Indian Journal of Radio & Space Physics
Vol. 15, October & December 1986, pp. 375-380

Evolution of Research in Different Astronomies in India

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The evolution of astronomical studies is reviewed with special reference to important achievements on Indian soil since the introduction of telescopic observations in the early seventeenth century. Important activities in nineteenth and early twentieth century in theoretical and observational astronomy have been covered. The growth of non-optical methods of observations and their applications by scientists in India have been briefly described. The paper also summarizes the present state of astronomical research in the country.

Astronomy is a very old science. In fact it arose from a series of the oldest questions that the human mind was confronted with in trying to understand Nature. The incisive logical thinking to understand the seasonal changes of the sun, the waxing and waning phases of the moon, the regular pattern of movements of the planets, the nature of the star-studded deep dark skies, has been helpful in building up the edifice of present knowledge in the field.

India has been a seat of learning over the ages. Along with other branches of natural philosophy, pondering over the science of celestial objects had engaged the attention of our ancient sages. In this paper, instead of tracing the ancient history, including the golden age of Indian science between the fifth and twelfth century A.D., I shall deal only with the happenings in more recent times, starting with the introduction of new techniques in astronomy which came from Europe.

Introduction of telescopes, in fact, overlapped with the older methods of observation in India. A magnificent example of old instrumentation can be seen in the heart of our present day capital city of New Delhi. Jantar Mantar, as it is popularly known, is one of the five observatories set up by Raja Sawai Jai Singh of Jaipur. The entire structure and instrumentation is of brick masonry, the angular accuracy of position determination resting solely on the enormity of their dimensions. But the principle of optical imaging rendered such huge structures unnecessary; better accuracies were possible with telescopes of much smaller dimensions. Thus the huge instruments of Jai Singh's observatory became obsolete as a result of development of science.

Besides providing more accurate positional measures, the optical telescopes provided two distinct advantages, viz. (i) Intensification of the images, and (ii) Angular magnification and resolution. It enabled astronomers to see many more faint objects and to study brighter objects in detail—a feat which was not possible with the older instruments. Optical telescopes were first used on the Indian soil a few decades earlier to the magnificent endeavour of Jai Singh. Earliest reference dates back to 1689 when Father Richaud, a Jesuit Priest at Pondicherry, discovered a comet through a telescope. He also discovered that the southern bright star, alpha-centauri, was in fact a double star.

Chronologically the next important event describes the use of a small optical telescope by William Petrie, an East India Company official, for the determination of latitude and longitude of a few places in Southern India in 1786. Three years later Madras Observatory was established by the East India Company with the same set of instruments donated by Mr Petrie. A proper observatory building came up in 1792; from then onwards regular records of observations in the form of Annual Reports of Madras Observatory are carefully preserved.

Scientists at the observatory achieved several important discoveries during the next hundred years. Mention may be made of compilation of a star atlas by Taylor and discovery of five asteroids and variable nature of several stars by Pogson. It was also during this period when Chintamani Raghunathachary discovered the variable nature of the star RR Reticuli. He appears to be the first Indian astronomer on record to publish a scientific paper on astronomy using modern instruments.

Three more observatories at Lucknow, Poona and Trivandrum were also functioning during the nineteenth century. They also employed current types of equipment prevalent at that time. Lucknow observatory was patronized by the Nawab of Oudh and functioned under the directorship of Wilcox. The observatory, however, was closed down after the death of Wilcox in 1849, and the astronomical activities could not be revived. Trivadrum observatory was similarly patronized by the Maharaja of Travancore-Cochin and was started in 1837. Broun who was in charge maintained the basic activities, but his personal interest was in geomagnetism. His main discovery is now hailed as one of the fundamental principles of geomagnetism, that magnetic disturbances on earth are not localized but are worldwide phenomena. This observatory has, till today, remained in a dormant form with sporadic attempts to revive the activities from time to time.

The observatory in Poona was less fortunate in having a source of similar regular financial support. The guiding force behind the activities was Prof. Kawasji Naegamvala, a Professor of Physics at the Elphinstone College in Bombay, who used to collect donations to run the observatory. One of the chief donors was Maharaja Takhtsinghji of Bhavnagar who contributed the nucleus of a fund from which a 20-in reflector telescope was purchased and installed. After the death of Naegamvala, the source of funding completely dried up and the observatory was closed down in 1912. The 20-in telescope was sent to Kodaikanal, where it lay packed in boxes, until Dr A.K. Das set it up in the early fifties. Then, this became the largest operational optical telescope in the country, and was used in the International Mars Observational Program 1954-55. After M.K. Vainu Bappu took over charge of the observatory, he made major modifications in its focal plane instrumentation, and put this into regular observational programmes. Two of his students got their doctorate through observational material collected by this telescope. Still later, Kodaikanal Observatory was transformed into an autonomous research institute, and a new observatory was established at Kavalur, where this telescope was shifted. Its importance at Kavalur, however, was overshadowed by larger telescopes which were installed subsequently. At the present moment, this telescope has been installed at Leh, in the Laddakh region of Kashmir, where a temporary observatory has been set up to assess the suitability of this place for a future high altitude astronomical station.

Before I move over to the narration of much more comprehensive astronomical activities of the present century, I must mention three important solar eclipses whose paths of totality crossed over India in the later half of the nineteenth century. All the three events brought in new information in astronomy. The three events took place in 1868, 1871 and 1898 The first one is a memorable one and is often referred to as the event heralding the birth of the subject of astrophysics, because, during this eclipse two teams located at two places in present day Andhra Pradesh discovered a yellow line in the chromospheric spectra which could not be due to any known element. Sir Norman Lockyear named this as Helium—the element on the sun. It was years later when this was discovered by Ramsay on the earth as a decay product of radioactive elements. This was the first instance when information about physical conditions on an inaccessible celestial source could be obtained. This observation had set the trend for observations in future eclipses.

The 1871 eclipse was also fruitful when the celebrated French astronomer Jansen discovered what is known as the F-corona. The 1898 eclipse is memorable on two counts: it was during this eclipse that a British team obtained the first ultraviolet extension of chromospheric spectra. John Evershed, who was a member of the team, had his first visit to India, where later, he was to play a very important role in astronomical achievements. Secondly, it was during this eclipse when Naegamvala successfully organized setting up of an observation camp and obtained results of importance. This was perhaps the first completely independent Indian effort for an eclipse expedition

The dawn of the twentieth century in India saw some new activities in the field of astronomical investigations. Two new observatories, one at Kodaikanal on a 8000 ft high peak near Madurai and the second one at Begumpet, in the outskirts of the twin city of Hyderabad-Secunderabad, were established. First important results came from Kodaikanal, where John Evershed discovered a very important feature of solar physics. In 1909, from precise spectroscopic investigations he discovered a systematic flow of material around sunspots. This is the famous "Evershed Effect", which has engaged the attention of scientists since that time, and which later has developed into the subject of solar magnetohydrodynamics of today.

Nizamiah Observatory at Begumpet, after its establishment, entered into an international programme in positional astronomy observations. The observatory joined the "Carte du Ciel" programme of mapping part of the celestial sphere. The observatory prepared a catalogue of 800000 stars, listing their accurate positions and magnitudes, which has proved invaluable in astronomical investigations of today Very often we hear of new sources in radio, infrared or ultraviolet regions discovered by modern techniques which are ultimately tied down to some faint stellar sources from the old catalogues, several of them in recent times have been traced to the stars listed in the Hyderabad catalogue.

Meanwhile, a rather rare celestial phenomenon kindled the interest of the intelligentsia which resulted in the formation of the first Astronomical Society of India with its headquarters in Calcutta in 1910. I am referring to the apparition of Comet Halley in that year. The society encouraged astronomical observations and started a journal. The enthusiasm, however, could not be maintained for long and no issues of the journal appeared after 1921. But during its brief existence, the issues of the journal contained scientific articles written by leading physicists of the time, like C.V. Raman and M.N. Saha.

Any description of the evolution of astronomy in India will remain incomplete without reference to the enterprising exploits of Meghnad Saha during this epoch. Calcutta, at that time, did not have any regular astronomical observatory. Two colleges, St. Xaviers and Presidency had small telescopes, but no regular programmes of investigation, and yet, one of the greatest puzzles in astronomy at that time was solved by a young scientist, working solely on the basis of his deep insight into the physical processes occurring in the outer layers of stars. Eddington had listed Saha's work on ionization theory as one of the ten most important findings in astronomy since the introduction of telescopes by Galileo.

Saha was basically a theorist, and most of the important work in astronomy was centred around his laboratory at Allahabad University Some front ranking results of theoretical astrophysics were reported in the thirties by his students; mention may be made of some of the original work on stellar interiors and on degenerate cores of white dwarfs by D.S. Kothari, R.C. Majumdar and others. Saha had dreamt of setting up of a leading centre in Laboratory Astrophysics in Allahabad, but the rapid advancement of scientific measurement technology in other developed countries, coupled with lack of adequate financial support for science by the state frustrated his plans.

Two more centres of theoretical studies grew up during the thirties at other places. The first was in Calcutta led by Prof. N.R. Sen and second by Prof. V.V. Narlikar at the Banaras Hindu University. Einstein's theory of relativity had brought in a new look at the physical happenings in the universe, and both the teams engaged themselves in solving questions in relativity and cosmology. Some brilliant pieces of original work emerged out of these endeavours; mention may be made of solution for gravitational collapse of spherical dust clouds by B.B. Datt and of rotating cosmological model by A.K. Ray Chaudhuri in Calcutta, and solutions of a radiating mass by P.C. Vaidya at Banaras.

All these years, the observational astronomy was played on a low key. Except for some solar research at Kodaikanal, and the Nizamiah Observatory's work in the "Carte du Ciel" programme no outstanding observational work was pursued. The wind of change came towards the end of the second world war; the person responsible was again, Saha, who persuaded the Government of India into action. A committee was set up to draw up a co-ordinated plan under his Chairmanship; the report was the document on which the development plans in astronomy were hinged for the next thirty-five years. Only recently, realizing the tremendous advancement achieved in the field, attempts have been made to define new thrust areas in different branches of astronomy.

Saha's recommendations covered both teaching and research. Along with the development of observatories, a strong plea was made for starting new departments of astronomy in the universities. The implementation of the latter recommendation has not been very fast, but not altogether disappointing; today, as many as 22 universities in the country teach astronomy in some form in their post-graduate classes. Saha's recommendations mainly concerned optical astronomy; but outside the committee's deliberations he made valiant attempts to start several other new branches using radio, particle and ultraviolet techniques. I shall mention these briefly at the appropriate points of context.

The period after independence has witnessed tremendous changes in activities in optical astronomy, and the pivotal role was played by a young scientist, Late Dr M.K.V. Bappu. He almost grew up in an observatory, his father being an astronomer at Nizamiah Observatory. He was an amateur astronomer at school, adopted astronomy as his profession and later became a colossus in the history of Indian astronomy. After his master's degree from the Madras University he chose a course of astronomy at Harvard and returned to India after a couple of years' post-doctoral work in various institutions in the US. His first contribution was in finalizing plans for a 48-in telescope for the Osmania University; next, he moved over to Banaras, and established a new modern observatory at Nainital and then moved over to Kodaikanal. Within a few years he established a most modern observatory at Kavalur. He was barely 28 years of age when he established the Nainital Observatory. At the age of 32 years, he was the youngest Director of the Kodaikanal Observatory. He had set the Kavalur Observatory moving before he was forty. He was unanimously elected as the President of the International Astronomical Union; he headed this world body till his premature death at the age of 55.

Bappu introduced many new ideas in observational astronomy in India. He had brought with him essential components needed to build photoelectric photometers and started photoelectric photometry with the available telescopes. He built a spectrograph and attached the same to the old 20-in telescope at Kodaikanal. He built a photoelectric scanner for direct measurement of stellar spectra and modified it later for the introduction of the first computer-controlled spectrum scanner in the country.

Within the limited funds which could be spared for astronomy, Bappu ordered a moderate-sized but highly versatile telescope from M/s Carl Zeiss. UP State Observatory at Nainital, which was originally started by Bappu, decided to repeat the order. This was met from the Uttar Pradesh State funds for scientific research, perhaps the only State in India to show such interest in basic research. Both the telescopes were almost simultaneously installed early in 1972. These two instruments are highly reliable ones and have many a time played a frontal role in observational astronomy.

At Kavalur, Bappu incorporated several auxiliary instruments, in which some of the vital components of his own design figured prominently. He brought in the first on-line computer in optical astronomy in India; the use of which accomplished several new types of observations One of them consists of fast-light-curve-recording of transient events which earned the credit of new discoveries of unknown ring structures around the planets Uranus and Saturn. For the first time in the present age, observations in India unfolded new discoveries. These definitely represented a welcome departure from the era when Indian astronomers had to play second fiddle in observational ventures. Similar growth in observational facilities was also noticed in other optical observations.

So far I have dealt with only optical astronomy, but there are good reasons for this. Astronomy using other forms of radiation came into existence quite late in human history. This is illustrated in Table 1. From the earliest times of human civilization until quite recently, the only detector available was the unaided human eye. New forms of radiation and development of their detectors have been recent phenomena.

Greatest advancement in non-optical methods of observation has been achieved in the field of radio astronomy. It was Prof. Saha in the early fifties who dreamt of taking a lead in this field. Young workers in large numbers were attracted to this new subject, which had started producing unexpected bits of information about the universe. Experimental ventures were considerably helped by availability of war-surplus stocks of electronic equipment at very low

Table 1—Development of Astronomical Techniques: A Chronology of Events

Year	Event	Significance
1610	Galileo begins telescopic observations	Limits of detection by human eye extended
1668	Newton builds first reflector telescope	Possibility of large instruments later opened
1789	William Herschel builds 48-in telescope	Beginning of large instruments
1800	William Herschel detects infrared radiation in solar spectra	Discovery of infrared
1801	Ritter detects ultraviolet radiation in sunlight	Discovery of ultraviolet
1840	Draper takes first photograph of the moon	Introduction of photography
1850	First stars photographed (Vega & Castor)	First stellar photography
1888	Hertz generates and detects radio waves	Discovery of radio waves
1891	Spectroheliograph invented	Systematic study of solar astrophysics
1894	J.C Bose demonstrates experiments on millimetre waves	Millimetre wave techniques developed
1896	Roentgen discovers X-rays	New tool for high energy astrophysics available
1901	Rutherford discovers γ-rays	Another new tool for high energy astrophysics available
1912	Hess proves extra terrestrial origin of cosmic rays	Cosmic ray astronomy begins
1917	100-in Hooker reflector at Mt Wilson	Era of large modern telescopes begins
1932	Jansky detects extra terrestrial radio waves	Birth of radio astronomy
1937	Saha describes his idea of space observatory	Conception of space astronomy
1939	Hetzler detects infrared radiation from cool stars by special photographic emulsions	Infrared photometry technique becomes operational
1946	First scientific payload launched by rocket	Birth of space astronomy; ultraviolet experiments
1948	200-in telescope completed at Mt Palomar	Telescope aperture crosses 5 m target
1955	Jodrell Bank radio dish commissioned	First large steerable radio dish
1957	Sputnik I launched	Satellite era begins
1959	Lunokhod Russian probes unveil first picture of the farside of moon	First successful space probe
1962	Mariner 2 surveys Venus	First successful planetary probe
1962	Scorpio X-ray source detected	Birth of X-ray astronomy
1968	Solar neutrino observations undertaken	Birth of neutrino astronomy
1969	γ-Ray source detected	Birth of γ-ray astronomy
1976	234-in telescope completed at Zelenchukskaya	Telescope aperture reaches 6 m target

prices, which encouraged several groups to undertake new instrumentation Subsequently most of them went abroad and worked with leading groups at different parts of the world. It was the foresight of Homi Bhabha who lured a sizable group of them back to India and thus created the radio astronomy group at Ooty V. Radhakrishnan came back to India in 1972, and built independently another powerful group around him at Bangalore. He amalgamated the active instrumentation group of Indian Institute of Astrophysics (IIA) in a joint instrumentation venture. The group at the Physical Research Laboratory (PRL) collected by Vikram Sarabhai was basically oriented towards aeronomy and adopted radio astronomy techniques in investigations of interplanetary medium. Radio astronomy experiments at the frontiers of this discipline are now done by the three instruments at Ooty, Gauribidanur and Bangalore.

Another branch of astronomy which has attracted attention is the infrared (IR) Experiments in photographic IR started at Kodaikanal in sixties and later on in the near infrared range at PRL, closely followed by scientists at the Tata Institute of Fundamental Research (TIFR) They built up IR photometers employing cooled PbS and InSb detectors and employed them at the focal plane of optical telescopes at Kavalur, Rangapur and Nainital. PRL is planning extension of the observation band from the existing 1-3 to 8-12 μm, using liquid He-cooled, germanium-doped bolometer detectors and employing a new 122-cm telescope with vibrating secondary. The telescope is in the final stages of fabrication and expected to be installed at a new observatory at Gurusikhar near Mount Abu shortly.

Considerable interest exists for observation of IR around 100 μm, which can only be done from satellites, rockets or very high-flying balloons. The IR group at TIFR, Bombay, had built up a balloon-borne IR instrument, which, unfortunately was lost after a successful flight. A second improved instrument has been built and is expected to be used for a series of launches.

The next branch in order of interest is the X-ray astronomy. Two groups in India, TIFR and ISSC (Indian Scientific Satellite Centre), Bangalore are doing these experiments. The earliest experiment was performed in 1968, when a four-channel X-ray proportional counter payload was launched in rockets to detect X-ray sources India's first satellite Aryabhata contained similar payloads. Harder components of X-rays were also detected by balloon-borne hard X-ray detectors.

Interest in this field is more widespread. Groups of theoreticians from several institutes and universities are busy modelling the structure and mechanism for X-ray emission. Simultaneous ground based optical and infrared observations are also being taken to obtain data for complete analysis; several collaborative programmes are in progress. As the amount of X-ray data from Indian instruments are insufficient, some of these collaborations presently include teams of scientists working at foreign institutions.

We have at least two groups in India doing experiments in gamma-ray astronomy. Both use the method of Cerenkov light flashes in our atmosphere when gamma ray photons interact. First is the TIFR group, whose main experimental centre is at Ooty, and the second one is the DAE (Department of Atomic Energy) group at Srinagar. Both the ventures are only a few years old.

No experimental work in ultraviolet astronomy has been done in India. There are several theoretical investigators who get all the data from foreign sources like IUE.

There are other branches of astronomy in which information contained in particle streams has been made use of. A few varieties of particles are included in these studies, of which the major ones are cosmic rays, solar wind and neutrinos. Even though cosmic rays were discovered more than seventy years ago, their origin is still shrouded in mystery. Various theories seeking to explain their sources and acceleration mechanisms have been put forth, but they have not been found entirely satisfactory. There are several groups in India which are engaged in these studies, of which the TIFR group is the most active. They have recently flown an experiment "Anuradha" on the space shuttle which was built by joint efforts of a few institutions in India

Interest in cosmic rays was very high from the early days. After the nature of cosmic origin was proved early in the second decade of this century, India has undertaken many experiments on cosmic rays. The earliest one perhaps was in 1926 when Arthur Compton of the University of Chicago collaborated with P.L. Bhatnagar of the University of Punjab at Lahore in setting up an equipment on a lake 17000 ft high in Kashmir. Saha was the first to start cloud chamber work at the Palit Laboratory in Calcutta in 1938 and later start a high altitude observing station at Darjeeling In 1956, just prior to his untimely death, he drew up an elaborate plan for cosmic ray research in which a station at 16000 ft on the Darjeeling-Lhasa road was proposed to be set up. But the plan did not materialize.

In the early fifties, cosmic ray research in different physical laboratories was widespread where attempts to deduce the nature of primary cosmic rays from measurements of secondary particles were made. The dawn of space age in the late fifties changed the situation completely. It became now possible to directly measure primary cosmic rays from satellite-borne detectors, making ground-based measurements obsolete. Only experiments like "Anuradha" remained relevant.

Emanations from the sun during disturbed periods were known for quite some time, but the steady solar wind was detected only in the space age. All experiments require satellite payloads, and have since been the exclusive concern of space programmes of the developed countries. Large number of scientists interested in the study of solar wind obtain their experimental data from such sources.

Experiments in neutrino astronomy have not yet been done in real sense in India. Among the existing problems are the solar neutrino anomaly and the missing mass of the galaxy, on which some theoretical investigations have been made.

The story of evolution of astronomy in India will be incomplete without mention of vast amount of the high theoretical work that has been done in the past and is being continued at present. The earliest example is the immortal series of papers by Prof. Saha, and later by his students in Allahabad, namely, D.S. Kothari, R.C. Majumdar and others. The Allahabad group was concerned about stellar interiors, while questions in relativity and cosmology were being tackled by N.R. Sen and his associates in Calcutta, and V.V. Narlikar in Banaras. In course of time scientists from these groups dispersed all over India and generated new schools at various institutions.

Saha's original papers were about thermodynamics of stellar atmosphere; some of his students who continued in this direction were P.L. Bhatnagar, H.K. Sen and A.C. Banerjee. S. Chandrasekhar did monumental work on radiative transfer problem; he did not return to India, but sent several of his Indian students back to continue theoretical work. Many of the existing theoretical astronomy groups are centred around such scientists at various institutions.

I have described, very briefly, the course of evolution of astronomical studies in India in our times. At this moment, India is poised for a big leap forward. Several large observing instruments have been set up, still bigger ones are coming up. Interest and confidence in areas of astronomical research are very high. There is a concerted move to expand astronomy teaching facilities in universities to draw more talent to this branch. Intrinsically, astronomy has a romantic appeal to young minds; in the past, in the absence of a proper atmosphere, we have lost several brilliant minds to other institutions abroad, who could have brought back the ancient glory of India in cosmical sciences. That did not happen then, but we have the situation considerably altered now. We may hopefully look forward to a very brilliant period of Indian astronomy in near future.