

were obviously different from what we get by modern computations. Therefore, an error of several hours in computing the soli-lunar days (*tithis*) is not unusual.

Throughout his article, Chandra Hari mentions the sun's rising exactly in the east on the day of summer solstice! Obviously, this is incorrect. The sun rises exactly in the east, for a non-equatorial place, only on the two equinoctial days and not on the solstitial days.

In conclusion, the date of the Sanakanika inscription must be 27 June 402 AD (Julian) and not in the month of May.

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1. Chandra Hari, K., *Curr. Sci.*, 2008, **95**, 117–124.
  2. Sharan, M. A. and Balasubramaniam, R., *Curr. Sci.*, 2004, **87**, 1562–1566.
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## Summer solstice and Udayagiri

Chandra Hari<sup>1</sup> has discussed the astronomical significance of the cave at Udayagiri in great detail. However, there seems to be some confusion about the direction of the rays of the rising sun on summer solstice. As has been shown in the context of the Vidyashankara temple in Sringeri<sup>2</sup>, the direction of the rising sun may be calculated from the formula

$$\sin \delta = \sin \phi \sin a + \cos \phi \cos a \cos A, \quad (1)$$

where  $\delta$  is the declination of the sun,  $a$  the altitude,  $\phi$  the latitude of the place and  $A$  the azimuth. Using the fact that at the time of rise (and set)  $a$  is zero, the azimuth is calculated as the direction of the rising sun.

The direction has been observed by Sharan and Balasubramaniam<sup>3</sup> to be  $25^{\circ}56'$ . This fits exactly into eq. (1) for a latitude value of  $23^{\circ}31'$  for the date of summer solstice. It should be noted that

neither 29 May nor 22 June satisfies this requirement for CE 402. It is well known that owing to the precession of equinoxes, the date of solstices has been shifting gradually. In fact, this was responsible for the reformation of calendar 400 years ago. Thus an extrapolation from today naturally leads to some discrepancies, which can be accounted for. Hundreds of stone inscriptions with the dates of solstices have been identified all over India and their study corroborates with the gradual shift of solstice dates. Thus the date was around 25 June in the 11th century and therefore 26 June as the date for CE 402 is not unrealistic. Moreover, the type of small differences in the declination of the sun as depicted in table 4 of the paper can be observed only after compiling the data over several decades. Solstice is an event and not a day. Thus some margin should be allowed depending on whether the solstice occurred at noon or some other time of the day. For example, in the year 2008 the solstice occurred at 05:29 am IST and therefore, the noon shadow would not reflect the exact event. However, any such architectural plan will incorporate a finite margin so that about a week on either side of the solstice, the rays of the sun enter the cave, as in the case of the Gavi Gangadhreshwara Temple in Bangalore<sup>4</sup>.

The paper mentions about the sun rising exactly at the east on the day of Sanakanika inscription, which cannot be true. As is well known the sunrise at the exact point east happens only on the days of equinoxes all over the globe. This can also be deduced from eq. (1) by putting  $\delta=0$ . The paper mentions that on summer solstice the earth is nearest to the sun. The situation is the opposite – the aphelion passage occurs on 4 July every year.

The observation by Balasubramaniam and Dass<sup>5</sup> that the shadow near the south wall disappears on summer solstice at noon is a simple extension of the eq. (1). At meridian transit the value of  $A$  is  $180^{\circ}/0^{\circ}$ . Then, eq. (1) simplifies to

$$\sin \delta = \sin \phi \sin a. \quad (2)$$

The disappearance of the shadow implies that  $a = 90^{\circ}$  or that  $\delta = \phi$ . This is true for CE 402 and any other year. In fact, observing the noon shadow on solstice was and is one of simplest methods of finding the latitude of a place.

In light of the above simple explanation, the lengthy discussion on the min-

ute variation of declination and the discussion based on sunrise at 'exact' east point are uncalled for. Likewise, the second part of the paper and appendix throw no light on the Udayagiri architecture. The appendix completely ignores the fact that Manasara gives a rule to apply correction for the change in declination of the sun within a day. There was no assumption that the sun remains 'stationary' for 21 days.

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1. Chandra Hari, K., *Curr. Sci.*, 2008, **95**, 117–124.
  2. Shylaja, B. S., *Curr. Sci.*, 2007, **92**, 846–849.
  3. Sharan, M. A. and Balasubramaniam, R., *Curr. Sci.*, 2004, **87**, 1562–1566.
  4. Jayanth Vyasnakere, P., Sudeesh, K. and Shylaja, B. S., *Curr. Sci.*, 2008, **95**, 1632–1636.
  5. Balasubramaniam, R. and Dass, M. I., *Curr. Sci.*, 2004, **86**, 1134–1142.
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### Response to comments from S. Balachandra Rao

(i) 'The authors of the earlier historical note are right in their observation that the direction of the rising sun at the place of latitude  $23^{\circ}31'$  on the day of summer solstice is  $25^{\circ}56' \dots$ '.

Nobody will dispute the result of a basic equation like the one quoted by Sharan *et al.* and I have given reference to that:

$$\sin \delta = \sin \phi \times \sin h + \cos \phi \times \cos h \times \cos A.$$

At a place of latitude  $23^{\circ}31'$ , can the direction of  $25^{\circ}56'$  be due east, when the azimuth will be  $64.06^{\circ}$ ?

Azimuth has to be  $90 - \phi$ , i.e. 90-latitude and those who had the date of the Sanakanika inscription fixed had this knowledge and the observational skill to make out that the sun rose due east on *āsāḍha śukla ekādaśī* of the year 402 AD, which fell on 29 May 402 AD.

(ii) 26 June 402 AD in *Śravana*.

I stand by my understanding and analysis given. I have replied to Sharan's comments already. Data given of the new moon and full moon suggests that the *Caitra* that began on *Suklapaksha* (1), i.e. 21 March 402 CE corresponded to sidereal and tropical solar month of *Mesha*. Full moon of that month had occurred at the 15th degree of *Tula* and the month could as well have been called *Vaisakha*. I preferred the nomenclature beginning with *Caitra* according to the later siddhantic practice which considered *Caitra* as synonymous with *Mesha* transit of the sun. When *Caitra* is configured so the next month of sun transiting *Vrshabha* becomes *Vaisakha* and solar *Mithuna* becomes *Ashadha*. Given the full moon position ( $\lambda = 222.96$ ), the *Vrshabha* solar month may have been called *Jyeshtha* also. But the *Mithuna* transit of the sun as we can configure from the data could not have been *Jyeshtha*, as suggested by Sharan.

Confusion has been due to the mix-up of the solar and lunar reckoning of the months. Given the positions of table 1, lunar *Caitra* could be considered from 19 February to 20 March, lunar *Vaisakha* from 21 March to 18 April, lunar *Jyeshtha* from 19 April to 18 May, and lunar *Ashadha* from 19 May to 17 June.

In 402 CE, *Ashadha* marked the beginning of the rainy season as the month ended close to summer solstice. *Ashadha* was coeval with solar *Mithuna* and ended close to or overlapping summer solstice and the tumult of rains. Therefore, Kalidasa described the appearance of clouds in *Ashadha*. *Chaturmasyam* too had to begin before the heavy rainfall after summer solstice and so I find no contradiction for the date fixed for Sanakanika inscription. There is no missing month if the sun-moon data given in table 1 are named in terms of lunar months from *Caitra* as mentioned above.

(iii) Rao mentions that Indian computation of the tithis may have been in error by several hours. This is a wrong statement; tithi has been one of the most accurately computed element of Indian astronomy. Rao speaks of an old system (pre-Aryabhatan) with poor results. To quote Rao:

'Throughout his article, Chandra Hari mentions the sun's rising exactly in the east on the day of summer solstice...'

I have not mentioned so. I have given the correct discussion on azimuth and have fixed the date to be 29 May 402 AD for sunrise due east. Maybe Rao has misunderstood. But he mentions the following to emphasize the alleged mistake on my side.

'The sun rises exactly in the east for a non-equatorial place only on the two equinoctial days and not on the solstitial days.'

As I understand, east is defined as  $90^\circ$  azimuth. As the sun's declination changes to north/south of the equator, the respective latitudes shall see the sun rising due east to their location when azimuth equals  $90 - \phi$ . Direction of  $90 - \phi$  azimuth will be at an angle of  $\phi$  from the equator, either north or south. So between the tropics there will be two days when the sun rises due east to the location (see below).

#### Response to comments from B. S. Shylaja

(i) Confusion about the direction of rays of the rising sun on summer solstice.

I think there is no confusion. It may be noted that for a place of  $\phi = 23^\circ 31'$ , the direction of the rising sun computed as (90-azimuth), i.e. departure from the equator on the summer solstice day is  $25^\circ 56'$ , as can be obtained from the standard formula. But on this date when  $\delta = \omega$ , the rising sun will not be due east at latitude  $\phi$ . For precise eastern sunrise, the value (90-azimuth) has to be equal to the latitude of the place. Or the azimuth value for sunrise due east is  $90 - \phi = 90 - 23^\circ 31' = 66^\circ 29'$ . This is what I have shown in table 3 and for altitude zero, this azimuth is achieved on 29 May 402 AD as explained in the paper.

Shift of the solstices has nothing to do with the observed phenomenon of sunrise

due east when the dates are given according to the tropical calendar.

Rest of the discussion is irrelevant to the contents of my paper.

(ii) '*The paper mentions of sun rising exactly at east on the day of Sanakanika inscription which cannot be true.*'

This is what I have illustrated in table 3, with the altitude and azimuth data of 29 May 402 AD. Now you say that the sun rises on the east only on the day of equinoxes. According to the basics of astronomy, on the day of equinoxes the sun rises at the equator at  $\delta = 0$ . As  $\delta$  increases, the rise due east slowly drifts northward and for any place in between the  $\phi = 0$  and  $\phi = \omega$ , there will be two dates when the sun rises due east. One needs to consider the case when  $\delta \neq 0$  and the azimuth is  $90 - \phi$  when altitude is zero. Putting altitude as 0 and azimuth  $A = 90 - \phi$ , we can deduce from the same equation, the declination corresponding to due east sunrise for different  $\phi$  values.

$$\sin \delta = \sin \phi \times \sin 0 + \cos \phi \times \cos 0 \times \cos (90 - \phi),$$

$$\delta = \sin^{-1} (\cos \phi \times \cos (90 - \phi)).$$

It can be seen easily that at  $\phi = 23.5$ ,  $\delta$  for due east sunrise must be  $21.5^\circ$  and this has been discussed in the paper to establish that on the date of the Sanakanika inscription, the sun rose precisely in the east.

At Bangalore  $\phi = 13^\circ$  and  $\delta$  for due east sunrise must be  $12^\circ 40'$  and this happens during both Uttarāyana and Dakṣiṇāyana as declination waxes and wanes.

(iii) I did not state that on the summer solstice day, the sun is nearest to sun. Distance of the sun from the earth is also not a topic of discussion.

(iv) Against the above background, I think the other comments need not be addressed at all. Algebra on the basic equation can be worked out as I have shown above.

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