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COVER IMAGE

The Wolfe Creek Crater, an impact crater 860 m across in Western Australia with an estimated age of 300,000 years, as depicted by Aboriginal artists. According to one legend, a pair of rainbow serpents created the crater, as shown in the upper right-hand painting. An origin from an object falling out of the sky (center top pair) is also present in Aboriginal oral lore: "A star bin fall down… It fell straight down and made that hole round, a very deep hole. The earth shook when that star fell down." (See the paper by Duane Hamacher and John Goldsmith starting on page 295.)

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TRANSITS OF VENUS AND MERCURY AS MUSES

William Tobin
6 rue Saint Louis, 56000 Vannes, France.
E-mail: william.tobin@wanadoo.fr

Abstract: Transits of Venus and Mercury have inspired artistic creation of all kinds. After having been the first to witness a Venusian transit, in 1639, Jeremiah Horrocks expressed his feelings in poetry. Production has subsequently widened to include songs, short stories, novels, novellas, sermons, theatre, film, engravings, paintings, photography, medals, sculpture, stained glass, cartoons, stamps, music, opera, flower arrangements, and food and drink. Transit creations are reviewed, with emphasis on the English- and French-speaking worlds. It is found that transits of Mercury inspire much less creation than those of Venus, despite being much more frequent, and arguably of no less astronomical significance. It is suggested that this is primarily due to the mythological associations of Venus with sex and love, which are more powerful and gripping than Mercury's mythological role as a messenger and protector of traders and thieves. The lesson for those presenting the night sky to the public is that sex sells.

Keywords: Transits, Mercury, Venus, artistic inspiration

1 INTRODUCTION

Transits of Venus across the face of the Sun are rare. Only seven have been seen by human eyes, in 1639, 1761, 1769, 1874, 1882, 2004 and 2012.[1] From the very first they have inspired artistic creation. This paper surveys some of this rich heritage, though the enumeration is certainly far from complete. Transits of Mercury are considerably more frequent. There have been 51 since Gassendi first saw one in 1631, though not all were observed. They too have inspired writers and artists, but to a far lesser extent than transits by the Cytherean planet. I will suggest that this is because the mythological associations of Venus remain more powerful and attractive than those of Mercury, and that this provides a lesson for those presenting the heritage of the night sky to the general public. In what follows, translations are mine, unless indicated otherwise. Works treating transits in astrological terms have been omitted.

2 TRANSITS OF VENUS PRIOR TO 2004

Venus, the goddess of love, beauty, sex, fertility, prosperity and military victory, was the Roman equivalent of the Greek goddess Aphrodite. Her birth was singular. In one version of the myth, the Titan Cronos used his jagged sickle to unman his father Uranus, the primal sky god. The severed organs fell into the sea where they produced the spume and engendered Aphrodite, who rose to the surface fully-adult on a scallop shell. The wind-god Zephyr blew her ashore first on the island of Cythera, and then to Cyprus, while sea nymphs adorned her with flowers and gold (Figure 1).

In 1639, Jeremiah Horrocks and William Crabtree were the first people to see a transit of Venus, from Much Hoole and Salford, respecttively, in Lancashire. After Horrocks had calculated that the transit would in fact be seen best from North America, where no one could know to look for it, he broke into Latin verse to remonstrate with the planet in female personification (Hevelius, 1662: 118):

> Quid fugis ab formosa tuas? quid diva negatos
> Europa vultus, visu dignissima condis?[2] …

which Whatton (1859: 135) translates as:

> Why beauteous Queen desert thy votaries here?
> Ah! Why from Europe hide that face divine,
> Most meet to be admired? on distant climes
> Why scatter riches? or such splendid sights
> Why waste on those who cannot prize their value?[3]

2.1 Poetry

Subsequent transits continued to provide poetic inspiration, both comic and serious. Consider Ann Williams, postmistress of Gravesend. She penned the following 'impromptu' in 1773, "... on reading that all the gentlemen were taken ill the day after viewing the transit of Venus." (Williams, 1773: 100). It seems likely she was reacting to news of Chappe d'Auteroche's feverstriken observing expedition to Baja California in 1769:[4]

> Presumptuous man, how could you think to trace,
> Or view unhurt bright Venus' lovely face?
> Cupid for this has play'd you all a trick,
> And for your bold presumption made you sick.

A similar warning was issued at a later transit (Dalloz, 1883; my English translation):

> In levelling thus at me your 'scope
> You think you'll capture me;
> But if imprudent near you come,
> Right quick will stop your heart.

Earlier in the nineteenth century the French entomologist Hugues Fleury Donzel wrote a fable in which a man explains why he cannot take his dog for a walk (1849: 194; my English translation):

> I have calculated the transit
> Of Venus across the Sun:
> I await it. Would it be wise

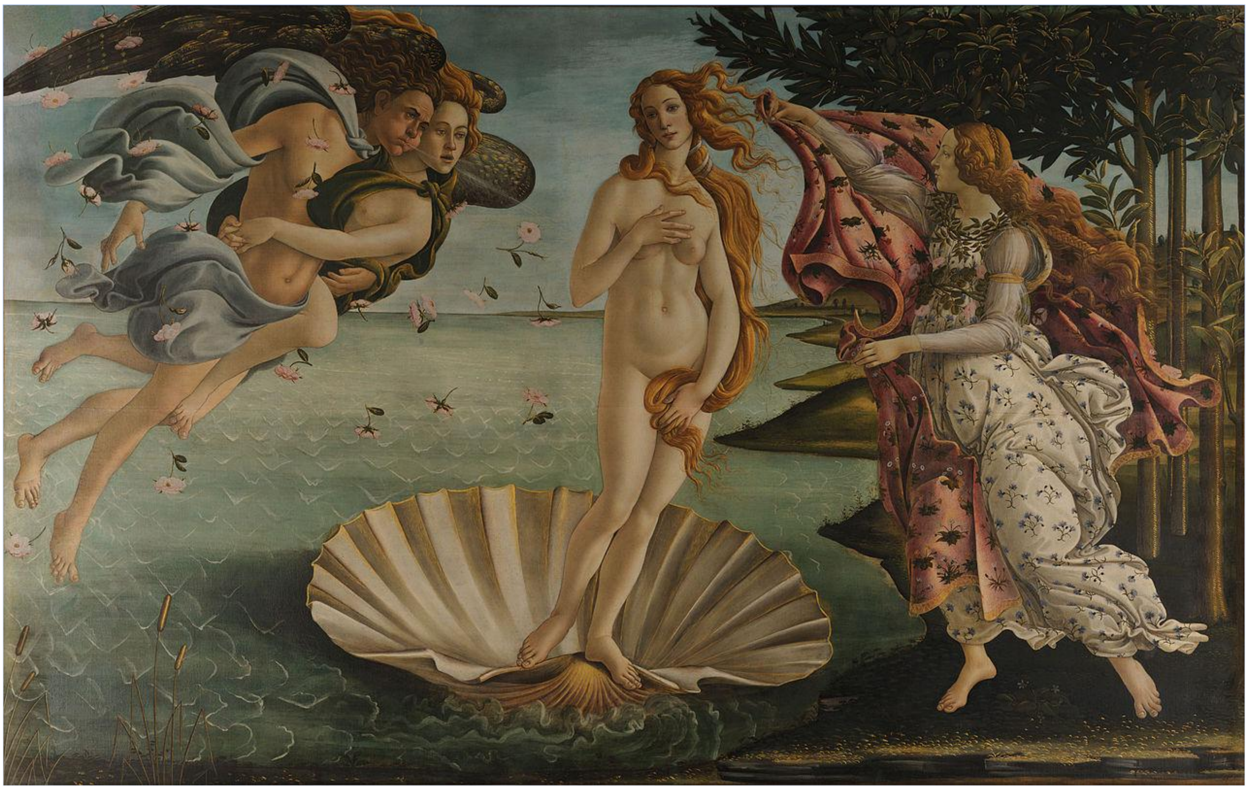

Figure 1: *La nascita di Venere* by Sandro Botticelli (1445–1510) (courtesy: Wikimedia Commons).

> To give up the benefit
> Of such a phenomenon?
> Go without me ...

Punch, or the London Charivari, frequently engaged with topical scientific issues (Noakes, 2002). The 1874 transit was no exception (Figure 2),[5] despite not being visible from Britain, though the following sample poem suggests that its author may not have appreciated that transits across the Sun are day-time phenomena (The astronomer at home, 1874):

> I hold, whatever PROCTOR writes,
>   Or LOCKYER, or AIRY,
> Out-door observing, these chill nights,
>   A snare for the unwary ...
>
> Let who will, mid Kerguelen's snows,
>   Seek freezing-post and thawing-room,
> My Venus one short transit knows—
>   From dining-room to drawing-room.[6]

The realities of observing were fully appreciated, however, in a later ditty (The Transit of Venus, 1874a):

> Home troop the astronomers various,
>   And bring their celestial log,
> Some rendered by sunshine hilarious,
>   Some dampened by inopportune fog.

More serious was the Dublin poet Thomas Caulfield Irwin (1874):

> Mind reckons distance of the motion—Time:
> Mind, with a world, measures the sun sublime.
> Now o'er the ocean, winged with steam and sail,
> Speed forth ye ships of science ...

The French writer Eugène Lambert produced a poem entitled *Le passage de Vénus* (1876: 125), which ends (my English translation):

> Savants travel so very far, in such grand style,
> To spy upon your track across the Sun.

Figure 2: Guard page for the 1874 volume of the British satirical magazine *Punch*, reflecting frequent references to that year's transit in the magazine (courtesy: David Miller).

> In the sky, a telescope tracks your course;
>
> But, Venus, if there, for these savants of a day,
> You are only a black spot on the Sun, a blemish,
> You will remain for us the star of love!

Hermann Krone, one of the photographers on the German expedition to New Zealand's subantarctic Auckland Islands in 1874, summarized the party's goal in more serious verse (Krone, ca.1901: 55; my English translation):

> You peer out searching into space,
> You seek to measure how far removed
> Is your viewpoint here on Earth
> From the glare of the warming Sun.

The American jurist and poet, Oliver Wendell Holmes, invoked glaring too, in his *The Flaneur* (1883). Holmes had been waiting on Boston Common to pay a dime to look at the 1882 transit through a telescope:

> I gain at last the envied place,
> And pay the white exiguous coin:
> The sun and I are face to face;
> He glares at me, I stare at him;
> And lo! my straining eye has found
> A little spot that, black and round,
> Lies near the crimsoned fire-orb's rim.

Cloudy skies in London for this mid-week transit provoked *Punch*'s writers into the following rather garbled attempt at humour "By a disappointed Would-be Observer of the late Transit" (Cockney Conceit, 1882):

> Vain the desire to "focus" thee, fair Venus
> (On this thy latest only living man's day),
> With this vile veil of London smoke between us.
> Alas! "Sic transit gloria mun—" no, Wednesday!

The weather does not seem to have been any better in France. Henri Bourette (1885: 190) versified on the coming-together of Apollo and Venus modestly shielded by a cloud. The 1882 transit also prompted what now seem like pompous and surprisingly humourless verses from the Berlin-based satirical magazine *Kladderadatsch* (Kladderadatsch, 1882).

Transits continued to inspire poets in the transitless twentieth century. It is perhaps unsurprising that the cigar-smoking Amy Lowell should have written a poem entitled *Venus Transiens* (1915), even if the poem's subject is Botticelli's painting (Figure 1) rather than a celestial transit, because Lowell was born in the transit year 1874 and was the youngest sister of Percival Lowell of canals-of-Mars fame. In 1920s Paris, the rich, American *bon vivant* Harry Crosby was fascinated by the Sun and its associations. He wrote the poems in his *Transit of Venu*s (1928) soon after meeting and beginning an affair with Josephine Rotch, who would die with him the following year in what may have been a suicide pact. In his diary, Crosby stated that he chose the book's title because he saw both Rotch and Venus as "... the Youngest Princess of the Sun." (Fama, 2012). Below, Crosby evokes their *First Meeting*:

> When you are the flower
> I am the shadow cast by the flower
> When I am the fire
> You are the mirror reflecting the fire
> And when Venus has entered the disk of the Sun
> Then you are that Venus and I am the Sun.

The little-known Lee Eisenstark treats departure in his *Transit of Venus* (1972):

> You closed the door without a sound
> You always did things gently …

while discovery and exploration form the theme of a volume of poems by the Australian Alex Galloway (1993).

Another Australian poet, A.D. Hope, had earlier taken the British expedition to Tahiti in 1769 as the setting for his 200-line *Transit of Venus* poem published in 1985. In it Joseph Banks is (inaccurately) represented as uninterested in women. Spurned, the goddess of love sets a honey-trap:

> The transit of my planet across the Sun
> Shall be the bait—an intellectual one—
> Watching its flight from limb to glowing limb,
> He shall not notice *me* observing *him*.

The "unclad beauty" of the Tahitian women will be "an unfailing snare":

> Those naked bosoms and voluptuous flanks
> Will make short work, I swear, of Mr Banks.

Banks was friendly:

> … but still maintained
> A well-bred abstinence, to say the least,
> Remained agreeable, but forebore the feast.

And:

> As for the transit, he ignored it too …[7]

2.2 Novels and Short Stories

Other transit-inspired literary forms include the novel and the novella. Among the former are *Der Durchgang der Venus* (1880) by Richard Forstner (who seems to have written little else); Thomas Hardy's *Two on a Tower* (1882) with astronomer Swithin St Cleve ("... the astronomical world is getting quite excited about the coming Transit of Venus. There is to be a regular expedition fitted out. How I should like to join it!"); and the extraordinary *Transit of Venus* novel-of-the-psyche by Australian author Shirley Hazzard (1980; "Tice said, 'The calculations were hopelessly out.' Siding with the girl. 'Calculations about Venus often are.'"). Hardy's and Hazzard's novels have been subjected to scholarly analysis (e.g. DeWitt, 2007; Marroni, 2010 for the former; Brooks, 1998; McDougall, 1995; and especially Birkerts, 2009 for the latter). With the *Transit of Venus* title we also have the novellete by the American bandmaster John Philip Sousa (1920) (“... the little black disc we call Venus … behaved like a real lady”). We can imagine the content of *Élodie, ou le Passage de Vénus* (Durand, 1926) from its cover (Figure 3). The astrophysicist J.-P. Luminet’s *Le Rendez-vous de Vénus* (1999) pretends to be the memoirs of French astronomer J.J. Lalande. It recounts the tribulations of the French transit-observers Chappe d’Auteroche, whose fatal expedition to Baja California has already been mentioned, and Guillaume Le Gentil, whose sorry lot it was to fail to observe both eighteenth century transits. Le Gentil’s story is also told in Lorenz Schröter’s German-language *Venus-Passage* (2001).

There are numerous short stories, or collections thereof, entitled *Transit of Venus,* or the equivalent in other languages. In one from the 1880s, a young astronomer asks his father for 500 francs to defray expenses associated with observing Venus in transit—in reality, for entertaining a show-girl (Deslilas, 1882). In another, by the free-thinking, anti-clerical feminist Marie-Amélie Chartroule de Montifaud, a disappointed wife asks two priests to verify her unperforming husband’s manhood. This they attempt by having two young women pass in front of the naked man, though in fact the man is an imposter, hired by the handicapped husband, and the women are mechanical automats (de Montifaud, 1883). Prior to WWI there is a short story by the mid-western author Samuel Marshall Ilsley (1908) in which a strikingly handsome but cold-eyed young woman crosses paths with an equally-handsome, would-be poet. In the inter-War years the English-Canadian humorist Stephen Leacock (1926; see also Chopra, 1989) wrote a “... delicious story of the astronomy professor who captured a star of the very first magnitude ...”, while the English fantasy writer Michael Harrison (1936) published an ‘erotophobic’ demolition of the desert island as an Eden (Stableford, 1998: 17). Tom Hopkinson’s *The Transitory Venus* (1948: dust jacket) collects

> ... stories [that] are studies in the effects of … those love affairs which, although they may only last a short time can, nevertheless, profoundly alter a whole life.

More recently the *Transit of Venus* title has been used by the American science-fiction writer Miriam Allen deFord for a short story (1962: 41; “Nobody really knows when the rite of the Buticontest began. Some archaeologists place it as far back as the 20th century ...”) and by her countryman Mark Seymour (2007: 25): “He watched her emerge out of the tepid surf, glistening hips swaying on either side of the vertical strip of her yellow tanga.” The same title has been used for a Pacific-Ocean travelogue “... simply because travelling through the islands … had felt like crossing another planet.” (Evans, 1992; 2012) and for thoughts on the author’s Pitcairn-Island ancestors (Metcalfe, 2004). The title *Venus in Transit* was adopted by the British author Audrey Laski for her first published novel (1964), and by Douglas Sellick for the writings of early Australian women travellers (2003).

Transits of Venus appear in creative writing in other ways. The great age of the Earth and the origin of species are amongst the issues parodied in Mark Twain’s *Some learned Fables for Good Old Boys and Girls.* Published soon after the 1874 transit, the short story explicitly mentions transits of Venus, and the 1874 expeditions are the clear inspiration behind passages such as (Twain, 1875: 126):

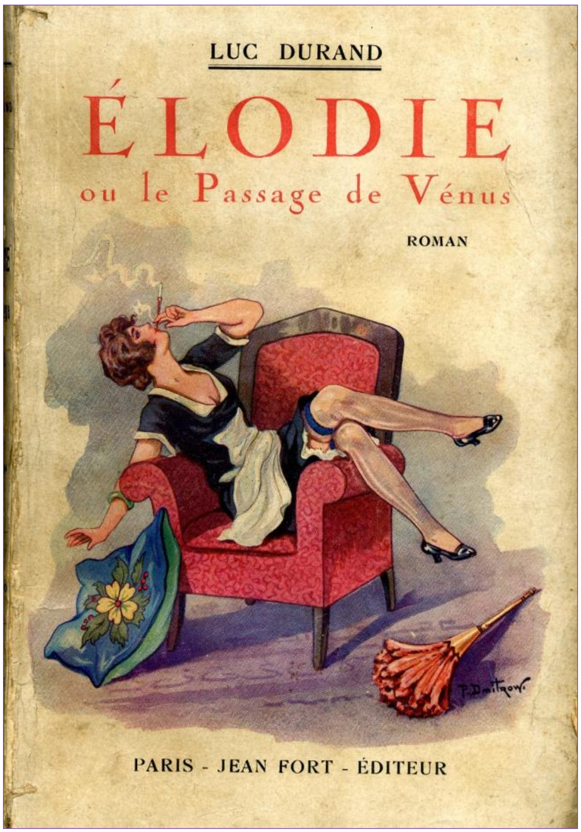

Figure 3: Cover of the novel *Élodie, ou le passage de Vénus* (author’s collection).

> Once the creatures of the forest held a great convention and appointed a commission consisting of the most illustrious scientists among them to go forth … It was the most imposing enterprise of the kind the nation had ever embarked in … How the members were banqueted, and glorified, and talked about!

Over the years there have appeared many variations of J.D. Wyss’ moralistic *Der Schweizer-*

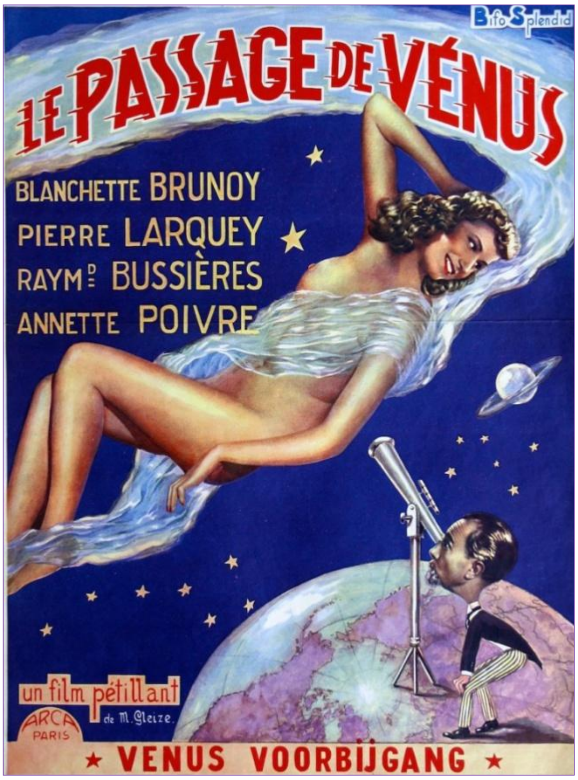

Figure 4: Poster for the 1951 film directed by Maurice Gleize (after: www.cinema-francais.fr).

ische Robinson (1812). At least one includes the transit of Venus (*The Swiss Family Robinson*, 1859: 380):

Figure 5: The French Academy of Sciences personified as Urania reporting the results of Siberian transit observations from 1761. Engraved from a drawing by Jean-Baptiste Le Prince (courtesy: Google Books).

> Astronomy made them such friends, that Mr. Horner petitioned me to allow him to take my son to Europe … Many tears were shed at our parting … but Mr. Horner made some observations about the transit of Venus, so interesting that Ernest could not resist.

In the utopian novel *A Voyage to Venus* by Australian author Dominic Healy (1943: 85) the "... memorable transit ..." of 2004 appears as the one during which Earthlings supposedly determine that Venus is "... inhabited by primitive forms of life".

2.3 Plays

Playwrights were busy too. Garnet Walch's one-act pantomime *Adamanta … or … the Transit of Venus* was performed in Melbourne over Christmas 1874, complete with astronomer Phokuss (Walch, 1874). A few months later *Le passage de Vénus* opened in Paris, scripted by the dramatists Henri Meilhac and Ludovic Halévy (1875), who at the same time were collaborating on the libretto for Bizet's *Carmen*.[8] Their astronomer was more conventionally named. In 1921 the dramatist Miguel Zamacoïs produced a charming 'fantasia' in rhyming verse. Set in Ceylon in the minutes before the 1769 transit, Léonard, an astronomer from France, is surprised by the unexpected arrival of his erstwhile paramour. In search of consolation, she had been travelling east to marry a spice merchant, but her ship has been blown off course. The captain will sail with the next tide, so Léonard must chose at once between life with his earthly Venus or a few hours with the celestial one which will make his fame in Paris (Zamacoïs, 1921: 176; my English translation):

> Between dream and desire, which to make my
> fate?
> One is in a hurry, and the other will not wait!

Zamacoïs' play does not appear to have been performed publicly, which is a shame, because of all the transit literature I have read, it is my favourite. However it was broadcast on the radio a decade later.[9] Also broadcast on the radio, much later, was a "... comédie-bouffe pour les ondes ..." by the multi-faceted French writer Armand Lanoux (1960).[10]

Harold Harwood's play *The Transit of Venus* is a critique of western civilisation, performed in London in 1927 (Harwood, 1927; Ambassadors Theatre, 1927a).[11] A play of the same name by Maureen Hunter was first performed in Winnipeg in 1992. It is another work centring on the unfortunate Le Gentil and gave rise to an opera with libretto by Hunter (2007) and music by Victor Davies. There is even a film (Figure 4) starring the wistful-looking Blanchette Brunoy, which derived from an earlier stage play by the author-actors Georges Berr and Louis Verneuil.[12] After a night's drinking, of which he remembers little, the normally-austere astronomer Chantoiseau becomes convinced that he is the perpetrator of a theft and rape.

2.4 Religious Tracts

Transits have also inspired religious tracts. At first glance, the meaning of the anonymous and entertaining pamphlet *Some Reasons for Doubting the Alleged Transit of Venus* (1875: 10-24) is far from clear. The reasons are that transits are "... improbable ...", that "... Horrocks was a clergyman; and we know that clergymen, though eminently amiable and well-intentioned, are yet not, as a rule, a class upon whose accuracy and judgment we can very safely rely ..."; that concerning those sent to observe the 1874 transit, for Americans "... a very exact way of speaking is not among their pre-eminent virtues ...", for Germans "... their forte lies more in the region of speculative thought than in practical observation ...", for French "... who can expect from a people ardently courageous and impulsive, that calmness—that judicial impartiality—which is so essential for clear, dispassionate evidence ...", for Russians "... that the wilds of Siberia are far too remote and barbarous to admit of our even investigating [their] testimony ...", for English "... what can we expect but assent, when the storm of popular prejudice has set determinately in favour of the Transit?"; and concerning astronomers in general, "... they are the very worst witnesses which could be called … for they are all of them committed to the Transit beforehand." The anonymous author continues by decrying the quality of the evidence. The times recorded at Calcutta differ from those at Kurrachee, and no transit was observed by "... the multitudes who thronged the quays of Dublin, the streets of Glasgow, the avenues of Hyde Park." The author praises the toil of Spinoza, Tindal, Gibbon, Comte and Strauss and asks to what end they have toiled (Some Reasons for Doubting the Alleged Transit of Venus, 1875: 26):

> [if] we ... are to be found yielding to the old impulse of superstition against which they raised their loudest protest, and accepting on *mere testimony* statements and narratives that will not stand even the mildest application of those laws and rules which they so rigorously applied and so nobly maintained?

The author's meaning is revealed by the comment in the catalogues of the British Library and National Library of Scotland that the pamphlet is "... a satire on religious scepticism." The opposite of what is said is meant throughout. It is in fact a tract in favour of revelation and the truth of scripture. No such complexity of interpretation is necessary for *A Sermon Suggested by the Transit of Venus* delivered in Philadelphia's First Baptist Church on the evening of the 1882 transit (Boardman, 1882). The imutable laws of nature, as indicated by the transit, are proof of God's equally immutable covenant with man.

2.5 Paintings and Art

In painting and art, productions have until this century mostly been commemorative. A first example comes from the Abbé Chappe d'Auteroche's enormous, folio-sized report of his voyage through Siberia in order to observe the 1761 transit (Chappe d'Auteroche, 1768). Vexed by the Abbé's poor opinion of Russia, Catherine the Great described this work as "... a bad book, superbly printed." (Antidote, 1770: 1), and the frontispiece is certainly magnificent (Figure 5; see also Levitt, 1998). The legend underneath praises Louis XV for having sent out scientific expeditions while spending heavily on fighting the Seven Years' War.[13] The purpose of Chappe's expedition is indicated by the *putti* hovering near the Sun complete with telescope and dividers, while Urania, muse of astronomy, is reporting the results. Louis XV provides a link to an object celebrating the second eighteenth-century transit. It is a barometer from the Passemant School which belonged to Madame du Barry, the King's last *maîtresse-en-titre.* One of its decorative enamel panels shows a *putto* surveying the sky with a telescope; another shows him contemplating his observations with an open book marking the 1769 transit (Figure 6).

Figure 6: Decoration on an 18th-century Passemant-school barometer celebrating the 1769 transit of Venus (courtesy and ©: The Metropolitan Museum of Art).

In 1859 a stained glass window was installed in Much Hoole Church celebrating Horrocks' observation nearby of the 1639 transit (Figure 7), as part of the then-Rector's 'Horrocks fever' (Myres, 1884). In the following decades paintings were produced by British artists Ford Madox Brown, Eyre Crowe and William Lavender of the moment of observation of the transit by Horrocks or his friend Crabtree. Of course nothing is known about the actual physical appearance of these two young men. Brown's painting is one of twelve made for Manchester Town Hall celebrating key events in the locality's

Figure 7: Window installed in St Michael's Church, Much Hoole in 1859 commemorating Horrocks' observation of the 1639 transit (courtesy: Wikimedia Commons/Chuck Bueter, CC BY-SA 3.0).

history (Figure 8). It is a fresco, painted using the Gambier Parry technique, and was completed in 1883. The 24-year old Crabtree is represented as a bony old man observing the transit with his family in the attic of his draper's shop.[14] The winter transit date is indicated by a frosted window on the floor beneath. Knobel (1903) tells us that the depicted means of projecting the solar image was derived from perusal of a drawing[15] in Scheiner's *Rosa Ursina* (1626-1630); a battered copy of this volume leans against a cupboard in the fresco.

Crowe's picture (Figure 9) was exhibited at the Royal Academy in 1891 and described by one critic as "... a somewhat grotesque tribute ..." (The Royal Academy, 1891). Sir Norman Lockyer assisted by providing a telescope and for the background Crowe is said to have visited the room in Carr House at Much Hoole, where Horrocks may have observed (Summerwill, 2012). The equatorial 'helioscope' is copied from *Rosa Ursina,* but Southport (1903) has pointed out that the impoverished Horrocks was unlikely to have owned such an expensive mount for his Galilean telescope.

Lavender's picture (Figure 10) was painted with input from two Southport astronomers, G. Napier Clark and D.E. Benson (Southport, 1903), and indeed it seems probable that it was commissioned by Clark to coincide with the British Association's meeting in Southport (near Much Hoole) in 1903.[16] Efforts were taken to have the painting conform as closely as possible to Horrocks' description of his procedure, such as a projection that fills the calibrated circumference of a circle drawn on a card (Clark, 1916). However, as with the two other paintings of the 1639 transit, Venus is mispositioned.[17]

The French celebrated the nineteenth century transits with a number of works. The painter and decorator François-Émile Ehrmann produced an allegorical canvas (Figure 11) showing a lightly-clad Venus passing in front of the giant face of Phoebus Apollo (the Sun). The work was exhibited at the 1875 *Salon* and was dismissed by one critic as too small and by another as quasi-farcical (de Montaiglon, 1875: 512; Claretie, 1876: 363). One can imagine that similar remarks might have been made about another design, published after the 1882 transit by Paul Avril (1883), who later became notorious for his explicit erotic illustrations (Figure 12).[18]

At least two artists proposed designs for a medal to commemorate the 1874 expeditions: Eugène André Oudiné (exhibited at the *Salon* in 1876) and Alphée Dubois (shown at the *Salon*

Figure 8: Ford Madox Brown's fresco in Manchester Town Hall completed in 1883 picturing Crabtree watching the 1639 transit. The painting measures 3.20 × 1.45 m (courtesy: Manchester City Council).

Figure 9: *The Founder of English Astronomy,* Eyre Crowe's oil painting from 1891 of Horrocks observing the 1639 transit. The canvas measures 1.00 × 0.76 m (courtesy: National Museums Liverpool/BBC Your Paintings).

the following year) (Correspondance, 1875; Exposition Universelle Internationale, 1878: 92, 107-108). Dubois' design was adopted and he cut the die, which showed Venus and Apollo observed by Urania. The hellenist Émile Egger of the Académie des inscriptions et belles-lettres devised a Latin motto which translates as "By their meeting, the stars reveal the distance which separates them" (*Académie des Sciences*, 1877: 417-418). The medal was struck afresh after the 1882 expeditions (Figure 13). The 1879 *Prix de Sèvres* for ceramics had as its topic the transit of Venus. The prize was won by Joseph Chéret with a 2-metre tall vase which was installed in the Bibliothèque Nationale (Manufacture de porcelaines de Sèvres, 1879; Lechevallier-Chevignard, 1908). After the 1882 transit, the Professor of Drawing at the École Polytechnique, Edmond-Louis Dupain, painted a huge circular allegory which since 1886 has decorated the Council Room in the west rotunda

Figure 10: Horrocks observing the 1639 transit, as imagined by William Richard Lavender in 1903. The oval measures 0.92 × 0.61 m (courtesy: Astley Hall Museum and Art Gallery/BBC Your Paintings).

Figure 11: Engraving of F.-É. Ehrmann's *Le passage de Vénus devant le Soleil* (Exposition du Havre, 1875) (author's collection).

Figure 12: *Le passage de Vénus sur le soleil* (Avril, 1883) (courtesy: gallica.bnf.fr).

Figure 13: Medal designed by Alphée Dubois and awarded to members of the French expeditions and others in 1874 and 1882 (author's collection).

of the Paris Observatory (Figure 14).[19] Débarbat (2005) notes that besides showing Apollo in his chariot and an approaching, bare-breasted Venus being observed by Urania, the painting includes vignettes of Halley, Delisle and Le Verrier.[20]

American painters appear to have found transits less inspiring. The only work I have discovered is by the British-born J.G. Brown who imagined street urchins watching the 1882 transit through smoked glass (Figure 15). Brown's painting was copied for the cover of *Har*-

Figure 14: E.-L. Dupain's allegory of the transit of Venus decorating the ceiling of the Paris Observatory Council Room. The canvas is some 4 m in diameter (author's photograph).

per's Weekly and later the *Illustration Européenne.*[21] The original sold recently at Christie's New York for US$122,500.

2.6 Songs and Musical Compositions

Many composers and musicians have taken transits of Venus as their theme, or at least title. Eighteenth-century transits inspired the actor G.A. Stevens' *Transit of Venus* song (1772: 150; also Rosenfeld, 2011b):

> Astrologers lately a bustle have made,
>   How round the sun *Venus* cou'd dance it,
> With *optic, catoptric, dioptric* parade,
>   To spy how genteel was her transit ...
>
> Bedew'd by the salt-water spray as she rose,
>   To *Apollo* her Beautyship run,
> Intending to dry her Olympical Cloaths,
>   So stood between us and the Sun.

Come ye lads and lasses with speed: The transit of Venus was another (lewd) song from the same place and period.[22] The nineteenth century saw a *Transit Galop* (Case, 1881), a *Venus Polka Quadrille* (Heinemann, 1883), a *Venus Waltz* (Armstrong, 1884) and a *Transit of Venus March* by bandmaster Sousa (1883). In 1898 James T. Tanner scripted a two-act musical comedy with lyrics by Adrian Ross and music by Napoleon Lambelet (*The Era*, 1898). Reportedly, the close of the first act was "... highly ingenious ...", involving nine sets of lyrics for eight principals and a chorus of gendarmes (Short and Compton-Rickett, 1938: 136). In the 1960s New Zealand schools often rang with children singing *The Ballad of Captain Cook* by folk singer Willow Macky (1959) with its lines "But I must be off to the isles of the south / To observe the transit of Venus". The transit also features in the celebration of Cook's voyage *Love 200* by the Australian composer Peter Sculthorpe and rock band Tully in 1970 (e.g. Tully, 2010). In the 1990s *Transit of Venus* tracks featured in albums by British free-jazz saxophonist Evan Parker and Tuvan throat singer Sainkho Namtchylak (1996); by the American composer Stephen Scott (1996); and by the Brussels-based Dutch guitarist Paul Curtiz (1997). Cook's Nordic naturalist, Hermann Spöring, provided the central theme for a *Transit of Venus* 'radiophonic meditation' by the Finnish sound artist Simo Alitalo (1999).

2.7 Cartoons

Transits have furnished a rich lode mined by cartoonists. In 1793 Robert Sayer & Co. published an engraving of a transit maiden being examined through a quizzing glass by a man whose lascivious intent is made clear by the nearby statue of a satyr (Figure 16). Sixteen years later, the Duke of York's ex-mistress, Mrs Clarke, created scandal by selling access to her former lover to officers aspiring for promotion. A cartoon showed the Sun of the Duke crossed by the Venus of Mrs Clarke (Figure 17). The same visual theme was repeated almost 70 years later with autocratic government eclipsed by the Third Republic (Figure 18; Gill, 1875). Another theme adopted by more than one cartoonist is that of a female being transported. Apollo may be present, shining brightly (Figure 19). Venus may be a substantial maiden on a litter, carried by policemen or Egyptian porters, depending on whether she is drunk or not (Figures 20 and 21). Or she may be a matron purportedly transported across London by spirit means, or a difficult-to-move statue (Figure 22).[23] The transport theme has also been used with no aim at irony in a sickly-sweet painting by the English genre painter Charles Garland (Figure 23). Observers on Earth may be seen as voyeurs (Venus: "How earth stares at me. It makes me feel quite beauti-

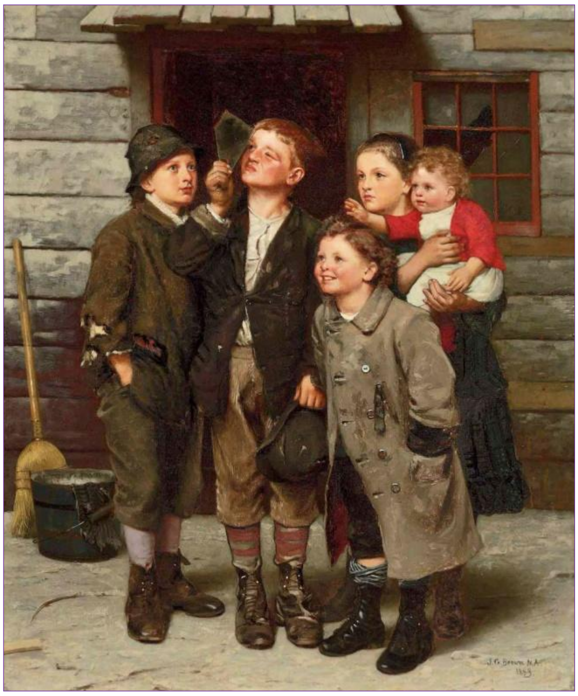

Figure 15: John George Brown's *Transit of Venus* painted in 1883 (courtesy: Christie's New York).

Figure 16: Satirical print from 1793 (courtesy: NASA).

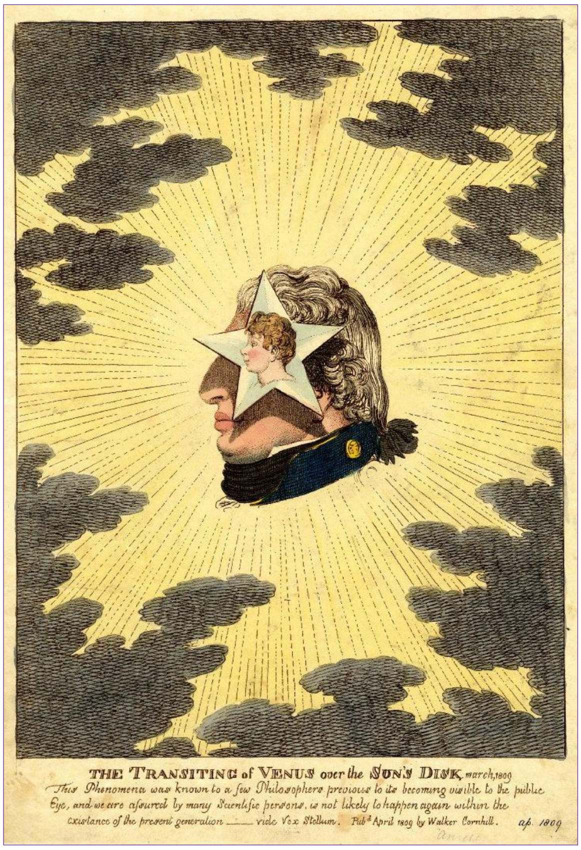

Figure 17: British satirical print from 1809 showing the Duke of York darkened by his former mistress, Mrs Clarke. The legend adds "This Phenomena was known to a few Philosophers previous to its becoming visible to the public Eye … and is not likely to happen again within the existance [sic] of the present generation ..." (courtesy and ©: Trustees of the British Museum).

Figure 18: The Third Republic triumphing over autocratic government. A new French constitution was being enacted when this cartoon appeared in 1875 (author's collection).

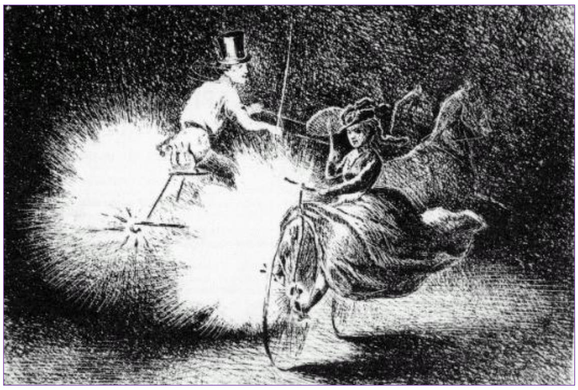

Figure 19: *The Transit of Venus as observed by our special astronomer in his Patent Duplex Elliptical and Diaphragmatical Reflecting Instrument ...* (The Transit of Venus, 1874b). "Patent Duplex Elliptical" is flummery drawn from the technology of hooped skirts (courtesy: Library and Archives Canada).

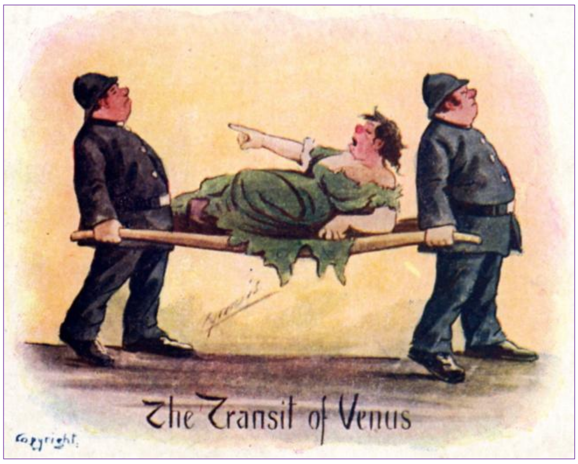

Figure 20: Postcard dated 1907 by the Scottish cartoonist Cynicus. He had published a similar image some years earlier in a book (Cynicus, 1891) (author's collection).

ful") or the disc of the planet may be seen as a beauty spot (Two successful observations by our artist, 1882). The vicissitudes of the weather have been satirized with a fig leaf (Figure 24). In another nineteenth-century French cartoon it is an anaconda or other large snake that is preventing transit observations by a "... savant sent to South America."[24]

Figure 21: *The Transit of Venus* from Lance Thackeray's *The Light Side of Egypt* (1908) (courtesy: Google Books).

2.8 Other Homages to Transits of Venus

Finally, it should be mentioned that in the 1870s there was a racehorse in New Zealand named *Venus Transit* that even won a race (e.g. Special Telegrams, 1877), while Cottam, et al. (2012) report a transit of Venus flower arrangement in 1882 at Delmonico's Restaurant in New York. In 1980 the British abstract sculptor Deborah Stern produced a transit-themed work in bronze. Commemorative stamps have been issued by many postal authorities, including those of Curaçao, China, the French Southern & Antarctic Territories, Mauritius, New Zealand, Norfolk Island, South Africa and Tuvalu (e.g. see Figure 25).

3 THE TWENTY-FIRST CENTURY TRANSITS OF VENUS

The two latest transits have seen an explosion of artistic production, or at the very least, its availability on the internet, and it is practical to mention only a small selection of the available material. Table 1 counts the items that I have discovered in a less-than-systematic search, so the numbers should only be considered illustrative. The marked rise in poetry and painting between 2004 and 2012 is due to the emergence between these dates of venues for their on-line display, such as wordpress.com and deviantart.com, whereas musical production has been less affected.

3.1 Poems

Poems in books or books of poems with a transit verse or title include Acharya (2010), Bennett (2010), Edgar (2006), Hahn (2010), Lavarreda (2012), Lomer (2007), McGuire (2013), Miller (2012), Potter (2005), Riach (2001) and Torwl (2012). From the plethora of poetry in blogs in 2012, here are three three-liners, all with rather similar themes:

Venus transit over Sun
that face pimple I wish
would move and go away too.
(Chunghoo, 2012)

transit of Venus
the mole
on her upper lip.[25]
(Pierides, 2012)

On the powdered cheek of the Sun
Venus the coquette
Has placed her beauty spot.
(Catheau, 2012; my English translation)

3.2 Works of Art

Numerous paintings, photographs, digital art works and other pictures were prompted by the recent transits. Figure 26 shows a cartoon that illustrated a newspaper opinion piece by Pasachoff (2012). Figure 27 presents thumbnails of a selection of other striking images.

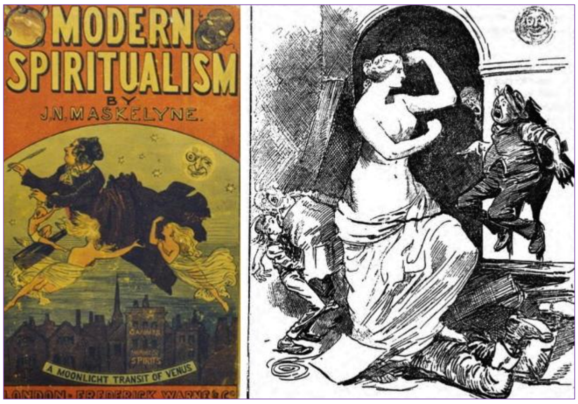

Figure 22: (Left) Spirits transport Mrs Samuel Guppy across London with the ink still wet in her pen (Maskelyne, 1876) (courtesy: liveauctioneers.com). (Right) The Venus de Milo, arms restored, gets the better of workmen attempting to move her (Furniss, 1887) (courtesy: Google Books).

Figure 23: C.T. Garland's *Transit of Venus* as reproduced in *The Graphic*'s Christmas Number for 1884 (author's collection).

Figure 24: Parody of poor weather from *L'Éclipse*, a French comic newspaper (Hadol, 1874). The caption says "At the moment of the transit of Venus, astronomers see their telescopes changed into vine leaves" (courtesy: Universitätsbibliothek Heidelberg, CC BY-NC-SA 3.0).

Figure 25: Transit of Venus commemorative stamps issued by New Zealand in 1969, the French Southern & Antarctic Territories in 2001, Mauritius in 2009 and Portugal in 2012 (author's collection).

Table 1: Artistic works entitled *Transit of Venus* (or similar) inspired by the two most recent transits. Appearance during 2000-2009 has been associated with the 2004 transit and during 2010-2013 with the 2012 transit.

Genre	2004	2012
Short stories	3	2
Books of poems	1	5
Individual poems	8	43
Paintings/prints etc,	3	76
Music albums/CDs	5	7
Musical pieces/tracks	15	12

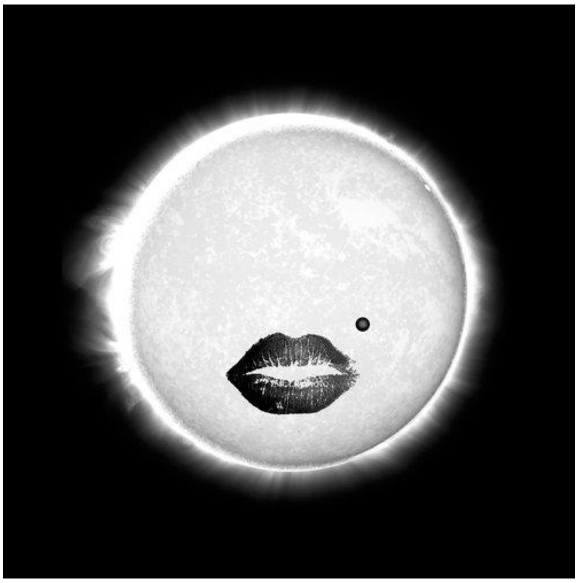

Figure 26: Cartoon from *The New York Times* by Valero Duval (courtesy: Jay Pasachoff collection).

3.3 Literary Works

Amongst stories, the Indian surgeon-writer, Kalpana Swaminathan, published *Venus Crossing: Twelve Stories of Transit* (2009), which won that year's Vodafone Crossword Book Award. Tarrin Lupo and Ruby Hilliard (2012) have written a horror story about a Venus-obsessed sect:

> She drifted in and out of consciousness as she alternated between watching Venus transit the face of the sun ... and the congregation indulging in gratuitous sex acts. She could make no sense of any of it.

There are *Transit* graphic novels too (Figure 28;[26] Maurer, 2009), and a Dr Who audio-book (Rayner, 2009).

3.4 Musical Compositions

Among the classical music spawned by the recent transits are pieces by Houston Dunleavy and Laura Goodin (2003, for sopranos, alto and piano); by John Wesley Barker (2004, for the flute, inspired by a drawing from Cook's expedition of a Tahitian playing a flute); by Joby Talbot (2005); by Julia Usher (2009, for the clarinet and saxophone); by William Zeitler (2012, for the glass armonica, an instrument redefined and named by Benjamin Franklin in transit year 1761); and by Frédéric Bousquet (2009, for the Cristal Baschet, an armonica-like instrument). A computer-guided piece has been produced by the Australian composer and performer Lindsay Vickery

Figure 27: Thumbnails of some graphic art found on the internet and inspired by the 2012 transit. From upper left: by the Sydney printmaker Ann Condon (my favourite), by KBu77, by OjouLaFlorDeNieve, by Officer-Sarcasm, by persare, by scheinbar, and by amethystmstock.

(2009) in which the sounds of three independent instruments occasionally align. Fabio Keiner's *Venus Transit* (2012) provides another abstract soundscape. Amongst those who have produced albums more-or-less named *Transit of Venus* are the Austrian jazz composer Franz Koglmann (2001), Jill Connolly (2005, Massachusetts), the Cherry Blue-storms (2007, Los Angeles, their début album), Jazz Sabbath (2008, California), Black Forest Fire (2012, Texas), John Paul Davis (2012, New York), Fair Moans (2012, Chicago), Hangedup & Tony Conrad (2012, Montreal), Magic Jackson (2012, Ohio) and Three Days Grace (2012, Toronto). There is a *Transit of Venus* girl band in Auckland (transitofvenusproject.com) and a *Transit of Venus* record label based in Philadelphia.

3.5 Cartoons

Figure 29 presents two transit cartoons from New Zealand (Nisbet, 2004; 2012). One from Britain in 2004 shows a couple in their back yard watching the transit. "The Transit of Venus, the European Elections," says the man, "don't say we never have any fun." (Matt, 2004). The economy was a recurrent theme in 2012. In one a Euro symbol transits a Sun labelled "Debt Crisis" (Matson, 2012). In another, Europe's economy crashes into the Sun (Englehart, 2012). In a third, astronomers observing the transit say "We'll likely not live to see the next one" as a large meteor labelled "Economy" hurtles towards them (McKee, 2012). Also frequent was the theme of a Venus (de Milo, or Botticelli's) in a Ford Transit van or pickup, or in a metropolitan transit-system railway carriage.

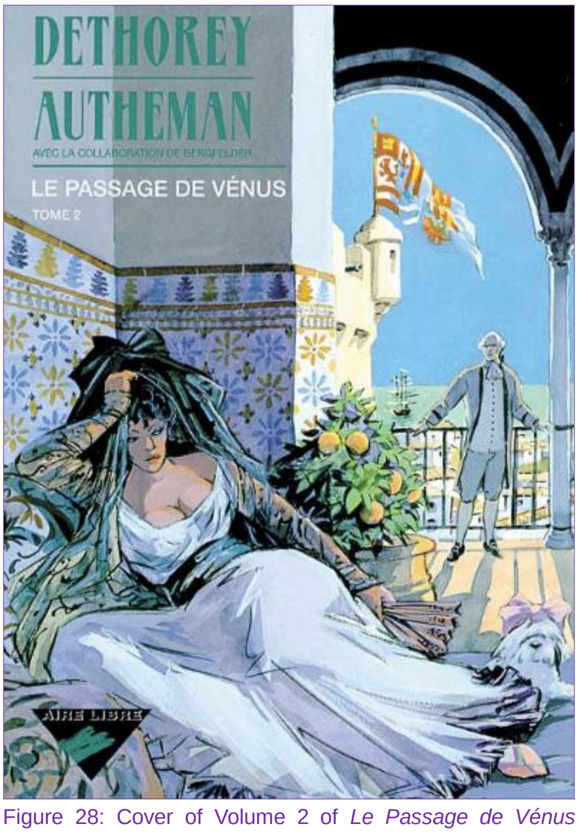

Figure 28: Cover of Volume 2 of *Le Passage de Vénus* (Dethorey, et al., 2000).

Figure 29: Twenty-first century transit cartoons from Christchurch. (Left) Comment on a missed penalty shot by footballer David Beckham in 2004. (Right) Comment on the snow that hid the 2012 transit (courtesy: Al Nisbet/The Press).

Figure 30: Google doodle that appeared on the search engine's front page for the 2004 transit (courtesy: google.com/doodles).

Figure 31: Garden designed by New Hall alumna Sue Goss for the 2007 Chelsea Flower Show (courtesy:www.behance.net, CC BY-NC-ND 3.0).

3.6 Novel Artistic Creations

Artistic creation went in novel directions in 2004 and 2012. Google honoured the 2004 transit with a doodle (Figure 30). The same transit prompted a series of radio talks (Adds, et al., 2007) while three years later a transit of Venus garden was presented at the Chelsea Flower Show by New Hall College, Cambridge (Figure 31). In Tasmania's Campbell Town, where a US Naval Observatory expedition had observed the 1874 transit (Orchiston and Buchanan, 1993; 2004), a transit of Venus sundial was installed in Valentine's Park. Devised by Tony Sprent of the University of Tasmania, the sundial was made from old farm machinery, including the wheels from a timber jinker, a tractor seat and gears from a cultivator. Also in Australia, the physics-trained artist, Tim Wetherell, crafted a steampunk sculpture which is now part of the University of Western Sydney's art collection (Figure 32).

Figure 32: Steampunk *Transit of Venus* sculpture by Tim Wetherell. Inside the portholes a piebald sphere carries the inscription *From where I stand the world looks black* on one side, and ... *the world looks white* on the other (courtesy: the artist).

In 2012 the Gold Reef City Mint in Johannesburg struck celebratory silver and gold medallions showing a sable antelope charging across the Sun on the obverse. The reverse pictures Mary Cummings, one of three women who observed the 1882 ingress from the Huguenot Seminary in Wellington, near Cape Town (Koorts, 2006). Celebratory medals were also produced by the Shanghai Brilliance Billiton company, with a very pert-breasted Venus. Seamstresses produced transit of Venus quilts and hats (Figure 33) and an historian of astronomy took the transit as her wedding theme (Figure 34; Solomon, 2013). The Manchester Digital Laboratory ("community space for … hackers, tinkerers, innovators and idle dreamers") re-enacted Madox Brown's Crabtree fresco (Figure 35, cf. Figure 8).

Nor were the arts of the table neglected. Transit foods from 2012 include a pizza with black olive slices delineating Venus' track, a black sesame dumpling in a strawberry ginger coulis, and cookies with a single chocolate chip.

Figure 33: Transit-inspired hat by Crafty Sod (courtesy: clickclicksnapsnap.wordpress.com).

Figure 34: Harvard's Wheatland Curator of the Collection of Historical Scientific Instruments, Dr Sara Schechner, weds Mr Kenneth Launie under a Transit of Venus chuppah (nuptial canopy). The inset shows Venus' track more clearly. Ken proposed during the 2012 transit, between first and second contact (courtesy: the bride and groom).

To wash down these delights, the Mishawaka Brewing Company in Indiana produced a *Transit of Venus Sunrise Ale,* while a *Venusian Ale* was brewed by The Livery in Benton Harbour, Michigan. Arkwright's Brewery in Preston, Lancashire, brewed transit ale and stout as part of the Preston Guild, a centuries-old celebration held every twenty years (Figure 36). California's Crew Wine Company bottled *Chasing Venus* wines made with sauvignon blanc and pinot gris grapes.

Exhibitions and exchanges took transits as their theme. An audio-visual installation was held in Hoole Parish Church under the guidance of Preston artist David Henckel and the aforementioned composer Julia Usher. Transit-themed exhibitions were held by the Northern Indiana Pastel Society in South Bend, and the Hornsby College Open Studio in Northern Sydney. A New Zealand-German 'Poetry Exchange' was organised by several organisations includeing the Goethe Institute and the New Zealand Ministry of Culture & Heritage. Three German and three New Zealand poets watched the 2012 transit from Tolaga Bay and then worked collaboratively, presenting their poems at the Frankfurt Book Fair four months later. Also in New Zealand, a transit time capsule was buried in the grounds of Tolaga Bay Area School, and the Royal Society's annual Manhire Prize for creative science writing took the transit of Venus as its theme. In *Fourteen*, Brian Langham, winner in the fiction category, sums up Le Gentil's tribulations (2012: 6):

Figure 35: MadLab director David Mee plays Crabtree in this 2012 re-enactment of Ford Madox Brown's fresco (courtesy: MadLab/flickr.com, CC BY-SA 2.0).

> ... he's been away like over 11 years, He finds his wife shacked up with a new bloke … his relatives have all ripped into and thieved off with

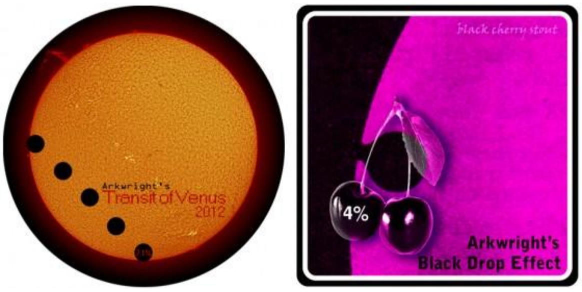

Figure 36: Beer labels from Arkwright's Brewery in Lancashire. (Left) *Transit of Venus* India pale ale. (Right) *Black Drop Effect* black cherry stout (courtesy: thetwohats.co.uk).

Figure 37: Mercury, god of commerce, holding his caduceus and wearing winged cap and sandals. From *The Apotheosis of Washington* fresco in the eye of the Capitol Rotunda, Washington, DC, painted by Constantino Brumidi in 1865. Mercury is handing a purse of gold to Robert Morris, financier of the War of Independence (courtesy: Architect of the Capitol).

> his property. The poor prick just couldn't get a break.

The examples given in Sections 2 and 3 are but a sample of works prompted by transits of Venus. Tobin (2013) illustrates some additional cases and there are unquestionably more to be found from deeper searching of the internet and elsewhere. Also, the choice of languages has been limited. De Freitas Mourão (2009) provides examples in Portuguese.

Figure 38: Cartoon of *The Transit of Mercury on the 7th of May 1799* (courtesy: Lewis Walpole Library, Yale University).

4 TRANSITS OF MERCURY

The Roman god Mercury (Hermes to the Greeks) was the child of Zeus and the nymph Maia. Besides being herald of the Gods to humans, Mercury was protector of shepherds, cowherds, thieves and orators, and patron of poetry, letters, weights and measures, inventions and commerce (Figure 37). Transits of Mercury are some eight times more frequent than those of Venus. Nor are they devoid of scientific interest. The first one observed, by Gassendi in 1631, showed an unexpectedly small value for Mercury's diameter, causing a rethink of planetary sizes (van Helden, 1976), while during the nineteenth century it was analysis of transits of Mercury between 1661 and 1848 that led Le Verrier to discover the anomalous advance of the planet's perihelion (Morando, 1995). More recently, satellite observations of the 1999 transit clarified the origin of the black-drop effect (Schneider, et al., 2004; Pasachoff, et al., 2005).

Transits of Mercury have prompted artistic production too, but the quantity is far less. The following is an almost complete list of the examples I have found.

In his poem *De solis ac lunae defectibus* ("On the Sun, Moon and eclipses"), the Dubrovnic-born Jesuit, Ruđer Bošković, wrote of the "... son of Maia [and] ... charming Venus", and noted that when at "...their orbital nodes, they should cover the Sun with a blackish veil ..." (Boscovich, 1760: 52).[27] Seventy years later, the French man of letters, Pierre Daru, referred to the first observed transit of Mercury in 1631 when he wrote "L'art mesura son orbe ..." (1830: 201):

> Science measured its orb and Gassendi's eye
> Followed its daring dash across the Sun.

However both poems refer to many celestial phenomena. They are not works inspired solely by a Mercurian transit. One poem in which a transit of Mercury holds a principal place is that by Anna Barbauld recounting watching the 1786 transit in the company of the Anglophile and flirtatious Baron de Stonne (Aikin, 1825: 161; McCarthy and Kraft, 2002). The poem's full title is *To the Baron de Stonne, Who had Wished at the Next Transit of Mercury to Find Himself Again between Mrs La Borde and Mrs B[arbauld]*:

> In twice five winters more and one,
> Hermes again will cross the Sun ...
>
> But changed mortals hope in vain
> Their lost position more to gain ...[28]

Overcast weather during the 1868 transit prompted the aforementioned photographer, Hermann Krone (1874: 9; my English translation), to pen subtle verses that end:

> When the sky brightens, I'll already be gone –
> You won't catch me, not this time!

Perhaps it was the same transit, without clouds, which inspired Eta Mawr (1870: 149):

> Speck on the Sun's resplendent eye –
> What eyes are lifted here.

In this century, the Romanian cosmopoet, Andrei Dorian Gheorge, incorporated the 2003 transit in his poem *Mother and 2003* (2003):

> May 7th. The transit of Mercury across the Sun
> like a slow and dark meteor in the light.

The Transit of Mercury on the 7th of May 1799 is the legend on a cartoon by John Eckstein which appears to be mocking astronomers' and the public's interest in the transit, as indicated by the monkey looking through a bottle (Figure 38).[29] The owl is presumably the symbol of Athena, representing knowledge. One can imagine that observing the transit reflected in a bowl of punch was one way of reducing the Sun's brightness. Perhaps the imbibing cleric is the Astronomer Royal, the Reverend Dr Nevil Maskelyne. Certainly, the arched eyebrows and prominent dimpled chin concord.

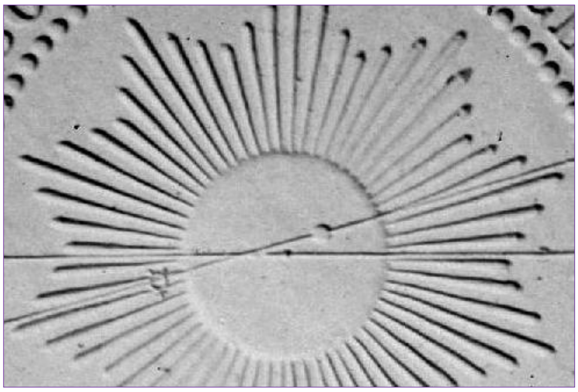

Figure 39: Detail from the seal of the Royal Philosophical Society of Glasgow approximating the track of Mercury across the Sun in 1802. The size of the planet is greatly exaggerated (courtesy: royalphil.org).

The Royal Philosophical Society of Glasgow first met on the day of the next transit of Mercury, in 1802. The event is recorded in the Society's seal (Figure 39). A century later the Italian futurist painter, Giacomo Balla, produced several drawings and oils inspired by the 1914 transit (Figure 40). The same theme has been broached more recently by the Georgia-based painter, Sid Smith (www.sidsmithart.com).

Figure 41 shows a *Punch* cartoon dating from 1938 (a transit of Mercury had occurred the previous year). It shows Sir John Reith (later Lord Reith) at the moment when he suddenly gave up being Director-General of the British Broadcasting Corporation to become Chairman of Imperial Airways. Mercury, as a messenger, obviously incarnates the BBC. As for "PPC", which stands for "pour prendre congé", it was evidently still usual to leave one's card so inscribed when leaving town. The grandiose classical pose is characteristic of the cartoonist, Sir Bernard Partridge, who was 76 years old at the time.

A flurry of creation followed the transit on 8-9 November 2006, some of which is illustrated by the thumbnails in Figure 42. The 2006 transit was also the inspiration behind the name of the Tucson-based alternative rock band *Mercury Transit* (2011; Figure 43).

The choice of Mercury over Venus in Eileen O'Hely's children's book *Penny in Space* (2009: 170) lends verisimilitude to the narrative:

Figure 40: Thumbnails of four versions of *Mercurio transita davanti al sole* by Giacomo Balla (after: www.italianfuturism.org and, from left, Casa Balla, Philadelphia Museum of Art, MUMOK, Peggy Gugenheim Collection).

Figure 41: *Punch* Transit of Mercury cartoon commenting the departure of Sir John Reith, Director-General of the BBC, to become Chairman of Imperial Airways (Partridge, 1938) (courtesy: David Miller).

> '... Can anybody guess which planet is transiting this afternoon?'
> 'Venus,' said Colin.
> 'I'm sorry, Colin. It's the other one,' said Ursula Major.

The Californian contemporary jazz musician, Bruce Anderson, produced a snappy *Transit of Mercury* track (ca. 2009). Wife-and-husband choreographer-and-writer Sally Bomer and Robert Lawson created the musical *The Transit of Mercury Across the Face of the Sun* which centres on a man with a neurological condition (e.g. Diaz, 2010). And finally, the Californian gay poet, D.A. Powell, has penned a *Transit of Mercury* poem which makes reference to the difficulty of catching a transit – or a lover (2012: 89):

> Run, brief page, lest I should catch you.

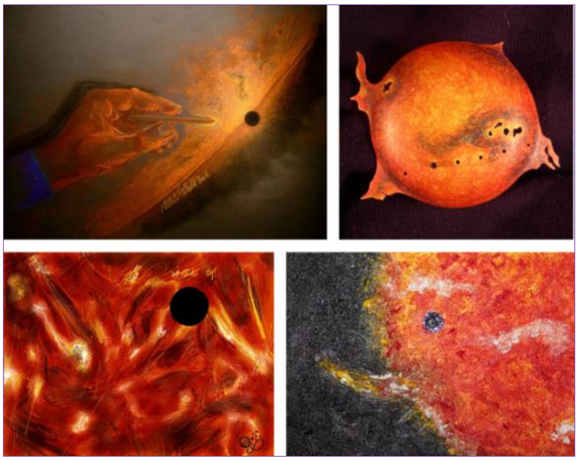

Figure 42: Thumbnails of internet art subsequent to the 2006 transit of Mercury. From top left: *Hand Drawn Transit* by Mark Seibold, chosen for NASA's Astronomy Picture of the Day on 17 November 2006; a brass pin-head decorated by Ontarian Jeff Polzin which won an art competition organised by the website spaceweather.com; a work on paper by Peter Lakenen inspired by a scene in the film *Sunshine* (released in 2007) in which the crew of the spaceship *Icarus* watch a transit of Mercury; an oil painting by DEC.

5 DISCUSSION

Some general remarks are in order before attempting to draw some conclusions from the plethora of creations detailed in the previous sections.

First, art inspired by astronomy is a subject of current interest, as indicated by the series of International Conferences on the Inspiration of Astronomical Phenomena, beginning with INSAP I in 1994 and now reaching INSAP VIII.

Second, we may be surprised by Horrocks' and Bošković's poems, but it should be noted that expressing scientific results in poetry was common at the time, and indeed into the eighteenth century (Horrocks, 2012).

Third, not all comments on transits of Venus were positive. In the period following the French defeat at Sedan we can read (Zède, 1872):

> The French budget – what a Sisyphean rock! … We ask every reasonable man, is it absolutely necessary that in the vexed position in which France finds itself, we should be spending 300,000 francs to observe the transit of *Venus across the Sun*?

or (Acarin, 1876: 47):

> So let us subsidise the most important things … three-fifths of our people do not know how to read and write ... they have certainly remained indifferent to the transit of Venus, to the expeditions aiming to discover the North Pole ...

Fourth, if works from Australia and New Zealand seem over-represented, this may in part be due to the author's Antipodean links. But it should be remembered that after observing the 1769 transit of Venus, Cook went on to survey the coasts of New Zealand and Australia. Transits of Venus are an important element in the history of the European occupation of both countries.

Fifth, the corpus does not contain much 'lab lit', that is, writings that "... contain scientists as central characters plying their trade ... [but] tend to focus on the intricacies of scientific work and scientists as people." (Rohn, 2010). Luminet's book, which is more biographical than a novel, comes closest; in other works the intricacies of scientific work are incidental, while those based on Cook's expedition concentrate more on exotic locations and people than science.

Sixth, many of the creations are similar. Le Gentil and Cook are themes that have inspired several artists, and Émilie du Châtelet springs to mind as another science-related personality who has inspired multiple works: garage rock by The Voltaires (2008), plays by Giron (2010) and Gunderson (2010), and an opera, *Émilie,* performed in Lyon and Amsterdam (Saariaho and Maalouf, 2010). The similarity of the three short poems quoted in Section 3 has already been noted, and they are similar to the graphic by Doval reproduced in Figure 26. The compositional similarity of the *art pompier* in Figures 11-14 is striking, and they in turn resemble Chappe d'Auteroche's much earlier frontispiece (Figure 5). The reader will find other recurrent motifs, such as forests of telescopes (Figures 2, 12, 18, 38), or transits refusing to be seen. Some of these similarities are certainly independent inventions, but art, like science, often builds on what has gone before, and one can imagine that a cartoonist such as André Gill (Figure 18) had studied British satirical prints (Figure 17).

What is most striking, however, is the far greater number of works inspired by transits of Venus compared to those of Mercury. In addition, though there are many historical or commemorative works for transits of Venus (e.g. Figures 7-14, 25), there is none for Mercury, which is surprising since detection of the non-Newtonian advance of the latter's perihelion is surely one of the major results of nineteenth century astronomy. I suggest two causes for these imbalances. The first is that the general public has, historically, been more aware of transit of Venus observations because of the accessibility and immediacy of the final goal (determining the distance to the Sun), the heroism and romance of expeditions sent to far-off lands, and their great expense. Though most Venusian creations cluster around transit dates, there are a non-negligible number produced at other times which, I suggest, reflects the lasting impact of Cytherean transits on popular awareness. In contrast, creations spurred by Mercurian transits cluster close to actual transit dates.

Examination of the heritage reported in Sections 2 and 3 reveals the second and I believe more important cause for the greater artistic interest in transits of Venus. There is a preponderance of imagery of Venus personified as a young, voluptuous woman who is perhaps amorous or the subject of desire. The goddess of love and beauty wins hands down compared to the deity of cowherds and SI units. Sex sells!

Presenters of the night sky should therefore sex up their narrative. If the mythology embodied in the constellations provides possibilities for northern observers, La Caille's southern constellations of octants, clocks and air pumps have little connection with sex (except perhaps for the especially imaginative). However, themes can be found in the lores of indigenous peoples. Let me cite some examples from Māori mythology (Orbell, 1995; Leather and Hall, 2004).

In the creation legend, father Ranginui lies in carnal embrace with mother Papatūānuku. Their love-making is interrupted by their son Tāne, who pushes them apart to create the sky and the Earth. This myth has a particular resonance, I feel, for all parents who have been interrupted on a Sunday morning by their offspring.

Pare-ārau is associated with the planet Jupiter. Because she wanders from star to star, she is perceived as promiscuous, though it is not explained why the (presumably male) stars who enjoy her generosity escape this epithet. Another wanderer is Te Rā, the Sun. In the tradition of the Tūhoe tribe, Te Rā has two wives, Hine-raumati (the summer wife) and Hine-takurua (the winter one). In his course across the sky, Te Rā lingers at the declination of one, enjoying her company, before rushing to and then lingering at the declination of the other.

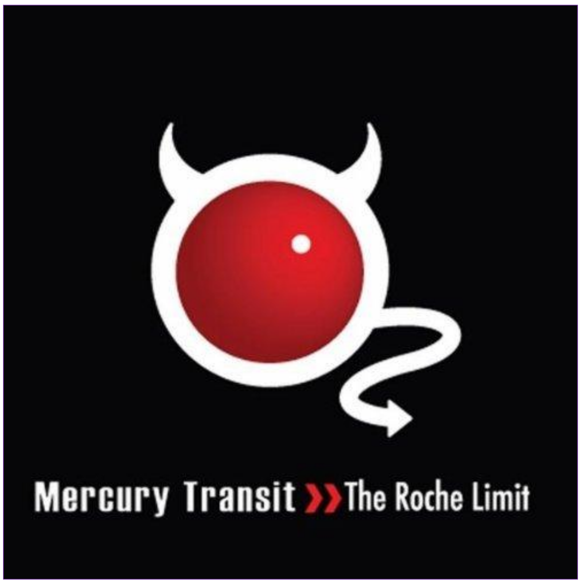

Figure 43: Album cover by the *Mercury Transit* rock band (2011).

Let me end with the kumara, or sweet potato. In one legend, Rongo-māui climbed to the sky to steal the kumara from his brother Whānui (the star Vega), placing it in his penis for the journey back to earth. In due course Rongo-māui's wife Pani-tinaku gave birth to her kumara children.

Narrators of the night sky should search out further saucy examples for their presentations!

6 NOTES

1. Purported observations of medieval transits are not convincing (Goldstein, 1969).

2. Horrocks died soon afterwards. His papers were published over twenty years later by the Polish astronomer Hevelius (1662) in an appendix. See Aughton (2004).
3. Roger Horrocks (2012: 117) notes that his namesake's original Latin lines are dactylic hexameters. Concerning Whatton's translation, he says "Although Whatton changes the Latin metre into iambic pentameters, and at times his translation is too free, he does convey the basic spirit of the original."
4. Rosenfeld (2011a) wonders whether the author, identified only as A. Williams on the title page of her book, might be Anna Williams, a member of lexicographer Samuel Johnson's household from 1748 to 1759 and then from 1765 until her death in 1783. She was not. A. Williams was Mrs Ann Williams, appointed postmistress of Gravesend in 1766 (British Postal Museum & Archive, POST 58). In the years following publication of her book, which was dedicated to the two Postmasters General of the time, she bred silkworms (Williams, 1784). Rosenfeld also questions whether Williams' poem refers to the Baja California expedition because the English-language account did not appear until 1778. The French original, however, appeared in 1772 (Chappe d'Auteroche, 1772) and was commented upon in Britain by (at least) *The Scots Magazine* in August 1773 where it is reported that "The sickness and mortality did not attack the astronomical party till two days after the transit." (M., 1773: 430). But news of Chappe's death reached London in late March 1770 and was widely reported (e.g. Yesterday arrived the Mails, 1770a; 1770b), so it seems probable that Mrs Williams could have learned of the expedition's sorry fate before publication of her poem in 1773.
5. Another grandiose engraving appears as a fold-out in *Punch's Almanac for 1875*. Hordes of astronomers observe a bare-breasted, Sun-occulting Venus followed by a retinue of women in the costumes of the various countries from which the transit was observed.
6. The American writer, Willa Cather, also made the transit of Venus into a night-time event in her short story *Two Friends* (Cather, 1932). In fact she was confused, and really was referring to the 1893 occultation of Venus. See letters dated 16, 21 and 23 August 1932 indexed at cather.unl.edu. Another garbled reference to a night-time "passage de Vénus" occurs in the Marquis de Sade's *Le Président Mystifié* (written 1787-88, but first published in 1926).
7. Banks' supposed continence in Hope's poem is contradicted by his affair with the Tahitian Teatea (Salmond, 2009: 155-156).
8. *Carmen* opened at the Opéra Comique on 3 March 1875 while *Le Passage de Vénus* opened two months later (3 May) at the Théâtre des Variétés (Meilhac and Halévy, 1875).
9. Zamacoïs' play was performed privately in May 1921 (Dans le monde, 1921) and on the radio ten years later (e.g. Les principales émissions françaises, 1931).
10. Lanoux's play was first broadcast on 9 October 1960.
11. Perhaps appropriately, the play was followed by one called *The Spot on the Sun* (Ambassadors Theatre, 1927b).
12. *Le Passage de Vénus*, a *Comédie-bouffe* in three acts, opened at the Théâtre Sarah-Bernhardt in Paris on 23 February 1928. The stated author is Georges Berr (Théâtre Sarah-Bernhardt, 1928); the Bibliothèque Nationale de France holds a programme and collection of press cuttings with the same attribution (call no. 8-RF-52082); and a review of the play lists him as the sole author (d'Ouvray, 1928). However, when the play was published after Berr's death, it was advertised as written by Louis Verneuil "ín collaboration" with Berr (Verneuil, 1944: 153, 157).
13. It should be noted that Louis XV, especially when young, was fascinated by astronomy, and witnessed the transit of Mercury in 1753 as well as both eighteenth-century transits of Venus (e.g. Wolf, 1902: 132).
14. Hueffer (1896: 349, 361) states that the model for Crabtree was C.B. Cayley, translator of Homer and Dante, who, when the studies were done in 1881, was 58 years old. Madox Brown's grandson, Oliver Hueffer, was the model for a child. Mrs Crabtree is portrayed knitting, "... a lawful Sunday recreation in anti-Puritanical days".
15. Hughes (2005) claims that the "'drawing" is that on page 150 of *Rosa Ursina*, but there are other engravings that Brown could have used as a guide, such as on the title page or on page 77.
16. The Lancashire Record Office holds a commentary on the painting by Napier Clark (PR3157/14/29), but I have not been able to examine this. Also possibly pertinent are letters from his daughter (PR3157/2/6) about the painting, which she gave to Astley Hall Museum and Art Gallery in 1962.
17. Van Roode (2012) notes that Horrocks used a Galilean telescope, which produces an upside-down but not left-right reversed image. Venus entered the Sun in the top left quadrant of the projected image, not the top right one as shown. The error originated with Hevelius (1662), who must have been confused, and when publishing Horrocks' account changed left, as stated by Horrocks, to right. Aspects of Brown's and Crowe's paintings

have been discussed by Hughes (2005).

18. The design is signed "P. Avril". This is Édouard-Henri Avril (1849–1928), who used the pseudonym Paul, which can lead to confusion with his brother, Paul-Victor Avril, who worked as an engraver. However, Beraldi (1885: 81) confirms that the pseudonymous Paul worked for *Le Monde Illustré*, where Figure 12 appeared, and notes his "... visible propensity to depict nudes."
19. In 1889 Dupain made a preparatory sketch for a painting for the east rotunda ceiling to commemorate Le Verrier's discovery of the planet Neptune, but the project was not completed. See expositions.obspm.fr/leverrier/Le-Verrier/reperes/dupain.html.
20. Unfortunately, Débarbat's reproduction is mirror reversed. Dupain's painting was exhibited at the *Salon* in 1886. One critic noted the skyline extending to the edge of the painting at the top, and interpreted this as a marine horizon. "Your sea, Monsieur Dupain, is going to gush down into the halls below," he wrote. "Beware of the water! The deluge is imminent." (Olmer, 1886: 54).
21. Dated 28 April 1883 and 24 April 1887 respectively.
22. A copy is held in the British Library; it was published anonymously, presumably in London, perhaps in 1774. The song equates a libidinous episode reported by Cook with the transit of Venus.
23. A more finished (and armless) photogravure of the Furniss sketch is presented on old.transitofvenus.org/misc.htm. It comes from the revised edition of Furniss' book (1888).
24. I have been unable to track down the source of this cartoon.
25. Presumably the author has feminized the Sun in order to strengthen the association of the mole with beauty.
26. The storyline derives from Philibert Commerçon, the naturalist aboard Bougainville's circumnavigation of the globe. However the transit of Venus connection is unhistorical because Bougainville returned to France three months before the 1769 transit. Rather it is Commerçon's assistant and lover, Jeanne Baré, who transits across the oceans, disguised during the voyage as a man.
27. I have translated Bošković's words from the very free translation into French published by de Barruel (1779: 111).
28. Barbauld's astronomy is wrong. Subsequent transits of Mercury occurred in 1789 and 1799, but not 1797.
29. There is some confusion over the identity of the artist. The British Museum website suggests he is probably the son of the sculptor and portrait painter Johannes Eckstein who died in Havana in 1817. An example of the engraving was sold by Bloomsbury Auctions in 2006 on which the full title was clearly printed, whereas it appears only as a ghostly shadow in the copy conserved at the Lewis Walpole Library (cropped in Figure 38, see the high-resolution view available via the Library's website). This suggests that the cartoon was sold again at the time of the 1802 transit, minus the 1799 date, which in turn supports the interpretation that it is the excitement surrounding the transit that is being mocked rather than some concurrent political event (cf. Figures 17, 18 and 41). From the catalogue entries, it appears that the 1799 date is not prominent on the examples of the engraving conserved at the British Museum, the Library of Congress and the New York Public Library.

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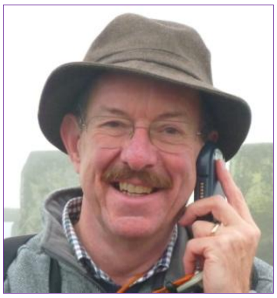

Dr William Tobin was for many years on the academic staff of the Department of Physics & Astronomy at the University of Canterbury, New Zealand, but has now retired to Brittany. He has published a highly-illustrated, comprehensive biography of Léon Foucault, the French adaptation of which was awarded the *Prix spécial du jury* of the *Prix du livre de l'astronomie–Haute Maurienne-Vanoise 2003.*

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A COMPARISON OF ASTRONOMICAL TERMINOLOGY, METHODS AND CONCEPTS IN CHINA AND MESOPOTAMIA, WITH SOME COMMENTS ON CLAIMS FOR THE TRANSMISSION OF MESOPOTAMIAN ASTRONOMY TO CHINA

J.M. Steele
Department of Egyptology and Ancient Western Asian Studies, Brown University,
Box 1899, Providence, RI 02912, USA.
E-mail: john_steele@brown.edu

Abstract: Mesopotamia and China have long traditions of astronomy and celestial divination, and share some similarities in their approach to these subjects. Some scholars have therefore argued for the transmission of certain aspects of Mesopotamian astronomy to China. In this paper, I compare four aspects of ancient astronomy in these cultures in order to assess whether there is any evidence for transmission. I conclude that the similarities between Chinese and Mesopotamian astronomy are only superficial and there is no evidence for the transmission of Mesopotamian astronomy to China.

Keywords: Chinese astronomy, Mesopotamian astronomy, celestial divination, mathematical astronomy, transmission.

1 INTRODUCTION

An interest in the movement and appearance of the Sun, Moon, planets and stars can be traced back in contemporary written sources to at least the Old Babylonian period in Mesopotamia (first half of the second millennium BC) and to the Shang Dynasty in China (mid to end of the second millennium BC). In Mesopotamia, Old Babylonian cuneiform tablets contain omens drawn from the appearance of lunar eclipses (Rochberg, 2006) and schematic lists of the length of day and night throughout the year (Hunger and Pingree, 1989: 163-164). In China, references to astronomical phenomena such as eclipses and comets appear on the so-called 'oracle bones' (Xu et al, 1989; Xu et al., 1995). Except for so-called 'star-clocks' and related astronomical material from ancient Egypt, no *contemporary* writings on astronomical subjects are known from other cultures this early.

Although cuneiform texts containing astronomical material are preserved from all periods in the second and first millennium BC, material is very scarce until the Late Babylonian period (ca. 750 BC to AD 100), with the vast majority of texts coming from the last four centuries BC. A similar situation holds for China: after the Shang Dynasty oracle bones we only have a very few documents containing astronomical records (principally the *Zhushujinian* 竹書紀年 "The Bamboo Annals" and the *Chunqui* 春秋 "The Spring and Autumn Annals") until the second century BC. After this time we have an extensive and continuous tradition of astronomical writings contained within the 25 *Zhengshi* 正史, generally referred to in English as the "Dynastic Histories", and many individual books on astronomical topics, down to modern times.

The plentiful supply of original sources, albeit often not yet translated into a Western language (but see Pankenier et al., 2008; Xu et al., 2000), makes Chinese and Mesopotamian astronomies attractive for comparative studies. Indeed, very soon after the decipherment of cuneiform astronomical and astrological texts had been undertaken by scholars such as A.H. Sayce, J. Epping, and F.X. Kugler, Western scholars began to compare Chinese and cuneiform astronomical texts. In particular, C. Bezold (1919) in an paper entitled "Sze-ma Ts'ien und die babylonische Astrologie" published in *Ostasiatische Zeitschrift* in 1919 compared Mesopotamian astrological omens with astrological portents given in the *Shiji* 史記 written by Sima Qian 司馬遷 around the turn of the first century BC. He claimed that there were striking similarities both of form and content and since the Babylonian sources he was using dated mainly to the seventh century BC put forward the proposition that the idea of a system of celestial divination originated in Mesopotamia and was transmitted to China. Bezold's frequently-cited study has recently been critically analysed by Pankenier (2014) who has shown that Bezold's claims cannot be supported.

In the following decades, other Western historians took up the idea that some Chinese astronomical and astrological ideas and techniques originated in Babylonia. For example, H. Chatley, writing about Chinese astronomy in a wide-ranging review paper entitled "Ancient Chinese Astronomy" published in the first volume of the *Occasional Notes of the Royal Astronomical Society* in 1939 remarked that:

> After the Bactrian contacts with China one might expect some transmission of astronomical ideas from the West. Although there is no

> record of such in the Chinese histories until the third century A.D., it is a fact that many foreign curiosities entered China from about 40 B.C., and we find in A.D. 25 Liu Hsin [Liu Xin] producing an astronomical treatise, *The Three Principle Calendar*, which far excels its predecessors for accuracy and system, and antedates Ptolemy's *Almagest* by over 100 years. (Chatley, 1939: 66).

Later in the same paper he continues

> To the historian of astronomy there are questions of originality and parallelism of development, or, alternatively, the importation of ideas from the West. Scholars are divided as to the extent of early foreign importations, but it seems quite certain that some ideas and a few figures filtered through to China from Chaldea and Greece in the fourth century before the Christian era, and again in the first century. After the introduction of Buddhism in the first century A.D. there can be no doubt as to the inflow of Indian ideas, but the community of notions as to the twenty-eight mansions between India and China in, say, the eighth century B.C. leaves little doubt as to indirect contact at an earlier date. (Chatley, 1939: 71).

Chatley's view is that there likely was transmission of astronomy from Mesopotamia to China and probably also from India to China (perhaps tellingly, he does not consider the possibility of transmission in the opposite direction). In particular, Chatley links one of the key developments in Chinese mathematical astronomy, the *Santongli* 三統曆 "Triple Concordance Calendar" devised by Liu Xin 劉歆 in the first century AD, with western influence. Recent scholarship has shown this system of mathematical astronomy to be firmly within the tradition of Chinese astronomy (Sivin, 1969). Nevertheless, further claims for Babylonian influence on Chinese mathematical astronomy have been made (Jiang, 1988).

Joseph Needham in the section of his monumental *Science and Civilisation in China* concerning astronomy also postulates Babylonian influence on the development of early Chinese astronomy. In particular he posits a Babylonian origin for the system of *xiu* 宿 'lodges' (Needham, 1959: 254-256). Again, more recent scholars have argued for an indigenous Chinese origin for the *xiu* system (Chen and Xi, 1993).

The year before Needham's section of astronomy was published, H.H. Dubs took a different view in an paper on early Chinese astronomy published in the *Journal of the American Oriental Society*. Dubs' conclusion (1958: 298) was that "… down to at least Han times, then, Chinese astronomy was largely an indigenous development." Nevertheless, works have continued to appear, both by Western authors and by scholars in China, which have claimed a Babylonian origin for parts of Chinese astronomy.

Evidence for the transmission of astronomy from one culture to another is often hard to prove. Even contemporary sources can be deceptive in claiming a foreign origin for an idea in order to add to its creditability. For example, in several Greek and Latin works we find scientific ideas and methods attributed to the antiquity of Egypt, when they are clearly nothing of the sort. The similarity of astronomical methods may or may not indicate a common origin. For example, very similar approaches to the use of cycles to predict eclipses (or rather the syzygies at which eclipses are *possible*), are found in Babylonian sources (Steele, 2000) and in Mayan codices (Lounsbury, 1978), but it is historically impossible that these are related. In order to propose the transmission of astronomical methods from one culture to another it is necessary to be able to demonstrate an historical context that points towards such transmission having taken place in other areas of learning. Furthermore, in cases where there is direct evidence of the transmission of astronomical knowledge, when this transmitted astronomy is assimilated into an existing astronomical tradition it inevitably changes, sometimes even at quite a conceptual level. For example, the Babylonian zodiac was a band through which the planets travelled, but the Greeks transformed it into a great circle on the celestial sphere (Steele, 2007). Clear evidence of transmission can often only be demonstrated for non-trivial numerical parameters, especially when they are given with high precision.

The purpose of this paper is to compare selected astronomical concepts, terminology and methods in Chinese and cuneiform sources and to consider whether such comparisons provide any evidence for the transmission of astronomy from Babylonia to China. I have chosen four topics to discuss: celestial omens, the language used to describe eclipses, systems of positional measurement in the heavens and mathematical astronomy.

2 CELESTIAL OMENS AND ASTROLOGY

Beginning in the mid-thirteenth century, Shang Dynasty oracle bones attest to the early adoption of divination as a practice in China (Figure 1). A heated poker would be inserted in a drilled hole on the back of a polished animal bone or turtle plastron producing a pattern of cracks. These cracks would then be interpreted by a diviner and the results of the divination, along with observed verifications, would then be recorded on the bone. Astronomical references in the oracle bones appear only in the observations that are the results of the divination. For evidence of the practice of interpreting events in the heavens themselves as omens, we must move into the first millennium BC.

The earliest extensive source for Chinese cel-

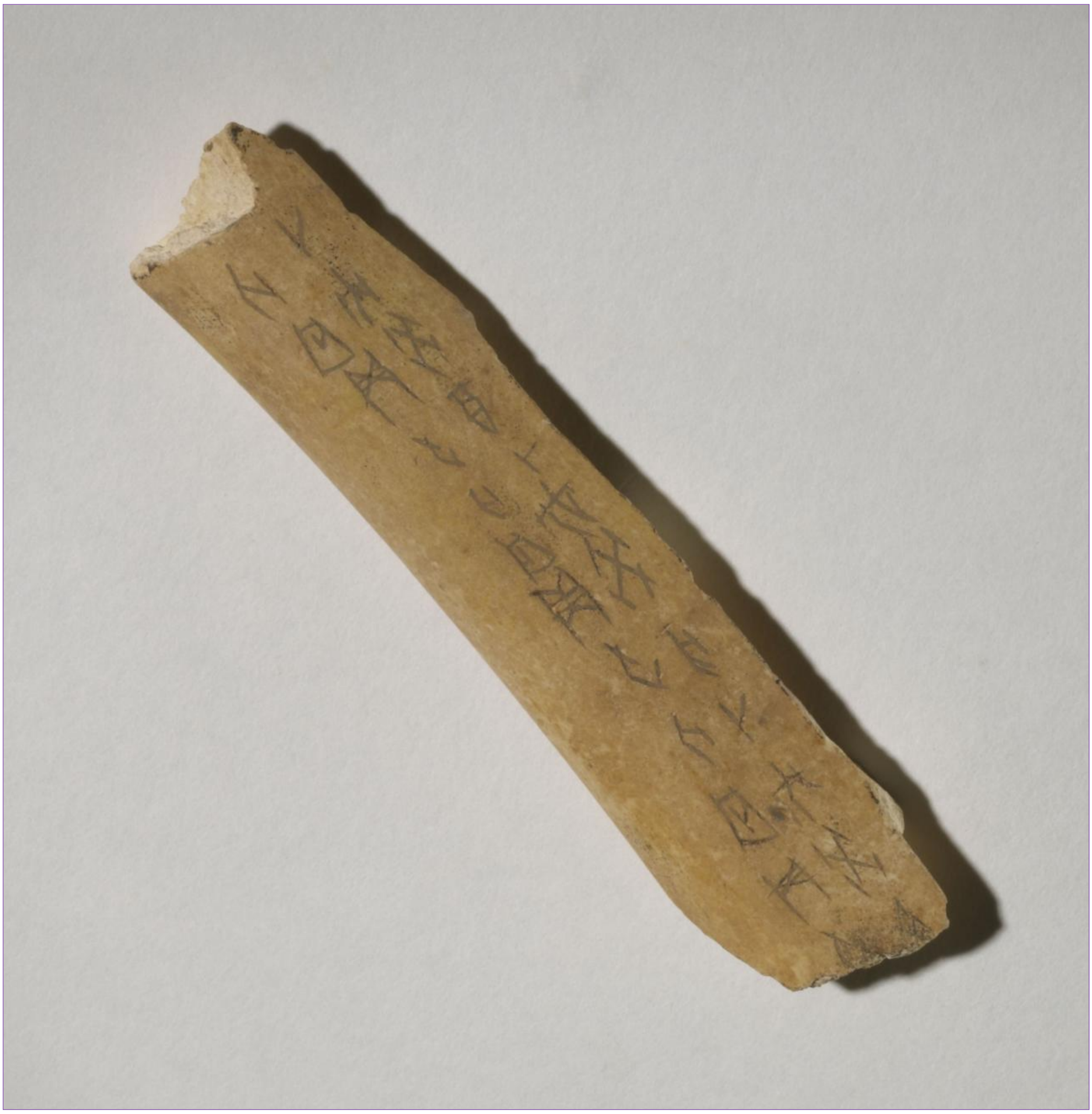

Figure 1: A Shang Dynasty oracle bone (© Trustees of the British Museum).

estial omens is the *Shiji* compiled by Sima Qian around the turn of the first century BC. Chapter 27 of the *Shiji* is a treatise on *tianguan* 天官 (‘Celestial Offices’; an annotated translation is given in Pankenier, 2013). Later dynastic histories usually call this subject *tianwen* 天文 (‘Heavenly Pattern Reading’). In modern Chinese *tianwen* refers to the subject of astronomy. In ancient and medieval China, however, the term is perhaps better translated as ‘observational astrology’ since it is the study of observations of celestial phenomena and their interpretation as portents. The investigation of the motions of the celestial bodies and the development of methods to predict the positions of the Sun, Moon and planets and their resulting phenomena such as eclipses, is part of the study of *li* 曆 ‘calendrical astronomy’, or what would be commonly called in the history of Western astronomy ‘mathematical astronomy’.

Although written in the seventh century AD, the *tianwen* treatise of the *Jinshu* 晉書 is typical of the style of the *tianwen* treatises in the *Shiji* and later dynastic histories. The whole treatise, Chapters 11 to 13 of the *Jinshu*, has been translated into English by Ho Peng Yoke (1966). It contains discussions of cosmological theory, astronomical instruments, stars and constellations, and accounts of observations of astronomical phenomena together with their astrological interpretations arranged by type of phenomena. For example, an observation of a solar eclipse in AD 260 is reported as follows:

> A solar eclipse occurred on a *i-yu* [*yi-you*] day [i.e., 22 of the sexagesimal cycle], the first day

> in the first month of the 5th year (of the same reign period [i.e., the reign period given above]. According to the prognostications of the *Ching Fang I* [*Jing Fang Yi*] whenever a solar eclipse falls on an *i-yu* day it presages that the Emperor will lose his power to his ministers and that the Minister of War will revolt against him. During the fifth month the crime of Ch'eng Chi [*Cheng Ji*] was committed. (*Jinshu* ch. 13; Ho, 1966: 155-156. Comments by the present author in square brackets).

Frequently, the author of the *tianwen* treatises will link an observed celestial portent with an event here on Earth. In the example just cited, the author links the observation of a solar eclipse with the assassination of the Emperor by Cheng Ji 成濟.

All celestial portents in China are directed towards the Emperor and his Government. An Emperor only governed through the mandate of heaven and it was believed that unexpected events in the sky were heaven's way of criticising the rule of the Emperor, warning him that his rule would be extinguished unless he improved his conduct. Crucially, only unexpected celestial events presaged real danger and so the ability to predict an event in advance removed much of the portent from its occurrence. Thus, more easily-predictable lunar eclipses were of far less astrological importance than their harder to predict solar counterparts, as is made clear in the *Shijing* 詩經 "Book of Odes":

> That this moon is eclipsed is but an ordinary matter; but that this sun is eclipsed—wherein lies the evil. (Karlgren, 1950: 100).

Because all astronomical portents were directed towards the Emperor, there was a clear link between astronomy and politics in China (Eberhard, 1957). The recording of astronomical events was very often politicised, as is shown in this example from the *Houhanshu* 後漢書:

> The sun was eclipsed in the 22nd degree of *tung-ching*. *Tung-ching* is the mansion [lodge] in charge of wine and food, the duty of the wife: 'It will be theirs neither to do wrong nor good, only about the spirits and the food will they have to think.' In the winter of the previous year, the (Lady) Deng had become empress. She had the nature of a man, she participated in and had knowledge of affairs outside of the palace, therefore Heaven sent a symbol. During that year floods and rain damaged the crops. (*Houhanshu* 27; Beck, 1990: 162).

From Mesopotamia we have two primary sources for celestial omens: compilations of celestial omens, principally the canonical omens series *Enūma Anu Enlil*, and omens cited by the scholars employed as advisors to the Neo-Assyrian Kings Essarhaddon and Assurbanipal. In both cases the omens are written as conditional clauses with the protasis generally preceded by the DIŠ sign, either to be read as a logogram for the Akkadian word *šumma* 'if' or, as suggested by Erica Reiner, as simply a paragraph marker. Linking the protasis and the apodosis is the conjunction *-ma*.

The tablets containing omen compilations are generally set out very rigidly so that the same signs lie under one-another in successive lines. This emphasizes the schematic nature of the omen compilations, in which all possibilities of a particular kind of phenomena are listed. For example, here is an excerpt from a collection of Venus omens edited and translated by Reiner and Pingree (the systematic nature of the list is easier to see in the cuneiform so I include an edition of the Akkadian text here with the translation):

> [MUL *dil-bat ina*] ITI.N[E KUR-*ha* ŠÈG.MEŠ (*ina* KUR) GÁL.MEŠ *ub-bu-tú* GAR-an]
>
> [MUL *dil-bat ina*] ITI.KIN KU[R-*ha* ŠÀ KUR DÙG-*ab*]
>
> [MUL *dil-bat ina*] ITI.DU$_6$ KUR-*ha* SA[L.KÚR.MEŠ *ina* KUR GÁL-MEŠ EBUR KUR GIŠ]
>
> [MUL *dil-bat ina*] ITI.APIN KUR-*ha* KUR [SAL.KALA.GA DIB-*bat*]
>
> [MUL *dil-bat ina*] ITI.GAN KUR-*ha* SU.K[Ú ŠE *u* IN.NU *ina* KUR GÁL]

> [If Venus rises in] Month V: [There will be rains in the land, there will be …]
>
> [If Venus rises in] Month VI: [The land will be happy]
>
> [If Venus rises in] Month VII: [There will be hostility in the land, the harvest will prosper]
>
> [If Venus rises in] Month VIII: [Hard times will seize] the land
>
> [If Venus rises in] Month IX: [There will be] famine [of barley and straw in the land]

> (Sm.1480+1796, 5–9; Reiner and Pingree, 1998: 146-147).

Just as we saw for the Chinese celestial portents, the omens apodoses of Babylonian celestial omens always refer to the country as a whole. The only individual mentioned in apodoses is the King, as his fate was tied to that of the land. Again, as in China, celestial omens were at times of major political importance. For example, astronomical omens are one of the most frequently-discussed topics in the correspondence between the Neo-Assyrian kings and their scholars, and some of the scholars tried to use the omens as the means to put forward their own political opinions. The scholar Bel-ušezib in particular frequently wrote letters to the King which go far beyond the mere interpretation of celestial omens. For example, after sighting a meteor, Bel-ušezib takes this as an opportunity to present his views about a forthcoming military campaign to the King:

> To the king of the lands, my lord: your servant B[el-ušezib]. May Bel, Nabû and Šamaš bless the king, my lord!

> If a star flashes like a torch from the east and sets in the east: the main army of the enemy will fail.
> If a flash appears and appears again in the south, makes a circle and again makes a circle, stands there and again stands there, flickers and flickers again, and is scattered: the ruler will capture property and possessions in his expedition.
> If the king has written to his army: "Invade Mannea," the whole army should not invade; (only) the cavalry and the professional troops should invade. The Cimmerians who said, "The Manneans are at your disposal, we shall keep aloof"—maybe it was a lie: they are barbarians who recognize no oath sworn by god and no treaty.
> [The char]iots and wagons should stay side by side [in the pass], while the [ca]valry and the professionals should invade and plunder the countryside of Mannea and come back and take up position [in] the pass …
> (LABS 111; Parpola, 1993: 89-90).

Bel-ušezib continues for many lines offering detailed advice on military strategy, none of which is based upon the omens that are ostensibly the subject of the letter.

The development of predictive astronomy in Mesopotamia did not reduce the importance of omens drawn from events that could now be predicted in advance with some degree of accuracy, such as eclipses (Brown and Linssen, 1997), as it did in China. Instead, there is a suggestion that the ability to know in advance that a particular celestial event was forthcoming enabled the Mesopotamians to make advance preparations for ritual responses to the omens.

Although Bezold (1919) claimed that there were direct parallels between a small number of omens found in the *Shiji* and in *Enūma Anu Enlil*, Pankenier (2014) has clearly demonstrated that most of these similarities are due to mistranslations of the Chinese text. Furthermore, even if there were a few similar omens, given that the Babylonian omen corpus contains several thousand individual omens, and that both Chinese and Babylonian celestial divination is primarily concerned with the state, it would not be surprising to find cases in which similar astronomical events predict things like "… the king should not go out …" or "… the army will suffer a defeat …", and there is no need to argue for a common origin to such basic omens.

A new form of astrology developed in Mesopotamia in the late fifth century BC (Rochberg, 1998): personal horoscopic astrology. Horoscopic astrology existed in parallel with the older *Enūma Anu Enlil* tradition of celestial omens in Mesopotamia during the late period. Here we do have clear evidence of the spread of an astronomical tradition from Mesopotamia to China, through Sanskrit intermediaries. The earliest horoscope yet found in an East Asian source is from Japan and for the year AD 1112, although we know several books describing horoscopes from the Tang Dynasty, for example the *Xiuyaojing* 宿曜經 which was translated from an Indian source by Bukong 不空 in AD 759 (Nakayama, 1966).

3 ECLIPSES

The earliest references to eclipses in China are found in the Shang Dynasty oracle bones dating from *circa* 1250–1050 BC. The character used to indicate an eclipse is an early form of *shi* 食 which carries the literal meaning 'to eat' (Xu, Yau and Stephenson, 1989). This character in its standard form continued to be used to indicate an eclipse of the Sun or Moon throughout Chinese history, along with its related homophone *shi* 蝕, formed by the addition of the radical 虫. The use of a character with the meaning 'to eat' suggests that the phenomenon of an eclipse was thought to be caused by something eating the Sun or Moon. Mythological explanations of eclipses along these lines are common throughout the world.

In China, the idea of a creature eating the eclipsed body influenced the terminology employed to describe eclipses and these became standard technical terms. For example, a total eclipse is usually indicated by *ji* 既. The literal meaning of *ji* is 'to complete, have done' and it marks a completed action (Schuessler, 2007: 298); it seems likely that *ji* refers to a total eclipse having been fully eaten (cf. Stephenson, 1997: 223). Other terms used by astronomers in describing eclipses are more prosaic: *kui chu* 虧初 'loss begins', *shen* 甚 'greatest' and *fu man* 復滿 'return to fullness' are generally used to refer to the beginning, maximum phase and end of an eclipse respectively.

In Late Babylonian astronomical texts eclipses are always referred to using the logogram AN.KU$_{10}$ to be read in Akkadian as *attalû*, 'eclipsed', and apparently always to be understood as a technical term. Related Akkadian words such as *adāru* 'to become worried, upheaval', have been shown by Goetze (1946) to be secondary, drawn from the association of eclipses with portended upheaval on Earth. There is no evidence of any mythological explanation for the language used to denote an eclipse. Eclipse myths did exist in Mesopotamia, however. For example, in the sixteenth tablet of the incantation series *utukkū lemnūti* seven demons are said to encircle the Moon during an eclipse, covering the Moon completely (Geller, 2007: 252). But this myth is not reflected in the language used to describe an eclipse.

Although eclipse mythology did not inform the choice of language used to describe eclipses in Mesopotamia, apotropaic rituals did. The period of maximum phase of an eclipse is customarily referred to in Late Babylonian astronomical texts using the logogram ÍR to be read as the Akkadian word *bikītu* ‘weeping, lamentation’ (Huber and de Meis, 2004: 14). This refers to the ritualised performance of drums and the reciting of laments during the eclipse. For an example of a text describing an eclipse ritual, see Brown and Linssen (1997).

4 POSITIONAL MEASUREMENT IN THE HEAVENS

Defining the position of a body in the heavens is an essential part of astronomy. There are many ways in which the position of a celestial object can be measured. For example, it is possible to measure the distance between one body and another body along the straight line that connects them; alternatively, one could measure the altitude of a body above the horizon and combine this with a measure of its azimuth along the horizon to produce a coordinate pair; or one could measure a pair of coordinates in the sky in some invisible reference system. The choice of one system of measurement over another may be a reflection of the cosmological framework in which one is working, or simply a matter of convenience, depending upon what instruments are available to help in the task.

Throughout Chinese history the main system for defining the position of a celestial object employed the *xiu* 宿 ‘lodges’. The *xiu* are a division of the sky into 28 zones defined by a determinative star. The zones are unevenly distributed around the celestial equator and fixing their widths was a continuing task for Chinese astronomers throughout the ancient and medieval periods. According to Pankenier (2013), the origin of the *xiu* arose from observations of the Moon’s daily motion, and prior to the 5th century BC there were only 27 lodges, 360/27 being closer to the lunar sidereal period. It was only after the 5th century that lodges were regularized to 28 so as to be evenly divisible into 4 cardinal palaces of 7 lodges each. By the Han period at latest the lodges were linked to the celestial equator, called *chidao* 赤道 ‘red road’.

The celestial equator was taken as the reference system for almost all of Chinese astronomy. Within the various calendrical systems of mathematical astronomy, solar, lunar and planetary motions were always calculated along the equator, although as early as the first century AD the problems with doing so had been noted by Jia Kui 賈逵 in a memorial submitted to the Emperor:

> Your servant has previously submitted a memorial pointing out that when Fu An and his colleagues used the Yellow Road [= the ecliptic] to measure the [positions of] sun and moon at half and full moons, they were mostly correct. But the astronomical officials, who all used the Red Road [= the celestial equator], were not in agreement with the sun and moon … The Red Road is the middle of Heaven, and is 90 *du* from the pole. It is not the path of the sun and moon, and [the effect alleged above] is because one has used such an incorrect standard to measure the sun and moon, and missed the real motions. (Cullen, 2000: 359-361).

Jia Kui is correctly pointing out that the Sun and Moon do not move along the celestial equator. The Sun moves along the *huangdao* 黃道 ‘yellow road’, the ecliptic, and the Moon and planets move along paths running above and below the ecliptic. Nevertheless, the ecliptic only played a secondary role in Chinese astronomy, and all movements were translated into (much more complicated) movements relative to the equator.

The terms used to refer to the equator and the ecliptic, ‘red road’ and ‘yellow road’, may have their origin simply in the coloured lines drawn on star maps during the Han period to indicate the equator and ecliptic (Sun and Kistemaker, 1995). The orbit of the Moon was often called *baidao* 白道 ‘white road’.

Measurements of positions in the sky used the angular measure *du* 度. A *du* was defined by equating the number of days in a solar year with one complete revolution of the heavens. Thus a *du* corresponds to about 360/365.25 degrees. The actual angular extent of a *du* varied at different periods as different lengths of the solar year were adopted in the different caledars. For example, in the *Sifenli* 四分曆 promulgated during the Eastern Han, there were 365 1/4 *du* in a circle, whereas in the *Xuanshili* 玄始曆 used during the Northern Liang, there were 365 1759/7200 *du* in a circle (year lengths taken from Yabuuti, 1963: 459).

The angular measure *du* was only used for measurements parallel to the equator. For other distances, such as those perpendicular to the equator, linear measures such as *chi* 尺 ‘foot’ or its multiple, *zhang* 丈 ‘10 feet’, were used (Cullen, 1996: 41). As we will see, a similar distinction between east-west and north-south measurements appears in Late Babylonian astronomy.

In contrast to its importance in Chinese astronomy, the celestial equator does not feature directly in Mesopotamian astronomy. Indeed, there is no term corresponding to the equator. However, the concept of the daily rotation of the sky and stars that cross a meridian at the same moment is found in several aspects of Mesopotamian astronomy, in particular with the concepts of *ziqpu* stars. Several texts contain lists of simultaneously culminating stars and/ or lists of the time intervals between the culminations of certain stars. A statement at the end of one *ziqpu* star list notes that

> [A tota]l? of 12 leagues of the circle of (those that) cul[minate] amidst the stars of the Path of [Enlil] [British Musuem 38369+ ii' 20–21; Horowitz, 1994: 92).

This implies that the full circuit of *ziqpu* stars corresponds to 12 *bēru* 'leagues' or 360 UŠ '(time) degrees', but does not refer to the celestial equator.

Figure 2: A Babylonian cuneiform tablet listing the zodiacal constellations in which the Sun is located each month (© Trustees of the British Museum).

In the Late Babylonian period, celestial positions are generally recorded in one of two systems: using distances *e* 'above' or SIG 'below' (and occasionally *ina* IGI 'in front of' or *ár* 'behind') one of the so-called Normal Stars used as reference markers in the sky; or as positions within the zodiac. Positions relative to the Normal Stars are normally given in units of KÙŠ 'cubits' and their subdivision SI 'fingers', where there were 24 SI in a KÙŠ during the Late Babylonian period (at earlier times there were generally 30 SI to a KÙŠ). As their name suggests, KÙŠ and SI are primarily spatial units, not angular measures. The directions 'above', 'below', 'in front of' and 'behind' correspond roughly to measurements in an ecliptical coordinate system. However, as the direction of motion of the Moon or a planet through the zodiac is more or less indistinguishable from running parallel to the ecliptic over short time-scales, it is quite possible that the Babylonians conceived of these directions as being along a planet's path and at right angles to that path (Swerdlow, 1998).

The movement of the Moon and planets through the sky takes place in a narrow region of stars in what are called 'zodiacal constellations'. In the early astronomical compendium MUL.APIN the eighteen constellations through which the Moon, Sun and planets pass are listed. By the fifth century BC, an abstract system of twelve equal length zodiacal signs had been developed out of these eighteen constellations (Figure 2). The position of the Moon, Sun or a planet could now be given as so many UŠ 'degrees' within a zodiacal sign, where each zodiacal sign contained 30 UŠ. The twelve zodiacal signs therefore make up 360 UŠ.

The zodiac was used in both observational and theoretical astronomy by the Babylonians. In the theoretical astronomical texts it functioned in a way similar to an ecliptical coordinate system, but there is evidence that the Babylonians themselves did not conceive of it in this way.

For example, although positions within zodiacal signs, equivalent to celestial longitudes, were given in UŠ, measurements up or down within the zodiacal band were generally given using the KÙŠ-system. The UŠ and KÙŠ systems were strictly convertible with 1 KÙŠ taken to be 2 UŠ, but making the choice to use two different units suggests that the Babylonians were not thinking in terms of a coordinate system, but of two separate measurements (Steele, 2007).

Although the Babylonians used the zodiac, they did not apparently consider the zodiac to be necessarily linked to the ecliptic. Indeed, there appears to be no concept of the ecliptic within Babylonian astronomy. Instead, we find that the paths of the Sun, Moon and planets are defined as being within individual paths (*mālak*) which have widths; for example in a procedure text concerning Jupiter:

> … in the width of the path … At first station ½ cubit it is high. At second station ½ cubit it is low. (British Museum 36680 + dupl.; Steele, 2005).

Each path has a middle known as DUR MÚRUB 'the ribbon/band of the middle', and upper and lower boundaries. For the Moon we have several texts which detail the upper and lower boundaries of its path, giving their distances above and below each Normal Star (Steele, 2007). The position of the Sun, Moon or planet could be given as the number of degrees within a zodiacal sign, and the height or depth above or below the middle of its path. This system is very close to an ecliptical coordinate system, such as that found in ancient Greek astronomy, but is conceptually and in some measure practically different.

5 MATHEMATICAL ASTRONOMY

Considerable effort was exerted in China and Babylonia to the development of mathematical astronomy. In early China, the tradition of mathematical astronomy is attested in a few manuscript sources such as the *Wuxingzhan* 五星占 and in the *li* 曆 'calendar' treatises of the dynastic histories. The main focus of early Chinese mathematical astronomy is the determination of the day of the beginning of each month and intercalation in the luni-solar calendar. Other phenomena calculated in Chinese mathematical astronomy are eclipses and the synodic phenomena and motions of the five planets. The same set of astronomical phenomena were the focus of Babylonian mathematical astronomy.

The main tool of both early Chinese and Babylonian mathematical astronomy is the identification and use of astronomical cycles. Cycles provide the means for predicting an astronomical phenomenon based upon a previous occurrence of that phenomenon. For example, the synodic phenomena of Venus repeat on approximately the same day in a luni-solar calendar, and at approximately the same position amongst the fixed stars, after 8 years. Furthermore, the knowledge that this phenomenon will take place 5 times during that 8 year period allows the mean date of all occurrences of this phenomenon by simply repeatedly adding 8/5 years onto the date of the first observation. This basic approach is used widely in early Chinese mathematical astronomy (Sivin, 1969) and in Babylonian 'goal-year' astronomy (Steele, 2011), both for the planets and for eclipses (Aaboe, 1972). However, the way in which the cycles are used differs in the two astronomies. In Chinese mathematical astronomy, the mean period between two successive phenomena derived from the cycle is repeatedly added onto an initial date, usually many thousands of years in the past, known as *liyuan* 曆元 'system origin' on which it is assumed that all astronomical cycles begin. By contrast, in Babylonia, there is no equivalent to the 'system origin' and each cycle operates separately, generally starting from a fairly recent observation or calculation of the phenomenon (Figure 3).

The subdivision of the synodic arc of the planets and the velocity of the planet in each part of its synodic cycle is a common topic in both Chinese and Babylonian astronomy. For example, the *Wuxingzhan* includes statements such as the following:

> When Great White [Venus] comes out in the west, it moved 1 *du* and 187 parts in a day. After 100 days its motion becomes slower, and in a day [it moves] 1 *du* so as to wait for it for 60 days. Then its motion becomes slower still, so that in a day it moves 40 parts, and in 64 days it goes in in the west. That is 224 days in all. (*Wuxingzhan* 132; Cullen, 2011b: 246).

This section describes the synodic cycle of Venus as an evening star (Cullen, 2011a). Beginning at its first evening visibility, it moves at a velocity of 1 *du* and 187 parts per day for 100 days, after which it moves at 1 *du* per day for 60 days, and then slows its motion further to 40 parts per day for 64 days before its last evening visibility. Similar discussions may be found in Babylonian astronomical texts; for example, in a Jupiter procedure text we read:

Figure 3: A Babylonian cuneiform tablet containing reports of observed and predicted lunar eclipses arranged in 18-year cycles (© Trustees of the British Museum).

> From setting (last visibility) to appearance (first appearance) it moves 0;12,30 per 'day'. After the appearance for 30 'days' it moves 0;12,30 per 'day'. [For 3 months it moves 0;64,40 per 'day', then it is stationary. For 4 months] it moves backwards 0;4,10 per 'day', [then it is stationary]. (British Museum 34081+ Obv. III 24–25; Ossen-drijver, 2012: 255).

Although there are similarities in the presentation of the schemes for the subdivision of the synodic arcs of the planets in the Chinese and Babylonian texts, on closer scrutiny the two systems are in fact very different. This difference arises in large part because the Chinese system concerns the motion of the planets through the 28 *xiu*, essentially an equatorial system, whereas the Babylonian texts concern the motion of the planets parallel to the ecliptic. Thus, the 'motion per day' of a planet refers to the motion measured in different directions in the Chinese and Babylonian systems, making it extremely unlikely that one system was derived from the other system.

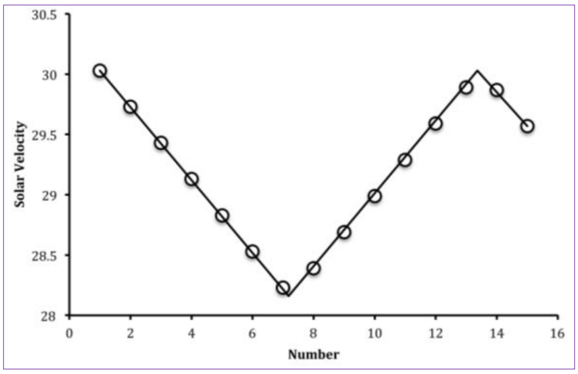

Figure 4: The Babylonian System B zigzag function for the sun's velocity along the ecliptic. Note that the independent variable is the number of the phenomena not the month of the year.

Jiang (1988) has noted apparent similarities between the Babylonian System B model for solar motion and the model for the Sun's motion found in the Chinese *Huangjili* 皇極曆 system of the seventh century AD. Both systems use piecewise continuous linear functions to represent the solar velocity: a linear zigzag function in the Babylonian System B model and a more complicated system employing several zigzag functions in the *Huangjili* (Figures 4 and 5). Jiang concludes that:

> The sudden appearance of these new methods such as the quadratic difference form and linear zigzag function in China in the 6th-7th centuries A.D. seem not to be accidental phenomena. For example, the 12 Babylonian signs of the zodiac appeared in Chinese documents of the Sui Dynasty (581-618 A.D.). Therefore, it is very possible that in the 6th century A.D. some Babylonian astronomical theories were known to the Chinese and accepted by traditional Chinese astronomy. (Jiang, 1988: 831).

Historically, it is not impossible that certain aspects of Babylonian mathematical astronomy could have been transmitted to China via India in the middle of the first millennium AD; along with the zodiac, the tradition of horoscopic astrology entered China by this route. However, the zigzag function is a very basic mathematical tool used to represent variable phenomena—perhaps the most basic—and we should not be surprised to find that it was developed independently in different astronomical traditions. There are further problems with the conclusion that the Chinese solar motion function is based upon the Babylonian System B function. First, the Babylonian function operates with a non-integer period whereas the *Huangjili* function is much simpler in employing an integer period. Secondly, the *Huangjili* function is not a true zigzag function varying linearly between a maximum and a minimum, but rather a piecewise continuous function made upon several linearly-varying sections (Jiang, 1988: Figure 2). It therefore seems very unlikely that there is any dependence of the *Huangjili* solar model on the Babylonian one.

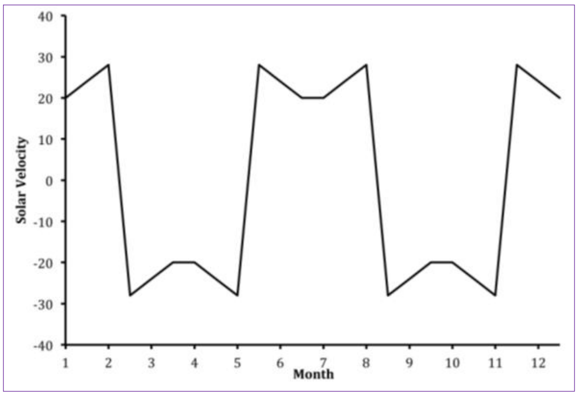

Figure 5: The solar velocity function in the Huangjili (based upon Jiang, 1988: table 2). Note that the solar velocity is calculated along the celestial equator, and the independent variable is the month.

6 CONCLUSION

The aim of this paper has been to compare a small selection of astronomical terms and concepts in Chinese and Mesopotamian astronomy. Although one must be cautious in drawing conclusions regarding the possibility of transmission of astronomy from one culture to another based upon this study, I believe a few remarks can be made. First, it is clear that independent traditions can be very similar, but that this is not evidence for the dependence of one tradition on the other. For example, historically and textually I see no evidence that Chinese celestial divination originated in Babylonia; nevertheless, in both cultures the heavens were used to provide portents, and in both cases these portents were at times exploited for political purposes. Similarly, mathematical astronomy both in Babylonia and in early China dealt with many of the same astronomical phenomena (eclipses, the synodic phenomena of the planets, and the determination of the lunar calendar) and relied upon the use of cycles, but the way that the cycles were used to predict these phenomena differed. Rather than providing evidence for the dependence of Chinese astronomy on Babylonian astronomy, these similarities, such as they are, suggest instead that there are a limited number of astronomical phenomena which are amenable to being modelled without the use of complicated mathematical analysis, and that there are only a limited number of ways to model them. The fact that similar phenomena were modelled using similar methods completely independently by the Mayans lends support to this conclusion.

Finally, there were clear differences between how the Babylonians and the Chinese conceived of celestial measurement—unsurprisingly, given their different cosmologies. Although this would not by itself preclude the transmission of astronomical knowledge from one culture to another, it would make it significantly harder and does, I think, place the onus on historians claiming the transmission of Babylonian astronomy to China to explain how this problem was overcome.

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John Steele has B.Sc. and Ph.D. degrees from the University of Durham. He is currently Professor of the Exact Sciences in Antiquity in the Department of Egyptology and Ancient Western Asian Studies at Brown University (USA). He serves on the Editorial Boards of the *Journal for the History of Astronomy*, *Isis* and the book series *Time, Astronomy and Calendars: Texts and Studies* and *Wilbour Studies in Egypt and Ancient Western Asia*. John's main research focus is into the history of Babylonian astronomy. He is the author of more than fifty research papers and author or editor of several books including: *Observations and Predictions of Eclipse Times by Early Astronomers* (2000), *Under One Sky: Astronomy and Mathematics in the Ancient Near East* (2002, co-edited by Annette Imhausen), *A Brief Introduction to Astronomy in the Middle East* (2008), *Living the Lunar Calendar* (2012, co-edited by Jonathan Ben-Dov and Wayne Horowitz), and *Ancient Astronomical Observations and the Study of the Moon's Motion (1691-1757)* (2012).

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A POSSIBLE HARAPPAN ASTRONOMICAL OBSERVATORY AT DHOLAVIRA

Mayank Vahia
Tata Institute of Fundamental Research, Homi Bhaba Road,
Colaba, Mumbai 400 005, India, and Manipal Advanced Research Group,
Manipal University, Manipal, Karnataka 576 104, India.
Email: vahia@tifr.res.in

and

Srikumar M. Menon
Manipal School of Architecture and Planning,
Manipal University, Manipal, Karnataka 576 104, India.
Email: srikumar.menon@gmail.com

Abstract: Astronomy arises very early in a civilisation and evolves as the civilisation advances. It is therefore reasonable to assume that a vibrant knowledge of astronomy would have been a feature of a civilisation the size of the Harappan Civilisation. We suggest that structures dedicated to astronomy existed in every major Harappan city. One such city was Dholavira, an important trading port that was located on an island in what is now the Rann of Kutch during the peak of the Harappan Civilisation. We have analysed an unusual structure at Dholavira that includes two circular rooms. Upon assuming strategically-placed holes in their ceilings we examine the internal movement of sunlight within these rooms and suggest that the larger structure of which they formed a part could have functioned as an astronomical observatory.

Keywords: Harappan Culture; Dholavira, astronomical observatory

1 INTRODUCTION

The Harappan Civilisation[1] is probably the largest and the most sophisticated of the Bronze Age civilisations in the world (Agrawal, 2007; Possehl, 2009; Vahia and Yadav, 2011). During its peak period, between 2500 BC and 1900 BC, it covered an area of more than 1.5 million square km and traded over several thousand kilometres to western Asia and the Horn of Africa (Wright, 2010). The Civilisation itself was settled along the banks and upper reaches of two major rivers east of the Thar Desert in what is now Pakistan and India (Figure 1).

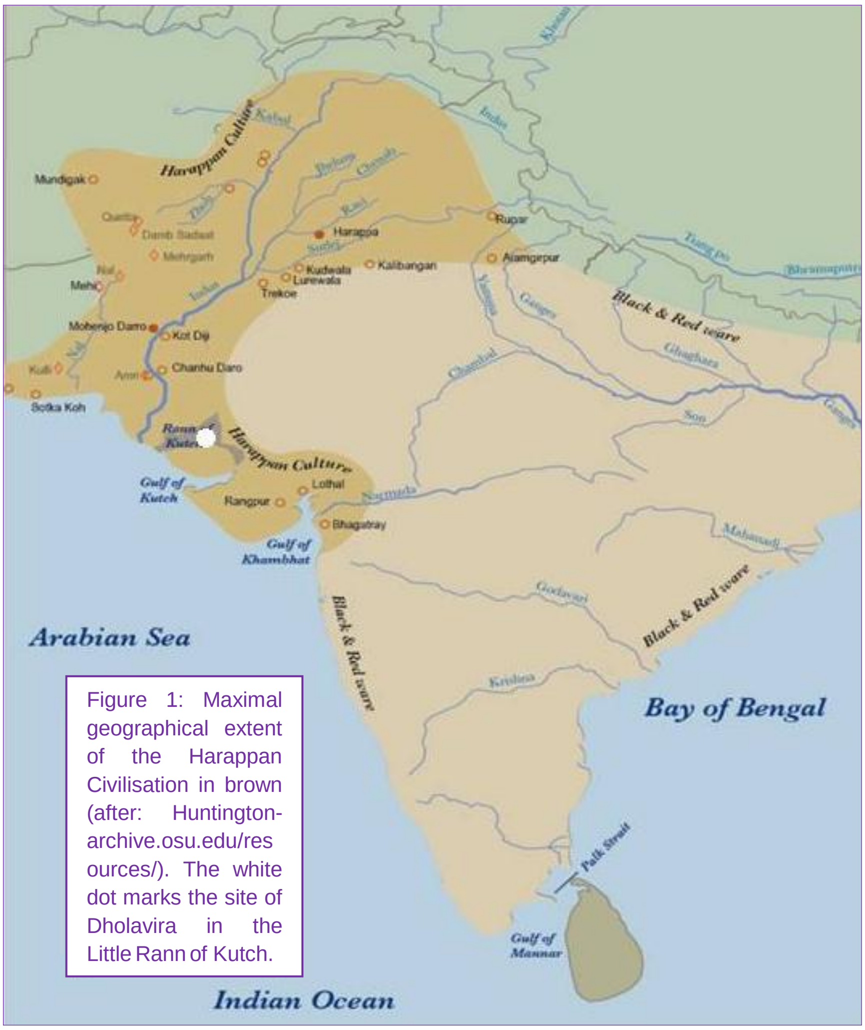

Figure 1: Maximal geographical extent of the Harappan Civilisation in brown (after: Huntington-archive.osu.edu/resources/). The white dot marks the site of Dholavira in the Little Rann of Kutch.

One of its most interesting features is several large and medium-sized settlements in the present-day Gujarat region in what is called the Kutch (Chakrabarti, 2004; Rajesh and Patel, 2007). Studies of the sites in the Kutch region suggest that the Little Rann of Kutch was covered with water with a few scattered islands. Several Harappan settlements have been found along the higher points in this region reinforcing the idea that the sites in Gujarat were used as trading outposts from which the Harappans traded with West Asia. This is further reinforced by the nature of the settlements, ports and industries

Table 1: Dimensions of Dholavira (after Danino, 2010: 198).

Location	Measurements (meters)	
	Length	Width
Lower town (entire city)	771.1	616.9
Middle town	340.5	290.5
Ceremonial ground	283	47.5
Castle (inner)	114	92
Castle (outer)	151	118
Bailey	120	120

found in this area. Several of these were urban centres, but in addition there were villages, craft centres, camp sites, fortified places etc. (see Ratnagar, 2006).

2 DHOLAVIRA

The largest Harappan site in this region of Gujarat was the city of Dholavira (Bisht, 1999), which was on the banks of two seasonal rivulets, and close to a port from which extensive trading is believed to have occurred.

Dholavira was divided into several functional sectors, in keeping with what has been found at other Harappan cities of this period (Bisht, 2000; Joshi, 2008), and Figure 2 shows a town plan, while dimensions of different parts of the city are listed in Table 1.

For the purpose of this paper, the area of interest is the region referred to as the 'Bailey' in Figure 2, which lies immediately to the west of the Citadel.

2.1 The Bailey

In the Bailey region of the city is a structure with a plan-form that is markedly different from all of the other structures in the city and from Harappan plan-forms in general. It consists of the plinth and the foundations of what was probably a 13-room rectangular structure, which included two circular rooms. It is located west of the 'citadel' and is near the edge of the terrace forming the Bailey, which drops off to the west. The flat featureless horizons to the north, west and south are visible without any obstruction, while to the east the mound of the citadel obscures the horizon to a large extent. It is possible that buildings—of which only foundations are visible today—may have obscured the northern horizon to some extent when the city was occupied. The ground slopes down to the south, so it is unlikely that any structures would have obscured the southern horizon (assuming that they were all only single-storied).

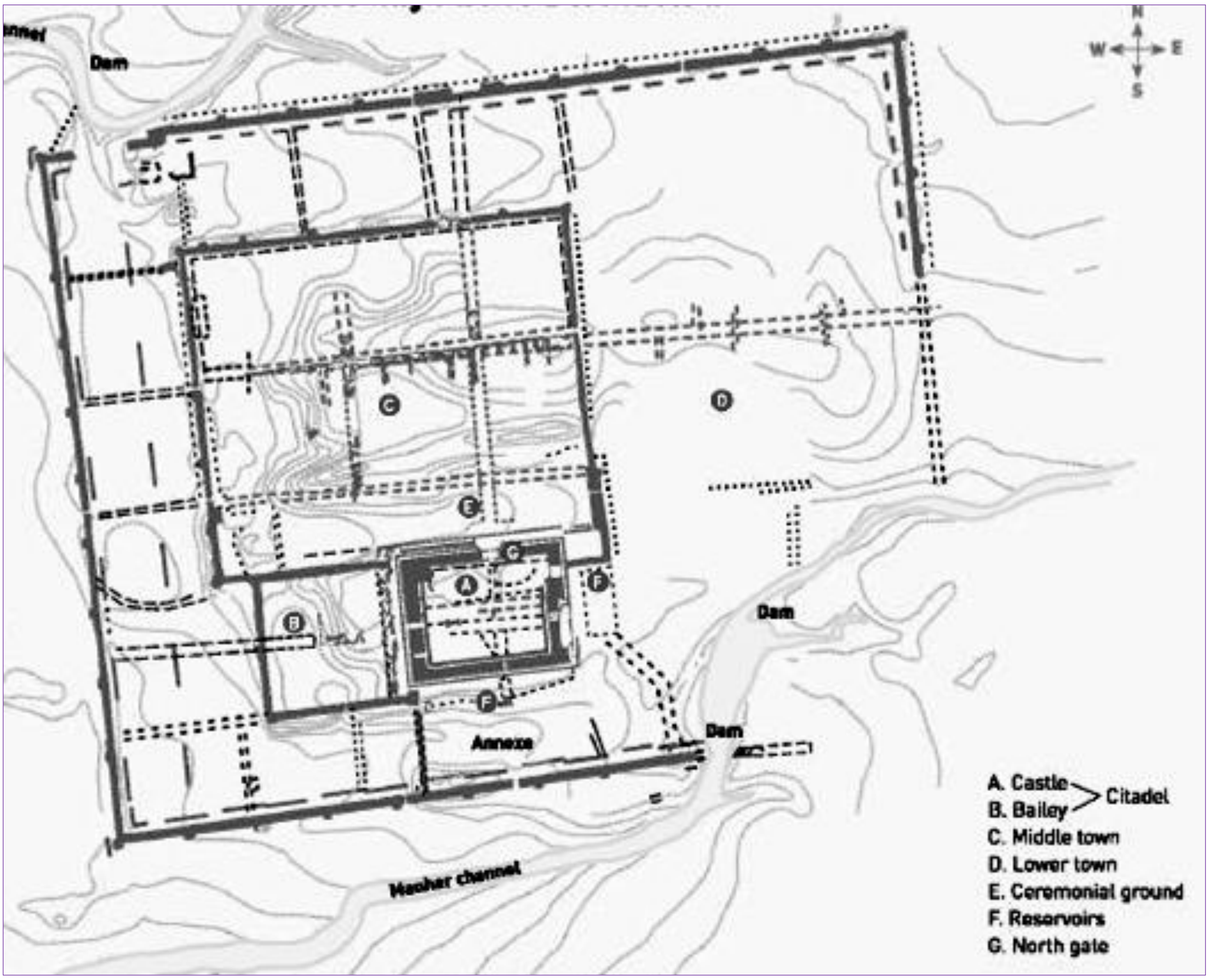

Figure 2: A plan of the site of Dholavira (from the web site of the Archaeological Survey of India, http://www.asi.nic.in/asi_exca_2007_dholavira.asp), showing the location of the 'Bailey' (B). To indicate the scale, the 'Bailey' measures 120 × 120 meters.

Figure 3: Photograph of the Bailey structure at Dholavira. There are two circular rooms, one to the right of the picture and the other in the centre. The one on the right has a central structure that faces due North.

In Figure 3 is a photograph of the Bailey. As can be seen, the structure consists of rooms of circular and square shape. Since most other residential and workshop buildings in Dholavira are rectangular, it generally has been assumed that the Bailey structure also dates to the Late Harappan Period or an even later period. However, we suggest that the Bailey structure dates to an earlier period, because of its unique combination of rectangular and circular rooms. Furthermore, we suggest that the two circular rooms were designed for non-residential purposes, because:

1) The rectangular rooms adjacent to the circular rooms had bathing and other utilitarian areas, but these were missing from the circular rooms.
2) Each rectangular room typically was connected to one or more other rooms, but each of the circular rooms had only one entrance.
3) Each of the circular rooms was far too small to have served as a residence.

It also is clear that the Bailey structure was built on top of an earlier Harappan structure. We suggest that the entire Bailey area was infilled and reconstructed at the peak period of the city, thereby acquiring its present shape.

2.1.1 Survey of the Bailey Structure

In December 2010 we surveyed the remains of the Bailey structure (see Figure 4), and noticed a number of unique features of the construction. Firstly, at three places where E-W oriented cross walls met a N-S oriented wall, they were offset by the thickness of the wall. Since the obvious common sense approach would have been to carry on the cross walls in the same line, this misalignment must have been deliberate (although the reason for this remains obscure).

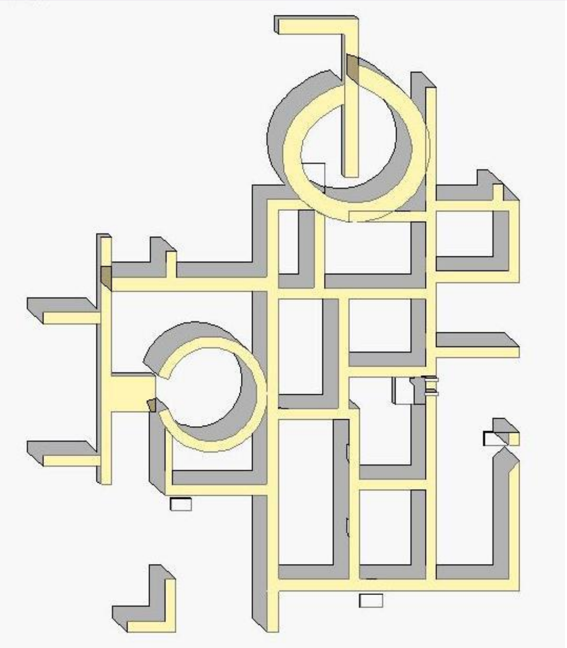

Figure 4: A plan of the Bailey structure at Dholavira showing the two circular rooms. North is to the top.

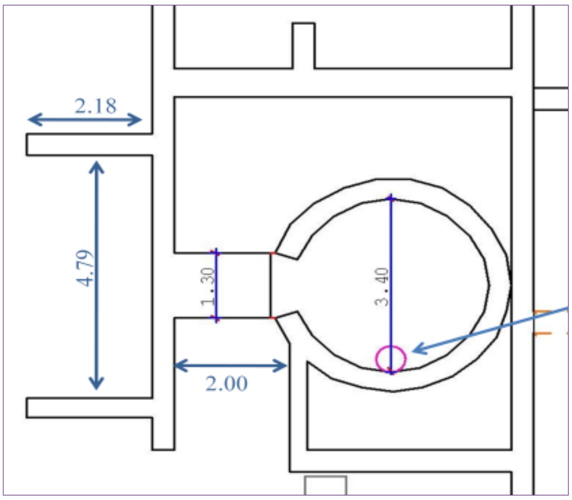

Figure 5: The ground plan and dimensions of the western circular room. All dimensions are in meters. The red circle marked by the blue arrow indicates the location of the presumed hole in the ceiling.

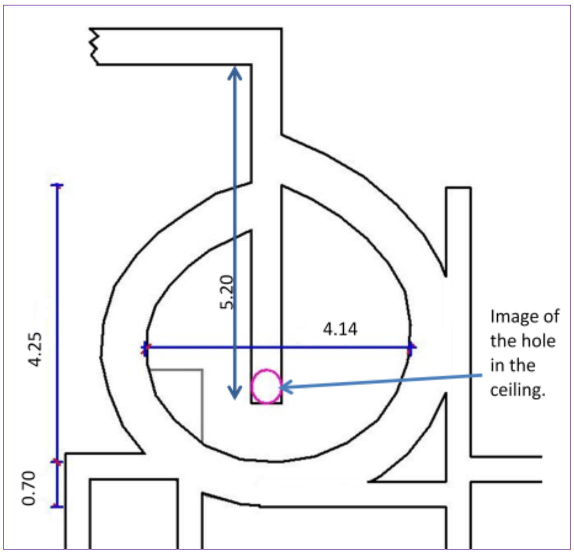

Figure 6: The ground plan and dimensions of the northern circular room. All dimensions are in meters.

As Figure 4 indicates, there are two circular rooms—one in the north and one in the west, and details of these are presented in Figures 5 and 6. The western room is perfectly circular with a mean internal diameter of 3.4 m and a wall thickness of 0.75 m, while the northern circular room is like a spiral in plan such that the line of the outer surface of its wall comes in line with its inner line at its northernmost point as it completes 360° (presumably without letting too much diffused light into the room). A 'straight wall' or walkway 0.75 m in thickness extends N-S into the room at this point for 4.0 m. A wedge-shaped segment 1.5 m on two sides and bounded by the curvature of the circular wall of the room is situated in the southwestern quadrant of the room.

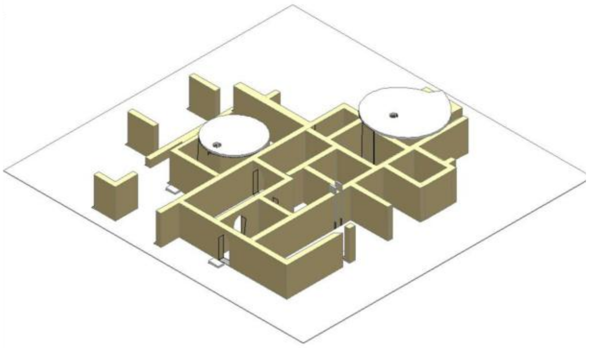

Figure 7: Showing the hypothetical reconstruction of the Dholavira Bailey structure with 2.5m high walls.

In the course of our investigation we noticed the following unusual aspects of the entire area:

1) The city of Dholavira is located at latitude 23.5° N, on the Tropic of Cancer.

2) While the city is aligned 6 ± 0.5° from true north, features associated with the two circular rooms pointed exactly to the west (270 ± 0.5°; see Figure 5) and the north (0 ± 0.5°; see Figure 6).

3) Unlike all other regions of the settlement, the land surface in the Bailey area rises from south to north with an inclination of nearly 23.5°, which corresponds exactly to the latitude of the site. Hence, for someone standing at the southern end of the Bailey, the North Pole would be at the top of the slope, and all stars seen would be circumpolar.

It is logical to assume that like other major early civilisations, the Harappans also were familiar with astronomy, and the precision with which the ramparts of major Harappan cities, including Dholavira, has been laid out testifies to the fact that they were well-versed in positional astronomy, sufficient to determine the cardinal directions (as pointed out by the principal excavator of Dholavira—see Bisht, 1999). So let us now investigate whether the Bailey structure could possibly have had an astronomical function.

2.1.2 Our Simulation

Assuming a wall height of 2.5 m (see Bisht, 2000; Danino, 2008; Joshi, 2008) for the Bailey structure[2] and entry to these northern and western circular rooms from the north and west respectively, we simulated the response of the rooms to solar geometry for the latitude of Dholavira. The assumptions and the simulation procedure are detailed below.

For the northern circular room we assumed that the entry point was via a break in the 2.5 m high circular wall where the 'straight wall' penetrates from the north. The width of the entry was taken as 0.50 m—which is the thickness of the 'straight wall'. The 'straight wall' was interpreted as a walkway just 0.60 m high. In keeping with our knowledge of Harappan architecture (ibid.) a flat roof was assumed for the room,[3] with a circular opening 0.50-m in diameter located directly above the termination point of the walkway (see Figure 7).[4]

Upon simulating the summer solstice day, the circle of light cast by the aperture in the roof slides down the circular wall in the west and across the floor and, at local solar noon, falls directly upon the extreme south portion of the walkway (Figure 8) before continuing across the floor and up the eastern portion of the circular wall. This is expected since we have deliberately positioned the aperture over the southern end of the walkway and the Sun is directly overhead at local solar noon at the time of the summer solstice for the latitude of Dholavira. But what is particularly exciting and caught our attention is that when we simulated the movement of the Sun at the time of the winter solstice, using this same geometry, the circle of sunlight travels down the N-W part of the circular wall and when it is on the top surface of the walkway, its northern edge grazes the bottom edge of the circular wall (see Figure 9). However, when this circle of sunlight moves off the walkway and onto the floor 60 cm below it shifts northwards and grazes the offset wall (since the imaging plane is now lower). This provides a possible explanation for the otherwise ‘illogical’ offset of the walls at this point (see Figure 6).

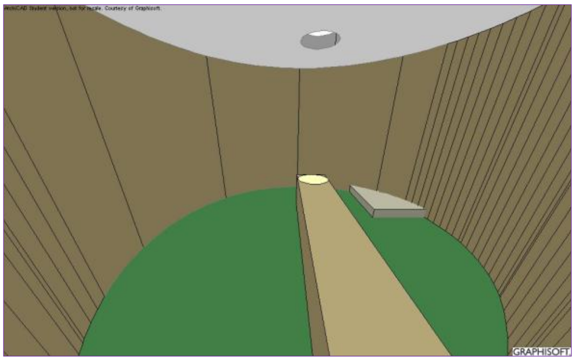

Figure 8: The circle of light cast by the roof aperture for the northern circular room at noon on the summer solstice. The view is from north looking towards the south.

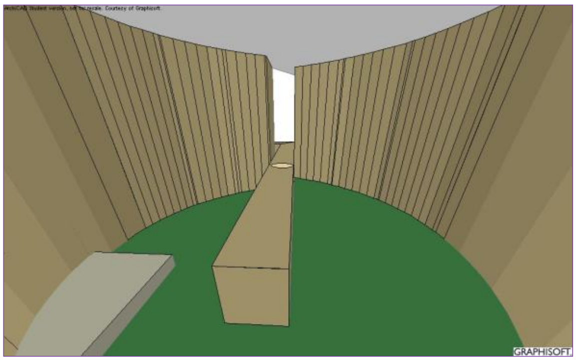

Figure 9: The circle of light cast by the roof aperture for the northern circular room at noon on the winter solstice. The view is from south looking towards the north.

Similarly, for the western room, we assumed that the entry was via a break in the 2.5 m high circular wall where the straight wall joins from the west. The width of the entry is taken as 1.30 m, which is the thickness of the straight wall. The straight wall is once again taken as a walkway just 0.60-m high. A flat roof was assumed for the structure, with a circular opening 0.50m in diameter at the southern extreme.

Upon simulating for the summer solstice day, the circle of light cast by the aperture in the roof slides down the circular wall in the S-W and is on the floor at local solar noon, its southern edge grazing the bottom edge of the southern wall before continuing up the S-E portion of the circular wall (see Figure 10). This is expected since we have deliberately positioned the aperture over the southern extreme and the Sun is directly overhead at local solar noon on the summer solstice at Dholavira, as mentioned earlier. Simulating the Sun’s movement on the day of the winter solstice and using this same geometry, the circle of light travels down the N-W part of the circular wall and when it is on the straight wall, its northern edge passes close to the bottom edge of the circular wall (Figure 11).

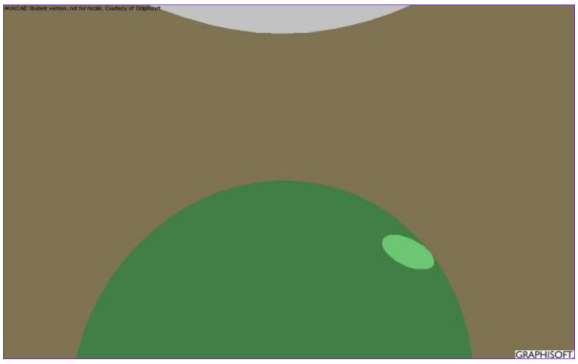

Figure 10: The circle of light cast by the roof aperture for the western circular room at noon on the summer solstice. The view is from west looking towards the east.

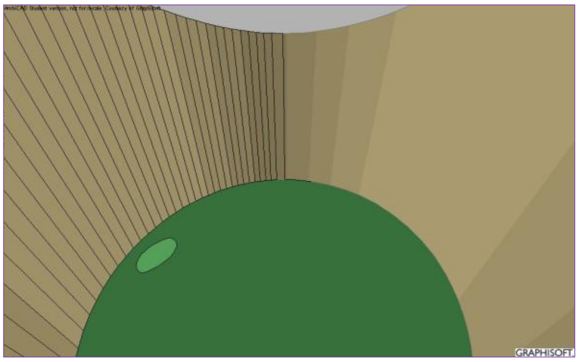

Figure 11: The circle of light cast by the roof aperture for the western circular room at noon on the winter solstice. The view is from west looking towards the east.

In addition, it is seen that the two sections of E-W oriented walls to the west of the west circular room frame the extreme points of the setting Sun as seen from the 1.30 m wide slit in the circular wall. In other words, the shadow of the northern of these walls touches the northern extremity of the slit at sunset on the summer sol-

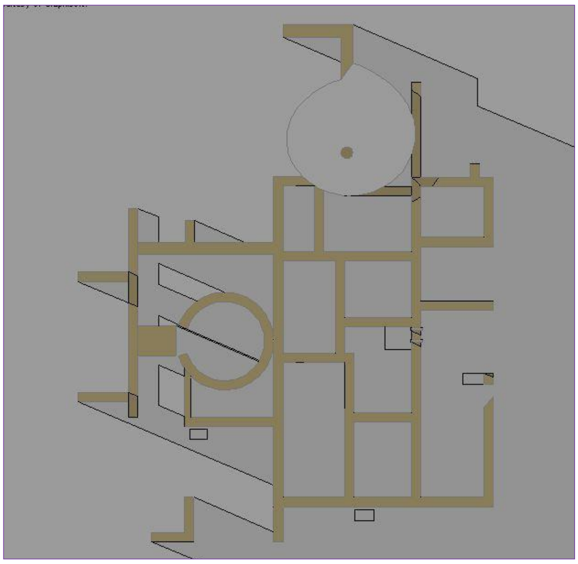

Figure 12: The shadows of the flanking walls (black lines) with respect to the entrance of the western circular room at sunset on the summer solstice.

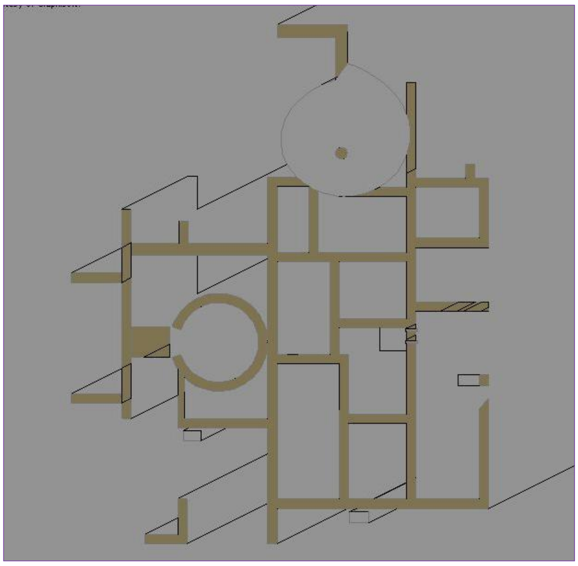

Figure 13: The shadows of the flanking walls (black lines) with respect to the entrance of the western circular room at sunset on the winter solstice.

stice day and that of the southern of these walls touches the southern extremity of the slit on the winter solstice day (Figures 12 and 13).

3 DISCUSSION

The city of Dholavira is located on the Tropic of Cancer. Thus the shadows of the Bailey structure would always be to the north of that structure, except at noon on the day of the summer solstice when the Sun would be at the zenith and no shadows would be cast. This is clearly something that the Harappan astronomers would have noticed.

The Bailey structure at Dholavira is unusual in several ways. It was built on what seems to be an intentional incline that points to the region of sky where stars always would be circumpolar. The structure also included two circular rooms, a rare occurrence for the 'rectangle-loving' Harappans. However, the workmanship of these two anomalous rooms and their inter-connection with neighbouring ones indicates that they all were contemporaneous. While structures erected by the Harappans normally did not have stone walkways leading to their entrances, these two circular rooms had such walkways. While the whole city was inclined 6° to the west of north, the two circular rooms in the Bailey structure had openings that faced due north and due west respectively. In addition, the west-pointing room had two walls to the west that were constructed so that their shadows would just touch the entrance to the room on the winter and summer solstice days.

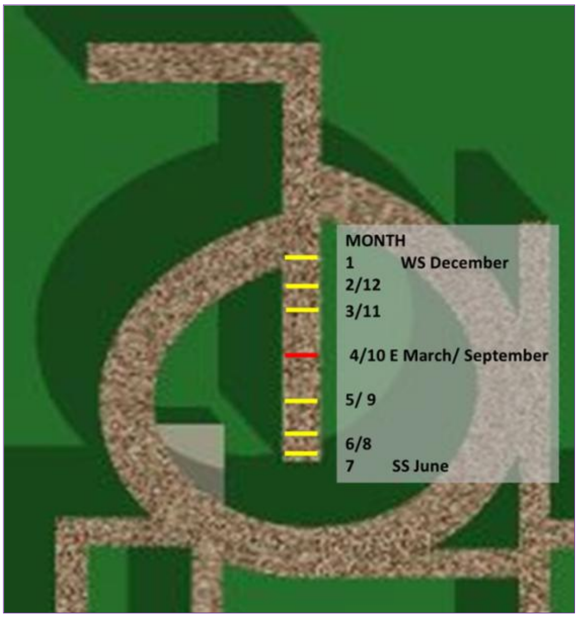

Figure 14: Diagram showing the way in which the northern circular room could act as a calendrical observatory.

In seeking to explain the function(s) of the two circular rooms we made assumptions about the superstructure, such as the height of the walls (2.5 meters), the presence of flat roofs and the presence of an aperture of a certain size (which was not crucial for our simulations) and positioning. Note that none of these parameters is at variance with what is currently known about Harappan architecture (e.g. see Joshi, 2008; Possehl, 2009).

Figure 15: Diagram showing the way in which the western circular room could act as a calendrical observatory.

Adopting these assumptions, we then simulated the movement of the circles of light cast by the holes in the ceilings of these two rooms. In the course of the year these circles of light clearly illuminated specific spots within these rooms, and important days in the solar calendar could easily be identified. The narrow beams of light entering these rooms (which had unusually narrow entrances compared to other rooms at Dholavira) would also have accentuated the movement of the Sun over the course of a year.

In the case of the northern circular room, what is interesting is that by positioning the aperture in the roof above the southern extremity of the walkway, the southern edge of the walkway marked the point where the circle of light was cast at noon on the summer solstice while a point on the walkway adjacent to the left hand circular wall marked its position on the winter solstice. But, in addition, if a marked wooden plank was laid along the walkway, the position of the Sun at noon would vary systematically throughout the year (see Figure 14), and in this way the room also could function as a calendrical observatory.

In the case of the western circular room, once again by positioning the aperture in the roof directly above the southern boundary of the circular wall, the extremes of the N-S diameter of the room marked the points where the circle of light was cast at noon on the solstices. Meanwhile, shadows cast by the two E-W oriented walls to the west of the entrance to the circular room just reached the entrance at sunset on the solstice days, also allowing these specific days to be easily identified. Meanwhile, if a N-S oriented marked wooden plank was laid across the room, this also would show the changing position of the Sun at noon during the year (Figure 15), so this room, too, could serve as a calendrical observatory.

4 CONCLUDING REMARKS

It can be safely assumed that astronomers in the intellectually-advanced Harappan Civilization had detailed knowledge of positional astronomy. However, apart from some stray references (e.g. see Maula, 1984; Vahia and Menon, 2011), up to now there has been no positive identifiation of any structure or artefact with obvious celestial associations at any of the 1,500 or so known Harappan archaeological sites.

The Bailey structure at Dholavira may have been constructed specifically in response to the solar geometry at this site, and it is possible that the two circular rooms in the structure were designed for solar observations. If this supposition is correct, then this is the first identified example of a Harappan building that was used specifically for observational astronomy. We would argue, however, that other astronomical structures must have existed at major Harappan cities, but their design probably was quite different in that Dholavira was unique because of its location on the Tropic of Cancer. Archaeologists, therefore, should be on the look-out for unusual structures at other Harappan sites, structures that might otherwise be disregarded or dismissed as mere anomalies.

Finally, we should mention that since Dholavira was an important centre of trade and commerce, keeping track of time would have been crucial, but to date no structures that obviously served this purpose have been identified.

We hope that this speculative paper will inspire further research, and help us learn more about Harappan astronomy.

5 NOTES

1 The Harappan Civilisation sometimes is also referred to as the ‘Indus Civilisation’.

2. An arbitrary figure of 2.5 meters was chosen because in traditional architecture the height of the walls in hot regions like this usually ranges between 2.5 and 3 meters. However, this figure is not critical, as our simulations work equally well for wall heights of between 2.3 and 2.7 meters.

3. Flat roofs were assumed simply because Dholavira is in a hot dry region where people conventionally build houses with flat roofs of mud and thatch on rough timber supports. Moreover, drawings of Harappan houses in the literature show flat roofs. However, flat roofs are not critical for the simulations, so long as it was possible to cut holes in the roofs.

4. For the purposes of the simulations, the positioning of the holes in the roofs was critical given the latitude of Dholavira. However, the diameter of each hole was not critical, and in fact an east-west oriented slit rather than a circular or oval-shaped hole would work just as effectively. But given the widespread use of circular skylights in buildings in this region we persisted with the circular holes for our simulations.

6 ACKNOWLEDGEMENTS

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Mayank Vahia has B.Sc. and Master of Physics degrees from the University of Mumbai (India). He is currently a Professor at the Tata Institute of Fundamental Research in Mumbai. He has worked on several projects involving Indian satellites flown on Indian, Russian and American missions to study high energy emission from the Sun and other objects. He has more than 200 publications in most of the major journals in astronomy and astrophysics as well as computer science. Mayank is a member of the IAU Commissions 41 (History of Astronomy) and 44 (Space & High Energy Astrophysics). For the past six years he has been researching the origin and growth of astronomy in the Indian subcontinent and has published about 30 papers on the subject, several of which have appeared in earlier issues of this *Journal*.

Srikumar M. Menon is an architect with a B. Arch. degree from University of Kerala, India. He has a Ph.D. in archaeoastronomy from Manipal University. He currently teaches in the Faculty of Architecture at Manipal University, India. His research interests are prehistoric architecture of India and early temple architecture of the same region. He is the author of the book *Ancient Stone Riddles: Megaliths of the Indian Bubcontinent* (2013, Manipal, Manipal University Press).

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INDIAN ASTRONOMY AND THE TRANSITS OF VENUS.
1: THE EARLY OBSERVATIONS

R.C. Kapoor
Indian Institute of Astrophysics, Koramangala, Bangalore – 560034, India.
Emails: rck@iiap.res.in, rckapoor@outlook.com

Abstract: This paper, the first of two, is about sightings and astronomical observations of transits of Venus across the disk of the Sun made from the Indian region. The period covered in this first paper is from ancient times up to and including the 1769 transit. The sources of the information presented here range from some classical texts and historiographies to publications and records of institutions, and accounts by individuals. Of particular interest is the 1761 transit, which was observed from atop the Governor's house in Madras by the Reverend William Hirst, who made a significant observation. During ingress he noticed a nebulosity about the planet, which he attributed to the atmosphere of Venus, and this was duly recorded in his paper reporting the transit observation that appeared in the *Philosophical Transactions of the Royal Society* of London. However, in a recent analysis, Pasachoff and Sheehan (21012) have shown that it was not the Cytherian atmosphere that Hirst and other astronomers observed in 1761.

Keywords: transits of Venus; Indian observations of the 1761 and 1769 transits; discovery of Venus' atmosphere

1 INTRODUCTION

Transits of planets across the disk of the Sun are among the most fascinating phenomena in Solar System astronomy. As seen from the Earth, transits of only Mercury and Venus are possible. These held great importance in early telescopic astronomy when the transits, specifically of Venus, enabled astronomers to determine the solar, *p*,[1] with what was regarded as unprecedented accuracy, and thus establish the scale of the Solar System.

On the average, there are thirteen transits of the planet Mercury each century. If we refer to the transit predictions tables by Fred Espenak (2012), all transits of Mercury over a period of seven centuries, from 1601 to 2300 CE occur in the months of May or November. As the orbit of Venus (with a mean value 0.7233 AU) is much greater than that of Mercury (0.3871 AU), a transit of Venus is much rarer. In its course, Venus passes in between the Earth and the Sun and a line-up takes place every 584 days (the synodic period—the time between two successive inferior, or superior, conjunctions). However, a transit does not always occur since the orbit of Venus is inclined 3.39º to that of the Earth, so when a line-up takes place Venus is usually above or below the disk of the Sun. In the event that the line-up occurs at or very near a place where the paths cross, a transit will happen.

A transit is difficult to notice visually since the planets are much smaller than the Sun in angular dimensions. Venus (with a mean radius of 6,051.8 km) is not only larger than Mercury (at 2,437.6 km), but it is closer to the Earth at the time of its inferior conjunction. At that time, it has an angular diameter much larger than that of Mercury. Even then, compared to the ~31.5′ of the Sun (with a mean radius of 695,950 km), Venus subtends an angle of only about 1′, and while in transit appears as a small spot against the extremely bright disk of the Sun. This angular size is also at about the limit of detection by normal human eyes (for someone with 20/20 vision). There are numerous ancient claims, particularly from China, Japan and Korea, of sunspots visible to the naked eye (e.g. see Clark and Stephenson, 1978), but during a transit, Venus would only have been distinguished from a sunspot by its perfectly circular shape and its comparatively rapid motion across the Sun's disk.

Every millennium there are about twelve transits of Venus. Interestingly, these have a 243-year repetition, with two transits in December, eight years apart, followed 121.5 years later by two transits in June, eight years apart. There have been eight transits of Venus since the invention of the telescope. There was no transit in the twentieth century, following the last transit of Venus that took place more than 130 years ago, on 6 December 1882. In the twenty-first century, the first transit of Venus occurred on 8 June 2004, and this was followed by another on 5-6 June 2012; both were visible from India. In Table 1, below, is a list of post-telescopic transits.

Through the period 5000 BCE to 10000 CE, the Earth has witnessed or will witness 178 transits of Venus. A listing of literature on the various transits of Venus is available on van Gent's (2012) web-site. The map constructed by van Roode (2011) for the transit observations made from various locations on the Earth, and also the interactive Google maps of transits produced on Jubier's (2012) website, are excellent references of their kind.

This paper expands substantially on Kapoor (2012) and discusses early Hindu knowledge of planetary transits and possible naked eye observations of transits of Venus prior to 1631 before

Table 1: Historic transits of Venus (after Espanek, 2012).

	Transit Contact Times (UT)					Minimum	Sun	Sun	Transit	
Date	1	2	Greatest	3	4	Sep.	RA	Dec	GST	Series
	h m	h m	h m	h m	h m	″	h	°	h	
1631 December 07	03:51	04:59	05:19	05:40	06:47	939.3	16.912	–22.64	5.045	6
1639 December 04	14:57	15:15	18:25	21:36	21:54	523.6	16.738	–22.34	4.888	4
1761 June 06	02:02	02:20	05:19	08:18	08:37	570.4	04.957	22.69	16.988	3
1769 June 03	19:15	19:34	22:25	01:16	01:35	609.3	04.805	22.44	16.842	5
1874 December 09	01:49	02:19	04:07	05:56	06:26	829.9	17.056	–22.82	5.182	6
1882 December 06	13:57	14:17	17:06	19:55	20:15	637.3	16.881	–22.56	5.025	4

Figure 1: Outline map of present-day India showing Indian localities mentioned in the text. Note that Chittagong and the area on this map previously known as 'Islamabad' (not to be confused with present-day Islamabad in Pakistan) originally were in India, but they are now in Bangladesh.

briefly mentioning Horrocks' and Crabtree's observations of the 1639 transit. The remainder of the paper discusses successful Indian observations of the transits of Venus in 1761 and 1769. For Indian localities mentioned in the text see Figure 1. A second paper, about India-based observations of the 1874 transit (Kapoor, 2014), will be published in a later issue of this *Journal*.

2 PLANETARY TRANSITS IN THE HINDU ASTRONOMICAL WORKS (THE *SIDDHĀNTAS*)?

It may seem odd but Venus (or *Shukra*) in India is male. See, for example *SriGargaSamhitā* by Garga (100 BCE–100 CE, *SriBalBhadraKhanda*, 6:13: 373-375), where Shukracharya, in his attempt to woo a beautiful Jyotishmati in penance, claims to be the Guru of the demons, and a poet. In the *Purānas* (Indian mythologies), *Shukra* is similarly identified.

While discussing planetary conjunctions (*yuti*) many Indian astronomers have considered *bheda-yuti* (occultations) of planets, as the *Siddhāntic* (astronomical) texts by Vatesvara (b. 880 CE; Selin, 1997), Bhattotpala (also Utpala; 966 CE) and Bhāskarācharya (Bhāskara II; 1114–1185 CE) bear out. An excellent review of this subject is presented by Shukla (2000: Chapter 8). In the event of a *bheda-yuti*, the particular situation occurs when the longitudinal separation between the two planets becomes smaller than the sum of their radii, with the lower planet wholly or partially covering the disk of the higher planet. The situation is then treated as akin to a solar eclipse and the computation is made accordingly for contact, immersion, emersion and separation. In his *Brhat Samhitā* (505 CE, Bhat, 1986), the Ujjain (Figure 1) astronomer, mathematician and astrologer, Varāhamihira (Figure 2, 485–587 CE; Rao, 2005), devotes a chapter *Grahayuddha* ('planet wars' = Chapter XVII) to planetary conjunctions, which are classed as occultations, grazing incidences, etc. In the *bheda-yuti*, taking the Sun as the object being occulted and assuming the occulting planet as the Moon, Vatesvara, Bhattotpala and Bhāskarācharya describe an elaborate procedure for the computation that enables one to examine if an eclipse-like situation will occur, and to determine the time of the apparent conjunction.

The planetary sequence given by Āryabhatta (476–550 CE) in his work *Āryabhatiya* (499 CE) is as follows: Earth – Moon – Mercury – Venus – Sun – Mars – Jupiter – Saturn – Fixed stars. As distinct from a usual *bheda-yuti* which can be an extreme situation only, did astronomers also look at the more likely situation where the *higher* planet happened to be the Sun? To recall, Venus transited the Sun in Vateswara's time on 23 November 910 CE. The transit commenced in India during the night, but the event ended as the Sun rose at Ujjain, the egress phase only just completed. Indian astronomers knew the inclinations of the planetary orbits to the ecliptic, as the *Sūrya Siddhānta* (ca. 400 CE by an unknown writer, and a work in progress until as late as ~1100 CE) gives these. Comparative values of the inclinations, as fixed in the various *siddhāntas*, are available in Naik and Satpathy (1998: 37). The astronomers did not factor these into their computations since the magnitudes were small. The only inclination that mattered was that of the Moon with respect to the computation of lunar and solar eclipses (Somayaji, 2000: 181-182). If, in the course of computation and observation one found that *pātas* (nodes) exist and that with respect to the Sun a node is placed in longitude rather critically, a planetary transit situation could in principle be visualized. In order to have an exposure to a modern *Siddhāntic* procedure to compute planetary conjunctions, one may find Rao and Venugopal (2009) useful.

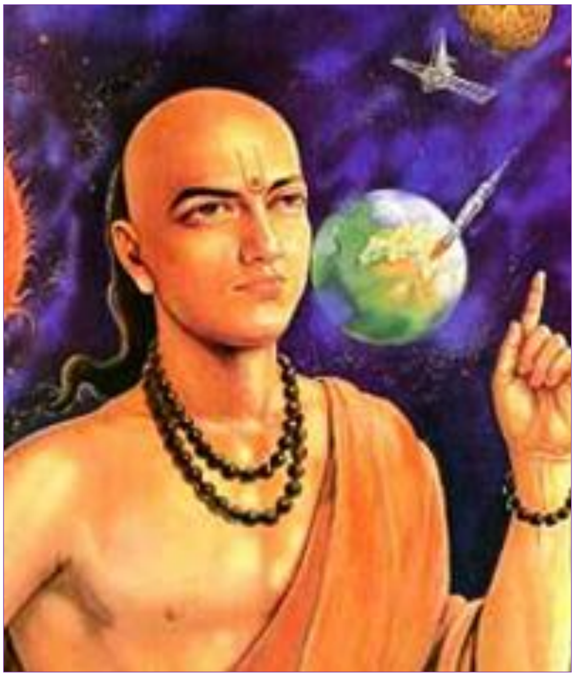
Figure 2: An artist's depiction of Varāhamihira (after indianetzone.com).

In at least two *Siddhānta* texts we find *planetary transits* are considered, and both in independent chapters. *Dhruvamānasa,* written in 1056 CE by the astronomer and mathematician Sripati Mishra (1019–1066 CE), is a text in Sanskrit devoted to computation of planetary longitudes and eclipses (see O'Connor and Robertson, 2000). This is the first Indian astronomical work where planetary transits also are considered. Pingree (2008a) lists the names of the chapters in Sripati's *Siddhāntaśekhara* where planetary transits are mentioned. Interestingly, Sripati was just 13 years of age when Venus transited the Sun on 24 May 1032 CE, but this transit was not visible from India. However, the next transit that occurred, on 22 May 1040 CE, was. Sripati's first work, *Dhikotidakarana*, on lunar and solar eclipses, was written in 1039 CE. Therefore, as someone working on planetary longitudes and latitudes, it is likely that he would stumble upon certain critical situations amounting to a transit by a planet. Recall that Sripati's period is soon after al-Bīrūnī (973–1048 CE) visited India (during 1019-1029 CE), although he may not have been aware of the latter and his works.

Venus next transited the Sun on 23-24 November 1153 CE., at a time when the great Indian mathematician and astronomer, Bhāskarāchārya (Bhāskara II, 1114–1185 CE), also lived. He authored a number of highly-acclaimed texts on mathematics and astronomy, such as *Siddhānta Shiromani* (composed 1150 CE). The transit would not be visible from India. However, anyone who traditionally computed mean and true motions of the planets and conducted observations to follow planetary kinematics, particularly around the times of heliacal rising and setting, and their conjunctions would know about the forthcoming inferior conjunction of Venus with the Sun (*astamaya* according to *Sūrya Siddhānta*). They also would have noticed that the paths critically crossed, as in the case of a solar eclipse. Even though Bhāskarāchārya gave a procedure for computing *bheda-yuti*, we do not have any commentary from him specific to a transit of Venus event (nor even on the spectacular-looking Halley's Comet, which appeared in 1145 CE).

King Vallālasena (Ballāl Sena; ascended the throne in 1160 CE; Vallālasena, 12th century: vi) deserves mention here for his great interest in astronomy. He was a learned man who made astronomical observations, determined winter and summer solstices and considered celestial phenomena, including comets, in his tome *Adbhutasāgara* that he began in 1168 CE. He died before he could finish it. The work was completed by his son, Lakshmanasena, the great military leader and ruler of Bengal (1122–1205 CE; ascended the throne in 1168; Vallālasena, 12th century: viii). *Adbhutasāgara* is composed along the lines of the *Brhat Samhitā* and draws from Garga, Vruddha Garga, Parāshara, Varāhamihira, Yavaneswara, Brahmagupta and *Sūrya Siddhānta*, and even from the *Purānas*, the epics *Mahābhārata* and *Vālmiki Rāmāyana* etc. (Vallālasena: ix; Prasad, 1956: 205). The *Adbhutasāgara* has a chapter on *Grahayuddha* (planet wars), and mentions Venus-Sun and Mercury-Sun conjunctions (Vallālasena, 12th century: 46) and the *ayana* points (solstices) that Vallālasena 12th century: 26) says he tested out himself. In the process, whether he encountered the extraordinary Venus-Sun inferior conjunction of 1153 CE we do not know. On the other hand, in the chapter on the Sun, he refers to situations where a hole occurs in the disk of the Sun when Mercury/Venus is positioned *below* it (Vallālasena, 12th century: 46-48). There are several stanzas devoted to hole(s) in the Sun with attendant ominous repercussions, but these were naked eye sunspots. Clark and Stephenson (1978) have examined ancient Korean and Chinese records that mention sunspots, and there are references to those seen during the period of interest here, namely in 1160 CE, 1171 CE, etc. A similar indication comes from Figure 1a in Vaquero (2007), which shows sunspot numbers peaking around this time. Therefore, when Vallālasena talks about holes in the Sun, he may have only been referring to sunspots.

Centuries later, in the times of the astronomer and mathematician Kamlākara (b. ca. 1610 in Varanasi; Pingree, 2008b), there were two transits of Venus, on 7 December 1631 (visible from India) and 4 December 1639. Kamalākara (1658) is well known for his book *Siddhānta Tatva Viveka* that he composed on the pattern of the *Sūrya Siddhānta*. In the various chapters, topics such as eclipses of the Sun and the Moon, mean and true motions of the planets, planetary diameters and distances and the heliacal rising and setting, etc., are dealt with. Chapter 11 considers the phenomenon of planetary conjunctions, and includes stanzas dwelling on planetary transits. Here, certain observations by him are appropriate in the context of the transit of Venus. In stanza 28 in the chapter titled *Bimbādhikara*, which deals with planetary diameters, Kamalākara asserts that

> I do not agree with the objection raised by certain learned people to the idea that Mercury and Venus create a hole-like appearance on the Sun from whom they acquire the brightness. (Rathnasree et al., 2012; their English translation).

Indian astronomers did not know that a transit of Mercury cannot be seen with the naked eye. But what is significant is that the transit concept existed, and was contested. In fact, in the few stanzas that follow the one above, Kamalākara points out how at conjunction, Venus is quickly lost in the dazzling light of the Sun but shall be visible on the disk of the Sun's during the daytime when their separation is sufficiently small. Kamlākara is so clear on the concept that we can only wonder how he missed the two eclipse-like situations with Venus that came to pass in his younger days, but more importantly, that he thought that the 'hole' made by Venus in the Sun would be large enough as to be seen. His perceptivity is visible in yet another observation: during the moments of a solar eclipse, those living on the Moon should see the eclipse taking place on the Earth (Prasad, 1956: 215). Just consider the angular size of the spot of umbra (~200 km) and you will find him right, knowing that the circumference of the Moon's orbit that he would have used may be at variance with the modern value, but not substantially so.

3 WERE SOME EARLY TRANSITS SEEN WITH THE NAKED EYE?

In some historical records, instances have been cited suggesting that naked eye observations of some early transits of Venus were carried out, for instance by the Assyrians in the sixteenth century BCE and by medieval Arab astronomers in the years 840, 1030, 1068 and 1130 CE, etc. However, no transit occurred in any of these years, so we can safely assume that the sightings were of sunspots. The reader will find more on this in Johnson (1882) and Odenwald (2012).

The Persian polymath Abū Alī Ibn Sīnā (Figure 3; 980–1037 CE), known to early Western sources as Avicenna, records in one of his works, *Compendium of the Almagest*, that "I say that I saw Venus as a spot on the surface of the Sun." The date and place of this observation are not given. This statement has been quoted subsequently by some Muslim astronomers, for example by Nasīr al-Dīn al-Tūsī (1201–1274 CE). A transit of Venus indeed took place in Ibn Sīnā's lifetime, on 24 May 1032 CE (Julian date). Did Ibn Sīnā see this transit or did he merely see a sunspot? In recent times, this question has been addressed by Goldstein (1969) who concluded that "… this transit may not have been visible where he lived." This conclusion was based on input provided by Brian Marsden who in turn used mathematical tables prepared by Jean Meeus (1958) and gave sets of limiting terrestrial latitudes and longitudes where the first and second ingress contact would just be visible.

We have re-examined the question employing Fred Espenak's Transit Predictions and Xavier Jubier's interactive Google transit of Venus maps (Kapoor, 2013). The astronomical circumstances of the transit episode and his specific commentary on it in his monumental work *Kitāb al-Shifā* show that Ibn Sīnā could indeed have obtained a glimpse of the transit of Venus just before sunset from the place he may have observed—Isfahan or Hamadan. That also is the best time to view a transit with the naked eye, should seeing conditions permit. In other words, when Ibn Sīnā said he saw Venus on the face of the Sun, he meant it. We have also considered if Ibn Sīnā's observation could have been of a sunspot. As is apparent from some works on historical sunspot sightings, it is probable that in 1032 CE the Sun was rather quiet. So although the sunspot option cannot be dismissed altogether, it does not emerge as a cogent proposition.[2]

4 *VENUS IN SOLE VISA*: THE TRANSITS OF THE SEVETEENTH CENTURY

After the telescope, the first of the transits of Venus predicted by Johannes Kepler (1571–1630 CE) happened on 7 December 1631 CE, but the next, according to him, was not until 1761 (Whatton, 1859: 17). The Parisian astronomer Pierre Gassendi (1592–1655 CE), who had already observed the transit of Mercury on 7 November 1631, tried unsuccessfully the following month to detect Venus passing over the disk of the Sun even though he observed for the greater part of three successive days (Whatton, 1859: 17). As it happened, the final egress contact was already over at 06:47 UT before the Sun rose at Paris (where sunrise was at 07:34 UT).

Figure 3: The Persian astronomer Abū Alī Ibn Sīnā (after: crystalinks.com/Avicenna.html), who may have observed a transit of Venus in 1032 CE.

Looking through Kepler's (1627) *Tabulae Rudolphinae*, the British amateur astronomer Jeremiah Horrocks (1619–1641 CE; Applebaum, 2012; Chapman, 1990)[3] deduced that there was yet another transit situation, due on 24 November 1639 (Whatton, 1859: 43; i.e. 4 December 1639 CE Gregorian calendar). He planned and was able to observe it using the projection technique from a place fifteen miles north of Liverpool, possibly from Much Hoole. Since he came from a family of watchmakers, we can imagine how Horrocks would have striven to obtain precise observations. Horrocks also told his friend William Crabtree (1610–1644) about

Figure 4: James Gregory, 1638–1675 (after: molecular. magnet.fsu.edu/optics/timeline/people/gregory.html).

the transit and he, too, successfully observed it, from near Manchester (Whatton, 1859: 25, 44-45).

What is of interest here is that Mercury and Jupiter were in conjunction with the Sun around this time, and that Horrocks wrote about that too (Whatton, 1859: 39). This happened around the time the telescope was waiting for the English astronomer William Gascoigne (1612–1644) to introduce a crosswire into the eyepiece, and a micrometer, so as to transform it into a powerful astronomical measuring instrument by 1640. Horrocks had discovered that the Moon's orbit was an ellipse with the centre midway between the two focus, and demonstrated that its apsides slowly advance in the direction of its motion (Whatton, 1859: 12-14). From just three observations that he made during the transit, he drew conclusions that were of unprecedented importance and recorded these in his work, *Venus in Sole Visa* … (published by Johannes Hevelius in 1662), where he described Venus on the Sun as a round body of perfect black colour; he also gave its size as 1′ 16″, a great improvement on the figure of 7′ attributed by Kepler; and he reported the angular diameter of the Sun as 31′ 30″. The event also gave Horrocks an opportunity to correct the mean motion of Venus; find its node; and correct the inclination of its orbit, to 3° 24′. He concluded that the solar parallax could not be greater than 14″, a value much smaller than the figure of 57″ that Kepler had arrived at. This new parallax value corresponded to a mean Earth-Sun distance of 15,000 Earth radii, and since this was substantially different from the prevailing one it had attendant implications for the canonical worldview. Chapman (2005: 17) provides a modern evaluation of Horrocks' observations of the 1639 transit of Venus and the deductions that he made based on these.

Figure 5: Edmund Halley, 1656–1742 (after: www.s9.com/ Biography/Halley-Edmund).

It was James Gregory (Figure 4; 1638–1675) in his 1663 book *Optica Promota*, and later Edmund Halley (Figure 5; 1656–1742) in a paper published by the Royal Society in London (see Teets, 2003; van Roode, 2005), who proposed that one should be able to determine the solar parallax, *p*, and deduce a precise value for the distance from the Earth to the Sun by timing the ingress and egress of a transit of Venus from locations on the Earth that differed greatly in latitude. Horrocks' value for the solar parallax contrasts with a figure of 45″ that Halley had derived from his observations of the transit of Mercury on 7 November 1677 (Gregorian calendar) made from the island of St. Helena with a 24-foot telescope. However, Halley considered the value to be inexact since, decades later, he presented a value of 12.5″ when he proposed in his famous paper in the *Philosophical Transactions of the Royal Society* (Halley 1716:454) the method that should be used to determine parallax of the Sun from observations of the upcoming transits of Venus in 1761 and 1769 from locations far apart in latitude so that a more exact value could be derived.

5 THE TRANSITS OF VENUS IN THE EIGHTEENTH CENTURY

Unfortunately, Halley did not live to see the next pair of transits of Venus, which occurred in 1761 and 1769. As the time drew near, these rare and important astronomical events evoked great scientific interest in Europe, and observers were sent to diverse places in different parts of the globe in order to obtain long baselines. In addition, the transits were observed from many observatories in Europe. The British and the French emerged the major players in these activities, notwithstanding the fact that Europe's Seven Years' War (from 1756 to 1763) was raging when the first of the all-important transits occurred. What happened is now part of history and has been well documented by numerous authors (e.g., see various papers in Kurtz, 2005; Maor, 2000; Proctor, 1882; van Roode, 2012; Woolf, 1959; and Wulf, 2012).

5.1 The 1761 Transit of Venus

In London, the Royal Society made plans to observe the 1761 transit. One of its expeditions, led by Nevil Maskelyne (1732–1811) who would later become the Astronomer Royal, went to the island of St. Helena, while the other expedition, led by Charles Mason and Jeremiah Dixon, was destined for Sumatra, but they were forced to observe the transit from the Cape of Good Hope.

While the event would elude American astronomers as it was night-time when the transit happened, the mathematician astronomer John Winthrop (1714–1779) led Harvard's expedition to St. John's, Newfoundland, so as to catch the final phase of the transit just as the Sun rose (see Brasch, 1916).

The French, for their part, prepared four expeditions, to Siberia, Vienna and two southern locations: the astronomer Alexandre Guy Pingré (1711–1796) was sent to the island of Rodriguez in the Indian Ocean, about 1,300km east of Madagascar, while Guillaume Le Gentil (1725–1792) proceeded to India.

The Dutch clergyman Johan Mohr (1716–1775) observed the transits of 1761 *and* 1769 from Batavia, present-day Jakarta, in what then were the Dutch East Indies (see van Gent, 2005).

5.1.1 The Travails of Le Gentil

Guillaume Le Gentil, a French astronomer, originally set sail in 1760 for the French port of Pondicherry in India so that he could observe the 6 June 1761 transit of Venus. Le Gentil had been inducted into astronomy by Jacques Cassini at the Paris Observatory at a young age, and he grew to be a dedicated astronomer. His expedition was part of the international French campaign to use the 1761 transit in order to solve the solar parallax problem that confronted all leading astronomers at this time. However, Le Gentil fell victim to the Seven Years' War which engaged the two European superpowers of France and England at the time, and on 24 May 1761, when off the coast of Malabar, he learnt that the British had taken Mahe and Pondicherry (Proctor, 1882: 55). So he had to return to the Isle de France (now Mauritius) and it was on this voyage, between Point de Galle (in Ceylon, or present-day Sri Lanka) which they reached on 30 May and their arrival at the Isle de France on 23 June that with great difficulty he observed the 6 June transit from the moving ship with a cumbersome refracting telescope of fifteen feet focal length. From the times of the contacts, Le Gentil gave the total duration of the transit as 8h 27m 56 1/2s (The Transit of Venus, 1874).

Disheartened, yet determined not to give up after having ventured so far from France, Le Gentil knew that the next transit, on 4 June 1769 (local time), was also visible from India and South-east Asia, and so he decided to stay in that part of the world for the next eight years in a bid to complete his mission. So it was that he eventually arrived in Pondicherry, on 27 March 1768, more than a year before the transit. By this time the Seven Years War was over and Pondicherry once more was under French control. When Le Gentil landed, Jean Law de Lauriston, the Governor General of French territory in India, treated him well and invited him to find a suitable site and build an observatory. This facility was completed by 11 June, and a drawing of it amongst the ruins of war-torn Pondicherry is shown in Figure 6. The British in Madras then provided Le Gentil with an excellent achromatic telescope of three feet focal length so that he could observe the transit (Hogg, 1951). Le Gentil then began by precisely determining the latitude and longitude of Pondicherry.

In the course of this work he was exposed to Indian astronomy and marveled at the fine art of eclipse calculation developed by the locals and even tried to learn the technique himself. A local Tamil Brahmin then spent just 45 minutes computing the circumstances of the lunar eclipse of 30 August 1765, that Le Gentil had previously observed, and when he compared the Indian astronomer's figures with tables published by Tobias Mayer—then considered the best in Europe—he was astonished to find that the Tamil results were more accurate. Phillimore (1945: 156) has shown that it was Tamil Brahmins from Trivalour (Trivalore, now Tiruvallur near Chennai) who successfully taught Le Gentil the art of lunar eclipse calculations, and "… they communicated to him their tables and rules which were published by Le Gentil as the 'Tables of Trivalore', in the memoirs of the Academy in 1772." (cf. Banerjee, 1920: 157). However, when it came to solar eclipses, Le Gentil found the computations much more difficult to comprehend and to

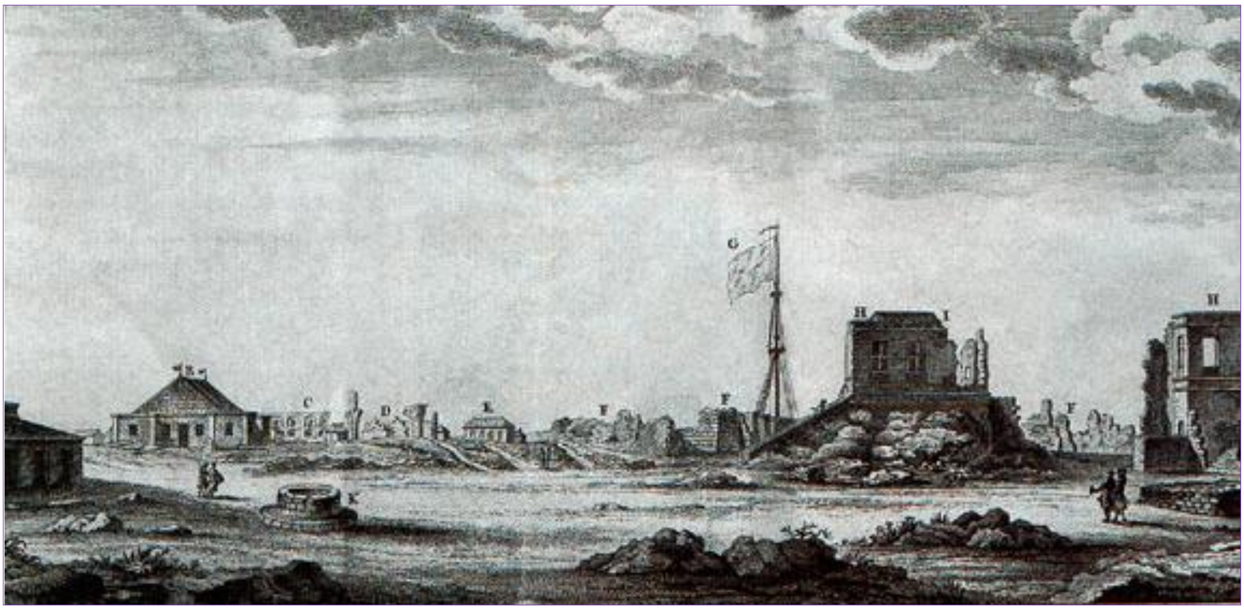

Figure 6: View of part of the ruins of Pondicherry in 1769, seen from the north. Le Gentil set up his observatory in the ruins of the former Governor's palace, the foreground structure (marked H, I) to the right of the flag pole (after en.wikipedia.org).

master. One can only wonder what the Tamil astronomers made of planetary transits once they found out that Le Gentil had come to Asia from the far side of the globe in order to observe two of them. The irony, however, was that on the vital day in 1769 Pondicherry was clouded out, so Le Gentil never got to observe his second transit of Venus and—on this occasion—record accurate contact times.

In a four-part 'essay', Helen Sawyer Hogg (1951) presents us with a wonderful peep into the life and travails of Le Gentil, based on his memoirs, *Voyages dans les Mers de l'Inde fait par Ordre du Roi, à l'Occasion du Passage de Vénus sur le Disque du Soleil le 6 Juin 1761, & le 3 du Même Mois 1769*, which were published in two volumes in 1782. And given the disappointing outcome in 1769, Hogg (1951: 37) poignantly refers to Le Gentil's unsuccessful 11-year voyage to the Indian Ocean to observe transits of Venus as "… probably the longest lasting astronomical expedition in history."

5.1.2 The British Observations

Like Le Gentil, the British also planned to observe the 1761 transit from India, but in this instance from several different locations, and primarily with the cooperation of the East India Company (EIC).

The EIC, which was founded in England in 1600, originally established itself in India in 1608 when the Mughal Court of Jehangīr permitted it to start a 'factory' (i.e. a secure warehouse) at Surat (see Figure 1), an important centre of the Mughal Empire for commerce with overseas nations. The EIC was eager to initiate and promote commerce between England and the East. To strengthen its trading activity on the eastern side of the Sub-continent a base was established at Masulipatam on the Coromandal Coast (Figure 1) in 1611. Later the Company established a factory, which it called Fort St. George, at Madraspatnam. The Fort, founded in 1639-1640 and completed in 1653, initially served as a transit outpost, but with the passage of time it grew in importance and eventually became the seat of the expanding British power. Apart from Fort St. George, the EIC had Fort William in Calcutta and the Bombay Castle as its other main seats of power (see Figure 1). These were independent presidencies of the EIC that were governed by a President and a Council. The latter were appointed by the Court of Directors of the EIC in England (see Bowen et al., 2003; Farrington, 2002; Keay, 2010).

Fresh from their victory in 1757 at the Battle of Plassey (Palashi) that established the rule of the EIC in Bengal, the British initiated scientific surveys in order to familiarize themselves with this new territory. This was a great strategic decision that paved the way for rich scientific and other dividends in years to come. As a result, the Trigonometrical Survey of India was founded in 1767, which should be seen as the earliest modern scientific institution in the country.

It was within this atmosphere of emerging scientific endeavour that the 1761 transit of Venus occurred. According to Love (1995: 590), the Royal Society prepared to send two astronomers to Fort Marlborough (Figure 1) to carry out observations of this transit, and the EIC decided to provide local support to them. The EIC Directors also called for volunteers to contribute observations of the transit, and also instructed 'any competent persons' in Fort St. George at the time also to conduct observations (ibid.).

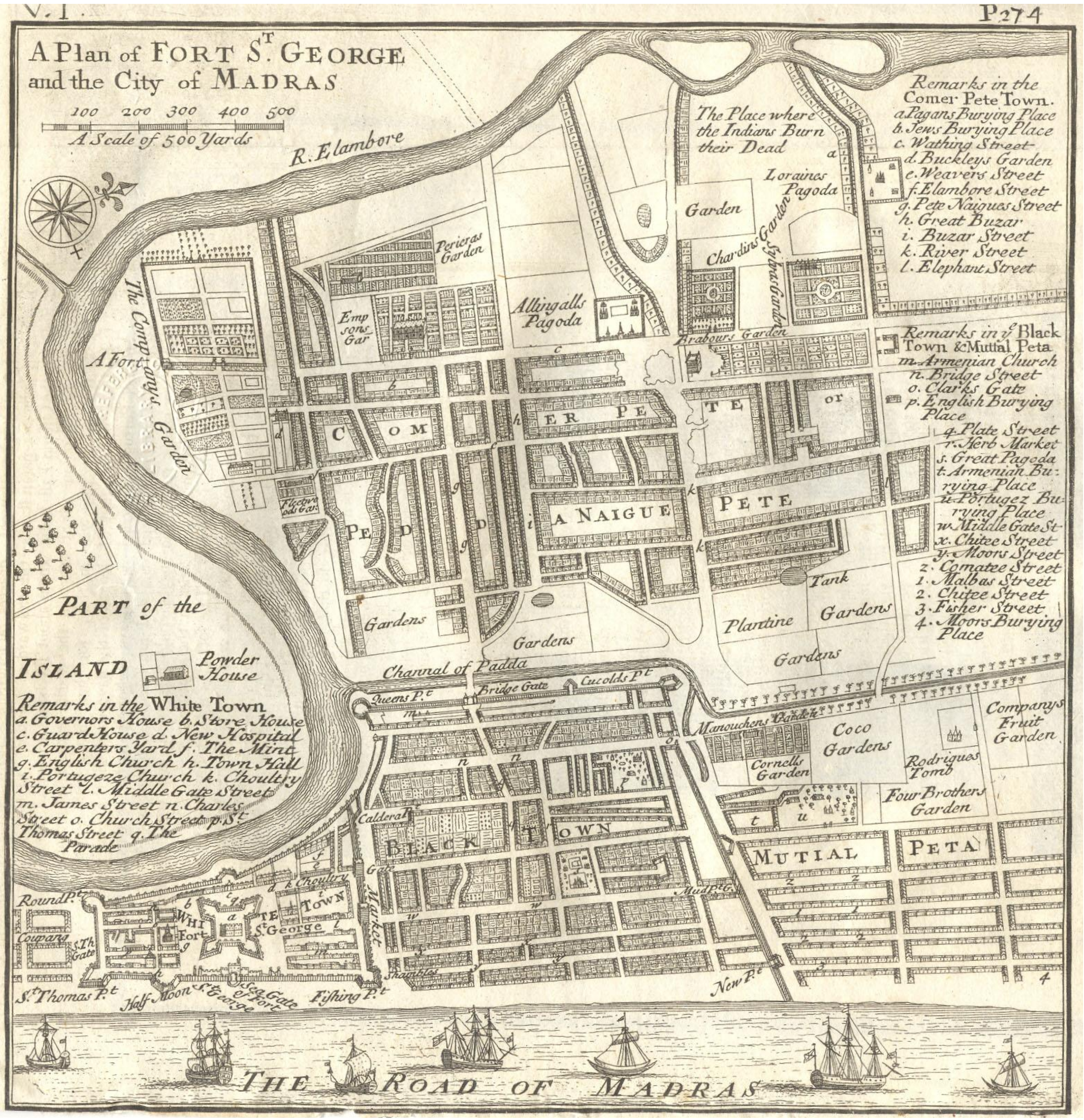

Figure 7: "A Plan of Fort St. George and the City of Madras" by Herman Moll (after Salmon, 1726). Governor Pigot's house (marked with an 'a') is the rectangular building in the White Town on the left of the picture, about half way between the shore and the river.

5.1.2.1 The Observations at Fort St. George, Madras

The 1761 transit of Venus was observed from on top of the Governor's house at Fort St. George, Madras (see Figure 7), by an astronomer, the Reverend William Hirst (d. 1774; Goodwin, 1891; The Royal Society, 2012). Hirst, a chaplain aboard one of His Majesty's ships, had been deputed by the Royal Society to conduct observations of the transit from Madras, and he mentions

> … a reflecter 2 feet long, made by Mr. Adams, of Fleetstreet, London, and lately sent, as a present, by the East India company, to the Nabob Mahommed Allah Cawn, of whom the Governor Pigot was so kind to borrow it, on this occasion. The governor himself, and, also Mr Call, a very ingenious gentleman, assisted in the observation; the former with a 4 feet reflecter, of Mr Dolond's new construction, the latter with a 2 feet reflecter, formerly belonging to Dr. Mead. (Hirst, 1761-1762).

The afore-mentioned 'Nabob Mahommed Allah Cawn' is actually Muhammed Ali, Nawab of Arcot, 'Governor Pigot' is Sir George Pigot (1719–1777) and 'Mr Call' is Captain John Call (1732–1801) who was Chief Engineer of the EIC in Fort St. George (Phillimore, 1945: 153). It was Pigot, who had gifted the 'reflecter' to the Na-wab on behalf of the Company. In his communication to the Royal Society, Hirst writes that the Jesuits for *Pondichery* calculated that the transit would begin at 06h 57m, but London calculations, reduced to the meridian of Fort St. George, gave 07h 26m 35s apparent time. In fact, when the transit occurred, the ingress contact timings were 07h 31m 10s and 7h 47m 35s, and the egress timings were 13h 39m 38s and 13h 53m 44s (apparent time). On 1 July 1761 Hirst wrote to the President of the Royal Society that he had made a significant observation, having seen at the moment of ingress a nebulosity around the planet:

> The morning proved favourable to the utmost of their wishes, which the more increased their impatience. At length, as Mr Hirst was stedfastly looking at the under limb of the Sun, towards the south, where he expected the planet would enter, he plainly perceived a kind of penumbra, or dusky shade, on which he cried out 'tis a-coming, and begged Mr. Call to take notice of it. Two or three seconds after this, namely, at 7^{h} 31' 10" apparent time, happened the first exterior contact of Venus with the Sun, which all the three observers pronounced the same instant, as with one voice. Mr. Hirst is apprehensive, that to be able to discern an atmosphere about a planet at so great a distance as Venus, may be regarded as chimerical; yet affirms that such nebulosity was seen by them, without presuming to assign the cause. They lost sight of this phenomenon as the planet entered the disk, nor could Mr. Hirst perceive it after the egress. (Hirst, 1761-1762).

Figure 8: Sir George Pigot, 1719–1777, painted by George Willson some time after he left Madras in 1763 and returned to England (after: en.wikipedia.org).

By the time the 1769 transit of Venus came along Hirst was back home in England, and he observed this transit from the Royal Observatory at Greenwich, where Nevil Maskelyne and several others were stationed (Maskelyne, 1769). Hirst's report (1769) on this latter transit is interesting because he reaffirms his impressions about the existence of an atmosphere around Venus (even though he did not notice it on this occasion):

> … when I took the observation of the transit of Venus at Madras, in the year 1761, I saw *a kind of penumbra or dusky shade, which preceded the first external contact two or three seconds of time, and was so remarkable, that I was thereby assured the contact was approaching, which happened accordingly ...* I may venture to say, that my observation of the transit of the present year [1769] seems to corroborate my assertion, in the account of the transit observed in India, in 1761. (His italics).

In addition to his claim to have detected an atmosphere, at ingress Hirst mentions that the planet assumed the shape of a bergamot pear, with the preceding limb of the disc clearly illustrating what is known as the 'black-drop effect'. He tried to rectify any possible defect in his telescope by checking its focus several times, but remained convinced when the same effect also was seen at egress.

On 2 October 1761 Governor Pigot (Figure 8) specifically mentioned Hirst's observations in his report to the Directors of the EIC, as per a packet to England dated 2 October 1761:

> We have the pleasure to inclose to you in this Packet a particular Account of the Observation made on the Transit of Venus the 6th of June by the Reverend Mr. Hirst. This Gentleman is a Member of the Royal Society, which Circumstance, and his extreme Modesty, is the Occasion of this Account being addressed to Lord Maclesfield instead of to you. From all Accounts We have had of the Observations made in these Parts, none are to be depended on equal to this; and we wish, for your Honour and the Interest of this Worthy Clergyman, whom We recommend to you in a particular manner, that it may appear to have been the most accurate. None has equalled us in pains We can venture to assure you. (Love, 1995: 590-591).

Hirst's paper on the 1769 transit also contains another interesting observation made in 1761. In his 1769 paper Hirst reproduces an extract from his original 1761 letter to Lord Macclesfield that was not published at the time, in which he discusses his search for a satellite of Venus. Before the transit Hirst came across a paper by Mr Short in the *Philosophical Transactions of the Royal Society* where he reported observing a stellar-like object near Venus, giving rise to speculation that the planet may have a satellite. Furthermore,

> … a corroborating circumstance was added, viz, M. Cassini, in his *Elements d'Astronomie* mentions a like observation. This I regarded as a favourable opportunity, concluding, that if Venus had a satellite, it must be seen at its transit over the Sun's disc; accordingly, I gave notice of this to Captain Barker, of the Com-

> pany's Artillery [now Colonel Sir Robert Barker], who took the observation at Pondicherry. I also mentioned it to the Jesuits, who observed at the Great Mount, about 7½ miles S. 50º W. of Madras, but neither of them saw any appearance in the least like a satellite. I also spoke of it to Governour Pigot [now Lord Pigot], and Mr. Call, who with myself saw not the least speck attending that planet; whence we may now venture to affirm, *That Venus has not a Satellite*.

5.1.2.2 The Bengal Observations

The report from the Bengal Council in Calcutta (now Kolkata) that was sent to the EIC Directors in England was not as enthusiastic as Pigot's missive from Fort St. George:

> In consequence of your directions … We delivered copies of the Instructions relative to the Transit of Venus to such gentlemen here as were inclined to make the observation … The only reports we have received are One from Mr. Plaisted taken at Chittagong, and one from Mr. Magee taken here [in Calcutta] ... but for want of proper Instruments they are not of a sufficient exactitude to be of any material use. (Phillimore, 1945: 153).

The EIC was involved in an extensive geographical survey of Bengal, and Bartholomew Plaisted (d. 1767; Sinha, 1949: 357), who originally was trained in nautical astronomy as a sailor and developed an aptitude for determining latitude, surveyed the Chittagong coast in 1760-1761, mostly using observations of the Sun (Phillimore, 1945: 151). He observed the transit of Venus from Chittagong (Figure 1), which is now located in Bangladesh. The Astronomer Royal used Plaisted's observations to derive a longitude of 91º 45′ for Islamabad, as that area was known since the Mughal occupation (Phillimore, 1945: 153). Chittagong, along with Burdwan and Midnapore (Figure 1), had only been ceded to the EIC in the previous year.

William Magee was a notary public in Calcutta. He observed the transit, and subsequently published the contact times listed in Table 2.

Using the semi-diameter passage time as a guide, he estimated that the transit must have commenced at 08h 04m 50s, so its total duration was 6h 22m 48s. As Proctor (1882) later noted:

> At Madras, Mr. Hirst, and at Calcutta, Mr. Magee (whom M. Dubois converts into Magec) observed the duration of transit, obtaining respectively the periods 5 h. 51 m. 43 s., and 5 h. 50 m. 36 s., values which differ much more from each other than parallax will account for.

The Directors of the EIC communicated Magee's observations to the Royal Society via Charles Morton, M.D., F.R.S. Magee (1763) had noted the contact times with a "… stop-watch of Mr. Ellicott's, having no pendulum-clock or time-piece." He made a point of commenting on the behaviour and accuracy of the watch. For several days prior to the transit the sky was cloudy so Magee could not determine the accuracy of the watch, but on the day of the transit he compared its reading with "… a meridian line in the town-hall …", and did so again on 7, 8 and 9 June when the Sun was on the meridian. His contact times listed above are after due corrections. The stop-watch that Magee referred to was manufactured by John Ellicott (1706–1772), an eminent London clockmaker. It was a centre-seconds watch, and a photograph of a similar one that was made by Edward Ellicott senior in 1778 can be viewed at the website of The British Museum (2013) where it is stated that "It is unfortunate that Mr Magee did not mention the number of the Ellicott watch he used".[4]

There is something odd about the position of Magee's reported observing site in his 1763 paper in the *Philosophical Transactions of the Royal Society*. The title of this paper includes his position as "… Latitude 22º 30′, Longitude East from London nearly 92º", but since the co-ordinates of Calcutta are 22° 34′ N, and 88° 22′ E. this would suggest that he did not observe from there but rather from a site about 25 km northeast of Chittagong (which has co-ordinates of 22º 22' N and 91º 48' E). Bearing in mind the precision that Plaisted was able to achieve, no observer of the transit could have been so much in error about his location, so we have a little mystery here!

5.1.3 Observations by Some Jesuits

From Tranquebar (now Tharangambadi) in Tamil Nadu (see Figure 1), the transit was observed by some Jesuit priests. Van Roode (2011) has identified the site where the observations were made, near the present-day St. John Primary School. The reports of their observations, together with those made from the "Government

Table 2: Contact times recorded in Calcutta by William Magee (after Magee, 1763).

Observation	Time h m s
Centre of Venus on the Sun's limb at ingress	08 12 54
Interior contact at ingress	08 20 58
Interior contact at egress	14 11 34
Centre of Venus on the Sun's limb at egress	14 19.38
Egress ends	14 27.38

Table 3: Contact times recorded in Tranquebar and Madras (after The same observed …, 1762).

Observation	Madras h m s	Tranquebar h m s
First external contact of Venus with the Sun	07 28 28	07 29 39
Total emersion on the disk of the Sun	07 45 13	07 46 52
Beginning of emersion from the disk of the Sun	13 37 01	13 40 25
Total emersion of Venus's from the disk of the Sun	13 53 07	13 56 34

House, at Madrass", subsequently were published in the *Gentleman's Magazine* in 1762 (Observations of the transit …) and 1764 (Chandlee, 1764), without identifying the observers, but according to Wulf (2012: 207-216) they were British. A later report in the *Gentleman's Magazine* (The same observed …, 1762) gives the contact times for both locations, and these are listed in Table 3. Note that the Madras contact times listed here differ slightly from those that were communicated by Hirst (1761-1762).

What is worth a read is Chandlee's (1764) analysis of the transit event in the *Gentleman's Magazine* where, beginning with Doctor Halley's proposition for transit observations to be made from locations far apart, he comments on the various reports on the transit, including those from Madras and Tranquebar, as giving nothing more than the timings. He asks "… whether the necessary observations were made in places pertinent to the Doctor's design of obtaining the Sun's horizontal parallax …" He laments "… not one of them that I have yet seen, has attempted to say what her [i.e. Venus'] Latitude was at that time, or at any other interval of that transit …" Chandlee (1764) eventually presents that when, using the Tranquebar timings, he goes on to compute and construct, in a very simple but logical manner, the circumstances of the Transit of 1769 for London:

> … from which Times, if we subtract from 30 to 40 minutes, we shall have the Times of beginning, &c. for several places in *Ireland.* Here it is evident, that the Transit of 1769, instead of being, of such short duration, only touching, as it were, the upper limb of the Sun, and invisible to *Europe*, will be as large as that of 1761, come as near the Sun's center, the beginning for a good while visible to the west coast of *Europe* …

Chandlee's (1764) contact times can be comparpared with those predicted by Espenak (2012) for the 1769 transit; and differ by only 16 minutes.

5.1.4 Discussion

The 1761 transit produced widely-differing values for *p*, the solar parallax (Verdun 2004). For instance, the French results ranged from 8.6″ to 10.6″ (Débarbat, 2005: 43).

Table 4: Solar parallax values published by Short in 1762.

Site	*p* (″)
Grand Mount	8.07
Tranquebar	8.36
Madras	9.71
Calcutta	10.34

In a detailed analysis, the Scottish telescope-maker and astronomer James Short (1762; 1764) calculated *p* by reducing the contact times reported by different stations to the meridian of Greenwich. These observations included also those made at Calcutta, Pondicherry, Tranquebar, Madras and Grand Mount, Madras. The last station is identified as "… a place about 8 miles to the S. West of Madrass." (Short, 1762). No details of the activities or observers at Pondicherry and Grand Mount are available. Actually, the Grand Mount, mentioned here refers to the St. Thomas Mount (Parangimalai), a little 300-ft high hillock in Madras which is where the Jesuit Fr. Duchoiselle made his transit observations, and Van Roode (2011) identifies St Thomas Church, near the Grand Mount, as his observing site. The values of *p* that Short (1764: 305) initially derived from the observations of the Indian stations showed considerable variation (see Table 4), but from a careful reanalysis of all of the observations Short (1764) subsequently published a mean solar parallax value of 8.56″.

Wulf (2012: 207-216) provides a detailed list of 1761 transit observers of various nationalities in the Indian region. We find the following people listed who independently observed the transit but did not submit formal reports: Messrs Martin, Ferguson and Robert Barker, three British observers in Pondicherry; a Mr Harding in Bombay; and John Knott in Chittagong. Hirst (1769) also mentions a "Capt. Robert Barker of the Company's Artillery …" Hirst (1761-1762) also was aware that there were Jesuit observers in Pondichery, but he does not name them.

The only Jesuit observer I have been able to identify is Gaston-Laurent Coeurdoux (1691–1779), who was in Pondicherry at the time, and Ines Zupanov, an authority on the French Jesuits in Pondicherry, agrees with this (pers. comm., 2013). Coeurdoux had observed the 'great comet' of March-April 1759, which a few years later would become known as 'Halley's Comet'. Meanwhile, the 'Mr. Martin' mentioned above would have to be Claude Martin (1735–1800) who was an officer in the French army and later joined the army of the East India Company after the French lost Pondicherry to the British on 16 January 1761.

Compared to what was deduced by Horrocks from his observation of the 1639 transit and assumed by Halley in 1716 in his transit of Venus proposal, the 1761 transit results were a step in the right direction, but the spread in the values of the solar parallax far exceeded Halley's expectations.

Muthiah (2011: 1002-1005) quotes an interesting observation made by Nirupama Raghavan,[5] that the Valleswarar Temple on South Mada Street in Mylapore (Madras)—believed to have been built about 300 years ago by a community called Sengunathars—was possibly consecrated on 6 June 1761, the day of the transit of Venus. This temple is dedicated to *Velli* (*Shukra* – Venus). *Sukra* is, of course, male.

5.2 The 1769 Transit of Venus

The next transit of Venus occurred on 3-4 June 1769, and since the plan was to carry out observations from widely-separated locations, some astronomers were destined to embark on long and arduous voyages. But the Seven Years War was over, which helped, and the astronomers knew what was in the offing and so were better prepared than in 1761.

In 1768, the Royal Society in London petitioned King George III to fund scientific expeditions to observe the up-coming transit of Venus. Undoubtedly, the most famous expedition undertaken was to Tahiti in the Pacific, led by James Cook (1728–1779). A comparatively young and relatively unknown junior officer, Cook was promoted to the rank of Lieutenant and given command of His Majesty's Bark *Endeavour*. Cook also served dual roles, for he was one of the two official astronomers on the expedition; the other was Charles Green. Both astronomers were supplied with the latest instruments by the Royal Society and the Royal Observatory. See Orchiston (2005) for a detailed account of Cook's Tahitian expedition. Meanwhile, the Royal Society also organized expeditions to Ireland, Cornwall, Norway and Hudson's Bay.

The French also prepared to observe the transit, from home and from abroad (e.g. see Débarbat, 2005).

Subsequently, Thomas Hornsby (1771) published a value for the solar parallax of 8.78″ on the basis of British and selected other international observations of the transit in 1769, and this just happens to be very close to the currently-accepted value of 8.794148″ (Dick et al., 1998). Meanwhile, the French derived a number of different parallax values (based on different suites of observations) and these ranged between 8.43″ and 8.80″, leading to intensive scrutiny in the quest for a precise value (see Débarbat, 2005).

5.2.1 Indian Observations of the 1769 Transit

Love (1995: 591) documents how, on 22 January 1768, the Royal Society once again sought help from the East India Company (EIC) regarding the up-coming 1769 transit of Venus:

> In obedience to the Orders of the Royal Society, I take the liberty to apply to you in their name, and Solicit your concurrence in an affair of some importance to the Advancement of Science and the honor of this Country. The next Transit of the Planet of Venus over the Disc of the Sun, which is expected on the June 3rd, 1769, will afford the only means of ascertaining some of the principal and hitherto unknown elements in Astronomy, and of improving both Geography and Navigation. The first Phenomenon of this kind ever taken notice of was observed above a Century ago, by an Englishman, and the last, which happened in 1761, excited the Curiosity of most Nations in Europe; but on account of the War and the want or inexperience of the Observers, the fruits expected from this Observation, and foretold by the great Dr. Halley, were but partly obtained. An opportunity of the same kind will again offer itself, and as it is the last which the present and succeeding Generations will have for at least a hundred Years to come, it is to be hoped, and indeed expected, that an universal emulation will extend itself all over the Continent on so interesting an occasion. The honor of this Nation seems particularly concerned in not yielding the palm to their Neighbours, and the Royal Society intends to exert all its strength and influence in order to have this observation made with the greatest accuracy, and, if possible, in the most uniform and satisfactory manner in various parts of the British Dominions. The experience they have had of the readiness of this potent Company to forward every great and national undertaking does not permit them to doubt of their taking a share in this. They therefore hope that it will be early and earnestly recommended to such of the Company's Servants at Madras, Bombay, Bencoolen, or other Places in the East Indies as have been accustomed to Astronomical Observations to prepare for and exert themselves in this … (cf. Sinha, 1949: 114-115).

In this letter, the 'East Indies' would mean the Indian region together with the mainland southeast Asia, Indonesia and the Philippines, while 'Bencoolen' was the original name of the city of Bengkulu in Sumatra. Going by the letter's language, there seems to be an element of persuasion here, but this had the desired effect as the Directors of the EIC once again sent out requests to its staff, stressing the importance of this transit (Phillimore, 1945: 153), and

> Recommend to such of the Company's servants at Madras, Bombay, Bencoolen ... as have been accustomed to Astronomical observation to prepare for, and exert themselves in this … Instruments required,
> 1. Reflecting Telescope. 2 ft. focus, with apparatus of smoked glasses.

2. A Pendulum Clock.
3. An Astronomical Quadrant, of 1 ft, radius at least, or in lieu of it, an Equal-Altitude Instrument.

For its part, this letter also produced the desired result, for on 3/4 June 1769 the transit was observed from a number of different locations in India.

5.2.1.1 The Dinapoor Observations

Luis Degloss, the Captain of Engineers who was employed at the Dinapoor gun foundry, observed the transit from Dinapoor with three quadrants and a reflecting telescope, assisted by J. Lang and A. Stoker. At sunrise, it was cloudy but at 05h 20m 32s, "… the Sun disengaged from the clouds when Venus appeared on the ☉'s disk." (Degloss, 1770). Degloss timed the first egress contact at 07h 5m 22s and the second egress contact at 07h 23m 36s. He gave his co-ordinates as 25º 27′ N. Dinapoor (Dinapore, now Danapur; which has a latitude of 25º 38′ N and longitude of 85º 03′ E according to the *Imperial Gazette of India*, 11: 355) is very close to Patna in Bihar. Interestingly, post-transit, a dispatch from Fort William to the Court of Directors (see Sinha, 1949: 584) advised that

> The Instruments you sent out to observe the transit of Venus with did not arrive in time to be of any Service. Captain Du Gloss is the only person who hath made any observations on the Transit which agreeable to your orders are recorded on our Consultations and we have also sent you a Copy of them a Number in this Packet.

5.2.1.2 The Phesabad Observations

Captain Alexander Rose of the 52d Regiment observed the transit from Phesabad in Bengal (latitude 25º 30′ N; see Figure 1) with a telescope (of undisclosed aperture) and a stopwatch. Rose (1770) only began observing the transit at 05h 35m 57s (local time) when it was in an advanced stage. He timed the first egress contact at 06h 52m 25s and the last egress contact at 07h 10m 47s, the duration of the egress therefore being 18m 22s. These observations were contained in a report dated 20 August 1769 that Rose (1770) sent to the mathematician Dr Patrick Murdoch, F.R.S. (d. 1774; The Royal Society, 2013) who, from the times of the contacts, determined that the planet's centre was on the limb of the Sun at 07h 01m 36s. Murdoch then added his own comments: "… this compared with an observation of the central egress made at a different place will give the sun's parallax." (ibid.). Murdoch said that the stop-watch had been regulated the previous day by equal altitudes of the Sun, and he deduced the longitude of Phesabad to be 81º 45′ east of Paris. This value indicates that Rose's observing site was ~10 km south-east of Buxar in Bihar.

5.2.1.3 Observations Planned for Fort St. George Pondicherry and Masulipatam

Apparently, on this occasion there was little interest shown in the transit by those stationed at Fort St. George (Love, 1995: 591), and sensing this, the Astronomer Royal, Nevil Maskelyne, persuaded the Chief Engineer, John Call, to observe the event. However, a sudden storm on the crucial day led to a thick cloud cover, dashing any hope of making successful observations:

> The Instruments which your Honors sent for observing the Transit of Venus having arrived in time, Mr. Call with the assistance of the other Engineers undertook to adjust every preparative for an accurate observation; but after taking great pains to regulate the time-keeper, and adjust the Instruments, the expected Observation was entirely frustrated by a change of weather coming on the 3rd June, which occasioned so cloudy a morning on the 4th that the Sun was not visible till 10 o'clock; the same ill success attended Monsr. Gentil [180 n.3] sent purposely the year before from France to Pondicherry, and Mr. Stevens [92] who had fitted an apparatus at Masulipatam was equally disappointed … The Instruments for Bombay could not possibly be sent thither in time … (Phillimore, 1945: 153-154):

The 'Mr. Stephens' referred to here is William Stevens (d. 1778), who was then Engineer at Masulipatam, and employed on fortifications and works (Phillimore, 1945: 385-386).

In his memoirs, Le Gentil also talks about John Call's aborted observations:

> There was the same thing at Madras, where Mr Call, chief engineer of that place, had been commissioned by N. Maskelyne to make the observations …The observers were sleeping tranquilly when they were awakened by a most abundant rain and by a gusty wind, which carried off the tent and upset a part of their instruments … This whirlwind was felt along the coast of Coromandel for more than thirty leagues advancing along the land of the peninsula. (Hogg, 1951: 132).

We should recall that John Call assisted the Reverend William Hirst when he successfully observed the 1761 transit from Fort St. George.

6 CONCLUDING REMARKS

This review demonstrates that India contributed to the international campaigns to observe the 1761 and 1769 transits of Venus, especially during the earlier transit when clear skies allowed some uninterrupted observations. Undoubtedly, one the most interesting observations made from the Subcontinent was the reported detection by the Reverend William Hirst and his

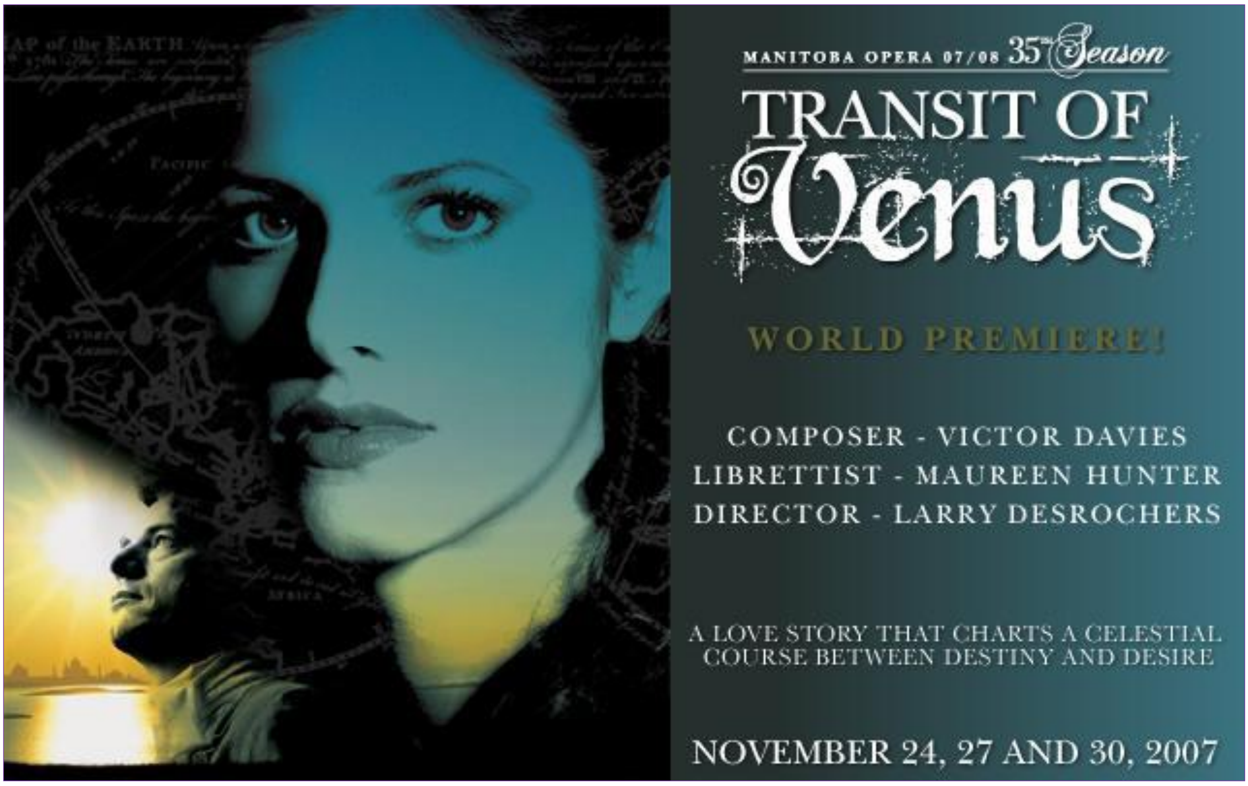

Figure 9: Advertisement for the 'Transit of Venus' opera (after: http://www.manitobaopera.mb.ca/transitofvenus/).

colleagues of an atmosphere around Venus in 1761. However, they were not the only astronomers at this time who claimed to have made such observations, and the reputed 'discovery' of the Cytherian atmosphere by the Russian astronomer Mikhail Lomonosov (1711–1765) is perhaps the best known of these (e.g. see Marov, 2005). However, recently Pasachoff and Sheehan (2012: 3) clearly demonstrated that the 'aureole' or 'dusky ring' observed around the planet was not an atmosphere:

> It has only recently become clear that these effects are produced by the smearing of the isophotic contours of the planet's disk by a combination of solar, instrumental and terrestrial-atmospheric effects.

Similarly, the black-drop effect which Hirst et al. also noticed, was not associated with Venus' atmosphere, and is now known to have been caused

> … by a combination of the point-spread function of the telescope smearing any image, in combination with the solar limb darkening, which is especially marked in the arcsecond or so nearest the limb that shows the black drop. (Pasachoff and Sheehan, 2012: 1; cf. Pasachoff et al., 2005; Schneider et al., 2004).

It is only fair to mention that at this time most astronomers assumed that other planets in the Solar System harboured life, so the appearance of an atmosphere around Venus was pretty much taken for granted (see Pasachoff and Sheehan, 2012: 5-6).

In marked contrast to Hirst's otherwise successful observing campaign is Le Gentil's unsuccessful bid to obtain accurate contact times for either the 1761 *or* the 1769 transit, and his 11-year sojourn in the Indian Ocean and in India must rank as one of the saddest tales in the saga of international eclipse and transit of Venus expeditions. Is it little wonder then that there is an opera titled *Transit of Venus* which was inspired by his fateful expeditions (see Figure 9). It is in three Acts and is based on a play with the same name by the Canadian playwright, Maureen Hunter, and presented "… a love story that charts a celestial course between destiny and desire." (Manitoba Opera, 2007).[6] In his own memoirs, Le Gentil reflects on this:

> That is the fate which often awaits astronomers, I had gone more than ten thousand leagues; it seemed that I had crossed such a great expanse of seas, exiling myself from my native lands, only to be the spectator of a fatal cloud which came to place itself before the Sun at the precise moment of my observation, to carry off from me the fruits of my pains and my fatigues ... I was unable to recover from my astonishment, I had difficulty in realizing that the transit of Venus was finally over … (Hogg, 1951: 132).

As the 1874 transit of Venus drew near and public excitement grew, *The New York Times* published in its 25 July 1874 edition Le Gentil's life history, from articles by M.W. De Fonvielle in *La Nature*, that revealed his travails from the period 1760 to 1771 and his observations in more detail. The account revealed that while he was absent from France Le Gentil had been replaced at the Academy of Sciences (he was reinstated subsequently) and his property was claimed by his relatives after his death was announced many times over (*The New York Times*, 1874). Nonetheless, Le Gentil's name remains etched in astronomical history, not so much for his abortive transit observations, but rather for his discovery of a few deep sky objects, including the Lagoon Nebula and the companion to the Andromeda Galaxy. It is only fitting that he was honoured in 1961 when a crater on the Moon was named after him (see Frommert and Kronberg, 2012).

Finally, the 1769 transit of Venus was unique in that it was followed a few hours later by a total solar eclipse which was visible from the Arctic region. One can only imagine what an impact this would have had on international astronomy had the eclipse occurred a few crucial hours earlier, with the path of totality traversing more accessible northern latitudes.

6 NOTES

1. The 'solar parallax' is defined as one half the equatorial diameter of the Earth as viewed from the Sun. The currently-accepted value is 8.794148″ (Dick et al, 1998).
2. We also should mention here Mirzā Abū Ṭālib (1752–1805/6), a well known Persian astronomer and natural philosopher, who served the Nawab Asaf ad-Dawlah of Awadh. Ṭālib wrote on diverse topics in astronomy, including the phenomenon of planetary transits, and a short account of his work (in Persian) is presented by Ansari (2002). While supporting the heliocentric system through the instance of Venus and Mercury seen as dark spots transiting the disc of the Sun, Ṭālib refers to Qutbuddīn Shīrāzī (1236–1311 CE) being in the know about transits of Venus. Shīrāzī, who was a disciple of the legendary Persian astronomer Naṣīr al-Dīn al-Ṭūsī (1201–1274 CE) and trained at Marāgha Observatory, wrote on Ptolemaic planetary theory and about the transits, and he may have learnt about these from the works of Ibn Sīnā and Ibn Bājja (ca. 1095–1138/9 CE).
3. Sometimes his name is given as 'Horrox', as in the Register of Emmanuel College, Cambridge (e.g., see Whatton, 1859: 3, 5).
4. It is interesting to note that John Ellicott also observed the transit, but from London, in the company of John Dollond (Wulf, 2012).
5. Nirupama Raghavan was a student of M.K. Vainu Bappu (1927–1982) at the Kodaikanal Observatory in the 1960s, and the first woman to take up observational astronomy in India after Independence.
6. It is worth mentioning that although inspired by Le Gentil's saga, both the play and the opera are largely fictitious.

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Dr Ramesh Kapoor began his career in 1971 at the Uttar Pradesh State Observatory (now the Aryabhatta Research Institute of Observational Sciences, ARIES) at Naini Tal in observational astronomy. From 1974 until 2010 he was with the Indian Institute of Astrophysics (IIA) in Bangalore where he worked on various topics in relativistic astrophysics. He also participated as an observer and organizer in a few IIA solar eclipse expeditions. His current interest is in the historical side of the lesser-known comet sightings and observations made from the Indian region. He is active in popularizing astronomy, and has also published on Indian systems of medicine.

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FROM THE DEATH OF THE SOLARIANS TO THE BIRTH OF ASTROPHYSICS

Alan H. Batten
2594 Sinclair Rd, Victoria, B.C., Canada, V8N 1B9
E-mail: ahbatten@telus.net

Abstract: William Herschel's solar model in which the Sun was believed to be a dark solid body surrounded by two atmospheres, of which the outer was luminous, continued to be accepted by astronomers well into the nineteenth century. Developments in spectroscopy and in our understanding of thermodynamics eventually led to the abandonment of this model in favour of one in which the Sun was considered to be gaseous throughout, but traces of the older theories can be found even in the early twentieth century.

Keywords: solar models, gaseous stars, Arago, Eddington, Emden, Faye, Herschel, Janssen, Kirchhoff, Lane, Lockyer.

1 INTRODUCTION

In a recent contribution to this *Journal*, Michael Crowe (2011) has shown that the belief that the Sun might possibly be inhabited survived for a surprisingly long time into the nineteenth century. As Crowe points out, such a belief is quite incompatible with our modern knowledge of the structure and evolution of the Sun and other stars. There is, therefore, a related question to ask: when did it come to be generally believed that the Sun is gaseous throughout? The answer to this question is again that the belief was not generally accepted until surprisingly late—early in the twentieth century. We who were active in research in the twentieth century tend to think of it as a period of unequalled growth not only in astronomy but also in the other sciences. The nineteenth century, however, was also a period of rapid growth, if one measures that growth by comparing what was known at the beginning of the century with what was known by its end, even if that progress sometimes seemed slow to those working during that time. Our understanding of solar structure, in particular, seemed to change slowly and some were reluctant to adopt new ideas, and this is but one example of changes in all the sciences during the nineteenth century. At the beginning of that period, scientists still called themselves 'philosophers'; by the end, they were referring to themselves as 'men of science'. (Most of them *were* men then, and many disliked the neologism 'scientist' coined by William Whewell in response to the poet Samuel Taylor Coleridge criticizing the use of the word 'philosopher'.)

2 HERSCHEL'S SOLAR MODEL

As Crowe made clear, the generally accepted solar model at the beginning of the nineteenth century was basically the one described by William Herschel (Figure 1; 1795; 1801). The French astronomer François Arago (Figure 2; 1786–1853) described it well both in his *Astronomie Populaire*, published posthumously, and in an

Figure 1: Sir William Herschel, 1738–1822 (courtesy: http://www.sterrenkunde.nl/deepsky/hulpmiddelen-ol.htm)

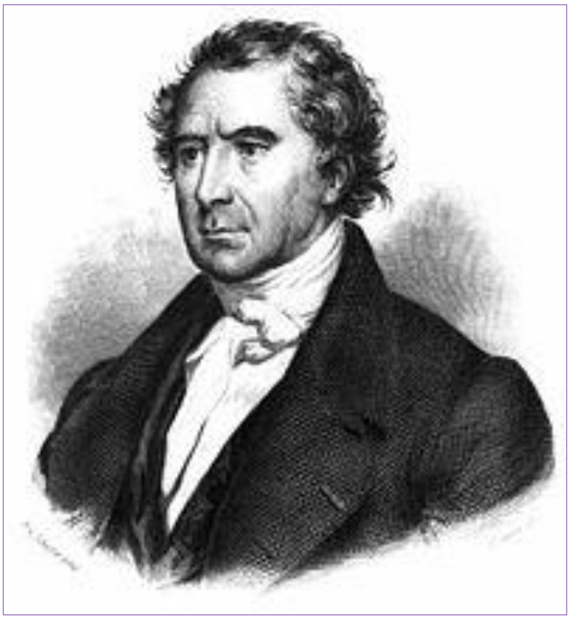

Figure 2: Francois Arago (courtesy: en.wikipedia.org).

Figure 3: A photograph of Sir John Herschel, taken by Julia Margaret Cameron in 1867 (courtesy: en.wikipedia.org).

account of his lectures published anonymously by "… *un de ses élèves* …", which went through several editions during Arago's lifetime (Anonymous, 1849; Arago, 1855: 131-132). In these works Arago set out a tripartite model of the Sun: (i) a nucleus or core, which was a "… dark body …" (French *corps noir*); (ii) a very dense cloudy atmosphere; (iii) a luminous atmosphere which, he adds, German astronomers have called the *photosphere.* This he describes as the generally accepted model of the Sun. As Crowe has also pointed out, he thought it quite possible that intelligent beings could exist on the central dark body, but explicitly refrained from saying that he believed that they actually did so. He also pointed out in the anonymous version of his lectures that human beings could not exist there, since they would have 28 times the weight they experienced here on Earth. He further stated that if the Sun were incandescent throughout, then life could not possibly exist there. Arago was convinced that he had found proof that the visible surface of the Sun was gaseous and neither solid nor liquid. He had observed the Sun with the polariscope (his own invention) and found that sunlight was not polarized, either from the centre of the solar disc or from the limb, whereas light that he observed from the limb of an incandescent solid body was polarized.

Figure 4: Hermann von Helmholtz (courtesy: en.wikipedia.org).

This latter conclusion was to be criticized by Arago's contemporary, J.F.W. Herschel (Figure 3; 1792–1871). A large part of the younger Herschel's library is now in the possession of the University of Toronto (Broughton, 2013, and private communication) and includes an Italian translation of *Leçons d'Astronomie*, the anonymous account of Arago's public lectures. John Herschel wrote in the margin of his copy: "???This is simply absurd". The 'absurdity' could not have been Arago's notion that the visible surface of the Sun was a luminous atmosphere, since Herschel shared that belief. Rather, it was Arago's claim that his polarization observations had *proved* the surface to be gaseous that Herschel criticized, as he later made clear in the fifth edition of his *Outlines of Astronomy* (Herschel 1858: 245-246). If the surface of the Sun were a *rough* incandescent solid, Herschel argued, Arago would have obtained the same result.

3 THE TURNING POINT

In a later paper, John Herschel (1864: 219) opened his discussion with the following remark:

> The physical constitution of the sun and the nature of the source from which its expenditure of light and heat is supplied, must be regarded as by far the most important astronomical problem which remains unsolved …

Indeed, it remained unsolved into my own lifetime and, as we know, astronomy had to draw on the related science of physics to find the solution. In 1854, Hermann von Helmholtz (Figure 4; 1821–1894) first speculated in a lecture that the source of the Sun's light and heat was gravitational contraction—a notion that surely implied a gaseous model for the Sun. The lecture was not published for many years: eventually A.J. Meadows (1970) reprinted an English version of it that was published in 1907. Meadows' book, incidentally, is an excellent source for this period, not only because of his own historical introduction, but because he also reprints (in translation if necessary) several of the seminal papers. It is perhaps because of this long delay in Helmholtz' publication that we now speak of Kelvin-Helmholtz contraction, but that is a little unfair since Kelvin first tried to explain the Sun's source of heat by the influx of meteoric material, and turned his attention to the contraction hypothesis only when he realized that the other was totally inadequate.

The real turning point, however, came from another branch of physics, namely, spectroscopy. In 1861, Gustav Kirchhoff (Figure 5; 1824–1887) published two important papers (both reprinted by Meadows). The first (Kirchhoff, 1861a) was an account of the experiments he and Bunsen had performed on the line spectra of elements which showed that the spectrum of the Sun and stars could be explained by assuming that the photosphere was surrounded by a cooler atmosphere that selectively absorbed the continuous photospheric radiation. The second paper (Kirchhoff, 1861b) contained Kirchhoff's Law, that the emitting and absorbing powers of material bodies are proportional, and it also introduced the modern concept of a *black body.* Clearly*,* the addition of a cooler atmosphere *above* the photosphere made the assumption of a similarly cooler atmosphere *below* it look like an unlikely complication, especially because Kirchhoff believed the photosphere to be an incandescent solid. Nevertheless, many found it difficult to abandon the elder Herschel's solar model.

4 NEW BEGINNINGS

We have already referred to John Herschel's 1864 paper, which was titled "On the solar spots*".* Many of the papers in this period that were concerned with the nature of the Sun in fact dealt at some length with sunspots. This was because, on the tripartite model, the spots were thought of as windows through which we were able to see the surface of the putative dark body of the Sun. Although this 1864 paper is often cited as presenting a gaseous model for the Sun, I do not read it as a clear endorsement of the idea. There are two significant comments in the paper. On page 222 Herschel wrote: "… the enormous pressure at the surface of its solid globe (if it have any such) …" and, on the following page,

> It is inconceivable, indeed, that the actual surface of the solid globe (*if there be any such definite surface*) surrounded as it is by an *enceinte* of such a temperature as that of the photosphere, should be otherwise than in a state of the most vivid incandescence. (Herschel, 1864: 223, his italics).

Clearly, John Herschel was beginning to have doubts about his father's model but he did not seem ready to abandon it completely. Indeed, Meadows points out that even in the 1869 edition of his *Outlines of Astronomy* the younger Herschel still put forward the elder's model of the Sun.

Figure 5: Gustav Kirchhoff (courtesy: en.wikipedia.org).

In the same year Angelo Secchi (Figure 6; 1818–1878,) also discussed the possibility of a gaseous Sun in one of two papers which have recently been translated and published on line (Secchi, 1864). Again, however, there is no more than a suggestion that the Sun might be completely gaseous, although Secchi does explicitly say that he does not believe in Herschel's model.

Early in the following year, the French astronomer Hervé Faye (Figure 7) presented two papers to the Academy of Sciences in Paris titled: "Sur la constitution physique du soleil." Faye, 1865a; 1865b). They are often referred to as two of the first papers to propose a gaseous model of the Sun but, despite their title, like the earlier papers of Herschel and Secchi, they are largely concerned with sunspots. Only towards the end of the second paper does Faye (who

Figure 6: Angelo Secchi (courtesy: en.wikipedia.org).

Figure 7: Hervé Faye, 1814–1902 (courtesy: en.wikipedia.org).

worked under Arago at the Paris Observatory and clearly thought of himself as Arago's successor) venture to speculate a little on the nature of the Sun and stars. He proposed three stages in a star's life. The first, which he tentatively identified with planetary nebulae, was a diffuse object that would show an emission-line spectrum. The *fluid* (i.e. not explicitly gaseous) mass then contracts, the outer layers cool, a photosphere is formed, some molecules even form, a typical stellar spectrum is seen, and the light emitted from any part of the solar (or stellar) disc is not polarized, as Arago had found. In this stage contraction could supply heat and light, as Helmholtz had suggested. Finally, the star would cool further, the photosphere would become very thick and assume the consistency of a liquid, paste, or even a solid. Light from the limb of the object would then be seen to be polarized. This discussion is entirely qualitative and Faye did not put forward a mathematically- or physically-coherent model of a gaseous star.

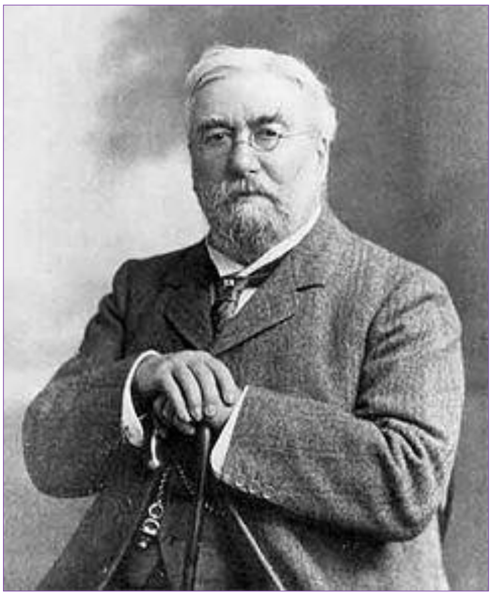

Figure 8: The image of Sir Norman Lockyer that appeared in 1909 in the *Proceedings of the Royal Society* (courtesy: en.wikipedia.org).

The honour for making that important advance undoubtedly goes to J. Homer Lane (1819–1880) in a paper published in 1870. Lane's work and its significance have been thoroughly discussed by Powell (1988). Lane appears to have entertained his ideas for some time before publishing but held back because he himself did not think them fully plausible. Perhaps he was encouraged by the papers by Faye and Herschel as well as one by William Thomson, Lord Kelvin (1862) which introduced the concept (and term) of *convective equilibrium*—which was the basis of his own model. (The concept of *radiative equilibrium* was introduced by Karl Schwarzschild (1906) much later.) Because Lane was a physicist rather than an astronomer, he was not as enamoured as his predecessors had been with Herschel's tripartite model. He was also more familiar with the advances that were being made in thermodynamics and the kinetic theory of heat and this, no doubt, helped him to devise a physically-coherent model.

However, there were still problems. What we would now call the effective temperature of the Sun was poorly known, with estimates ranging very widely. More importantly, Lane and his contemporaries were well aware that the pressures at the centre of a wholly gaseous Sun would be enormous and that the laws for ideal gases could not be expected to apply there, yet the solar model assumed the ideal-gas laws. Van der Waals' corrections to those laws were not published until 1881 and, even after Lane, investigators such as Georg August Dietrich Ritter (1826–1908) and Jacob Robert Emden (1862–1940) continued to assume that the ideal-gas laws applied. This was a real barrier to the acceptance of wholly gaseous stars right up to the time of Eddington. Another was the belief that if the photosphere was gaseous the limb of the Sun should not appear sharp—hence Kirchhoff's solid photosphere. Ritter soon followed Lane with a series of eighteen papers published in *Wiedemann's Annalen*, the sixteenth of which was translated and reprinted in the *Astrophysical Journal* (Ritter, 1898) and is also available on line. The classic text, of course, is Emden's famous book, *Gaskugeln*, which appeared early in the twentieth century (Emden, 1907).

5 OBSERVATIONAL ADVANCES

Nineteenth-century advances in methods of observing the Sun played an important role in advancing the understanding of the nature of that star. At the beginning of the century, prominences and the corona could be observed only during a total solar eclipse and astronomers were uncertain whether these phenomena were appendages of the Sun or of the Moon. Secchi is credited with having shown at the eclipse of 1860 that they must be appendages of the Sun and the invention of the spectrohelioscope independently by J. Norman Lockyer (Figure 8; 1836–1920;) and Jules Janssen (Figure 9; 1824–1907;) settled the matter and enabled prominences to be studied in much more detail. A photosphere that was only a relatively thin 'luminous atmosphere', underneath which was a cooler cloudy atmosphere would seem less likely when it was understood that massive jets of gas could be thrown up above that photosphere. Janssen (1879) appears to have accepted the new ideas; he quotes Arago's opinion:

> … if anyone asked me if the Sun could be inhabited by a civilization like ours, I would not hesitate to say 'yes' … [and adds] Such a reply would be almost ridiculous today.

It is of interest that Crowe (2011) points out that Lockyer still believed in the possibility of solar life in 1870—he appears not to have been so easily convinced of the new ideas as his rival Janssen had been, although in 1869, together with the chemist E. Frankland, Lockyer wrote a paper in which they rejected Kirchhoff's solid or liquid photosphere, saying that the latter must be "… cloudy or gaseous or both."

In another respect, however, Lockyer was ahead of his time, although for a wrong reason. Because he worked at low spectroscopic dispersions, he could not always distinguish between closely neighbouring Fraunhofer lines in the solar spectrum. He came to believe that the spectra of iron and calcium had some lines in common and he regarded this as evidence that atoms could be broken down into something simpler and these simpler bodies produced what he called the 'basic lines'. Later, he came close to the modern concept of ionization (Meadows, 1970: 73-81) and all this before the discovery of the electron, let alone Ernest Rutherford's work on atomic structure.

6 DENOUEMENT

As we all know, it was the early work of Arthur Stanley Eddington (Figure 10; 1882–1944) that finally brought us to our modern concepts of stellar structure, but even he was imbued with nineteenth-century ideas from which he had to break loose. In a recent paper, Matthew Stanley (2007) has pointed out that Eddington wrote an article on "Stars" for the famous eleventh edition of the *Encyclopædia Britannica* in which the following statement is found:

> The spectrum consists of a continuous band of light crossed by a greater or less number of dark absorption lines or bands. As in the case of the Sun, this indicates an incandescent body that might be solid, liquid, or a not too rare gas, surrounded by and seen through an atmosphere of somewhat cooler gases and vapours … (Eddington, 1911).

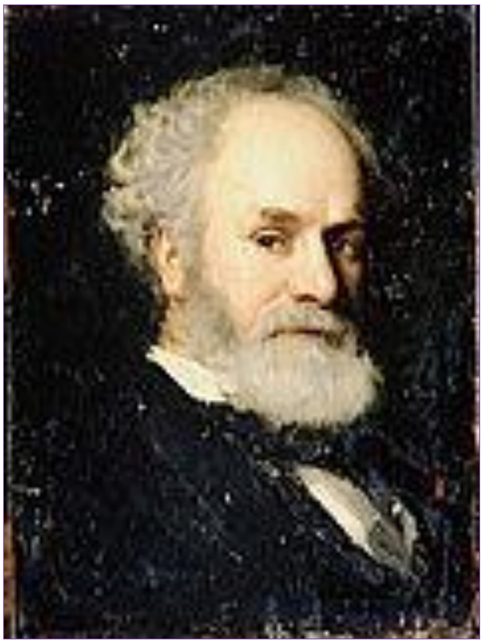

Figure 9: A painting of Jules Janssen by Jean-Jacques Henner (courtesy: en.wikipedia.org).

It is almost incredible that this should have been written by the man who, within the next two decades, was to lay the foundations of all our modern ideas of stellar structure and evolution. We might recall, however, that James Hopwood Jeans' (1919) famous work on the stability of rotating fluid masses, published even later, treated both compressible and incompressible (liquid) fluids.

Emden's *Gaskugeln* had been published some three years before Eddington wrote his encyclo-

Figure 10: Sir Arthur Eddington (courtesy: en.wikipedia.org).

pædia article and we know that he read the book at some time, because he often cited it in later work. In fact, we know that Eddington owned a copy because D.S. Evans (1998: 102, 108) records that he purchased it after that man's death. We don't know whether Eddington had read Emden before he wrote the article for the *Britannica*. The key to understanding Eddington's hesitancy in accepting a gaseous model for the Sun rests, of course, in the phrase "… a not too rare gas". That models based on the laws for ideal gases should be able accurately to represent real stars was still rather hard to believe. We can see this even more clearly in Eddington's (1927) great work, *The Internal Constitution of the Stars*, in which he presents the mass-luminosity relation. At the time, it was believed that giant stars could perhaps be described by theories based on the laws for ideal gases, but that dwarf stars, including the Sun, could not. Eddington's comment on his discovery that the one relation satisfied both kinds of star is worth quoting:

> The agreement with observations was a complete surprise for it was not at all the result that was being looked for. Nearly all the accurate data relate to dwarf stars; Capella had been used to fix one of the constants of the curve; and it was reluctantly decided that no other truly gaseous stars were available to test the curve. (Eddington, 1927: 164).

He soon, of course, saw the solution: atoms in the deep interiors of stars were stripped of all their electrons and the nuclei, being much smaller than the neutral atoms, could behave *en masse* like an ideal gas. Lockyer was vindicated in a surprising way: the last obstacle to accepting completely gaseous stars had been removed, and modern astrophysics was born. Even then, however, Eddington was reluctant to accept the conclusion adumbrated in Cecila Payne's (1925) thesis *Stellar Atmospheres*, that the stars, including the Sun, were predominantly composed of hydrogen. It took several more years for that to be accepted. The full story is well described by David DeVorkin (2000: 199-220) and I cannot improve on that treatment here.

After I had completed a draft of this paper, my attention was drawn to a paper by Robitaille (2011) which covers much the same ground as I have attempted to do in this paper. Robitaille presents the history in support of his argument, not generally accepted, that the Sun is composed of hydrogen in the liquid metallic phase.

7 CONCLUDING DISCUSSION

At the beginning of this paper I suggested that the expansion of astronomical knowledge, and indeed all scientific knowledge, was as rapid in the nineteenth century, in comparative terms, as it was in the twentieth. This may seem counter-intuitive; after all, the second half of the twentieth century was one of explosive growth in astronomy. We became able to observe from above the Earth's atmosphere and in many wavelength regions other than the optical one. The diameters of the largest optical telescopes available doubled in the same period and plans are well advanced for further increases. New types of objects that we never even suspected (e.g. pulsars and quasars) have been found. Cosmology has developed from being largely speculation to becoming a rigorous science. In the particular matter of the nature of the Sun and stars, we have built well on Eddington's foundations. If we look outside astronomy, we recall that physics underwent two major revolutions in the early twentieth century, and in biology the famous discovery of the structure of DNA completely revolutionized the whole science with effects that are impacting each one of us directly. How could the nineteenth century equal this tremendous progress?

To answer that last question, we must recall how little was actually known at the beginning of the nineteenth century. No distance to any star other than the Sun was known. More importantly, the necessary physics for understanding stellar structure still had to be developed. We have seen how astronomers had to adopt the techniques of spectroscopy and photography and to digest the developments of thermodynamics and the kinetic theory of heat. We might also recall that the nineteenth century saw the growth of studies in electricity. Faraday's experiments, although not directly impacting astronomy, led to Clerk-Maxwell's derivation of the equations of electro-magnetism which, in turn, were to impact on Einstein's relativity theory. If, again, we look outside astronomy and physics to biology, we see Darwin's theory of evolution, which was more fundamental and probably about as revolutionary as the discovery of the structure of DNA. Coincidentally, each of those discoveries came about halfway through their respective centuries.

What lessons can we learn from this story? First, the story illustrates a dictum often ascribed to Max Planck to the effect that new ideas do not win acceptance, their opponents die out. If one looks at the birth dates of the people discussed in this paper, one is struck by the fact that nearly all those born in the eighteenth century either stuck with the tripartite solar model or abandoned it only very reluctantly. On the other hand, nearly all those born in the nineteenth century were open to the new ideas which, in fact, they helped to develop. More important, perhaps, is the lesson that can be summed up in another famous quotation: "Those who cannot remember the past are condemned to repeat it

…" (Santayana, 1905: 284).

Contemplation of this history should instill a proper humility about some of our own ideas. It is easy to laugh at the notion of a dark core at the centre of the Sun, let alone the idea of solarians, but the astronomers who entertained such ideas were arguing reasonably by analogy from the only astronomical body of which they had direct experience, namely, the Earth. They could do no better until other branches of science were sufficiently developed. Our ideas of stellar structure, at least for the main-sequence stars, are now probably surely founded. We are most unlikely to see a revolution in them as far-reaching as the one described here. There are other areas of our science, however, where we are still on uncertain ground. Will astronomers one or two hundred years hence marvel at the confidence with which we talk of 'dark energy' and 'dark matter'—or perhaps even of the 'Big Bang'—every bit as much as we marvel that a scientist of the stature of Arago could confidently state that the Sun was a dark body surrounded by a dense cloudy atmosphere and an outer luminous one?

Crowe (2011) mentions Arago's story of a Dr Elliot, tried at the Old Bailey for murder, whose friends mounted a defence of insanity on the grounds that Elliot believed in the possibility of an inhabited Sun. Crowe also records Arago's dry comment that the opinions of a madman have now become generally accepted. Unfortunately, he leaves off the final (to us) ironic twist: "The anecdote appears to me to be worthy of figuring in the history of the sciences." (Arago, 1855)!

8 ACKNOWLEDGEMENTS

I am grateful to R. Peter Broughton who drew my attention to the collection of John Herschel's books at the University of Toronto and to his criticisms of Arago, thereby stimulating my interest in this study. He also drew my attention to the paper by Robitaille. Joe Tenn and Derek McNally have kindly read an early draft and made useful suggestions, as has also an anonymous referee.

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Alan H. Batten spent his active career at the Dominion Astrophysical Observatory in Victoria, B.C., Canada, where he studied spectroscopic binary systems. He served as a Vice-President of the International Astronomical Union from 1985 to 1991 and is a member of the Editorial Board of this *Journal*. His latest book, *Our Enigmatic Universe*, was published in 2011.

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ABORIGINAL ORAL TRADITIONS OF AUSTRALIAN IMPACT CRATERS

Duane W. Hamacher
Nura Gili Centre for Indigenous Programs, University of New South Wales, Sydney, NSW, 2052, Australia.
Email: d.hamacher@unsw.edu.au

and

John Goldsmith
Curtin Institute for Radio Astronomy, Curtin University, GPO Box U1987, Perth, WA, 6845, Australia.
Email: john.goldsmith@icrar.org

Abstract: In this paper we explore Aboriginal oral traditions that relate to Australian meteorite craters. Using the literature, first-hand ethnographic records and fieldtrip data, we identify oral traditions and artworks associated with four impact sites: Gosses Bluff, Henbury, Liverpool and Wolfe Creek. Oral traditions describe impact origins for Gosses Bluff, Henbury and Wolfe Creek Craters, and non-impact origins for Liverpool Crater, with Henbury and Wolfe Creek stories having both impact and non-impact origins. Three impact sites that are believed to have been formed during human habitation of Australia—Dalgaranga, Veevers, and Boxhole—do not have associated oral traditions that are reported in the literature.

Keywords: Aboriginal Australians; ethnoastronomy; ethnogeology; impact craters (Dalgaranga, Gosses Bluff, Henbury, Liverpool, Veevers, Wolfe Creek); geomythology

Notice to Aboriginal and Torres Strait Islander Readers: This paper contains the names and images of people who have died.

1 INTRODUCTION

Prior to the European colonization of Australia by the British in 1788, Aboriginal Australians were a predominantly hunter/gatherer people with several hundred distinct languages and dialects spanning all corners of the continent. Genetic and archaeological evidence shows that Aboriginal people migrated to Australia from Southeast Asia over 40,000 years ago (Bowler et al., 2003), with upper limits exceeding 60,000 years (Rasmussen et al., 2011). Aboriginal cultures did not develop written languages, relying instead on strong oral traditions where knowledge was passed through successive generations in the form of story, song, dance, art and material culture. Aboriginal knowledge is typically transmitted through the 'Dreaming', which is the embodiment of the oral traditions, laws, customs and culture of the community (Rose, 1992). In Aboriginal cultures, the Dreaming is sometimes thought of as a time in the distant past when spiritual ancestors and beings formed the land and sky. It can also be thought of as a current parallel reality and is generally considered non-linear in time.

Aboriginal knowledge systems include explanations about the natural world, which have practical applications and are used for predictive purposes. This research area is known as 'ethnoscience'. Ethnoscience relates to environmental and atmospheric science (Clarke, 2009), astronomy (Clarke, 1997; Norris and Hamacher, 2009), ecology (Vigilante, 2004), botany (Clarke, 2007), zoology (Isaacs, 1996) and geography (Walsh, 1990). Aboriginal knowledge regarding meteoritics is evident in oral traditions of impact events that currently are not associated with impact sites known to Western science (see Hamacher and Norris, 2009), meteorites (Bevan and Bindon, 1996), meteors (Hamacher and Norris, 2010) and comets (Hamacher and Norris, 2011). The hypothesis that Aboriginal people witnessed impact events and recorded them in their oral traditions is a form of 'ethnogeology', which provides explanations for the formation and nature of geological features (Murray, 1997). For example, the ethnogeology of Wolfe Creek Crater has been explored by Reeves-Sanday (2007) and Goldsmith (2000), and also is the focus of Goldsmith's (2013) Ph.D. thesis.

Of the 26 confirmed meteorite impact craters in Australia (Bevan and McNamara, 2009), the six smallest craters, Boxhole, Dalgaranga, Henbury, Liverpool, Veevers and Wolfe Creek, each with diameters <2 km, are also the youngest (and their locations are shown in Figure 1). Each of these craters is identifiable as a prominent unusual feature in the landscape. Four of them are believed to have been formed during the Holocene era, only 25% of the minimum time humans have inhabited Australia: Henbury (≤4,700 years), Boxhole (5,400 ± 1,500 years), and possibly Veevers (<4,000 years) and Dalgaranga (<3,000 years) (Haines, 2005). Because of this, we searched for records of these six impact sites in Aboriginal oral traditions. Many of the larger craters are either buried or eroded to such a point that they are not easily distinguishable from the surrounding landscape and are geologically very old. Therefore, we do not

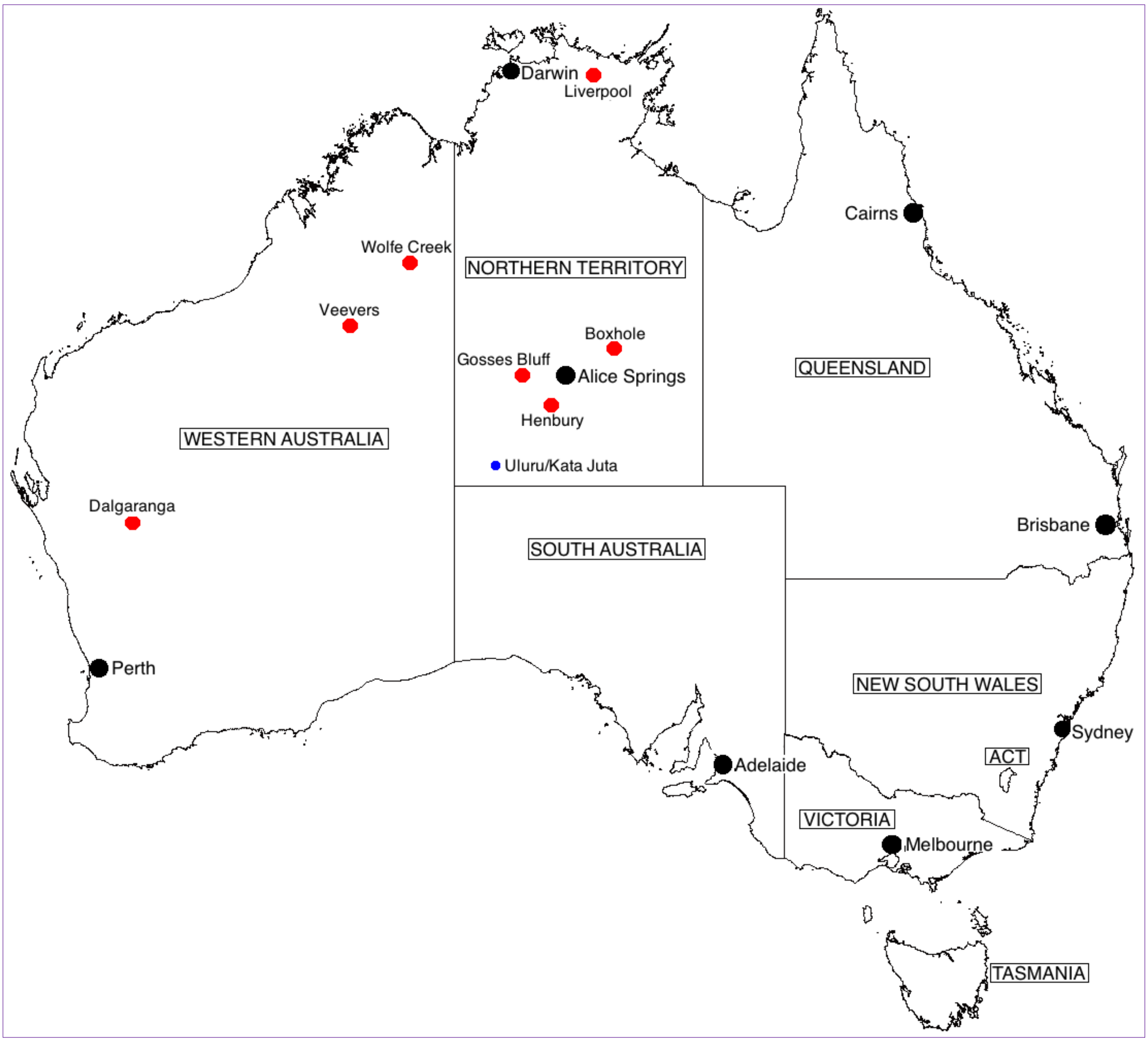

Figure 1: Map showing Australian meteorite craters (in red) discussed in this paper.

expect to find stories associated with these structures. Some of the larger, older craters are more prominent on the landscape, such as Gosses Bluff (Northern Territory) or Goat Paddock (Western Australia), or possess unusual features, such as Spider Crater (Western Australia). Other craters may form bodies of water, such as Lake Acraman (South Australia) or Shoemaker Crater (formerly Teague, Western Australia). We might expect to find oral traditions associated with such structures but we do not expect them to relate to a cosmic impact. We also suspect that oral traditions associated with some craters exist, but simply have not been collected or published.

In this paper we explore Aboriginal traditions relating to Australian impact craters and seek to find out if these traditions describe craters as originating from a cosmic impact. Data used in this paper were collected from ethnographic fieldwork, published ethnographies, historical and ethno-historical documents, linguistic sources and Aboriginal artworks. This paper represents a synthesis of Aboriginal traditions regarding confirmed Australian impact craters and includes new information that has not been reported previously in the literature.

In the following Sections we describe traditional knowledge regarding Gosses Bluff and Henbury, Liverpool and Wolfe Creek Craters. We find no traditions associated with the Boxhole, Dalgaranga or Veevers Craters. We are faced with several possibilities that may explain the presence or absence of these stories:

1. The story is based on a witnessed event and was recorded in oral traditions;
2. The formation of the crater was not witnessed, but was deduced and then incorporated in oral traditions;
3. The formation of the crater was not witnessed, and stories explaining it as an impact site are coincidental;
4. The origin or nature of the crater is not part of

Figure 2: Gosses Bluff (*Tnorala*) as seen from the south (photograph: D.W. Hamacher).

a structured oral tradition (Dreaming), but is generically attributed to supernatural elements or grouped with general landscape features;
5. Impact stories were influenced by Western science;
6. Related stories may have once existed but have been lost for whatever reason; or
7. No stories of the crater ever existed.

It is difficult to know which possibility is true in each instance, but in the following Sections we explore each of these with reference to the craters mentioned above.

2 CRATERS WITH KNOWN ORAL TRADITIONS

2.1 Gosses Bluff Crater (*Tnorala*)

Gosses Bluff (Figure 2) is a highly-eroded complex structure 22 km in diameter with the central uplift forming a ring-shaped mountain range measuring 5 km wide by 250 m high (Milton et al., 1996). The crater is 160 km west of Alice Springs, and was formed from an impact 142.5 ± 0.8 million years ago (Milton and Sutter, 1987). It was identified by Edmund Gosse in 1873 (Crook and Cook, 1966). The structure was mapped by the Bureau of Mineral Resources in 1956 and was considered to have formed by either a volcanic or an impact event (e.g. Crook and Cook, 1966; Cook, 1968). Only in the early 1970s was Gosses Bluff finally accepted as an impact structure (Milton et al., 1972).

Gosses Bluff is called *Tnorala* in the Western Arrernte language, and is registered as a sacred site. Herman Malbunka was the custodian of the *Tnorala* story. Upon his death, his wife, Mavis, became the caretaker (*kurturngula*) of the story. The story of *Tnorala* is now well known thanks to documentaries (e.g. Malbunka, 2009) and film dramatisations, mainly for the fact that the Aboriginal story mirrors the scientific explanation of the crater. According to Mavis Malbunka (Thornton, 2007), in the Dreaming a group of women took the form of stars and danced in a corroboree (ceremony) in the Milky Way. One of the women was carrying a baby boy, and she put him in a *coolamon* (or *turna—a* type of wooden basket) and placed it on the Milky Way. When the woman went back to continue dancing with the others the *turna* slipped off the Milky Way. The baby struck the Earth and was covered by the *turna*, the force of which drove the rocks upwards, forming the mountain range we see today. The baby's mother, the evening star, and father, the morning star, continue to search for their baby to this day (see also Parks and Wildlife Commission of the Northern Territory, 1997: 1; Cauchi, 2003).

Mavis Malbunka continues:

> We tell the children don't look at the evening star or the morning star, they will make you sick because these two stars are still looking for their little baby that they lost during the dance up there in the sky, the way our women are still dancing.

Mavis Malbunka never identified Venus as the morning or the evening star, although this is assumed. She notes that the morning and evening star are not always visible: "They don't show themselves all the time. No! Only every now and then." This is consistent with a reference to Venus, but instead Mavis Malbunka identified the 'morning' and 'evening' stars as a mysterious phenomenon known as the 'min-min lights'. These 'ghost lights' are prominent in the Aboriginal folklore of eastern Australia. For example, Pettigrew (2003) recounts an anecdote about two health workers at Hermmansburg (Ntaria) in Central Australia (131 km southwest of Alice Springs) who were pursued by a min-min light, which she claimed was the baby's mother searching for her lost child. It is possible that the story of the min-min light was imported from communities further east and incorporated into the current oral traditions.

Mavis Malbunka states that the celestial *turna* "… is still there. It shows up every winter." Although she did not identify the celestial *turna* in the media that featured the *Tnorala* story, during

Figure 3: The constellation Corona Australis. The curve of stars is seen as the *turna* falling from the Milky Way. Image from Stellarium software package (www. Stellarium.org).

the 2012 Meteoritical Society fieldtrip to the Central Desert, the tour-guide pointed out the *turna* in the sky as the constellation Corona Australis (the Southern Crown). This arch of stars forms the same shape as a *turna* seen from the front (Figure 3) and is visible south of the galactic bulge high in the winter night sky after sunset. The guide claimed to have learnt the identity of the celestial *turna* from members of the local community, but this was not reported in the published literature or discussed in ethnographic field notes.

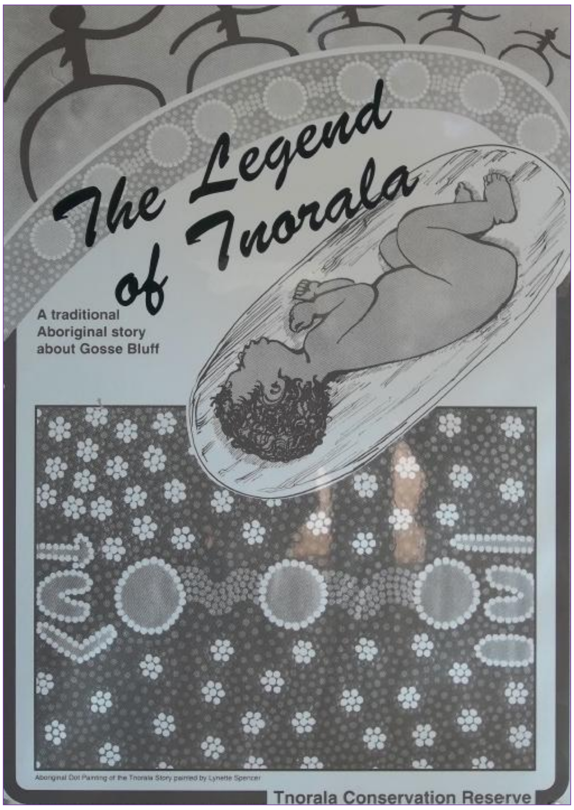

Figure 4: Information sign at the Tnorala Conservation Reserve. Painting by Lynette Spencer (photograph: D.W. Hamacher).

The story is visualized in an Aboriginal painting by Lynette Spencer, which is featured on the bottom of tourist signs at the site (Figure 4). The meanings of the motifs in the painting are not provided, although the anthropomorphic figures that feature at the top of the sign are based on Arnhem Land figures. These are not part of the painting by Spencer.

According to Arrernte traditions (as noted on signs at the site):

> Tnorala was a special place where many bush foods were created by rubbing special rocks made by the falling star, the Milky Way baby. On the baby's body were many sacred stories, about other matters of importance, which were held in these rocks. Men were responsible for some rocks and women for others. Each rock represented a particular bush food. Men or women would rub the rock and sing, so that there would be a good supply of the food that rock represented.

The signs claim that the sacred 'rubbing rock' has gone missing. Because of this, a food called *puraltja* no longer grows in large quantities, except after heavy rain, and Mavis Malbunka now asks visitors not to take rocks from *Tnorala*. There is no information regarding the identity of these rocks, but they could not be remnant fragments of the impactor.

Local traditions describe the center of *Tnorala* as the site of a massacre. The story of the massacre does not appear in the anthropological literature, but is provided on signs posted in the Reserve, and is based on local traditional knowledge. The story tells that long before Europeans came to Australia, a community lived in *Tnorala*. One day one of the men went hunting for kangaroos. When he returned, he found that all of his people had been murdered, including the women and children. He knew this was the act of the Kurdaitcha men—fierce warriors who lived in the desert to the south. The man informed the rest of his family, who lived in the ranges nearby. They formed a party and hunted down and killed the Kurdaitcha men. Because of the massacre, *Tnorala* is known as a 'sorry place' and the center of the crater is considered sacred ground. It is not clear if this story is based on an actual event or is mythological in nature.

Nothing is reported in the anthropological literature about the Dreaming story of *Tnorala*. It only appears in media reports and in local knowledge. Four possibilities exist regarding the origin and nature of this Dreaming story:

1. The story pre-dates colonization, and the impact story is coincidental to *Tnorala* being an impact crater; or

2. The story pre-dates colonization, but the impact origin was deduced by Aboriginal people on the basis of the structure's morphology (one can make the shape of a crater like this by dropping a heavy stone in sand); or
3. The story is post-colonisation, and was inspired by the intensive scientific research that has been conducted at the crater over recent decades; or
4. The story pre-dates colonization, but was changed to incorporate new knowledge gained from Western science.

In this fourth case, the term 'pre-dates colonisation' could be replaced with 'before European interest in the site', even if the story developed after colonisation. Mavis Malbunka does not say how old the story is, and it is not known how many generations passed on this story. The nature of Aboriginal traditions is such that stories do not necessarily have an 'origin' in linear time. New events may be incorporated into existing oral traditions or may form the basis of a new oral tradition (e.g. see Hamacher and Norris, 2009). One should be warned that asking an Aboriginal person about the 'date of origin' of a story may be inappropriate, as the Dreaming in many Aboriginal cultures still exists and is not restricted to a time in the distant past.

It is probable that scientists researching the site have had some influence on local traditions, but the degree of this influence is unknown and we cannot assume that impact stories associated with Gosses Bluff *must* have originated from Western science. A number of impact stories can be found across Australia with no associated impact structures or meteorite falls known to Western science (see Hamacher and Norris, 2009)—and some of these are from Arrernte country. A survey of meteoritic traditions might help us understand the story of *Tnorala*. In some Arrernte traditions, meteors signified that the spirit of a person who died far from home was returning to their home country (Basedow, 1925: 296). Meteors also could represent the presence of an evil magic called *Arungquilta* (Spencer and Gillen, 1899: 566). Other Arrernte traditions identify meteors as the fiery eyes of celestial serpents that drop into deep waterholes (Strehlow, 1907: 30). A story recorded by Róheim (1945: 183) highlighting this view comes from Palm Valley in the nearby MacDonnell Ranges. In the story, a star fell into a water hole where the serpent *Kulaia* lived, making a noise like thunder. Western Arrernte traditions claim that the first human couple originated from a pair of stones that were thrown from the sky by the spirit *Arbmaburinga* (Róheim, 1971: 370).

Unfortunately, none of these stories sheds any light on the *Tnorala* story, as it did not relate to serpents, evil magic or death. It only involved a lost baby, and the parents searching for their child. The *Tnorala* story does not explicitly say that the baby died when it fell from the heavens, only that it was covered by the *turna*. Future work with Arrernte custodians may help clarify these points.

2.2 Henbury Crater Field (*Tatyeye Kepmwere*)

The Henbury crater field (Figure 5) is approximately 130 km south of Alice Springs and comprises 13-14 simple impact craters spread out over a square kilometer (Alderman, 1932; Haines, 2005). The craters, ranging in size from ~10 m to 180 m in diameter, were formed from the impact of a nickel-iron meteoroid that fragmented prior to impact ≤4,700 years ago (Kohman and Goel, 1963). Given the relatively young age of the impact, one might expect that the event is recorded in Aboriginal oral traditions.

The craters lie on Henbury Station which is 5,273 km^2 in area and was operated on a pastoral lease from 1877, founded by Walter and Edmund Parke (Buhl and McColl, 2012: 13). Walter Parke identified the craters in 1899, and wrote to the noted ethnologist Francis Gillen, describing the area as "… one of the most curious spots I have ever seen in the country." Parke was unsure of the structures' origin and stated:

> To look at it I cannot but think it has been done by human agency, but when or why, goodness knows! (Buhl and McColl, 2012; Parks and Wildlife Commission of the Northern Territory, 2002: 2).

In January 1931, thirty-three years after Walter Parke found the craters on Henbury Station, a prospector named James Maxwell Mitchell sent a meteorite fragment to the University of Adelaide. Through a series of events it came to the attention of a young geologist named Arthur Alderman, who conducted the first scientific investigation of the site a few months later, in May 1931 (Alderman, 1932). In an addendum in Alderman's paper, L.J. Spencer included communication with Mitchell who had visited the site some years earlier and was the first person on record to identify it as a meteorite impact site (see Buhl and McColl (2012) for a full treatise on the history of research at Henbury).

According to Mitchell (1934), when he visited a blacksmith in Todmorden in 1916 he noticed a peculiar piece of metallic iron that he believed contained nickel. When he learned that the object had been taken from 'blowholes' at the Henbury Station he visited the Station and found a number of large metallic stones around the craters and concluded that they had

Figure 5: The larger cluster of the Henbury craters, as seen from the Bacon Range looking to the northeast (photograph: D.W. Hamacher).

> … dropped from a molten mass falling at great speed … [and that] huge masses of metal probably lay buried in the bottom of the craters.

Unfortunately, Mitchell passed away the following year, in 1935. His obituary (Anonymous, 1935) claims that while he was on a prospecting expedition in 1921 his attention was further drawn to the craters after his Aboriginal guide refused to go near them. According to the obituary (ibid.), local Aboriginal traditions described the place as where "… a fire debil-debil came out of the sky and killed everything in the vicinity."

Alderman's study confirmed the craters were of meteoritic origin. The discovery of a well-preserved crater field surrounded by meteorite fragments was of worldwide interest and in July 1931 newspapers across the globe reported the find (e.g. see Anonymous, 1931a, Anonymous, 1931b). During this period, reports clearly stated that Aboriginal people in the district "… have no legends or stories regarding the place, nor do they appear particularly interested in it." (Anonymous, 1931a).

At some time between July and November 1931 Mitchell (1934) took an Aboriginal elder to the site, but he would not venture "… within half a mile … [of any crater or] … camp within two miles of them …", describing them as "… *chindu chinna waru chingi yabu …*", roughly meaning "… sun walk fire devil rock ..." The Aboriginal man expanded upon the meaning of the name and told Mitchell that a fire-devil (*chinka waroo*) lived in the rock-hole (*yabo*). He claimed his paternal grandfather had seen the fire-devil and that it came from the Sun. He also said that Aboriginal people did not drink water that collected in the bottoms of the larger craters, as they feared the fire-devil would "… fill them with a piece of iron." The Aboriginal man warned Mitchell not to go near the craters and told him that the only reason the fire-devil did not attack him during daylight was because he was "… grey-headed." This affirms Mitchell's earlier encounter in 1921 with a local Aboriginal guide who refused to approach the Henbury craters.

Anonymous (1945) claims that while the craters were being studied by Alderman in 1931, the custodian of the Aboriginal traditions of the Henbury area was nowhere to be found, having decamped elsewhere. This would not be an unexpected reaction if the custodian felt the area was taboo. The newspaper article stated that this view of the craters was held across the Petermann Ranges and surrounding areas (Mitchell, 1934). News reports with headlines reading "Sun Walk Fire Devil Rock" (Anonymous, 1931b) appeared, promoting the new find and suggesting that geologically the formation of the craters was a fairly recent event.

Professor J.B. Cleland planned to investigate stories about the craters (Anonymous, 1932b), but nothing is found in the literature that reports on his findings.

In March 1932, an unnamed local resident of Kadina undertook an independent investigation of the Henbury craters (Anonymous, 1932a). The individual claimed that he and his friend contacted the Aboriginal 'doctors' or 'wise men' (elders) from the 'Western tribes' to learn more about their perspective on the crater field. According to the resident's Aboriginal contacts, all young [Aboriginal] men and the women were forbidden from approaching the craters. An Aboriginal contact said of the place: "*Schindo waroo chinka yabbo shinna kadicha cooka* …", which he translated as "A fiery devil ran down from the Sun and made his home in the Earth. He will burn and eat any bad blackfellows ..." (Anonymous, 1932b).**[1]**

This account is interesting for two reasons. First, it clearly suggests a living memory of the Henbury impact. Second, the destructive event was seen as divine punishment. Such disasters are often attributed to people breaking laws and taboos. In a similar vein, the Hopi people of Arizona in the United States recounted an oral tradition about a "… blazing star which fell years ago, when the oldest of the ancient cliff dwellings was new …" at a place called Meteor Mountain (Anonymous, 1912), known today as Meteor (Barringer) Crater, which formed 50,000 years ago—long before humans are believed to have settled the Americas (e.g. see Fagundes et al., 2008). According to their traditions, the Hopi had

> … offended a Great Spirit, and this blazing star had come as a warning, lighting up the Earth for hundreds of miles around, and spreading terror throughout the repentant tribes … (Anonymous, 1912).

It is uncertain if Western scientists influenced the story or if the meteorite impact was conflated with more recent volcanic eruptions nearby about a thousand years BP (Malotki, 1987). In either case, the Hopi traditions describe the impact as divine punishment for unrepentant, or 'bad', people. Similar accounts relating meteors and punishment are evident throughout Australia (see Hamacher and Norris, 2009; 2010).

According to Spencer and Gillen (1904: 28), Aboriginal people who camped near the Finke (Larapinta) River at Henbury Station were Arrernte speakers but called their camp at Henbury *Waingakama.* The Finke River lies 7 km north of the crater field. Further studies show that the Henbury craters lie within country that is crossed by multiple Aboriginal language/dialect groups, including Arrernte, Luritja, Pitjantjatjarra and Yankunytjatjara. An investigation of the Aboriginal words describing the Henbury craters recorded by Mitchell and the Kadina resident reveals that they are from the Luritja language (Hansen and Hansen, 1992). Luritja is a dialect of the Western Desert language that shares close similarities with Pintupi, Pitjantjatjarra and Yankunytjatjara (Goddard, 1992). The identity of the words cited by Mitchell and the Kadina resident in the Luritja language are as follows (based on Hansen and Hansen, 1992): *chindu* or *schindo* (*tjintu*) refers to the Sun (page 145); *chinna* or *hinna* (*tjina*) refers to feet or foot-prints (page 145) but can also indicate a foot action like walking or running; *waroo* (*waru*) refers to fire or heat (page 171); *chinka* (*tjinka*) is a word used in various Western Desert languages and means 'dead' or 'devil' (David Nash, pers. comm.); *yabu* or *yabbo* (*yapu*) refers to a rock or hill (page 188); and *cooka* (*kuka*) refers to meat or eating meat (page 31). The word *Kadicha* (*Kurdaitcha*) is common among Central and Western desert groups, including the nearby Arrernte and Warlpiri. The term has multiple but similar meanings, generally referring to a spirit that punishes evil-doers (e.g. see Spencer and Gillen 1899: 476).

Interest in the Henbury craters and associated meteorites led to a demand for fragments, and by 1945 Aboriginal people in the region had taken note of this and began selling "… pieces of the star that fell from the sky." (Vox, 1945). It was not uncommon for Aboriginal people to recognise and take advantage of the demand for meteorites and tektites. Aboriginal people in the Western Desert often collected tektites to sell to white prospectors (which the Aboriginal people colloquially called 'meteorites') until the demand waned and specimens were lost or simply discarded (Hamacher and O'Neill, 2013). There is little doubt that public and scientific interest in the craters and meteorites had an impact on the local Aboriginal people, but it is not known whether this also influenced their traditions.

Unlike Mitchell or the Kadina resident, Alderman was unable to find any stories about the site from the local Aboriginal community. Consequently, he concluded that the Aboriginal people seemed to have no interest in the Henbury craters or any ideas as to their origin. Even though information about Aboriginal traditions of the crater field had been published, for many years newspaper accounts continued to claim that no Aboriginal traditions existed regarding the craters (e.g. see Anonymous, 1934). There are a number of possible explanations for Alderman's inability to obtain any oral traditions about the site. Aboriginal people did not often share their information or stories with white people unless a trust and rapport had been developed first. It was not uncommon for a stranger to ask an Aboriginal person about a story or place and be given a dismissive response or one of feigned interest, while a more trusted white person would be given the full account.

The Aboriginal Areas Protection Authority advises that a sacred site is recorded from the center of the crater field, which is called *Tatyeye Kepmwere* (*Tatjaka-para*) in the Arrernte language (Parks and Wildlife Commission of the Northern Territory, 2002: 15). The Commission reports that stories of the site are known but only will be "… used for interpretation purposes after agreement by the Aboriginal custodians of the site."

The only story recorded in the literature is from Mountford (1976: 259-260),[2] which relates to the largest crater only. In this story, *Mulumura* (a lizard-woman) was camping within the largest crater. The woman picked up handfuls of soil and tossed them away, creating the structure's bowl shape. The discarded soil formed the ejecta rays that once were visible at the site. The rays at Henbury are unique for terrestrial impacts and closely resembled ejecta rays associated with lunar craters (see Fortowski et al., 1988; Milton and Michel, 1977). Unfortunately, traffic and prospecting at the site have almost completely destroyed the rays (Buhl and McColl, 2012). The story reported by Mountford (ibid.) also mentions piles of meteoritic iron that once were in the crater but were tossed out along with the soil.

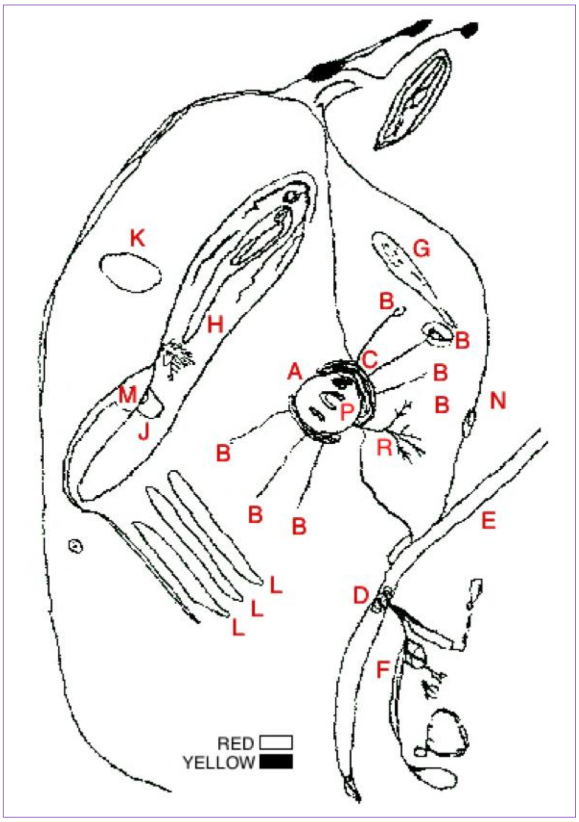

Figure 6: A map of the Mulumura story from Henbury (adapted, by Hamacher, from Mountford, 1976: 260).

Mountford (1976: 260) even provides a map detailing the various elements of the story, and this is reproduced here in Figure 6. In this Figure, **A** was the camp *of Mulumura,* **P** was where she slept; **C** was her windbreak; **B** represents the soil she picked up and discarded from the crater forming the ejecta rays that were once visible at the site, and it also includes piles of meteoritic iron; **R** represents her windbreak, and the acacia tree; **D** represents the water hole on the Finke River; **F** is the Henbury Cattle Station; **G** is a low hill covered with acacia trees; **E** is the Finke River; and **N** is a creek emptying into the river. To the south of the craters is a ridge, called Bacon Ridge, which is denoted by **H**. Sacred ceremonial objects in Arrernte culture, called *tjurungas*, were kept in a small cave **J** near the top of this ridge; **K** is one of the stone *tjurungas*; **L L L** represent the long wooden *tjurungas* that were placed in the cave at the conclusion of ceremonies; and **M** indicates marks of blood that were poured on the walls when the objects were stored in the cave. Mountford was unable to obtain stories about the other craters, but claimed that "… there is little doubt that such myths exist." (p. 260). Mountford (1976: 259) cites this story as evidence that the Aboriginal people have no living memory of the meteorite fall. It should be noted that *Mulumura* is prominent in Pitjantjatjarra traditions relating to *Kata Juta*, a large rock formation also known as The Olgas, which is located 250 km west-southwest of Henbury (Mountford, 1976: 488).

Mountford's record of the *Mulumura* story probably relates to Aboriginal oral traditions of the Finke River within Henbury Station about a great totemic lizard god. Worms (1952: 554) translates passages from Strehlow (1907), a German Lutheran missionary who documented the Arrernte and Luritja languages:

> In Henbury at the Finke River, the *tjunba* (*Varanus giganteus* grey – the largest species of monitor lizards in Australia) men lived ages ago. In a plain near Henbury, where many eternal men and women were living, the inhabitants of this camping place had already been instructed by *tjunba* (i.e. the great Lizard and totem-god). Southwest of Hermannsburg, there is the great totem place, called *Manjiri*. Once many lizard-men (*atna tjunba*) were living here.

It is also possible that the Henbury craters were generically attributed to spirits or spirit activities ('devils') by the Luritja, while other language groups incorporated the site into part of the *Mulumura* Dreaming story. The evidence suggests that the local Luritja people recognized the Henbury craters as a place where an unusual event involving fire and destruction had occurred. This recognition, combined with a fear that the fire-devil, which came from the Sun and made his home in the craters and would fill them with iron if people ventured too close, indicates either a living memory of the event or an acknowledgement of how the craters were formed. But one must use caution when interpreting this translation in the absence of context.

Bevan and Bindon (1996: 99) suggest that Western knowledge of the site influenced the Aboriginal account noted by Mitchell. This is certainly possible, as the meteoritic nature of Henbury was probably known to locals (or at least the idea was discussed) prior to Mitchell's confirmation of Henbury as an impact site. There are other examples of Western knowledge influencing crater traditions, as we will see with Wolfe Creek Crater in Section 2.4.

It is possible that the Henbury impact was witnessed, incorporated into local oral traditions and then was dispersed across the country (Bevan and Bindon, 1996). An example comes from Paakanji country near Wilcannia in northwestern New South Wales, 1,400 km southeast of Henbury (Jones, 1989). According to the story, a large fiery star rumbled and smoked as it fell from the sky, crashing to the Earth, burning some people and killing others. Jones gave the location of the event as a place called *Purli Ngaangkalitji* (meaning 'Fallen Star') in the Darling riverbed near Wilcannia. Jones provided a map of *Purli Ngaangkalitji*, but when Australian National University astronomer and comet-hunter Robert McNaught surveyed the area, he found no evidence of an impact or of meteoritic material (Steel and Snow, 1992: 572). Jones claimed she first heard the story in 1927 and that it was "… very old". Other stories from across Australia describe fiery objects falling from the sky, lighting up the surrounding landscape and striking the Earth with a deafening roar, sending debris into the air and causing fire, death and destruction (see Hamacher and Norris, 2009 for a treatise on this subject).

The obvious question here is whether or not an oral tradition can survive for thousands of years. As a test of short-term memory regarding a meteoritic event, we examine the indigenous Evenki (Tungus) people of central Siberia, who witnessed a meteoritic airburst in 1908 that destroyed 2,150 square kilometers of forest near Tunguska, Russia. Some 15 years passed before researchers finally reached the site and began collecting stories and accounts of the airburst from local villagers and indigenous groups. According to researchers who visited the region (Krinov, 1966: 125-143), memory of the event was still alive in the minds of the local people. Using accounts reported in newspapers shortly after the event, it seems that details of the airburst in Evenki folklore changed to the point that numerous discrepancies and contradictions were evident after only 15 years. Because of this, the researchers faced an "… insurmountable difficulty in establishing the truth …" of the event (ibid: 135).

This is not entirely unexpected, as events that took place many years in the past are susceptible to changed and altered memories in the minds of the witnesses. These altered memories could be due to any number of memory errors known to psychologists. An example is *transience*—the loss of memory as time passes (Schacter, 2011: 243). This affects the quality of a memory, the details of which tend to deteriorate from specific to general. Other forms of memory error include *confabulation*—the recollection of inaccurate or false memories (Loftus, 1997); *unconscious transference*—misattribution of the source of a memory (Deffenbacher et al., 2006), *imagination inflation*—details of a memory that are exaggerated in the mind (Mazzoni and Memon, 2003); or *schematic errors*—where a schema (organized pattern of thought) is used to assist in constructing elements of an event that cannot be recalled (Kleider et al., 2008). It is evident that specific and accurate details of an event in memory will deteriorate over time. Therefore, we would not expect to find 'accurate' details of a meteorite impact in oral tradition after thousands of years, if at all. General details of an event could remain in memory, although the length of this time is the subject of ongoing discussion. Examples of 'deep time' oral tradition, which could last for thousands of years (e.g. Henige, 2009), have been proposed by a number of authors (e.g. Echo-Hawk, 2000; Hamacher and Norris, 2009; Piccardi and Masse, 2007), but the topic remains one of ongoing debate.

2.3 Liverpool Crater (Yingundji)

Liverpool Crater in Western Arnhem Land, Northern Territory, is a 1.6-km wide simple impact structure that formed during the Neoproterozoic (Haines, 2005). Confirmed as an impact structure in 1970 (Guppy et al., 1971; Haines, 2005), Liverpool Crater lies ~2 km north of the Liverpool River and is only accessible via helicopter. The Aboriginal name of the crater is *Yingundji* in the Kunwinjku language (Shoemaker and Shoemaker, 1997).

Upon visiting the site in 1996 to shoot the York Films documentary "Three Minutes to Impact", Eugene and Carolyn Shoemaker were accompanied by a family of Aboriginal men, including the famous artists, brothers Johnny Maurirundjul and Jimmy Njimimjuna, of the *Kurulk* clan (Shoemaker and MacDonald, 2005: 479). While Eugene mapped the structure, Maurirundjul exchanged stories with Carolyn regarding the origin of the structure. He explained that in their traditions the crater was the nest of a giant catfish. Later, on visiting some of the rock shelters in the crater, the Shoemakers found several Aboriginal paintings, one of which showed the giant catfish.

Fish comprise a majority of rock art motifs in Western Arnhem Land and large catfish inhabit the Liverpool River system (Taçon, 1988). Numerous motifs of giant catfish appear in Arnhem Land rock art, and the catfish is important in some ceremonies (Elkin, 1954; Taçon, 1988; Paul Taçon, pers. comm.). We were unable to identify any rock art from the Liverpool Crater in

Figure 7: An aerial view of Wolfe Creek Crater (photograph: John Goldsmith).

the literature, but we plan to conduct ethnographic and archaeological research at the site.

2.4 Wolfe Creek Crater (*Kandimalal*)

Wolfe Creek Crater (Figure 7) is the largest impact structure in Australia from which meteorite fragments have been found (Haines, 2005). This simple crater is located ~130 km south of Halls Creek on the edge of the Great Sandy Desert in the East Kimberley, Western Australia (Bevan and de Laeter, 2002; Guppy and Matheson, 1950). It is approximately 860 m in diameter with an estimated age of ~300,000 years (O'Neill and Heine, 2005). Frank Reeves, N.B. Suave, and Dudley Hart were the first Westerners to identify the structure (Reeves and Chalmers, 1949). The crater was sighted in 1947 during an aerial survey of the Canning Basin (Bevan and McNamara, 2009). A.J. Jones, a constable from Halls Creek, claimed that an Aboriginal tracker had shown him the crater in 1935, but this claim has yet to be substantiated (Gard and Gard, 1995).

Figure 8: Jaru elder Stan Brumby telling the story of *Kandimalal* (photograph: J. Goldsmith).

The crater lies within the traditional lands of the Jaru, who call the structure *Kandimalal* (Tindale, 2005: 376). Nearby language groups include the Walmatjarri, Kukatja and the Ngarti (Horton, 1996). In the late 1990's, Peggy Reeves-Sandy, a University of Pennsylvania anthropologist and the daughter of Frank Reeves ('co-discoverer' of Wolfe Creek Crater), visited the crater and conducted ethnographic fieldwork on Aboriginal knowledge relating to the crater and representations of the crater in art (Reeves-Sandy, 2007). The results of her work were presented in an exhibition titled "Tracks of the Rainbow Serpent" and in the book *Aboriginal Paintings of the Wolfe Creek Crater, Track of the Rainbow Serpent* (ibid.).

Since 1947 other researchers have collected cultural knowledge of *Kandimalal*, including Norman Tindale in 1953 (Tindale, 2005: 376) and the second author of this paper (Goldsmith, 2000) between 1998 and 2011. An extensive investigation into Aboriginal astronomical knowledge and beliefs relating to *Kandimalal* is the subject of Goldsmith's (2013) Ph.D. thesis.

Early accounts state that *Kandimalal* has "… no particular meaning in their language, and no legend exists to hint of its origin." (Cassidy, 1954), a claim reminiscent of the Henbury craters. However, Aboriginal communities continue to maintain various stories associated with *Kandimalal* (sometimes spelt *Gandimalal*). One of these stories tells of a pair of subterranean Rainbow Serpents that created the nearby Wolfe and Sturt Creeks. One Serpent emerged from the ground, creating the circular structure of *Kandimalal* (Bevan and McNamara, 2009; Goldsmith, 2000; Reeves-Sanday, 2007). Similar Dreaming stories are found in the Western Desert, which typically involve a pair of ancestral snakes burrowing under the earth, forming rivers, and emerging from the ground to form rock holes and claypans (Graham, 2003: 32). Crater features are incorporated in the oral traditions. For example, in some Jaru traditions, the head of the serpent formed a depression on the south-east rim of the crater as it emerged from the ground (Reeves-Sanday, 2007: 99). Other Jaru artists claim that the crater was formed by an 'Old Fellow' digging for yams. They say the word *Kandimalal* is based on *karnti*, the Jaru word for yam (ibid.). Since these stories were not collected until after scientists investigated the structure, we cannot know with certainty the age of the stories.

Other elders recount stories that explain the structure's origin as an impact crater. Just prior to his passing in 1999, Jaru elder Jack Jugarie (1927–1999) told Goldsmith a story about the crater's origin. Jugarie said the story came from his grandfather's grandfather, suggesting that the account originated before the 1947 'discovery' of the crater. Jugarie clearly indicated that the story was

> … according to the old people, early days mob, wild people that haven't seen gardia (white) people.

He explained that one night, the Moon and the evening star passed very close to each other. The evening star became very hot and fell to the Earth, causing a brilliant, deafening explosion. This greatly frightened the Jaru and it was a long time before they ventured near the site, only to discover it was the spot where the evening star had fallen (Goldsmith, 2000). Jugarie explains further:

> A star bin fall down. It was a small star, not so big. It fell straight down and hit the ground. It fell straight down and made that hole round, a very deep hole. The earth shook when that star fell down. (Reeves-Sanday, 2007: 26).

Jugarie cites the Jaru word *coolungmurru* for a large meteor that caused the Earth to shake. He said that after seeing a large meteor, the people would wait for the sound and feel the Earth shaking. Sonic effects caused by large exploding meteors (bolides) are well known to scientists, but are an uncommon phenomenon.

Jaru elder, Stan Brumby (1933–2012; Figure 8), tells stories about Wolfe Creek Crater, particularly through his Aboriginal art. He features in a video exhibit at the Cosmology Gallery, Gravity Discovery Centre in Perth (Goldsmith, 2011) in which scientific and Aboriginal perspectives of Wolfe Creek Crater are shared. The video contains an interview with Brumby, recorded by Goldsmith while he was conducting ethnographic fieldwork:

> I sing him, that star, language, singing stick, I can sing 'im now. That's 'im song, Warda, Big star, bin fall down, from top from sky, Warda wandinga morunga.

Aboriginal oral accounts relating to Wolfe Creek Crater are also closely related to contemporary Aboriginal artworks that feature the crater. Aboriginal artists who have depicted Wolfe Creek Crater are mainly based in Halls Creek, or at Billuluna (the nearest community to the crater). There are four main themes represented in these artworks (see Figure 9). Firstly, the story of the star that fell to Earth, forming the crater is shown in several of the paintings. Secondly, there are paintings that represent the crater itself, and essentially no other features, or the crater, the landforms and bush food in its general vicinity. Thirdly, some paintings show the story of the two Rainbow Snakes and the crater (as referred to in the National Park signage). One painting (Figure 9, top left) shows a representation of a Rainbow Snake, coiled in the centre of the crater. Fourthly, some paintings show the belief that there is an underground tunnel which leads from the centre of the crater and emerges at Sturt Creek, at a place called Red Rock.

Jaru elder, Speiler Sturt (b. 1935) from Billuluna, explains the cosmic origins of Wolfe Creek Crater through story and illustration (Reeves-Sanday, 2007: 15; Figure 10):

> That star is a Rainbow Serpent. This is the Aboriginal Way. We call that snake Warnayarra. That snake travels like stars travel in the sky. It came down at Kandimalal. I been there, I still look for that crater. I gottem Ngurriny – that one, Walmajarri/Jaru wild man.

Many recorded stories about *Kandimalal* describe the structure originating from a cosmic impact (see Reeves-Sanday, 2007). One such account presented here is said to originate prior to the 1947 Western discovery of the crater, however in general it is difficult to determine whether this or similar accounts have been derived (or influenced by) the scientific explanations of the crater. In 2002, Walmajarri artist Jack Lannigan (b. 1924), a Jaru speaker, cited the story about the structure being formed from a giant serpent emerging from the ground (Reeves-Sanday, 2007: 97). When Reeves-Sanday asked him if the snake that formed the structure came from the sky, he replied "nah",

Figure 9: Examples of Aboriginal artworks featuring Wolfe Creek Crater, by Stan Brumby, Barbara Sturt, and Frank Clancy (photograph: J. Goldsmith; reproduced by permission of the Yarliyil Art Centre.)

the star-story was "… white-man's story." (ibid.: 99). The influence of the Western scientific explanation of the crater on local Aboriginal stories is evident. When artists developed paintings of the crater they were encouraged to include the 'star story', and were given directional advice about the theme.

Figure 10: A painting of *Kandimalal* by Speiler Sturt, 2003. (after Reeves-Sanday 2007: Plate 16; image used with permission).

In 1953, the anthropologist Norman Tindale (1953: 907-910) interviewed three Jaru men regarding stories related to the crater. According to the men, it was known as *Kandimalal* but they did not have any stories about it. From this, Tindale concluded that *Kandimalal* had no 'special significance' to the Aboriginal people he interviewed. It is therefore unclear if the impact story predated the scientific rediscovery of the crater or if interest in the crater by scientists influenced the oral traditions. It seems that Aboriginal artists have indeed incorporated the impact story into their oral and artistic traditions. According to Reeves-Sanday (2007), the inclusion of the scientific story strengthened the power of the painting, revealing a willingness to embrace and incorporate new knowledge into pre-existing traditions.

3 HOLOCENE IMPACT CRATERS WITH NO ASSOCIATED ORAL TRADITIONS

3.1 Boxhole Crater

Boxhole Crater, located ~170 km northeast of Alice Springs, is a simple impact structure approximately ~170 m in diameter. It was discovered by Joe Webb, a shearer at Boxhole Station. The age of the structure is uncertain, but estimates by Kohman and Goel (1963) using ^{14}C dating give 5,400 ± 1,500 years, while Shoemaker et al. (2005) and Haines (2005: 484-485) provide an estimate of ~30,000 years using $^{10}Be/^{26}Al$ dating.

Given the crater's geologically young age, it is likely that Aboriginal people witnessed this event. This was apparent to Cecil T. Madigan (1889–1947), the first scientist to survey the crater, on 20 June 1937:

> It seems hard to believe that the crater was formed before the country was occupied by the aborigines, yet such an explosion would surely have been noticed and recorded by them, whose lives are so uneventful and who are yet so observant of natural phenomena. It must have been audible, or visible at night, from a hundred miles away … (Madigan, 1937: 190).

Madigan was surprised that the local Aboriginal people seemed to have "… no legends connected with the crater … [and took] no particular interest in it …", although he noted that Aboriginal people had dug a shallow soakage in the center of the crater, where water collected. Webb and his nephews, who were in "… sympathetic contact with the Aborigines and masters of their language …", confirmed this.

A fragment of the Boxhole impactor was found in the Harts Range, 60 km south of Boxhole Crater, and de Laeter (1973) concluded that it most likely was transported there by Aboriginal people. Nothing more about the Aboriginal significance of this meteorite, or the Boxhole Crater, is reported in the literature.

3.2 Dalgaranga Crater

Dalgaranga Crater is one of the smallest impact structures in the world, one of the first to be identified in Australia, and the only terrestrial impact associated with a mesosiderite projectile (Nininger and Huss, 1960). This simple crater is located 100 km northeast of Yalgoo in Western Australia, and has a diameter of 24 meters (Bevan, 1996). Although the age of the structure is not well known, its well-preserved nature suggests it might be as young as 3,000 years (Shoemaker and Shoemaker, 1988).

An Aboriginal stockman named Billy Seward discovered the crater in 1921 (Wellard, 1983: 95-97). Seward informed the station manager, G.E.P. Wellard, who returned to the site and found meteorite fragments in the area (ibid.: 94-96). A study of the meteorites did not appear in the literature until 1938 (Simpson, 1938), and the crater was only surveyed in 1959 (Nininger and Huss, 1960). Details of the 1959 survey, which included Harvey Nininger, his wife, Addie, and amateur geologist Allen O. Kelly, were included in Kelly's unpublished memoirs (Kelly, 1961). Kelly identified flint flakes around the crater, which he thought might have marked places where meteorite fragments had been recovered by Aboriginal people as "… an exchange gift for the fiery god that came out of the sky." (Kelly, 1961: 153-154). He speculated that the impact could have occurred within the last few hundred years and thought there was "… little doubt …" that Aboriginal people witnessed the impact. However, no Aboriginal stories relating to this structure were identified in the literature, and Shoemaker et al. (2005: 542) conclude that the crater could have been formed anywhere between 3,000 and 270,000 years ago.

A meteoritic slug found at Murchison Downs in 1925, some 200 km away, was identified as a fragment of the Dalgaranga impactor (Bevan and Griffin, 1994). Like the Boxhole fragment, Bevan and Griffin suggest that Aboriginal people may have transported the slug from Dalgaranga. For a full history of research at Dalgaranga, see Hamacher and O'Neill (2013).

3.3 Veevers Crater

Veevers Crater is a simple impact structure in the Canning Basin of central Western Australia, measuring 70 m in diameter (Haines, 2005). The crater was identified by the Bureau of Mineral Resources and the Geological Survey of Western Australia in 1975 and was confirmed as an impact structure in 1985 (Shoemaker and Shoemaker, 1985). The age of the crater is not known, and estimates range from <20,000 years using cosmogenic nuclide exposure dating (Glikson, 1996) to <4,000 years based on the excellent preservation of the rim (Shoemaker and Shoemaker, 1988). No Aboriginal stories associated with this structure are reported in the literature.

4 CONCLUDING REMARKS

We find oral traditions associated with Henbury, Liverpool, and Wolfe Creek—three of the six youngest and smallest impact craters in Australia. Since many of the larger craters are either buried or eroded to such a point that they are not easily distinguishable from the surrounding landscape, we are not surprised that we were unable to find stories associated with most of them. The only large (D>2 km) impact crater with an associated oral tradition was Gosses Bluff. Aboriginal traditions regarding Boxhole, Dalgaranga, and Veevers are not reported in the literature. As discussed before, we suspect that oral traditions associated with these and other craters may exist, but simply have not been collected or published. This will be the focus of future work.

Of craters associated with reported Aboriginal knowledge, Gosses Bluff, Henbury and

Wolfe Creek have oral traditions that relate to a cosmic impact, although it is uncertain if these stories pre-date colonisation or scientific investigations of these craters. Meanwhile, the only oral tradition relating to the largest of the Henbury craters that is described in the anthropological literature does not refer to an impact event. However, Aboriginal traditions of Henbury in historical records indicate an impact event. Oral traditions relating to the Liverpool Crater are not associated with a cosmic impact. Both the Henbury craters and Wolfe Creek Crater are associated with both impact and non-impact oral traditions, although the influence of Western science on these traditions is evident, and is confirmed by some Aboriginal elders for Wolfe Creek.

Aboriginal people seek explanations regarding the origin of natural features, including meteorite impact craters. These explanations, which are informed and influenced by new experiences and new information, are encoded in oral traditions that are passed through successive generations. This new information may be influenced by Western science. One Aboriginal informant claimed that his star story regarding the Wolfe Creek Crater originated before contact with white people, whereas some informants stated that views from Western science were incorporated into their traditions. We do not know if this has occurred with respect to the Gosses Bluff or the Henbury craters, but we do know that Carolyn Shoemaker discussed the origin of the Liverpool Crater with Aboriginal custodians. It would be interesting to know if contemporary Aboriginal traditions now include some of the information that she provided.

The Aboriginal accounts of the Henbury craters suggest that the impact event has survived in living memory after more than 4,500 years. However, we are unable to definitively demonstrate that Aboriginal traditions of meteorite craters existed prior to colonisation or scientific investigation that describe them as having an impact origin. Local interest in the Henbury craters existed for decades before they were confirmed as impact craters and it is unknown if and how this interest influenced Aboriginal traditions relating to the site. Similarly, scientific interest in Gosses Bluff may have influenced local Aboriginal traditions, but we have not been able to locate evidence of this in the literature. Instead, we must rely on the Aboriginal custodians of the stories themselves or on historical accounts, such as those relating to Henbury. It must be emphasized that contemporary traditions are just as important as 'pre-colonisation' traditions, whether they incorporate Western knowledge or not. Contemporary Indigenous traditions of impact craters have relevance to the identity and spirituality of modern Aboriginal people.

Additional ethnographic and archaeological research at these sites is required and will be the subject of future work. Goldsmith conducted ethnographic fieldwork at Wolfe Creek Crater for his doctoral thesis, and this will be published in the near future.

Aboriginal knowledge regarding impact craters continues to be developed though art and storytelling, especially in regards to Wolfe Creek Crater. Art and story are important ways for contemporary Aboriginal people to share and preserve this knowledge for future generations, and we hope that further research will allow us to expand on the Aboriginal oral traditions of impact sites for the Aboriginal and scientific communities.

5 NOTES

1. An interesting note relevant to the Henbury research is taken from Spencer and Gillen (1899: 549), before the craters were known to Westerners. In some Central Desert groups, the Aboriginal people believed in a type of evil magic called *Arungquiltha*. This magic sometimes took the form of a meteor streaking across the sky "like a ball of fire". In the Central Desert, mushrooms were believed to come from falling stars and contained *Arungquiltha*. They were considered taboo and their consumption was forbidden (Spencer and Gillen, 1904: 627). According to Spencer and Gillen, a man 'out west' was found dead and mutilated. The suspected perpetrators were certain men living at Henbury on the Finke River, who were accused of projecting the *Arungquiltha*. The Henbury craters are just 7 km south of the Finke River (Spencer and Gillen, 1899: 549).
2. Minor elements of this story are deliberately excluded since they are considered secret and are not pertinent to the paper. Although Mountford collected this story from a male informant, one of the authors (Hamacher) was asked to leave out certain elements of the story, as they are considered sensitive.

6 ACKNOWLEDGEMENTS

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Dr Duane Hamacher is a lecturer in the Nura Gili Indigenous Centre at the University of New South Wales in Sydney, Australia. He publishes extensively on cultural and historical astronomy and meteoritics, with a focus on Indigenous Australians. He earned B.Sc. and M.Sc. degrees in astrophysics and completed a Ph.D. at Macquarie University in Sydney with a thesis titled "On the Astronomical Knowledge and Traditions of Aboriginal Australians". He is a consultant curator and astronomy educator at Sydney Observatory and the founder and Chair of the Australian Society for Indigenous Astronomy.

John Goldsmith is a researcher and astrophotographer in Perth, Western Australia. He earned B.Sc. and M.Sc. degrees in Environmental Science and recently completed a Ph.D. at Curtin University in Perth with a thesis titled "Cosmos, Culture, and Landscape: Documenting, Learning and Sharing Aboriginal Astronomical Knowledge in Contemporary Society". He chaired and coordinated the development of the Cosmology Gallery at the Gravity Discovery Centre (Gingin, Western Australia), has been the Curator of the WA Astrofest Astrophotography exhibition since 2009, and is the creative developer behind the "Celestial Visions" exhibition. He is a member of a global astrophotography network, "The World At Night", and in 2011 was the inaugural tertiary recipient of the de Laeter Science Engagement Scholarship at the Gravity Discovery Centre Foundation. John also is the co-Chair of the Australian Society for Indigenous Astronomy.

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ECLIPSES IN THE MIDDLE EAST FROM THE LATE MEDIEVAL ISLAMIC PERIOD TO THE EARLY MODERN PERIOD. PART 1: THE OBSERVATIONS OF SIX LUNAR ECLIPSES FROM THE LATE MEDIEVAL ISLAMIC PERIOD

S. Mohammad Mozaffari
Research Institute for Astronomy and Astrophysics of Maragha (RIAAM),
PO Box: 55134-441, Maragha, Iran.
E-mail: mozaffari@riaam.ac.ir

Abstract: This paper deals with the analysis of data obtained from observations of two sets of three lunar eclipses in the Late Medieval Islamic Period. The first trio consists of the lunar eclipses of 7 March 1262, 7 April 1270 and 24 January 1274, observed by Muḥyī al-Dīn al-Maghribī from the Maragha Observatory (in north-western Iran), and the second includes those of 2 June and 26 November 1406, and 22 May 1407, observed by Jamshīd Ghiyāth al-Dīn al-Kāshī from Kāshān (in central Iran). The results are that al-Maghribī's values for the magnitudes of these eclipses agree excellently with modern data, and his values for the times when the maximum phases occurred agree to within five minutes with modern values. Al-Kāshī's values for the times of the maximum phases show a rather larger divergence from modern data, varying from about ten minutes to about one hour. The errors in all six values both astronomers computed from their own solar parameters for the longitude of the Sun at the instant of the opposition of the Moon to the Sun in these eclipses remain below ten minutes of arc. The motivation for doing these observations was to measure the lunar epicycle radius r in the Ptolemaic model. Al-Maghribī achieved $r = 5;12$ and al-Kāshī $r \approx 5;17$,[1] in terms of the radius of an orbit of $R = 60$ arbitrary units. It is argued that comparing with modern theory, neither of these two medieval values can be considered an improvement on Ptolemy's value of $r = 5;15$.

Keywords: lunar eclipses, Middle East, Late Medieval Islamic Period, al-Maghribī, al-Kāshī, Maragha Observatory

1 INTRODUCTION

Over the last few decades around fifty observational reports of solar and lunar eclipses dating to the Early Medieval Islamic Period (ca. AD 801-1000) have been investigated in depth. Alongside reports preserved by other cultures (particularly the Chinese), they have been used to obtain estimates for the rate of the deceleration of the Earth's rotation and the cumulative amount of the change in the length of the day, or Δ*T*, that is, the difference between Terrestrial Time and Universal Time (e.g., see Morrison and Stephenson, 2004; Steele, 2000; Stephenson, 1997; 2011).

This was perhaps a main characteristic of the rise of astronomy in communities where eclipses were seen as remarkable and frequent celestial events, and were observed so that the data obtained (regardless of how accurately they might be determined) could be compared with those computed on the basis of contemporary tables and theories. This was perhaps the reason why a great deal of energy and effort was employed to make more precise observations of eclipses. For example, Ibn Yūnus (d. 1007) from Cairo gathered reports from some local astronomers and others who had witnessed eclipses, and data they supplied helped him to determine a better estimate for the magnitude of each eclipse and solar-lunar altitudes at specific phases (e.g., in the case of the solar eclipse of 13 December 977, see Ibn Yūnus: 110; and also Caussin de Perceval, 1804: 163; Stephenson, 1997: 473). And the earliest known attempts to reconcile theory with observations in Medieval Islamic astronomy might have been produced in this way. For instance, Ibn Yūnus reported that the Baghdad astronomer Ibn Amājūr (ca. the late ninth to the early tenth century) found that the true longitude of the Moon was 16′ behind that computed from the *Mumtaḥan zīj* composed by Yaḥyā b. Abī Manṣūr at Baghdad in about AD 830 (Ibn Yūnus, 99-100, Caussin de Perceval 1804: 111, 113).[2]

2 SOLAR AND LUNAR ECLIPSES IN THE LATE MEDIEVAL ISLAMIC PERIOD

In the Late Medieval Islamic Period (AD 1001-1450), as large observatories were founded and more astronomical tables were compiled, the number of observational reports of eclipses diminished, and astronomers instead presented the values they had computed for the occurrence times of eclipses in their *zījes*. In Islamic astronomy, the mean motions of the Sun (in longitude) and the Moon (in longitude, in anomaly, and the retrograde motion of its orbital nodes) and their orbital elements (eccentricity, radius of the epicycle) were determined more frequently than the corresponding planetary parameters. Of around twenty-five values that I know for the solar eccentricity and ten values for the lunar orbital elements dating from the Medieval Islamic Period, nearly half were determined in the Early Medieval Islamic Period and the other half in the Late Medieval Islamic Period. Nevertheless, twenty-six of the thirty-four known values for the planetary orbital elements in Islamic astronomy date to the Late Medieval Islamic Period. There can be found an equal number of values (if not more) for the solar, lunar and planetary mean motions both

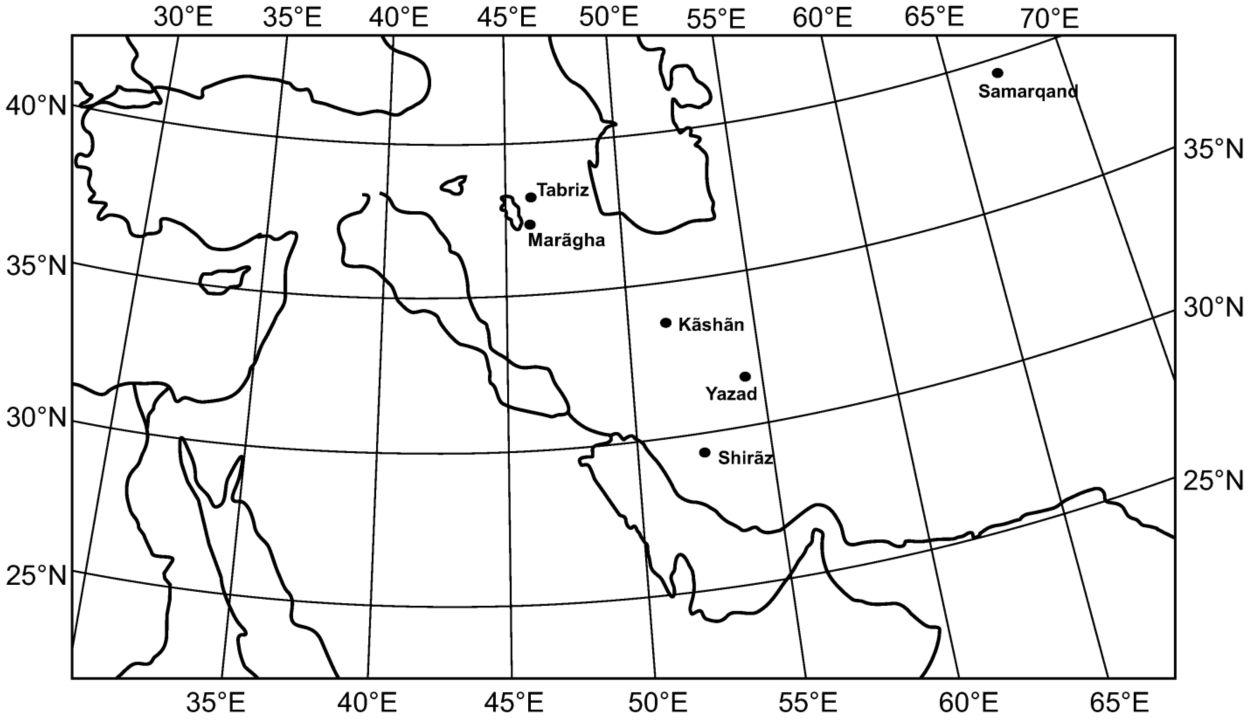


Figure 1: Localities mentioned in the text where eclipses were observed or calculated during the Late Medieval Islamic Period.

in longitude and in anomaly for this Period. An observer could then examine which set of parameter values led to better agreement with the observations. For example, see the case of Ibn al-Fahhād, Bākū or Shirwān, who flourished ca. AD 1172 (van Dalen, 2004: 836).

Figure 1 shows the places in the Middle East for which eclipses were computed or where they were observed in the Late Medieval Islamic Period, and their historical and modern geographical coordinates are listed in Table 1. I know of four worked out examples of solar eclipses that date from the Late Medieval Islamic Period. Three of these, on 30 January 1283, 5 July 1293 and 28 October 1296, were calculated by Shams al-Dīn Muḥamamd al-Wābkanawī al-Bukhārī (who lived at Maragha and Tabriz, between about 1270 and 1320). The first is for the latitude of Mughān (historical: φ = 38°; a green plain in northwestern Iran, modern: φ = 38.5-39.5° N and λ = 45-47° E) and is given in Wābkanawī's *Zīj al-muḥaqqaq al-Sulṭānī*, "Testified zīj for the sultan" (Mozaffari, 2009; 2013a; 2013b). The next two are for the latitude of Tabriz and are recorded in Byzantine Greek sources. These sources (see Pingree, 1985) include the translation of Ibn al-Fahhād's *'Alā'ī zīj* (written around 1172) and some fragments of another *zīj* called the *Revised canon* which was based on the oral instructtions that an Iranian astronomer named Σάμψ Πουχαρής (= Shams al-Bukhārī) gave to Gregory Chioniades when Chioniades was at Tabriz at the turn of the fourteenth century. This astronomer may be identified as Wābkanawī. In the translations, the computation of these two eclipses is embedded within the worked out examples that Wābkanawī provides in order to instruct Chioniades on how the parameters of an eclipse (time, duration, magnitude, etc.) may be computed. The *Revised canon* appears to be the translation of some parts of Wābkanawī's *Zīj* before it was completed around 1320. Information about the 28 October 1296 eclipse for the latitude of Yazd is also found in the anonymous *Sulṭānī zīj* (fols. 138v-140r); some computational examples concerning the various parameters of solar eclipses for the latitude of Shirāz may be found in the *Ashrafī zīj* V.18. While the dates are not indicated, some computations appear to be related to the solar eclipse of 3 April 1307. Critical documentation on this event are a solar longitude of around 20-22°at the beginning and end of the eclipse, and a value of 203° 36′ for the longitude of the lunar ascending node (see Kamālī: fol. 149r).

In the case of lunar eclipses, five worked out examples may be found in the *zījes* of this period: 30 May 1295 for the latitude of Tabriz in Chapter 36 of the Greek translation of the *'Alā'ī zīj* (Pingree, 1985: 352ff.), and for the latitude of Yazd in the *Sulṭānī zīj*; 23 November 1295 in the *Sul-ṭānī zīj* (fols. 137r-138r); 4 January 1303, 9 May 1305, and 14 December 1312 in the *Ashrafī zīj* (Kamālī: fols. 133v-134r, 145v-146r).

These worked out examples were to instruct the reader how the magnitude and times of the phases of eclipses were calculated in a Ptolemaic context using the different procedures passed down to astronomers of this period (either from Greek or Indian sources, or those developed by their Islamic predecessors). In some accounts (e.g. Wābkanawī's computation of the

Table 1: Historical and modern co-ordinates of places shown in Figure 1 where eclipses were observed or computed.

Site	Historical		Modern	
	Latitude	Longitude*	Latitude	Longitude
Marāgha	37;20,30° N	82;00° E	37;24° N	46;12° E
Kāshān	34;00	86;00	33;59	51;27
Tabrīz	38;00	82;00	38;05	46;18
Yazd	32;00(1)–32;15(2)	89;00	31;54	54;22
Shirāz	29;30(3)–29;34(4)	88;00	29;37	52;32

* Measured from the Fortunate Islands (Canary Islands).
(1), (4) *Īlkhānī zīj*, C: p. 197.
(2), (3) *Khāqānī zīj*, IO: fol. 73r.

annular solar eclipse of 30 January 1283), the computed results were compared with the data obtained from observations, or *vice versa*, in order to show whether or not they were in agreement. Surviving computations of eclipses from the Late Medieval Islamic Period show that the theoretical results were acceptable in the Ptolemaic context of medieval astronomy. Wābkanawī's account of the solar eclipse of 30 January 1283 maybe is now a well-known example. The other two examples are the times computed for the middle of the lunar eclipses of 30 May and 23 November 1295 in the *Sulṭānī zīj* for the latitude of Yazd, which are only around –22 and +4 minutes in error (the complete account of the computations of these eclipses will appear in the second part of this paper).[3] Other historical facts reinforce the idea that the accuracy of the eclipse predictions based on the Islamic *zījes* was of interest at this time. For instance, Yelu Chucai (1189–1243), a Chinese astronomer who used some techniques from the Islamic *zījes* to adjust the Chinese calendar during his stay in Samarqand (Transoxania) around 1220, greatly appreciated the accuracy of the eclipse parameters calculated with the aid of Islamic *zījes* (see van Dalen, 2002a: 331).

What is said above maybe explains the reason why the observational reports were no longer given with or accompanied by the computations. The astronomers appear to have found it sufficient to only assert that the solar and lunar parameters they adopted were accurate enough to establish a fair degree of agreement between theory and observation.

Very late in the Medieval Islamic Period and in the Pre-modern Period (ca. 1451-1700), there are some scattered allusions to, and a few surviving accounts of, the computation of eclipses, which show that eclipse parameters were still computed using the same traditional procedures. This Period saw the first attempts to transmit Renaissance astronomy (heliocentricism, the Tychonic system, and so on) to central Iran (see Ben-Zaken, 2009). Nonetheless, the first detailed accounts of the computations of eclipse timings and magnitudes based on modern astronomy appeared (seemingly, for the first time) in the *Muḥammadshāhī Zīj*, a Persian *zīj* completed in Jaipur, India, around 1735 under the patronage of Sawā'ī Jai Singh (1688–1743) (Pingree, 2002), named after Muḥamamdshāh, the Moghal Emperor of India (1702–1748, r. 1719-1748). This work seems to be the first in Islamic-Indian astronomy, in which new astronomy and elliptical orbits were employed practically in order to determine planetary longitudes. The new underlying parameters were adopted from the astronomical tables of Philippe de La Hire (Paris, 1727; see Dalen, 2000 and the references mentioned therein). Included in this *zīj* are some worked examples for computing the longitudes of the Sun, the Moon, Mars and Mercury, as well as the parameters of the partial solar eclipse of Monday 30 Dhu al-Qa'da 1146 H/3 May 1734 and the lunar eclipse of Sunday 15 Dhu al-Hijja 1144 H/8 June 1732 (P1: 206-208, 212-222; P2: 274-276, 280-291; N1: 189-190, 193-201; in P1 and P2 the date of the lunar eclipse is wrongly given as *10* Dhu al-Hijja. Also, note that the dates are not according to the Hijra civil calendar but to its astronomical calendar).

The first computation of the parameters of eclipses on the basis of modern astronomy in the Middle East occurred around the mid-nineteenth century. In the *Nāṣirīd ephemeris* written by Maḥmūd Khān (1866) of Qum (a city in the vicinity of Tehran) for King Nāṣir al-Dīn of the Qājār Dynasty of Iran, the author gives the astronomical ephemeris for the year 788 Jalālī/1282-1283 H/1866-1867 AD for the longitude of Tehran (p. 7), the Iranian capital. It contains lists of the magnitudes and times of two lunar eclipses: 31 March and 24 September 1866 (the times of the phases of these eclipses are given in local mean sidereal time). Maḥmūd Khān also lists the parameters of the partial solar eclipse of 6 March 1867, but doubts that this solar eclipse will actually occur because, in order to compute the eclipse, knowledge of the latitude of the place is necessary, while the latitude of the capital was not known with certainty. The computational accounts of the eclipses mentioned above will be studied in the second part of this paper.

Besides comparing observational and theoretical results and other factors of the same sort, there was another important factor that constituted a principal motive especially for the observation of lunar eclipses: the structural parameters defining the orbit of the Moon in the Ptolemaic model were determined from observations of lunar synodic phenomena. The observation of three lunar eclipses was essential for determining the radius of the epicycle, and the observation of the Moon at quadratures (quarter Moons) for measuring the eccentricity. In *Almagest* IV.6, Ptolemy proposed a mathematical method for determining the size of the lunar epicycle in terms of the radius of its deferent, using data obtained from the observations of a trio of the lunar eclipses (cf. Duke, 2005; Neugebauer, 1975(1): 73-80; Pedersen, 2010: 172-178; Thurston, 1994, Appendix 4: 204ff.; Toomer, 1998: 190-203). To the best of my knowledge, only three Middle Eastern astronomers in the Medieval Islamic Period gave observational data on a trio of lunar eclipses and explained how they determined the lunar epicycle radius from them. They are as follows:

(1) Abū al-Rayḥan al-Bīrūnī (in *al-Qānūn al-mas'ūdī*, *Volume 2*: 742-743): the three lunar eclipses in the period AD 1003-1004, observed from Jurjān (Gurgān, northern Iran), nos. 07224, 07225, and 07227 in NASA's Five Millennium Catalog of Lunar Eclipses (henceforth, referred to as 5MCLE);
(2) Muḥyī al-Dīn al-Maghribī (in *Talkhīṣ al-majisṭī*, fol. 69v): the three lunar eclipses in the period AD 1262-1274, observed from Maragha (northwestern Iran); and
(3) Jamshīd Ghiyāth al-Dīn al-Kāshī (in *Khāqānī zīj*, IO: fols. 4r-v; P: 24-25): the three lunar eclipses in the period AD 1406-1407, observed from Kāshān (central Iran).

Al-Bīrūnī's trio of lunar eclipses have already been analyzed by Said and Stephenson (1997: 45-46) and Stephenson (1997: 491-492), but the reports by the other two astronomers have hitherto remained unnoticed and have not been investigated. These appear to be the only preserved observational reports of lunar eclipses from the Late Medieval Islamic Period, and they are the main focus of the remainder of this paper.

3 THE LUNAR ECLIPSES OBSERVED FROM MARĀGHA BETWEEN AD 1260 AND 1280

Not very much is known about al-Maghribī. His full name is "Abū al-Shukr/Abu al-Karīm/Abu al-Fatḥ Yaḥyā b. Muḥammad b. Abī al-Shukr b. Ḥumīd of the Maghrib (of Tunis, of al-Andalus, or of Cordoba). Al-Maghribī spent some years (after 1237 and until 2 October 1260) in the service of King Nāṣir of Damascus (reign: 1237-1260) in Aleppo before the King was killed by Mongols, and then he was sent to the Maragha Observatory. Other than a short stay in Baghdad in the latter part of the 1270s, he seems to have lived and observed at the Maragha Observatory until his death in June 1283. He taught some students in the Observatory, and appears to have written about 26 works on mathematics, astronomy, and astrology (see Brockelmann, 1937 (Supplement): 868; 1943(1): 626; Rosenfeld and Ihsanoglu, 2003: 226; Sarton, 1953: 1015-1116; Sezgin, 1978: 292; Suter, [1900] 1982: 155; see, also Comes' entry (pages 548-549) in Hockey et al., 2007). Some of al-Maghribī's mathematical works have been studied (e.g. see Hogendijk; 1993; Voux, 1891), and Tekeli's short entry about al-Maghribī in the *Dictionary of Scientific Biography* (Gillispie et al., 1980(9): 555) only covers his mathematical works. Two of his works are the astronomical tables accompanied by explanatory instructions on how to use them, the so-called *zījes*: *Tāj al-azyāj* (written at Aleppo ca. 1257; see Dorce, 2002-2003) and *Adwār al-anwār* (written at Maragha in 1276).

Al-Maghribī's astronomical activities at the Maragha Observatory made him such an outstanding figure that his contemporaries and immediate successors called him by unique honorific titles that denoted his skill in making observations. For instance, Ibn al-Fuwaṭī, the Librarian at the Observatory, called him "... the geometrician of the observations ..." (Ibn al-Fuwaṭī, (5): 117). His observational program is often referred to as 'the new Ilkhānīd observations', to distinguish it from the purported observations conducted at Maragha for the preparation of the *Īlkhānī zīj*. His fame was so widespread that his astrological doctrines were treated with great respect (nine of his treatises are on astrology). An amazing example of this is the interpretation of the appearance of the comet C/1402 D1 based on his astrological dogmas, which led to a very decisive war in the Middle East at the turn of the fifteenth century (see Mozaffari, 2012: 363-364).

In his *Talkhīṣ al-majisṭī*, "Compendium of the *Almagest*", written seemingly after the *Adwār* (i.e., in the latter part of the 1270s), al-Maghribī presented his solar, lunar and planetary observations and computations. The contents of this work have already been introduced by Saliba (1983; 1985; and 1986). Table 2 presents the lunar eclipses observed by him at the Maragha Observatory, arranged chronologically (nos. 07878, 07897, and 07907 in 5MCLE).

Column 1 contains the numbers that al-Maghribī used to refer to each eclipse.

Column 2 presents the dates of the observations given in the text according to the Yazdigird era, and their corresponding dates in the Julian calendar and in Julian Day Numbers. The Yazdigird era originated on 16 June 632, and is used with the Egyptian/Persian year consisting of 12 months of 30 days plus five epago-

Table 2: Lunar eclipses observed by al-Maghribī at the Maragha Observatory.

Nos.	Date	Time	Type	Magnitude	$\lambda_{\odot}$	Stars' Altitudes
1	Night of Wed. 28/2/631 Y 7 March 1262 JDN 2182069	630 y 1 m 27d 8;18 h	TD	total	354;22,50	*At the start of totality:* Regulus (α Leo): 51° West *At the end of totality:* Spica (α Vir): 17° East
2	Night of Tue. 1/4/639 Y 7 April 1270 JDN 2185022	638 y 3 m 0d 10;13 h	P	≈ (1/2)+(1/3) from south	24;53, 1	*At the beginning of the eclipse:* Arcturus (α Boo): 42° East *At the end of the eclipse:* Regulus (α Leo): 35° West
3	Night of Wed. 18/1/643 Y 24Jan. 1274 JDN 2186410	642 y 0 m 17d 14;0 h	P	≈ 4/5 from north	311;41,28	*At the beginning of the eclipse:* Arcturus (α Boo): 35° East *At the end of the eclipse:* Arcturus (α Boo): 68° East

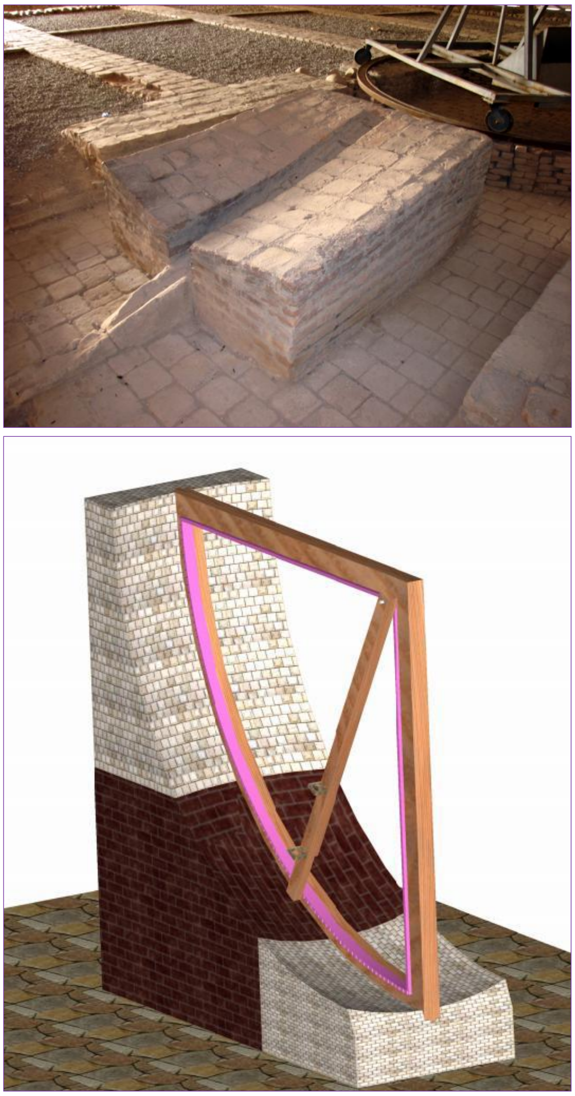


Figure 2: The central quadrant of the Maragha Observatory. (a): The remnant of the instrument's base (picture taken by the author), (b): a virtual reconstruction of it based on the dimensions given by al-'Urḍī, the instrument-maker at the Observatory (drawn by Dr. Elkhan N. Sabziev).

Table 3: Al-Maghribī's measured times of the maximum phases of the three lunar eclipses observed from Maragha in comparison with modern data.

Nos.	al-Maghribī	Modern	Error
1	08:18 h	08:13 h	+5 m
2	10:13 h	10:08 h	+5 m
3	14:00 h	13:57 h	+3 m

menal days which, in the Early Medieval Islamic Period, were put after the eighth month. But in the Late Medieval Islamic Period, they were transferred to the end of the year. In order to convert the dates from the Yazdigird era to the Julian one, it needs to be kept in mind that in Islamic chronology the day is traditionally reckoned from sunset, and hence 'night' precedes 'day'. As a result, for example, the night of Wednesday, 28/2/631 Yazdigird, is the time interval between sunset on Tuesday, the 27th and sunrise on the 28th. This confusion cannot occur when we use the equivalent Julian dates. Since al-Maghribī has made the precise time of the maximum phase of each eclipse available (see Column 3), the dates can be converted conveniently.

Column 3 presents the times of the eclipses, that is, the instants when the maximum phases occurred, counted from the beginning of the Yazdigird era. Al-Maghribī counted the hours using a clepsydra, from the instant of the meridian transit of the Sun (true noon), which was observed using the central quadrant of the Observatory erected on the local meridian line (see Figures 2a and 2b).

The instants of true noon for the days of the eclipses are, respectively, 12:10, 12:00 and 12:15 (-1 day), according to the mean local time (MLT) of Maragha (≈ UT + 3hr 4m). The true times of the maximum phase of the three eclipses are 20:23, 22:08, and 02:12, respectively, calculated from 5MCLE for the longitude of Maragha. Thus, the times of the eclipses after true noon, measured in hours, are as listed in Table 3.

The central quadrant had been engraved for each 0.5′, and the majority of al-Maghribī's meridian altitude measurements were performed with the aid of it. Al-Maghribī appears to have been so interested in the instrument that he composed a poem during his observations of AD 1265-1266 to praise it, and an astrologer named Majd al-Dīn Abū Muḥammad al-Ḥasan b. Ibrāhīm b. Yūsūf al-Ba'albakī engraved the poem on the quadrant (Ibn al-Fuwaṭī, Vol. 4, 413-414).

Al-Maghribī frequently referred to the application of a clepsydra, to which the Persian name *pangān* (Arabicized as *bankām;* Pl. *bankāmāt*) was assigned, in his systematic observations (however, he wrongly mentions its name as *mankām*). We only know the general shape of the instrument: it was in the form of a floating bowl (*ṭās*), with a hole in its apex and two graduated scales (usually drawn with the aid of an astrolabe) for both the equal and unequal hours on its peripheral surface. When this bowl was placed in a vessel containing water, as the water drained into it the level of the water determined the time at each moment. The first description of this type of clepsydra in the Medieval Islamic Period appears in al-Ṣūfī's *Book on the Astrolabe* (1995: Chapters 354-357: 299-302). This type of clepsydra can be traced back to Babylonian and Indian texts from the first millennium BC (Pingree, 1973: 3-4). Archaeological excavations have un-earthed its earliest models in India, apparently be-longing to the same period (Rao, 2005: 205-206).

Based on the information given by al-Maghribī, one can only speculate about its calibrations, as nothing more is known about its structure. The clepsydra used, of course, appears to have been of a good accuracy, so that it could establish time intervals to within a few minutes (and in the case of the lunar eclipses, the errors were within ±5 minutes). Thus, it does not seem that it was a simple drainage clepsydra. It should be mentioned here that in medieval Chinese astronomy the use of clepsydras having compound mechanical components had been established since at least the eleventh century (Needham, 1981: 136). Due to the verified cultural relations between Iran and China, in the Mongolian Period, and especially considering the fact that some Chinese astronomers (e.g., at least Fu Mengchi, also referred to as Fu Muzhai) worked at the Maragha Observatory (van Dalen, 2002a: 334; 2002b; 2004), perhaps there was a connection between the clepsydra of the Maragha Observatory and the elaborate Chinese time-measuring devices.

Column 4 in Table 2 indicates the type of the eclipse; TD denotes 'Total eclipse with a perceptible duration (lit. 'staying', *makth*)', while P stands for 'Partial'.

Table 4: Al-Maghribī's values for the magnitudes of the three lunar eclipses observed from Maragha in comparison with modern data.

Nos.	al-Maghribī	Modern
1	total	1.77
2	0.833	0.823
3	0.8	0.77

Column 5 in Table 2 presents the magnitude of the eclipse. Modern values are listed in Table 4 (from 5MCLE). These might be a naked eye estimate; however, two different types of optical devices used for directly measuring eclipse magnitudes had by this time been invented, and examples of both were constructed at the Maragha Observatory. Ptolemy (*Almagest*, V.14) used a dioptra, originally described by Hipparchus, that was four cubits, or about 185.28 cm, in length (Toomer, 1998: 56). This had a fixed lower pinnula on which there was a hole for sighting, and a movable outer pinnula, which was placed in front of the Sun. The solar/lunar angular diameter meter was calculated based on the movable pinnula's width and the distance between the two pinnulae. In his *Fī kayfīyya al-arṣād*, "How to make the observations", Mu'ayyad al-Dīn al-'Urḍī (d. 1266) modified the dioptra so that it could be used to determine the eclipsed area/ diameter of the Sun or the Moon (Seemann, 1929, 61-71). Thus, al-Maghribī had a specific instrument for measuring the magnitude of eclipses at his disposal, which he may have applied to these three lunar eclipses. In the *Risāla al-Ghāzāniyya fi 'l-ālāt al-raṣadiyya,* "Ghāzān's treatise on observational instruments", and in Wābkanawī's *Zīj* (IV.15, 8: Y: fols. 159r-159v, T: fols. 92r-92v), an instrument used as a pinhole image device is introduced that can measure the magnitude of solar eclipses. This treatise contains physical descriptions and applications of twelve new observational instruments that date from the second period of the Maragha Observatory, and these are presumed to have been the inventions of Ghāzān Khān, the seventh ruler of the Ilkhanid Dynasty of Iran (reign: 21 October 1295-17 May 1304) (see Mozaffari and Zoitti, 2012: 419-422; 2013; Zotti and Mozaffari, 2010: 165, 167).

Column 6 in Table 2 gives the true longitude of the Sun, $\lambda_{\odot}$, at the time of the maximum phase of each eclipse. Al-Maghribī has indeed calculated these values based on his solar tables; in other words, they are not observational data. In order to measure the lunar epicycle's radius, it is necessary as the first step to obtain the Moon's longitudes at the instants of the maximum phases of a trio of lunar eclipses, i.e., when it was in true opposition to the Sun. Then they can readily be calculated as $\lambda_{\rightmoon} = \lambda_{\odot} + 180°$. A comparison with the modern values is shown in Table 5.

Column 7 in Table 2 shows the observed altitudes of some bright stars which were generally used in order to determine the duration and the

Table 5: Al-Maghribī's computed values of the longitude of the Sun at the time of the maximum phases of the three lunar eclipses observed from Maragha in comparison with modern data.

Nos.	$\lambda_{\odot}$	
	al-Maghribī	Modern
1	354;22,50°	354;20,04°
2	24;53,01	24;52,17
3	311;41,28	311;36,54

Table 6: Lunar eclipses observed by al-Kāshī in Kāshān: the times of the maximum phases after midnight.

Nos.	Date	al-Kāshī's local times		Modern local times		Error	
		Apparent	Mean	Apparent	Mean		
1	30/6/775 Y 2 June 1406 JDN 2234752	3;14,30 h	2;56,29 h	4;08,59 h	4;07,01 h	–54.5 m	–70.5 m
2	27/12/775 Y 26 Nov. 1406 JDN 2234929	1;13,05	0;48,46	1;06,07	0;57,27	+7.0	–8.7
3	18/6/776 Y 22 May 1407 JDN 2235106	4;18,30	3;58,46	4;43,52	4;40,05	–25.4	–41.3

time of the phases of each eclipse. The position with respect to the horizon of a particular celestial body may be given by means of its altitude plus its direction with respect to the meridian line; e.g., '51° East' means an altitude of 51° at a given instant, while located east of the meridian. An important note here is that in the case of eclipse No. 1, the directions al-Maghribī cites for the measured altitudes do not express the direction of the star with respect to the meridian, but with reference to the lunar disk. Otherwise, the altitudes should have been expressed as 51° East for Regulus and 17° East for Spica at, respecttively, the start and end of totality.

Based on what al-Maghribī says (*Talkhīṣ*, fol. 67v), these were the eclipses that he "... dealt with observing them with extreme accuracy ...", and thus he could rely on his observations and be confident about the correctness of the data obtained from them. While he was based at the Maragha Observatory, nine other lunar eclipses were observable at their maximum phases from Maragha, and al-Maghribī may have witnessed these as well.

4 THE LUNAR ECLIPSES OBSERVED FROM KĀSHĀN IN AD 1406 AND 1407

Jamshīd Ghiyāth al-Dīn al-Kāshī (ca. 1380–1429) was an Iranian mathematician and astron--omer, who is maybe better known for his computation of sin 1° (Aaboe, 1954; Rosenfeld and Hogendijk, 2002/2003). He flourished in his native city, Kāshān (in central Iran), where he observed the three lunar eclipses considered here, but later he moved to the Samarqand Observatory established by Ulugh Beg (1394–1449) (see Kennedy, 1983: 722-744). Al-Kāshī revised the *Īlkhanī zīj*, which was written at the Maragha Observatory around one and a half centuries earlier. The results were apparently incorporated into his *Khāqānī zīj* (for a brief survey of it see Kennedy, 1998a; for its parts on spherical astronomy see Kennedy, 1998b: Part XVIII, and for the account of planetary latitudes in it see van Brummelen, 2006). Al-Kāshī invented some instruments that served as mechanical computers for doing astronomical calculations, and one of these was a lunar eclipse computer (Kennedy, 1983: 448-480).

Al-Kāshī's three lunar eclipses are summarized in Table 6 (nos. 08220, 08221, and 08222 in 5MCLE). Column 2 presents the dates given by al-Kāshī according to the Yazdigird era and their corresponding dates in the Julian calendar and in Julian Day numbers. It is worth mentioning that for eclipses Nos. 1 and 2 the civil date is given, but for eclipse No. 3 it is the astronomical date (from noon to noon); the civil date of the eclipse No. 3 is 19/6/776 Y. Columns 3 and 4 contain al-Kāshī's time of the maximum phase of each eclipse, respectively, in apparent and mean local times. Columns 5 and 6 show the modern times, obtained from 5MCLE, for the longitude of Kāshān. Columns 7 and 8 contain the difference between al-Kāshī's times and modern times.

The values that al-Kāshī took for the equation of time (the difference between the apparent and mean local times in Columns 3 and 4 in Table 6) can be obtained from his table for the equation of time (al-Kāshī, IO: fols. 126v-127r; cf. Kennedy, 1998b: Part VII), in which the equation of time is tabulated as a function of the true solar longitude. For example, for eclipse No. 2, the Table gives $E(252°) = 0;24,17^h$ and $E(253°) = 0;23,52^h$ for the beginning of the year 712 Y and thus, by means of linear interpolation between the two, the figure for the equation of time at the time of eclipse No. 2, for which al-Kāshī gave $\lambda_\odot = 252;13,53,38°$, is calculated as $E(252;13,53,38°) \approx 0;24,11^h$. There are also changes in the equation of time over long time intervals (per century, and over seven centuries) included in the Table; for $\lambda_\odot$ from 250° to 257° the Table gives the amount of the correction as 11 seconds per century counted from the year 712 Y, and thus it is $11 \cdot (775–712)/100 \approx 7$ seconds for the year 775 Y. As a result, $E(252;13,53,38°) \approx 0;24,18^h$ for that year.

As we have already seen, al-Maghribī simply took the point diametrically opposite the Sun as the position of the Moon on the ecliptic at the times of the maximum phases of the lunar eclipses, but al-Kāshī considered the difference in the positions of the Moon on the ecliptic and in its orbit due to the ~5° inclination of the latter to the former (Figure 3), as shall be explained presently. Al-Kāshī tabulated some other parameters

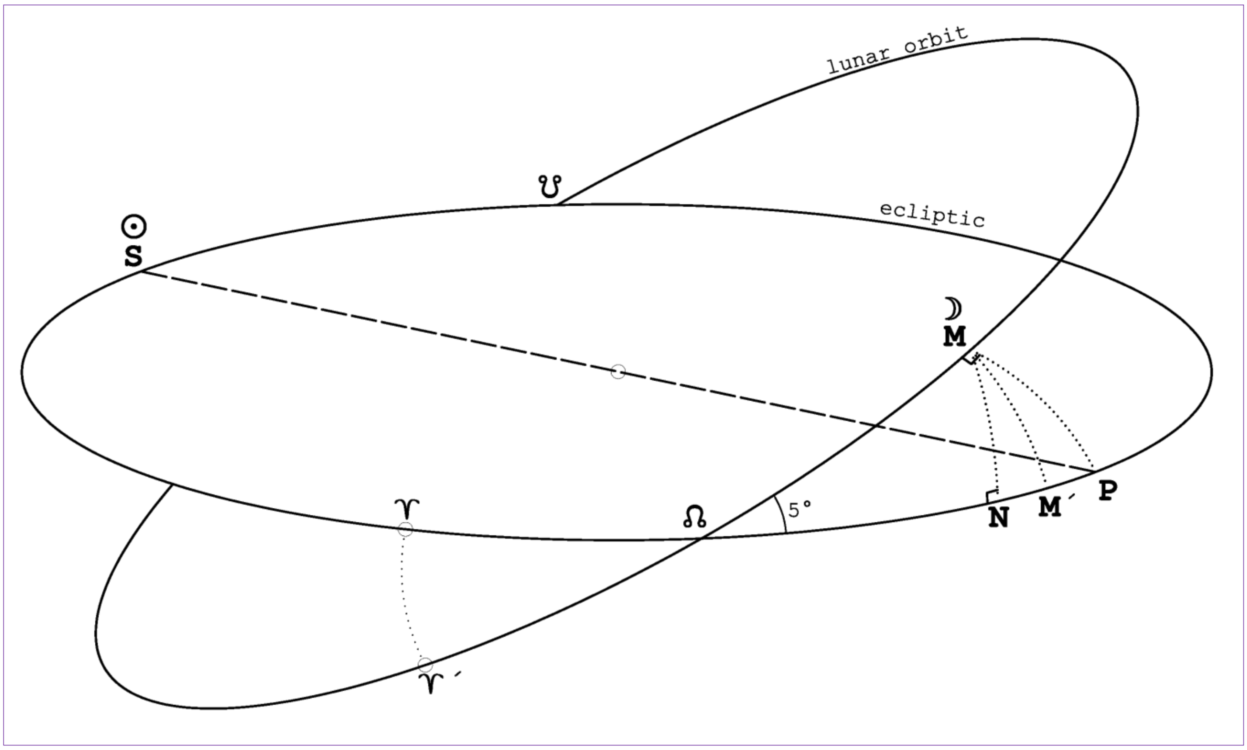


Figure 3: The inclined lunar orbit and the ecliptic.

for the instants of the maximum phases of these eclipses, which are presented in Table 7. They include the solar longitude, $\lambda_{\odot}$ (Column 2); the longitude of the lunar ascending node counted in the direction of decreasing longitude, i.e., 360°– $\lambda_{☊}$ (Column 3); and the difference between $\lambda_{\odot}$ and the longitude of the lunar orbital node that was close to the Sun at the time, i.e., the ascending node for the eclipses Nos. 1 and 3 and the descending node for the eclipse No. 2 (Column 4). In fact, it is the sum of Columns 2 and 3 minus 360° for eclipses Nos. 1 and 3, and minus 540° for the eclipse No. 2. (but of course al-Kāshī did not use the positive and negative signs as shown in Table 7; they are used here to show when the Sun was ahead of the node in longitude, i.e., +, or behind it, i.e., –). That is equal to the difference in longitude between the centre of the Earth's shadow and the other lunar node, which is near the Moon at the time of the maximum phase of the eclipse, i.e., the descending node in the case of eclipses Nos. 1 and 3 and the descending node in the case of eclipse No. 2.

With regards to Figure 3, at the time of the maximum phase of a lunar eclipse, the Sun is at S, close to the lunar descending node, and P is the centre of the Earth's shadow near the lunar ascending node. The distance S☋ = $\lambda_{\odot} - \lambda_{☋}$ is equal to P☊ = $\lambda_{☽} - \lambda_{☊}$. The intersection of the lunar inclined orbit with the great circle passing through P and S that is perpendicular to the lunar inclined orbit defines the position of the Moon on its inclined orbit at the time of the observation, i.e., M. M′☊ is taken as equal to M☊, and N is the projection of M onto the ecliptic. From the values of the distance between the centre of the Earth's shadow and a node, i.e. the values of $\lambda_{\odot} - \lambda_{☊}$ (or ☋) listed in Column 4, al-Kāshī computed its difference from the distance of the Moon from that node (Column 5), which is called the 'equation of shift' (*taʿdīl-i naql*; or 'reduction to the ecliptic' in the modern terminology). The values of $\lambda_{\odot}$+180° were then adjusted by this equation to produce the lunar longitudes, $\lambda_{☽}$, with reference to its inclined orbit, i.e., M♈′ in Figure 3 (Column 6).

As al-Kāshī points out, Ptolemy already noticed the difference between the positions of the Moon in its orbit and on the ecliptic (*Almagest* IV.6; Toomer, 1998: 191; Pedersen, 2010: 199-200; note that al-Kāshī wrongly referred to *Almagest* VI.6), but since its effect is small enough to be ignored he did not consider it in the determination of the lunar parameters or in the computation of the eclipses. From the earliest steps in the rise of astronomy in medieval Islam, astronomers took this equation into account; a table showing it first appeared in Yaḥyā b. Abī Manṣūr's *Zīj al-mumtaḥan* (Kennedy and Pingree, 1981: 168 and 310). Al-Maghribī, in *Talkhīṣ al-majisṭī* V.11, calls it 'the equation of the inclined sphere of the Moon' (*taʿdīl al-falak al-māʾil*) or 'the equation of shift', just like al-Kāshī, but in the other *zījes*, it is called the 'third equation' after the 'first equation', which is the 'equation of centre', and the 'second equation', which is the 'equation of anomaly'. The 5° inclination of

Table 7: Al-Kāshī's longitudes of the Sun and lunar ascending node for the times of the maximum phases of the lunar eclipses.

No.	$\lambda_{\odot}$	$360° - \lambda_{\text{☊}}$	$\lambda_{\odot} - \lambda_{\text{☊}}$ (or ☋)	Equation of shift	$\lambda_{\text{☽}}$ (inc. orb.)
1	78;55,10,41°	274;32,46°	−6;32,03°	+0;1,29, 2°	258;56,39,43°
2	252;13,53,38	283;54,51	−3;51,15	+0;0,52,40	72;14,46,18
3	68;14,18,43	293;17,40	+1;31,59	−0;0,20,58	248;13,57,45

the Moon's orbit to the ecliptic also means that the maximum phase of a lunar eclipse does not always occur exactly at the time when the Moon is in opposition to the Sun, except in the case of central lunar eclipses when the lunar latitude is exactly zero. Jābir b. Aflaḥ (Spain, the first half of the twelfth century) noticed this difference (see Bellver, 2008: 63). Some medieval astronomers (e.g., see Wābkanawī, III.11.4: T: fol. 63r, Y: fol. 114r, P: fol. 96r) believed that the inclination of the lunar orbit should be taken into account in order to compute a more accurate value for the duration of the eclipse's phases.

The equation of shift, c, may simply be calculated by

$$c = \tan^{-1}(\tan(\lambda_{\text{☽}} - \lambda_{\text{☊}}) \cos 5°) - (\lambda_{\text{☽}} - \lambda_{\text{☊}}) \qquad (1)$$

It does not matter whether $\lambda_{\text{☽}}$ is the lunar longitude with reference to the ecliptic or to its inclined orbit. The equation is subtractive in the first and third quadrants ($0 < \lambda_{\text{☽}} - \lambda_{\text{☊}} < 90°$, $180° < \lambda_{\text{☽}} - \lambda_{\text{☊}} < 270°$) and additive in the second and fourth quadrants ($90° < \lambda_{\text{☽}} - \lambda_{\text{☊}} < 180°$, $270° < \lambda_{\text{☽}} - \lambda_{\text{☊}} < 360°$). The maximum value of the equation is 0;6,33° for $\lambda_{\text{☽}} - \lambda_{\text{☊}} \approx 45°$. In the majority of the tables found in the Islamic *zījes*, the maximum value is 0;6,40° (e.g., Khāzinī, fol. 135r, *Īlkhānī zīj*, C: 84; al-Maghribī, *Talkhīṣ*, fol. 83v; Kamālī, fols. 67r and 243v; Wābkanawī, T: fol. 156r). Al-Bīrūnī (*al-Qānūn*, 2: 810), Kāshī (IO: fol. 133v; P: fol. 51v), and Ulugh Beg (P1: fol. 126v; P2: fol. 145r) accurately gave 0;6,33°.

It is noteworthy that al-Kāshī employed this equation in the inverse manner: from the *zījes*, the longitude of the Moon with reference to its inclined orbit was first computed and the resultant was then adjusted by the equation of shift to produce the ecliptical longitude of the Moon, while al-Kāshī had the latter and wished to compute the former. The recomputed values for the equation of shift in the three eclipses are, respectively, +0;1,28,45°, +0;0,52,38°, and −0;0,20,59°.

The longitude of the Moon at the maximum phase of the eclipse was obtained from the solar longitude which was computed from the solar parameters (eccentricity, mean motion, longitude of the apogee) which were already determined or adopted by other astronomers. Al-Maghribī determined a set of the solar parameters for the Maragha Observatory (see Saliba, 1985), and based upon these he computed the lunar longitudes for the maximum phases of his three lunar eclipses (Table 5). Through his project of revising the *Īlkhānī zīj*, al-Kāshī adopted the values employed in it for the solar eccentricity and mean motion, which are those that Ibn Yūnus applied in his *Zīj al-kabīr al-ḥākimī*. Unlike al-Maghribī, al-Kāshī does not supply us with an account of his solar observations (if any), which would have been very useful as we could have calculated the longitude of the Sun and of the lunar ascending node at the times of the maximum phases of these eclipses taken from the *Īlkhānī zīj* and compared them with the longitudes given by al-Kāshī (Table 7, Columns 2 and 3) and with modern data. It may then have been possible to determine to what extent they were dependent upon each other and/or if al-Kāshī's revision of the *Īlkhānī zīj* might have improved the quantities computed from it in comparison to modern data. In the tables of the geographical coordinates of the cities in the Islamic *zījes*, there is a 4° difference between the longitudes of Maragha and Kāshān (*Īlkhānī zīj*, C: 197; al-Kāshī, IO: fols. 73v-74r), corresponding to a time difference of 16 minutes between the two sites. Thus, 16 minutes were subtracted from al-Kāshī's mean local times (cf. Table 6, Column 4 and Table 8, Column 2), and the values of $\lambda_{\odot}$ and $\lambda_{\text{☊}}$ were calculated from the *Īlkhānī zīj* for the resulting times (Table 8, Columns 3 and 4). The modern values are given in Columns 5 and 6. The difference between the modern longitude values and those of al-Kāshī and the *Īlkhānī zīj* are presented in Columns 7-10. As we can see, al-Kāshī's values for the solar longitude are more exact than those computed from the *Īlkhānī zīj* by around 10′. Considering the longitude of the lunar ascending node, there are systematic errors of +14′ and +18′, respectively, in the values given by the *Īlkhānī zīj* and al-Kāshī.

5 DISCUSSION

5.1 Accuracy of the Medieval Values for the Lunar Epicycle Radius

From *Almagest* IV.11 (Toomer 1998: 212-213), it is clear that Hipparchus had already established the principle that it was necessary to use a trio of lunar eclipses close in time, so that any long-term error in the mean motions would have a minimal effect on the determination of the size of the lunar epicycle. This was strictly followed by al-Bīrūnī and al-Kāshī while al-Maghribī apparently selected his three lunar eclipses from those observed during a 12-year period.

Based on their observations, al-Bīrūnī and al-Maghribī calculated the lunar epicycle radius as r = 5;12 and al-Kāshī as r = 5;16,46,36, while

Table 8: Longitudes of the Sun and lunar ascending node according to the *Īlkhānī zīj* for al-Kāshī's times of the maximum phases of the lunar eclipses.

No.	Mean local time of Maragha	*Īlkhānī zīj*		Modern		*Īlkhānī zīj*–Modern		al-Kāshī(*)–Modern	
		$\lambda_{\odot}$	$\lambda_{☊}$	$\lambda_{\odot}$	$\lambda_{☊'}$	$\Delta\lambda_{\odot}$	$\Delta\lambda_{☊}$	$\Delta\lambda_{\odot}$	$\Delta\lambda_{☊}$
1	2;40,29	78;46,10°	85;23,24°	79;01,46°	85;08,52°	–0;15,36°	+0;14,32°	–0;6,35°	+0;18,22°
2	0;32,46	252;23,18	76;01,17	252;12,57	75;46,54	+0;10,21	+0;14,23	+0;0,57	+0;18,15
3	3;42,46	68;05,42	66;38,28	68;18,49	66;24,02	–0;13,07	+0;14,26	–0;4,30	+0;18,18

(*) See Table 7, columns 2 and 3.

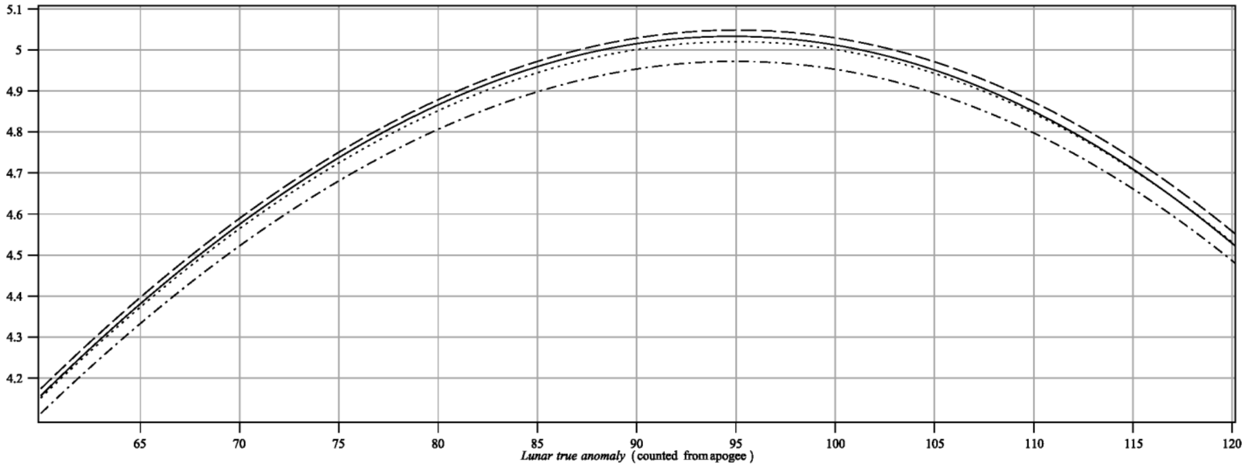
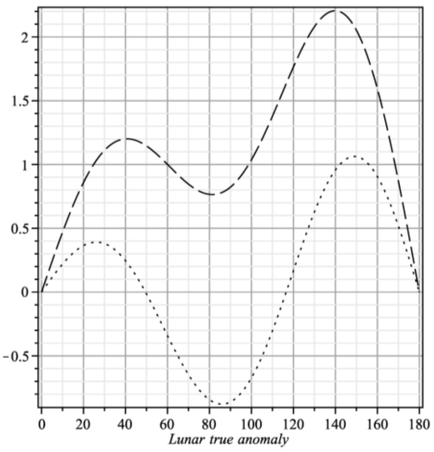


Figure 4(a) top: The two major terms in the formula for finding the difference between the lunar true and mean longitudes in modern astronomy are 22640″ · sin α – 769″ · sin 2α (called 'major inequality') and 4586″ · sin (2$\overline{\eta}$ – α) (called 'evection'), where α is the mean anomaly of the Moon, measured from apogee and $\overline{\eta}$, its mean elongation from the Sun. In the Ptolemaic sense, the 'first inequality of the Moon' is relevant to the syzygies, i.e., when $\overline{\eta}$ = 0 or 180°, and is given by $\tan^{-1}$ (r ·sin α/(R + cos α)). According to modern theory, its size is then computed from ~ 5.015° · sin α – 0.214° · sin 2α. The graphs shows the values of the first inequality of the Moon (measured in degrees) based on Ptolemy's r = 5;15 (the dotted graph), al-Kāshī's r = 5;16,46,36 (the dashed graph), and al-Maghribī's and Bīrūnī's r = 5;12 (the dotted-dashed graph) (R = 60). The continuous graph is based on the above-mentioned modern formula. Figure 4(b) right: The difference between the values computed for the first inequality of the Moon from the modern theory and from Ptolemy's and al-Kāshī values for r, shown respectively, as the dotted and dashed graphs.



Ptolemy reported r = 5;15 in terms of the radius of an orbit of R = 60 arbitrary units. The accounts of the determination of the lunar parameters by these medieval astronomers will be studied in three separate papers by the present author. It may, nonetheless, be appropriate to take a look at their achievements in comparison with modern theory. In the Hipparchan and Ptolemaic lunar models, the epicycle is to account for the first inequality of the Moon in the Ptolemaic sense (see Neugebauer 1975(3): 1106-1108). Figure 4a depicts the graphs of this inequality based on the three above-mentioned values for r (Ptolemy: the dotted graph, al-Bīrūnī and al-Maghribī: the dotted-dashed graph, and al-Kāshī: the dashed graph) and on the modern formula (the continuous graph). Figure 4b shows the difference between the values computed for this inequality from modern theory and from Ptolemy's and al-Kāshī's values for r (respectively, the dotted and dashed graphs). It is then evident that Ptolemy's value of 5;15 for r keeps the values of the first inequality in closer agreement with modern theory than do the two medieval values for r.

5.2 Accuracy of the Lunar Eclipse Observations in the Late Medieval Islamic Period

As mentioned earlier, making use of bowl-shape clepsydras may be traced back to Babylonian and ancient Indian astronomy. It is probable that the Babylonians utilized clepsydras in order to determine eclipse timings (Stephenson, 1997: 59). In Chinese astronomy there was a long-term intention to measure the times of the phases of eclipses directly with the aid of clepsydras (Stephenson, 1997: Chapter 9). The accuracy attained is around 15 minutes. However, there is evidence to verify that Chinese astronomers could measure the times of sunrise and sunset with an accuracy of around 5 minutes (Stephenson, 1997: 278). In medieval Islamic astronomy eclipse timings were usually measured directly from the altitude of the Sun (in the case of solar eclipses) or reference stars (in the case of lunar eclipses). In mid-latitudes and for mid-altitudes, such measurements might be accurate to within 5-6 minutes (Stephenson, 1997: 466). Although time-measuring instruments were in common use in medieval Islamic society, no details of the application of any device for measuring the times of the phases of eclipses may be found in medieval Islamic astronomy prior to al-Maghribī. As suggested earlier, the clepsydra he used may have been a Chinese model that was brought to the Maragha Observatory by Chinese astronomers. Since then, the use of the two methods (altitude-clepsydra) together appears to have been established as the standard in the second period of the Maragha Observatory (1283-1320). The times measured by *Pangān* were called *sāʻāt al-bankām*, 'Pangān's time', in order to distinguish them from the times computed from altitude readings, *sāʻāt al-irtifāʻ*, or 'altitude time'. For instance, Wābkanawī (IV. 15.8–9: T: fols. 92r-v, Y: fols. 159r-160r, P: fols. 139r-140r) emphasized that this might reduce the probable errors in time measurement. The use of the two methods simultaneously is also proposed in the already-mentioned "Ghāzān's treatise on observational instruments", written in the same period (the translation of the relevant passage in Mozaffari and Zotti, 2012: 419-421). It is noteworthy that during the seventeenth century, European astronomers still preferred to time eclipses by measuring altitudes rather than relying on mechanical clocks (Stephenson and Said, 1991: 207, note 26).

Unlike al-Bīrūnī and al-Maghribī, al-Kāshī did not explain how he measured the times during his observations of lunar eclipses. Neither was an instrument mentioned, nor did his account include any stellar altitudes. With regards to the times reported (Tables 2 and 8, Stephenson 1997: 491-492), it is obvious that al-Bīrūnī and al-Maghribī were better observers than al-Kāshī.

6 NOTES

1. Throughout this paper I use a sexagesimal notation, where a semi-colon always follows the number or primary unit (usually degrees or hours), after which comas are used. For example, in this Abstract 5;17 means 5 and 17/60 units, while in Table 1 on page 314 37;20,30° = 37° 20′ 30″. On page 318 in the second paragraph in the right hand column $0;24,17^h$ = 0h 24m 17s and 252;13,53,38° = 252 degrees 13 minutes 53 38/60 seconds. On page 320, immediately after Equation (1), 0;6,33° = 0 degrees 6 minutes 33 seconds, and later, in the second paragraph in Section 5.1, 5;16,46,36 means 5 + 16/60 + 46/3600 + 36/21600 (where 3600 = 60 × 60 and 21600 = 60 × 60 × 60).
2. For Islamic *zījes* considered in this paper see Kennedy (1956) and King and Samsó (2001). A new survey of Islamic astronomical handbooks has been prepared by Dr Benno van Dalen, and his *Islamic Astronomical Tables. Mathematical Analysis and Historical Investigation* will be published by Ashgate/Variorum in February 2014. Biographical sketches of astronomers mentioned in this paper can be found in Gillispie (1970-1980) and Hockey et al. (2007).
3. Note that I consider errors of around half an hour or so as tolerable because, as we will see later in the paper (in Section 5.1), the elements incorporated in the Ptolemaic model are to account only for the two lunar anomalies. Furthermore, the times given in purely observational reports from the Late Medieval Islamic Period differ in accuracy from about +5 minutes to about one hour, which is nearly equal to the errors in the theoretical values computed from the astronomical tables.

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Mohammad Mozaffari has M.Sc. and Ph.D. degrees in history of astronomy in medieval Islam from the University of Tehran and the Institute for Humanities and Cultural Studies, respectively. He is currently an Assistant Professor in the Research Institute for Astronomy and Astrophysics of Maragha (RIAAM). His research interests include the analysis of planetary parameters in ancient and medieval astronomy, the theory of eclipses, observational instrumentation, and astronomy in a social context. One of his recent publications is "Bīrūnī's four-point method for determining the eccentricity and direction of the apsidal lines of the superior planets", which appeared in the *Journal for the History of Astronomy*, 44, 207-210 (2013).

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A REVIEW OF MĀORI ASTRONOMY IN AOTEAROA-NEW ZEALAND

Pauline Harris
School of Chemical and Physical Sciences, Victoria University of Wellington, Wellington, New Zealand.
Email: Pauline.Harris@vuw.ac.nz

Rangi Matamua
Department of Māori Studies, Waikato University, Hamilton, New Zealand.
Email: rmatamua@waikato.ac.nz

Takirirangi Smith
Te Kawa a Māui, Victoria University of Wellington, Wellington, New Zealand.
Email: takirirangi@hotmail.com

Hoturoa Kerr
Te Poho o Tangaroa, Marine Unit, Te Wānanga o Aotearoa, Hamilton, New Zealand.
Email: Hoturoa.Kerr@twoa.ac.nz

and

Toa Waaka
Society for Māori Astronomy Research and Traditions, New Zealand.
Email: arotoaproductions@gmail.com

Abstract: Across the world indigenous people are seeking to reclaim their traditional knowledge. Within the last fifty years the Māori of Aotearoa-New Zealand[1] have made significant efforts to reclaim their language, arts and science. Part of this renaissance includes a growing Māori movement to reclaim their astronomical knowledge. Māori astronomical understanding was infused throughout much of pre-colonial Māori life, culture and belief. The Sun, Moon and stars were an integral part of practices pertaining to agriculture, architecture, fishing, calendrical systems and exploration. Although early ethnographers attempted to record this knowledge, their works seem to only reflect a somewhat superficial level of understanding. Thus this paper highlights some of the current research being conducted on Māori astronomy, which seeks a greater understanding of how the ancestors of the Māori perceived the heavens.

Keywords: Māori astronomy, *tātai arorangi*, *Matariki*, *Puanga*, navigation, *whetu*, SMART

1 INTRODUCTION

There is clear evidence indicating that the Māori had extensive knowledge of the night sky (Best, 1922). The numerous objects and events that make up the cosmos were well known to the Māori, and comprehensively understood well before the arrival of *Pākehā*.[2] The movements of constellations, the heliacal rising of stars, the arrival of comets, the phases of the Moon and many other astronomical phenomena were noted and examined. This detailed astronomical knowledge resulted in the Māori having a precise understanding of the seasons and helped the ancestors of the Māori to navigate across the vast expanse of the Pacific Ocean. Māori astronomical knowledge is known as *tātai arorangi*. *Tātai arorangi* was considered to be part of the body of knowledge known as *kauwaerunga*, which contained celestial knowledge, knowledge of the creation, the gods, stars and time (Best, 1924). The teachers and specialists of Māori astronomical knowledge were known as *tohunga kokorangi* and *tohunga tātai arorangi*. Although communities had a general knowledge of *tātai arorangi*, only a select few ever were taught the more in-depth information and given the responsibility to hold and use this knowledge.

1.1 Traditional Knowledge and Colonization

Contact with the new European settlers during the nineteenth century saw the introduction of diseases leading to population decimation; imposed legislation deterring the use of traditional practices; urban migration, and the detachment of later generations from their homelands, cultural practices and language (Dalley and McLean, 2005). These effects forced major changes in Māori society, which also affected the maintenance of traditional Māori astronomy. As other cultural and scientific knowledge entered into exchanges and education systems, Māori astronomy as with other Māori knowledge became sidelined, mixed with the new colonial knowledge and then was lost. Thus, today there are few individuals who are knowledgeable in the area of Māori astronomy. In a modern contemporary context the Māori have had over two hundred years of mixing with non-Māori through marriage, friendships and collegiality. Very few Māori live in what would be considered a traditional Māori setting, and Māori knowledge-holders certainly have had significant contact with and have been influenced by non-Māori as well as issues connected with globalization. Hence, any attempt to investigate true pre-colonial Māori astronomical knowledge can be challenging.

In the majority of this paper we endeavour to explore the pre-colonial concepts and understandings that the Māori had pertaining to astronomy, and we also discuss some of the contemporary efforts around revitalization. It should be noted that the discussion of Oceanic navigation in Section 2.6 pertains to recreated knowledge derived from individuals from other Pacific nations who were willing to share their ancestral knowledge with the Māori due to the close cultural affinity of the peoples of the Pacific. Thus, this section represents a fusion of traditional Māori, Pacific and contemporary concepts and ideas.

A number of early ethnographers wrote on Māori star lore and knowledge. The most comprehensive works were written by Elsdon Best (1856–1931), and included *The Astronomical Knowledge of the Māori Genuine and Empirical* (Best, 1922); *The Māori Division of Time* (Best, 1959) and *Children of the Mist* (Best, 1996). Other influential works included books by James Cowan (1930), Edward Tregear (1891; 1904) and Herbert W. Williams (1957).

Orchiston (2000) critically examined the works of these early ethnographers, in particular those penned by Elsdon Best. Best's *The Astronomical Knowledge of the Māori …* contains the Māori names, beliefs and rituals of the Sun, Moon, stars, comets and meteors, whilst his *The Māori Division of Time* outlines the Māori notion of time, explaining how the year was based on the rising of *Matariki* (the Pleiades) and *Puanga* (Rigel), which also incorporated a lunar calendar and seasonal phases based on various biological indicators. After he extensively reviewed these and other published works Orchiston concluded that only fragments of Māori astronomical knowledge are found in the published literature. He stated that the contents of these works were superficial and plagued with source limitations. Best (1922: 64) himself even stated that the amount of Māori astronomical knowledge collated was "… meager and unsatisfactory …" However, Best (ibid.) incorrectly concluded that all information on this topic had been collected, erroneously stating that "The available data concerning Māori sky-lore is now exhausted, and this account must be closed."

This assumption is in stark contrast to current discourse between Māori knowledge experts, who are now discussing a myriad of topics pertaining to Māori astronomy, which are not examined in the forementioned publications. Discussions between researchers and communities also often include criticism of early ethnographic works, with many Māori doubting the validity of some of the information that was given to the ethnographers by some informants. There also is concern that the sources of the information often were not disclosed by the ethnographers.

1.2 Revitalization of Māori Astronomy

In the early 2000's there was a resurgence of interest in Māori astronomical knowledge, seeded by the reactivation of mass celebrations of the Māori New Year, called *Matariki* (the Pleiades) or *Puanga* (Rigel) after the cluster/star that signifies its beginning. The resurgence in this celebration has seen interest spread not only through Māori communities but also to the general public of Aotearoa-New Zealand and even to other parts of the world. This sparked interest was preceded by a quest to revitalize oceanic navigation that began in the 1970s. Hector Busby and others in the Pacific were guided by master navigator Mau Pialug, and they revived traditional navigation techniques, including celestial navigation. Some forty years on Busby and his colleagues continue to educate young Māori and share their knowledge with the next generations (Matamua et al., 2013).

Towards the late 2000's, a group called the Society for Māori Astronomy Research and Traditions (SMART) was formed, and dedicated itself to the preservation and revitalization of Māori astronomical knowledge. This group consists of Māori knowledge experts, educators, navigators and scientists. SMART has embarked on research and publications centered on Māori astronomical knowledge (e.g. see Harris and Matamua, 2012).

Groups such as SMART are actively investigating aspects of Māori astronomy. This undertaking is supported by researchers from the University of Auckland, Te Whare Wānanga o Awanuiarangi and Victoria University of Wellington, who are exploring traditional knowledge associated with the Māori Moon calendar. In addition, SMART researchers are investigating alignments of pre-European contact meeting houses; linguistic influences of stars on the Māori language tribal-specific astronomical knowledge; as well as a myriad of other topics. Groups such as these will follow in the footsteps of earlier revitalizers, such as the Oceanic navigators, Māori medicine (*Rongoa* Māori) groups and canoe-builders, by revitalizing yet another part of

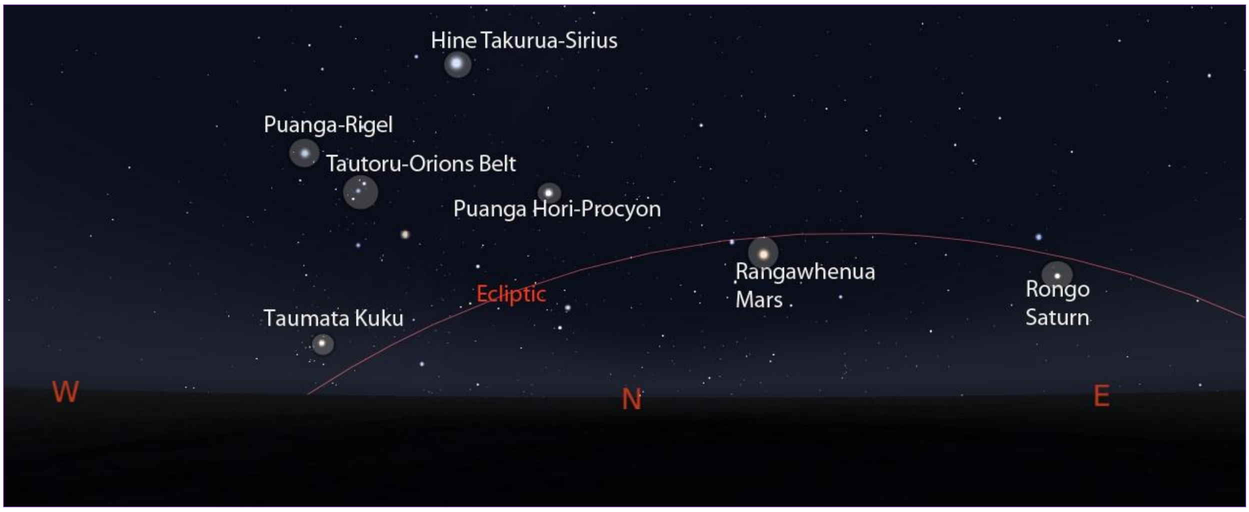

Figure 1: Part of the night sky, with the ecliptic marked in red. This indicates the path that the Sun takes during the day, and also indicates approximately the path the planets follow. Also shown are various star, constellation and planetary names, but these may vary tribally (picture created using Stellarium software).

Māori knowledge, namely, that pertaining to the heavens.

In this paper we touch on some of the more pertinent aspects of Māori traditional star lore. These include cosmological origins, language, food-growing practices, house-building practices and navigation. This is followed by a discussion on some of the efforts to revitalize Māori astronomical knowledge, and what research academics and the Māori community are currently conducting. We also include a summary of some of the main celestial objects, and a section on how the positions of the stars change in the sky throughout the year and how they are seen from different positions on the Earth, in order to assist the reader in understanding how celestial objects were used by the Māori and by other cultures.

1.3 The Motions of the Earth, the Sun, the Moon and the Stars in the Sky

Our Solar System consists of the planet Earth orbiting the Sun, along with seven other planets, dwarf planets, an asteroid belt, dust and other debris. Each planet orbits the Sun at different rates, with the Earth completing one orbit in 365.24 days. All of the planets orbit the Sun in approximately the same plane, so they appear to move across the sky along much the same path as the Sun, which is called the ecliptic. Figure 1 shows a snapshot of the night sky, which contains the names of well known stars, constellations and planets, both in Māori and English. In this figure, the ecliptic is indicated by the red line. Against the background stars the planets can be distinguished as different because of their movement along the ecliptic.

As the Earth revolves around the Sun, different stars fields are visible at different times of the year. Of course this also means that at certain times of the year different stars are obscured from view. Figure 2, shows how certain stars can only be seen at certain times of the year. When the Earth is at position 1, stars at position 3 will not be visible, and when the Earth is at position 2, stars at position 4 will not be visible. In this paper we shall see that certain stars were used as markers for certain times of the year, when they just became visible again in the night sky.

During the day the Sun traverses the sky from east to west. If we observe the daily rising points of the Sun on the eastern horizon, we will notice that the Sun moves incrementally about one-third of a degree per day in Aotearoa-New Zealand, moving towards the North to a maximum point and then moving back towards the South. The extreme points mark the winter and summer solstices.

The Moon orbits the Earth and returns to the same place against the background stars every

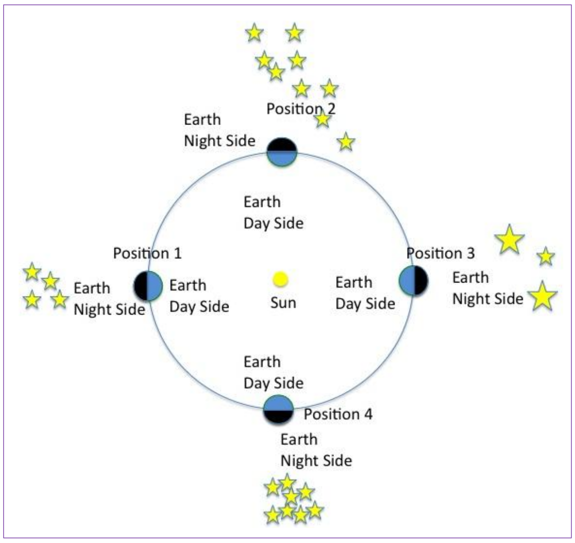

Figure 2: The Earth's orbit around the Sun (not to scale) and the different stars in the night sky visible from different positions during the year.

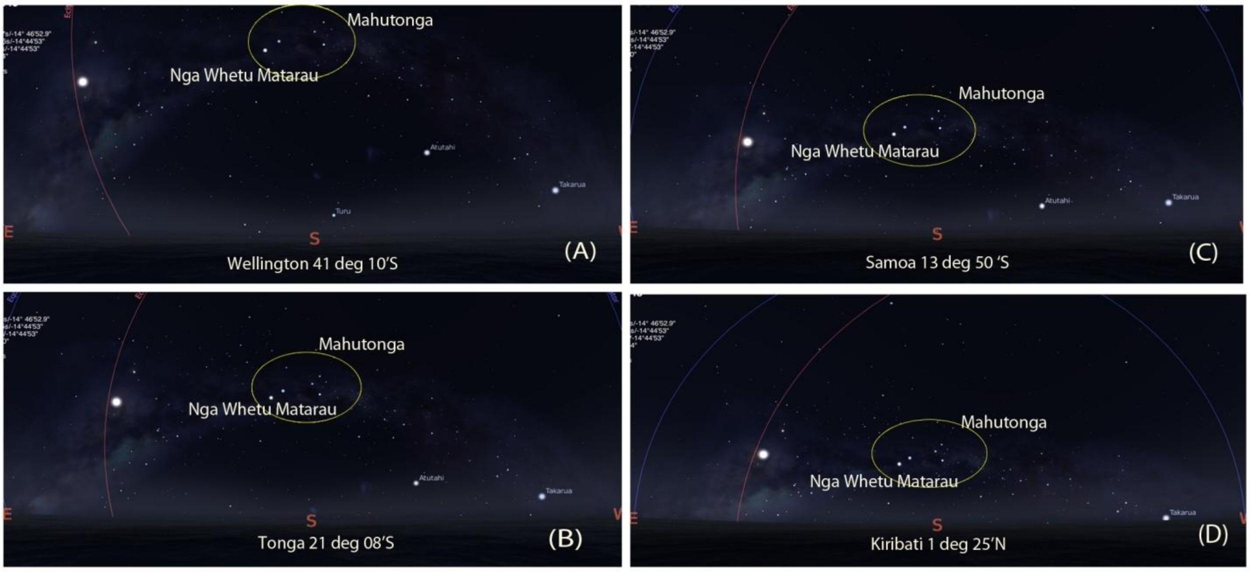

Figure 3: The shift in star positions with changing latitude. Stars to the south will get progressively closer to the horizon as one travels north.

27.32 days, which is its sidereal period. However, the Moon's phases from one new Moon to the next take 29.53 days, and this is its synodic period. To the Māori, this was particularly relevant in tracking the lunar month.

In regards to how we view the night sky from different positions on the Earth, it is best to think of ourselves in a giant spherical bubble where the stars are fixed attached points. This bubble is called the celestial sphere. As we change our position on the Earth, for example moving in latitude from Aotearoa-New Zealand to Hawaii, different stars on the sphere will become visible and others will no longer be seen. If we look at the Pacific region and take a snapshot of the night sky at one time from four different positions on the Earth, Aotearoa-New Zealand, Samoa, Tonga and further north to Kiribati (these were chosen as they are approximately at the same longitude), we see that as we move northwards in latitude some stars to the south that were visible in more southern latitudes will now no longer be visible. This is because as we shift north over the curved surface of the Earth our horizon drops lower in the north and new stars will appear whilst to the south the horizon relative to the celestial sphere shifts higher. Figure 3 shows the snapshots of the stars for the four above-mentioned locations, and Table 1 shows the co-ordinates of the islands these sky views are associated with. *Mahutongo* is shown in the figure, which is the Southern Cross, and *Ngā Whetu Matarau* are the Pointers. As one moves northwards from A to D in Figure 3 the Southern Cross gets closer and closer to the horizon. These concepts are particularly important when understanding celestial navigation techniques.

Table 1: Geographical co-ordinates for island nations in the Pacific.

Figure	Country	Latitude	Longitude
A	New Zealand	41° 10′ S	174° 46′ E
B	Tonga	21° 08′ S	175° 12′ W
C	Samoa	13° 50′ S	170° 50′ W
D	Kiribati	01° 25′ N	173° 00′ E

1.4 Celestial Names

The names for various celestial objects are given in Table 2, in both Māori and English. These only include the names of those planets which are visible to the unaided eye. It should be noted that names of celestial objects may vary from region to region within Aotearoa-New Zealand, so only a cross section of different names is presented in this table.

2 MĀORI ASTRONOMY

Māori astronomy impacted on many aspects of Māori culture, traditions and belief, from the origins of the Universe, to traditional calendrical systems, to the use of astronomy in language, architecture, agriculture and oceanic navigation. The extent to which astronomical knowledge impacted on pre-colonial life was impressive. This section discusses some of the more pertinent aspects of these areas to astronomy, which reflect a subset of current research which is being conducted by SMART researchers.

2.1 Cosmology: Origins of the Universe

Māori views on the origin of the Universe and life vary from tribe to tribe, but are still underpinned by thematic similarities. Many of the narratives start with *Te Kore*, the void, followed by *Te Pō*, the night, and lead to the creation of *Ranginui*, the sky father, and *Papatuanuku*, the earth mother. In many of the recollections of the creation of the Universe, it is said that *Rangi* and *Papa* produced more than seventy children (Pio, 1885-1901: 1187, Smith, 1913: 115). These

Table 2: Māori celestial names.

Māori Name	Western Name
Autahi, Atutahi, Aotahi	Canopus
Puanga, Puangarua, Puaka	Rigel
Matariki, Tātai o Matariki, Huihui o Matariki	Pleiades
Waiti	A star in Matariki
Waitā	A star in Matariki
Tupu-a-nuku	A star in Matariki
Tupu-a-rangi	A star in Matariki
Waipuna-ā-rangi	A star in Matariki
Ururangi	A star in Matariki
Tautoru, Te Kakau	Orions Belt
Mahutonga, Te Taki o Autahi, Te Punga	Southern Cross
Taumata Kuku	Aldebaran
Ngā Whetu Matarau	The Pointers
Te Waka a Tamarereti,	Tail of Scorpio
Whānui	Vega
Poutūterangi	Altair
Putara	Betelgeuse
Rehua	Antares
Whakaahu	Castor, Pollux
Takurua	Sirius
Te Mangaroa, Mangoroa, Te Ika a Maui, Te Ika nui, Te Ika roa	Milky Way
Tamanuitera, Ra, Komaru, Mamaru	Sun
Marama, Mahina, Hina	Moon
Whiro	Mercury
Meremere-tū-ahiahi, Kōpū, Tawera	Venus
Papatuanuku	Earth
Rangawhenua	Mars
Pareārau, Hine i Tiweka, Kopu nui, Wahine Tiweka, Wahine Karihika	Jupiter
Rongo	Saturn

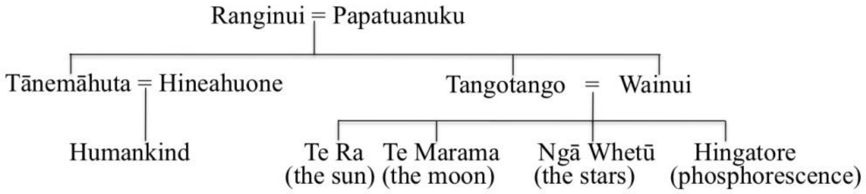

Figure 4: The relationship between humans and various celestial objects.

children were trapped between their parents as they embraced each other. The children's desire to get free led them to separate their parents against their will. The separation of *Rangi* and *Papa* is recalled in tribal recollections to have been finally caused by *Tāne Mahuta*.[3] Following the separation of *Rangi* and *Papa*, knowledge was fetched from the uppermost realm of the sky parent. Included with this knowledge were the celestial beings, the Sun, Moon and stars.

The stars were perceived as beings, who were bound together as a family through a hierarchical structure. The lineage of the stars begins with *Rangi* and *Papa* and the union of their children *Tangotango* and *Wainui* (Best, 1922: 7). After the separation of *Rangi* and *Papa* narratives from Mataatua (Best, 1996: 748) state that *Tāne Mahuta* asked his siblings *Tangotango* and *Wainui* to give the children to him so that he could adorn their father, *Ranginui*. The children he wanted were *Tamanuiterā* (the Sun), *Marama* (the Moon) and *whetū* (the stars), and once he received them he sought the help of his relative, *Tamarereti*, who was the owner of a canoe called *Puna Ariki*. Three baskets were placed in the canoe. The first two baskets contained the Sun and Moon, while the third basket contained the stars in the Milky Way (*Te Mangaroa*). Being the eldest of all the stars, *Atutahi* (Canopus) was suspended from the outside of the basket, and he remains the brightest star in the sky outside of the Milky Way. The *whakapapa* (lineage) relationship between these celestial objects and humans is given in Figure 4.

2.2 Māori Traditional Calendars

From ancient times, civilizations have used the heavenly bodies to track the passage of time. The regular motions of the Sun, Moon and stars were used as clocks for agriculture, rituals, festivities and other activities (Aveni, 1983: 297). The Māori, too, used the observations of the stars, the Moon and the local environment to determine the time of the year and to predict various events.

For the Māori, the seasons of the year and the start of the year were measured by the heliacal rising and setting of stars. During the year certain stars or constellations were obscured from view for varying periods due to the position of the Earth as it orbited the Sun (see Section 1.3). *Matariki* (Pleiades) was such a star cluster, which was no longer visible in the night sky around April, and rose again in late May or early June. Therefore the Māori New Year was celebrated by the heliacal rising of *Matariki*, or *Puanga* (Rigel), depending on which region one lived in (Best, 1959: 12). Although *Matariki* has become increasingly popular nationwide for the celebration of the Māori new year, *Puanga* was used by the tribes in the far north such as the Ngā Puhi, to the west in Taranaki, in the central North Island around the Ruapehu area, as well as in the South Island where *Puanga* took on a dialect variant, *Puaka*. In these regions as part of a growing movement to revitalize this knowledge, *Puanga*/*Puaka* celebrations are held. According to *Mātauranga* Māori experts in the far north, the New Year starts during the first Full Moon called *Rākaunui* following the appearance of *Te Puanga*, and when the tide is incoming, called the *Taipari* (Rereata Makiha, pers. comm., 2013). As for *Matariki*, this seems to be recognized by the rest of the country as a New Year indicator.

The main seasons were known as *Raumati* (Summer), *Ngahuru* (Autumn), *Takurua* (Winter) and *Koanga* or *Mahuru* (Spring), and these seasons were signified by the appearance of certain stars and the changing path of the Sun during the year between its extreme solstice points on the horizon. Mahupuku (1854) describes how it was *Paaia* (the Milky Way) who placed certain stars in the sky to indicate to his siblings when certain seasons had arrived. He states that *Takurua*, *Wero-i-te-nihinihi* and *Wero-i-te-kōkota* are the stars that travel in the winter. He also describes *Makeo* and *Tautoru* (Orion’s Belt), as stars that separate summer and winter.

The monthly calendar (*maramataka*) was based on the phases of the Moon. The beginning of the month was signified by the phase immediately following New Moon, as this was the time when the Moon was said to have died and gone to bathe in *Tāne te Waiora*, the life-giving waters of *Tāne*. The *maramataka* was instrumental in determining when to plant and harvest crops, as well as the appropriate times to hunt and fish for specific animals. It helped the Māori monitor seasonal changes, weather, migratory patterns of birds and fish, as well as enabling the accurate tracking of rituals and other important matters. There were many *maramataka*, as they varied from tribe to tribe. Recently, Roberts et al (2006) presented 43 published and unpublished *maramataka* from various tribes, and they found that within these the number of Moon nights per month varied from 28 to 32. The year, however, had 12 months (Best, 1922), therefore some sort of reconciliation had to occur to synchronise lunar cycles with star risings at New Year. This occurred in other cultures which fine tuned their calendars to best synchronise the two by adding an extra (intercalary) month every couple or so years. Māori astronomers may also have added a 13th month from time to time (e.g. see Roberts et al., 2006: 16), but this still needs further investigation.

Within a *maramataka* information pertaining to fishing and planting was found, so it was an essential tracker for when it was time to go out and catch specific species of fish. Planting also was associated with the Moon, whereby plants needed to be planted on certain Moon nights and oriented in a certain way to ensure better growth. These planting techniques are used today by many people, both Māori and non-Māori, and especially by those seeking to return to traditional food-gathering and growing techniques. Prayers were also said to acknowledge the Sun, the Moon and the stars when planting and harvesting occurred, and this is discussed later, in Section 2.5.

2.3 Te Reo o Ngā Whetū: The Language of the Stars

Due to the oral nature of traditional Māori society, astronomical knowledge was often contained in mythology, rituals, incantations, songs and the arts of carving and weaving. Therefore, a unique genre of language pertaining to Māori astronomy developed, and examples of this language can be found within Māori idioms, proverbs, chants, songs, incantations and laments. This language uses naturally-occurring astronomical events to describe and discuss people or groups, their characteristics, behaviour and interactions.

References to the stars and the movements of the heavenly bodies can be found in everyday conversation. For example, the following phrase, “*Ka tō he rā, ka whiti he rā*” (Best, 1996: 801) literally means: “The Sun will set and the Sun will rise again.” However, in a wider context it describes the never-ending progression of time. This phrase can be used to remind people that no matter how complex or difficult life can be, time will not cease.

When someone is referred to as *Pareārau wahine tīweka*, they are likened to a woman with questionable morals. *Pareārau* is the planet Jupiter, and to the Māori this planet is a woman. Unlike the stars that move across the sky in a predictable fashion *Pareārau* wanders according to her desires, and she might start her journey close to one star and end near to another (Best, 1996: 810).

There are a number of proverbs that mention stars and other astronomical events. These proverbs take inspiration from the heavens, and apply the examples of the celestial bodies to human interactions. For example the proverb, *"E whai i muri i a Rēhua, kia kai ai koe i te kai*." (Mead and Grove, 2007: 50), speaks of the greatness of the star *Rēhua* (Antares) in Scorpius. Loosely translated this proverb means: follow behind *Rēhua* in order to be fed. *Rēhua* is a chiefly star, located near to other smaller and less-important stars. This saying speaks of the benefits that others gain by befriending and positioning themselves near people of standing. It also is a term that can be applied to those who live on the reputation of others.

References to stars are often found in lamentations for the dead. In a particular sonnet for a deceased relative, *Tūhoe* songstress *Mihi ki te kapua* refers to the Pleiades and states:

> I gaze up at the stars,
> And the Pleiades are gathered together
> Which gives rise to many thoughts
> That well up within, and freely
> Do the tears pour forth
> And flow shamelessly from mine eyes.
> (Ngata, 2007: 121-122; his English translation).

In another dirge from the Waikato region, *Tawera* (Venus) is very close to the Moon, or about to be occulted, and this is seen as an ill omen denoting death:

> Breaks the dawn
> And Tāwera (Venus) is biting (the Moon)
> 'Tis the dread omen of death.
> (Ngata, 2007: 398-399; his English translation).

Likewise, references to the stars can be found in songs and phrases used to express feelings for a lover or a betrothed. The proverb, "*Mehemea ko Kōpū e rere ana i te pae*" (Mead and Grove, 2007: 295) translates to mean "like Venus as it appears over the horizon in the morning", and is applied to an attractive person.

In her famous love song, Pakiri of the Ngā Puhi tribe likens the approach of her lover to the rising of Vega and Canopus:

> Lo, Vega and Canopus
> Have risen quietly o'er the horizon.
> Silently too, did *Whatitiri* draw nigh;
> Your stealthy hand reached out
> And gently caressed this body of mine.
> (Ngata, 2007: 162-163; his English translation).

The above quotes are a very small cross-section of examples that show how the astronomical knowledge of the Māori contributed to the development of a unique style of language. This particular language has been recorded to some extent within the numerous stanzas, laments, proverbs, traditional songs, prayers and sayings of the Māori. It is evident that a more detailed study of the language of Māori astronomy is needed to reveal the extent of this contribution to the Māori language.

2.4 Astronomical Alignments and Traditional Architecture

Astronomical alignments have been most famously linked to cultures such as the Inca and Mayans in which buildings and structures were orientated towards the Sun at certain times of the year such as the solstices or equinoxes (Aveni, 1983: 296). According to tradition, Māori meeting houses always faced the rising Sun. Houses needed to be positioned so that the Sun encroached upon the porch, and if this did not occur it was considered an *aitua*, or a sign of miscalculation that could lead to death. In some districts, such as on the East Coast of the North Island, this meant that the porches had an easterly orientation.

The creation narrative of *Rangi* and *Papa* formed the basis of the construction of a meeting house. The land on which it was placed was *Papa*, and upon her a raised structure was built, this being *Rangi*. The structure itself represented the separation of the Earth and sky by *Tāne*, and the creation of light and darkness.

The position of the Sun on the horizon from the winter solstice to the summer solstice and its pathway throughout the year was traditionally known as *Te Ara Whānui a Tāne*, or the broad path of *Tāne*. In stories of creation, this was the path that *Tāne* took each day when pursuing the dawn, *Hine Tītama*, who continually fled from him towards darkness. Where the Sun rose and set were two primary spatial designations from which all subsequent orientations and calculations regarding building construction were made.

Te Ara Whānui a Tāne is also sometimes referred to as *Te Tāhuhu a Rangi* or the backbone of the sky parent *Rangi.* In pre-colonial meeting houses on the East Coast of the North Island, the Sun rose, then it travelled and descended along the backbone of the house. Also, central to the construction of the meeting house was the Milky Way, which in traditions was often referenced by its shape as a fish. The various names include *Te Ikaroa* (the long fish), *Te Ikanui* (the great fish), and *Te Mangoroa* (the long Mango shark). During the Māori New Year in mid-winter and at the time of the winter solstice the *tāhuhu* lay in the same position as the 'great fish' or '*Maui's* fish' in the sky. This significant representation was adorned as patterns on the ridge-beam of the meeting house. Extending from the ridge-beam or backbone of the sky were the rafters which connected to wall panels, which were sometimes carved to represent ancestors. In pre-colonial times the rafters were often painted in patterns that resembled shapes of star groupings that were observed in the sky. These patterns also related to foods and resources that were accessed seasonally by the tribe. A contemporary Māori artistic representation of the Milky Way is shown in Figure 5.

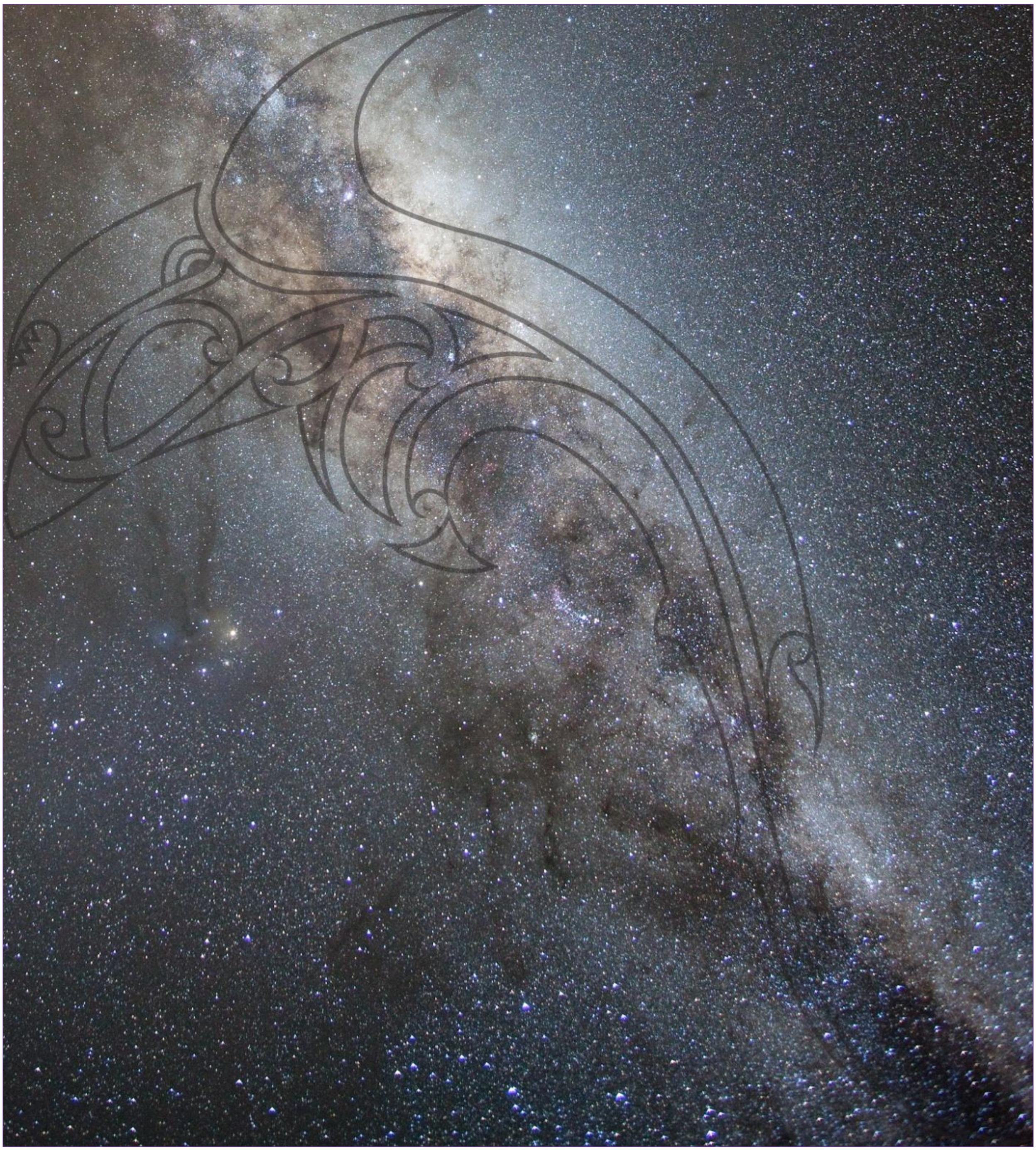

Figure 5: *Te Mangaroa*, the shark, and the home of the stars (the Milky Way) (image provided by SMART and illustrated by Kāterina Kerekere, with the photograph kindly gifted by Fraser Gunn).

2.5 Astronomy in Traditional Māori Growing Practices

The Sun, Moon and stars were an integral part to the growth cycle of plants and humans, with the Moon and stars in particular prevailing in this domain. In general, the Sun was the *mauri* (essence) that provided energy for growth in the realm of daylight (*te ao mārama*) and the Moon was the *mauri* which provided energy, warmth and nurturing for growth in darkness. However, the Moon and stars were the key factors during planting and incubation (Smith, 2011: 8).

The appearance of particular stars at a certain time of year acted as planting and harvest indicators. For example, during March and April such foods as *tuna* (eels) and *kūmara* (a type of sweet potato) were harvested, so they could be stored for the winter months. On the East Coast of the North Island, it was the appearance of the star *Poututerangi* that would coincide with the inspection of the *kūmara*, and the storage pits would be prepared, whilst in the Mataatua district *Whānui* (Vega) signalled the inspection for the *hauhakenga* (harvest). Hamiora Pio (1814–1901) of the Ngāti Awa tribe described how the *kūmara* came to Earth in the story of *Whānui* and *Rongo Maui* (Pio, 1885-1901: 1187). *Rongo*

Maui, who dwelt on the Earth, wanted some of the *kūmara* children of *Whānui*, and asked him if he could take them back to Earth. When the request was denied *Rongo Maui* kidnapped them leaving *Whānui* bereft and lamenting for his children. In revenge he sent down various types of grubs, such as the *Anuhe*, to destroy their harvests as punishment.

The Moon played a particularly important role in planting, in that certain phases were a more optimal time to plant than others. These particular phases were better in supporting the influence of the Moon on plant growth. Moon calendars, called *maramataka*, contained information about the suitable phases for planting and fishing. For example, a *maramataka* from the Ngāti Kahungunu tribe (Mitchell, 1972: 261-262) contains information for the phase following the New Moon called *Hoata*, which is a "Good day for planting and fishing, the moon is well shown …", or for the night *Tamatea-kai-ariki*, which is a "Bad day for planting and fishing, [as the] sea is disturbed by ocean currents."

Each night contained these types of descriptions, which were specific to a particular region of Aotearoa-New Zealand. As described in Section 2.2, thus far 43 *maramataka* have been documented (see Roberts et al., 2006), but many more unpublished versions exist.

Along with planting at the correct time of year and lunar phase, tribes often used prayers or *karakia* in conjunction with planting and harvesting practices (Smith, 2011: 14). These *karakia,* for example, would be chanted to render the soil fertile (Pio, 1885-1901: 1187) or to protect the crops (Mitchell, 1972). The following excerpt is from a *karakia* to protect the crops from frost, and it acknowledges the stars *Atutahi* (Canopus) and *Takurua* (Sirius), which are among other stars found later in this *karakia*:

> Tupurupuru, potential from beyond,
> Ascending with the long Sky parent
> Feed into the face of the present situation
> Atutahi, potential from beyond
> Climbing with the Sky parent
> Feed down into the face of the present situation
> Takurua, potential from beyond.
> (Smith, 2011; his English translation).

Detailed knowledge of the environment and ecology were needed to understand the optimal times for agricultural and hunting practices, and early ethnographic accounts of Māori growing practices often were veiled by colonial bias and a lack of in-depth understanding of the cultural context. Land loss also impacted greatly on traditional growing practices, as did discouragement by missionaries to practice pre-colonial *karakia* relating to crops (Smith, 2011: 3), so by the 1850's in many tribal districts the pre-colonial systems of growing and harvesting crops had already been abandoned in favour of the promise of economic prosperity associated with a European lifestyle.

2.6 Oceanic Navigation

Since the 1970's significant efforts have been made to revitalize Oceanic navigation techniques by the likes of Hekenukumai (Hector) Busby and others. They, along with other Polynesians such as Nainoa Thompson, have learnt and adapted knowledge from Mau Pialug, a *tohunga* (expert) from Satawal in the Caroline Islands, to produce a form of knowledge and skills resembling that of the first Māori who voyaged to Aotearoa-New Zealand. It is thought that following the main migration of the Māori to Aotearoa-New Zealand, exploration of this strange new land became a priority over return journeys to their ancestral homeland. Thus, knowledge of Oceanic navigation was lost after several generations, and would remain dormant for perhaps a thousand years. The renaissance of Ocean navigation was seeded by the earlier efforts to revitalize Māori art, crafts and canoe-building in the 1920's by Sir Aprirana Ngata and Sir Peter Buck (Te Rangi Hiroa) and then later, in the 1930's, by Princess Te Puea, who initiated a canoe-building project for the 100th anniversary of the Treaty of Waitangi (Matamua et al., 2013). This later project brought together master canoe-builders, and taught a new generation of young Māori the skills needed to continue this craft.

Successful Oceanic navigation requires a knowledge of the Sun, the stars, currents, cloud formations, wave patterns and the migratory behaviour of birds and sea life (Howe, 2008; Matamua et al., 2013). This, in combination with years of accumulated experience and a sense of inherent knowing, can enable a captain and the crew to safely arrive at their destination.

The celestial component of Oceanic navigation relies on knowledge about the rising and setting of particular stars during a journey. These rising and setting stars are measured by the type of 'star compass' shown in Figure 6. These star compasses are split into sections, called houses, and are based on the view of the horizon from the *waka* (canoe/boat), which is located at the centre of the compass. By understanding where particular stars rise and set, the navigator can steer in the right direction.

Stars that appear directly overhead are called zenith stars, and they can be used to identify the latitude and thus help identify a component of a particular island's position. But due to the rocking of a boat it sometimes is difficult to identify zenith stars, so instead the angular displacement of certain stars that appear above the horizon near the north and south celestial poles is used to provide a more accurate indication of latitude. Examples of how a star's angular dis-

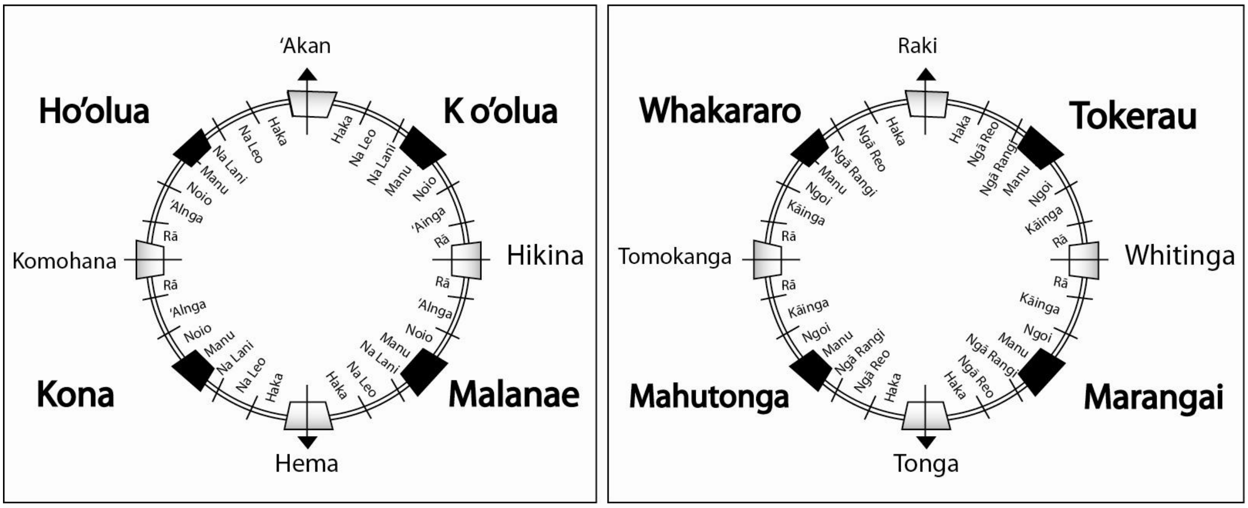

Figure 6: The Hawaiian (left) and Māori (right) star compasses used in navigation (image reproduced from Te Aurere Education Package, Rarotonga–Aotearoa 1995 Voyage).

placement above the horizon varies with latitude was discussed in Section 1.3.

The Sun is used to steer during the day, the rising Sun indicating the general direction of east, while the Sun sets in the west, but within a two month period the Sun can move up to two houses. Typically journeys from Aotearoa-New Zealand to Tahiti would take about 3.5 weeks, so during this interval the Sun and stars would drift into other houses and this needs to be allowed for when travelling between these islands.

Celestial navigation has captured the hearts and imagination of many an enthusiast, and these masterful experts continue to revitalize this old tradition. For many years navigation schools in Aotearoa-New Zealand and Hawaii have been training the next generations of navigators, so this knowledge base seems now to be in safe hands and to be steadily heading in a successful direction.

3 DISCUSSION AND CONCLUDING REMARKS

Māori astronomical knowledge permeated much of Māori life, culture and traditions. From the origins of the Universe, to the tracking of time, to the planting and harvesting of food, the Sun, Moon and stars were no doubt an important and substantial part of Māori knowledge. With more than two hundred years of colonial and global contact, disease, displacement from traditional lands, and an education and legal system aimed at assimilation, Māori knowledge, culture and traditions have undergone significant loss.

In a time of renaissance, the Māori have endeavoured to revitalize their knowledge of language, medicine, song, dance, carving, weaving, science, and now astronomy. The formation of language nests and Māori schools to ensure the survival of the Māori language; Māori universities to ensure educational success of Māori communities; carving and weaving programs to bring back the ancient arts and crafts; the use of Māori medicinal practices to cater to Māori health needs; and revitalizing the practice of celebrating the Māori New Year, have all sparked the establishment of research around the country into Māori astronomy.

As groups such as SMART endeavour to research astronomical knowledge we see researchers from academia and communities collaborating in this effort of reclamation. As Māori communities engage in dialogue, the celestial knowledge of the past continues to emerge, enabling researchers to record details that were hidden from the early ethnographers, thus countering Best's claim that all sources of information on Māori astronomy have been exhausted. Clearly, further investigation of this vital and exciting area of Māori knowledge and practice is warranted.

4 NOTES

1. 'Aotearoa is the most commonly-used Māori name for New Zealand, and is usually translated as 'The Land of the Long White Cloud'.
2. '*Pākehā*' refers to the non-indigenous people of Aotearoa-New Zealand who predominantly are descendents of people who originally came from Europe or Great Britain.
3. *Tāne Māhuta* was the god of the forest and creator of human kind and one of the children of the great sky father *Ranginui* and the earth mother *Papatūānuku*.

5 ACKNOWLEDGEMENTS

We would like to acknowledge the contribution of the members of the SMART trust, as well as our family and friends who support the endeavours of SMART. We also would like to acknowledge our ancestors who have gone before us. Special thanks are due to the Foundation for Research Science and Technology, now the

Ministry of Science and Innovation in New Zealand for their support of this research, and to UNESCO and Te Puni Kokiri for their continued support of this *kaupapa* (topic) as well. Many thanks to our colleagues for their personal communications, especially to Mātauranga Māori experts Mr Rereata Makiha and Mr Ockie Simmonds. Ngā mihi nui ki a koutou katoa.

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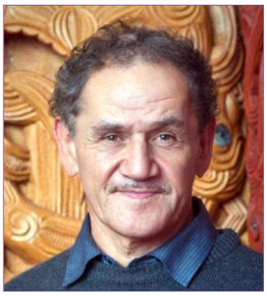
Dr Pauline Harris is from the Rongomaiwahine and Ngāti Kahungunu tribes. She has a Ph.D. in astroparticle physics from the University of Canterbury in Christchurch, New Zealand, where she investigated gamma ray bursts as possible sites for high-energy neutrino production. Pauline is currently a Research Fellow at Victoria University of Wellington, where she is dedicated to searching for extra-solar planets and the collation and revitalization of Māori astronomical star lore. Pauline has been involved in the revitalization of Māori star lore for the past ten years, giving many talks pertaining to Māori astronomy and *Matariki*/ *Puanga* in Aotearoa-New Zealand and overseas. She currently is the Chairman of the Society for Māori Astronomy Research and Traditions (SMART).

Dr Rangi Matamua is from the Ngāi Tuhoe tribe. He is a graduate of the Panekiretanga o Te Reo Māori language excellence programme and has a Ph.D. degree focussed on Māori research. He currently facilitates a Ph.D. programme, and co-ordinates a number of Māori students enrolled at various institutions throughout the central region of Aotearoa-New Zealand. He lectures on Māori language and customs, including Māori methodologies and Māori research frameworks. Rangi is highly esteemed for his competence in research and critical analysis and has published an extensive array of research. He is also engaged in providing research services in management and Māori development issues.



Dr Takirirangi Smith is a Master Carver from Ngāti Kahungunu. Since the early 1980's he has served in the role of *Tohunga Whakairo* (Master Carver), teaching and mentoring Māori carvers at Victoria University of Wellington, Wairarapa Polytechnic and The Te Heru a Rangi Culture and Education Center, Masterton. He focuses on the connections between indigenous

artworks and knowledge and transformations, lecturing internationally on these. As an accomplished canoe carver, Takirirangi has a particular interest in reviving the use of Māori small sailing canoes. He has also led the carving of seven meeting houses, and several *marae* entrances, gateways and facades. Takirirangi completed a Ph.D. in Education in 2007, and in 2012 he received an honorary doctorate as well for his contribution to Māori knowledge and carving.

Hoturoa Kerr is from Tainui and is a lecturer at Te Wānanga o Aotearoa. Hoturoa is one of the most recognized experts in Oceanic navigation. He is greatly involved with the teaching of traditional knowledge, narratives, lineage, history and stories related to *waka* (canoe/ sailing vessels) and ancestral voyaging expertise. Hoturoa is dedicated to passing on the spirit, traditional knowledge and confidence of the early way-finders to *rangatahi* (youth) and is committed to enhancing their sense of identity and self esteem.

Toa Waaka is a Matauranga Māori specialist in *Tatai Arorangi* (Māori astronomy). He studied Māori Anthropology papers at Auckland University of Technology and plans to complete his Masters degree at Te Wananga O Raukawa, majoring in Māori Cosmology and Astronomy. Over the past fifteen years Toa has worked as a cultural adviser to the Auckland City Council and various other organizations. In particular, he was involved in the refurbishment of the Carter Observatory in Wellington between 2007 and 2008. In 2010, Toa was recognised by UNESCO and the International Astronomical Union for his commitment and outstanding contribution to the success of the International Year of Astronomy (2009) in Aotearoa-New Zealand.

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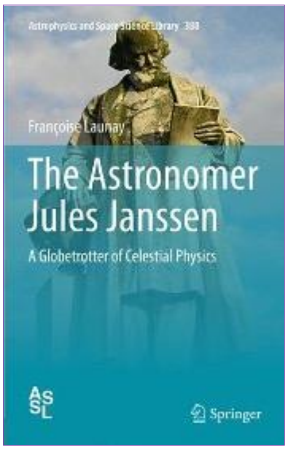
BOOK REVIEWS

The Astronomer Jules Janssen: A Globetrotter of Celestial Physics, by Françoise Launay (New York, Springer, 2012). Pp. xxii + 220. ISBN 978-1-4614-0696-9 (hard cover), 160 × 242 mm, US$99.00, €83.29, £72.00.



For me, Jules Janssen has long been a favourite figure in the history of solar physics, so it is a great pleasure to review this entertaining and copiously-illustrated biography, penned by the Paris Observatory astronomer Françoise Launay. This is a timely English translation (courtesy Storm Dunlop) of the original French edition—which I enjoyed reading when it first appeared—but Janssen is too important a figure to be shared only by those who read French, so I am delighted that this English edition has been published. All credit to Springer, for keeping us supplied with a variety of new books on astronomical history. But I digress …

Pierre Jules César Janssen—better known simply as Jules Janssen—was born in Paris on 22 February 1824, and after a long and adventurous life died in Meudon on 23 December 1907. His parents intended that young Jules should pursue a career in painting, but fortunately history decreed otherwise and astronomy gained a champion. Yet his obvious artistic talent shines through in Launay's well-illustrated book, which contains five different pencil portraits sketched by Janssen.

Because of my own particular research interests I have always held Janssen in high esteem for four 'crowning achievements' and the first of these relates to his observations during and immediately after the total solar eclipse of 18 August 1868, while based at Guntoor in India. Thanks in part to the presence of an enormous prominence, which the British party also sited at Guntoor referred to as 'The Great Horn', Janssen was able to use spectroscopic observations to determine its chemical composition, but more importantly, he devised a method of successfully observing prominences at times when there was no eclipse. The British astronomer, Norman Lockyer, also came up with the same idea quite independently, and this major breakthrough in solar physics is discussed by Launay in Chapter 4.

Janssen may be famous because of the 1868 eclipse, but he was far from inactive during his next visit to India just three years later, for the total solar eclipse of 12 December 1871. As Launay explains:

> It is thus easier to appreciate the efficiency of Janssen who did everything: overall visual observation with one eye, spectroscopic observation with the other, and who took the time to make a drawing, to admire, to dream, to record everything in his head, and who still had a few seconds to make polarimetric observations! (p. 67).

Chapter 6 is devoted to this eclipse.

To my mind, Janssen's second 'crowning achievement' was his invention of the 'revolver photographique', which was used to take multiple images of the 1874 transit of Venus. The French sent out six expeditions to observe this transit, and Janssen led the one destined for Nagasaki in Japan. The saga of this successful expedition is discussed by Launay in Chapter 7.

The following chapter is devoted to another of the 'crowning achievements' I refer to above in that it recounts Janssen's key role in the founding and early development of the Meudon Observatory, with what at the time was the second-largest refracting telescope in the world, and an excellent short-focal length (f/3) 1-m aperture reflector. This was France's first facility set up solely to address the research challenges of 'The New Astronomy', and in this chapter Launay refers to it as the "Paris Observatory for Physical Astronomy". Janssen, then aged 51, was appointed its founding Director, even though

> He was a graduate of neither the École normale supérieure nor the Polytechnique and, until then, had only held temporary assignments from the state. He finally saw the outcome of 18 years of research in the service of science ... (p. 93).

Chapter 9, which follows, just happens to discuss the fourth and final 'crowning achievement', Janssen's accomplishments in astronomical photography. He is justly famous for his 1877 and 1885 images of solar granulation, and for obtaining the first successful photograph of the head *and* tail of a comet, namely Comet C/1881 K1 (Tebbutt) in 1881 (see Orchiston, 1999 for details). Despite his penchant for spectroscopy, Janssen also realised the future potential of photography when applied to astronomy, so it is little wonder that "... he created, without delay, a department for celestial photography ..." at Meudon (p. 113).

The subtitle of this book, *A Globetrotter of Celestial Physics*, certainly portrays Janssen's peripatetic existence, achieved—we must remember—in an era prior to international air travel. Solar eclipses took him to Italy, India (twice), Algeria, Siam (present-day Thailand), the Caroline Islands (in the Pacific) and Spain, while the 1874 and 1882 transits of Venus saw him in Japan and Algeria. In order to carry out terrestrial or celestial spectroscopic observations he visited the Bernese Alps, Italy and Lake Geneva. On other occasions, astronomy also saw him visiting or passing through Austria, the Azores, Ceylon, England, Germany, Greece, Hawaii, Hong Kong, Ireland, Italy, the Marquesas Islands, Panama, Peru, Portugal, Scotland, Singapore, Spain, Switzerland and the USA.

While the subtitle of Launay's book may highlight Janssen's extensive travels, it does not quite capture his somewhat adventurous—and even at times life-threatening—existence. While in Peru in 1857, on his very first overseas journey, to help pinpoint the magnetic equator, he fell seriously ill with "… dysentery, intermittent fevers and hepatitis …" (p. 14), and it was more than six months before he was well enough to return to France. Meanwhile, getting to the Algerian eclipse of December 1870 posed a special problem because the Franco-Prussian War was raging at the time and Paris was under siege. Although his British friends arranged safe passage for him through enemy lines, Janssen decided instead to escape by balloon. There were no balloonists available and although he had never piloted a balloon

> … I did not feel I should let myself be stopped by this difficulty, and, being convinced that theoretical knowledge, carefully acquired, and experience in travel would suffice to give me the confidence and the necessary inspiration to control my aerostat properly, I undertook its supervision. (p. 90).

Needless to say, he made a successful escape.

Speaking of danger, Janssen had a strong affinity for mountains, especially if they happened to be volcanic. In 1864 he ventured to the summit of the Faulhorn in the Bernese Alps to observe the solar spectrum from nearly 3,000 metres. Three years later he was atop Mount Etna in Sicily for three days, then he went to Santorini in Greece to carry out dangerous observations of the magnetic field at an active volcano and of the spectrum of the gases emitted by it. After observing the 1868 solar eclipse in India he spent three months in the Himalayas. In 1883, after observing yet another total solar eclipse, he visited Hawaii and spent a night conducting research in the crater of Kilauea.

But Janssen's major alpine achievement, surely, was the establishment of an astronomical observatory on the summit of Mont Blanc at 4,810 metres. In 1890, when Janssen was 66 and could not walk too freely let alone conquer France's highest peak, he had to be carried up and down the mountain, first on a 'ladder-chair' that he designed especially for the occasion, and at the higher altitudes on a sledge. This was Janssen's first ascent of Mont Blanc and immediately convinced him that his Meudon observatory should establish a branch observatory there, well above much of the oxygen and water vapour in the Earth's atmosphere. This ambitious endeavour came to fruition towards the end of 1893, when Janssen made his second visit to the summit. His third conquest of the summit occurred two years later, when Janssen was 71 years of age, and he oversaw the installation of a polar refractor with an objective 30 cm in diameter. Meudon could now boast a flourishing high altitude observing station, and Launay devotes all of Chapter 12 to it, complete with a wonderful array of illustrations. This iconic observatory was built on consolidated ice, not on bedrock, and it was only demolished in 1909, two years after Janssen's death, when it was no longer safe.

Janssen's final encounter with mountains occurred in 1904, just three years before his death, when he was carried to the summit of Mount Vesuvius in a sedan chair. When they arrived Vesuvius was active, ejecting lapilli and volcanic bombs, and they were lucky not to be hit. The guides wanted to descend immediately but Janssen refused to allow this until he had taken photographs and collected samples. This was typical Janssen ... determined, and totally committed to science, right to the end.

One of the things that comes through strongly in Launay's book is that Janssen was a 'people's person' and made friends easily. In astronomy, for instance, he formed close life-long friendships with the noted British astronomers, Warren De La Rue, William Huggins and Norman Lockyer, and had a special affection for British astronomy. There were only two astronomers of note he did not get along with at all: the Italian spectroscopic expert, Father Angelo Secchi, and his French colleague, Henri Deslandres, who eventually succeeded him as Director of the Meudon Observatory. Delandres' exchanges with Janssen at a staff meeting on 28 July 1906 make interesting reading (see pp. 195-196), and after Janssen's death, Deslandres continued to make life difficult for Mrs Janssen and her daughter.

A number of topics in this fascinating book took me by surprise. For instance, although he only ever enjoyed one balloon trip, for Janssen "... this represented the beginning of a sustained and visionary interest in aeronautics." (p. 56), and he was elected the inaugural Chairman of the Société française de navigation aérienne in 1873. His long and intimate involvement with 'aerostats' is recounted by Launay on pp. 56-61, including the first use of balloons for high altitude astronomical observations.

I also was surprised to read how impressed Janssen was with Edison's famous invention, the phonograph. Indeed, Launay assigns an entire short chapter (pp. 137-142) to this.

Janssen was closely involved with the (French) Académie des Sciences, L'Association Française pour l'Avancement des Sciences, the Société Française de Photographie (as a one-time President), the Société Astronomique de France (also as a one-time President), and even the British Association for the Advancement of Science, but perhaps I should not have been surprised given his diverse interests that he also felt equally at home in non-scientific circles. Janssen was a brilliant public speaker, and as portrayed in Chapters 13 and 14, he frequented Madame Adam's literary salon, and was active in the French Alpine Club (also as a one-time President), the Académie Française, the Société Philomathique, the Société de Géographie (yet again as a one-time President) and the Marmite, an interesting republican society of which he also at one time was President. He counted among his closest non-astronomical friends various politicians, Gustave Eiffel and the noted painter, Jean-Jacques Henner.

One paragraph in Launay's book truly amazed me:

> Janssen did not write any original work, and this has certainly contributed to his neglect during the twentieth century. His scientific publications are in the form of reports, certainly many of them, but rather short, published either in the Académie des sciences, or in the journals of the learned societies before whom he had given papers ... (p. 186).

Wrongly, it would seem, I had assumed that he was a prolific publisher of research papers, in keeping with his impressive research portfolio.

Finally, I have to say that I was touched by Janssen's obvious affection for his (normally) ever-patient Henriette, who spent far too many weeks, not to mention months, at home alone while her husband happily toured the globe all but wedded to astronomy! Yet theirs was a deep loving relationship, as evidenced by some of Jules' letters to Henriette that Launay reproduces throughout the book, and his true feelings for her were very apparent in 1883 at a meeting in Vienna. There, rather than graciously accepting Palisa's offer to name a new minor planet after him, Jules instead assigns it to his beloved wife:

> ... as a consequence, I begged the gathering to accept the name of Henrietta, by which Madame Janssen was baptized. Everyone cheered your name, and everyone returned to congratulate me or rather, to beg me to pass on their congratulations to you. (p. 128).

This long and detailed review reflects my admiration for Françoise Launay in assembling a book on one of the great names in French astronomy. She has managed to pack a great deal of interesting information into a mere 220 pages, the last 20 of which contain a Janssen 'Chronology', a 'Bibliography' and a 'Name Index'. All that is missing is a Subject Index! Nonetheless, *The Astronomer Jules Janssen* ... is well researched and well written. It is easy—at times captivating—reading, and is sprinkled with 78 figures. This very reasonably-priced book is a 'must' for anyone interested in French astronomy, or the history of astrophysics or solar physics, but in fact it deserves a much wider audience.

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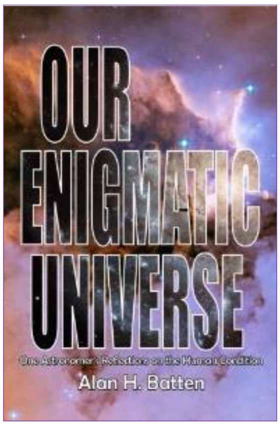
Professor Wayne Orchiston
National Astronomical Research Institute of Thailand, Chiang Mai, Thailand
Email: wayne.orchiston@narit.or.th

***Our Enigmatic Universe: One Astronomer's Reflections on the Human Condition*, by Alan Batten (Ely, Melrose Books, 2011). Pp. xiv + 205. ISBN 978 1 907732 03 4 (paperback), 156 × 234 mm, £8.99.**



The reader who picks up this book expecting to learn the latest on the structure and content of the Universe may feel slightly misled by the title. The book does touch on a wide range of topics, which (if we put cosmology as such aside) include: Darwinian evolution, God, religion, genetics, the brain, Newtonian gravity, the Solar System, Bayesian probability, Intelligent Design and many more. A better guide to the contents is the book's subtitle. Alan Batten is an astronomer and an active Christian (he has served on the Synod of the Anglican Diocese of British Columbia). He argues that "… it is quite rational for one to be open to the idea that the world contains entities that transcend our senses." (p. 24), and questions Francis Crick's contention that "… our thoughts and hopes and wishes [are] … 'nothing but a pack of neurons.'" (p. xii).

The book's ten chapters (with such titles as, "How we perceive the universe", "Belief in God" and "Reason and revelation") are wide ranging in the topics they touch upon, although certain themes are recurrent. The—very useful—Name Index provides an indication of which people have most strongly influenced the book's central argument. Apart from God (He is mentioned more than anyone else), Charles Darwin's name appears most often, followed by the astronomer Arthur Eddington. A bit less frequently we come across the physicists Albert Einstein and Isaac Newton, the philosopher Bertrand Russell and the evolutionary biologist Richard Dawkins. Only Dawkins is still active; the other five have been dead for over forty years (Newton for almost three centuries). While I wouldn't make too much of this simple name-counting, it does show how the book has been at least as much driven by contemplating human evolution as by considering cosmology.

By tracing the flow of topics and arguments in one chapter, the reader can perhaps gain an impression of how the book makes its case. Chapter 4, "Argument from design," begins with Thomas Aquinas' five arguments for the existence of God. The last – God as designer – is, notes Batten, an ancient argument. Newton could explain the motions of the bodies in the Solar System, but could not account for the fact that the planets orbit the Sun in almost the same plane. In this he saw the hand of God. But Laplace, a century later, would explain the planetary configuration in the context of his nebular cosmogony, concluding that he had "… no need for God." This, notes the author, illustrates the danger of invoking God to plug gaps in our understanding. One could then counter that God is still present as He laid down the laws later discovered by Newton, Laplace, et al., but this is the aloof Aristotelian godhead, not the Christian God of love. By the twentieth century, man, the Earth, even the Sun, are no longer central in the Universe, and with Darwinian evolution (and Freud's ideas about the mind) we have a "… principle of mediocrity." Via a Universe with special properties (one with niches fit for life) we arrive at the anthropic principle. In a multiplicity of Universes —running parallel—we only exist in the one(s) suitable for us. This brings up the idea of the multiverse (a relatively modern concept in cosmology), the existence of which is said to be compatible with belief in God (R. Collins) or can be seen as a form of deism (P. Davies). The testability of multiverse theory has been questioned, and if untestable, then it falls outside the realm of science. After considering recent ideas about Young's two-slit experiment, the author puts forward the explanation for the existence of life that he favours, "… the universe was created with the deliberate intention that intelligent self-aware life should emerge." The argument then proceeds via "design" in biology, fixity of species, evolution, natural selection, genetics, to Intelligent Design, in particular the perceived impossibility of organs (like the eye) and processes (blood clotting) to have arisen by natural selection. Finally, after touching on other homeostatic systems, the mind, the effect organisms have on their environment (and vice versa), the chapter's conclusion is that design arguments ultimately fail to prove God's existence.

As I noted at the beginning, the book is not really about the cosmological Universe. Modern cosmology and the evolution of the Universe do turn up occasionally (as in the brief consideration of multiverses in Chapter 4). Early in the book there is some discussion (p. 3) of the Big Bang and Steady State models, but there is no reference to the microwave background or to its tiny irregularities, although brief mention is made of today's enigmas of cosmology: what is the nature of dark matter, and what is dark energy. For its central argument the book refers to other astronomical topics (to the extent that they are invoked at all) than cosmology.

The text is clearly written—Batten has a pleasant, easy to read prose style. I particularly admire his objectivity while navigating controversial subject matter. He has a point of view, as noted above, but has no axe to grind, and clearly points out the strong and weak arguments put forward on all sides. He has consulted a huge body of literature—if only as a guide to those writings the book is of interest. The short Subject Index is valuable, but would have been more so if it had been somewhat expanded.

To sum up (though that is difficult to do in such a wide-ranging book), I quote from a passage near the end (p. 195):

> In essence, theism is the belief that the power that sustains this enigmatic universe is also the source of life, and that we can have a relationship with that power that is analogous to the most intense relationships that we enjoy with our fellow human beings. Some people may find that hard to believe, or even unnecessary, but after a lifetime spent in scientific research, I do not know of any result that compels us to abandon the belief.

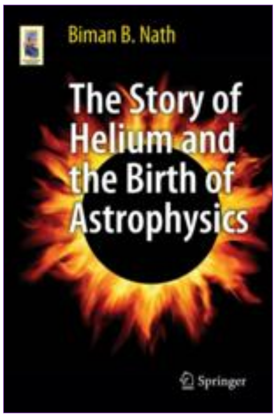
Professor Richard Strom
University of Amsterdam & ASTRON
Email: strom@astron.nl

***The Story of Helium and the Birth of Astrophysics*, by Biman B. Nath (New York, Springer, 2013). Pp. xii + 274. ISBN 978-1-4614-5362-8 (paperback), 151 × 235 mm, €39.96.**

This is a badly-needed book, for as the author, Indian astrophysicist Biman Nath, points out,

> The most interesting—in fact the most singular—aspect of its [helium's] discovery story is that it is largely forgotten … What has remained in our collective memory, and on the pages of history books, is a distorted story, in which the chronology of events has been all jumbled up, and in which some scientists have been given wrong credits while some other names have been unceremoniously left out ... (pp. 4-5).

First Nath 'sets the scene', as it were by providing background information about helium in Chapter 1, which is titled "The Unbearable Lightness of a



'Noble' Element", while early concepts of elements and the development of chemistry are in a short second chapter.

The following four chapters provide a summary of early developments in astronomical spectroscopy, and highlight the major achievements of all of the key 'players' through to the 1860s. Thus we encounter all-too-familiar names, like Brewster, Bunsen, Foucault, Fraunhofer, John Herschel, Huggins, Janssen, Kirchhoff, Lockyer, Miller, Rutherfurd, Secchi, Talbot and Wollaston, but not in that order. This is well-trodden turf for those familiar with the history of astronomical spectroscopy, and is covered in far more detail in Hearnshaw's classic *The Analysis of Starlight* … (1986), while parts of the story appear in individual books and major review papers on some of these astronomers. However, Nath does provide a useful 'refresher course', and he makes very effective use of quotations taken from nineteenth century published sources.

So we come to Chapter 7, titled "James F. Tennant, Soldier Turned Astronomer" and to the total solar eclipse of 18 August 1868, which has already been mentioned in passing in several of the previous chapters given its critical role in the discovery and identification of helium. In fact Tennant played very little part in the 'helium' story, but it was his lobbying and that of Edmund Weiss that draw widespread attention to the 1868 eclipse, the fact that the maximum duration of totality would be an extraordinary 6 minutes and 50 seconds, and that the path of totality would pass through Aden, India, Siam (Thailand), Borneo, New Guinea and the New Hebrides, thus offering many potential observing sites. The British decided to mount an expedition, led by Tennant and sited at Guntur. Norman Pogson, the new Director of the Madras Observatory, also decided to arrange a separate expedition, and Nath devotes the rest of this chapter to the preparations that he and Tennant made. Pogson would be based at the coastal port of Masulipatam, and Tennant a little inland, at Guntur. Janssen also selected Guntur for his observing site, and Chapter 8 summarizes the final preparations of all three.

Chapter 9, titled "The Perpetual Eclipse of 1868", includes accounts of the observations of the eclipse made by the various Indian-based observers. Here is where the story of the discovery of helium begins: during totality when they looked at the spectra of the prominences Janssen, Tennant and Pogson all saw a conspicuous bright emission line in the yellow, but while Janssen and Tennant attributed this to the D-line of sodium, Pogson was not sure that its position coincided exactly. The remainder of this chapter deals mainly with polarization observations of the corona, and Janssen's momentous discovery that he could observe the spectra of the prominences on the days following the eclipse. And so the concept of the spectrohelioscope was born.

By a strange coincidence, Norman Lockyer had conceived the idea of observing the spectra of prominences outside of eclipses nearly two years earlier, but delays in the completion of his spectroscope meant he only was able to make the critical observations in October 1868, two months after Janssen. Nevertheless, letters about their discoveries from Janssen and Lockyer reached the French Academy of Sciences at the same time and were read at the same meeting. In 1872 a medal was struck by the French Ministry of Public Instruction assigning equal credit for the discovery to both men. All this is recounted by Nath in Chapter 10.

However, this fascinating Chapter contains even more, for it reports Lockyer's discovery, on 6 November 1868, of the chromosphere (which was then confirmed by Janssen), and it deals also with the identification of the anomalous bright yellow spectral line queried by Pogson. On 15 November 1868 Lockyer was convinced that this line was not due to sodium, while Janssen reached the same conclusion in mid-December. So here was a new line in the solar spectrum, and its identification occupies the remainder of Chapter 10 and all of Chapter 11 ("The Ghost Element that Refused to be Identified"). Lockyer decided to name it helium, but only in 1895 was it finally detected in the laboratory by William Ramsay, bringing to an end nearly thirty years of confusion and controversy (see especially pages 230-240 in Chapter 12, "Helium on Earth").

The Story of Helium is Nath's first history of astronomy book, but I hope it will not be his last (although more careful proof-reading of future manuscripts should eliminate many of the 'typos' that appear in this book). Nath has an easy writing style, and reading the text is a little like reading a detective novel—except that in this instance fact surely is stranger than fiction!

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Professor Wayne Orchiston
National Astronomical Research Institute of Thailand, Chiang Mai, Thailand
Email: wayne.orchiston@narit.or.th

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