3.5 PERIODIC NATURE OF COMETARY MOTIONS AS KNOWN TO INDIAN ASTRONOMERS BEFORE ELEVENTH CENTURY A.D.

S.D. Sharma
Physics Department, Punjabi University,
Patiala, India
India.

Apparitions of comets were thought to be a bad omen in earlier times in almost all the old civilizations. This led to correlating these apparitions with some particular events which took place simultaneously. Although the information was collected and recorded merely for astrological purposes, yet these records are in no way less important from astronomical points of view. Ancient Indian astronomers like Garga, Marīci, Asita, Devala and others made cometary studies and recorded their trajectories(Bṛhat-saṃhitā, Chapter on Ketucārādhyāya).

In earlier times there was a notion that the comets were heavenly bodies and their apparitions, paths, rising and setting in the sky, could not be found out by mathematical calculations as is clear from the following śloka(Bṛhat-saṃhitā, Chapter on Ketucārā dhyāya).

Darśanātamayo vā na sakyate jñātum /
Divyāntarikṣabhaumāstrividāḥ syaḥ ketavo yasmāt //

i.e. "The rising and setting times of comet(s) (*Ketus*) cannot be known by (mathematical) means because there are three types of *Ketus* (a more general name for some phenomena (celestial appearances) with names *Divya* (coming from sky), *Ānrtarikṣa* (appearing from places other than those of planets and constellations) and *Bhuma* (coming from the earth)". Although the algorithms for predictions of cometary positions could not be developed, yet the observed appearances, trajectories and physical characteristics etc. were recorded by ancient seers in all the old civilizations. Indian astronomers had the naked eye observations and compiled them in encyclopedic works known as *Saṃhitās*. It may be pointed out that although Varāhamihira (5th-6th century A.D.) in the opening of the chapter on comets (*"Ketu-Cāradhyāya"*) in his *Bṛhat-saṃhitā* expresses inability to predict the appearances and positions of comets, yet he has clearly stated the trajectory points among asterisms in case of some comets indicating that the motion was known to be periodic. For example, in case of *Calaketu* he gives the trajectory and other characteristics as follows:

Aparasyām calaketuḥ śikhayā yāmyāgrayāṅgulochritayā /
Gacched yathā yathodak tathā tathā dairghyamāyati //
Saptamunīn saṃspṛśya dhruvamabhijitameva ca pratinivṛttaḥ /
Nabhasordhamātramittvā yāmyenastamupayāti //

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i.e. "The *Calaketu* is one which rises in the west having tail directed towards south and about one *aṅgula* (one finger) in length, increasing in size as it moves towards north. It touches the Great-Bear, Pole Star and the Abhijit (Vega or α Lyrae) and then returns. Having described half part of the sky it sets in the south".

This shows that Varāhamihira was sure about the path of a comet. It may be noted that in the above-stated stanza the present tense is used in stating the various stages of the comet's apparition, which clearly indicates that this report is the final version of the universally factual phenomenon observed from time to time. It is in no way a single isolated report of the observation in the life-time of the author. The same trajectory is found reported in other saṃhitās too. This inference might be the result of investigations of earlier records and also Varāhamihira's own observations.

Another ancient astronomer, Bhadrabāhu (contemporary of Varāhamihira) in his Saṃhitā (named after his name as *Bhadra-bāhu-saṃhitā*) gives a categoric statement about periodic nature of motion of some short-period comet(s) as follows:-

> Sattriṃśat tasya-varṣāṇi pravāsaḥ parmaḥsmṛtaḥ /
> Maddhyamaḥ saptaviṃsastu jaghanyastu trayodaśa //

i.e. "the maximum period of disappearance of a comet is 36 years; the average period, 27 years; and the minimum period, 13 years".

This shows that Bhadrabāhu had knowledge about the periodic nature of cometary kinematics and it is believed that such reports could be verified in one's own life span too, by comparing the earlier records of apparitions and the physical characteristics (which help in recognizing the comet on its subsequent returns after disappearances).

Bhaṭṭotpala, (10th century A.D.) in his commentary on *Bṛhatsaṃhitā* (see Dikshit 1981) gives a list of time-periods of some long-period comets as follows:

> *Paitāmaha Ketu* has period of 500 years,
> *Auddālaka Śvetaketu* has period of 110 years,
> *Kāśyapa Śvetaketu* has period of 1500 years,
> *Vibhāvasuja Ketu* has period of 100 years, etc.

Note that here the names of comets are based on the names of the seers who estimated their time-periods. This tradition is similar to the one adopted in modern tradition of cometary studies.

From the above it appears that significant progress in cometary studies was made between the times of Varāhamihira (6th century) and Bhaṭṭotpala (10th century)

Edmond Halley in the year 1686 A.D. claimed periodic nature of motion of the comet, now known after his name as Halley comet and predicted his period to be about 76 years. He also determined periods and trajectories of some other comets using mathematical techniques based on the universal law of gravitation expounded by his contemporary Newton in his 'Principia'. This was a great advancement in the computational techniques for predicting positions of comets. As evidenced in this exposition, the Indian records show awareness of ancient astronomers with regard to the periodic nature of motions of comets. Some records on cometary kinematics are preserved in *Saṃhitās*. There are statistical data too, which deserve exhaustive mathematical analysis. The work in this direction is in progress and it will be interesting if some of the records of Halley's comet could be decoded from these texts.

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DISCUSSION

O.P. Gingerich : There are about 100 currently known periodic comets, that is, comets that return in less than a few hundred years. Of these, only Halley's Comet is bright enough to be seen easily by naked eye. Hence, to discover the periodicity of comets with naked-eye observations, this comet provides the only possiblity. However, the period is somewhat variable, so that not until the last century were sufficiently precise perturbation calculation made to identify apparitions of Halley's Comet prior to 1531. Because the comet comes inside the earth's orbit, it is seen in quite different directions in successive apposition, and so there is no way to recognize the comet without specific computations of the elements of the ellipse. You may recall that Kepler analysed Halley's comet (1607) in terms of straight line motion in space. Thus, until you have a gravitational theory (conic sections and the law of areas) it is quite impossible to establish the periodicity of comets from observations alone. Hence I believe Prof. Sharma's conclusions are unwarranted and misleading.

S.D.Sharma : It is not to some extent possible to infer both periodicity and path of comets from naked eye observation. In fact physical characteristics (tail forma-

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tion, colour etc.) may not be of much help, but the path can be ascertained certainly if conjunctions of comet with stars are recorded. In Brhat Samhitā, Calaketu is reported to occult Abhijit (α lyrae) and some other stars on its path. Such naked eye observation helps to ascertain the path among stars because the paralaxes of comets in general are not so large and node positions have quite less perturbation over a sufficient number of cycles of the comet. The periods might have been determined by noting velocity over the visibility period.

The occultations are meaningful in case of comets beyond 5 AU or even more. In case of Halley's comet, the difference in annual parallaxes in consecutive returns can be large, so it belongs to the category of "Aniyat-dik-prabhava" (Appearing in variable directional positions) comets as discussed in Bṛhat-Samhitā and it is not Son of any direction, instead it is Son of Brahma. (The God with four heads in all the four directions).

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