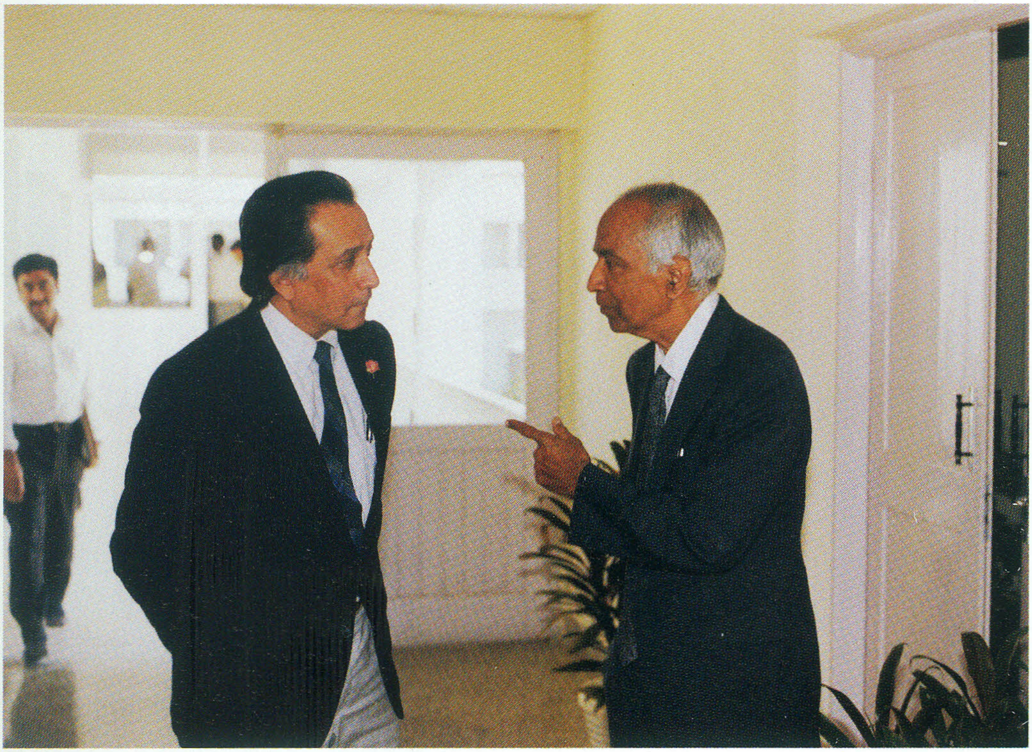
Reaching for the Stars

From Nungambakkam to Hanle



Prof. S. Chandrasekhar in conversation with Prof. R. Cowsik, during his visit to the Institute on January 11, 1993.

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From Nungambakkam to Hanle

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www.iiap.ernet.in

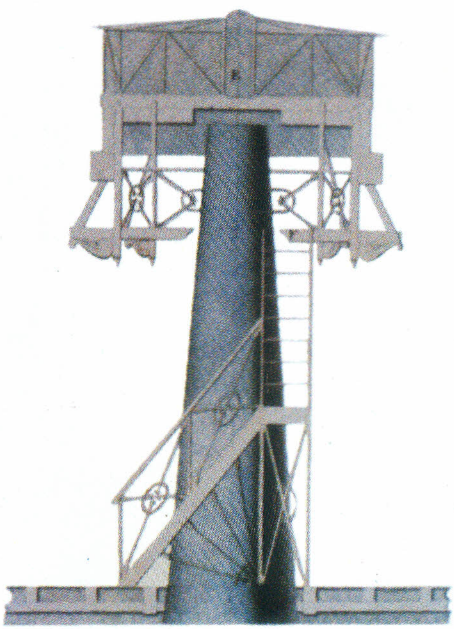
This brochure was released
on the occassion of the
Namakarana and Dedication Ceremony
of the
Himalayan Chandra Telescope
at the
Indian Astronomical Observatory,
Mt. Saraswati, Hanle, Ladakh
by
Dr. Murli Manohar Joshi
Honourable Minister for Science & Technology,
Human Resource Development & Ocean Development
Government of India
on
29 August, 2001
at
Centre for Research and Education
in Science and Technology, Hosakote
in the venerable presence
of
Shri S.M. Krishna
Honourable Chief Minister of Karnataka

Telescope astronomy then, from here

The earliest use of a telescope to observe an astronomical event from the Indian soil dates back to the 17th century, a little over 40 years later than Galileo's first astronomical use of it. The event was transit of the planet Mercury across the disk of the Sun, the observer Jeremiah Shackerley, and the place Surat. A more astronomically significant incident is the discovery of the brightest star in the constellation of Centaurus, Alpha Centauri, as being a double, by a Jesuit priest Jean Richaud in 1689 from Pondicherry. Shackerley's was an innovative use of the telescope and on the other hand Richaud's was a systematic effort who practised and taught astronomy until his last.

The observatory at Nungambakkam

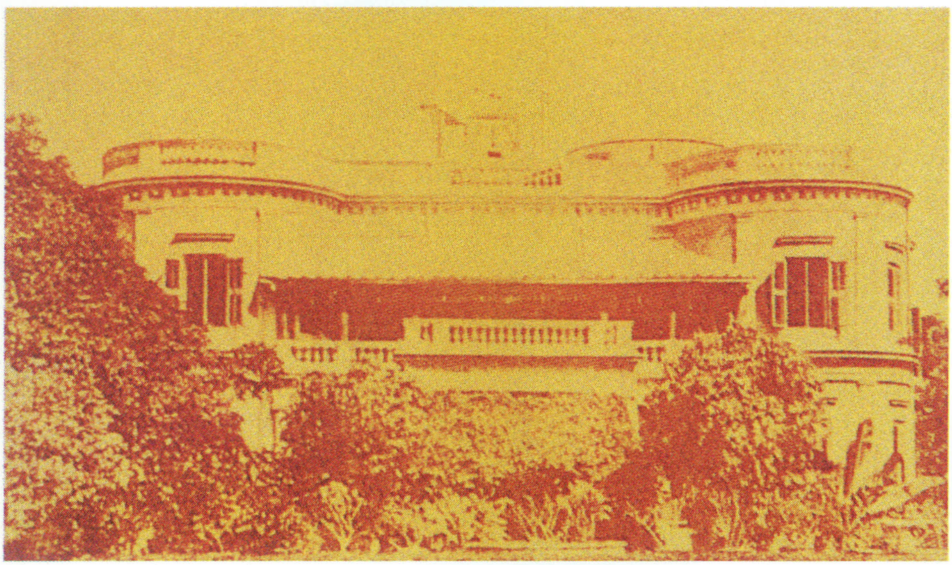
Although there were instances of occassional use of telescopes over the eighteenth century for observing astronomical events, as a regular activity, the first astronomical observatory to come up on the Indian soil was a private one. William Petrie, an officer with the East India Company established an observatory at Egmore in Madras in 1786. The company's new trained astronomer surveyor Michel Topping persuaded the company to take over the observatory for promotion of the science of astronomy. The observatory was taken over by the Company in 1790. The observatory moved over to its new premises at Nungambakkam two years later whenceforth it came to be known as the Madras Observatory. It is this observatory that evolved to the present day Indian Institute of Astrophysics.



Sketch from a 1792 manuscript of the 18 ft high granite pillar erected that year to mount the telescope. An inscription on the granite pillar illustrates the company's resolve.

The Madras Observatory initially came to serve as the reference meridian for the work on the Great Trigonometrical Survey of India. Subsequent work at the Observatory was mainly positional astronomy - recording positions of bright stars on the celestial sphere. Introduction of new instruments in the early nineteenth century enabled work of greater astronomical relevance and precision. The highlights include the preparation in 1843 by Thomas Taylor of the famous Madras Catalogue of about 11,000 stars in the southern sky, acclaimed as the best catalogue of the times and, Norman Pogson's discovery of five asteroids and six variable stars. Even his assistant, C Ragoonatha Charry, made an astronomical discovery-namely the variability of light of the star R Reticuli in 1867.

During the nineteenth century, a few observatories came up in different parts of the country. The science of astrophysics came into being with the introduction of spectroscopy and photography to astronomy in the western world, and in India, it was pursued in due course. In this regard the most notable development was the identification of a new spectral line in the solar spectrum by Norman Pogson during the total solar eclipse of 1868 from Masulipatam. This was also independently observed by the French astronomer Janssen during the same eclipse at Guntur, and by Norman Lockeyer outside the eclipse. The line could not be attributed to any known element and thus named as 'helium' by Lockeyer. The new element was isolated in laboratory years later. Madras Observatory had also conducted observations during the total solar eclipse of 1871, and the annular solar eclipse of 1872. During this eclipse, the spectrum of the solar chromosphere recorded by Pogson was the first ever at an annular eclipse.



An undated photograph of the Madras Observatory building. On top are two domes housing the 6 inch and 8 inch telescopes.

The sunny days at Kodaikanal

After the great famine of the 1870s, the emphasis changed to solar activity. By 1899, Michie Smith shifted the astronomical activity to Kodaikanal. Equipped with new instruments, and with clear skies and a favourable ambience at an altitude of about 2300 m, the Kodaikanal Observatory began work, centered round the Sun. In 1909, John Evershed made the surprizing discovery that the flow of gases in a sun spot was radial - one of the major findings made in solar physics, now named as the Evershed effect. This was in fact the first astrophysical illustration of interaction between plasma and magnetic field and has played an important role in our understanding of the physical properties of sunspots and the evolution of solar activity. During his directorship (1907-23), Evershed added lots of instruments to the Observatory. Since the year 1904, a spectroheliograph here has been in operation to take pictures of the sun on every clear day in a narrowband centered around the K-line of ionized calcium. Evershed introduced another spectroheliograph working at the wavelength of hydrogen alpha line. While the former provide information on the upper layers of the chromosphere of the sun, the hydrogen alpha pictures help us know more about the lower chromosphere. The wealth of the photographic material collected at the Observatory has a great archival value since it covers eight sunspot cycles each of 11 years period. Only at the observatories in Paris and on Mount Wilson comparable records exist. The extensive data spanning through a long period now provides a very good opportunity to study the variation in the solar rotation rate using sunspots and calcium K-line plages and variation of supergranulation size with solar cycle phase. In 1934 the Observatory received as a gift a spectrohelioscope from Mount Wilson Observatory which has been used for visual observations of the sun. A new solar tower telescope was acquired in 1958 which has served as a major equipment for spectroscopic studies of the sun.

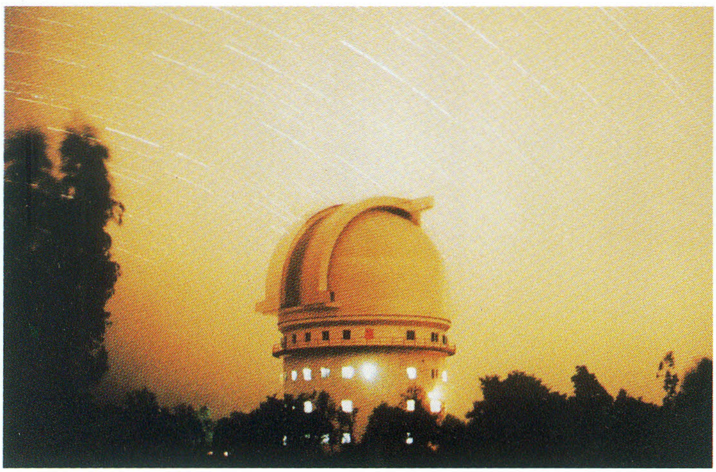
Prof. & Mrs. S. Chandrasekhar seen with Prof. M.K.V. Bappu during their visit to Kodaikanal in November 1961.

The starry nights at Kavalur

A notable phase in the history of the Kodaikanal Observatory began with the arrival of M K Vainu Bappu in 1960 as director. Until that time, the Observatory specialized in solar astronomy. There was no modern equipment to be used for intensive work in night time astronomy. One needed large telescopes and sophisticated auxiliary instrumentation to be in tune with the times. So, Bappu set about to find a suitable location which has an access to southern sky as well as proximity to centres of technology. His efforts bore fruit and an observatory was set up, in the middle of sandal wood forests and Javadi Hills at Kavalur. The beginning was humble, with an indigeneous 34 cm reflecting telescope that was put to use in 1968. Four years later a 102 cm Carl Zeiss telescope was acquired and installed.

The 1-m telescope immediately started making significant contributions through the detection of atmosphere around Ganymede in 1972, a satellite of the planet Jupiter. Uranus which was earlier known to have 5 satellites only acquired the distinction in 1977 of being yet another planet in the solar system with a ring system of its own. The rings were discovered serendipitously, while making photometric observations while Uranus occulted a star, by astronomers of the Institute and of the U.S. Later, a group of the Institute's astronomers discovered an outer ring system surrounding the planet Saturn. In 1988, a minor planet was discovered from Kavalur which has been named Ramanujan, in the memory of the great mathematician. Significant studies were made in the Observatory of the supernova SN 1987a - the spectroscopic monitoring showing enhanced nitrogen abundance in the surface layers.

Meanwhile work on an indigeneous 2.34 m telescope, the largest of its kind in Asia had started. Although the telescope was a brainchild of M K Vainu Bappu, he could not live to see it completed. The telescope was inaugurated by the late Prime Minister Shri Rajiv Gandhi on Jan. 6, 1986 who formally named it Vainu Bappu Telescope (VBT) and the Kavalur Observatory the Vainu Bappu Observatory.



Vainu Bappu Telescope building, Kavalur.

Prime Minister Shri Rajiv Gandhi with Profs. M.G.K. Menon (Chairman, Governing Council) and J.C. Bhattacharyya (Director).

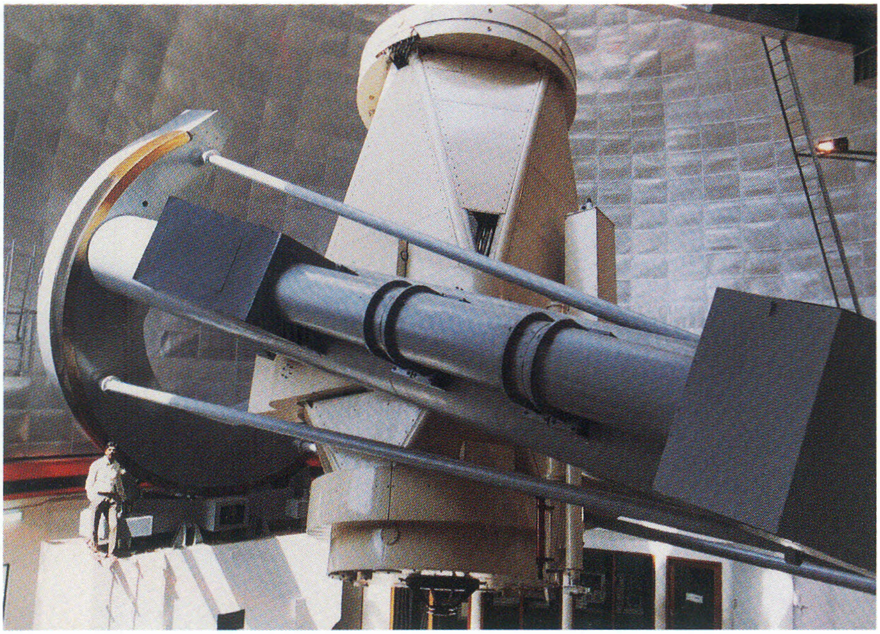
The Indian Institute of Astrophysics Today

In the year 1971, the Kodaikanal Observatory became an autonomous society, the Indian Institute of Astrophysics. The headquarters were shifted to the present campus at Bangalore in 1975. Today, funded by the Department of Science and Technology, the Institute ranks as a premier institution devoted to research and education of astronomy and physics in the country.

Vainu Bappu Observatory

About 180 km from Bangalore, the Vainu Bappu Observatory is situated in the Javadi hills of Tamil Nadu, at an elevation of about 900 metres above the mean sea level. There are four major telescopes in use at the Vainu Bappu Observatory:

- **2.34 m Vainu Bappu Telescope (VBT)** : The VBT is operated as a National Facility for Optical Astronomy. It has two foci, an f/3.5 prime focus (image scale 27 arcsec/mm) and an f/13 Cassegrain focus (image scale 6.7 arcsec/mm). At the prime focus, CCD cameras are used for imaging with various filters, whereas at the Cassegrain focus, an OMR spectrograph is used for medium to low resolution spectroscopy. A Boller and Chivens CCD spectrograph earlier used for medium to low resolution spectroscopy has been converted into a spectro - polarimeter.



The Vainu Bappu Telescope

The VBT has been used fruitfully for studying solar system objects like comets, and asteroids etc. Information on the surface and atmospheres of planets and their satellites has been obtained by studying the relatively rare mutual eclipse events. In the area of stellar astronomy, attention has been focussed on the young pre-main sequence Herbig Ae/Be type stars, star clusters, late stages of stellar evolution - born again redgiant phenomenon AGB and post AGB stars etc. With these one learns a lot about the chemical composition of the stars, their variability or even the explosive phenomena like novae and supernovae, presence of dust in their environment and mass loss etc. In such pursuits, the astronomer also takes advantage of the data obtained through the satellites in the infrared, ultraviolet and x-ray region of the electromagnetic spectrum.

The VBT is also well suited for extragalactic research work. It has been used in the study of star forming regions in nearby galaxies, surface photometry of field galaxies and clusters of galaxies, mapping of absorbing dust and H-alpha emission in elliptical galaxies, star burst galaxies, spectroscopy, photometry and polarimetry of extragalactic supernovae, afterglow of gamma ray bursts (GRB), quasars and active galactic nuclei (AGN).

The other telescopes in use are, respectively, 1 m Carl Zeiss telescope, 0.75 m telescope, 0.45 m Schmidt telescope and also a 34 cm telescope.

Kodaikanal Observatory

Located at an elevation of 2343 m, where clear skies and a peaceful atmoshere together provide an ideal work place, the Kodaikanal Observatory is predominantly active in the area of solar observations. Here, the main facilities are:

- **The solar tower telescope** made by Grubb Parsons which was installed in 1960. Here a system of three extremely fine quality 60 cm diameter mirrors direct the light of the sun into a 60 metres long underground tunnel onto a 38 cm, f/90 achromat (focal length 36.5 m), a lens which forms

a 34 cm diameter image of the sun and which provides a high spatial resolution (5.5 arcsec/mm). It is also equipped with a Littrow type spectrograph and a spectroheliograph with a spectral resolution of 10 mA in the 5th order and a high spectral dispersion of 9 mm /A in the 6th order blue. The solar spectra enable one to understand the magnetic field in the sunspots and complex movement of gases in the sun's atmosphere.

- **The twin spectroheliographs** which give 6 cm size solar images in the Calcium K and Hydrogen alpha light. The system consists of a 30 cm diameter Foucault siderostat and a 30 cm, f/22 Cooke triplet lens. Pictures of prominences over the full disc are also obtained in K by blocking the solar disc. The data is used to study solar flares and prominences.

- **A 15 cm telescope** is being used to obtain broad band images of the sun on a regular basis, since 1904. These images are being used to study solar activity and solar rotation using sun spots as tracers.

- **A Hale spectrohelioscope** used for observations of the sun in the visual band.

The Kodaikanal Observatory has workshops for mechanical, electrical and electronic equipments. With a 20 cm refractor, occassional cometary and occultation observations are made. At times this telescope is used for showing the celestial objects to visitors. There is an Astronomy Museum in the Michie Smith Hall, with astronomical pictures on display. There is also an arrangement to show a large size image of the sun produced by a siderostat, and for the Fraunhofer spectrum of the sun. The Library at the campus is a very special attraction for the bibliophile: it has an excellent collection of archival astronomical literature.

The Institute has organized several expeditions to locations at home and abroad for observations of the solar corona, visible briefly during total solar eclipses, A notable result from the observations during the 1970 solar eclipse was the discovery of cold clouds (~ 10,000 degrees) in the solar corona. The Institute's astronomers installed a specially designed telescope at Maitri, the permanent Indian station at Antarctica during 1989-90 in order to obtain continuous records of the sun which are essential for a study of evolution of supergranules (the calcium-K network cells) which have a lifetime of about 20 hours.

Solar Terrestrial Physics

In the Institute, there is a group working on the ionosphere and the magnetic field of the Earth, the experimental facilities of which exist at the Kodaikanal Observatory. These observations, conducted from about four degrees north of the magnetic equator around the fringe of the equatorial electrojet belt in the Indian sector, provide useful insights into the dynamical aspects of the ionosphere.

Round the clock monitoring of the ionosphere is done with a IPS-42 digital ionosonde (which replaced an analog model C-3 ionosonde that was in operation since mid 50's) and of the geomagneic field with a La Cour variometer (since 1949). The ionospheric and geomagnetic data are used by scientists at home and abroad for investigation of wide range of problems in the inter-disciplinary field of Solar Terrestrial Physics. In addition an HF Doppler radar is operated to monitor the small scale ionospheric vertical plasma motions with high sensitivity (10's of meters) and time resolution (6 sec) associated with a variety of geophysical phenomena. These include geomagnetic sudden commencements, substorms and storms. The La Cour variometer will soon be replaced by a digital DMI fluxgate magnetmeter to provide geomagnetic data with high time resolution (1 min) and sesitivity (1 nT).

Geomagnetic and Geodynamic Facilities

The kinematics and structure at the extremities of the Indian plate are being studied by installing broadband seismometers and GPS receivers in Hanle, Ladakh and in Kodaikanal. Through a special permission, the GPS data is decoded, after a mandatory time-lapse, using the c-code giving about 1 mm precision in the geodetic position of these stations.

Gauribidanur Observatory

Since 1976, the Institute operates a decametre wave radio telescope jointly with the Raman Research Institute at Gauribidanur (Lat: 13 deg, 36 min 12 sec; Long: 77 deg, 26 min, 7 sec E), about 100 km north of Bangalore. The Gauribidanur telescope consists of 1000 dipoles arrayed in a 'T' configuration - with a 1.4 km east-west arm and a 0.5 km south arm. It has been engaged in the study of radio waves at 34.5 MHz emanating from diverse objects in the sky. Studies have been done of pulsars, gaseous remnants of exploding stars and the apparently vacant space between the members of a cluster of galaxies also. However, at present the main studies pertain to solar activity.

The Gauribidanur radioheliograph.

- **Gauribidanur radioheliograph :** A radio heliograph for obtaining two dimensional pictures of the outer solar corona simultaneously at many frequencies in the range 40-150 MHz is also functional here since Apr 1997. At present, a few maps of the Sun are made every day with the heliograph, at transit. A prototype tracking unit has been installed on a limited number of antennas to understand the various aspects of the system. The completed system will enable continuous observations of the sun for about 6 hours every day. One of the primary goals of the Gauribidanur radioheliograph is to try and detect weak, pre-event signatures of the onset of a coronal mass ejection (CME).

- **Digital Spectrograph :** A digital radio spectrograph is also being used in conjunction with the heliograph for obtaining a dynamic spectrum of the transient burst emission from the solar corona at a distance of about 1.2-1.6 $R_{\odot}$ from the centre of the Sun. The two main advantages of the present system over the existing conventional solar radio spectrographs are: (i) it allows the user to select the frequency bands which are completely free of inteference, and (ii) the desired spectral accuracy can be achieved by just changing the delay resolution in the digital receiver. This instrument is expected to play a particularly useful role during the maximum of the present solar cycle(Cycle 23) since we have the unique opportunity of also locating the position of the burst sources using the two dimensional images obtained with the Gauribidanur radioheliograph.

A view of the Mauritius radio telescope.

In addition, there is a large synthesis telescope operating at 151.5 MHz which has been constructed at Mauritius in collaboration with the University of Mauritius and the Raman Research Institute. The telescope is 'T' shaped and simulates a dish antenna of 2 km diameter. It has been in operation since 1992 and is presently used for making a radio map of the entire southern sky. An added advantage of the location is that a more thorough study of the Galactic centre is possible since it has a high elevation as it passes over Mauritius.

Bangalore Campus

Equipped with an extensive library and several laboratories, the Bangalore campus is in fact the central engine of the Institute. Most of the scientific staff is based here whose multifarious activities -research, teaching, instrumentation and service to the community- make the place a much sought after centre for astronomy and physics by scientists and students from all over.

The Library

The library of the Institute is more than 200 years old. Most of the archival literature is kept at the Kodaikanal Observatory library. However, a certain part is kept in the Bangalore campus library too. The library is in the possession of a rare catalogue for the years 1794-1812 written by calligraphers during the Madras Observatory years. It lists 102 books and journal volumes and 52 manuscripts. Notable among the great historical collections is 'Astronomia Nova' (1609) by Johannes Kepler which is the oldest book in the library. It also has 20 books, published in the 18th century including three volumes of Flamsteed's 'Historiae Coelestis' (1725). The oldest journal volume is 'Philosophical Transactions' of 1794 and the oldest almanac available is that for the year 1767. The place of pride however goes to the 'Annual Report' of the Madras Observatory for the year 1792. As time marched on, the library was enriched with books, periodicals, catalogues and reports obtained from sources all over the world and which form today what can be easily called not only the largest but the rarest bibliographical collection in astronomy in the country. A part of this wealth is distributed among the libraries at Kavalur and the new campus at Hosakote as well.

Today the library has one of the most extensive collections of books and periodicals in the field of astronomy and astrophysics, in addition to a large number on physics, mathematics, computers, electronics and geophysics. It also has a collection of reference works, namely abstracts, encyclopaedias and dictionaries, slides and photographs and many journals and catalogues in the microfiche form. The book catalogue is available on-line and can be searched using various key words. The library subscribes to several on-line journals in addition to paper copies. It also has taken up a programme for preservation and digitization of archival material in collaboration with C-DAC, Bangalore. The library has contributed to the Astronomy and Astrophysics Thesaurus', a project of the IAU Commission No. 5. The Thesaurus is a great refernce work useful for libraries and serves as a standard in the indexing and abstracting of astronomical papers and other publications.

The Cyberspace

The Computer Centre in the campus is a high activity area. It is duly equipped with computational facilities to meet the needs of the scientific community. There are at present eight Sun Ultra-10 and two Sun Ultra-1 systems, apart from a number of the Pentium III PCs.

The major areas of theoretical research

The Institute has a strong group of astrophysicists and physicists working on problems related to the complex phenomena in the exterior and interior of the sun and stars, the solar system, the stellar evolution , the interstellar medium, the galaxies and those related to the origin of the universe. Only an outline is given here.

Work connected with the sun and the stars is mainly concerned with the star formation, transport of energy produced in their interiors, formation of lines in their spectra and their evolution, the determination of chemical elements etc. Here due regard is paid to various physical effects such as reflection, scattering, polarization, advection and aberration etc.

The research in plasma astrophysics takes a critical look at the magnetohydrodynamic processes, supernova remnants and the radio bursts of the sun. The studies of the interstellar medium concentrate on planetary nebulae, dust in the stellar environs and the space in between stars, the vast regions of ionized hydrogen and giant molecular clouds in our galaxy etc.

Variability in the light of stars whether regular or irregular, and their explosive nature form an important aspect of the studies. As powerful sources of radiation whether radio, optical, x-rays or gamma rays, extensive work on pulsars, black holes, quasars and active nuclei of galaxies is undertaken. The stellar system studies range from star clusters to clusters of galaxies and their collsions. This apart the data on galaxies obtained through satellites is analysed, numerical simulations of their dynamics are carried out and models are constructed of the central engines of the most energetic objects in the Universe, the quasars. These studies compliment the work being done on the early phases of the evolutionary models of the Universe and the likely presence of invisible, i.e., the so-called dark matter and its nature. These works are basically particle physics oriented and try to reconstruct the early expansion of the Universe in the light of extensive developments in experimental particle physics.

There is a group of physicists persuing the study of low energy consequences of unification of the fundamental forces at high energies. The thrust is on theoretical as well as experimental aspects. Theoretical work is mainly on the parity and time reversal violation in atoms.

Experimental Physics

Non-accelerator techniques have provided very important results on phenomena involving very high-energy particles, several aspects of neutrino physics, physics at certain symmetry breaking and unification scales etc. The experimental activity at present is focused on using torsion balances and atoms for studying particles physics. There are two torsion balance experiments and one atomic beam experiment that are in progress. These experiments are done in collaboration with Tata Institute of Fundamental Research (TIFR), Mumbai. One torsion balance experiment, set up at Gauribidanur, attempts to study the possible violation of the Equivalence Principle at a sensitivity exceeding 10^{-13} . This has important implications to any particle theory that predicts new long-range forces that are composition dependent. Another torsion balance experiment is attempting to measure with high precision the Casimir force arising from confining the quantum vacuum between conducting plates. This experiment is probably the only one at present sensitive enough by design to see the finite temperature corrections to the Casimir force. The results from such experiments have implications to the existence of the recently speculated, hypothetical dark energy that drives the accelerated expansion of the Universe. There is also an experiment that tries to measure the Casimir-Polder force, between atoms and metal surfaces, originating in quantum fluctuations of the vacuum energy. Several high precision instruments that have been designed and fabricated by the group are employed for these experiments. The future activity is planned around high precision torsion balance experiments, and measurements using laser cooled atoms and ions to address important questions in particle physics. The NAPP experimental group has collaborations with physicists at the University of Washington, St. Loius, University of Virginia, Charlottesville, and Ecole Normale Superieure , Paris.

Technology Development

The use of the major facilities described above requires their effective maintenance and the development of new sensitive devices and auxilliary instrumentation in an ever evolving process. It involves a fruitful and continuous interaction of the scientists and the engineers.

The various laboratories at the Bangalore campus have worked together to develop instruments of variuos kinds : photometers and spectrographs and sophisticated data acquisition systems, instruments such as solar vector magnetograph, extreme UV spectroheliometer speckle camera system, and a rotational shear interferometer, just to name a few.

The Institute has been developing cryogenically cooled mosic CCD cameras both for astronomy and other usages.

Photonics Division

The Photonics Division's research and developmental activity is focussed on instrument design, optical fabrication, optical metrology and thin film coating etc. The division has contributed to some external projects too. These include fabrication of beam line optics for synchrotron radiation, sponsored by Bhabha Atomic Research Centre (BARC) and VHHR sun shield panels for space-borne radiometers sponsored by Indian Space Research Organization (ISRO).

Students Programme

A significant part of the Institute's activity is the graduate studies program. It comprises of Ph.D. and other training programmes in astrophysics and physics. The students are admitted after qualifying written and oral tests. The present strength is about thirty and in the last decade about twenty Ph.D theses in research areas ranging from instrumentation to cosmology have been awarded. The Institute is also a major partner in the Joint Astronomy Program conducted by the Indian Institute of Science.

Indian Astronomical Observatory

The Background

Over the years the demand for observing time on the telescopes at Kavalur has been outstepping the time available. There has been a growing need for large telescopes and new technology instrumentation. There have been occasions when the astronomer's best efforts got thwarted by hostile weather and bad skies. However, a more fundamental limitation is the Earth's atmosphere itself which allows only a small window in the electromagnetic spectrum through which a ground based astronomer can observe the celestial objects. One needed to surmount these hurdles. In 1989, under the auspices of the Planning Commission, in a number of meetings of astronomers with eminent scientists the future possibilities were discussed. The main conclusion that emerged was that a modern astronomical telescope be set up at a suitable site which will be used for both optical and infrared observations. In addition, this would also complement the observations carried out with other national facilities such as the Giant Metre Wave Radio Telescope (GMRT), the high energy Gamma ray telescopes and the X ray telescope atop Indian satellites. The Indian Institute of Astrophysics was considered most appropriate to carry out this task which they felt had a proven track record. In 1992, the Institute deliberated on these recommendations and concluded that a superlative site was a key factor to achieve these goals. It should not be affected by the two monsoons and it has got to be on a high enough mountain. The higher the altitude, the lesser would be the atmosphere above. In quality, it should match Mauna Kea in Hawaii which has had the distinction of having the world's highest located observatory where the observing conditions are exceptionally good at an altitude of 4200 m (13,000 ft) above the sea level. Where could one find such a place in India? It could be only in the Himalayan region.

Hanle region : Location map

So, a great site hunt was launched with an expedition consisting of six teams of astronomers from the Institute. Based on their reports, attention zeroed in on a place called Hanle in the Ladakh region, about 250 km south-east of Leh. It satisfied the various criteria the astronomers apply while deciding on a site to establish an observing facility.

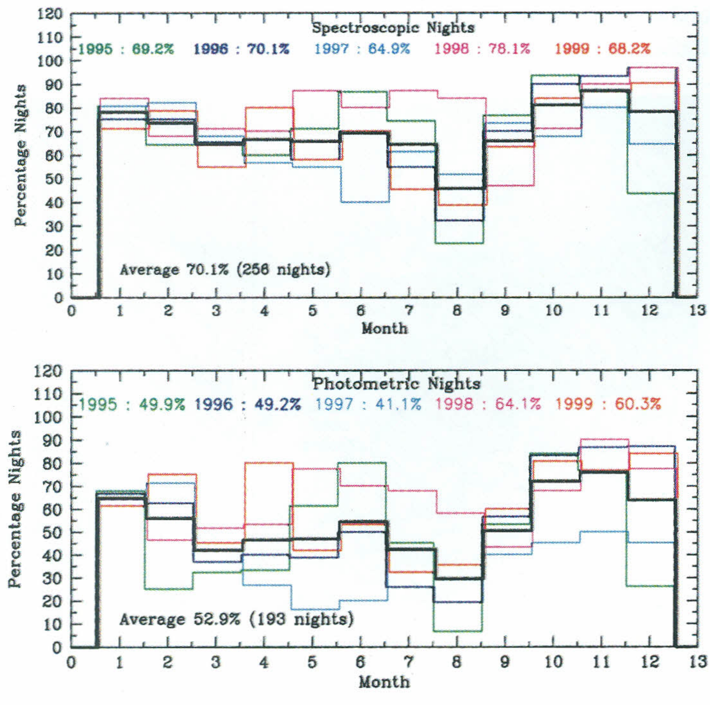
The Hanle Advantage

Sparsely populated, Hanle is a high altitude desert (Longitude 78 deg. 57 min. E, Latitude 32 deg. 47 min.), at an elevation of 4300 metres above the mean sea level. The best thing about it is its good accessibility round the year. An all weather road maintained by the Border Roads Organization connects Leh to Hanle- 200 km along the Indus up to a place called Loma and then 50 km along the Hanle river to the Nilamkhul Plain, Hanle. The observatory site was chosen to be the peak of a mountain range Digpa Ratsa Ri which is a bit off centre in the Nilamkhul Plain. It has been named Mt. Saraswati (4517m). It is among the driest and calmest sites in the world, far away from any light or other pollution human settlements may create.

The Site Characteristics

Hanle is an astronomical site par excellence. Considering that the water vapour content of the atmosphere is very low- in fact, the annual precipitation of rain and snow is less than 10 cm whereas the precipitable water vapour is less than 2 mm during the better part of the year- the sky at night is exceptionally dark and the extinction in the starlight caused by the overlying atmosphere

Distribution of Clear Nights at Hanle



is low. Based on meteorological and satellite data on the atmospheric conditions and after carrying out a standard astronomical site assessment programme, Hanle was found to be the best observing site for a study of the celestial objects in the infrared, sub-millimetre and millimetre regions of the electromagnetic spectrum, normally beyond the reach of astronomical observatories at lower altitudes. The number of nights one can do astronomical spectroscopy is about 260 while the photometric nights are 190 plus; these are distributed nearly uniformly through the year so that it is possible to have an access to celestial objects of all right ascensions. Hanle has low concentration of atmospheric aerosols. The extinction in V band is about 0.1 mag/airmass and the sky brightness is 21.5 (V) mag /sq. arcsec. Another important factor is the low seismicity.

Infrastructure

Once identified, the site needed to be developed from a stage where nothing existed in the name of an infrastructure. It may be pertinent to mention here that originally Hanle was selected as a part of the Himalayan Infrared Optical Telescope (HIROT) Project of the Institute. Being remote and with minimal infrastructure, it was decided to first develop it with the installation of a smaller, 2-metre telescope and get experience in remote operation capabilities. Preparing the site from this point of view therefore has been a challenging task. The most basic requirements for any upcoming establishment are transportation, power, telecommunication and a place of stay for the field staff. This required well planned and specially organized efforts. The Institute has had an impressive track record of fabricating and establishing observational facilities. Professor Ramanath Cowsik has been the prime mover of the project which has been supported by the Department of Science and Technology, Govt. of India. A National Advisory Committee consisting of several eminent Indian scientists under the Chairmanship of Professor K Kasturirangan and a Project Management Board, headed by Professor Yash Pal, monitored its progress over the years.

A project of this sophistication and magnitude called for the most advanced technology and a dedicated effort from a good team of workers and specialists. Beginning 1997, work progressed at a fast pace in diverse areas ranging from the process of precision testing of the telescope to setting up of a base infrastructure of the observatory and the telescope enclosure at Hanle, the satellite uplink facilities at Hanle and Bangalore to effect communucation, acquisition and downloading of observational data and the focal plane instrumentation. The extreme climatic conditions of the site where oxygen levels are low and the temperature ranges between +25 degrees to -30 degrees Celsius posed challenges to the mechanical design, the optics, the installation and operation of the telescope.

The Indian Institute of Astrophysics developed the new field station at Hanle in a record time, which has been christened the Indian Astronomical Observatory. With its becoming operational, it has become the only one of its kind at an altitude unsurpassed so far by any other similar establishment. The continuing site assessments have further corroborated this. What is noteworthy is that any astronomical facilities installed here will be the only ones for a variety of studies over half the globe between Canary Islands (20 deg. W) and Eastern Australia (157deg. E), thus fulfilling the long felt need for an astronomical facility in the wide longitude interval.

The infrastructure suiting the needs of the Observatory has been constantly under development. Nearly 640 acres of land including the Digpa Ratsa Ri mountains and some flat area near its base has been transferred to the Institute by the state of Jammu & Kashmir. A permanent laboratory building, named the 'Megh Nad Saha Astronomical Archives' has been constructed at the base. Where there was none, an 8.5 km long road now leads us from Hanle to the Mt. Saraswati peak. There is no commercial electrical line serving Hanle at present. The Observatory has set up two solar power plants with 30 kVA peak, and with battery and diesel power backup to last for 30 hours at a stretch. A 5 lt/hr capacity liquid nitrogen plant procured from Stirling Cryogenics & Refrigeration, Netherlands, has been installed at the base station.

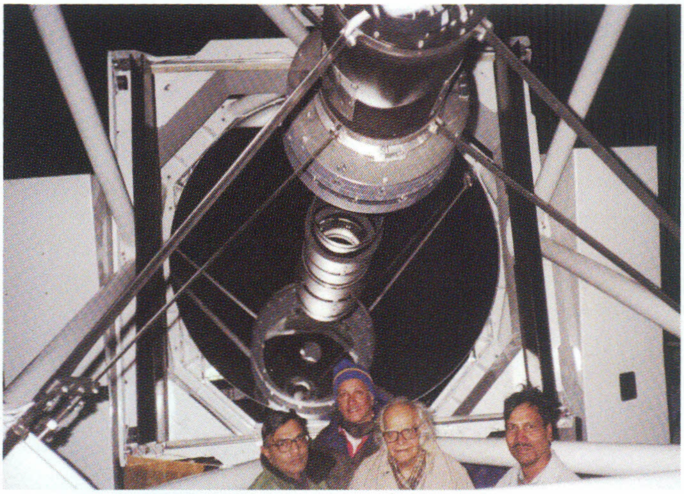
RABMN satellite links have been established at Hanle and Leh which serve to facilitate communications between Hanle, Leh, Bangalore as well as Kavalur.

The earliest installation at the site, a 0.3m site survey telescope serves as a Differetial Image Motion Monitor, i.e., as a 'seeing monitor'. A 220 GHz radiometer is functional in a tower in a closed dome having a transparent slit. It has been in continuous operation under computer control since December, 1999.

An Automated Weather Station is also functional at Mt. Saraswati since July 1996. Every effort is undertaken to ensure that ecology and environment in the region are not disturbed by any other activity within 10 km radius from the facility.

The 2-metre Telescope Project and CREST

Over the years, the Hanle project been a tremendous task - from the first proposal in 1992 and preparation of a detailed project report on the telescope to the selection of the site, the formal approval as a national facility in 1997 from the Government of India, to the installation of a 2-m remotely controlled telescope in September 2000. The EOS Pty Ltd, Australia fabricated, installed and commissioned the 2-metre optical telescope with a close interaction of the Institute. It has a modified Ritchey-Chretien system where the primary mirror is a meniscus mirror of ULE ceramic with a 100 mm thickness which can withstand extreme weather conditions at the site. The assembly of the telescope was carried out from several relatively independent modules and the new technology telescope saw the first light pass through it on the night of 26/27 September 2000.



Profs. Yashpal, R. Cowsik, R. Srinivasan and T.P. Prabhu with the Himalayan Chandra Telescope.

The telescope has been named 'Himalayan Chandra Telescope' in the memory of Professor Subramanyan Chandrasekhar, Nobel Laureate. The telescope mass would be less than 20,000 kg. The crucial characteristics are as under:

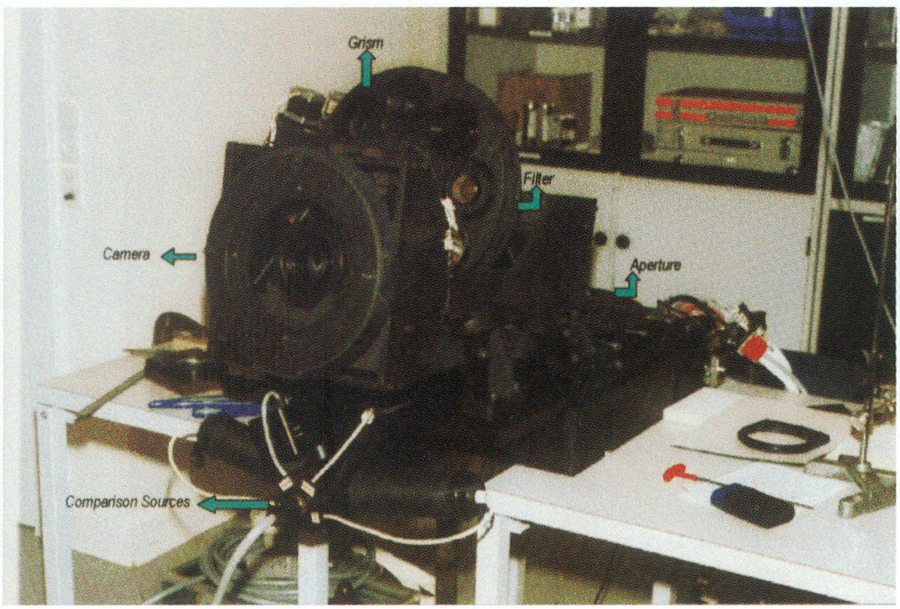
Mount	Altitude over azimuth
Focus	Cassegrain; provision for Nasmyth
F-ratio	f/1.75 primary; f/9 Cassegrain
Image scale	11.5 arcsec/mm
Field of view	7 arcmin; 30 arcmin with corrector
Image quality (zenith)	80% powe in < 0.33 arcsec dia
Jitter & periodic errors	< 0.25 arcsec on each axis
Pointng accuracy	< 0.45 arcsec over 17 arcsec move < 1.5 arcsec for > 10 deg move
Tracking accuracy	< 0.55 arcsec rms over 10 minutes < 0.3 arcsec with autoguider

The instrument mounting cube is designed to have four side ports and one axial port with a mirror turret so that instruments can be mounted on all the ports, allowing a selection within a minute. One of the ports is used for the autoguider. The first light phase instruments are a mosaic CCD imager, a medium-resolution optical spectrograph, an infrared imager in the range 1.0–2.5μm, and a low resolution spectrograph.

The first light optical imager was designed by IIA and it uses a SITe 2k x 4k thinned VISAR-coated ST-002AB CCD of pixel size 15μm. The filter wheel unit was also designed and fabricated by the Institute. The commissioning tests were done with broadband UBVRI filters. These apart, a number of narrow band filters will be used.

The Near-Infra Red Imager is built around a 512 x 512 HgCdTe array of 0.8μm pixel size so as to be sensitive to the wavelength range 0.8–2.5μm. This will thus contain the K band enabling the astronomer to fully utilize the high altitude advantage when much fainter limits can be reached. The instrument will have two cameras giving a 1.8 arcmin x 1.8 arcmin field at a resolution of 0.2 arcsec/pixel, as well as 3.6 arcmin x 3.6 arcmin at 0.4 arcsec/pixel.

An optical imager cum spectrograph- the Hanle Faint Object Spectrograph Camera (HFOSC) has been built in collaboration with the Copenhagen University Observatory which is designed to operate in the range 300–900nm. It is highly efficient because in an exposure of 10 minutes, it can allow a 3σ detection of a point source of $m_v \doteq 25.5$ and an extended source of $m_v \doteq$ 21.5 mag/arcsec^2. A 30 minute exposure can give a spectrum of a point source of m_v=18 at $R \doteq 150$ and m_v=14 at $R \doteq 3000$ with S/N = 50.



The general layout of HFOSC.

To remotely operate the telescope through a satellite, the Hosakote campus of the Institute near Bangalore has specifically been developed. Here, a Centre for Research and Education in Science and Technology (CREST) has been set up. A part of the building houses the remote control room for the facilities at IAO, Hanle, and the data analysis and archiving facilities are being set up. A 2 mbps communication link ,in addition to a 128 Kbps satellite communication link, between Hanle and the Institute has been set up with a view to download observational and meteorological data and for remote operation of the telescope. The Link was inaugurated by Dr Farooq Abdulla, the honourable Chief Minister of J & K on June 3, 2001. At the same time it was inaugurated by Prof. B V Sreekantan from the Hosakote campus.

Dr. Farooq Abdulla with Prof. R Cowsik at Hanle, at the time of inauguration of the communication link.

A computer control system will transmit data inclusive of the possibility of on line diagnostics on the telescope. The telescope and dome automation can be controlled from the CREST. The dome tracks the telescope to within 0.2 deg which is sufficient for the purpose. It is configured to operate in normal and automated modes. An integrated control system involving the telescope, the dome , the weather and cloud monitor has been evolved, supported by video-conferencing between the two stations. These facilities enable an observer at the CREST as if she was operating fron Hanle itself. Tests of image quality and optical performance have been carried out.

Prof. B.V. Sreekantan with Prof. N.K. Rao at the time of inauguration of the link at Hosakote

Remote control and data acquilition centre, Hosakote

And after the first light

An important part of this project is archiving of data, recorded in the course of observations. Data-archiving software with important key-words to important files has been developed in a very suitable format. Data is compressed in processed or unprocessed form before its archiving and renamed suitably for easy searches. Continuous recording of data fron the telescope has been going on, and this has testified the fine quality of the telescope.

The second generation instruments for the telescope will be: (a) 1-5 micron infrared imager-spectrograph (b) a wide field mosaic CCD camera, and (c) a high resolution optical spectrograph.

Other scientific activities

In addition to astronomy, other activities that have been initiated at the CREST campus include laser physics and gravitational physics. A general physics laboratory with clean-room environment has been developed here. The main objectives of the laboratory are to pursue a variety of experimental investigations in the areas of quantum and nonlinear optics.

Hanle as an active observatory now offers an opportunity for any scientific activity that may have been limited by environment, pollution or low altitudes. The site is very well suited for studies of cosmic rays, atmospheric Cerenkov detection of high and ultra high energy gamma rays, ionosphere and stratosphere, meteorology, seismology, geodynamics and geomagnetics. A few initiatives have already been undertaken in this direction. These programmes include-development of a multiwavelength solar radiometer, optical imaging of mesospheric gravity waves, environmental monitoring of ozone, OH, aerosols, broad band seismology for delineating the deep structure of the region, GPS geodesy to study the kinematics and dynamics of continental deformation zones and geomagnetism. Scientists from the Raman Research Institute and University of Tokyo have conducted studies of atmospheric transparency at 220 GHz. The radiometer is mounted in a dome with transparent slit on a 2.5 m high tower. It has an off-axis 8 cm parabolic mirror with the front end receiver at its focus and a personal computer for control and data acquisition. Very low values for the atmospheric opacities have emerged which is very encouraging for studies in the infrared and sub-mm windows.

Looking Ahead

Where do we go from here?

The future holds a great promise. The first things that come to mind are — upgradation of existing facilities with state of the art technology, creation of new facilities and preparing the next generation that will carry forward a tradition of 200 years plus.

The strong theory group at the Institute is deeply involved in its work on everything that is up there in the sky. There are several frontline areas of research that the group will focus on in particular, namely, high energy astrophysics, spectral line formation in solar and stellar atmospheres etc. Other topics of interest are giant extra-solar planets and brown dwarfs, origin of ultrahigh energy cosmic rays, interacting galaxies including gas dynamics, the phase space structure of dark matter in the Galaxy and development of new and fast numerical methods. Those working in theoretical atomic physics intend to explore the physics beyond the Standard Model. Bose-Einstein condensation is an intensively pursued area where the interest will be in theory as well as in experiments.

Vainu Bappu Observatory

The science from Kavalur will become spectroscopy intensive, focussing on (a) chemical evolution of the Galaxy - through the observations of metal poor halo stars, (b) evolved stars (c) variable stars (d) star forming regions in the Galaxy (e) transient phenomena - novae, supernovae, bright gamma ray bursts. A fibre-coupled, high resolution echelle spectrograph is being assembled which will provide a spectral resolution from 25,000 to 70,000 for point sources. Area spectrograph (Integral spectrograph) opens up the area to spatially resolved spectroscopy of extended objects such as galaxies, planetary nebulae, shells around old novae and circumstellar shells around evolved stars. As complementary programmes the observations of southern objects not accessible from Hanle will continue to be undertaken from Kavalur. The activities are expected to peak in the near future.

Indian Astronomical Observatory

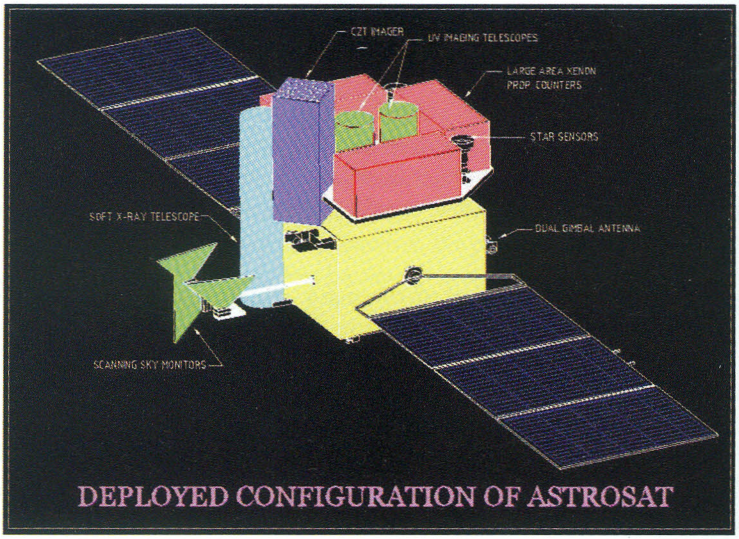
The major research activities to be pursued in the future are briefly given below :

- **The Himalayan Chandra telescope** : The 2-m Himalayan Chandra telescope has begun probing the skies. What scientific returns does one expect from such a venture ? Astronomers visualize making observations that will enable them to throw light on cosmology and large scale structure of the universe. This is possible because with this telescope at Hanle, we can image galaxies that are just being formed when the age of the universe was only $\sim 10^9$ years, less than 1/10th its present value. There are reasons to believe that most of the matter in the universe is invisible and only a small fraction, about a tenth, of it is in the form of visible matter (galaxies, quasars, stars, gaseous clouds). The invisible matter may be in the form of collapsed stars, protons and neutrons, non-zero mass neutrinos, or some exotic species of elementary particles. Dark matter will show up through its gravitational influence since it apparently does not emit radiation. Studies of the dynamics of individual galaxies and their clusters will then come handy in shedding light on 'dark matter' which has played a vital role in the formation of the universe. One can do photometry and spectroscopy of high redshift radio galaxies and supernovae. Stellar evolution is an important area of research in astrophysics where observations with the Himalayan Chandra telescope are expected to be crucial. It will serve as a complement to the GMRT, the Gamma Ray Observatory and the UV and X Ray telescopes aboard Indian satellites.

- **Hanle Binocular Telescope (HBT)** : Hanle as one of the best high-altitude sites for astronomy, has evoked considerable interest nationally and internationally in developing a major facility here, namely, a 6-8 m class binocular telescope. In fact, the groundwork towards achieving this objective in a reasonable period for the telescopes to be fabricated and erected is under way.

- **Antipodal telescope for transient phenomena** : The Institute and the Macdonell Center for the Space Sciences of Washington University, St Louis, USA are in the process of developing two 50 cm f/10 Cassegrain telescope observatories nearly 180 deg apart in longitude-one at Hanle and the other in Arizona. The objective is to create a facility that will enable nearly a round the clock monitoring of transient phenomena. The telescopes have CCD imagers with 1k x 1k CCD detectors of 24 μm pixel size. The telescopes and instruments are designed to be controlled by a single computer at each location and are to be used predominantly for the continuous photoelectric monitoring of the active galactic nuclei and some other objects.

- **UV Imaging Telescope aboard ASTROSAT :** One of the major projects that has just been undertaken by the institute is the Ultraviolet Imaging Telescope (UVIT) Project. The UVIT is expected to be launched on a PSLV around 2005 as part of ASTROSAT, a multiwavelength astronomy satellite mission. The UVIT will perform a unique imaging survey of the entire sky at a spatial resolution of 1 arc sec and 21 mag sensitivity in the wavelength range between 1200 Å and 3500 Å. It consists of two 40 cm telescopes, optimised to far and near UV and will be usable in survey and pointed modes, deep imaging in narrow bands as well. It would provide the pointed mode observations as part of multiwavelength studies, ranging from 80 keV to 1 keV. The Photonics Division of the Institute will design and fabricate the related optics.



DEPLOYED CONFIGURATION OF ASTROSAT

The science goals of the mission are galaxy evolution, pulsars, supernova remnants, star formation rate, stellar population in other galaxies, sky survey, dust properties, polarization, and time variability.

- **Sub-mm astronomy :** The altitude advantage of IAO, Hanle makes it one of the best suited for astronomy in the sub-mm astronomy. The Institute has been conducting some site characterisation in this area with national and international collaborations and these activities would be persued in the years to come.

- **Solar astronomy :** The Observatory will have facilities for the study of the sun. Low water vapour, a large number of clear days in a year and several hours in a day will allow coronographic and infrared observations of the sun. This opens doors to studies on the solar activity, coronal line profiles, supergranular cells, small scale coronal structures, phenomenon of triggering of solar flares etc.

- **Science Centre at Leh :** A Science Centre at Leh is also a part of the current venture which is aimed at taking science to the common person in the region. It will be equipped with a small telescope, computers, lecture hall and guest house facilities.

In the years to come, the IAO will create a strong base for optical astronomy. The doors are open to young people coming forward to pursue research in the field of optical astronomy and to fully use the existing optical telescopes and contribute to the growth of astronomy in India.

NGC 6819, taken through the Himalayan Chandra Telescope

Prepared by R.C. Kapoor on behalf of the Director, Indian Institute of Astrophysics, Bangalore.
Printed at ***Vykat Prints Pvt. Ltd.*** Bangalore.

Crab Nebula, taken through the Himalayan Chandra Telescope