e-mails was very helpful for me trying to understand the observational records from India. I got an opportunity to meet him in 2017 during a conference organized at NAOJ, Mitaka, by Profs Tanikawa and Soma. The meeting turned out to be very eventful giving me an opportunity to discuss the observations of stars and planets from India. His expertise on astrolabes, their construction and observational details helped me in my pursuit. His small back of the envelope sketch to explain the difference between the *yāmya* and *soumya* astrolabes (southern and northern) displayed his skill in drawing and his beautiful handwriting. The route map he prepared for a location in Shibuya was perfect down to the details of stations for change of train, platform and direction (indicated by the name of the next station).

Yukio was active in Commission C3 of the IAU for history of astronomy. He also was a member of the Executive Committee of the International Conference on Oriental Astronomy (ICOA), and he served on the Editorial Board of *Journal of Astronomical History and Heritage*. He was practically involved in every effort at the international level related to studies of astronomy in South East Asia. Orchiston has compiled a long list of his publications which include important papers in the international meetings on Indian astronomy[4].

Ôhashi was dedicated to reply to requests and meeting deadlines and to his educational commitments to the day before his death in October 2019. The small group of Indian astronomy enthusiasts will miss him for the expert comments as well as a good unassuming friend. We have also lost his authoritative book on *Classical Indian Astronomy* which was about to be finalized[4].

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B. S. SHYLAJA

Jawaharlal Nehru Planetarium,
T. Chowdaiah Road,
Bengaluru 560 001, India
e-mail: shylaja.jnp@gmail.com

Sundaresan Naranan (1930–2019)

Prof. S. Naranan belonged to the first generation of scientists in TIFR who pioneered development of Experimental Cosmic ray Physics that laid a solid foundation for the growth of experimental cosmic ray studies and investigations in high energy physics, for which TIFR came to be known internationally. With his demise, that era of TIFR has come to an end. Naranan was a close colleague of the late B. V. Sreekantan, and both played major roles in developing experimental Cosmic Ray and X-ray Astronomy in India. His other significant achievements include: (i) Discovering new applications of physics-based models for Information Theory/Bibliometrics and quantitative linguistics. (ii) Applying laws of statistics and mathematics to several topics. His publications on these diverse topics include, 'Arithmetic of Quotas' the 'Elephantine (Diophantine) equation', 'Kaprekar constant', 'Universal calendar', and the 'A statistical study of failures in solving crossword puzzles'. For the latter, he meticulously analysed 35 years of his own data from solving the Hindu Crossword Puzzles! (iii) 'Kolams' are an ancient South Indian art and tradition. He created and published kolams based on the Fibonacci number series.

Naranan was born on 17 April 1930 in Kattupputtur, near Tiruchirapalli, Tamil Nadu. He obtained his BSc, with first

rank from Utkal University in 1948. He chose Banaras Hindu University for advanced studies, and learned experimental spectroscopy from R. K. Asundi, and graduated in MSc (Physics) with record marks – 198/200.

The 1940s was marked by establishment of key institutions for developing India's science and technology. Naranan was among the pioneering group of scientists that Homi J. Bhabha recruited to establish the Tata Institute of Fundamental Research (TIFR). Notably, Naranan was the last PhD student of Homi J. Bhabha, and he worked closely with Sreekantan on cosmic rays. Naranan designed electron, mu_meson, and hadron detectors, and defined detector array layouts for the experiments. He also made comparisons between theory and experiment. He studied effects of cosmic rays in deep underground sites such as Kolar Gold Fields (KGF), under water (Sathanur Dam), in a tunnel (Khandala), and in Ootacamund. His PhD work on the interactions of muons in cloud chambers confirmed Bhabha's hypothesis on the Penetrating Component of Cosmic Radiation (1937). Later, Naranan contributed substantially to the TIFR team's findings on very high energy interactions ($>3 \times 10^{14}$ eV). Notably, this work contributed to the inference of creation of heavy nuclear active particles ($>10^{16}$ eV interactions), both from

arrival time structure and muon observations.

In 1962, collaboration between MIT and AS&E led to the discovery of Sco X-1, the first non-solar X-ray source in the universe, in a rocket flight experiment. Between 1967 and 1970 Naranan was a Visiting Scientist (MIT), and he participated in the MIT rocket-borne X-ray astronomy experiments that studied new X-ray sources. He also contributed to the development of Star Sensor algorithms for aspect measurement for the first X-ray astronomy satellite UHURU, being developed by AS&E. He also contributed significantly to GEMINGA, HB3 supernova remnants, and X-ray pulsing objects like Her-X1, SMC-X1. Upon returning to TIFR, Naranan and colleagues initiated the X-Ray Astronomy–rocket launching programmes from Thumba and Sriharikota. Sreekantan and Naranan were principal investigators of the early X-ray astronomy projects sanctioned by ISRO. One project identified X-ray sources with 2 Centaur rockets, while the other measured the distribution of soft X-rays in a very low energy band (0.1–2 keV) using 2 RH-560 rockets.

Between 1955 and 1985, TIFR's Cosmic Ray Astronomy programme also expanded. Data were gathered from cloud chambers and air showers, and Sreekantan assigned the KGF Air Shower Experiment to Naranan. At KGF, Naranan and colleagues worked on penetrating particles, observing and interpreting high energy mu mesons from cosmic ray interactions and decay in the atmosphere, as also from cosmic neutrinos. Naranan was also involved in experiments for detection of neutrinos produced in the atmosphere by cosmic rays. This led to the setting up of Proton Decay experiments at KGF mines, from which proton life time limits were deduced.

While working on astronomy, Naranan realized he could apply Fermi's model for Cosmic Ray particles to Bibliometrics/Information Science. He developed a model for Bradford's Law, a power law-based on the exponential growth in time, of the number of journals in a given field of science, and the concurrently similar growth in the number of papers carried by individual journals. His power law model for this 'back-to-back exponential growth', led to his most cited paper in the *Journal of Documentation*, 1971. Notably, this model was extended to other statistical laws, and is cited as 'Naranan's theorem' (L Egghe, U-Hasselt, Belgium). Naranan and the late Balasubrahmanyan (a former TIFR colleague), explored the application of power laws to language texts, the Indus Script, DNA sequences, and evolutionary genetics. Their fruitful collaboration led to 12 papers on applications of physics-based models and Information Theory, to linguistics and genetics (1992–2006). Two of these papers were published in *Current Science* (1992).

From a young age, Naranan was fascinated by 'kolams', the South Indian folk art of lines drawn around a grid of dots. He developed kolams based on the Fibonacci series of numbers (1, 1, 2, 3, 5, 8, 13, 21...). Kolams of different sizes and shapes were made from small symmetric modules, and this recursive process led to computer-aided-design of very complex Fibonacci based Kolams. In 2010, Martin Gardner, the leading, celebrated exponent of Recreational Mathematics, described these kolams as 'beautiful – deserves to be published', a few months before his demise. In 2019, Naranan was invited to contribute to a special issue on 'Mathematics and Sociology' in the Dutch Mathematical journal (*Nieuw Archiefvoor Wiskunde*). His paper entitled 'Kolam Designs based on Fibonacci series', was published two months before his demise.

Naranan collaborated extensively with MIT, NASA and NRL (Naval Research Lab), and could have settled in the USA. However, he always 'preferred to work at TIFR'. He retired from TIFR in 1992 as Professor of Physics after 42 years of research. His output as senior author, co-author and collaborator, include 39 papers on Cosmic Rays, 46 in X-Ray Astronomy, 12 in Quantitative Linguistics, and 16 papers on other topics. Full texts of most of his papers are available (https://www.researchgate.net/profile/S_Naranan).

VENIL N. SUMANTRAN

Kottivakkam,
Chennai 600 041, India
e-mail: venil.sumantran@gmail.com