In this section of *Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

Preparing for the Transit of Venus

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The upcoming transits of Venus in the years 2004 and 2012 provide an unprecedented opportunity for school and college students to take part in global efforts of recreating historical transit of Venus observations for measuring the Earth-Sun radius. The article summarises a simple understanding of the procedure underlying the determination of this distance, using transit observations and outlines possible co-ordinated activities for student groups.

We have two dates with Venus – the 8th of June 2004 and the 6th of June 2012, when very rare transits of Venus across the disk of the Sun can be seen – from India and many other parts of the world.

Transits of an inferior planet in front of the Sun are extremely rare events and give rise to considerable excitement amongst sky-watchers, who make elaborate preparations for viewing and capturing these events.

The utmost significance of transits lies in the fact that observing them carefully, particularly the Transit of Venus across the face of the Sun, offers a way of measuring the most important distance

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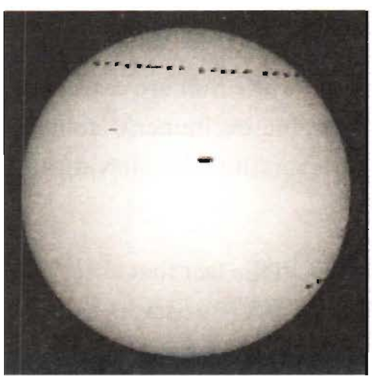
scale in our understanding of the Universe – the Astronomical Unit, or the mean distance between the Earth and the Sun. Historically, the transits of Venus were the first opportunity astronomers had, of measuring the Earth to Sun distance correctly. This distance had a deep importance for the understanding, not only of the Solar System, but the rest of the cosmos as well. It served as a yardstick for measuring accurately, the distances to the nearest stars, and progressively, the distances to further objects in the Universe, scaling the entire observable Universe.

Currently, the Earth-Sun distance is very well known, and the forthcoming transits would not allow us to determine it more accurately than it is already known, measured with modern day techniques. However, the upcoming transits give an unprecedented global collaboration towards helping students participate in making this measurement – recreating historical observations that were at the forefront of astronomical research, a hundred years ago.

The operative factor determining the Earth-Sun distance through transit measurements is the concept of parallax. Small shifts in the apparent location of a foreground object as seen against more distant background objects, from different locations.

Figures 1 and 2 show two tracks of the Transit of Mercury, as seen on the 7th of May 2003, from two different locations – Udaipur, India and Ghent, Belgium. After aligning and superposing the



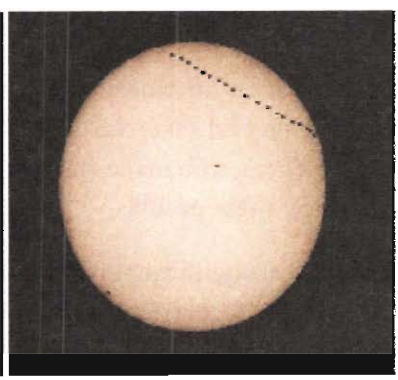


Figure 1 (left). The track of Mercury on the Sun, as seen on 7th May 2003, at the Udaipur Solar Observatory.
Figure 2 (right). A composite image of the Mercury Transit, taken by Dominique Derrick, Belgium, on the 7th of May 2003. (reproduced with permission)

two images, one can see the minute distance between the two parallel apparent paths of Mercury across the Sun as seen by two observers at different positions on Earth. This miniscule shift was the parallax of Mercury that was observed on the 7th of May 2003.

Edmund Halley's method was to use the parallax of Venus, when seen against the Sun, to indirectly arrive at the Solar Parallax. He also realized that the method would not work well with transits of Mercury, since its parallax was only marginally more than that of the Sun. A simple way of understanding the method indicated by Halley, may be summarized as follows.

The first ingredient, needed from the observations, are the contact timings. There are four important points of time during the transit that astronomers would like to measure. These are called I, II, III, and IV contact. The first contact, which is very hard to observe, is the point in time when the planet first touches, apparently, the disk of the Sun. The second contact is the time at which Venus is fully engulfed within the Sun's disk and is internally tangent to the disk. The third contact is when the disk of Venus just begins to leave the face of the Sun, and the fourth contact is when the disk of Venus has just completely left the Sun's disk and is externally tangent to it. *Figure* 3 clarifies these concepts.

The difference in timings of Contacts III and II for two different locations, could be translated as perpendicular distances between parallel chords on the surface of the Sun, corresponding to the two apparently different paths of Venus across the Sun, as seen from two different locations.

Choosing two points P and Q on the chords, in such a way that PQ represents the perpendicular distance between the two transit chords, the geometry between Earth, Venus and the Sun and the two points P and Q on the Sun can be represented as in *Figure* 4.

All the quantities in *Figure* 4, are self explanatory – AU, the Sun-Earth distance; D_O, the chord length distance between two

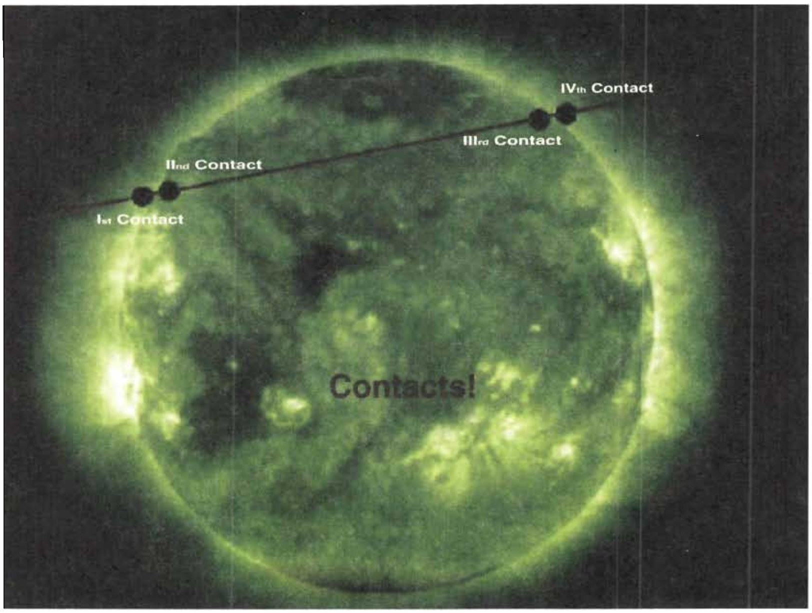


Figure 3. Definition of the contact timings.

observers on Earth; D_{EV}, the Earth-Venus distance; D_{VS}, the Venus-Sun distance; D_S, the diameter of the Sun and PQ, the perpendicular distance between two observed transits on the face of the Sun.

From similar triangles,

$$PQ = (D_O\, D_{VS})/D_{EV}$$

$$\Rightarrow \quad PQ = (D_O\, D_{VS})/(AU - D_{VS})$$

$$\Rightarrow \quad PQ = D_O/[(AU/D_{VS} - 1)] \qquad (1)$$

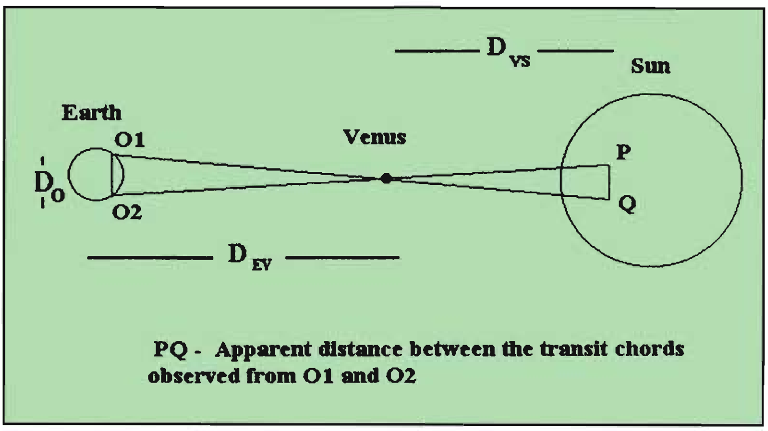


Figure 4. Geometry of transits for the determination of the astronomical unit.

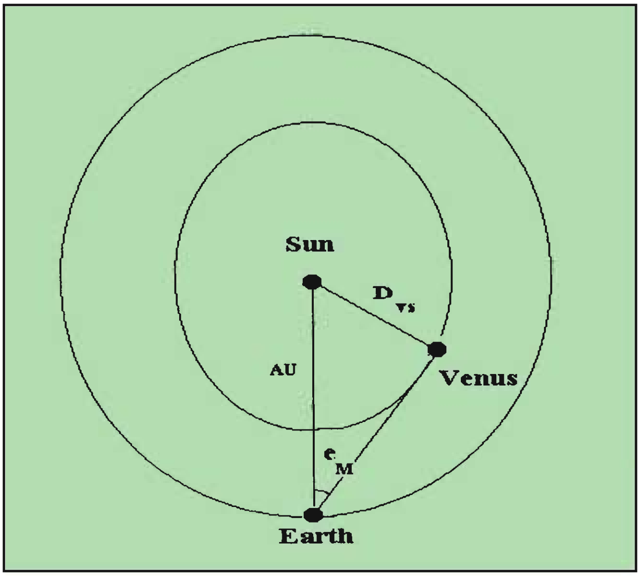


Figure 5. Definition of the maximum elongation of Venus.

AU/ D_{VS} can be related to an observable quantity called the maximum elongation of Venus.

Elongation of any celestial body is defined as the angular distance from that body to the Sun, as seen from Earth. For the two inferior planets Mercury and Venus, this elongation could vary from near zero when they are at inferior or superior conjunction to about 48 degrees for Venus and about 28 degrees for Mercury.

At the time of maximum elongation, the Earth-Venus-Sun angle is 90^0. And hence, as can be seen from *Figure* 5, at this instance, the ratio of the radii of the orbits of Venus and Earth is equal to the sine of the angle of maximum elongation e_M.

$$\sin(e_M) = D_{VS}/AU.$$

This ratio can thus be obtained by measurement of the elongations of Venus around the time that this quantity reaches a maximum, thus determining the maximum elongation. For the year 2004, for instance, the maximum elongations are reached by Venus, on either side of the Sun, on these two dates

Evening sky - 2004 Mar 29 46.460°E

Morning sky - 2004 Aug 17 45.458°W.

And, for the year 2012 –

Evening sky 2012 Mar 27 46.460°E
Morning sky - 2012 Aug 15 45.458°W.

Using the measured ratio between the orbits of Earth and Venus, in (1), one can estimate the distance PQ. From a measurement of the ratio PQ/D_S from an observational *Figure* 5 analogous to Figure above, showing the two observed chords, the diameter of the Sun can be estimated. From this quantity and its known angular radius, the distance of the Sun can be estimated.

It needs to be emphasized however, that the above is a highly simplified picture of the determination of the Astronomical Unit. The real estimation involves complicated spherical trigonometry involving Earth's heliocentric longitude, radii vectors of the Earth and Venus, distance from the centre of the Earth to the two observers, geocentric latitudes of the observers, sidereal time on the meridian of the two observers, the longitude of the planet's ascending node, inclination of the orbit of Venus to the ecliptic, and the angle swept by the planet, in its orbit, since passing through the ascending node. What one needs here is a solution for the equation of the tangent cone, to the spheres of the Sun and Venus, as seen from one location on Earth (see *Figure* 6).

A solution of the equation for this tangent cone, gives the second and third contact times, as seen by an observer at O, as a function of the quantities defined above. The difference in the contact timings between two different locations, can then be reduced to a function of observable quantities and the Astronomical Unit.

Planned Activities related to the 2004 Transit of Venus

The main excitement underlying the efforts with the contemporary transits of Venus, is the possibility of students making direct observational contributions towards a re-measurement of the Astronomical Unit, using a historical method

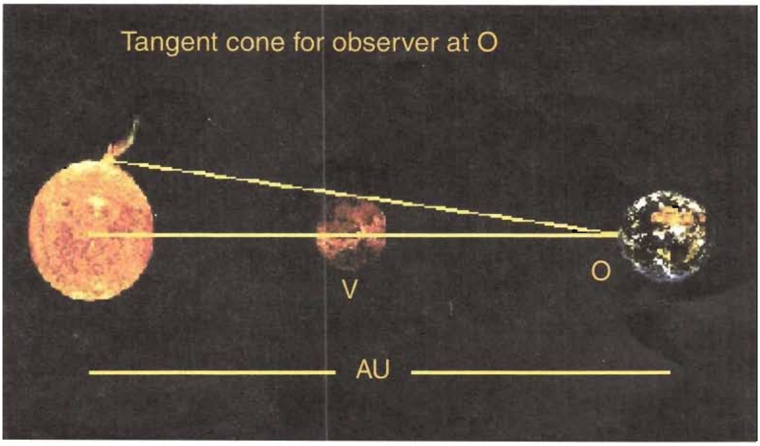


Figure 6. Common tangent cone for the Sun and Venus, from the observer.

– from the timing of the second and third contacts during the transit of Venus.

The estimation of this distance involves many other related observations that could be done by students, with simple equipment – observing the annual movement of Venus – its movement away from and towards the Sun, as seen from Earth. To obtain help towards this, all interested people can see the following group site started by the Nehru Planetarium, New Delhi –

http://groups.yahoo.com/group/VenusTransit.

Join the group to participate in activities related to transits of Venus.

The following activities done by student groups in schools and colleges would enhance the underlying appreciation of this event and place planetary movements in the Solar System, in perspective.

1. Analemma activity

This will be one year of activity, starting any time – not directly related to the transit, but, wonderful, for an appreciation of Solar System orbits.

The analemma results as a sum of the effects of the Earth's elliptical orbit around the Sun and the tilt of the Earth's axis in

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relation to the plane of its orbit around the Sun. As a combination of these two effects – the shape that would be seen for an analemma is in the form of a figure 8 – its extent, and tilt in the sky would depend on one's location in the sky and the constant time in a day, that is chosen as a reference, for making the analemma.

While making a simple analemma, one is not bothered about calibrated time, and, if one wishes only to have an appreciation of the annual movement of the Sun, in the sky – any simple gnomon or a small ring suitably placed to throw the noontime solar shadow on a vacant ground would do, to keep track of the analemma. One just needs to mount a gnomon or a ring around the school playground, keeping a sufficiently wide area around it, undisturbed for a year. Choose a convenient time of the day when the shadow of the ring or the tip of the gnomon may be seen on the ground easily, throughout the year. At exactly the same time of the day, for every observation, the position of this shadow needs to be marked, in some indelible manner. Observations can be taken 15 days apart.

A more ambitious Analemma activity would be to create an actual photographic image of the analemma, by using a fixed and undisturbed camera and giving it a one-year long exposure, clicking images of the Sun at predetermined times (the same time, for every observation) spaced at 15 day intervals. May not sound a very difficult thing to do, but, it may be daunting as well as inspiring to know that only about half a dozen people in the whole world have managed to create successful photographic analemma. It would be wonderful if an Indian amateur astronomer would create an analemma against the background of our wealth of monumental heritage – against the backdrop of the Konārk Temple, for instance!

2. Venus Elongation measurements

It will be an exciting activity in the last week of March and the first week of April 2004, or, at other suitable times – August

2004, and again, March and August 2012, for students to directly map the changing elongation of Venus

A direct way of measuring the elongation – using a sextant or a similar device and measuring the angle between Venus and Sun in the sky, is tricky and could be dangerous, in terms of inadvertently looking at the Sun with unprotected eyes. However, this could be attempted, if one has a good clear view of the horizon and makes these measurements at sunset time.

The year 2012 will be closer to a sunspot maximum period and it may be possible then, to see Venus pass close enough to a sunspot while transiting.

An indirect method of independently measuring the positions of the Sun and Venus, in equatorial co-ordinates, from a measurement of their local co-ordinates, in azimuth and altitude, would be the simplest. Any elementary astronomical text book would give a conversion between the local co-ordinates to equatorial co-ordinates, for objects in the sky.

An exciting possibility, for students of Delhi and Jaipur, would be the use of the Jayaprakash Yantra at Jantar Mantar, for the Venus elongation measurements. An opportunity to celebrate our astronomical heritage!

3. Sunspot Observations

Observing sunspots on the disk of the Sun, may not be directly related to transit measurements. However, observing these through Solar filters or through projection methods, will give an appreciation towards observing features on the disk of the Sun and comparing these features with the black dot of Venus, or Mercury, when observed during a transit. One could also practice locating features on the disk of the Sun, in terms of latitude and longitude on the Sun, while observing sunspots – these can be checked with online data giving the same, so that one could estimate one's errors in locating features on the Sun.

The year 2004 is not really close to a peak of the sunspot cycle. However, there does seem to be some anomalous activity on the Sun in this year and it may be interesting to compare a visible sunspot on the disk of the Sun, with the black dot of Venus, at the time of the transit. The year 2012 will be closer to a sunspot maximum period and it may be possible then, to see Venus pass close enough to a sunspot while transiting.

4. Finally, Transit Observations!

What is it that one will need, in order to be able to make the best of this event? It would be wonderful if one could have the following equipment – a moderate aperture telescope with mount to track objects in the sky, with a CCD or photography attachment and H-Alpha filters in order to be able to measure the First and the Fourth Contact timings. Armed with all of this equipment, one could plan to measure accurately all the four contact timings, photograph Venus on the disk of the Sun at fixed time intervals and/or videotape the entire transit sequence.

One would also need equipment to determine one's exact geographical location. Detailed ASI maps of one's location are available that will give the latitudes and longitudes of locations in any city or town of India. Having a GPS receiver will give one these co-ordinates in the most accurate manner possible. Having the correct time while observing, is another very important necessity. A GPS receiver will again give one the best possible calibrated time. Time signals transmitted at 5, 10 and 15 MHz could also be used for reasonably accurate time calibration.

In the absence of sophisticated equipment for the telescope – drive for tracking and CCD or other video equipment – it would still be possible to use a projection method with a suitable box built behind the telescope eyepiece, project the image of the Sun, during transit, and make reasonably accurate estimates of the contact timings.

Whatever be the level of equipment available to one, the upcoming transits promise to be a heady mixture of astronomy, geometry, instrumentation, history, geography and literature, to entice people with diverse interests!

It may also be of interest, that, one of the first few observations in history, of transits, was done on Indian soil – by Jeremiah Shakerely, in 1651 when he observed a transit of Mercury across the disk of the Sun, although he did not manage to make scientifically useful observations. Prior to this, there had only been observations by Gassendi, of the Mercury transit in 1631 and the important observations by Jeremiah Horrocks and William Crabtree, of the Venus Transit of 1639. It was also on Indian soil, at Muddapur, that an Italian expedition, during the 1874 transit of Venus, for the first time, made spectroscopic measurements confirming the existence of an atmosphere on Venus.

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Two Indian observers Chintamani Raghunathachary and Ankitam Venkata Narsinga Rao, are also associated with the observations of the 1874 transit of Venus. Raghunathachary seems to have had made preparations for the observations of this event and even printed a booklet in Urdu, preparatory to the transit. However, he does not seem to have submitted his observations after the event – perhaps he was clouded out?

Narsinga Rao, on the other hand, who owned a private observatory at Visakhapatnam, did observe the transit of 1874, with a Cooke Equatorial of 6 inches aperture, equipped with a drive for tracking, and submitted his observations to the *Monthly Notices of the Royal Astronomical Society* (*MNRAS*), where they appeared in the issue number 35, in 1875.

It will be a wonderful experience to recreate the historical observations of the transit of Venus and for students and interested people from all over the world, to come together and share this experience.

Suggested Reading

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[4] Narsinga Rao, *MNRAS*, Vol.35, p.317, 1 875.

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