 June 1802 letter from Herschel to Sir Joseph Banks, President of the Royal Society, and then states:

> Herschel offers the term 'asteroid' reluctantly from a suggestion from the antiquary Rev Steven Weston, though fully aware that the recently discovered Pallas and Ceres were not 'baby' stars. The usage is nonetheless dated to Herschel 1802 by the OED (Oxford English Dictionary). (Holmes, 2008: 509, note 134).

2 STEPHEN WESTON

To begin analysing this claim, we must first inquire who Stephen Weston was. The spelling of his name is an initial step. Every source we have seen spells his given name Stephen, not Steven. Only in the book by Holmes does his name appear as Steven.

Rev. Stephen Weston (Figure 2) was a grandson of the Bishop of Exeter of the same name (1665–1741). He was born at Exeter in 1747; was educated at Eton; matriculated at Oxford in 1764, and became a Fellow of Exeter College. Through the friendship of Lord Lisburne, the then-owner of Mamhead (a civil parish in Devon), he was presented to the rectory of that parish as their minister in 1777. In 1790 Weston's wife died, and he then resigned his position at Mamhead and moved to London. In 1792 he was elected a Fellow of the Royal Society, and in 1794 a Fellow of the Society of Antiquaries.

From the time that he left Devonshire, Weston's studies were principally directed towards the classics and oriental literature. In the latter area his knowledge was wide-ranging, with numerous translations of Persian poetry and Arabic works. His philological writings were also rather remarkable: he published a supplemental German Grammar, a set of notes on Shakespeare, and a specimen, as it is called, of a Chinese-English Dictionary.

His first work, in 1784, consisted of conjectures on the third century AD Greek grammarian Athenaeus, and from that time until 1830 scarcely a year passed without some fresh publication emerging from his busy pen. His name is to be found among the hundred or more scholars who have turned Thomas Gray's 'Elegy' of 1751 into Latin or Greek; and when he published a new edition of Horace, he added to it Greek versions of the odes 'o Fons', and 'Intermissa Venus'. The fame of Weston rests on his knowledge of the Asiatic tongues. He was a Hebrew scholar, and ventured on an attempt to explain by the aid of Benjamin Kennicott's collations the difficulties in the Biblical story of Deborah. He was also a Persian scholar, and edited a collection of 'Distichs' from Persian authors, and a volume of the annals of their kings (*Dictionary of National Biography*, *1885-1900*, Volume 60).

Weston died at his house in Edward Street, Portman Square, London, on 8 January 1820, aged 82. An obituary in the *Gentleman's Magazine* (1830) states that he "… always retained the greatest partiality for the elegant amusements and lively society of the French capital."

3 HERSCHEL SEEKS ADVICE FROM BANKS

Continental astronomers were quite content to regard Ceres and Pallas as planets, but Herschel believed they were a separate class of object since they differed from planets in several respects, including size, inclination and orbital distances from one another (Herschel, 1802a; Hughes and Marsden, 2007). Since there was no international organization in place to decide such matters, Herschel took it upon himself to invent a word that could be used for this new class. He felt further empowered in this mission by his belief that his observations were superior to those being made on the Continent. His comparison here is with the telescope of Johann Schroeter in Lilienthal, as used by his assistant Karl Harding (and the observational conclusions of Herschel versus Schroeter are considered in detail in Cunningham and Orchiston, 2012).

On 17 February 1802 Herschel (1802b) wrote to his friend Sir Joseph Banks (Figure 3), the long-serving President of the Royal Society (of London):

> I think that my determination of the magnitude of the new planet [Ceres] must be much more accurate than that of Mr. Harding of Lilienthal, both on account of the object with which I compared it, and of the magnifying power of my telescope.

At the time he was trying to develop the appropriate word for this newly-discovered object, and he had the field to himself. Piazzi did not suggest the word 'planetoid' to Herschel until 4 July 1802, as evidenced by a letter he wrote to Herschel on that date (Piazzi, 1802b), and no other appellation was forthcoming from any other astronomer.

Figure 3: Sir Joseph Banks, 1747–1830 (after *Garran*, 1887, *Volume 1*).

Not trusting his own capability to coin a suitable new word, he turned to Banks for advice on a name that would suitably describe Ceres and Pallas. One of the prime reasons for his choice of Banks was the fact that no one had a greater familiarity with the very problem Herschel was grappling with. In 1781 Erasmus Darwin (Figure 4) had begun a translation into English of *Systema Vegetabilium* by Carl Linnaeus (Figure 5), and he sent numerous letters to Banks for advice as he set out to establish a new botanic language, "… creating vernacular compounds in English as Linnaeus had done in Latin." (Uglow, 2002: 380).

Figure 4: Erasmus Darwin, 1731–1802, painted by Joseph Wright (courtesy: Wikipedia).

It is telling that when *System of Vegetables* was published in 1783 it was dedicated to Banks.

But why Banks? In fact he was the ideal candidate as he had established his reputation at age 23 by publishing the first Linnaen descriptions of the plants and animals of Newfoundland and Labrador, which he collected and classified on an expedition of 1766. Nearly three decades later he called Linnaeus "… the God of my adoration." (Banks, 1792). With a lifetime of experience classifying and naming newly-found objects, he was the man that both Darwin (in 1781) and Herschel (in 1802) could turn to for sage advice. And as Banks knew better than anyone, "… the seemingly simple function of naming objects does not present a simple connection between a thing and a word." (Goldstein, 1948: 196). Yet despite his vast experience, the seemingly simple task of creating the word needed to describe Ceres and Pallas eluded Banks.

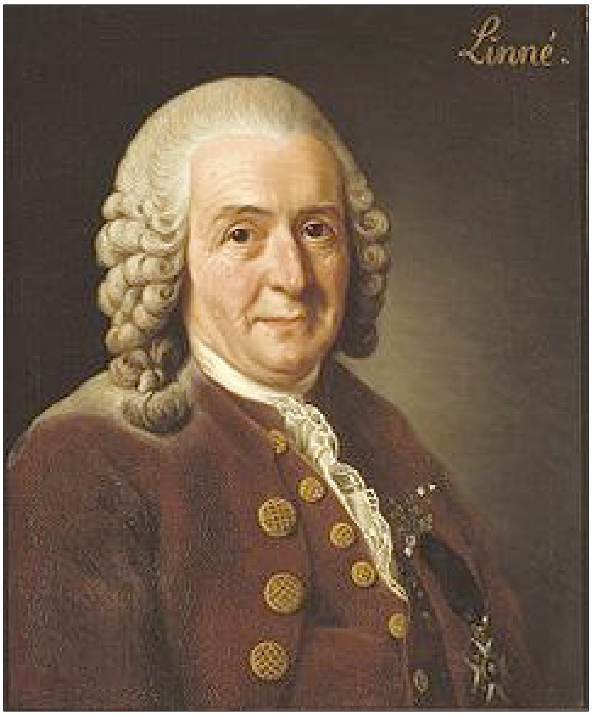

Figure 5: Carl Linneaus, 1707–1778, painted by Alexander Roslin in 1775 (courtesy: Wikipedia).

Herschel's first attempt to solicit Banks' help came on 18 April 1802:

> If any name should be fixed upon, by the President (Banks) and Council of our Society (The Royal Society), for the new planets, I shall be glad to know it, that I may call them accordingly; till when I continue to distinguish them by the names of the discoverers. (Herschel, 1802c).

Naming a discovery after its discoverer was another commensurable link with botany (Lemmon, 1878). Since no name was forthcoming, Herschel applied to Banks once again in early June 1802. Banks then turned to his philological expert, Stephen Weston, for help, before replying to Herschel on 7 June:

> I applied to Mr. S. Weston as I always do in these occasions to tend God Father to your new species of mocking stars and [he] has sent me a card which I enclose. I really think Aorate a good name a much better [one] than any that has been hitherto suggested and the more so as it is not probable that any of this new kind of wanderers are visible to the naked eye. (Banks, 1802b).

With the invention of the word 'aorate' Weston was employing the suffix '–ate'. This suffix occurred originally in nouns borrowed from Latin, and it also occurs in Greek. The origin of 'aor' is less certain, but may have come from the origins of the word meteor. According to the *Online Etymology Dictionary*, meteor is the neuter of the Greek 'meteoros' (adj.), which means "high up", from meta- "over, beyond" + –aoros "lifted, hovering in air". Combined with the Latin definition of –ate, namely "… having the appearance or characteristics of …", one may suggest 'aorate' to simply mean an object that has the appearance of being in the sky. Alternatively, 'aor' in Greek means a sword or dagger. So aorate would mean having the appearance of a sword, although this seems to make little sense. The most likely explanation is that Weston was using not the Latin but the Greek meaning on the suffix –ate. From this is derived the perfectly valid Greek word 'aoratos', which means either 'invisible' or 'never seen before.' Whatever Weston's intended meaning may have been, it did not pass muster with Herschel.

4 THE 10 JUNE 1802 LETTER

Since the substance of Holmes' argument rests on the content of the 10 June letter from Herschel to Banks, it is necessary to quote it here. This letter was Herschel's reply to the 7 June letter of Banks quoted in Section 3, above.[1]

> The names you have done me the favour to send I have carefully examined, and beg leave to give you my remarks on them. The title of them, "Names for the new Planet," shows immediately that none of them can possibly be used for the new species of bodies which we have to christen: for they are not planets.
>
> If Mr. [Stephen] Weston were to have a definition of the thing we want a name for, he might possibly find a better one than that of asteroids, which is not exactly the thing we want, though still the most unexceptionable (sic) of any that have been offered by my learned friends. Will you do me the favour to consult him once more upon the subject, and mention to him that the bodies to be named are neither fixed stars, planets, nor comets, but have a great resemblance to all the three? With this view before him he will probably succeed in an appropriate appellation. (Herschel, 1802d).

From this it appears that none of Weston's suggestions were accepted by Herschel, and unfortunately no response to this plea of 10 June exists in the archives. Herschel did not correspond directly with Weston, so it appears they were not well acquainted, although they may have met. The mention he makes to names "… offered by my learned friends …" certainly refers to Sir William Watson, who gave Herschel a suite of unhelpful names in a letter dated 27 April 1802 (Cunningham et al, 2009). There are no letters in the Herschel archives showing that anyone other than Watson gave Herschel any ideas in April or May (or at any other time) about the urgently-needed appellation.

That Herschel believed there was urgency in the matter is evident from his letter of 25 April to Watson. In it, Herschel (1802e) tells Watson that his paper about Ceres and Pallas is "… going to London by next Thursday …" which will be 6 May, just 11 days hence. Even though Herschel tempers his immediate request by saying he is "… hardly willing to press you so much for haste …", the implication is obvious and Watson responded to the letter just two days later. The temporal demand for a name before the paper was sent to the Royal Society forced Herschel's hand. Thus we can date Herschel's choice of 'asteroid' to somewhere between 27 April and 6 May, the date his paper was read before the Royal Society.

The use of the word 'unexceptionable' above is also interesting. Its first noted use in English was in 1664, with the meaning "… not open to objection." Did Herschel anticipate there would be objections to his newly-coined word 'asteroid'? If so, he was not to be disappointed, as virtually every astronomer in Europe rejected it in 1802 (Cunningham et al, 2009). He did, however, receive support from Banks in putting Ceres and Pallas in a separate class. Further observations, he wrote, "… will not consider these stars as Primary Planets but as another sort of revolving body such as have not before been discovered and of which more may hereafter be found." (Banks, 1802a).

Herschel faced criticism from within The Royal Society itself. In his *History of the Royal Society*, Thomas Thomson, a Fellow of the Royal Society like Herschel himself, impertinently suggested Herschel's reason for calling the new planets 'asteroids' was "… to deprive the discoverers of these bodies of any pretence for rating themselves as high in the list of astronomical discoverers as himself." (Thomson, 1812).

"I should require nothing further," wrote François Arago (1871) "… to annihilate such an imputation than to put it by the side of the following passage, extracted from a memoir by this celebrated astronomer (Herschel), published in the Philosophical Transactions for the year 1805." Here is the passage in question:

> The specific difference existing between planets and asteroids appears now, by the addition of a third individual of the latter species [Juno], to be more completely established, and that circumstance, in my opinion, has added more to the ornament of our system than the discovery of a new planet could have done. (Herschel, 1805).

Once Vesta, the fourth body between Mars and Jupiter had been discovered in 1807, Banks wrote a letter that Herschel must have considered some measure of vindication:

> It gives me much pleasure that more of these singular bodies should be discovered, and that the Germans should so readily and properly have adopted the distinction which you have made between them and planets. (Banks, 1807).

5 CONCLUSION

That the book *The Age of Wonder* by Holmes is replete with misleading statements is a fact that has been noted by Susan Eilenberg (2010), Associate Professor of English at the University of Buffalo:

> *The Age of Wonder* is not a book one ought to rely on for perfect factual accuracy. The footnotes, so reassuring in their mass, can one by one leave the curious reader stranded. Dates, victims presumably of transcription errors, are sometimes out by entire centuries. And sources sometimes fail to say what Holmes leads us to expect they will.

Such is certainly the case here, where the sources bear no resemblance to the claim about the word asteroid. The sequence of events is sufficient to decide the merits of the case. William Watson gave Herschel his ideas for a name in April 1802. In early May, Herschel incorporated the word 'asteroid' in his paper read at a meeting of the Royal Society. Not entirely content with the word asteroid, Herschel sought advice on a better appellation from Sir Joseph Banks who then turned the task over to Stephen Weston. The suggestions for a name by Weston were given to Banks in early June. Thus, the word 'asteroid' was coined by Herschel one month before Weston was given the task of developing a word to describe Ceres and Pallas. In addition, we have the words of Herschel himself, who specifically rejected Weston's offerings, as is made clear in his 10 June letter to Banks. Therefore, the claim by Richard Holmes that Stephen Weston coined the word asteroid can confidently be rejected.

6 NOTES

1. Note that in Cunningham et al. (2009), the name Weston was incorrectly transcribed as Watson.

7 ACKNOWLEDGEMENTS

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1 INTRODUCTION

The Working Group on Historical Instruments (WG-HI) was founded by the members of Commission 41 at the 2000 Manchester IAU General Assembly with two main objectives: to assemble a bibliography of existing publications relating to historical instruments, and to encourage colleagues to carry out research and publish their results. Since then the concerns of the Working Group have expanded to include efforts to preserve and protect old astronomical instruments, observatories, and related sites as world cultural heritage and material evidence of the development of astronomy in different parts of the globe.

The WG maintains liaisons with sister organizations through the involvement of its officers and board members in them. These include the Scientific Instrument Commission of the International Union for the History and Philosophy of Science/Division of History of Science and Technology (IUHPS-Scientific Instrument Commission); and the American Astronomical Society (AAS) Working Group for the Preservation of Astronomical Heritage.

2 INTERNATIONAL YEAR OF ASTRONOMY (IYA) 2009 INITIATIVE

In 2007, the WG began to organize an interdisciplinary conference—"Astronomy and Its Instruments before and after Galileo"—to be held in Venice in 2009 on the 400th anniversary of Galileo's first observations with a telescope. The goals were expressed as follows:

> The conference aims to highlight mankind's path towards an improved knowledge of the sky using mathematical and mechanical tools as well as monuments and buildings, giving rise, in so doing, to scientific astronomy. It will analyze similarities and differences among cultures and countries in exploiting the shared resource that the sky represents, and will examine the historical-political and scientific background favoring the progress of scientific astronomy in different epochs and countries, progress that led to a crucial turning-point for observational astronomy when Galileo turned the telescope to the night sky and initiated the New Astronomy. A major aim of the meeting is to help move forward the process of ensuring the recognition and protection of cultural properties around the globe that bear powerful witness to the development of astronomy in diverse cultural contexts.

The plan was endorsed by IAU Commission 46 (Astronomy Education and Development), Commission 55 (Communicating Astronomy with the Public), and by IAU Division XII (Union-Wide Activities).

Promoted as a joint symposium of the IAU and the INAF-Astronomical Observatory of Padova, "Astronomy and Its Instruments before and after Galileo" was held in Venice (on San Servolo Isle) from 27 September to 3 October 2009. It was also listed as an official event of UNESCO's International Year of Astronomy 2009, and was sponsored by the IUHPS Scientific Instrument Commission. Patrons included UNESCO; the Istituto Nazionale di Astrofisica (INAF); the Università degli Studi di Padova, Italy; the Facoltà di Scienze, Matematiche, Fisiche e Naturali, Università di Padova; the Centro Interdipartimentale di Ricerca in Storia e Filosofia delle Scienze (CIRSFIS); the Centro per la Storia dell'Università di Padova; the Accademia Galileiana di Scienze, Lettere ed Arti in Padova; the Arab Union for Astronomy and Space Sciences (AUASS); the Società Astronomica Italiana (SAIt); the Comune di Venezia; the Provincia di Venezia; and the Regione del Veneto.

The conference program and other details can be found on the web site http://web.oapd.inaf.it/venice2009/index.php. The proceedings were published (see Pigatto & Zanini 2010).

3 CONFERENCES

In addition to the aforementioned conference, several WG members presented papers on astronomical instruments at the Seventh International Conference on Oriental Astronomy (ICOA-7), which was held at Mitaka, Tokyo in 2010. The proceedings have been published (Nakamura, Orchiston, Sôma, and Strom, 2011). Between 2009 and 2012, other WG members have taken part (or will take part) in meetings of the IUHPS Scientific Instrument Commission (Budapest, Florence and Kassel), the Historical Astronomy Division of the American Astronomical Society (Washington-DC, Seattle and Austin), the Antique Telescope Society (Ann Arbor, Charlottesville and Tuscon) and various special symposia featuring the history of the telescope. Many of the papers presented at these meetings are in press.

Members of the WG are currently planning sessions on instruments for the General Assembly in Beijing in 2012. Among these, one session will focus on field expeditions, covering not only transits of Venus (of particular interest in 2012), but also solar eclipses, determination of longitude, and so forth.

4 PROJECTS

Prior to this triennium, the WG had begun preparation of a thesaurus of historical instruments used in astronomy and related disciplines such as geography, geodesy, navigation, meteorology, and chronology. It was to be a list of terms plus variants and synonyms from different countries, etymologies, general definitions, related bibliographic sources and images. A preliminary list of instruments was circulated among Working Group members. In 2009 during the current triennium, the project was discontinued when the WG learned that it duplicated work already done by the IUHPS Scientific Instrument Commission, museums with major holdings of historical scientific instruments, and other learned societies at the intersection of the history of astronomy and early scientific instruments. Moreover, the availability of these resources on the Web made the publication of a thesaurus by the WG redundant.

In anticipation of the 2012 transit of Venus, the WG is encouraging knowledgeable scholars and museums holding apparatus used for past transits to collaborate by adding additional material to a transit of Venus web site created in 2004 by the IUHPS Scientific Instrument Commission (http://transits.mhs.ox.ac.uk).

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Sara J. Schechner
Chair

IAU TRANSITS OF VENUS WORKING GROUP: TRIENNIAL REPORT (2009-2011)

1 INTRODUCTION

The previous Transits of Venus Working Group report #6, covering the time mid-2006 to mid-2009, was published by the undersigned in the *Journal of Astronomical History and Heritage*, Volume 12, p. 254 (2009). The present report, #7, covering the time up to mid-2011, has been prepared for the Reports to be presented at the IAU General Assembly in Beijing in August 2012. It is expected that after a flurry of publications in 2012/2013, the activities in the field of Venus transits will drop dramatically, and it is planned to terminate the activities of the working group after the Beijing General Assembly.

As already observed in the previous report, activities between the transits of 2004 and 2012 were most of the time at a low level. At the time of the 2012 transit, symposia are planned in Tromso (Norway) and in East Asia or Australia. There will also be a Historical Astronomy Division special meeting at the American Astronomical Society's Austin meeting on Sunday 8 January 2012.

2 PUBLICATIONS IN THE PAST TRIENNIUM

A list of publications that have appeared since 2009, with some older overlooked references, is given in Section 4. A web bibliography, mainly on the 17th to 19th century transits, with many links to original sources, is kept by R. van Gent (see Section 3).

3 WEB LINKS

Websites dedicated to historical Venus transits are:

Robert van Gent's *Transit of Venus Bibliography* is at:

http://www.phys.uu.nl/~vgent/venus/venustransitbib.htm

Another version of the 17th and 18th century transits is also available at:

http://transitofvenus.nl/wp/past-transits/bibliography-1631-1639/
and
http://transitofvenus.nl/wp/past-transits/bibliography-1761-1769/

Steven van Roode's *Historical Observations of the Transit of Venus* (with reports, photographs and engravings, coordinates, maps of sites of the 17th to 19th century observers, as well as photographs of commemorative plaques) is at:

http://transitofvenus.nl/wp/past-transits/

Other websites of interest are:

The French National Node of the VT-2004-2012 project at:

http://www.imcce.fr/vt2004/en/index.html

Chuck Bueter's page at:

http://www.transitofvenus.org/

Jay Pasachoff's page at:

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Popescu, Adrian Sabin, and Rusu, Mircea, 2007. Venus' transit 2004: observations and analysis of the black-drop effect. *Romanian Astronomical Journal*, 17(1), 77-86.

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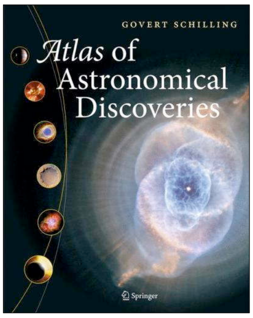
Any relevant information on past or future activities is gratefully acknowledged (please send emails to: hduerbec@vub.ac.be).

Hilmar W. Duerbeck (Chairman)

BOOK REVIEWS

***Atlas of Astronomical Discoveries,* by Govert Schilling (New York: Springer, 2011), iv + 234 pp., ISBN 978-1-4419-7810-3, US$39.95, 240 × 300 mm.**



This new book by prolific Dutch astronomy journalist Govert Schilling is a magnificent hybrid, at once a breathtakingly gorgeous coffee table book and a review of the history of astronomy since the development of the telescope in the first decade of the seventeenth century. Lavishly illustrated in a way that is increasingly rare in this post-economic-meltdown age, the book might also be called "A History of Astronomy from Galileo to Today in 100 Nutshells."

The book is divided into five sections, one for each century from 1608 to 1908, and then separate sections for each half-century from 1908 to 2008. Each 'nutshell' consists of a two-page spread, with one page devoted to a full-page photo showing off the capabilities of modern astronomical technology, and the other to two columns of text that summarize the particular scientific or technological achievement that Schilling considers a breakthrough for the profession as a whole. A second, smaller illustration appearing on the page of text sometimes makes use of historical data. Among such smaller illustrations, I particularly like Lord Rosse's 1845 sketch of a nebulous spot in the constellation Canes Venatici, marking his discovery of spiral nebulae, and Giovanni Schiaparelli's map identifying 'canals' on Mars. I admire the way Schilling's captions for both the full-page and the smaller illustrations not only identify both the subject and the source of each illustration but also include relevant additional information. For example, in the spread for 1728, on the discovery of the aberration of starlight by James Bradley, the box includes the information that the first star for which the aberration of starlight was discovered was Gamma Draconis, as well as the fact that each star in the sky shows an annual aberration in its position.

Readers of such a book, which is based on the author's own top-100 astronomical hits, are always liable to lament the absence of a personal favorite historical milestone or scientist. I regret, for example, that the only reference to Caroline Herschel—the first notable woman astronomer and discoverer, among other things, of eight comets—fails to mention her own achievements, acknowledging only that she joined her older brother William in Bath in 1772. Similarly, even if Annie Jump Cannon does not earn an entry of her own for introducing the first systematic classification of stellar spectra, Schilling might have mentioned her in his paean to the spectroscope, which he identifies as "… undeniably the most important instrument in the history of astronomy …" after the telescope. To his credit, however, Schilling does include a nice selection of women astronomers, some of whom merit their own two-page spreads (e.g. Henrietta Leavitt, Jocelyn Bell, Linda Morabito, Geneviève Soucail), while others share a spread with a male colleague (e.g. Elizabeth Scott, Louise Webster, Vera Rubin and Jane Luu), and yet others are mentioned in the text of spreads relevant to their work (e.g. Margaret Burbidge and Carolyn Shoemaker).

In addition to regretting the author's failure to include one's own favorite people from the history of astronomy, readers may also question why Schilling insists on including certain 'nutshells'. For example, why is it worth devoting a two-page spread to David McKay's seeming discovery in 1996 of signs of life in a Martian meteorite, given that "From the beginning, there is much skepticism about the interpretation of the facts by McKay's team ... As time passes, the evidence for fossilized Martian bacteria becomes less and less credible"?

These quibbles notwithstanding, I can think of no more esthetically satisfying way to review the highlights of the history of astronomy from Galileo to today than by dipping into Schilling's book. At only US$39.95 the book is also a bargain. I commend not only the author but also the publisher, Springer, for making such a beautiful book available to the public for such a reasonable price.

Dr Naomi Pasachoff
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***Giovanni Virginio Schiaparelli e l'Osservatorio di Arcetri,* by Simone Bianchi, Daniele Galli, Antonella Gasperini (Firenze, Fondazione Giorgio Ronchi, 2011), 87 pp., ISBN 978-88-88649-33-7, 10 Euros, 163 × 230 mm.**

It is remarkable that currently in Italy some young astronomers are carrying out historical research on the observatories where they work and on their original equipments. Therefore, research activities in history of astronomy are no longer restricted to retired astronomers, as often happened in the past, but is promoted in some cases as a result of a changing attitude and sensibility towards the conservation of astronomical heritage. It would be desirable that this promising new generation of historians of astronomy could be supported and encouraged by the management of the Italian National Institute for Astrophysics (INAF), which embodies the astronomical observatories.

For example, Arcetri Astrophysical Observatory, in Florence, is becoming a very active center of historical research. The booklet on Schiaparelli and the Arcetri Observatory is the latest work published by the history of astronomy team there, comprising astronomers Simone Bianchi and Daniele Galli, and Antonella Gasperini, who is the Observatory's librarian. This work casts a new light on the establishment of the Arcetri Observatory and the role played in the affair by the famous astronomer Giovanni Schiaparelli.

In 1873 the sudden death of Giovan Battista Donati, who had arranged to move the Florence Observatory to the Arcetri hill on the outskirt of the town, was a disaster for the newborn observatory: the construction was still in progress and the equipment was not complete. The difficult situation required an energetic Director, someone able to achieve an observatory that would be the most modern in Italy at the time.

The authors explore a lot of correspondence and archival material to outline the acceptance and the following renunciation of the Directorship of the Arcetri Observatory by Schiaparelli, apparently for familiar reasons. Nevertheless, he strongly supported the completion of the Observatory, by agreeing to inspect the buildings, provide instruments and supervise their installation. In 1875, after visiting the Arcetri Observatory, he wrote a detailed report for the Ministry on the conditions of the facility. The importance of this document is well stressed by Bianchi, Galli and Gasperini. However, all of the recommendations made by Schiaparelli for this "… always being born but never born …" Observatory—as he defined it—were definitively disregarded in the 1920s when it was decided to build a solar tower (the first in Italy) at the Observatory, thus changing the planned research program from astrometry to solar physics.

This little book examines the background behind the lengthy construction of the Observatory as well as the role played by men and institutions, and shows how it would have been in the original plan, thus plugging a gap in the historiography of the Arcetri Observatory and providing additional information on the history of Italian astronomy in the nineteenth century. The book is well documented, with many references to archival sources, and a selection of unedited letters, as well as Schiaparelli's important report, are published in the Appendices.

After recognizing the interesting contents, a few minor remarks could be made about the editorial choices: the illustrations are not plentiful, the lack of a name index is regrettable, and a larger font size would have been appreciated.

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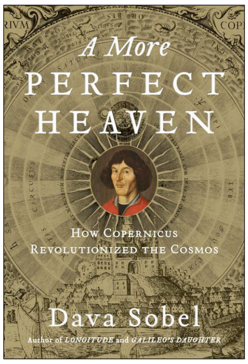
A More Perfect Heaven: How Copernicus Revolutionized the Cosmos, **by Dava Sobel (New York: Walker, 2011), xiv + 273pp., ISBN 978-0-8027-1793-1, $25.00 (hardcover), 145 × 217 mm.**



This beautifully-written and uniquely-structured contribution to Copernicus studies is essentially a homage to discipleship. Not exactly a straightforward biography of Copernicus, the heart of this book is a two-act, six-character, play about what might have happened when the young mathematician Georg Joachim Rheticus arrived in Frauenburg (now Frombork, Poland) in 1539 to convince the much older Nicholas Copernicus, about whose heliocentric cosmology he had heard, that he must overcome his reluctance to publish his work. The play is bookended by two sets of six chapters, the first set taking us from Copernicus's birth up to the time of Rheticus' unannounced visit, and the second bringing the story up to our own time. As Dava Sobel (prize-winning author of *Longitude* and *Galileo's Daughter,* among other books) notes in her preface, the idea of dramatizing this "… unlikely meeting …" first occurred to her in 1973, when the world celebrated the 500th anniversary of the birth of the man who made the Earth into a planet. She attributes the bookends concept to her editor, who argued that readers would benefit from the play being rooted in "… a fully documented factual narrative …" that not only tells Copernicus' life story but also outlines "… the impact of his seminal book, *On the Revolutions of the Heavenly Spheres*, to the present day."

In the summer of 2008 I saw a staged reading of an earlier version of the play, then and now called "And the Sun Stood Still", at the University of Zielona Góra in Poland, during a conference commemorating the 380th anniversary of Kepler's arrival in nearby Sagan (now Żagań). Much as I enjoyed that student production, I can report that over the intervening years the play has become more effective. Though some might find the emphasis on Rheticus' homosexuality and the liaison between Copernicus and his housekeeper, Anna, distracting, Sobel does a fine job of conveying the fact that world-altering work often takes place against the background of political and religious turmoil, with the human erotic impulse frequently complicating matters still further. While Sobel both telescopes the timeline and takes liberties with some historical facts, I can imagine professors assigning the play to their students, asking them to read the bookended material to see where playwright Sobel deviates from the facts biographer Sobel presents, and urging them to evaluate those artistic choices.

Though during Copernicus' lifetime, Rheticus was his only disciple, Sobel's concluding chapters clearly demonstrate that the line of Copernican disciples has continued over the centuries into our own. Of Rheticus' discipleship, we learn of the guilt he felt for not seeing through to the end his self-imposed task of proofreading the pages of *On the Revolutions* as they came off the printer Petreius' Nuremberg press. With Rheticus' departure in the fall of 1542 for a prestigious and well-paid teaching position at the University of Leipzig, the remainder of the proofreading was done by Petreius' friend, theologian Andreas Osiander. When *On the Revolutions* was finally published in March 1543, Rheticus was horrified to discover the inclusion of an anonymous note asserting that Copernicus' hypotheses "… need not be true nor even probable. On the contrary, if they provide a calculus consistent with the observations, that alone is enough." Rheticus suspected, but had no proof, that Osiander was responsible for the offending Preface, to which Copernicus would never have agreed. Kepler, a true Copernican disciple, had both proof that Osiander was the perpetrator and the opportunity to exact revenge. As chance would have it, Kepler obtained a second-hand first edition of *On the Revolutions*, whose previous owner, a Nuremberg mathematician, had written Osiander's name above the anonymous note. When Kepler's own *New Astronomy* was published in 1609, bringing Copernicus' work closer to completion, he attacked Osiander on the verso of the title page, thus also fulfilling Rheticus' wish.

Sobel next turns to Galileo, who suffered for his conviction that

> To ban Copernicus now that his doctrine is daily reinforced by many new observations and by the learned applying themselves to the reading of his book ... would seem in my judgment to be a contravention of truth.

In our own times, Sobel adds Harvard-Smithsonian Center for Astrophysics astrophysicist and historian of science Owen Gingerich to the list of disciples, for his decades-long effort to track down all extant copies of the first two editions of *On the Revolutions* and to study all the marginal notes their owners made in them as a way of disproving Arthur Koestler's assertion that Copernicus' masterpiece was "… the book that nobody read."

Sobel's book ends on what might seem a downbeat note, attributing to Copernicus the initiation of "… a cascade of diminishments …", taking human beings from the center of the Universe and thrusting them into a cosmos dominated by unseen dark matter and "… the still more elusive entity, dark energy …" in which "… the very notion of a center no longer makes sense." This picture, however, seems to me merely to suggest that there is much work for future Copernican disciples to undertake. By the time we celebrate the 500th anniversary of the publication of *On the Revolutions* in 2043 and the 600th anniversary of Copernicus' birth in 2073, which Copernican disciples will have made what contributions to our understanding of dark matter and dark energy? Stay tuned ...

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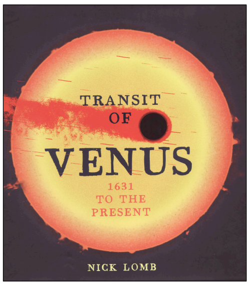
***Transit of Venus 1631 to the Present*, by Nick Lomb (Sydney, New South Publishing, 2011), 228 pp.; ISBN 9 781 74223 269 0, AU$49:95 (hardback), 237 × 237 mm.**



With the plethora of transit of Venus books prompted by the 2004 event, I really was not looking forward to the appearance of yet another volume, destined for the 2012 transit market, but Dr Nick Lomb's *Transit of Venus 1631 to the Present* came as a pleasant surprise.

Penned by the talented recently-retired Curator of Astronomy at Sydney Observatory, this book is a beautifully-produced and copiously-illustrated tome which—after an introductory chapter—takes us through the all-too-familiar story of the historic transits, from 1639 to the 1874 and 1882 events. Then we are introduced to the "Space-age transit: 2004" and provided with pointers for observing the 2012 transit on June 5/6. This is followed by a 2-page Glossary, four pages of references, and the all-important Index.

Although the basic 'story' of the historic transits is well known to those of us who research and write on these rare events, there are two features of this book that make this compelling reading nonetheless. One is the range of stunning photographs—many in colour—that support and embellish the text. The other notable feature relates directly to my own Antipodean research focus (so some will see this as an obvious bias), and this is the detailed coverage given to Australian and New Zealand observations of the 1874 and 1882 transits. In these two chapters, Nick Lomb has drawn freely on the wealth of pictorial material (much of it in colour) assembled by former Sydney Observatory Director H.C. Russell when preparing his popular book about the 1874 transit, which was finally published in 1892. But this very focus also underscores a weakness of this book, for although it provides a basic account, those wanting further details are hampered by a limited and rather selective bibliography. For example, an extensive published overview of the 1874 and 1882 transit observations made in Australia and New Zealand (Orchiston, 2004) is not mentioned, nor is the detailed account of the US 1874 transit program published by Dick et al. (1998). And although the focus is on the British and US observations of these two transits, Chauvin's (2004) outstanding book about the 1874 Hawaiian observations is conspicuously absent from the bibliography. There is also a wealth of literature on 1874 transit observations made by astronomers from other nations (e.g. see the lists of references in the various reports of the IAU Transits of Venus Working Group, published in this journal), but this is hardly mentioned.

This selective bibliography is also an issue in considering Cook's observations of the 1769 transit, where the invited 'Cook paper' (Orchiston, 2005) presented at a Transit of Venus Conference organized by the International Astronomical Union in 2004 is ignored (along with most other papers in the conference proceedings). Another key reference that is missing is Howse and Murray's (1997) reanalysis of the Tahitian data, where they show how accurate the original observations were, notwithstanding Cook's impression to the contrary. For example, Howse and Murray derive a value for the solar parallax of 8.78″ which compares very favourably with the currently-accepted figure of 8.794148″ that was adopted by the IAU in 1976.

These quibbles aside, *Transit of Venus 1631 to the Present* is a beautifully-illustrated book that does provide an overview of the historic transits, and it also presents useful material for those planning to view the 2012 transit. On this basis, it deserves to be on the bookshelf of every astronomer with a passion for these rare astronomical events.

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CORRIGENDUM

Re: Hamacher, D.W., and Norris, R.P., 2011. Comets in Australian Aboriginal Astronomy. *Journal of Astronomical History and Heritage*, 14(1), 31-40.

"Bortle (1998)", which I cite on page 35 does not appear in the References section.

The reference (which also has an incorrect date) is:

Bortle, J.E., 1997. Great comets in history. *Sky & Telescope*, 93(1), 44-50.

My apologies for not catching this previously.

Duane W. Hamacher

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