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.

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Venus Elongation Measurements for the Transit of Venus, using the Historical Jantar Mantar Observatory

Worldwide educational activities related to the Transit of Venus involved students in the measurement of the radius of the Earth, the maximum elongation of Venus (apparent angular distance from the Sun, as seen from the Earth), refined observational methods for accurate timing, helped locating one's geography and so on – all the ingredients needed to finally use the Transit of Venus observations towards a determination of the Astronomical Unit[1]. The March 2004 issue of *Resonance* published the article[1] – Preparing for Transit of Venus – that discussed the relevance of the above-mentioned measurements and activities towards a determination of the Astronomical Unit, using Transit observations.

[1] The mean distance between the Earth and the Sun.

This seemed an exciting opportunity to make use of the historical Jantar Mantar Observatory at Delhi and use instruments like the Jayaprakas and Ram Yantra at this observatory, which are designed for making celestial coordinate measurements of objects in the sky.

Keywords
Venus Transit, Jantar Mantar, measurements using Ram Yantra and Jayaprakas.

The observatory has been in disuse since the 18th century. It is thought to have been completed in the year 1724. While Jai Singh wished to use the instruments to make accurate celestial co-ordinate measurements and hence improve ephemeris tables for astronomical calculations, one of his aims in the construction of these massive instruments had also been that anyone (not necessarily an astronomer) interested in making celestial co-ordinate measurements should find it easy to do so, using these instruments.

Jayaprakas and Ram Yantra at the Delhi Jantar Mantar are the very instruments that allow anyone – including school students, to make easy measurements of the celestial coordinates of objects in the sky.

It was precisely this purpose which seemed to have been achieved again when it was possible to train students and visitors at the Delhi Jantar Mantar, on the 29th of March 2004, to make celestial coordinate measurements using the Jayaprakas and Ram Yantra instruments. The observers from the Nehru Planetarium, New Delhi included most of the staff – N Rathnasree, Sanath Kumar, O P Gupta, M K Jain, K Bala-chandran, Rajesh Harsh, R K Chhikara, Hukamchandra and Naresh Kumar. Two members of the Amateur Astronomers Association, New Delhi, Vikrant Narang and Kumar Gaurav, assisted in the evening observations of Venus.

Most public visitors are usually befuddled by the twin hemispherical bowls of the Jayaprakas and the imposing cylindrical buildings of the twin Ram Yantra at the Delhi Jantar Mantar. These, however, are the very instruments that allow anyone – including school students, to make easy measurements of the celestial coordinates of objects in the sky. The measurements on the 29th of March 2004 and in the week following that, were confined to obtaining local celestial coordinates of the Sun, Moon, planets and some bright stars – their altitude and azimuth at different times. The altitude and azimuth measurements of the Sun and Venus on the 29th of March, were used for obtaining the elongation of Venus on this date.

Here is how visitors to the Jantar Mantar were asked to visualize these coordinates, the altitude and the azimuth.

On first being asked how one would explain to someone at home, the location of the Sun or planets in the sky as had been seen by the visitors at the Jantar Mantar, the necessity of fixing a coordinate system and assigning coordinates to objects in the sky, immediately became clear to most of the students and visitors.

One then asked the visitors to think about any object in the sky – mentally pull it down to the Earth vertically – perpendicular to the horizon, and mark the point on the horizon where it should fall. One then asked them to start from the direction North – swing Eastwards till this marked location on the horizon was reached – this angle being the azimuth of the object in the sky and altitude being the angle perpendicularly measured between this marked point on the horizon and the actual location of the object in the sky.

The Ram Yantra is meant precisely for the observation of such coordinates, of objects in the sky. The Jayaprakas can also measure these coordinates as well as the more global equatorial coordinates.

Observations from the Jayaprakas

The Jayaprakas consists of twin hemispherical bowls placed facing the sky, each a reflection of the sky above and marked in sectors and gap regions. The bowls are complementary, in the sense that, the gap region in one bowl is the sector region in the other and vice versa. The idea being that, the observer needs to be inside the bowl, to take readings, which means that readings

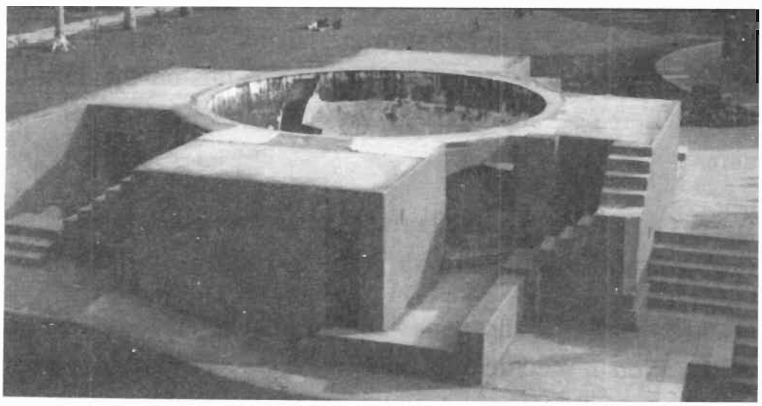

Figure 1. The southern bowl of the Jayaprakas instrument at the Delhi Jantar Mantar.

would not be possible in the regions where the observer would be able to walk, and hence the complementary bowl.

Figure 2. Stretching cross wires in the northern bowl of the Jayaprakas. The Sector aligned to the North is visible in the picture.

How does the instrument work? At the surface level on the depressed bowl, there are pegs in the North-South and East-West directions to hold cross wires. One has to view the shadow of the junction of the cross wires on the bowl of the instrument to determine the coordinates of the Sun in the daytime sky. The sectors on the surface of the hemisphere are marked with altitude and azimuth circles, the tropics and intermediate circles and also circles of the signs of the Zodiac. In the Delhi instrument most of these markings are rubbed off. The altitude and azimuth circles towards the center of the bowl are still visible, so that the Sun measurements in local coordinates, close to the noon time are still relatively easy. For measurements at other times and for equatorial coordinate or elliptical coordinate measurements more rigorous calibration will be needed.

Plastic wire was used for making a makeshift cross-wire for the Jayaprakas.

Once the crosswires were in place, one had to observe for the shadow of the intersection of the two wires to fall on the bowl of the instrument. Jayaprakas measurements were done once in the morning on the 29th of March 2004. We had with us theoretical values for every half hour – so that students could immediately check their values for accuracy.

Azimuth readings were easier – and fractions of degrees were read off from the existing markings by placing tape measure parallel to azimuth circles. Altitude readings were taken by measuring the radial length to the location of the shadow of the cross wire and using the entire sector length for calibration – from center to the surface of the hemisphere being 90 degrees of

Figure 3. Sanskriti school students and teacher marking the cross wire shadow in the Jayaprakas.

altitude – the complement of it actually – as an altitude of 90 degrees would mean the shadow falling at the center of the bowl and an altitude of zero when the shadow would fall at the surface of the hemisphere.

Observations with the Ram Yantra

Ram Yantra seems to have been constructed precisely to make it very easy for anyone to make local coordinate measurements of objects in the sky. Each of the cylindrical instruments consists of a circular wall and a gnomon at the center. The height of the walls and the gnomon, has been designed to be exactly equal to the inside radius of the building, measured from the outer circumference of the thick gnomon – that is, the height of the gnomon is exactly equal to the length of the floor of the instrument measured from the outer circumference of the gnomon to the inner circumference of the wall.

The walls and floor are graduated for reading azimuth and altitude angles – with the azimuth markings being a linear scale in degrees, while the altitude markings are in tangents of degrees and therefore not linearly marked. What is needed is to observe the shadow of the gnomon – determine its center and mark it on the floor or the walls of the instrument – wherever it falls.

Table 1. Some of the Jayaprakas Observational results. The calculated values have used the coordinates for the Jantar Mantar as 28° 37' 36" North Latitude and 77° 13' East Longitude.

Time of Observations	Altitude Observed (degrees)	Calculated Altitude (degrees)	Azimuth Observed (degrees)	Calculated Azimuth (degrees)
11:28 AM	61.75	61.38	148.67	148.63
11:30 AM	61.93	61.61	149.5	149.56
11:41 AM	63.16	62.73	–	154.92

(Observations of altitude and azimuth of the Sun – taken by students of Sanskriti School, New Delhi, on the 29th of March 2004).

The floor is divided into thirty sectors and thirty gaps of the same dimensions as the sectors. The gaps are for facilitating the movement of observers to read the markings and hence, the complementary instrument is designed in such a way that, the shadow falls on a sector of one of the instruments, if it falls in the gap for the other instrument. Each of the sectors is thus spanning 6 degrees of azimuth. The sectors are marked with six radial lines – so that each marking corresponds to a degree of azimuth. Etched at about five feet above the raised floor of the instrument on the gnomon itself is a circular scale of azimuth markings. The edge of one of the sectors is aligned to the North. This is marked as 360 degrees (in Hindi) on the gnomon markings. Once the center of the gnomon shadow (this is not so straightforward and is discussed later) is determined and marked with pencil – one can just read off the azimuth – by starting with the edge marked as 360 degrees and counting the number of sectors and gaps and individual degree markings up to the center of the shadow. A little trick here though – since the shadow marks a position exactly 180 degrees away from the actual position of Sun in the sky, 180 degrees would need to be added to the azimuth reading obtained by counting the sectors and degree lines. Thus angles of 1 degree each can just be read off the azimuth markings – finer graduations seem to be missing from the Delhi instrument, in its present condition, but temporary

Figure 4. The twin Ram Yantra instruments.

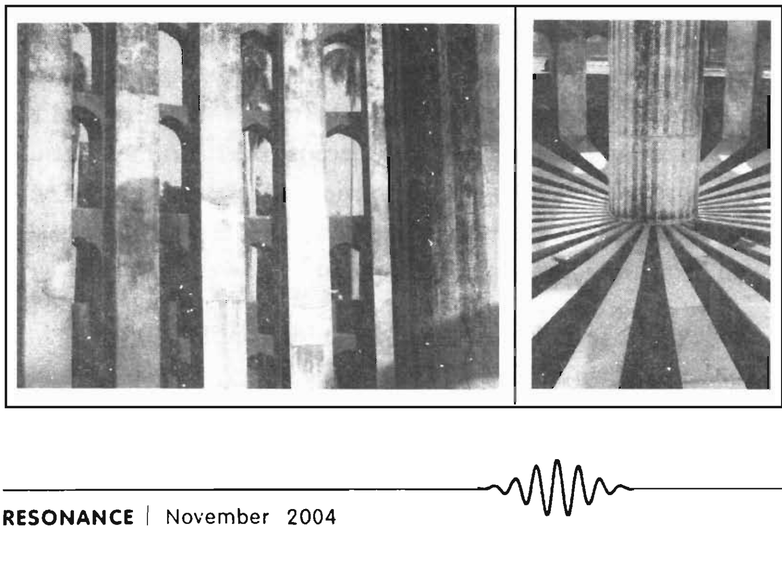

Figure 5 a (left). The inner walls of the Ram Yantra. 5b (right). The raised floor of the Ram Yantra marked in sectors and gaps.

It is the altitude markings in tangents of scale, that form the beautiful simplicity of usage of Ram Yantra.

calibrations for finer accuracy can always be achieved using tape measure placed parallel to azimuth circles.

The walls of the instrument are also graduated similar to the floor – each of the markings representing one degree in azimuth and one degree in altitude.

It is the altitude markings in tangents of scale, that form the beautiful simplicity of usage of this instrument. When the shadow falls at the top of the wall of the instrument, the altitude of the Sun is zero. As one moves down from the top of the wall to the bottom, there are 45 markings on the wall giving rise to an altitude of 45 degrees for the Sun, if the shadow falls at the junction of the walls and the floor. Another 45 degrees are marked inward from the wall towards the circumference of the gnomon, so that altitudes between 45 to 90 degrees can be read off on the floor of the instrument. Finer graduations than a degree are marked on some of the sectors; where they are missing one needs to remember that the scale is not linear any more (unlike for the azimuth) and thus more accurate altitude measurements (where fine graduations are missing) could be inferred by measuring accurately the length of the shadow and knowing that the height of the gnomon is equal to the length of the floor sector.

$$\text{Tan (Altitude)} = \text{Gnomon Height / Shadow Length.}$$

It is interesting to think of the accuracies possible with this instrument – a first-time observer, initially, feels rather disheartened due to the uncertainties in estimating the center of the gnomon shadow, the blurring between the umbra and the penumbra and so on. But, simply because the instrument is built on such a massive scale, the errors induced by these uncertainties are minimal and wonderful accuracies (for educational purposes) can be achieved with this instrument.

Some of the results from the observations on the 29th of March 2004 are shown in *Table* 2.

Observers	Time (IST)	Altitude (in degrees)		Azimuth (in degrees)		Remarks
		Obs.	Th.	Obs.	Th.	
Sanskriti School	12:18	65	64.82	174	175.37	With guidance
Sanskriti School	12:25	64	64.90	180	179.48	Independent
Samridhi/Sneh	13:00	63.53	63.88	199	199.67	Independent
Lady Irwin	14:30	51.35	51.45	235.75	235.67	Independent
DPS Noida	14:53	47	47.00	240	241.22	Independent
SBV/PBV/KB	15:00	44.1	45.78	243	243.06	With guidance
UshaMenon/VS	15:30	39.77	39.75	249	249.12	Independent
Cheena/Dolcy	16:00	32	33.49	254	254.24	With guidance
KDA/Hansraj/Jindal	16:30	22	27.09	258	258.71	With guidance
SKV	17:10(?)	16	18.38	252	263.95	Independent

Observers : 1. Sanskriti School – Teachers – Champa Biswas and Nidhi Kaucha and students; 2. Samridhi/ Sneh – Samridhi, Lady Irwin Sen. Sec. School and Sneh Kesari Nutan Marathi Sen. Sec. School; 3. Lady Irwin – Rupal Kashyap and Purnima Kashyap; 4. DPS Noida – Arun Kumar, Head Physics Department; 5. SBV/ PBV/KB – Students of SBV Subhash Nagar, Pratibha Vikas Vidyalaya and Krishi Bihar; 6. Usha Menon/VS – Usha Menon – Rolls Royce India and Dr Vinay Sharma of Pt GLM Sharma Hospital; 7. Cheena/Dolcy – Cheena Dang – Polytechnic student and Dolcy Chabra of Imperial Academy school, Indore.8. KDA/Hansraj/ Jindal – Sivaramakrishnan, and Kartik of KD Ambani Vidyamandir, Jamnagar, Gujarat, Archit Babbar of NC Jindal Public School, Delhi and Mukul Agarwal of Hansraj Public School, Delhi. 9. SKV – SKV Public School, Delhi.

Evening Measurements

Observer	Time (IST)	Object	Altitude (indegrees)		Azimuth (indegrees)	
			Obs.	Th.	Obs.	Th.
Public	18:37	Venus	45.6	45.28	272	273.32
Sanat/Vikrant	18:37:22	Venus	45.2	45.21	273.92	273.37
Sirius Group	19:50	Sirius	40.8	41.33	203.5	203.48
Samridhi/Sneh	19:03	Venus	39.66	39.37	276	276.10
Samridhi/Sneh	19:53	Jupiter	44.49	45.37	----	107.75

Observers: 1. Public – Acharya Anand Sagar, Dr Vinay Kumar, Mangal Singh and others present. 2. Sanat/ Vikrant - Sanath Kumar, Nehru Planetarium and Vikrant Narang, Amateur Astronomers Association, New Delhi. 3. Sirius Group – Abhishek Tibrewal, Sapna Tibrewal, Shikha Rao, Shweta Chaurasia. 4. Samridhi/ Sneh - Samridhi, Lady Irwin Sen. Sec. School and Sneh Kesari Nutan Marathi Sen. Sec. School.

Table 2.

And, finally, some discussions on the methods employed to determine the center of the gnomon shadow in the Ram Yantra. This is the most tricky aspect of the observations and it is felt that much better accuracies than above would also be possible by observers who gain a slightly longer-term experience of estimating the shadow center; most of the errors that creep into the observations arise from the uncertainties in this estimation. The extent of the gnomon shadow is quite huge and standing close to the edge of the shadow – the definition between the umbra and the penumbra of the shadow is too diffuse to give a good estimation of the exact center of the shadow – which is very crucial for accurate azimuth and altitude determination. It was felt that standing on the raised floor of the Ram Yantra and looking at the shadow in its entirety gave the best way of determining its center – more by an eye estimate. This method was used in all of the above observations and gave reasonably accurate results.

The observations were discussed in the yahoogroup, http://groups.yahoo.com/group/VenusTransit

A forum was started by Nehru Planetarium, New Delhi, for discussions between educators and students, related to the Transit of Venus. Concerns were raised by Bhudia of the Kutch Astronomy Club and Nirupama Raghavan, former Director, Nehru Planetarium, New Delhi, about the possible damage to the markings on the raised floor of the Ram Yantra by people climbing on it, particularly with footwear. Raghavan suggested the use of strings stretched taut to cut the umbra, while standing on the lower floor of the Ram Yantra as the proper method. This method was tried during several attempts and did yield very accurate altitude measurements. However, azimuth readings are more difficult with this method, as the umbra is relatively flat just at the center and locating the center of the umbra for azimuth measurement has errors well over a degree with this method.

While indiscriminate climbing on the raised floor by those who are not immediately observing and also while using footwear, is better to be avoided, it did emerge after extensive discussions that perhaps observers are meant to climb on the raised floor of the instrument, particularly keeping in mind that the azimuth circle marked at a height on the central gnomon which can be read only by standing on the raised floor of the instrument.

In conclusion, it emerges that even in their current state of disrepair, the two instruments Jayaprakas and Ram Yantra could easily be used with good accuracies for many possible student projects that can be done with simple celestial measurements. With a redoing of the markings on these instruments, these activities should become much easier to do.

The daily altitude and azimuth changes for the Sun, their seasonal dependence and other related aspects are very worthwhile long-term projects that can be undertaken in a simple manner with these instruments.

Students could look at the daily altitude and azimuth changes for the Sun, their seasonal dependence and other related aspects as very worthwhile long-term projects that can be undertaken in a simple manner with these instruments.

One could use any accurately predicted transient event – Lunar eclipses, Jupiter satellite events, Lunar occultations of planets, etc. as chronometers and simultaneously use the Ram Yantra for altitude measurements of bright stars to recreate historical methods of longitude determination – as one possible activity related to the Transit of Venus.

Suggested Reading

[1] N Rathnasree and Sanath Kumar, Preparing for the Transit of Venus, *Resonance*, Vol. 9, No. 3, pp.65-75, 2004.

[2] G R Kaye, *The Astronomical Observatories of Jai Singh*, Published by the Archeological Survey of India, 1910.

[3] G S D Babu and V R Venu Gopal, Programme for the restoration of the masonry instruments at Delhi Jantar Mantar, *Bull. Astr. Soc. of India.*, Vol. 21, p.481 B, 1993.

[4] Virendra Nath Sharma, *Sawai Jai Singh and his Astronomy*, Motilal Banarsidas Pvt. Limited, 1995.