THE TWELVE *RĀŚIVALAYA* INSTRUMENTS AT THE OBSERVATORY OF JAI SINGH IN JAIPUR

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Abstract: The Observatory at Jaipur (popularly known as Jantar Mantar) has many astronomical instruments of the eighteenth century devoted to measurements of time and angles. Most of the instruments are well studied, and the accuracies achieved by these large structures have been analysed in detail. However, the functioning of the 12 sundials designated as *Rāśivalaya* has yet to be understood clearly. Here we report our observations in an attempt to identify the functioning and the purpose of this set of instruments. They can be used for measuring the hour angle, daily motion and the ecliptic latitudes of not only the Sun but also the planets and the Moon.

Keywords: Indian astronomy; observatories of Jai Singh; *Rāśivalaya* instruments; twelve sundials; ascendant, *Lagna*, hour angle, *nata,* daily motion, *gati,* ecliptic latitude, *śara*.

1 INTRODUCTION

The well-known Kachva ruler Sawai Jai Singh (1688–1743) was a master of mathematics and astronomy. He established five large observatories in Delhi, Jaipur, Varanasi, Ujjain and Mathura in the eighteenth century for making accurate astronomical observations (Sharma, 1995). Among them four have been preserved (lost in Mathura) and are available for making measurements. The huge dimensions (the sundial is 63m tall) provide broadly spaced graduations rendering very good accuracy in measurements.

The instruments were designed for the measurements of angles and time, altitude and azimuth in particular. During the day, shadow angles provided time measures, while sighting tubes were used in the night. All the instruments were studied in detail for their functioning and accuracy (Kaye, 1917; Sarma, 2018; Sharma, 1995; Shylaja, 2011; Singh, 1978). In recent years they were effectively used for student projects (Rathnasree, 2017). They have also been the subject for attractive popular-level books (Barry, 2024) and with pop-up pages to explain the functions of the instruments (Shylaja and Sastri, 2015). Many websites have interesting photographs and time-lapse videos demonstrating the use of the instruments.

Among the instruments in Jaipur there is a group of twelve sundials named *Rāśivalaya*. A cursory glance at the site map (Figure 1) shows that these are all oriented in different directions (Figures 2a and 2b) and therefore, are not meant to serve the same purpose as the other sundials, such as the 63m tall *sāmrāṭ yantra* and the smaller *laghu sāmrāṭ yantra.* The remark "It seems to be entirely original but it is of doubtful utility as an instrument for observation." (Kaye, 1917: 40) clearly reflects the difficulty of identifying its function.

In view of the proposed construction of similar instruments in Mysuru (Figure 3), where already a large sundial similar to the *sāmrāt yantra* has been installed, we undertook observations at Jaipur to understand the functionality and utility.

As a first step, the radii of the dials and the heights of the gnomons of the instruments were measured. The slopes of the gnomons were calculated with these measurements. The altitudes were measured with a Bosch Professional GLM 500 Digital laser-measuring device. Table 1 provides these measurements and the details on the graduations of the scales on each instrument.

The orientations and elevations (Table 1) clearly show that they are all oriented away from the celestial north pole in a systematic way; the poles of all these gnomons trace a circle around the pole; i.e. the pole of the ecliptic. The small scale-model prepared for demonstration (Figure 3) also follows the same orientations as in the original, redesigned for the latitude of 12.25°N.

The angles of the gnomon are calibrated for the purpose of reading the shadow on the ecliptic as shown in Figure 4. (Generally, the

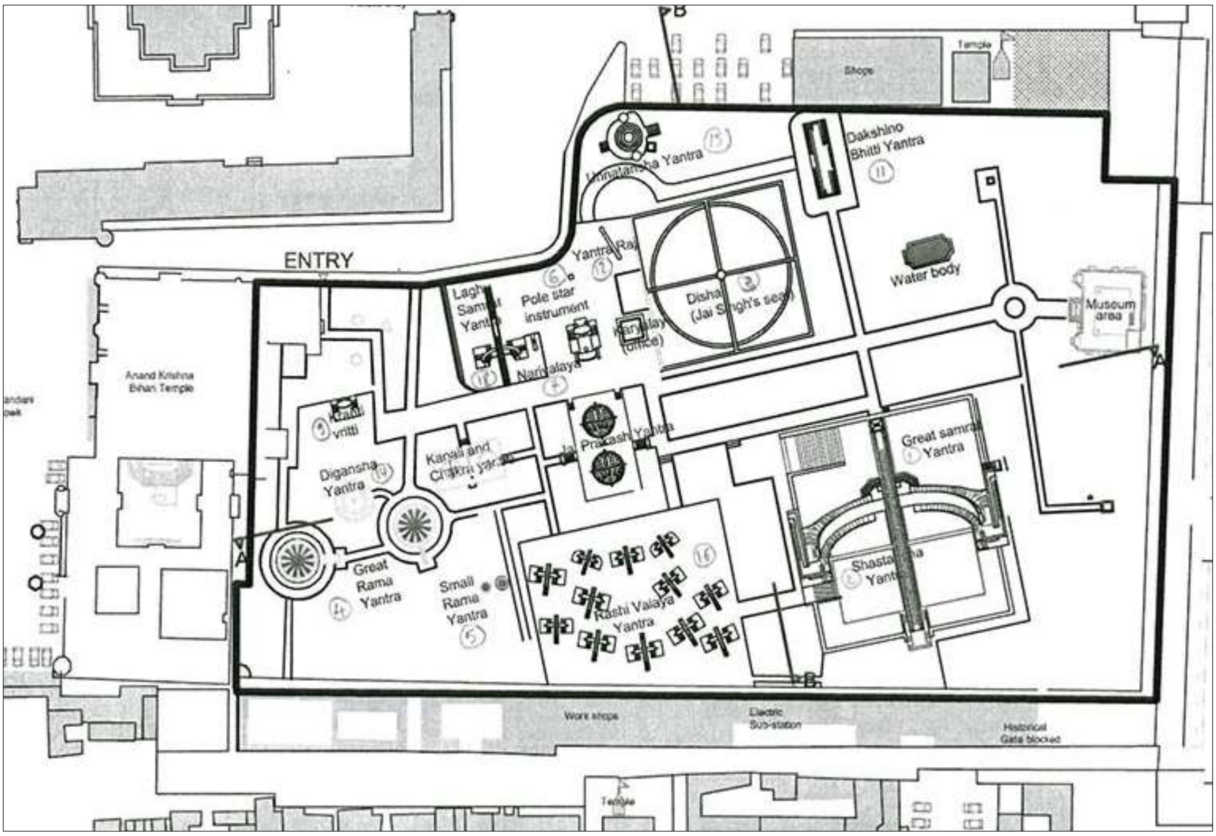


Figure 1: The site plan of the Jai Singh Observatory in Jaipur (after https://web.astronomicalheritage.net/show-entity?identity=20&idsubentity=1).

Figure 2a: The view of the Observatory from the top of the tall sundial. Among the other instruments, the *Jaiprakash Yantra* referred to in this paper, is at the right, to the north of the 12 sundials, in the shape of a bowl (photograph: the authors).

Figure 2b: The close up of the instruments at Jaipur, the differences in the orientations and the heights of the gnomons are easily recognisable (photograph: the authors).

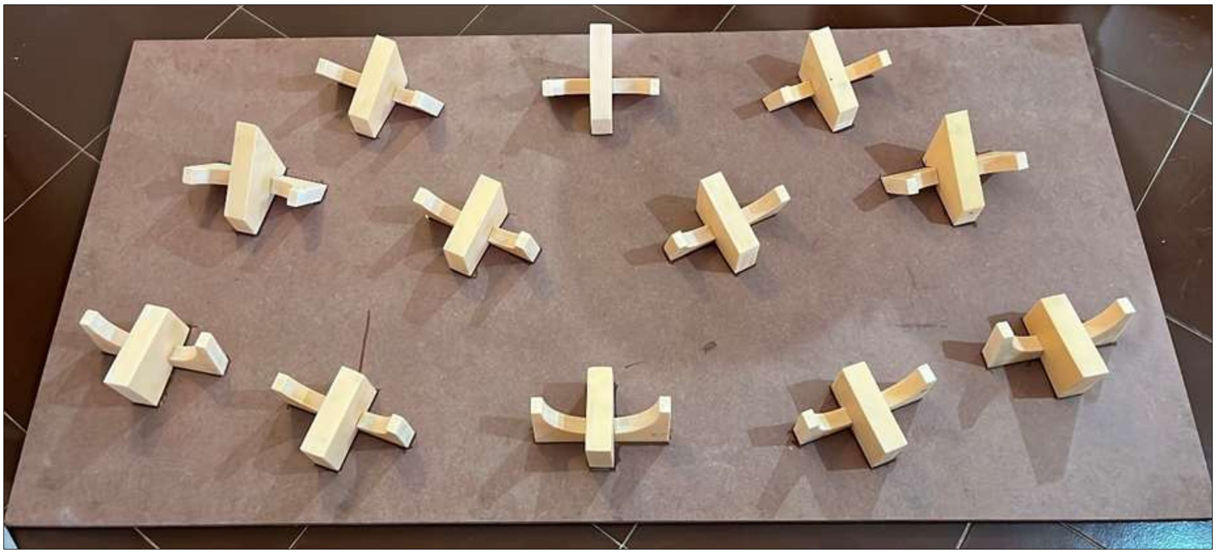


Figure 3: The scaled-down models in the Bharati Yoga Dhama, Mysuru (latitude 12.25° N), where the instruments are being constructed (photograph: the authors).

sundials have scales parallel to the equator so as to follow the diurnal motion of the Sun.)

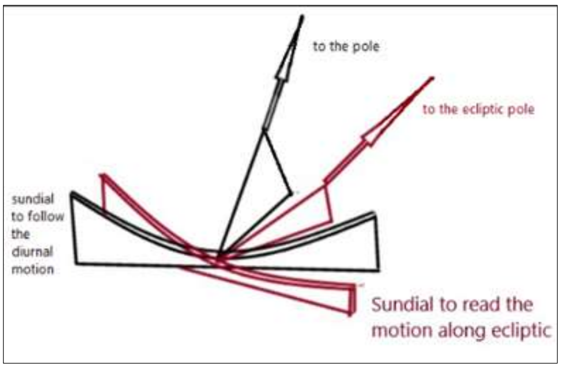


Figure 4: The *Rāśivalaya* dial compared to the other sundials (diagram: the authors).

Thus, it is a dial to be used for reading the ecliptic longitude or a measure related to it.

The intriguing part is the dial, which has graduations decreasing from West to East. Measurement of the shadow involves the diurnal motion; it is natural to expect the scale to be following the diurnal motion (Figure 5). However, it is the opposite here. For example, on 21 March, the Sun's longitude is zero. At sunrise on that day the shadow reads 104 on the Aries instrument and 345 on the Pisces instrument. An hour later, the shadow would approximately read 90° on Aries and 330° on Pisces. The meanings and utility of these numbers are to be deciphered.

Table 1: Measurements of the twelve instruments with dial graduation.

Name	Radius (m)	Graduation details			Orientation of the gnomon (as engraved on the instrument)		Measured Altitude	
		Centre	Left	Right	Azimuth	Altitude	GLM 500	Calculated
Aries/ *meṣa*	1.65	11°30′	101°30′	281°30′	–25°56.5′	24°32′	24°	23°52′
Taurus / *vṛṣabha*	1.24	35°30′	125°30′	305°30′	–21°17.5′	14°25′	14°	13°55′
Gemini / *mithuna*	1.24	61°30′	151°30′	331°30′	–12°6′	6°36.5′	6.5°	5°53′
Cancer/ *karka*	1.65	90°	180°	0°	0°	3°28.5′	3.7°	3°14′
Leo / *simha*	1.24	118°30′	208°30′	28°30′	12°15′	6°26.5′	6.2°	6°54′
Virgo / *kanya*	1.24	144°30′	234°30′	54°30′	21°17.5′	14°25′	14°	13°53′
Libra / *tula*	1.65	168°30′	258°30′	78°30′	25°56.5′	24°32′	24°	24°04′
Scorpio / *vṛścika*	1.24	194°30′	284°30′	104°30′	25°36.75′	35°33′	35°	35°59′
Sagittarius / *dhanu*	1.24	227°10′	317°10′	137°10′	17°40′	45°42′	45°	45°34′
Capricorn / *makara*	1.65	270°	360°	180°	0°	50°22.5′	50°	49°46′
Aquarius / *kumbha*	1.24	312°50′	42°50′	222°50′	–17°40′	45°42′	46°	43°10′
Pisces / *mīna*	1.24	345°30′	75°30′	255°30′	–25°36.75′	35°33′	35°	35°52′

The central values of the scales of these instruments appear to be non-uniformly spaced. The criterion for fixing these values, especially the first, is yet to be understood.

There is another scale that has different type of graduations. It starts with a zero on the Western edge and is marked in time units up to 15 to the centre. On the other quadrant it starts with a zero at the centre and increases to 15. The usage of this scale has not been documented so far. Here the units are *ghaṭi*s.

Time units in Indian astronomy, has a day is divided 60 *ghaṭi*s. Therefore, the second scale corresponds to time measures of the quarter of the day, from the meridian (towards West) and to the meridian (from the East).

2 THE OBSERVATIONS

The procedure as depicted by Singh (1978) and Sharma (1995), who have studied the principle of these instruments, can be summarised as follows. The observations commence with the reading on the Jayaprakash *Yantra* (Figure 6) which is a mirror of the sky, with graduations. The 5.3-m diameter hemisphere has the grids of parallels of ecliptic and azimuth circles marked so that the shadow of the midpoint is a mirror image of the Sun on the grid.

Two strings are tied along the East–West and North–South directions holding the ring on the top of the hemisphere. The shadow of the central ring gives the location of the Sun. The gap be-

Figure 5: Close-up view of the dial. The other smaller scale with time markers is also visible (photograph: the authors).

Figure 6: The *Jayaprakash yantra*; two strings are tied along the E–W and N–S directions holding the ring on the top. The shadow of the central ring gives the location of the Sun, since the bowl is graduated as a mirror image of the sky (photograph: the authors).

tween the scale allows the observer to move along. This instrument has a twin complementing the sectors of the gap. Then,

(1) One needs to look up the shadow in the *Jayaprakash Yantra*, which identifies the *rāśi* (zodiacal sign) on the meridian at that instant.
(2) Then proceed to the corresponding *yantra* and look up the reading of the shadow.
(3) The shadow reading should be subtracted from the longitude of the Sun to infer how many more degrees need to be covered or how many degrees have elapsed, for the meridian transit of the thirty degrees of the *rāśi*.

Thus, the procedure assumes a prior knowledge of the longitude of the Sun on the given day. The purpose is to find how much is covered in any *rāśi* and how much is still due for the meridian passage.

A couple of examples of the observations and the results (deduced as per this procedure demonstrated as being followed there) are presented here (Box 1).

As mentioned earlier, this procedure assumes that the longitude of the Sun is known, either from the Jayaprakash *yantra* or otherwise.

That raises the question of the purpose of the instrument, which was not for obtaining the longitude of the Sun. Let us examine the other possibilities.

Since the longitude of the Sun is almost constant during the day (it changes by about 1° in 24 hours), the numbers obtained in the calculations above are for the meridian passage. They refer to the angles from the meridian of the Aquarius sundial. This is equivalent to the hour angle on the equator. The 'covered' ranges, 13°, 17° and 26° in the examples in the box, when converted to time units provide how many *ghaṭis* are due before (or have elapsed since) the meridian passage of the Sun.

This is called the *madhyalagna*. Generally, the word *lagna* is associated with the ecliptic point on the horizon. Texts define three *lagnas,* the *udaya lagna* (ascendant, eastern horizon), the *madhya lagna* (meridian) and the *asta lagna* (western horizon). These were used as time markers. Stone inscriptions recording the donations and grants mention the *lagna* to indicate the time of the event (Shylaja, 2018).

Many instruments, Dhruvabharamaka for example, the *yantra*, incorporated scales to read out *lagna* based on shadow measurements (Sarma, 2018).

Box 1: Shadow measures and computation of the *madhyalagna*.

Example 1: Date: 12 February 2024. The Sun moved into Aquarius (300°–330°) on 21 January. Therefore, on 12 February its longitude would be 322°. At 12:08, the shadow marker on the *Jayprakash yantra* shows Aquarius 15°. On the Aquarius *yantra* among the *Rāśivalaya yantras*, the shadow reading is 309°. This shadow reading implies (322°–309° =) 13°, which is interpreted as 13° as 'covered' (the meridian passage) within the range of Aquarius. At 12:24, the Jayprakash marker shows Aquarius 21°. The Aquarius *yantra* shadow reading is 305°. By the same argument as above, the covered range is 17°. At 13:02, the *Jayprakash* marker shows Aquarius 30°. The Aquarius *yantra* shadow reading is 296°. By the same argument, the covered range is 26°.

Example 2: Date: 12 February 2024 (the same as in Example 1, above). At 13:42 the *Jayprakash yantra* marker shows 10° in Pisces. The shadow reading now has to be obtained from the Pisces *yantra*; it is 315.5°. The difference 322°–315.5° = 6.5°. Since the reading is on the Pisces scale, the difference is added to 330°, the commencing point of Pisces. It implies, 6.5° degrees are covered in Pisces.

Example 3: Date: 13 February 2024. From 21 January, 23 days have elapsed. The longitude is 323°. At 9:15 the *Jayprakash yantra* marker shows Capricorn 5° (midpoint is 270°). The Capricorn *yantra* reading is 319°. 323°–319° = 4°; i.e. the Capricorn 4° has been covered in Capricorn. At 9:45 the *Jayprakash yantra* marker shows Capricorn 15° (the midpoint is 270°). The Capricorn *yantra* reading is 312° (323°–312° = 9°); i.e. 9° have been covered in Capricorn.

2.1 *Nāḍi Valaya*

The instrument called *nāḍi valaya* as described in the *Sūrya Siddhānta* has a scale in reverse order so that the shadow reads the *lagna*, the ascendant. As shown in the Figure 7, the principle is easy to understand. If the Sun is in Aries when it is rising, its shadow will point to Aries. The scale may be graduated in *rāśi*s, degrees or numerals. After 2 hours when it has moved up by about 30°, the shadow will point to a specific point in Taurus which is at the eastern horizon. Thus, the shadow directly gives ascendant or the *udayalagna*. This is a time marker and many stone inscriptions use this method to indicate the time of the event. This practice continues today for many religious ceremonies. Yet another time marker is the *madhyalagna* which is the point on the ecliptic on the meridian. This is also marked in Figure 7. (It should be noted that the same name is used for the equatorial sundials on the name plates of all five observatories; an instrument which could have provided the *lagna* measures is designated *krānti-valaya* and is defunct now.)

It should be noted that the dial marks the names of the signs in the reverse order with respect to their order in the sky. Not all the scales of the *trāśivalaya* instruments follow this arrangement.

Let us explore the possibility that the purpose of the *rāśivalaya* instruments is to read *udayalagna*. Here we confront a difficult situation. When the Sun is rising its shadow is on the western edge and the reading should be that of the longitude of the Sun, itself on the eastern edge, which is not the case. Likewise, the reading at the western edge of the dial also does not match at sunset. The numbers readily match the position of the Sun on the meridian, as listed in Table 2. In the case of Aquarius for example, the central reading is 312|50, while on the western edge it is 42|50 and on the eastern edge it is 222|50. On face value it appears as though it is applicable for only one specific day.

However, there is a roundabout way to estimate the *lagna*, as explained above, when the longitude of the Sun is known. For example, on 21 January (the longitude of the Sun is 300°) two hours after sunrise the shadow would read 330, which, when subtracted from the reading the eastern edge (281) dial reading, provides the elevation of the Sun. This value 19, can be added to the longitude of the Sun to get the *lagna*, which is 319°. If this was the purpose of these instruments, the dials would facilitate it if they were in the reverse order, avoiding the extra arithmetic.

Since no measurements on this have ever

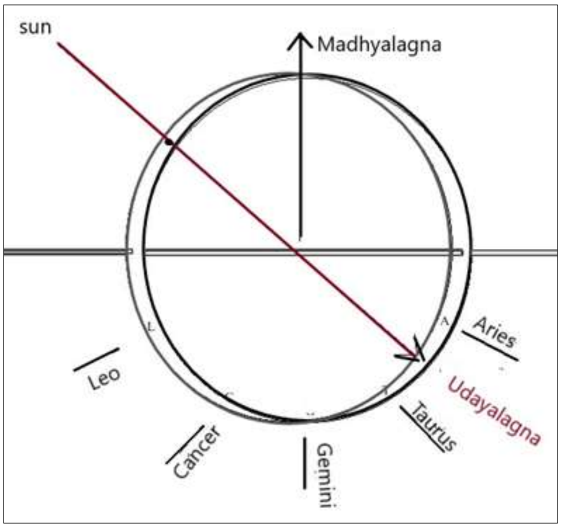


Figure 7: The *Nāḍi valaya* as described in the *Sūrya Siddhānta* (diagram: the authors).

Table 2: Shadow readings obtained in February 2024 with the *Kumbha* (Aquarius) sundial.

07|02|24		08|02|24		09|02|24		10|02|24		12|02|24		13|02|24	
Time	Reading	Time	Reading	Time	Reading	Time	Reading	Time	Reading	Time	Reading
12:06	309	09:43	341.5	10:36	330	11:15	321	11:52	313	09:18	348
		10:17	334	10:43	328.3	11:24	319	12:08	309	09:50	340.8
		10:57	325.6	11:50	313	11:37	316	12:24	305	10:58	325.5
		11:43	314.7	12:10	308.5	12:41	301.5	13:02	296	11:12	322
		12:24	304.5	12:41	301	12:51	299			11:53	313
		13:04	296							13:54	283
		14:19	277.5								
		14:59	268								
		15:44	257								

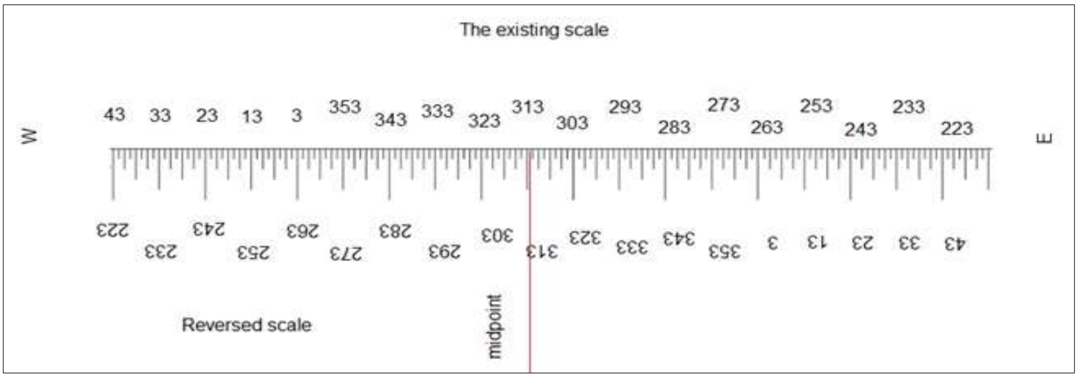


Figure 8: The graduations on the reversed scale (diagram: the authors).

been recorded, we checked the possibility of the scale being fixed in the 'wrong' way by mistake. This was essential since there is a remark (Kaye, 1917) that the instruments were disturbed. However, the author immediately lists the corrections, which essentially point to the angles of the gnomon and not the scales. We carried out the exercise of checking the shadow readings throughout the day during February 2024. The reversed scale is depicted in Figure 8.

Our observations of 8 February are listed in Table 3 and depicted in Figure 5 as well. We took the difference of the shadow reading with a central reading of 312|50. The difference is added or subtracted from the central value itself to get the *madhyalagna*. These values are included in the table in the column titled 'computed'. The table also lists the reversed scale

Table 3: Readings and results in computed from the reading, read out from a reversed dial and also from Stellarium for 8 February 2024.

Time	Reading	Com-puted	Dial Re-versed	Stell-arium
09:43	341.5	282	288	282
10:17	334	291	292	291
10:57	325.6	302	305	302
11:43	314.7	312	310	312
12:24	304.5	324	324	324
13:04	296	332	330	332
14:19	277.5	353	348	353
14:59	268	362	360	362
15:44	257	367	370	370

readings and those read out from Stellarium. (Stellarium is a free software incorporating the various needs of professional astronomers about the sky, Zotti et. al., 2020.) There is an excellent agreement on all days. We have provided only the one example of 8 February in Table 3. The agreement is also seen in Figure 9.

The shadow readings read out the diurnal motion and its projection on to the ecliptic. This allows conversion as a trigonometric identity, and the scale will be nonlinear.

Since the dials are placed along the plane of the ecliptic, with the orientation differing each month, we conclude that the readings on the dial will have to be on different dials corresponding to the position in the sky.

3 THE AZIMUTH ORIENTATIONS OF THE INSTRUMENTS

The basic operation of the instrument is exactly like a sundial, the gnomon pointing to the ecliptic instead of the geographic north pole. Therefore, it is necessary that the base should be along the ecliptic. That is the reason for the different orientations of the bases with dials depicted in Figures 2a, 2b, 3 and 4.

Now we explore the derivation of the exact azimuth directions for the different months. The measured azimuth values are included in the Table 1. To arrive at these values, we need to

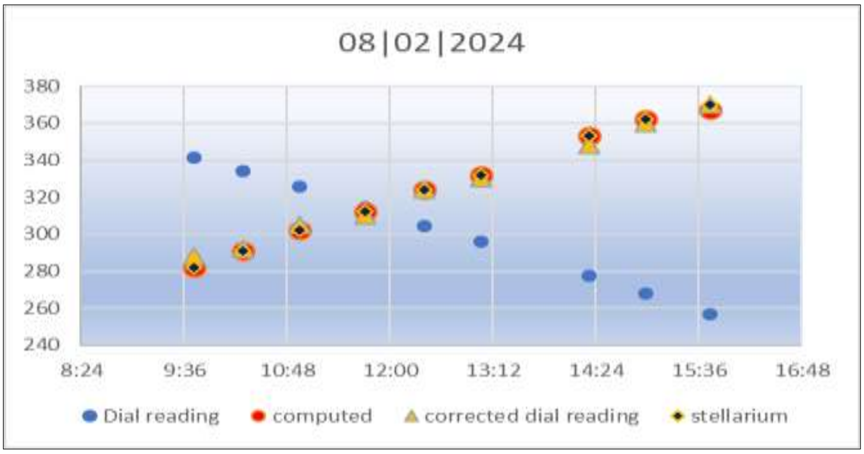


Figure 9: The readings and results from Table 3 represented graphically (plot: the authors).

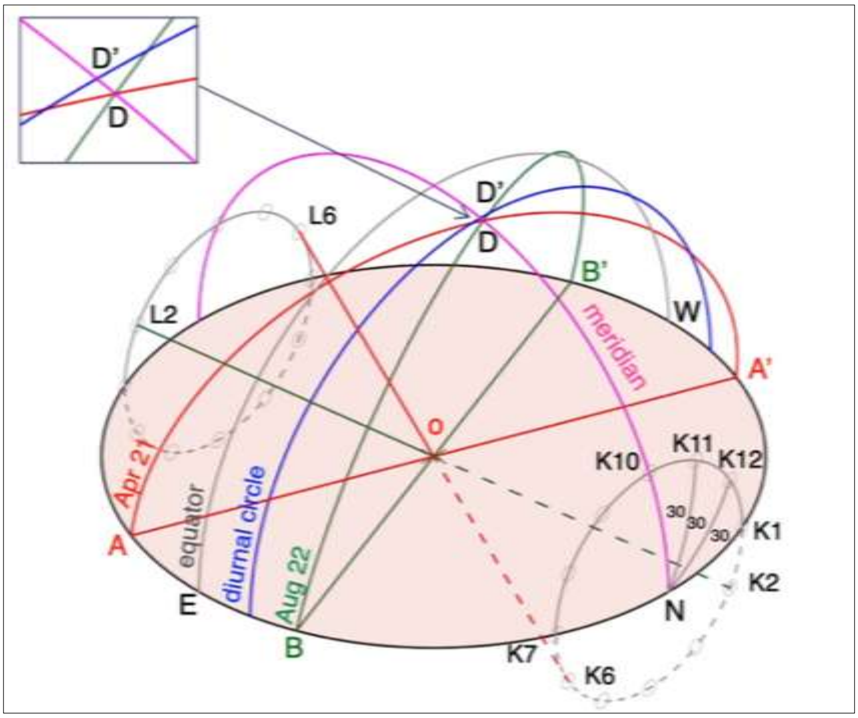


Figure 10: The depiction of the orientation of the base for the gnomon for 21 April and 22 August at latitude zero. The ecliptic poles are along L_6OK_6 (red) and K_2OL_2 (green) the orientation of the ecliptic along ADA' (red) and BDB' (green) form the base. The ecliptic pole traces 30 degrees every month. The meridian transit is shown as an inset. It is noticeable that the diurnal circle (blue circle, parallel to the equator) transits at D' (diagram: the authors).

project the gnomonic shadow of the dial on to the plane of the ecliptic. Here we need to understand how the projection is implemented since there are two ways of achieving this, as we show now for an observer on the Earth's equator.

3.1 The Pole of the Ecliptic Traces a Circle Around the Pole Through the Year

The motion of the pole of the ecliptic is divided into 12 equal parts of 30° each, representing the tropical months. Figure 10 shows the orientations of the ecliptic for the solstice and equinoxes and another diurnal circle for two specific dates 22 August and 21 April. This is for an observer on the equator—N is the North point on the horizon as well as the pole. The ecliptic pole traces a circle around N, along K_{11}, K_{12}, K_1, K_2 and so on. The corresponding points on the southern point can be designated L_{11}, L_{12}, L_1, L_2 and so on; here only the relevant points, namely L_2 and L_6, are marked. The lines L_2K_2 and L_6K_6 correspond to the orientation of the base of the gnomon.

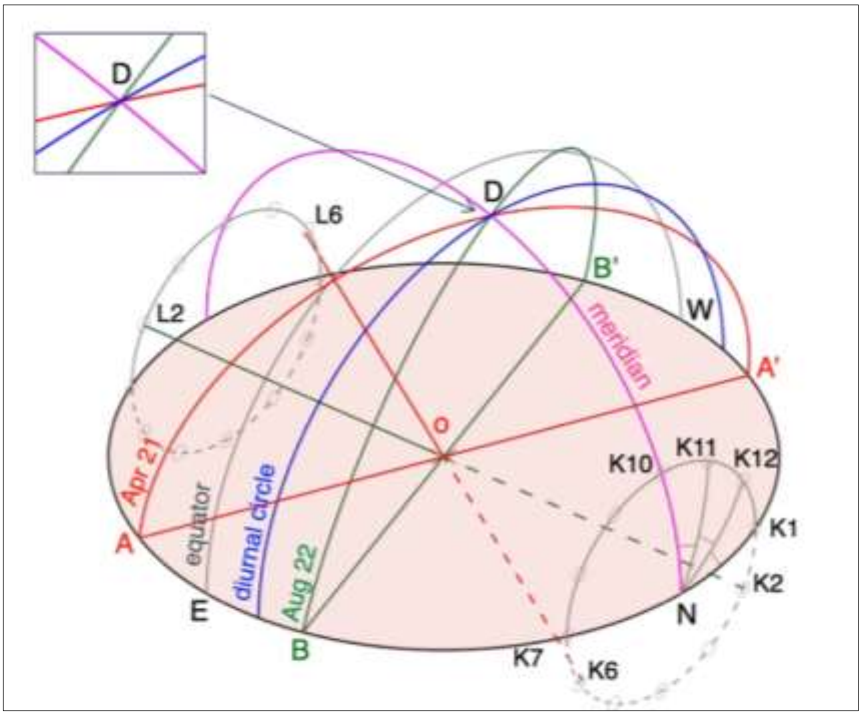


Figure 11: Fixing the orientation of the base line based on the actual motion of the sun (earth) for zero latitude. The inset zoomed version of the meridian transit shows the overlapping of the intersections at the point D on the meridian (diagram: the authors).

In the Figure 10, NESW is the horizon for the observer at O. The meridian is the circle joining N and S and the celestial equator is the circle joining E and W. The blue circle A A' is the diurnal circle parallel to the equator. On 21 April the Ecliptic will be oriented along the circle AA' at noon. On 22 August, it will along BB'. Therefore, we need to find the azimuth NB to fix the baseline BB' and AA'; in other words, we need to know the angles NA and NB for orientation of the base of the dial.

The pole of the ecliptic traces a circle around N. Its position will be at K_6 for 21 April and at K_2 for 22 August. Now we need to address the question of fixing the points A and B precisely. This can be done by dividing the circle of the ecliptic pole equally (30° per month) or by marking the points as per the monthly movement of the Sun (i.e. the Earth). Figure 10 shows the positions based on the uniform motion of 30° per month. The diurnal circle transit point on the meridian is slightly different, and is marked by D'. If we take D' as the reference, the corresponding point on the horizon for the ecliptic will have to be marked. This will not coincide with A and B for the specific dates.

Here we considered that a uniform motion of 30° per month was assumed in the design of the 12 instruments. We noticed a difference in the azimuth readings compared to the actual readings, as derived by this method.

3.2 The Ecliptic Pole Does Not Have a Uniform Motion

We now consider the situation that the division into equal parts of the ecliptic circle perhaps is not a reasonable approximation. This is because the movement in June–July is slower whereas in December–January it is faster. This can be fixed by successive intervals of the passages of the Sun. Figure 11 is a revised version of Figure 10, with the points K_2 and K_6 fixed based on non-uniform motion. We have used the angular divisions of the different months that are listed on the *Krāntivṛtta yantra.*

It may be noted that there is a small difference that is hardly noticeable on a small tabletop model, but not for the large structure in Jaipur. The exercise was repeated for the latitude of Jaipur, and the azimuth values were noted.

Figures 12 and 13a show the ecliptic for the same dates as in Figures 10 and 11 for Jaipur (see, also, Figure 13b). Since the horizon plane is inclined as decided by the declination, the small correction mentioned by Kaye (because of re-orientation of the gnomons) is important. Corrections were made for the height of the gnomon and for the orientation of the base. We arrived at the values for the azimuth by both methods 3a and 3b, listed in Table 4 as methods 3.1 and 3.2. We see that it is difficult to decide the method adopted and also the rea-

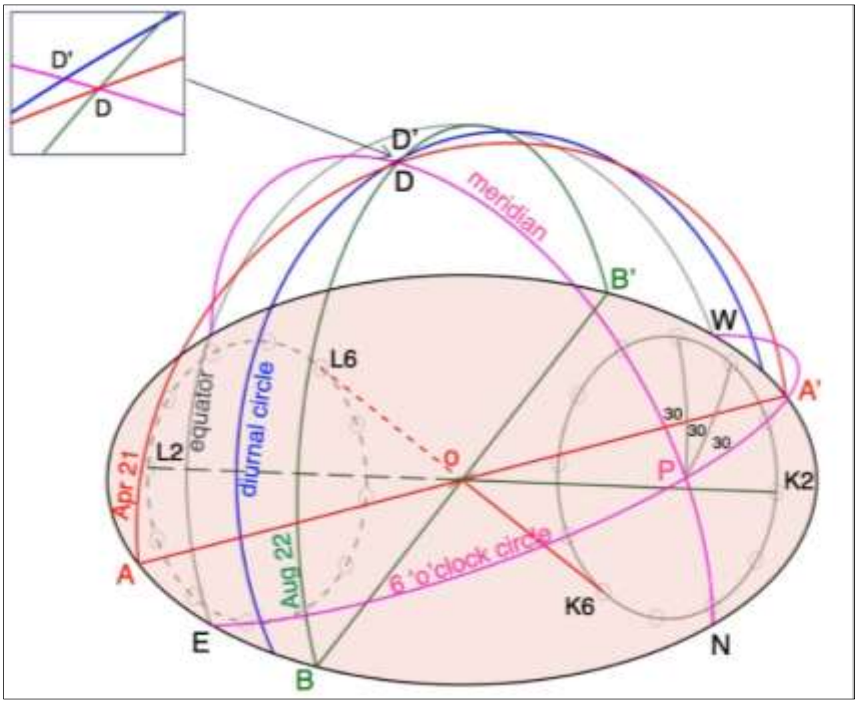
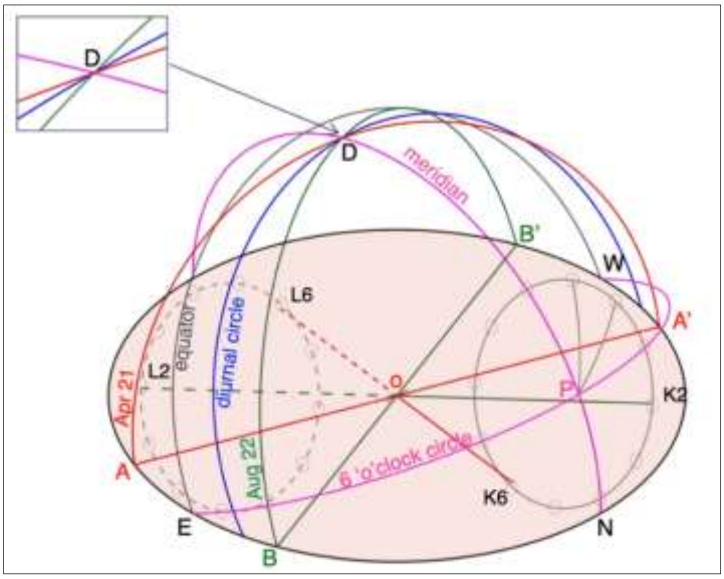


Figure 12: The orientation of the ecliptic for uniform motion of the ecliptic pole for the latitude of Jaipur; legends are same as in Figure 10. P is the pole. EPW is the 6' O clock circle. The small difference in the transit points D and D' is shown in the inset (diagram: the authors).

Figure 13a (right): The orientation of the ecliptic for non-uniform motion of the ecliptic pole for the latitude of Jaipur. P is the pole. Legends are same as in Figure 11. There is no difference in the transit points of the ecliptic and the diurnal circle as shown in the inset (diagram: the authors).



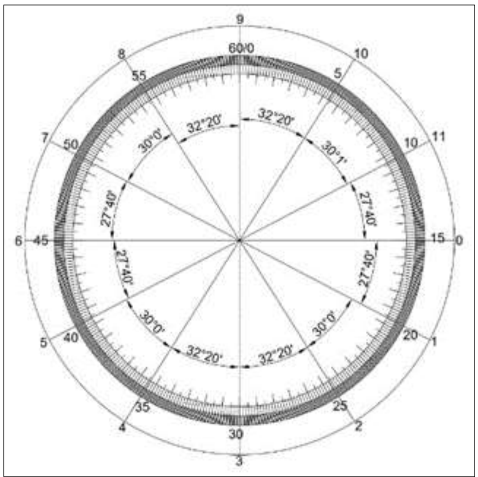


Figure 13b (left): The unequal divisions of the hour circles corresponding to the 12 divisions around the pole is generated using the tabulation provided in Jaipur on the instrument *Krāntivṛtta yantra* (diagram: the authors).

soning for the change of orientation mentioned by Kaye. The deviations appear large in the table especially around Gemini and Sagittarius. It is quite possible that the angles were arrived at by measurements from a set of table-top models within some observational limits. However, the method of non-uniform motion appears to be logical. This method was adopted for the new set of twelve instruments to be constructed at Mysuru.

4 OTHER POSSIBLE USES OF THE SET OF INSTRUMENTS

The *Rāśivalaya* is a very interesting arrangment of sundials and probably had many more applications. Now, we look for other possible uses of the instrument based on its unique design. This intriguing scale has been studied by Singh

Table 4: The angles for orientations of the base and the heights of the gnomons.

	Orientation Method – 3.1		Orientation Method – 3.2		Orientation before alteration (Kaye,1917: 54)		Current Orientation of yantras	
Zodiac	Azimuth	Altitude	Azimuth	Altitude	Azimuth	Altitude	Azimuth	Altitude
Aries	–25°56′52″	27°	–25°56′52″	27°	–26°	27°	–25°56.5′	24°32′
Taurus	–20°46′53″	14°46′6″	–20°28′5″	15°31′40″	–21°30′	15°30′	–21°17.5′	14°25′
Gemini	–11°32′34″	06°25′11″	–10°51′46″	06°50′57″	–12°30′	07°	–12°06′	06°36.5′
Cancer	0°	03°33′36″	0°	03°33′36″	0°	03°30′	0°	03°28.5′
Leo	11°32′34″	06°25′11″	10°51′46″	06°50′57″	12°30′	07°	12°15′	06°26.5′
Virgo	20°46′53″	14°46′06″	20°28′05″	15°31′40″	21°30′	15°30′	21°17.5′	14°25′
Libra	25°56′52″	27°	25°56′52″	27°	26°	27°	25°56.5′	24°32′
Scorpio	25°20′56″	39°13′54″	24°40′17″	38°28′20″	26°	38°	25°36.75′	35°33′
Sagittarius	16°44′40″	47°34′49″	15°39′02″	47°09′03″	18°	46°30′	17°40′	45°42′
Capricorn	0°	50°26′24″	0°	50°26′24″	0°	50°30′	0°	50°22.5′
Aquarius	–16°44′40″	47°34′49″	–15°39′02″	47°09′03″	–18°	46°30′	–17°40′	45°42′
Pisces	–25°20′56″	39°13′54″	–24°40′17″	38°28′20″	–26°06′	38°	–25°36.75′	35°33′

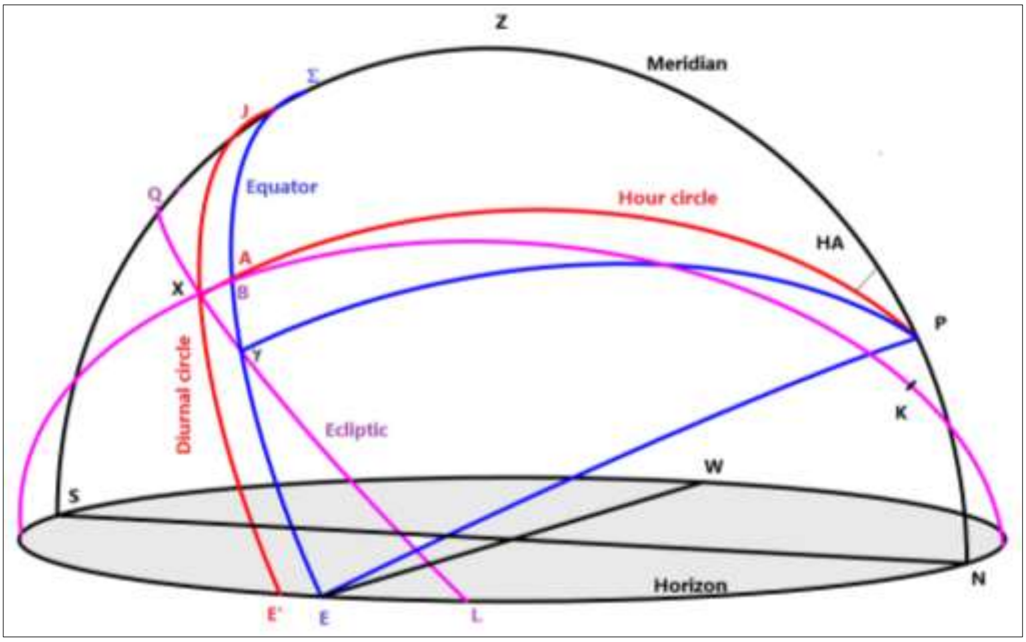


Figure 14: Explanation of *nata*, the hour angle. The angle JPX, called the Hour Angle, is common for both JX and QX. K is the pole of the ecliptic. JX is parallel to the equator and provides the corresponding time (diagram: the authors).

(1978) for a logarithmic representation of the longitude. Here, we consider other practical techniques.

4.1 Determination of *Nata*, the Hour Angle

It may be recalled that by definition the hour angle is measured from East to West. Since the dial is marked this way, it could be a measure of the hour angle.

The determination of the hour angle is a tedious process, as inferred from the texts. It is needed for the precise estimate of the timings and positional angles in eclipse calculations.

The word *nata* is used as the hour angle in this context. Generally, it is used in the sense of zenith distance, since the angle is measured from the Meridian along the ecliptic. Calculations provide estimates of the longitude and the ascendant. The difference between the two gives a quantity which has been named as y, *grahonalagna* = *graha una lagna* (l_{sm}) which simply means the difference of the *graha* (the Sun in this case), l_s and the *lagna*, l_m. This is the angle measured along the ecliptic from the meridian. Assuming that the Sun takes the same time to cover as the point would have covered along the diurnal circle, the hour angle is taken half the duration of the day with 5y in the ninth century text *Laghumānsavyākhyā* of Manjulācārya (Shylaja and Punith, 2024).

In Figure 14, which has the centre of the sphere as the observer, X is the position of the Sun. Its diurnal motion will be along the red circle JXE', which is called the diurnal circle. It is parallel to the equator SgE. The ecliptic is the circle QXL, and K is the pole of the ecliptic. The point where it meets the horizon, L, is the *uda-*

yalagna. The gnomon is oriented perpendicular to QXgL. But as time passes, the shadow moves perpendicular to SgE. Thus, at any instant we have to read the shadow as the projection SgE on QXL. The time required for the Sun to go from X to J is the hour angle. It is the same as the longitude value changing by an amount equal to XJ. The angle JPX is same as SPX and is equal to 90 – (gX + gE), which is converted to time units.

XA is the declination measured along the hour circle XP; XB is the latitude (*śara*) measured along XK.

The additional scale in time units will have a method of reading *nata* directly in time units. As per convention, the measures along the equator and the ecliptic are in units of time. This is very convenient for measuring the time intervals of events.

This method is approximate, as has been pointed out by Bhāskarācārya in the *Vāsanābhāṣya* (Chaturvedi, 1981). To measure it directly would require measuring along the ecliptic, which is inclined to the equator directing the diurnal motion. In other words, the diurnal motion should be projected onto the plane of the ecliptic. This is achieved by the *rāśivalaya* for different times of the year. Thus, the difference between the longitude and the reading provides the hour angle.

Owing to the projection effect, the reading would be accurate only for that instrument. The positions of the shadow on the other instruments are likely to be in error. We verified this by comparing the shadow readings from all instruments on the same day at approximately around the same time. Therefore, one should read the shadow measure on the appropriate instrument.

The *Nata* is usually measured in time units; hence the other scale finds a good use. As per convention, time (units of *ghaṭi*) is measured from the meridian, increasing to the West and decreasing to the East. Thus, the scale reads 0:00 to 15 on the western side and 15:00 to 0:00 on the eastern side.

A comparison with hour angles calculated demonstrates the principle.

4.2 Determination of *Śara*, Latitude

The ecliptic latitude is measured along the circle joining the ecliptic pole, which is perpendicular to the plane of the ecliptic. In all twelve instruments, the gnomon points to the ecliptic pole, with the dial perpendicular to it. There is another scale marked on the gnomon along the North–South direction. This is similar to the one on the gnomon of the big and small sundials (*sāmrāṭ yantra)* where it is used for measuring the declination (*krānti*). Since the declination of the Sun varies by just about 5° during a month, the scale on the *rāśivalaya* instruments appears redundant. Recall that the Indian system used the latitude or *śara* for all planets and the Moon, which is a measure along the circle joining the ecliptic pole and the planet, the application of the scale becomes meaningful for all bodies other than the Sun. In Figure 9, XA is the declination and XB is the *śara*. The longitude of the planets can be measured with the same procedure as explained for the Sun, with a sighting tube. It requires a reference line on the gnomon that corresponds to the latitude of the planet.

When the planet is transiting the meridian of this instrument one observer will hold a pointer on the gnomon, and the other observer will align the sighting tube to the planet. The corresponding reading on the gnomon will read *śara*. This is the same technique used on the *sāmrāṭ yantra* for the measurement of declination.

4.3 Determination of *Gati*, the Daily Motion

Since a particular instrument is devised for one month or 30 days, its meridian transit will correspond to a very small change in the reading at noon transit every day. However, the time of transit changes from day to day. This is easily noticeable in the details extracted from the observations done during 8–13 February. At the end of the month (300° to 330° longitude is more appropriate) we expect the time also to be 30 days. However, this will change to 29 or 32 days depending on the time of the year. Thus, we have an estimate of the *gati* or daily motion averaged over the month.

In all *siddhāntic* texts like the *Sūrya Siddhānta,* the mean motion of the Sun is given as 59′ 08″, which is to be corrected for the given date. The correction is decided by the positions of the Sun and its *ucca*, or the apogee (farthest point from Earth in its apparent orbit around the Earth). The procedure to calculate the apogee also is provided. The correction called the *mandaphala*, a quantity similar to that of First Equation, is applied to fix its position in the elliptical orbit (see solved examples in Shubha, et. al., 2020; Shylaja and Punith, 2024). The idea that the daily motion varies as the elliptical orbit is thus incorporated. Here we see that *rāśivalaya* instruments provide a mechanism to measure it.

5 DISCUSSION

Currently the *rāśivalaya* is being depicted as an instrument showing the angle covered (*bhukta*) in a particular *rāśi* (zodiacal sign) and the part remaining to be covered, (*bhogya*). It should be remembered that the instrument is designed for observations and therefore it records the positions corrected for precession (*Sāyana*). The Siddhāntic calculations follow the *nirayaṇa* system (without precession corrections). Although it does not alter the results, the choice of the instrument among the twelve here may be in error.

Here is an example of observations taken in October (Pandya A., personal communication). The precession corrected longitude was 211° rendering it to the instrument designated Scorpio (*Vṛṣcika)*. However, in the *nirayaṇa* system it reads 187 and the observer chose to measure the shadow readings with the Libra *(Tula)* instrument. The observations clearly indicated the need for a correction of about 25°.

That brings us back to the question of the purpose of the scale.

Considering that we are utilising only the difference in the shadow reading and the longitude of the Sun, a reversal of the scale cannot be ruled out as a mistake that may have happened during the renovation. That would have the additional advantage of reading out the ascendant from the shadow directly. In the absence of any records of observations carried out with these instruments it is difficult to draw any inferences.

As mentioned earlier, Kaye (1917) has pointed out that at some point in time, the instruments were realigned; he refers to the slopes of the different gnomons and points out the small differences. Other than this, there is no record of the readings taken and/or analysed.

6 CONCLUDING REMARKS

We carried out systematic observations of the *rāśivalaya* instruments, which are unique in design and application. The observations carried out reveal many unknown applications of this set of instruments. Currently the usage is for only the determination of the *madhaylagna*, the point on the ecliptic which is on the meridian. We realised that a scale in the reverse order would have facilitated this purpose. We have discussed other possible uses of these set of instruments. They can measure the hour angle close to the meridian passage, a quantity that is essential for eclipse computations. Their use for determination of the daily motion and ecliptic latitude in the case of planets and the Moon is viable. Recording observations carried out systematically throughout the year may reveal the range of applications. This also points to the need for search on past observations, which may remain unidentified in the archives.

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