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A Tribute to the Memory of the Late Yukio Ôhashi

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Amongst global scholars and outstanding researchers in the field of history of Indian astronomy and mathematics, Dr. Yukio Ôhashi is an outstanding figure who has displayed tremendous versatility and scholarship in a wide array of allied fields. Some remarkable features of Ôhashi include his ability to learn multiple languages, approach problems with new perspectives, and also take on well-established scholars with great confidence backed up by thorough research. As a doctoral student of the stalwart Prof. K. S. Shukla, he carried out extensive research on the instruments described in Indian astronomical literature. Following his untimely and unexpected demise, this article attempts to pay a tribute to him and spans two main sections covering a bibliographic note and highlights that showcase his acuity in research.

Keywords

Yukio Ôhashi, Tribute, Biographical Note, Research Overview, Obituary

Contents

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I Biographical Note

1 Educational Background

On March 13, 1955, Yukio Ôhashi was born in Shibuya, Tokyo. His educational background has spanned different fields, which certainly empowered him to carry out research in the highly inter-disciplinary domain of History of Mathematics and Astronomy. Having completed his undergraduate degree in Physics at Saitama University (Tokyo) in 1979, he went on to take up an M.A. from the Department of Chinese Studies at Saitama University and completed it in 1983. His Master's thesis was titled 'Some problems of Hùhàn sìfēn lì' wherein he discussed one of the oldest official calendars in China.

He then got himself enrolled in the doctorate program at Hitotsubashi University to study modern astronomy. In the meantime, Ôhashi seems to have been suddenly swept by a strong wave that made him drift towards the history of Indian astronomy, though we do not exactly know what particular reading or incident might have inspired and propelled him in this direction.[1] He then began learning Sanskrit and Hindi in the Eastern Institute (Toho Gakuin) and was awarded a scholarship by this institute to study in India. Encouraged by this, Ôhashi, at the age of 28, had set forth upon a new journey.

Photo of Dr. Yukio Ôhashi presenting his paper at the ICOA-5 conference in Chiang Mai in 2004

(Source: Orchiston and Nakamura (2020))

2 Studies in India: Meeting his mentor Prof. K. S. Shukla

He was accepted as a visiting scholar in the Department of Mathematics and Astronomy at the University of Lucknow in India, where he met his guide and mentor, the illustrious historian of Indian astronomy and mathematics, Prof. K. S. Shukla. Combining a flair for mathematics with a strong grasp of Sanskrit, Prof. Shukla is well known for his immense contributions in advancing our understanding of the history and development of mathematics and astronomy in India. Prof. Shukla's erudition and contributions are ably captured in Kolachana et al. (2019).

Ôhashi was indeed fortunate to have had the mentorship of Prof. Shukla, who not only shaped but also honed Ôhashi's skills to take up a completely new area of research into Indian astronomy. Taking up such research work in such domains demands expertise in Sanskrit as well as science. While this is an arduous task even for native scholars who would have an edge over foreign scholars (who may be completely new to the Sanskrit language in which most texts are available) Ôhashi seems to have had an unwavering mind and abundant enthusiasm to take up this challenge and acquire the skills necessary to carry out intensive research work.

Ôhashi reminisces about his early days in the following words written by him in the chapter titled "Reminiscences of Prof. K. S. Shukla" that was published in Kolachana et al. (2019).

1 In the obituary Orchiston and Nakamura (2020), it is shared that when Ôhashi "was an undergraduate student it was an inspiring lecture by Professor Hideo Hirose (1909 –1981), a former Director of Tokyo Astronomical Observatory that whetted his appetite to study the history of astronomy." Nonetheless we do not know what made Ôhashi turn towards India after having completed his masters in Chinese studies.

> I arrived at Lucknow in 1983. It was my first experience to go abroad. At that time, Prof. Kripa Shankar Shukla already had retired from the Department of Mathematics and Astronomy of Lucknow University, but sometimes came to the department… I studied the history of Indian mathematics and astronomy from 1983 to 1987 as a research scholar under the guidance of Prof. K. S. Shukla, and was awarded Ph.D. degree (History of Mathematics) in 1992.

The new environment would have posed challenges on both the cultural and the academic front. Nonetheless, we can infer that Ôhashi remained exuberant with a positive attitude and a mindset dedicated to learning, notwithstanding the obstacles and hardship one may have to face to accomplish the undertaking. He shares his experience in these words:

> At that time, I was young, and travelled several places in India to collect source materials. Photocopy was not so popular in India at that time, and I took several photographs of manuscripts by my camera… There are some corrections in manuscripts which cannot be seen clearly by pictures or photocopies. So, I visited Tagore Library several times to copy the manuscripts, and then visited Prof. Shukla's house. At that time, the primary mode of transport to go to Prof. Shukla's house was cycle rickshaw. (By the way, the Indian word "rickshaw" is originated in a Japanese word "jin-riki-sha", which means human-powered transport. "Jin" in Japanese means human, "riki" means force or power, "sha" means car. If it is driven by bicycle, it is called "cycle rickshaw", and if it is driven by motor cycle, it is called "auto rickshaw".)

Ôhashi also fondly recollects his close association with the son of Prof. Shukla and an affinity for the city and the entertainments it could offer in these words:

> Lucknow is a beautiful city with several historical sites. It was formerly "Awadh" ruled by Nawabs. It has a tradition of delicious cuisine. And also, Bhatkhande Music Institute was situated nearby Lucknow University, and I could enjoy Indian classical music several times. Mr. Ratan Shukla, a son of Prof. Shukla, was kind enough to take me to several historical places…

From the above descriptions, we can discern that Ôhashi grew to not only enjoy the close mentorship of Prof. K. S. Shukla but also went on to enjoy the culturally rich Indian life.

It may not be out of place here to quote a *subhāṣitā* that highlights with beautiful similies what values an astute learner should possess.

> काकचेष्टा बकध्यानं श्वाननिद्रा तथैव च ।
> अल्पाहारी गृहत्यागी विद्यार्थीपञ्चलक्षणम् ॥

> *kākaceṣṭā, bakadhyānaṃ, śvānanidrā tathaiva ca* |
> *alpāhārī gṛhatyāgī vidyārthīpañcalakṣaṇam* ||

> Perseverance of a crow, concentration of a crane, [light] sleep of a dog, moderate indulgence in food, and renouncement [from attachments] of home (comfort-zone!) are the five signs of one who is committed to learning.

These values seem to have been in a fully blossomed state in Ôhashi during his young, aspiring and learning days.

3 An exceptional student-advisor combination

Prof. Shukla had retired from the university department by the time Ôhashi had come in as a visiting scholar. Even then, Prof. Shukla gave special attention and close guidance to Ôhashi. He was indeed fortunate to be one among the only five doctoral students who were guided by Shukla directly. Since Shukla was not regularly visiting the department after his retirement, Ôhashi by and large used to learn at his residence. Referring to the extraordinary kindness of Shukla, Ôhashi says (Kolachana et al., 2019 p. 3):

> Prof. Shukla taught me how to read Sanskrit and Hindi texts on mathematics and astronomy, usually in his house.

Unlike today, back in the India of the 1980s, printing was done using the letterpress, wherein the typesetters used to compose the text in a metallic frame of a given dimension, employing a variety of metallic fonts stored in a huge type case. Also, the printing of a volume could not happen all in one go as we do it today. At most 16 or 32 sheets could be printed at one time, and if there were to be any slip in proofreading, it could not be corrected again since the frame would have been completely dismantled once the pages were printed. Hence the author had to be all the more careful in proof-reading the text.

Reminiscing how punctiliously and tirelessly Prof. Shukla worked to ensure that the books he edited were error-free, Ôhashi observes:

> When I was in Lucknow, the *Vaṭeśvara Siddhānta* and *Gola* of Vaṭeśvara was being printed at a press in Lucknow. Prof. Shukla visited the press almost every day, supervised its printing work by himself, and read its proofs very carefully. From this fact, we can understand why his edition is so reliable. These original sources are the most important foundation for future research.

Extolling Shukla's meticulous way of maintaining notes, and his commitment towards his doctoral students, Ôhashi notes:

> When we read his notes, we feel as if we are being taught by him directly. It should also be mentioned that he noted several parallel statements in other Sanskrit texts in the footnotes of his English translations. So, his English translations can also be used as a kind of annotated index of Sanskrit astronomical and mathematical texts. Only Prof. Shukla could do this…

This gives us a pointer to the great reverence Ôhashi had for his mentor and guide. The above statements did not remain a mere observation. Meticulously following the path of his mentor, Ôhashi had reflected it all through his research taking the torch forward. In the works of Ôhashi one can find elaborate notes, close and careful study of the various parallel statements and notings of the emendations made by various scholars. In a later section, we present some interesting points from the "Notes and References" sections of Ôhashi , which serve as testimony to this.

Ôhashi started to read *Yantra-rājādhikāra* (Chapter 1 of the *Yantra-kiraṇāvalī*) of Padmanābha, as two manuscripts were available in Lucknow itself. This was the beginning of his journey that led to marquee publications about early Indian astronomical instruments. His legacy of research publications first began from a conference held between November 13 and 15, 1985. This paper was titled "A note on some Sanskrit manuscripts on astronomical instruments." He shares his experiences in these words:

> In 1985, General Assembly of International Astronomical Union was held in New Delhi, and I went to New Delhi with Prof. Shukla by train in order to attend its colloquium on the history of oriental astronomy. It was my only one experience of travel with Prof. Shukla. The colloquium was held in INSA (Indian National Science Academy), and we met several specialists of oriental astronomy from many parts of the world.

After completing his studies in the role of a visiting scholar for about five years in India, Ôhashi returned to Tokyo in 1987. Then he seems to have enrolled for a doctorate in Social History of the East at Hitotsubashi University in Tokyo and in 1988 and 1989 completed the coursework component (Orchiston and Nakamura 2020). But apparently he withdrew from the doctoral program there and with the mentoring of Prof. K. S. Shukla, he worked with the University of Lucknow for his doctoral dissertation and was awarded his Ph.D. in 1992. The title of the dissertation is "A History of Astronomical Instruments in India". This dissertation was published in three issues in the *Indian Journal of History of Science* (IJHS):

1. Development of Astronomical Observation in Vedic and Post-Vedic India, IJHS 28(3), 1993, 185–251.
2. Astronomical Instruments in Classical *Siddhāntas*,

IJHS 29(2), 1994, 155–313.

3. Early History of the Astrolabe in India, IJHS 32(3), 1997, 199–295.

4 A life filled with challenges

After his Ph.D., life seems to have not been easy on Ôhashi. Despite his excellent academic achievements, he could not find a permanent research position anywhere. He had to work as a part-time lecturer of the Chinese language, history of science, and history of astronomy in several different universities. A close associate of Ôhashi, Prof. Michio Yano (2020) shares his memory:

> Whenever I was asked I wrote recommendation letters for him, but always in vain. He applied to the assistantship of the Institute for Research in Humanities at Kyoto University, but he was not successful and he became rather pessimistic in finding a permanent job and gradually he turned to be aggressive to the established institutes and scholars and he was proud of calling himself 'amateur historian of astronomy'. It seems that he wanted to say that amateurs represented by him are more learned than professional scholars who have permanent job.

While the academic career did not work out as Ôhashi may have much deservedly wished for, he was certainly not holding back in his research pursuits. By 1998 he had expanded his research areas to include Tibetan astronomy, astronomical history of China, Vietnam and Japan. In order to pursue such wide-ranging geographies Ôhashi must have possessed extraordinary skills to quickly and keenly learn classical languages including Sanskrit and Chinese. Orchiston and Nakamura (2020) share the following:

> Furthermore, in order to facilitate this research, over the years Yukio built up an outstanding private research and reference library. By the time he died this numbered between 7,000 and 10,000 books, plus runs of journals, which completely filled his once spacious home.

Ôhashi was a long-standing member of the International Astronomical Union, since 1997. He was also a member of the Executive Committee of the International Conference on Oriental Astronomy (ICOA), and he served on the Editorial Board of the Journal of Astronomical History and Heritage (JAHH). In that capacity, he was indeed refereeing several papers on the history of astronomy in Indian and South-East Asian astronomy.

Since he was living all alone in his residence in Tokyo, the exact date and time of the passing away of Dr. Yukio Ôhashi are not known. It was learned that he must have passed away sometime in October of 2019.[2] Prof. Michio Yano (2020) writes:

> I could not believe when I got this sad news on November 10. It was only on March 12, 2019 that we participated in the Seventh Symposium on History of Astronomy held at the National Astronomical Observatory in Tokyo. After the symposium we joined a dinner party together. We discussed various topics. Ôhashi was very eloquent. He drank two or three bottles of wine even though he said that he was told by his doctor not to drink too much. I was worried about him.

The author of this tribute has had a few occasions to listen to the talks given by Ohashi in a few conferences. This made him develop an appreciation for the novel ways of his thinking, and the sharp mind that Ohashi was blessed with. There were also occasions in which the author has witnessed him in his lower moments. In fact, upon finding Ôhashi in an unstable state, not able to walk properly on one of the days during a symposium held during March 2019 at the National Astronomical Observatory in Tokyo, it was painful to see a brilliant mind succumbing to the vagaries of human nature. Providence, as it was to Ôhashi, may be unfair many a

2 Orchiston and Nakamura (2020) mention the date to be 31 October 2019, in their article's abstract. Whereas, Ôhashi's close associate, Michio Yano (2020) states the exact date is unknown.

time, but he seemed to have sailed though various challenges with great optimism and enthusiasm. We only wish more help had found its way to him in time, which possibly would have enabled him to do more research and enrich the field by writing more articles.

II Acuity in Research

1 An overview of Ôhashi's publications

Prof. Michio Yano (2020) notes that Prof. Takao Hayashi prepared a list of Ôhashi's publications and enumerated about 80 papers, constituting about 30 papers on Indian astronomy, another 30 papers on Chinese astronomy, about 10 papers on Tibetan astronomy and others on the history of astronomy in South-East Asia and Japan.

Orchiston and Nakamura (2020) have discovered that the digital archives of the Japan National Diet Library contain 37 entries in Japanese, which were published between 1982 and 2019. Some of these Japanese papers seem to even have abstracts in English. Their listing estimates around 40 research papers by Ôhashi in the English language, written over a span of 36 years, from 1985 to 2020. The authors of the obituary have also presented some interesting analysis that most of his early papers were elaborate and voluminous ranging from 59 to 159 pages.

The diverse areas that Ôhashi has forayed into are well beyond the expertise of the author of this tribute. Hence this section is restricted to Ôhashi's contributions relevant to the history of sciences in India. Ôhashi's areas of interest in Indian astronomy can be thematically divided into two areas:

(1) the history of mathematical astronomy from the Vedic period to the Siddhāntic period.
(2) the history of astronomical instruments in the Post-Siddhāntic period.

Ôhashi made a significant contribution to the study of *Jyotiṣa-Vedāṅga*, at times even taking a critical view of certain conclusions made by the renowned scholar David Pingree. Ôhashi has also looked deeply into various postulations made in the history of astronomical texts and authors in the Classical Siddhāntic period. He has tried to construct a web of all possible theories by daring to enter into fuzzy areas such as the anonymity around the author of the *Sūrya-siddhānta*.

The second field where Ôhashi's achievements are significant is the history of astronomical instruments in India. It may be recalled that it had been a central theme of investigation in his doctoral thesis as well. Drawing some important contributions made by Ôhashi, the following sections present a few highlights from his work.

2 Insights into the calendrical system of the *Vedāṅga Jyotiṣa*

The *Vedāṅga Jyotiṣa* of Lagadha is a small monograph of astronomy written in Sanskrit. It has two recensions, namely, the Ṛg-vedic and the Yajur-vedic entitled *Ārca-jyotiṣa* and *Yājuṣa-jyotiṣa* respectively. For its text, English translation and detailed mathematical notes see Sastry and Sarma (1984). The calendar described there is a luni-solar calendar where two intercalary months are inserted in a 5-year cycle called *"yuga"*. Two intercalary months were inserted at the middle and the end of the 5-year *yuga*.

David Pingree conjectured that the length of one solar year of the *Vedāṅga Jyotiṣa* was originally meant to be 366 sidereal days, which is 365 civil days and that this was borrowed from Egypt or Mesopotamia (Pingree, 1973). Ôhashi presents a brilliant analysis and refutes Pingree's conjecture and states it is "untenable". In his paper, Ôhashi (1993) notes:

> Pingree interpreted that the "day" in the Ṛg-vedic recension is not the civil day, but the sidereal day. So, he conjectured that one solar year was 366 sidereal days, i.e. 365 civil days. The Yajur-vedic recension[3] clearly states that the number of sidereal days (lit. rising of Śraviṣṭha) in a *yuga* is the number of "days" plus five, and this statement shows that the "day" is the civil (*sāvana*) day. However, Pingree argued that this is due to the misunderstanding of the compiler of

[3] *Jyotiṣa-Vedāṅga* (Y. 29 (a–b))

the Yajur-vedic recension, and this recension is a much later work. Pingree, however, does not show any understandable reason for his argument that the "day" in the Rg-vedic recension is sidereal, except that 365-day year is the same as the Egyptian-Persian year[4]…

We should also keep in mind that sidereal days were never used for civil purpose in ancient India. Pingree conjectured that the 365-day year was introduced into India through Persia, but I shall show that the day in both recensions of the *Jyotiṣa-Vedāṅga* is definitely the civil day, and there is no similarity between the calendrical system of the *Jyotiṣa-Vedāṅga* and that of ancient Egypt or Mesopotamia.

Ôhashi goes on to consider the value estimated in modern times of 62 synodic months and 67 sidereal months of the moon, that are known to be:

62 synodic months = 1830.90 days,
67 sidereal months = 1830.55 days.

If one solar year is taken to be 366 days, then one *yuga* constitutes 1830 days, and this number is close to the above value. However, if one solar year is taken to be 365 days, then one *yuga* would constitute 1825 days, and nearly 6 days' error is produced regarding the syzygies, and other observable phenomena. Ôhashi argues that this "calendrical system was used for the determination of the time of rituals, including the new and full moon offerings, and 6 days' error is by no means possible, because the difference of lunar phase in 6 days is too much to go unnoticed. Therefore, I conclude that the length of 1 year of the *Jyotiṣa-vedāṅga* was definitely 366 days."

Ôhashi also supplied relevant quotes from *Vedāṅga Jyotiṣa* to show that the dates of the new moon and full moon were determined quite accurately based on the rising time of the moon as well as by observing the lunar phase. An error in the calculation of the lunar phase would be easily detectable through observation. However, changes in the date of change of seasons are not easily detectable through observation and hence, such an error in the length of the solar year may have been present. Ôhashi thus presents mathematical reasoning, textual evidence and logical reasoning to conclude that in the era of *Vedāṅga Jyotiṣa* a *yuga* consists of 1830 civil days and therefore a solar year of 366 civil days is purely of Indian origin. Though the earlier studies of *Vedāṅga Jyotiṣa* assigned 366 civil days to a year, Pingree took a deviant view, and sort of maintained it, even in his article published in 2007, not taking any note of Ohashi's work, published more than a decade before on the same topic.

3 Place of the composition of the *Vedāṅga Jyotiṣa*

Ôhashi also rejected Pingree's idea of the Mesopotamian origin of the ratio 2:3 of the shortest and longest daytime found in the *Vedāṅga Jyotiṣa*. He showed that the ratio was derived not from the interpolation of the data based on the observation of the solstices but from the extrapolation of those based on the observation around the equinoxes.

Ôhashi has analyzed the possible place of composition of the *Vedāṅga Jyotiṣa* by precisely looking carefully into the verses that pertain to the estimation of the length of the day. The following are the relevant verses. The first verse (Ṛg-vedic recension v.7 and Yajur-vedic recension v.8) reads:

घर्मवृद्धिरपां प्रस्थः क्षपाह्रास उदग्गतौ ।
दक्षिणेतौ[5] विपर्यासः षण्मुहूर्त्ययनेन तु ॥

4 See Neugebauer and Pingree (ed. and tr.), The *Pañcasiddhāntikā* of Varāhamihira, Part II, Copenhagen, 1971, p. 81.

5 In some printed versions of *Vedāṅga Jyotiṣa* brought out by R Shamasastry (1936) and Kuppana Sastry and KV Sarma (1984) a serious typographical error has gone unnoticed, thereby replicating into the work of Ôhashi as well. The reading found in those editions is: "दक्षिणे तौ". The word cannot be split since it is one compound formed of the two words दक्षिण + इतौ = दक्षिणेतौ. In the compound form it resembles the word उदग्गतौ used in the earlier half of the verse. The vocative case in both these phrases is to be understood as सतिसप्तमी. If split, then the word विपर्यासः would not go with the तौ and hence the former has to be modified to विपर्यस्तौ as found in one of the manuscripts, which the author could luckily lay his hands on. But this reading is neither warranted nor desirable.

gharmavṛddhirapāṃ prasthaḥ kṣapāhrāsa udaggatau ।
dakṣiṇetau viparyāsaḥ ṣaṇmuhūrtyayanena tu ॥

The increase of daytime and decrease of nighttime is [the time equivalent of] one *prastha* of water [in the clepsydra per day] during the northward course [of the sun]. They are in reverse during the southward course. [The total difference is] 6 *muhūrtas* during a half year.

The second verse (Ṛg-vedic recension v.22 and Yajur-vedic recension v.40) reads:

यदुत्तरस्यायनतो गतं स्यात् शेषं तथा दक्षिणतोऽयनस्य ।
तदेकषष्ट्या द्विगुणं विभक्तं सद्वादशं स्याद्दिवसप्रमाणम् ॥

yaduttarasyāyanato gataṃ syāt śeṣaṃ tathā dakṣiṇato›yanasya ।
tadekaṣaṣṭyā dviguṇaṃ vibhaktaṃ sadvādaśaṃ syāddivasapramāṇam ॥

[The number of days] elapsed in the northward course or remaining in the southward course is doubled, divided by 61, and added to 12. The result is the length of daytime [in terms of *muhūrtas*].

The above rule can be expressed as follows:

$$T = (12 + \frac{2}{61}n) \qquad (1)$$

where T is the length of daytime in terms of *muhūrtas* and n is the number of days elapsed from or remaining until the winter solstice. One *muhūrta* is 1/30 of a civil day or 0.8 hours. Thus from the above equation we see that according to *Vedāṅga Jyotiṣa* the duration of the day is a linear function, where the length of daytime changes by roughly one *muhūrta* during one solar month.

It may also be noted that according to formula (1), the ratio of daytime and nighttime is exactly in the proportion 2:3 at the time of the winter solstice. This proportion is akin to the one given by Mesopotamians and seems to be valid around the latitude 35° N. David Pingree conjectured that this value was borrowed from Mesopotamia during the Achaemenid occupation of the Indus valley (Pingree, 1973). Although this latitude, which passes through Kashmir, was not inaccessible for ancient Indian people, this proposition according to Ôhashi is not tenable, and he presents the following arguments (Ôhashi, 1993; 2019):

> … that formula (1) was not obtained by the interpolation of the *Jyotiṣa-vedāṅga* observations at the solstices, but by the extrapolation from the observations of the length of daytime around the equinoxes. Practically, there are two possibilities:
>
> 1. If the formula were obtained from one *muhūrta's* difference of the length of daytime during one solar month after the equinox, the most suitable latitude for this observation would be around 27° N.
> 2. If it were obtained from two *muhūrtas'* difference during two solar months, the most suitable latitude would be around 29° N.
>
> From the above consideration, I conclude that the *Jyotiṣa-vedāṅga* was produced at the latitude 27–29° N or so in north India (most probably the western part of the plain of the Gaṅgā where later Vedic people resided) without apparent foreign influence.

We find that Ôhashi's arguments are mathematically spot on, as we plot the linear function (1) and compare it to the actual lengths of the duration of days for various latitudes. Figure 1 graphically represents the variations in the actual length of the duration of the day from the winter solstice to the summer solstice at specific latitudes and also charts the linear function of the equation (1).

The length of the day for observers at different latitudes, at any location on the earth can be computed by calculating what is known as the ascensional difference given by the equation:

$$\text{Ascensional difference} = \sin^{-1}(\tan\varphi \tan\delta) \qquad (2)$$

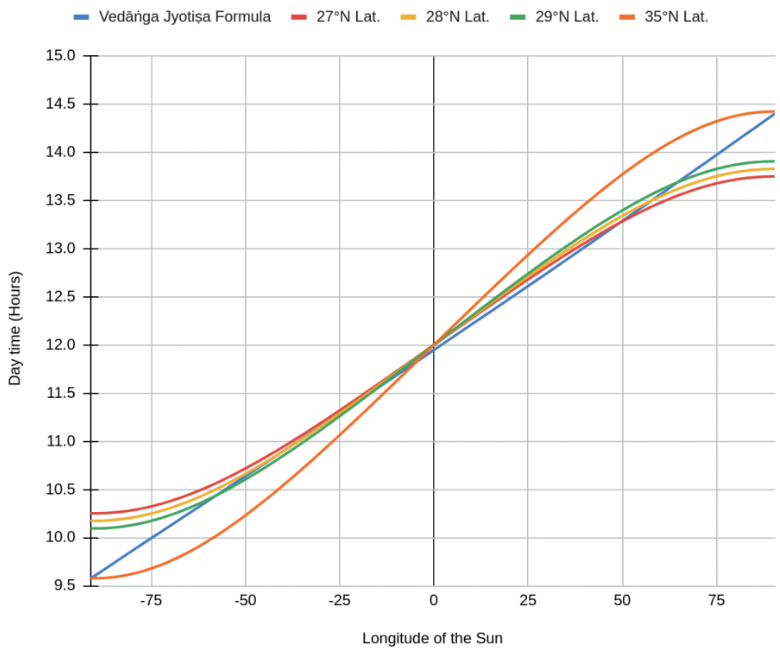

Figure 1. Annual variation of the length of day time

where φ is the latitude of the observer and δ is the declination of the sun. The magnitude of the ascensional difference when added to or subtracted from 6 hours gives the half-duration of the day.

The declination of the sun is conventionally taken to be positive when it is in the northern hemisphere and negative when it is in the southern hemisphere. It is computed using the formula $\delta = \sin^{-1}(\sin \varepsilon \sin \lambda)$ where ε is the obliquity of the ecliptic and λ is the longitude of the sun. For different latitudes, the length of a day's duration in hours has been plotted against the longitude of the sun in Figure 1. It is noted that the plot for latitude 35° N, though coincides with a straight line at the end-points, deviates significantly from the linear function in most places. However the plots corresponding to latitudes between 27° and 29° N are in close agreement with it.

To determine the latitudes that best correspond to the linear equation given by (1) in the *Vedāṅga Jyotiṣa,* we found the absolute difference between the change in the actual duration of the day computed using (2) and the change given by the linear function, and plotted the values, as it would give an estimate of the latitude for which the error is minimal. The change of linear function obtained by differentiating (1) obviously yields a constant value of 0.026229 hours (converted from *muhūrtas*). The change in the actual duration of the day was estimated by finding the difference between the duration of two successive days. If T_i is the computed duration of the `*i'th* day in hours, during the course of the sun from winter to summer solstice, then the change in the magnitude of the duration of the day is given by

$$\Delta T_i = | T_i - T_{i-1} |.$$

The graph depicted in Figure 2 shows that the error between the durations of the days computed using the equation given in *Vedāṅga Jyotiṣa* and the actual duration is the least for a place having the latitude 28° N. This makes Ôhashi's estimates to be highly tenable thereby compelling us to ignore other arguments presented by scholars like Pingree regarding the place of origin of *Vedāṅga Jyotiṣa*. Not limiting himself to critiquing Pingree's (1973) postulations regarding *Vedāṅga Jyotiṣa,* Ôhashi (2012) also carried out investigations on various Mesopotamian sources on their zig-zag functions and the data tables in those texts. He argues that, given the option to choose, we should consider the process of extrapolation to interpret functions of ancient astronomy, as the change in duration around equinoctial days is more pronounced than the ones happening around the solstitial days.

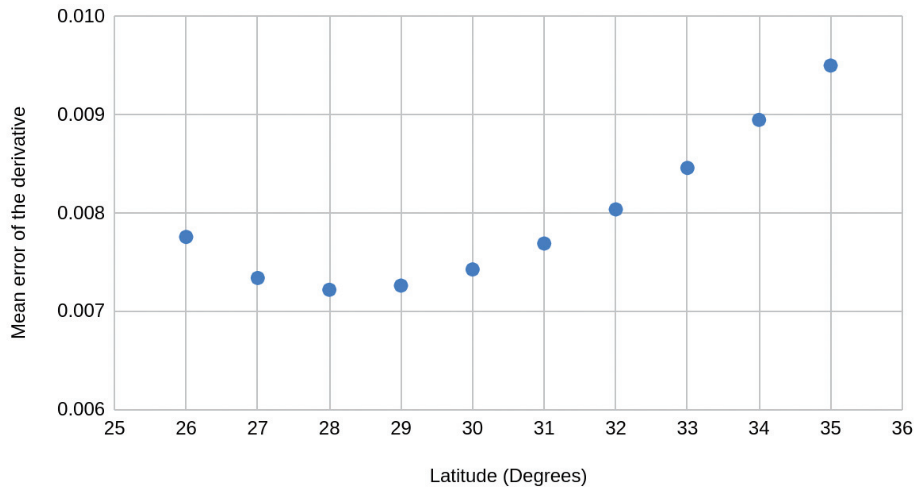

Figure 2. Error when *Vedāṅga Jyotiṣa* formula is applied to different latitudes

4 Sharp observations about the Classical Siddhānta period

Numerous historical theories have been put forward by Ôhashi in his discussions about the Classical Siddhānta, possible periods of Greek influence, the possible chronology of the key Siddhānta texts, the history and historiography of significant astronomers and mathematicians, their works, their lineage and associated schools of thought. In this section, with a couple of examples, we shall try to demonstrate how Ôhashi sheds fresh light through his original thinking, and does not merely subscribe to the views that have been promoted by various scholars in the past.

Scholars have time and again stated that the Greek horoscopy that was at some point introduced into India is evidenced in the *Yavana-jātaka* (CE 269/270) of Sphujidhvaja. [For its text and English translation, see Pingree (1978). Also see Shukla (1989).] The Sanskrit word *"Yavana"* is taken to refer to the Greeks. In his comments on the prominent influence of *Vedāṅga Jyotiṣa* based thought processes in this text, he shares the following:

> Only its last chapter (Chapter 79) is devoted to mathematical astronomy. The text tells that "the instruction of the Greeks" (*Yavana-upadeśa*) is explained there, but the developed Greek geometrical astronomy (epicyclic theory, etc.) is not found there. In contrast, according to my study, certain theory which is of the stage of Indian *Vedāṅga* astronomy is found there.

In short, Ôhashi presents an alternative narrative to that of Pingree. His argument is based on the formula given for the diurnal variation of the gnomon shadow in *Yavana-jātaka* (Chapter 79 verse 32) by contrasting it with the Mesopotamian formula. His analysis brings out that the Indian formula was developed from observational data at the summer solstice in north India (particularly at the Tropic of Cancer), while the Mesopotamian formula may have originated from the observational data at the equinox in Mesopotamia.

Some of his conclusions and historic comments are debatable, nonetheless, his study of this period is exhaustive in covering the different astronomers and mathematicians of the Classical *Siddhānta* period. His appendix on the anonymous author of the *Sūrya-siddhānta* and its commentators is noteworthy.

Although the *Sūrya-siddhānta* is one of the most popular works of astronomy written in Sanskrit, its author is not known. Based on his widespread reading and deep thought, Ôhashi postulates that there are two different *Sūrya-siddhāntas* that have come down to us. One is a text of the Ārdharātrika school of Hindu Classical Astronomy, which has been summarized in the *Pañca-siddhāntikā* of Varāhamihira (sixth century CE) but is no longer extant. According to Ôhashi, the other is the "modern *Sūrya-siddhānta*" (the version commonly referred to by simply *Sūrya-siddhānta*), which is the fundamental text of the Saura school of Hindu Classical Astronomy.

Ôhashi perseveres to date this text by examining external and internal evidences. His study leads him to the analysis that the quotations of the *Sūrya-siddhānta* in Bhaṭṭotpala's commentary (latter half of the tenth century CE) on the *Bṛhat-saṃhitā* of Varāhamihira (sixth century CE) are not found in the modern *Sūrya-siddhānta*. On the other hand, Mallikārjuna Sūri's commentary (1178 CE) on the (modern) *Sūrya-siddhānta* is extant, and so he says the (modern) *Sūrya-siddhānta* must have existed at that time. Referring to internal evidence, Ôhashi states that the position of the planets calculated by the (modern) *Sūrya-siddhānta* is most close to the actual planets around the eleventh century CE.

More than his efforts to date the *Sūrya-siddhānta*, what stand out are his careful readings of the text from various sources and commentaries. We noted earlier how appreciative Ôhashi was about the meticulous approach of Prof. Shukla in presenting different readings in all the editions of important works that he has brought out. Perhaps it was the training that Ôhashi received from Prof. Shukla that would have enabled him to embark upon his own research journey as well, which is quite evident from his writings.

There are several commentaries on the *Sūrya-siddhānta*. Ôhashi provides the authors who are known to have written commentaries which includes Mallikārjuna Sūri (1178 CE), Caṇḍeśvara (1185 CE), Madanapāla (end of the fourth century CE), Parameśvara (1432 CE), Yallaya (1472 CE), Rāmakṛṣna Ārādhya (1472 CE), Bhūdhara (1572 CE) and Tamma Yajvan (1599 CE). Among them, the commentary of Parameśvara has been published by his own mentor (Shukla, 1957). He also states that the most popular version of the *Sūrya-siddhānta*, that is in vogue, is the text with Raṅganātha's commentary (1603 CE). Having carefully studied different manuscripts of the text with commentaries, Ôhashi notes the following (Ôhashi, 2019):

> … a detailed comparative study of the different versions of the text is needed. I shall give one example here. In Raṅganātha's version of the *Sūrya-siddhānta* (XIII.21), the sand clock is mentioned, where the word *"reṇu-garbha"* (sand-receptacle) is used. However, in all other earlier versions which I listed above except for that of Mallikārjuna Sūri whose relevant portion has not been available to me, the word *"veṇu-garbha"* (bamboo-receptacle) is used there, and it is only a description of a kind of water clock. Apart from the *Sūrya-siddhānta*, the earliest Sanskrit work which mentions the sand clock is the *Yantra-prakāśa* (1428 CE) of Rāmacandra, and the second is the *Sundara-siddhānta* (1503 CE) of Jñānarāja. As Raṅganātha is later than both of them, it is not surprising if he was familiar with the sand clock.

We mention this primarily to indicate the amount of meticulous work done by Ôhashi by way of looking into the details that are available in various manuscripts — which are not easy to read, unlike the printed versions of the text.

5 Outstanding contributions on astronomical instruments of India

The second field where Ôhashi's achievements are remarkable is in tracing and documenting the history of astronomical instruments in India. The main part of his dissertation dealing with this topic was published in IJHS Vols. 29 (1994) and 32 (1997) as mentioned earlier. In IJHS Vol. 29 he analyzed Sanskrit texts dealing with astronomical instruments beginning with the *Āryabhaṭīya* of Āryabhaṭa (b. 476 CE) until Bhāskarācārya's *Siddhāntaśiromaṇi* (twelfth century). The work done as part of his doctoral thesis is one of the most informative resources in the domain of astronomical instruments in India.

In the *Vedāṅga* astronomy period, the gnomon (*śaṅku*) and the water clock are the only two astronomical instruments clearly known to have been used. The *śaṅku* was used continually in the later Siddhānta period. The relationship between the length of the gnomonic shadow, the latitude of the observer and time seems to have been developed in this period. A special chapter titled *Tripraśnādhyāy*a in the *Siddhāntas* was devoted exclusively to dealing with this subject. Some of the key astronomical instruments belonging to this period, their utility, and the principles behind their operation have been nicely brought out by Ôhashi.

(1) Instruments from the Classical Siddhānta period that have been studied by Ôhashi

The staff (*yaṣṭi-yantra*) is a stick that was used to sight an object that is far off—celestial or terrestrial. There are some variations of the staff, such as the V-shaped staff for determining an angular distance with the help of a graduated level circle. The circle-instrument (*cakra-yantra*) is a graduated circular hoop or board suspended vertically. The Sun's altitude or zenith distance is determined by this instrument. This is particularly useful as the local sidereal time can be calculated from it with reasonable accuracy. Variations include the semi-circle instrument (*dhanur-yantra*) and the quadrant (*turya-golaka*).

A circular board kept horizontally with a central rod is the chair-instrument (*pīṭha-yantra*), and a similar semi-circular board is the bowl-instrument (*kapāla-yantra*). The Sun's azimuth is determined by them and time is roughly calculated from them. A circular board kept in the equatorial plane is the equator-instrument (*nāḍīvalaya-yantra*) and it serves like an equatorial sundial. The combination of two semi-circular boards, one of which is in the equatorial plane, is the scissors-instrument (*kartarī-yantra*).

The armillary sphere (*gola-yantra*) in India is found to have been based on equatorial coordinates, and is different from the Greek armillary sphere, which was based on ecliptic coordinates, as discerned by Ôhashi. He also postulates that it was probably used to determine the celestial coordinates of the junction stars of the lunar mansions.

Ôhashi states that the water clock (*ghaṭī-yantra*) had been widely used until recent times. Unlike the water clock of the *Vedāṅga Jyotiṣa* period (which was outflow type), the water clock of this Classical Siddhānta period was a bowl with a hole at its bottom floating on water, where water flows into the bowl and it sinks after a certain time interval. The board-instrument (*phalaka-yantra*) invented by Bhāskarācārya and described in *Siddhāntaśiromaṇi* is a rectangular board with a pin and an index arm, used to determine time graphically from the Sun's altitude. Ôhashi states: "this is an ingenious instrument based on the Hindu theory of gnomon."

In addition to discerning these instruments from various source texts, Ôhashi also provides a visual treat through his meticulous diagrams that make the reader have a feel for the instrument as per the description in the texts. These diagrams that are so neatly drawn and aesthetically pleasing to see only show how passionately Ôhashi had carried out this study. A sample of the sketches that are hand-drawn by Ôhashi is presented in Figure 3.

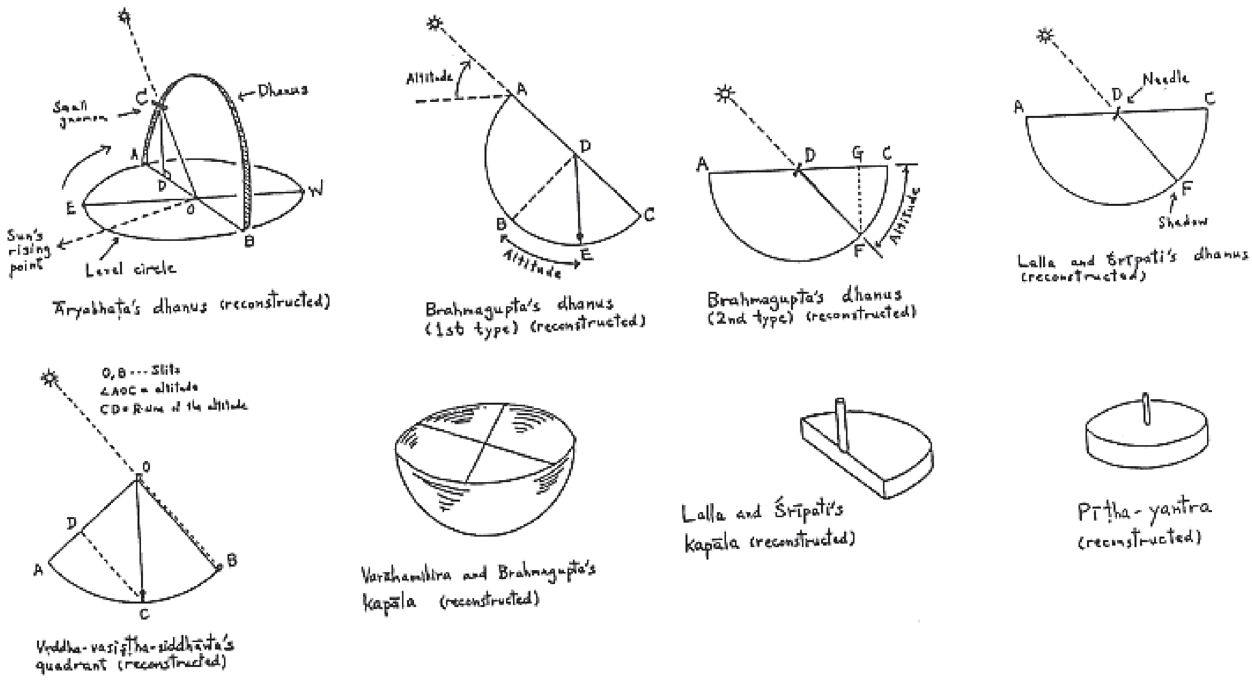

Figure 3. Astronomical instruments of Classical Siddhānta period sketched by Ôhashi (2019)

(2) Eye for detail

The "Notes and References" sections that appear at the end of each of his three papers based on his thesis are replete with evidence from which we can infer the countless hours spent by him in studying Indian astronomical works. In addition to listing references subsection-wise, these notes sections are filled with details about the manuscript folios that he was referring to, and how he came to know of some more later, discussions about emendations, mathematical notes wherever needed, and in some cases, his unreserved opinions and critiques as well. A few instances showcase some of the interesting insights obtained by him while describing Sanskrit phrases that could be apparently confusing and at times even misleading.

For instance, in his paper on the Astronomical Instruments in Classical Siddhāntas he has provided notes for his critique of the erroneous translation of a phrase "*śaṅku-dviguṇa-mānena*" by Bruno Dagens (1970) [p. 186]. This phrase has been translated by Dagens to mean that the diameter of the level circle to be drawn is double the length of the gnomon. Ôhashi argues by supplying internal as well as external evidence that it refers to the measure of the string that is taken to draw the level circle, and hence it is indeed the radius that is twice the length of the gnomon and not the diameter.

Now, what is interesting is that, Ôhashi has picked up the rationale provided by Dagens in the footnote that is originally in French and has presented a translation of it and says why it is an incorrect rationale. In his final notes section, he supplements the translation of the French reading with the original text in French [p. 305]. In another instance, in the notes section of his paper on the astrolabe in India, Ôhashi states that he has been referring to an English translation of a Russian text on stereographic projections and that he says that "I have borrowed some sentences and some ideas regarding the drawings from this book" [p. 291]. Securing these meticulous details when there was no internet and other easy modes of communication are highly commendable and clearly demonstrates the passion he had for research.

(3) Instruments and observatories in Post Siddhānta period

In his article published in Vol. 32 of the IJHS, Ôhashi offered detailed explanations of the astrolabe that was prevalent during the Delhi Sultanate. The astrolabe, which was called *yantra-rāja* (king of instruments), was one of the most popular astronomical instruments in those days. In this paper Ôhashi thoroughly expounds on the projection method pertaining to the astrolabe in general and also summarizes the history of astrolabe beginning with the *Yantrarāja* (1370 CE) of Mahendra Sūri.

The main part of this paper is on the *Yantrarāja-adhikāra* of Padmanābha (1423 CE). Ôhashi prepared the first critical edition of the Sanskrit text using two manuscripts belonging to the University of Lucknow and he provided English translation and commentary of the whole text. This is undoubtedly a monumental work in the history of astrolabe in India. Noting what makes Padmanābha's work very special, Ôhashi (2019) observes:

> During the reign of Fīrūz Shāh (reign ad 1351–88), the third Sultan of the Tughluq dynasty of India, the astrolabe was introduced into India from the Islamic world…
>
> The significance of Padmanābha's *Yantra-rāja-adhikāra* is that he explained the principle of the astrolabe using Hindu traditional mathematics. This fact shows that the astrolabe was well understood by Hindu astronomers soon after its introduction.

Even the design of the astrolabe seems to have been different from the ones that were designed in the West at that time, where the center of the astrolabe is the North Pole, whereas the center of Padmanābha's astrolabe seems to have the South Pole. Padmanābha is known to have composed the *Dhruva-bhramaṇa-yantrādhikāra* (Chapter 2 of his *Yantra-ratnāvalī*). This is a description of a kind of nocturnal, where time can be obtained from the direction of α and β Ursae Minoris. These unique facets and details of the various layers of the astrolabe, the application of stereoscopic projection have all been brilliantly discussed by Ôhashi, with the help of intricate

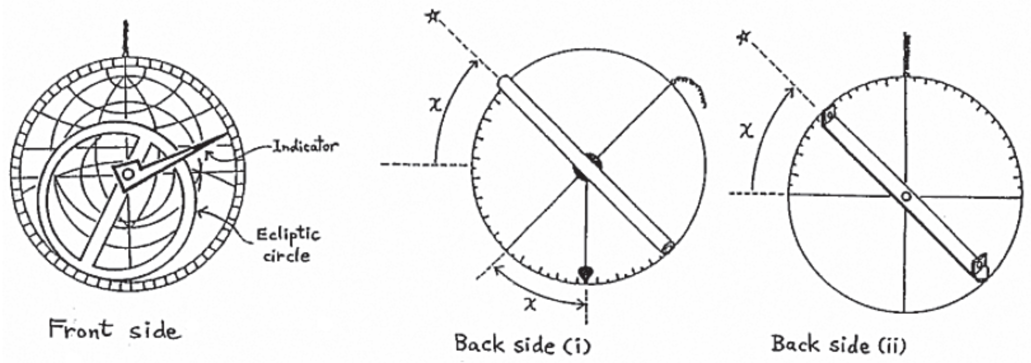

Figure 4: Sketches of the astrolabe of Padmanābha (Ôhashi, 2019)

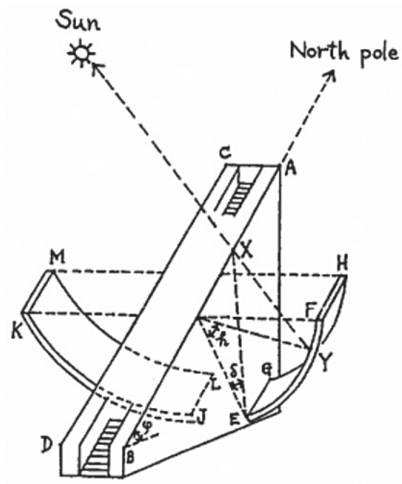

Figure 5: Ôhashi (2019) presents a picture and explains the principle of the *Samrāṭ-yantra*

diagrams and mathematical notes.

Ôhashi also had a keen interest in studying the traditional astronomical observatories that were built during the first half of the eighteenth century by the then Mahārāja of Jaipur, Sawai Jai Singh (reign 1699–1743 CE). Jai Singh's observatory is extant in Jaipur, Delhi, Banaras and Ujjain. His observatory in Mathura has already succumbed to the perils of neglect. Of these observatories, the one in Jaipur is the largest. Among the several instruments in Jai Singh's observatories, the most famous instrument is probably the *Samrāṭ-yantra* (lit. "emperor instrument"). The nomenclature of this instrument can be understood in two ways–based on its size and its utility. It is the most gigantic instrument, from which one could directly read the local sidereal time of the day, fairly accurate to minutes. It is essentially an equatorial sundial.

Ôhashi has explained the astronomical aspects of this historically significant observatory along with a well-annotated diagram that helps capture the different measurements that can be made in this observatory. Figure 5 captures the diagram given by Ôhashi. Here, φ is the latitude of the observer, δ is the Sun's declination and *h* is the Sun's hour angle. In the afternoon, the shadow of the gnomon (AB) is cast on the quadrant (EFGH), and its position (Y) indicates time. In the forenoon, the shadow of the gnomon (CD) is cast on the quadrant (JKLM). The position (X) indicates the Sun's declination.

III Concluding Remarks

In this paper, we have made an honest attempt to provide a glimpse of Ôhashi's remarkable passion and exceptional artistic skills in trying to bring out various facets of Indian astronomy. His pioneering work on Indian astronomical instruments is outstanding. A cursory view of his works is a testament to his rigorous research, enormous patience to draw meticulous sketches and graphs, ability to learn many languages, connect-the-dots across several traditional knowledge systems and mathematical prowess combined with his acumen in history. Unlike other historians, Dr. Yukio Ôhashi could work on the contributions made by various civilizations including but not limited to Indian, Chinese and Tibetan astronomy.

The snippets from his research highlighted in this tribute are but a fraction of his lifetime's works, limited to only Indian astronomy. More importantly, Dr. Yukio Ôhashi had courageously challenged the work done by some of the well-established historians of science such as Pingree and Neugabauer. It is quite unfortunate that Dr. Yukio Ôhashi passed away at just sixty-four years of age, while the life expectancy in Japan is usually greater than eighty years. Though his academic career did not turn out the way he/we would have liked, his scholarship has been top-notch and it is important that the rest of the academic community, and especially young scholars draw inspiration from the fertile research works of Ôhashi.

In his "Reminiscences of Prof. K. S. Shukla", Ôhashi (2019) wrote the following just a couple of years back:

> My life in India was my most exciting period. Now I am nearing the age of retirement. I was so lucky that I could study in India as a student of Prof. Shukla. Though I am writing this paper as his student, I am one of you. We shall study the history of Indian astronomy and mathematics, and exchange information. I am old, but I would very much wish to correspond with young researchers!

Those words resonate with the jubilant spirit, eagerness and passion with which he has approached this field of research. To young scholars too, in the very same article, Ôhashi has left behind an important message:

> … there are several modern manuscripts in Nāgarī script on foolscap. Still now, there must be several unstudied manuscripts in regional scripts or regional languages in local libraries etc. They are worth studying, but I, an old foreigner, cannot engage myself anymore to study them. I hope some young Indian researchers do research on the regional development of mathematics and astronomy in India!

Though Dr. Yukio Ôhashi is no longer with us, I truly believe that his works would continue to inspire young scholars and fulfill his dream in the years to come. In Ôhashi, Mother India found a son who could shed light upon significant aspects of her glorious scientific heritage for the benefit of the world. Needless to say, India truly misses this versatile scholar and dedicated researcher. We wish *sadgati* to this departed *ātmā*!

Finally, I would like to thank the organizers of the conference, particularly Mitsuru Soma for providing an opportunity to recall the works of Ôhashi. It is important we reminisce Ôhashi for his brilliance and versatility in research and pay tribute to his legacy as an exceptional scholar, for it may inspire many more in this interdisciplinary field to take up grand research questions audaciously and pursue them rigorously.

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