Part 7

MEETING SUMMARY

Richard Strom observing the transit

Transits of Venus: New Views of the Solar System and Galaxy
Proceedings IAU Colloquium No. 196, 2004
D.W. Kurtz, ed.

doi:10.1017/S1743921305001675

Shades of the goddess: Venus in transit

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Abstract. I review the talks given during IAU Colloquium 196, sometimes in a revised order to suggest certain connexions. The AU now, its definition, value and uncertainty, and its modern determination are contrasted with the situation in 1640. While there are differences, not least in the value of the AU and its error, some things have not changed. As an enduring constant we require: a correct theoretical framework, precise observations, and accurate calculations. The history and context of Horrocks' transit observations are set against the backdrop of our own sightings during the 2004 event, and our journeys to Carr House and other sites in Much Hoole.

The apparent success of the subsequent 1769 world-wide effort belied the limitations imposed by the 'black drop' effect, now said to have two causes: finite resolution and limb darkening. Some mysteries surrounding Henderson's determination of the parallax of α Centauri were dispelled, which led to a discussion of modern astrometry, both from the ground and in space. A passionate plea for continuing ground-based astrometry was followed by results from satellite observatories, in particular discordant values for the parallax of the Pleiades. A graph of parallax determinations since 1769 illustrates the steadily increasing precision reminiscent of a 'Livingston curve,' with improvement by an order of magnitude every 50 years. This progression is expected to continue, as the next space missions (Gaia, JASMINE) should better Hipparcos by large factors. Time on the Earth and our very definition of the second are quite naturally related to motion of the planets, and the dynamical history of the solar system.

The 19th-century transit efforts were the last gasp in a 250-year endeavour linking Kepler with his Victorian heirs: From the viewpoint of determining solar parallax the Venus transit must have had its day. Discussion of its history, though, can be expected to continue. Finally, I trace the progress in determining the value of the AU over nearly 400 years, and suggest that more rapid advancement could have been facilitated by the introduction of other techniques. The danger of sticking to one strategy for too long is perhaps the best lesson which the Venus transits have to offer.

1. Introduction

"I came in with Halley's Comet in 1835. It is coming again next year, and I expect to go out with it. It will be the greatest disappointment of my life if I don't go out with Halley's Comet." Mark Twain (1835-1910)

The reappearance of Halley's comet every three-quarters of a century is the astronomical event which best reflects the measure of a human lifespan. (It is perhaps fitting that the noted Dutch astronomer Jan Oort [1900-1992], whose contributions to our science included work on the origin of comets, could see two apparitions of P/Halley during his long life.) Total solar eclipses occur more frequently (though irregularly), but they are rare at any single location on the Earth. A transit of Venus (ToV), while less of a spectacle than the other two, does, by its rarity and its potential for probing the inner solar system, occupy a special place in astronomical legend, and practice. Indeed, the transits of the 17th, 18th and 19th Centuries can be seen as a bridge linking the 'new astronomy' of Kepler with modern astrophysics. This conference was an opportunity to celebrate the event (and experience the latest edition in an historical setting), cast an eye back to the three centuries preceding the one just completed, take stock of where we stand in the game of direct distance determination, and discuss where we might go from here.

It is in some sense poetic justice that a ToV involves the most mysterious (cloud-enshrouded) of the inner planets, the one associated with the goddess of love and beauty. On those rare occasions, Venus glides across our view of the Sun, providing both a visual spectacle and the potential for taking measure of the scale of our earthly orbit. With the poet we can affirm:

"Between the idea
And the reality
Between the motion
And the act
Falls the shadow" from *The Hollow Men*, T.S. Eliot

2. The Astronomical Unit: now, and in 1639

2.1. *The modern situation*

Modern determination of the Astronomical Unit (AU) has progressed in the past 50 years from classical (optical) triangulation to direct radar measurement (Standish, C196 [=these proceedings]). This has resulted in an immense decrease in the uncertainty, from $\simeq 80\,000\,\mathrm{km}$ in 1950, to a few meters anno 2004‡. Crucial to its value, however, is our definition of the AU. For the instantaneous Earth–Sun distance can be determined to high accuracy, but it constantly changes because of orbital ellipticity. For adopted values of the mass of the Sun, the gravitational constant (G) and the mean interval between vernal equinoxes (i.e., our definition of the tropical year), 1 AU is an average distance to the Sun for some assumed mean motion of the Earth. In the beautiful experiment we call the solar system, one sees Mother Nature integrating the equations of motion to perfection.

The resulting ephemerides have been used to test general relativity, the equivalence and Mach's principles, modern Newtonian dynamics, and to set limits to $\dot{G}$ and changes in the AU. Combining the very latest precision observations with numerical integrations of the equations of motion, including perturbations from the planets, the Moon and some 300 asteroids, highly accurate ephemerides are being calculated to carry out such tests (Pitjeva, C196). Possible changes in the AU, for example, can be investigated at the level of $\simeq 0.1\,\mathrm{m\,yr^{-1}}$.

2.2. *The AU in 1639*

When considering the work of Jeremiah Horrocks, it must be placed in the context of his time, with due consideration for its impact upon his contemporaries (Chapman, C196). Horrocks and his alter ego in things astronomical, William Crabtree, were 'grand amateurs,' quite unlike their continental examples Brahe and Kepler (who had noble and regal connections). Theirs was in a great English tradition of self-supporting savants, and they were, moreover, out to tackle the big questions in science: their interest was in true science, not mere phenomenology. Horrocks was widely read, and combined keen observing skills with the mathematical proficiency necessary to tackle Keplerian theory.

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‡ The same accuracy is not, however, achieved for the outer planets, where traditional optical methods are still in use.

Figure 1. An impressive battery of telescopes prepares to capture first contact of the 2004 Transit of Venus.

When his calculations led him to conclude that the 1631 ToV was to be followed by a second one in 1639, he felt that the realization just a month before the event must have resulted from divine providence (a reflection of his Puritanism). When he first observed the disk of Venus, he was astonished at its diminutive size, in much the same way that Pierre Gassendi had been surprised to see how small Mercury was during its 1631 transit.

In the short time available after his prediction, Horrocks could only warn a few friends, including Crabtree, the only other person whom we know observed it. The latter (who described Horrocks as "my friend and second self") observed the transit with rapture and awe (Kollerstrom, C196). The pair, to whom we can trace the Keplerian tradition in England, complemented one another in many of their scientific endeavours. Crabtree's determination of the diameter of Venus ($1'\,03''$) was, one can say in retrospect, more nearly correct than Horrocks' (Chapman, C196).

2.3. *In three and a half centuries, we've come a long way*

The observations of 1639 revealed not only Venus' diminutive angular scale, but also showed that it was round and opaque (not self-luminescent), that is it had the qualities of a planet. Moreover, and perhaps most important at the time, according to Horrocks' argument the implied distance to the Sun (the AU) was much larger than previously imagined, some 4.5× greater than Kepler's estimate. And yet Horrocks' value was barely two-thirds of the modern AU, or in absolute terms he was off by some 54 million km, while today's determination (given the provisos discussed by Standish, C196) is believed to be accurate at the level of a few meters. To achieve this, both now and in the 17th century, required the correct theoretical framework, precision observations, and accurate calculations.

3. 'T-day'

"The sight of a planet through a telescope is worth all the course on astronomy"
from *Essays*, Ralph Waldo Emerson

The day of 'our' ToV, 8 June 2004, was a memorable blend of observations, tourism and historical context. Before 6 AM BST we journeyed from Preston to the University's Alston Observatory well in time for first contact (05:19:46 UT), but under scattered cloud. The only disappointment was that a cloud prevented direct viewing of the instant of first contact, but observations (with an assortment of telescopes set up by the organizers) were possible shortly thereafter (see Fig. 1). In fact, good observations could be (and were) made during the entire transit (Figs 2 and 3).

3.1. *Carr House*

After a solid English breakfast, most of the conference attendees went on a tour of Horrocks sites in Much Hoole. This small community, quiet, obscure, and set in a "dark corner of England" (in the eyes of 17th-century Puritans; Walton, C196) is where Horrocks, more by default than design, made his momentous observations. The likely location was Carr House, which we were able to visit by the kindness of the present owners. The stately brick edifice, some 400 years old, would have been familiar to Jeremiah Horrocks and certainly delighted us (Fig. 4). We were able to peek through the very window from which, plausibly (the Sun could be seen), the 1639 observations were made (Fig. 5).

3.2. *St. Michael's Church*

There followed a visit to St. Michael's of Much Hoole, with its memorials relating to the 1639 ToV. Then as now, it was the parish church, and would have been frequented by Horrocks. His religion — Puritanism — should not be ignored when considering his scientific achievements. Its austerity (as illustrated by the sombre garb depicted in paintings of Horrocks by Eyre Crowe, and of Crabtree by Ford Maddox Brown) may have been its most tangible aspect from our perspective. Among their other qualities, Puritans were serious yet flexible, they believed in predestination, and to be a Puritan required literacy (Walton, C196) — and Jeremiah Horrocks *was* well read, consuming 15 or 16 books per year (Chapman, C196). Not long after his early death in 1641, Lancashire and much of England were engulfed in a bloody civil war pitting royalists against parliamentarians, Catholics against Protestants (or roundheads). Or, as humorously summed up last century, it was the

"*utterly memorable Struggle between the Cavaliers (Wrong but Wromantic) and the Roundheads (Right and Repulsive).*"
from *1066 And All That*, W.C. Sellar and R.J. Yeatman

3.3. *Hoghton Tower*

"A good time was had by all." Stevie Smith

The day's events were fittingly (and exquisitely) rounded off with a superb dinner at the 16th-century manor of Hoghton Tower, where James I, among others, was a famous visitor. (The stately building and its entrance are shown in Fig. 6.)

Figure 2. "Mad dogs and Englishmen / Go out in the midday sun." — English women also! from *Mad Dogs and Englishmen*, Noël Coward

4. The great 18th-century expeditions; Venus' planet credentials boosted

"I didn't go to the moon, I went much further — for time is the longest distance between two places." from *The Glass Menagerie*, Tennessee Williams

The most direct way of measuring the distance to an inaccessible object is to use parallax. (It is the main reason we have two well-separated eyes: originally, no doubt, to avoid being eaten, though later it helped put meat on the menu.) For a Venus transit, this requires the determination of tiny angles. It was the great English astronomer/naturalist Edmund Halley who, reflecting upon his own attempts to determine the parallax of Mercury in transit, hit upon the idea of converting the measurement of an angle into the determination of a time interval: in particular, the elapsed time between 2nd contact (ingress), and 3rd (egress). He outlined a global attack on the problem involving observers at widely separated terrestrial latitudes timing the transit. Although he did not live to see its practical application, Halley's approach would set the agenda for the next two-and-a-half centuries.

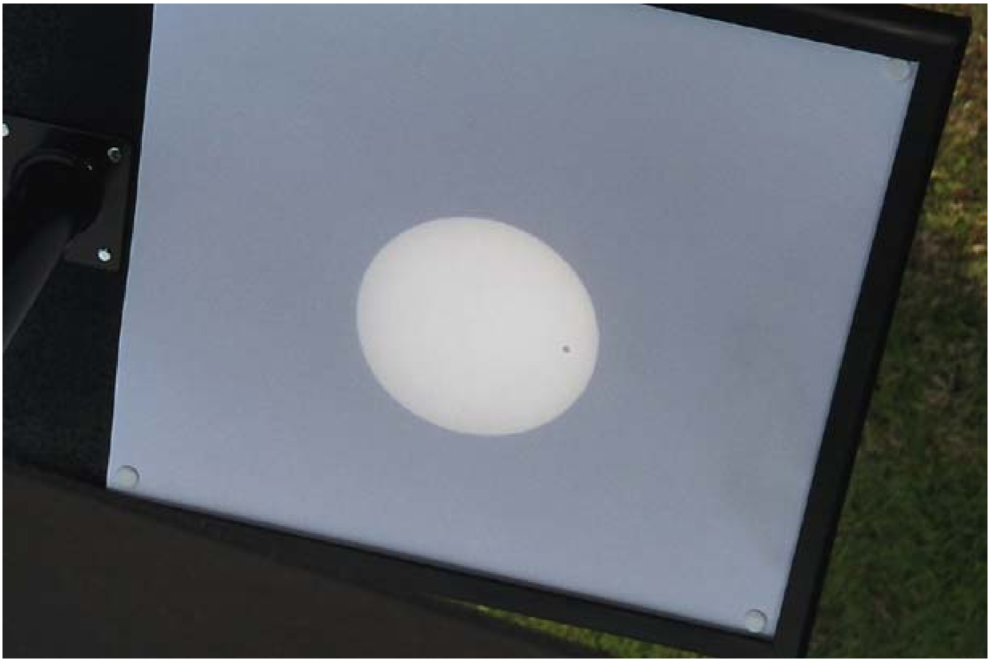

Figure 3. And this is what they saw: Venus' shadow near the solar limb (the small dot on the right side of the disk). "Looks like someone punched a hole in the Sun," was my sister's comment.

Figure 4. Conference delegates approach Carr House. Tradition has it that Jeremiah Horrocks observed the ToV from the second storey central bay window (see Fig. 5).

Figure 5. The bay window through which Horrocks' 1639 observations might have been made.

Figure 6. Delegates from the conference approach the entrance to Hoghton Tower.

4.1. *French and English expeditions*

While many groups took up the challenge, France and England set the tone in the 18th century. Débarbat (C196) described the origins of the French efforts, from Gassendi's Mercury transit observations of 1631 (and an attempt to see if the 1631 ToV might be visible from Europe, despite Kepler's prediction to the contrary) through Delisle's systematic preparations (he had discussed the matter with Halley during a trip to England in 1724). Yet despite the investment of effort (and money) and the acquisition of 120 observing reports from 62 stations, the results were not generally felt to be satisfactory.

These measurements of the 1761 ToV were carried out against the backdrop of warfare (the Seven Years War, which involved England, France and most of Europe), with all the hardships it imposed upon expeditions trying to reach remote (and often unexplored) parts of the Indian and Pacific Oceans. The two 18th-century transits were to provide romantic tales of the exploits of many of the protagonists. Among the most gripping are the tragicomic adventures of Guillaume Le Gentil de la Galaisière, whose attempts to observe the 1761 event having been effectively thwarted by the war, decided to remain in the east for an additional 8 years to plan for (and observe) the 1769 transit. Finally settling upon Pondicherry, India, as a suitable observing site (after having been expelled from the Philippines as a suspected spy), he invested much effort in building an observatory and getting all the instruments set up, only to have the weather turn sour the very day of the transit. Even his return to Paris after over a decade would have pained all but the most zealous of masochists.

A much happier and successful lot would befall James Cook, whose voyage (and later ones of discovery to the Pacific) and exploration of Australia and New Zealand are the stuff of legend (particularly in the Anglo-Saxon world). By 1769 the war was over, and observing the Venus transit seems to have become something of a matter of national pride (war by other means. . . ?). The British expedition organizers located a point in the Pacific as the ideal observing spot, and shortly thereafter as if by providence (and they weren't even Puritans! - § 2.2) Tahiti was discovered there (Orchiston, C196). Cook and his crew of nearly 100 sailed in the *Endeavour*, a former Whitby collier, making for Tahiti where they set up three observing sites as insurance against inclement weather. In the event, all the observations provided useful data, and the expedition can be adjudged to have been a success (even discounting the results of the subsequent explorations of the antipodes). When measurements from sites in Europe, Canada and the Pacific had been analysed, the resulting solar parallax ($\pi_\odot = 8''.78$) was in remarkably good agreement with the modern value ($\pi_\odot = 8''.794148$).

4.2. *Great observations! . . . pity about that black drop*

Despite the success of their measurements, all of the observers in Cook's expedition discovered that their timing was limited by an effect first observed by Bergman in 1761: near the moments of 2nd and 3rd contact, the edge of Venus near the solar limb becomes distorted, shaped rather like a drop of water. The effect has been much discussed and speculated upon, being variously attributed to the atmosphere of Venus, that of the Earth, and instrumental resolution. During satellite (TRACE) observations of a recent transit of Mercury, Pasachoff, Schneider & Golub (C196) observed a similar black drop effect. Since Mercury has no atmosphere and the observations were done from space, any atmospheric cause is ruled out. By decomposing the TRACE images, the authors are able to show that solar limb darkening as well as the expected telescope point spread function both play a role in producing the black drop. The assumption is that this will also prove to be the case in the Venus transit, a conjecture which the team was testing even as the rest of us were celebrating Jeremiah Horrocks in Much Hoole.

4.3. *Planet Venus has an atmosphere*

The black drop effect may not provide evidence for a Venusian atmosphere, but there were 18th-century ToV observations which could be so interpreted. The Russian scientist Mikhail Lomonosov was involved in expeditions to time the 1761 transit (Russia, an ally of France, was also at war with England), but was himself more interested in observing associated physical phenomena (Marov, C196). He was thus among the first to regard the occasion as an opportunity to study something other than the geometry of the solar system. At ingress, just before second contact, Lomonosov saw a sudden, brief crescent of light encircling the side of Venus farthest from the Sun. He correctly interpreted this as sunlight refracted through a dense atmosphere surrounding the planet, and further made philosophical speculations about inhabitable worlds. Venus not only had the simplest properties of a planet (round, opaque) as had been shown by Horrocks and Crabtree (§ 2.3), but with an atmosphere was even beginning to look earth-like. And if the 'roaming stars' bound to the Sun were planets not unlike our Earth, couldn't other stars also have them; couldn't there be exoplanets?

4.4. *Why did they bother (to observe the transit, that is)?*

Intellectual quest? Technical challenge? Lust for adventure? All of these no doubt helped stimulate the 18th-century scientists and explorers who risked (and sometimes gave) their lives to observe Venus transiting the Sun. Perhaps it was simply the next step in the exploration of our world (in the broadest sense of the word). The voyages of discovery of the 15th – 18th centuries had negotiated uncharted seas. We now had the measure of our world, while the revolution spawned by Copernicus–Kepler–Galileo provided a model for the world beyond Earth — the solar system. Its structure was established, but its dimensions poorly determined. What better way to use our knowledge of the size of the Earth than as a sighting platform for determining the parallax of Venus?

5. Stepping stone to the stars

"We sit in the mud . . . and reach for the stars."

from *Enough*, Ivan Sergeevich Turgenev

The parallax of Venus determined its distance from the Earth. Combined with Kepler's 3rd law, the distance to the Sun could be calculated, and hence the scale of the solar system established. The next rung on the distance-scale ladder would be to measure the distances to the nearest stars. Triangulation from the Earth being impossible (even with modern instrumentation, the parallax is too minute), the Earth's motion about the Sun could be used to give a baseline of 2 AU (some $23,000\times$ greater than the Earth's diameter). That is exactly what astronomers began to do in the first half of the 19th century.

5.1. *Henderson and the distance to α Centauri*

The observatory established at the Cape of Good Hope in the 1820s had a role similar to Greenwich Observatory: to obtain accurate stellar positions and provide time signals. Thomas Henderson, its second director (1831-1833), who hated the climate of the Cape, busied himself with astrometry, in particular to determine the declinations of 170 stars including α Cen (Warner, C196). Shortly before his departure for Scotland in 1833, Henderson learned that α Cen has a large proper motion. Concluding that it is likely to be nearby, he made additional observations during his last month at the Cape, and asked his successor, Thomas Maclear, to make still more. Although he clearly thought that α Cen must be nearby, why did he wait so long before analysing and publishing the data? Warner suggests that it was a combination of factors: the pressure of his new duties in Scotland, the fact that he didn't entirely trust the measurements he had made in 1832-1833 and so was waiting for Maclear's results, and the amount of work involved in the analysis itself. It was only Bessel's announcement of the parallax of 61 Cyg in 1838 that finally spurred him to action.

Though he was not the first to publish a fairly accurate stellar parallax (in fact his value was some 30% too large), Henderson is often credited with the first measurement. If we take the raw observations to be a 'measurement,' then this is, I suppose, strictly true. However, without calibration and data reduction, which would involve combining many observations taken at different times of the year, to separate the annual changes due to parallax from an even larger proper motion, the determination would be far from complete. As with the solar parallax results, from Horrocks to the present day (§ 2.3), data reduction is such an integral part of the 'measurement' that the observations alone are not sufficient to establish an outcome.

5.2. *For some passion: bring on the astrometrists!*

Anyone talking on a favourite topic can wax exuberant about it. However, passion is somehow not the first emotion most of us are likely to associate with astrometry (not in the way we might link it to cosmology, for example). Nonetheless, there was passion in Monet's plea for more ground-based astrometry, and in talks on the distance to the Pleiades Cluster.

5.2.1. *Parallax determinations from ground-based instruments*

The situation which astrometry from the ground finds itself in sounds rather precarious (Monet, C196). Although observations from space are immeasurably more expensive (and satellite observatories have much shorter lifetimes), there is plenty of money for space astrometry and practically none for terrestrial. If cost were the main factor, ground-based measurements would prevail, though space has the advantage when it comes to astrometric precision. A possible niche for future astrometry from the ground is, according to Monet, the combination of large aperture telescopes (2-m class) with wide fields of view (CCD detectors covering up to $0.5 \times 0.5\ \mathrm{m}^2$). In addition to the astrometry of faint ($R \simeq 24$) objects, such an instrument can detect fast-moving asteroids — indeed, searching for 'killer asteroids' may become its main selling point. Although terrestrial astrometry may be (all but) dead, there are many opportunities (but no funds).

5.2.2. *How far to the Pleiades?*

The Hipparcos Satellite has enabled us to extend the distance determination of stars to kiloparsec scales. But nearer to home, a well-known open cluster (known even to the ancients), the Pleiades, confronts us with a quandary. The expected distance from isochrone fitting to the main sequence is about 130 pc (or a parallax of, $\pi = 0\farcs0076$). Benedict explained how the Fine Guidance Sensors aboard the HST have been used to achieve astrometric precision to the $0\farcs0003$ level (Benedict & McArthur, C196). The technique has yielded distances for a dozen astrophysically interesting objects; for the Pleiades (based on six members) the distance is found to be 134.6 ± 3.1 pc, in good agreement with the 'expected' value.

The Hipparcos distance is significantly less than this: 120 pc ($\pi = 0\farcs0083 \pm 0\farcs0002$). In view of the discrepancy, van Leeuwen (C196) has reanalysed the Hipparcos data, evaluating and where necessary correcting for all possible sources of error. The result is not significantly different from the original value, with $\pi < 0\farcs008$ deemed highly unlikely. According to van Leeuwen, people should take the lower distance value seriously, and consider what its astrophysical consequences might be. In a subsequent talk, Southworth, Maxted & Smalley (C196) have reanalysed published data to derive a distance to the eclipsing binary and Pleiades member, HD 23642. They confirm the earlier value of slightly over 130 pc, but conclude that the smaller Hipparcos distance cannot be ruled out, noting that further observations could provide a determination accurate to ± 5 pc.

There is clearly a discrepancy in the Pleiades distance determination. Whether it is due to a problem in the Hipparcos calibration, or a misconception concerning the expected behaviour of Pleiades stars, was not settled at the conference (and is certainly unclear to this reviewer, although my impression is that the majority incline toward an instrumental problem). That the Hipparcos data contain many subtle effects was underlined by Pourbaix (C196), who discussed chromatic issues, in particular colour-induced position shifts, and how to correct for them. Problems have been reported for very red objects like Mira variables, although the influence on the distance scale is small. Correcting the achromatism results in a better period-luminosity relationship for the Miras.

Eclipsing binaries, also variable (but for reasons of geometry), have long been exploited for inferring stellar properties. Budding (C196) described the photometry required to extract accurate distances from apparent magnitudes, which can be an independent check on parallax determinations. The possible detection of planetary transits was noted.

Figure 7. Fr. Fintan O'Reilly, standing before the original observatory building, describes Stonyhurst and its telescope to an attentive group from the conference.

5.2.3. *The Ribble, Shires, Hobbits, a Dome Observatory and the Shireburn Arms*

After a day of discussing transits, orbits, astrometry and eclipsing binaries, what better way to wind down than to visit… an observatory? Stonyhurst College, a Catholic school with a long tradition, stands in the Forest of Boland where J.R.R. Tolkien (whose sons taught at the college) imagined much of his Hobbitarium. Stonyhurst also houses an historical telescope, still used by both students and a club. After an enthusiastic tour of the observatory (Fig. 7), we walked Dean Brook hoping to spot some of the small folk (but we're apparently better at looking up than down), ending up at the Shireburn Arms, overlooking the Ribble River Valley. (The observatory, it seems, was just a diversion to make the evening appear serious.)

5.3. *A digressionary comment on dark matter*

The effects of dark matter are well known on large scales (galaxies, clusters of galaxies), though they are also seen within individual galaxies (in flat rotation curves). Oort (1932 & 1960) suggested from the motions of stars perpendicular to the galactic plane that unseen material was required. The matter is, however, complex (Trimble 1987). Nonetheless, Bahcall, Flynn & Gould (1992) have found that there is only one chance in six that the local stellar motion can be explained without the need for dark matter. If this conclusion is correct, then it is interesting to note that while motion within the solar system (to scale sizes of perhaps 100 AU) can be explained to high precision without the need for dark matter, on a scale of 100 pc or so, a nonvisible component becomes indispensable. Perhaps with the next generation of astrometric satellites (Gaia and JASMINE), which will provide parallaxes for stars at tens of kpc, it will be possible to define a scale size for dark matter in the galactic disk (or discount the existence of such small scales).

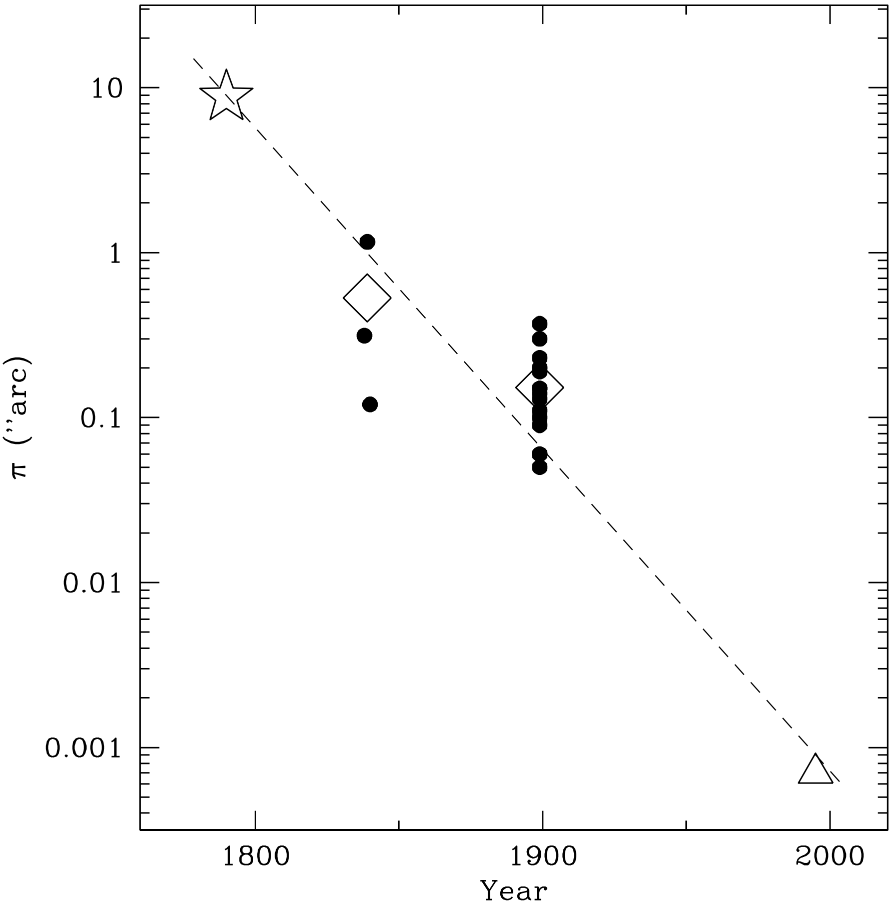

Figure 8. Parallax determinations over the past 200 years. The earliest point (star) is the solar parallax value after the 18th-century Venus transits (§ 4.1). The three points around 1840 are the earliest (successful) stellar parallaxes (§ 5.1), while those around 1900 come from Newcomb (1899). (Diamonds indicate averages of each group of points.) The most recent point (triangle) is based upon the smallest estimated Hipparcos error, σ_π (Perryman, Lindegren, Kovalevsky *et al.* 1997), and taken to be $2.5\sigma_\pi$. The dashed line is a fit through the large symbols.

5.4. *How far have we come with stellar astrometry, and where next?*

To get a sense of the progress made, Fig. 8 shows parallax determinations, beginning in the late 18th century with the ToV observations. There follow the first stellar parallaxes in the late 1830s, typical values around 1900, and finally the kind of measurements delivered by Hipparcos at the end of the last century. The result is a steady progression not unlike a 'Livingston curve' (originally used for comparing particle accelerators by M.S. Livingston in 1954; Panofsky 1997), with a slope suggesting improvement by a factor of 10 every 50 years. It is said that if a discipline's technical capability improves exponentially, then that is a sign of good health. On this basis, parallax determinations seem to have been vigorous for much of the past two centuries, and given new satellite missions on the planning board, should remain so for the foreseeable future.

During an evening lecture, Perryman (C196) illustrated in a lively manner the remarkable success of Hipparcos, describing the mission with the aid of three-dimensional sky images. In the coming decade, two successors to Hipparcos are planned: Gaia (an optical mission) and JASMINE (infrared). There is also a ground-based (radio) instrument, VERA. All three were described at the conference.

Gaia, the direct successor to Hipparcos, will improve upon its performance by several orders of magnitude in all dimensions of parameter space (Bailer-Jones, C196). It will perform an all-sky astrometric and photometric survey to $V = 20^{\mathrm{m}}$, and will detect galaxies, quasars and solar-system objects, in addition to stars, during its five-year mission. It will discover and investigate thousands of exoplanetary systems, and be able to detect planets of several $\mathrm{M}_{\oplus}$ in nearby systems. Gaia also has a spectrograph which will provide radial velocities for $V < 17^{\mathrm{m}}$ objects (Cropper, C196). It is particularly sensitive to unusual objects (rapid rotators, accreting stars, etc.), and could locate the nearby 'killer star' whose close encounter with the solar system might have disrupted the Oort cloud, unleashing cometary activity which could have been responsible for terrestrial mass extinctions.

The Japanese satellite JASMINE will have astrometric capability similar to Gaia but will operate at $0.9\,\mu$m, or z-band (Gouda, C196). It will observe stars with $Z < 14$. At this infrared wavelength it will obtain useful parallaxes for 10 000× more stars than Gaia in the direction of the galactic centre. In the galactic bulge it will observe some 700 000 stars. Its main goal is to study the structure and evolution of the disk and bulge of the Milky Way, with launch planned in a decade. (In addition to Gouda's talk, there were also several poster presentations related to JASMINE.) VERA, a Japanese ground-based radio project, also has galactic structure as its primary objective (Kobayashi, Kawaguchi, Manabe *et al.*, C196). The four VERA antennas, which were recently completed, will simultaneously observe H_2O masers and reference sources, thereby eliminating atmospheric fluctuations. At its 22-GHz operating frequency, VERA will achieve an astrometric precision of $10\,\mu$arcsec, enabling the measurement of parallax and proper motion of water masers throughout the Galaxy. The ultimate goal is to determine the kinematics and mass distribution of the Milky Way.

6. Planets around stars

"Observe how system into system runs,
What other planets circle other suns."
from *An Essay on Man*, Alexander Pope

Both Gaia and JASMINE will have the astrometric precision to detect more remote extra-solar planets by the recoil motion they induce in their 'sun,' adding to the impressive tally of recent years (see `exoplanets.org/almanacframe.html`). In fact, most of the exoplanet discoveries have resulted from the small Doppler shifts induced in the spectrum of the host star. Planetary transits *à la* Venus will occur in edge-on planetary systems, an effect which has been observed in HD 209458b (Henry *et al.* 2000; Charbonneau *et al.* 2000), and which the Kepler satellite hopes to exploit. In a mission already in orbit, the MOST satellite uses precision photometry to detect acoustic oscillations in Sun-like stars (Matthews, C196). It has, moreover, the capability of detecting reflected light from near-in exoplanets, and can thereby usefully constrain their radii and atmospheric properties. MOST achieves a sensitivity of a few millimag over periods of several days.

In addition to the (partial) occultation which a transiting exoplanet produces, its atmosphere (if any) can induce spectral changes, which have already been observed in the case of HD 209458b (Charbonneau *et al.* 2002). Such changes are unobservable from the ground, however, where the Earth's atmosphere limits photometric accuracy. However, Snellen (C196) outlined a method which exploits the Rossiter effect, whereby the star's rotation produces observable spectral changes.

The very first exoplanets were detected, in ground-based radio observations, around a millisecond-pulsar (or rapidly-rotating neutron star; the perfect clock for observing small Doppler shifts), PSR 1257+12 (Wolszczan & Frail 1992). Brisken (C196) described recent developments in pulsar astrometry, not so much for planet detections as for distances and proper motions. Although dispersion is a rough guide to pulsar distance, the scatter is large. VLBI observations can provide parallax as well as proper motion determinations to explore neutron star galactic distribution, kinematics, birthplace and age.

7. Earth and solar system

"Time is the measure of movement." (Medieval expression)
"What is actual is actual only for one time. And only for one place." T.S. Eliot

To carry out the accurate timing needed for the historical ToV measurements, as well as the determination of longitude (not to mention the precise frequencies required for the Doppler shifts just discussed), an accurate time standard is indispensable. Even Cook, Le Gentil, and their contemporaries took precision chronometers on their expeditions (§ 4.1). The Earth's rotation has, since life appeared on the planet, fulfilled the fundamental role of simple harmonic oscillator and provided our basic time interval. However, when it comes to precision timing, the Earth is not very accurate as is well demonstrated by historical solar eclipse records, for example.

McCarthy (C196) sketched the historical development of chronometry, which has seen accuracy improve by some eight orders of magnitude in ten centuries. A fundamental problem today is that the second, which has become our basic unit of time, is defined as a fraction (1/86,400) of the mean day in 1900, which is actually based upon observations of Earth rotation made in the 19th century, and from which atomic time is derived. Contemporary (VLBI) observations of the Earth's rotation, however, show that it is decelerating by $\simeq 1.7\,\mathrm{ms\,d^{-1}\,cy^{-1}}$ (due to geophysical processes: tidal friction, glaciation, etc.), requiring the regular insertion of leap seconds. As the rate at which this needs to be done may increase still further in the future, there are some who favour getting away from leap seconds altogether, or redefining the SI second. However, any change has implications: for physical equations; for navigation ($1\,\mathrm{s} \simeq 460\,\mathrm{m}$ at the equator); and there may be legal questions. In any event, the tendency is to move away from Earth rotation as the basis of our system of time.

Time also plays a fundamental role in observations of occultations of the moons of Jupiter and Saturn (Noyelles, Lainey & Vienne, C196). Why carry out such measurements? Because the timing can provide positional accuracies to better than 30 mas. Moreover, the events can be readily observed with small (50 cm) telescopes, and can provide improved ephemerides for studying tidal effects and predicting stellar occultations. Orbit determinations were also the subject of several other talks. De Saedeleer & Henrard (C196) have calculated the orbits of artificial satellites around the Moon. The approach is analytical, the important perturbations arising from lunar mass concentrations and the Earth's gravitational attraction. The results have obvious application to future space missions, as does an analytical model of Mercury's spin-orbit resonance (D'Hoedt & Lemaitre, C196). Using a Hamiltonian formalism, they calculate equilibrium states for four different configurations, concentrating upon the stable situation which prevails now. The work is being extended to include perturbations of Venus and the giant planets.

Near-resonance came into Message's (C196) exposition on the arithmetic of Venus transits. He showed, for the past millennium, the pattern of transits occurring in pairs at an eight-year interval, with each brace separated by 105 or 122 years. Approximate orbital resonance plays a role in this configuration. The more frequent Mercury transits have a similar pattern with some differences, the causes of which were discussed. The determination of orbital parameters from observations, particularly of asteroids, has been investigated by Gronchi and colleagues (C196). Classical methods, such as that due to Gauss, are often not applicable to modern data sets, which may only consist of a position and projected velocity vector. Under a set of reasonable assumptions, the distance and velocity can be constrained to an admissible region of parameter space, leading to a small number of possible orbits.

Finally, more complex orbital calculations have been undertaken by Tsiganis, Morbidelli & Levison (C196) to model the dynamic evolution of the solar system. In its formation and evolution, the Sun, planets and asteroids pass through several stages: shortly after the Sun forms, any remaining gas in the disk is driven out leaving proto-planets; the asteroid belt loses 99% of its mass; the outer (major) planets begin to migrate, and the Kuiper Belt (KB) forms. It is this last stage of migration and KB formation which is particularly addressed. The migration (Jupiter inwards, Saturn, Uranus and Neptune out) proceeds very slowly at first, but then accelerates by a dynamical mechanism. As this happens, KB members also migrate, and some are scattered away. This can account for three kinetic elements of the KB (stable, resonant [like Pluto], and scattered). From the timescales involved, it is suggested that the scattered KB objects may be responsible for the Late Heavy Bombardment of the inner solar system some 3.9 Gyr after it formed (and to which the lunar surface bears witness).

8. Wrapping up the historical Venus transit observations

"Most of us spend too much time on the last twenty-four hours and too little on the last six thousand years."
Will Durant

While England and France set the agenda for the 18th-century ToV expeditions (even while at war; § 4.1), they were by no means the only participants. Russian endeavours have already been noted in passing (§ 4.3), and the conference also heard about a Dutch and an Italian effort, as well as further British observations, in Ireland. The 19th century would see indigenous missions from the Americas too, and continued interest from the Old World as well, witness Lord Lindsay's 1874 expedition to Mauritius described in a poster (Brück, C196).

8.1. *Other 18th-century measurements*

In addition to the efforts of Delisle, Cook, Le Gentil *et al.* to execute Halley's grand plan (§ 4), lesser figures also contributed, in locations like Jakarta (as it now is), Rome and Ireland. At Batavia, the main Dutch colony on Java, the German-Dutch clergyman J.M. Mohr was initiated into the high art of 'transitry' by the 1761 event, during which he assisted the observers G. de Haan and P.J. Soele (van Gent, C196). With the zeal of the converted (and the wealth of his second wife), he built a stately mansion crowned by an observatory (total bill: 200 000 florins). No cost was spared in equipping it with the finest instruments shipped from Europe — for decades its quality would be unsurpassed in the region. Mohr succeeded in observing the 1769 Venus transit (although he was only able to see egress), and published the results. Their use in the greater — parallax determination — scheme was limited by uncertainty in the longitude of Batavia.

Longitude was also to play a role in a dispute which arose over observations of the 1761 transit by G.-B. Audiffredi. Pigatto (C196) sketched the history of the Santa Maria sopra Minerva Monastery in Rome, where Audiffredi, a Dominican, became the librarian in 1749. Being much enamoured of astronomy, he constructed an accurate meridian line in an upper loggia of the monastery to carry out observations. There, in 1761, he timed the transit of Venus and published the results. The French astronomer, A.-G. Pingré, described Audiffredi's data as "useless" since they seemed to conflict with Pingré's own determination of the longitude difference between the Observatoire de Paris and Saint Peter's in Rome. What Pingré had failed to grasp was that the transit observations had not been made from Saint Peter's, a fact which Audiffredi made clear in a refutation he later published.

After Mason (& Dixon)'s successful ToV observations in 1761 (& their famous M-D Line‡), Maskelyne implored him to once again set up a distant observing station for the 1769 transit (Butler, C196). Mason, by then tired of travelling to remote continents, refused to return to North America, but did finally agree to go to the Emerald Isle. Why observe from Donegal? Its northerly latitude would mean the Sun could be viewed at a higher elevation. The weather was (just in the nick of time) clear, and the measurements were a success. The problem was to determine their longitude, which took Mason months (and much encouragement from Maskelyne to persevere, and not abandon prematurely). In the end, ironically, the North American observations were of such high quality that Mason's would hardly figure in the parallax determination. But there was a spin-off from this, for it enhanced Ireland's reputation astronomically, and arguably (with not a modicum of assistance from Maskelyne) led to the establishment of at least one of Ireland's main observatories. Indeed, in the following century, Eire would (for a time) boast both the world's largest reflector *and* refractor.

8.2. *1874 & 1882: the last hurrah*

The 19th-century transits were to see 'new' nations of the western hemisphere actively enter the fray for the first time (they hadn't even existed as independent states in 1769). America, through the US Naval Observatory, mounted what were certainly the most professional campaigns of the period — and perhaps of all time (Dick, C196). Armed with a congressional appropriation of over a quarter-million dollars (for both transits), eight expeditions were sent out each time, fully trained and equipped with the latest instrumentation. Photographic plates were heavily relied upon, with hundreds exposed in 1874 (and over 1000 in 1882). Despite all the meticulous planning (to the point of erecting commemorative markers at the sites), the black drop effect (§ 4.2) still limited the ultimate parallax accuracy. Nonetheless, the final value derived by W. Harkness was within Halley's hoped-for 1/500th (giving an AU 0.17% smaller than the modern value, though the the estimated error exceeded the difference by over 2×). It was all written up but never published (galley proofs exist). The result did enter S. Newcomb's AU determination a few years later, but was given low weight (aberration was deemed 20× more important).

The American expeditions may have been among the most lavishly financed; Mexico participated in the 1874 transit on a shoestring (Allen, C196). It was a hard time for the country financially, but the Mexican president became convinced of the value of

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‡ The Mason-Dixon line is the traditional boundary between the North and the South in the United States.

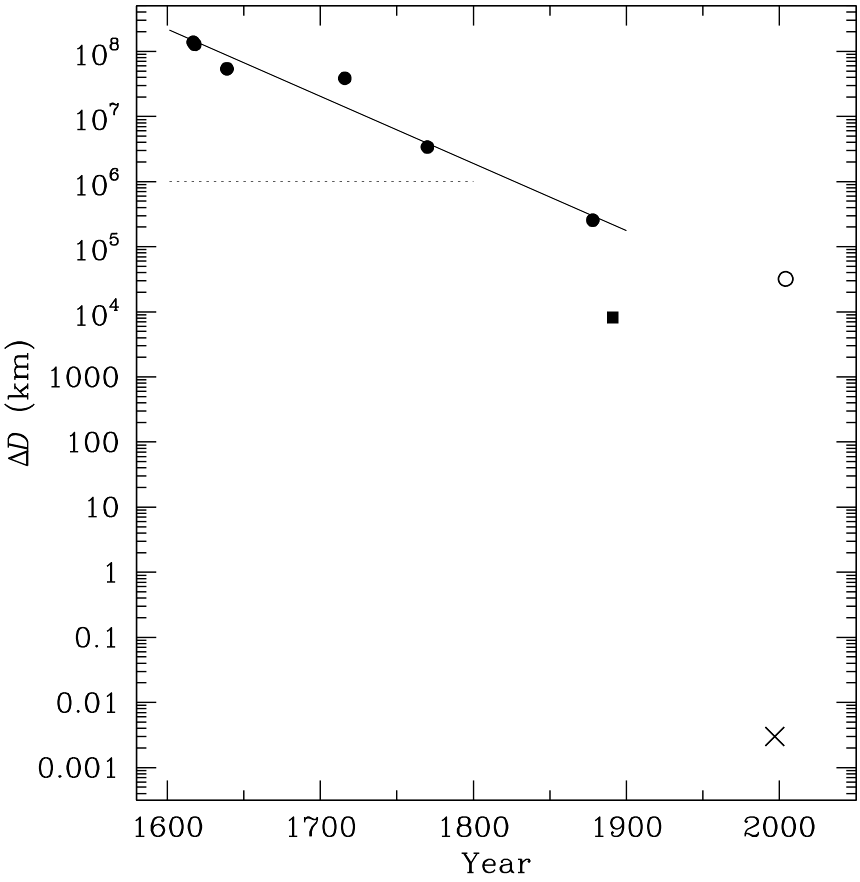

Figure 9. Absolute value of the deviation of AU measurements from the modern value. The first six points (solid circles) are based on classical methods, mainly involving the transit of Venus, and the solid line is a fit to them. The dotted horizontal line shows roughly where the black-drop effect begins to play a significant role. The most recent point (open circle) is based upon a provisional determination from the 2004 ToV (`www.vt-2004.org/central/cd-observers/obs-tim.html`). Newcomb's value from the 1890s (solid square) is an average based on several methods, including the ToV (though with low weight). The point with the smallest ΔD (×) shows the estimated uncertainty in the modern (radar-determined) value.

the enterprise and gave the go ahead for an observing party to head for Japan. Armed with the necessary telescopes and clocks, two stations were set up near Yokohama, and both produced usable results. They were published within a year (the first of the 1874 measurements to appear). While the Mexican expedition may be little more than a footnote in transit history, it had significant impact within the country. As in Ireland a century before (§ 8.1), it facilitated the establishment of a national observatory. It also strengthened relations with Japan, leading to the first equal treaty with that country. Mexican observations of the 1882 Venus transit from Guadalajara were described in a poster by de Alba Martínez (C196).

9. And where has it all brought us?

"…and history came to a."‡ from *1066 And All That*, W.C. Sellar and R.J. Yeatman

At this point, a conference reviewer would probably conclude with words to the effect that the subject is vigorous and healthy, and (s)he looks forward to significant progress in the field before the next meeting in a few years time. Here however, I think I can safely state that we have come to the end of Venus transit observations for the purpose of parallax determination (in fact, the end came in 1882; § 8.2). Fascination with the phenomenon will no doubt continue to inspire many, especially amateur, observations (and one website — `www.vt-2004.org/central/cd-observers/obs-tim.html` — reports, on the basis of thousands of [mainly amateur] timings of this ToV, a preliminary determination of the AU within 30 000 km of the current [radar] value). Further study of the history may also yield new insights. Allen (C196) noted the existence of a Mayan wall painting from the period 1200-1350, which might show a transit of Venus, although the interpretation seems far from unambiguous. Nevertheless, naked-eye transit observations are feasible, so a pre-Horrocks sighting is certainly possible. Oriental and Babylonian records would seem to be the likeliest sources.

How much progress did two-and-a-half centuries of observing Venus in transit achieve? Fig. 9 shows the deviation ($\Delta D = |AU_{\rm now} - AU_{\rm old}|$) in determinations of the AU from the modern value since the time of Kepler. We again see the steady progression typical of a Livingston curve: after each ToV campaign, the estimated Earth–Sun distance moves closer to the modern value. A fit to the values based upon measurements up to 1882 indicates that ΔD decreased by a factor of 10/century. The point in the 1890s is from Newton (§ 8.2) using several methods. Both it and the lowest value — based upon the estimated uncertainty in today's AU determination — lie well below the fit. This suggests that ToV measurements of the AU quickly became moribund (and remained so for over 200 years). The steepest possible exponential improvement shown by a Livingston curve occurs when new technologies are regularly introduced. The two lowest points, relying on completely different techniques (see §§ 2.1 & 8.2), suggest how much more rapid progress might have been. The plot also shows where the ΔD values should become limited by the black-drop effect, suggesting that not much more progress could have been expected from ToV determinations. (The preliminary 2004 value is also shown.)

Finally, what lessons can we learn from the transit of Venus experience? It seems ironical that although the black drop effect was well-documented by 1769, with a century to prepare for the 1874 transit (and a second chance eight years later), no effective strategy could be developed to mitigate its effect — even its cause remained obscure. But most likely the problem was (is?) insurmountable. If, as the Livingston curve (Fig. 9) suggests, new technologies were required for a breakthrough, then the weakness of pursuing only one scheme is exposed. However, it is difficult to see what alternatives there were. The ingenuity of the timing method (§ 4) lies in its conversion of a tiny angle into a small (but more readily measurable) time interval. Halley's hoped-for accuracy of 1/500th corresponds to an angular uncertainty in π of $\simeq 0\rlap{.}''05$, a value stellar astrometry would only reliably achieve around 1900. The one alternative I can imagine might have been precision timing of planets occulting stars. Clearly, a breakthrough like radar was essential. Perhaps the coming eight years will also teach us lessons we can discuss at the next (?) Venus transit conference in the antipodes.

‡ For those unfamiliar with British nomenclature, '.'='full stop' ["and history came to a *full stop*"]. Hence in their foreword [or "COMPULSORY PREFACE (*This Means You*)"] to *1066 And All That*, the authors note with some pride, "History is now at an end…; this History is therefore final."

“The party’s over, it’s time to call it a day.”
from *The Party’s Over*, Betty Comden and Adolph Green

Acknowledgements

I am grateful to the SOC for their invitation to attend this superb colloquium, and to the IAU for financial support. I also wish to thank my sister, Janet, for the wonderful photographs she took, and for letting me use some of them to illustrate this summary (Figs 1-7).

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Robert van Gent and Richard Strom

Part 8

8 JUNE 2004
TRANSIT OF VENUS
AND
CONFERENCE BANQUET

Sunrise on transit day: St. Walburge's Church, Preston

Viewing the transit began at the University of Central Lancashire's Alston Observatory.

Alston Observatory's planetarium-lecture hall was set up for a web broadcast of the transit from sunnier climates in the event of cloudy skies, but, as is obvious in this picture, it was sunny yet again in Lancashire, as it was 24 November 1639 for Jeremiah Horrocks (there have been other sunny days between); meeting participants were all outside at the telescopes observing the real thing.

Gordon Bromage, head of the LOC, put in months of work guiding the large team that set of the Alston Observatory facilities for the transit. His pleasure in the clear sky on transit day is evident.

June Kurtz and Don Kurtz

Some time after second contact people settled down to individual activities

Janet Strom and Richard Strom

Phil Cox on security duty

Once the transit was well underway, participants went to breakfast at Alston Hall, which neighbours the Observatory

Vladimir Elkin, Rick Collins, Steven Chapman, Arthur Missira and Andreas Papageourgiou

Malcolm McVicar, Gordon Bromage and Barbara Bromage

Allan Chapman and Brian Warner

Following breakfast the conference moved to Much Hoole to continue observing the transit from Carr House, believed to be the site of Jeremiah Horrocks's 1639 transit of Venus observations

left: The BBC was broadcasting the transit live from Carr House, including an interview with Allan Chapman; right: Ed Budding and Clive Elphick in the room where Horrocks is believed to have made his 1639 observations

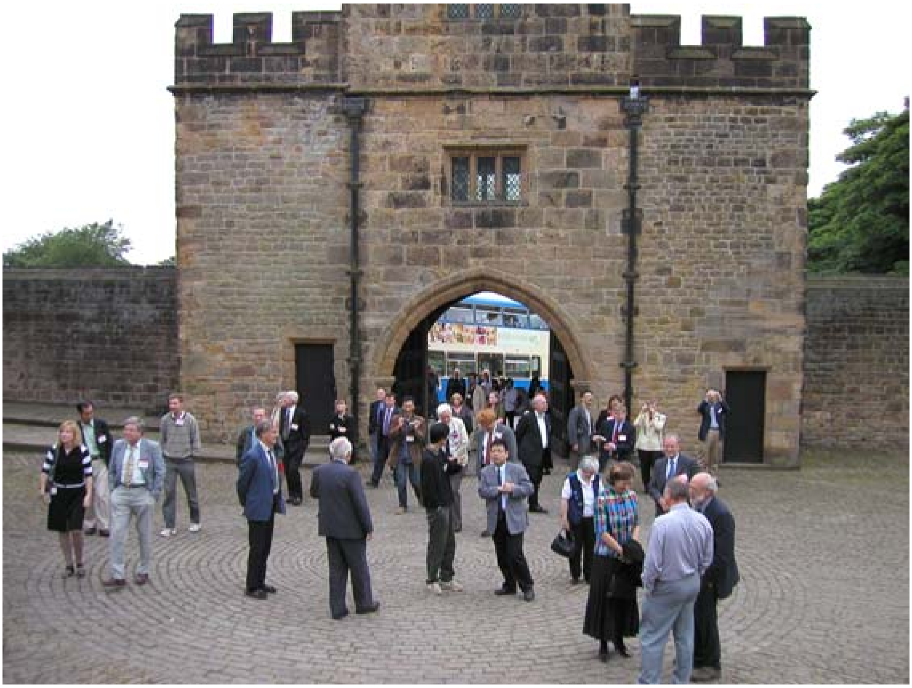
Groups of school children were invited to the transit at Carr House where they view the transit and talk to the astronomers

For the final stages of the transit and for third and fourth contact, the conference moved on the Much Hoole church.

The public turned out in large numbers at Much Hoole church to view the transit through telescopes of the University of Central Lancashire, along with explanations from university staff and PhD students.

The long entrance to Hoghton Tower

Hoghton Tower



Arrival for the banquet through the gatehouse

Announcement of the start of a tour of the house

left: Don and June Kurtz
right: Gordon Bromage, David Clarke and Suzanne Débarbat

Vladimir Elkin, Jon Riley, Jaymie Matthews, June Kurtz and Mikhail Marov

Bridget Bailey, Jackie Cunningham, Emma Woodward

Takuji Tsujimoto, Hideyuki Kobayashi, Naoteru Gouda and Yoshiyuki Yamada

John Southworth, Jon Riley, Steven Chapman, Mike Marsh and Mark Northeast

The high table in the background is the very one where King James I reputedly was served a loin of beef he so enjoyed that he drew his sword and knighted it "Sir Loin".

Allan Chapman and Paul Marston

Michael Perryman and Jaymie Matthews near the end of the evening

Robert Walsh, Clive and Jane Elphick

Clockwise from 12:00: Yukiyasu Kobayashi, Yoshiyuki Yamada, Seiji Ueda, Takuji Tsujimoto, Naoteru Gouda, Taihei Yano, Vladimir Elkin and Hideyuki Kobayashi