

# *Reaching for the Stars*



**Indian Institute of Astrophysics**  
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**NGC 6819, taken through the Himalayan Chandra Telescope**

# *Reaching for the Stars*

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ASTRONOMIA NOVA  
ΑΙΤΙΟΛΟΓΗΤΟΣ,  
SEU  
PHYSICA COELESTIS,  
tradita commentariis  
DE MOTIBVS STELLÆ  
MARTIS,  
Ex observationibus G. V.  
TYCHONIS BRAHE:

Jussu & sumptibus  
RVDOLPHI II.  
ROMANORVM  
IMPERATORIS &c:

Plurium authorum pertinaci studio  
elaborata Pragæ,  
ad P. C. M. S. Mathematico  
JOANNE KEPLERO,  
*Consensu C. M. S. privilegio speciali*  
ANNO MDCXXXIIII. MDLXXIIII.

## *Telescope astronomy then, from here*

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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 observe 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 occasional 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 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



**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.**

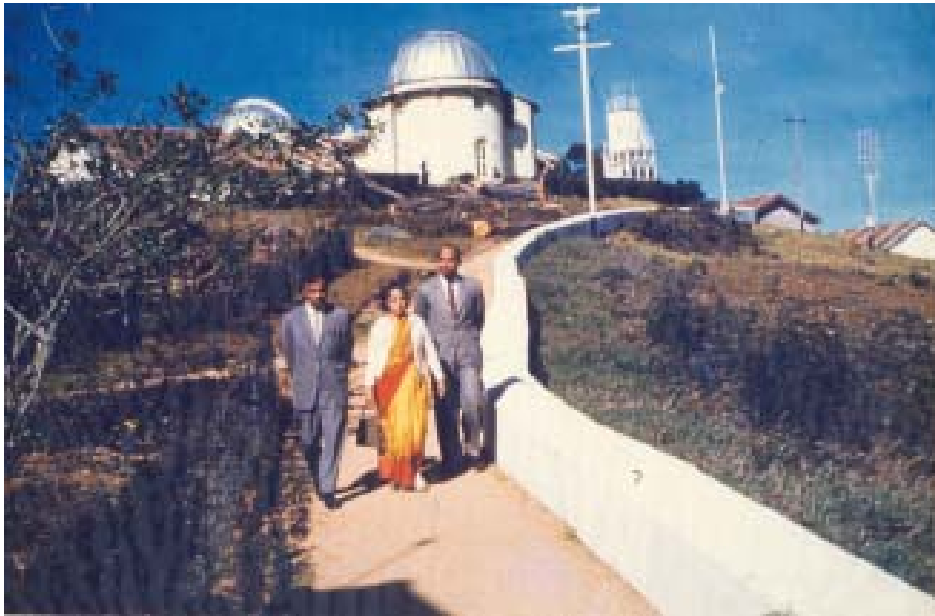
The Madras observatory. It is this observatory that evolved to the present day Indian Institute of Astrophysics. The Madras Observatory initially came to serve as the reference meridian for the work on the Great Trigonometrical Survey of India. Subsequent work at the Observatory was mainly positional 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, 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 physicist Janssen during the same eclipse at Guntur and Norman Lockyer outside the eclipse. The line could not be attributed to any known element and thus named as 'helium' by Lockyer. 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 2300m the Kodaikanal Observatory began work, centered round the Sun. In 1909, John Evershed made the surprising 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



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



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.

### *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 access to southern skies as well as proximity to centres of technology. His efforts bore fruits and an observatory was set up, in the middle of sandalwood 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 planet Jupiter. Uranus which was earlier known to have five 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 the telescope as Vainu Bappu Telescope (VBT) and the Kavalur observatory as the Vainu Bappu Observatory.





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



**Vainu Bappu Telescope building, Kavalur.**

## *In with Himalayas*

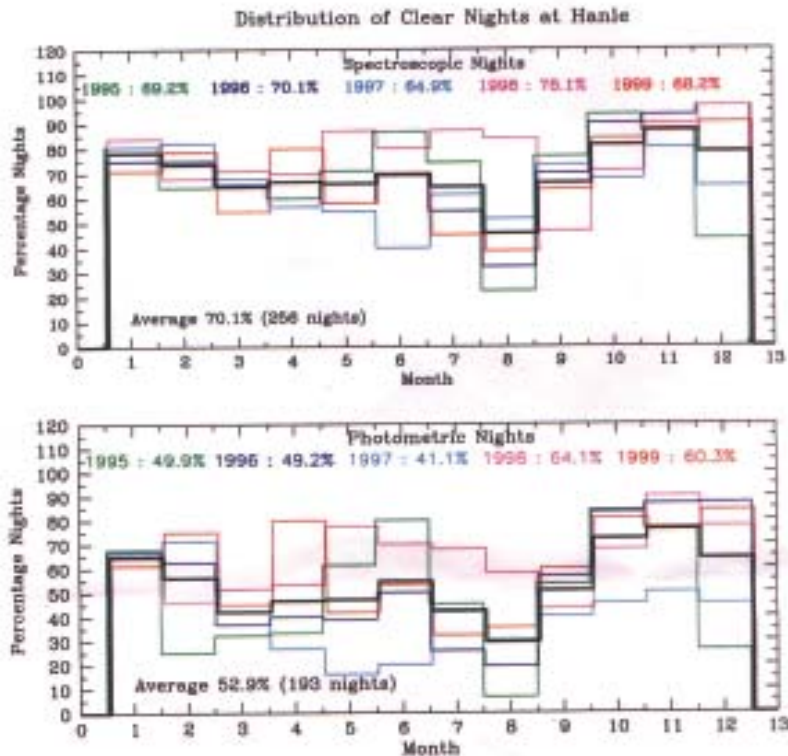
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Over the years the demand for observing time on the telescopes at Kavalur began to outstep the time available. There was a growing need for large telescopes and new technology instrumentation. In 1989, under the auspices of the Planning Commission, 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. In quality it should match Mauna Kea in Hawaii. Where could one find such a place in India? It could be only in the Himalayan region.

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So, a great site hunt was launched and attention zeroed in on a place called Hanle in the Laddakh 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. Sparsely populated, Hanle is a high altitude desert (Longitude 78 deg. 57 min. E, Latitude 32 deg. 47 min.) at an altitude of 4300 metres above the mean sea level. The best thing about it is its good accessibility round the year. The observatory site was chosen to be the peak of a mountain range Digpa Ratsa Ri which is a bit off centre in the Nilankhul Plain. It has been named Mt. Saraswati (4517m). It is among the driest and calmest sites in the world, far away from any light pollution human settlements may create. The sky at night is exceptionally dark and the extinction in the starlight caused by the overlying atmosphere is quite 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 23.2 (B), 21.5 (V) mag /sq. arcsec. Another important factor is the low seismicity. telescope, 0.75 m telescope, 0.45 m Schmidt telescope and also a 34 cm telescope.

Once identified, the site needed to be developed from a stage where nothing existed in the name of an infrastructure. Being remote and with minimal infrastructure, it was decided to first develop it with installation of a smaller, 2-metre telescope and get experience in remote operation capabilities. The extreme climatic conditions of the site where oxygen levels are low and the temperature range between +25 degrees to -30 degrees Celsius posed challenges to the mechanical design, the optics, the installation and operation of the telescope. Over the years the Hanle project has meant to be 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 its installation in Sept 2000. Ramnath Cowsik was the chief architect of the project. Beginning 1997, work progressed at a fast speed 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 communication, acquisition and downloading of observational data and the focal plane instrumentation. The EOS Pty Ltd, Australia did the fabrication, installation and commissioning of the 2-metre optical telescope. The assembly of the telescope was done from several relatively independent modules and the telescope saw the first light pass through it on the night of 26/27 September 2000. The telescope was named 'Himalayan Chandra Telescope' while the new field station at Hanle was christened the Indian Astronomical Observatory.



**Prof. Yash Pal, R. Cowsik, R. Srinivasan and T.P. Prabhu with the Himalayan Chandra Telescope**

With its becoming operational in 2001, the HCT has become the only one of its kind at an altitude unsurpassed so far by any other similar establishment at an altitude of 4517 metres above the mean sea level. The telescope is remotely controlled from the Hosakote campus of the institute near Bangalore via a dedicated 2 mbps satellite link. 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, where a Centre for Research and Education in Science and Technology (CREST) has been developed as a new sub-unit of IIA. Here a part of the building houses the remote control room for the facilities at IAO, Hanle, and the data analysis and archiving facilities are set up.



**Remote control and data acquisition centre, Hosakote**

Nearly 600 acres of land including the Digpa Ratsa Ri mountains and some flat area near its base was transferred to the Institute by the state of Jammu & Kashmir. A permanent laboratory building, named the 'Hanle House' was constructed at the base. An 8.5 km long road leads us from Hanle to Mt. Saraswati peak. There is no commercial electrical line serving Hanle at present. The Observatory has 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 is installed at the base station.

RABMN satellite links were established at Hanle and Leh to 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 Differential 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 Hanle. 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 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 in Koramangala 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. The Hosakote campus, near Bangalore houses the 'Centre for Research and Education in Science and Technology (CREST) with several laboratories. The main observing facilities of the Institute are located at Gauribidanur, Hanle, Kavalur and Kodaikanal.

### *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. Several programmes have been carried out with the fiber-fed Echelle spectrometer of the VBT. These include hydrogen deficient stars, H-alpha profiles in late type stars and variable Sodium I D spectral lines in certain lines of sight in the interstellar medium etc. with a resolution 30,000 - 65,000. By narrowing the slit, it is possible with the Echelle to obtain a spectral resolution better than 100,000.



**The Vainu Bappu Telescope**

The VBT has been used fruitfully for studying solar system objects like comets, and asteroids etc. including the recent observation of the deep impact: NASA's Deep Impact probe that artificially created a crater on the comet Tempel I in 2005. 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- $\gamma$  emission in elliptical galaxies, star burst galaxies,

spectroscopy, photometry and polarimetry of extragalactic supernovae, quasars and active galactic nuclei (AGN).

The other telescopes in use are, respectively, the 1 m Zeiss telescope, the 0.75 m telescope and the 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 atmosphere together provide an ideal work place, the Kodaikanal Observatory is predominantly active in the area of solar observations. For over a century, the Observatory has been an active centre for research in solar astronomy. Here the main facilities are:

**The solar tower telescope made by Grubb Parsons :** This was installed in 1960.



The solar tower tunnel telescope.

Here a system of three extremely fine quality 60 cm diameter mirrors directs 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 mÅ in the 5th order and a high spectral dispersion of 9 mm /Å 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 Ca 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 spot 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, occasional 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, including the one of 2003 in Antarctica, 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*

The group working on the ionosphere and the magnetic field of the Earth has their experimental facilities 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 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 geomagnetic 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 was replaced some time ago by a digital DMI fluxgate magnetometer to provide geomagnetic data with high time resolution (1 min) and sensitivity (1 nT).

### *Geomagnetic and Geodynamic Facilities*

The kinematics and structure at the extremities of the Indian continental plate are being studied by installing broadband seismometers and GPS receivers in Hanle, Ladakh and 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.

### *Radio Astronomy at IIA*

#### *1) Gauribidanur Radio Observatory*

**Gauribidanur telescope** : Since 1976, the Institute operates a decametre wave radio telescope jointly with the Raman Research Institute at Gauribidanur (Lat:  $\sim 13.60^\circ$  North; Long :  $\sim 77.44^\circ$  East), about 100 km north of Bangalore. The Gauribidanur telescope (GEETEE) consists of 1000 dipoles arranged 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 the Sun and various other diverse objects in the sky. The most notable observations with the array till date are: (i) first two-dimensional images of radio emission from slowly varying discrete sources in the outer solar corona, (ii) all-sky survey of radio sources at 34.5 MHz in the declination range  $-30^\circ$  to  $60^\circ$ , and (iii) low frequency carbon recombination lines in astrophysical sources. Studies have been done of gaseous remnants of exploding stars and the apparently vacant space between members of a cluster of galaxies also. The main studies at present pertain to pulsars with a new and sensitive backend receiver.



An aerial view of the E-W arm of GEETEE.

**Gauribidanur radioheliograph** : A radioheliograph for obtaining two dimensional pictures of the outer solar corona simultaneously at different frequencies in the range 40-150 MHz is also functional here since 1997. The basic receiving element used is a log-periodic dipole and the array consists of 192 of them. The dipoles are arranged in a 'T' configuration similar to the GEETEE. The present spatial and temporal resolution of the instrument are 5° and 256 ms, respectively. The array is in regular operation and the observing period is ~ 9 AM - 5 PM (03:30 - 09:30 UT), everyday. A 1024 channel digital correlator is used as backend receiver to extract the strength and positional information of radio emission from the solar corona and its various discrete structures. The frequency coverage of GRH is unique that it provides useful information on the solar corona in the height range ~ 0.2-0.8 R<sub>☉</sub> (above the solar surface), which is difficult to probe using both ground based and space borne white light coronagraphs. No other radio telescopes are presently operational in the above frequency range, anywhere in the world. Some of the



The south arm of the Gauribidanur radioheliograph.

notable observations with GRH till date are: (i) density/temperature diagnostics of pre-event structure of a CME, (ii) velocity/acceleration of a CME close to the solar surface, (iii) 'true' speed of a CME in the three-dimensional space, (iv) estimation of the parameters of a CME at ~ 40 R<sub>☉</sub> from the Sun through angular broadening observations of a distant cosmic radio source, (v) seismology of the solar corona using radio burst emission as tracers, (vi) coronal electron density gradient in the ~ 0.2-0.8 R<sub>☉</sub> height range above the solar surface, and (vii) plasma characteristics of radio emission associated with emerging magnetic flux from sub-surface layers of the solar photosphere.

**High resolution radio spectrograph :** A high resolution radio spectrograph is used in conjunction with the GRH for obtaining dynamic spectrum of transient burst emission from the solar corona. The antenna system consists of 8 log periodic dipoles. A commercial spectrum analyzer is used as the back end receiver to obtain spectral information with an instantaneous bandwidth of  $\sim 250$  KHz. The temporal resolution is  $\sim 43$  ms. The radio spectrograph and GRH together provide spectral and positional information on eruptive solar activity, again an unique combination. The observations so far have provided clues to: (i) electron acceleration associated with small scale non-thermal energy releases in the solar atmosphere, (ii) occurrence of radio bursts associated with successive magneto hydrodynamic shocks in the solar corona, and (iii) source region of a CME through observations of transient ‘absorption’ bursts.

**Polarization interferometer :** Based on theoretical formulations for the response of a correlation telescope to polarized radiation, an east-west one-dimensional array of 32 log periodic dipoles has been set up to probe the coronal magnetic field in the height range  $\sim 0.2$ - $0.8 R_{\odot}$ , above the solar surface.

The dipoles are arranged as 4 groups and they are oriented at  $0^{\circ}$ -  $45^{\circ}$ ,  $90^{\circ}$  -  $135^{\circ}$  with respect to the terrestrial north. This helps in capturing the polarization state of the incident radiation with good accuracy



A close up view of  $135^{\circ}$  and  $45^{\circ}$  oriented antennas

## 2) *Mauritius Radio Telescope*



An aerial view of the Maruitius radio telescope.

In addition to the above radio arrays, a large synthesis telescope operating at 151.5 MHz has been constructed on the island of Mauritius (Lat: 20.14° South; Long: 57.74° East) in collaboration with the University of Mauritius and Raman Research Institute. The telescope is 'T' shaped and simulates a dish antenna of 2 km diameter. It is in regular operation since 1992. The primary goal of this instrument is to make a radio map of the entire southern sky in the declination range  $-10^\circ$  to  $-70^\circ$  and generate a point source catalogue at 151.5 MHz. Once completed, this will compliment the existing Cambridge 6C catalogue on radio sources in the northern hemisphere. An added advantage of the location is that a better study of the center of our Galaxy is possible since the latter lies almost overhead there. The array is also being used for solar observations at the above frequency.

## 3) *Brazilian Decimetre Arra*



The Brazilian Decimetre Array

The Instituto Nacional de Pesquisas Espaciais (INPE), Brazil is building a decimetre radio telescope for observations of Sun and various galactic, extra-galactic radio sources. In its present configuration, the array has 5 parabolic dish antennas of 4 m diameter each, set up as a one-dimensional array in the east-west direction. The frequency of operation is 1.6 GHz. The length of the longest baseline in the array is 216 m. The temporal and angular resolution are 100 ms and 1.5' respectively. The array is located at Cachoeira Paulista (Lat: 22°.69 South; Long: 45°.01 West). Our solar radio astronomy group has contributed to the array configuration, software for data calibration and image synthesis. They have also designed and constructed the digital back end receiver for the telescope.

### *Indian Astronomical Observatory*

The Indian Astronomical Observatory is located 250 km south-east of Leh and is accessible throughout the year. The prime facility for night time astronomy is the 2-metre Himalayan Chandra Telescope (HCT), commissioned in 2001. The telescope is remotely controlled from the CREST, Hosakote near Bangalore through a satellite link. A High Altitude Gamma-Ray (HAGAR) Telescope is also being set up at the IAO site, in collaboration with the Tata Institute of Fundamental Research (TIFR), Mumbai.



### *The 2-metre Himalayan Chandra Telescope*

The Himalayan Chandra Telescope 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. A computer control system transmits data inclusive of possibility

of on line diagnostics on the telescope. The telescope mass would be less than 20,000 kg. The crucial characteristics are as under:



The 2-m Himalayan Chandra Telescope (HCT)

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% power in  $< 0.33$  arcsec dia

Jitter & periodic errors:  $< 0.25$  arcsec on each axis



Pointing 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 communication facilities between Mt Saraswati and the CREST campus comprise of a dedicated 2MBPS satellite link operating through Spacenet, DOS on the INSAT 3B. This link is used primarily for remote operations of the telescope, dome and backend instruments and for data acquisition and transfer from IAO to CREST.

A computer control system transmits data inclusive of the possibility of online diagnostics on the telescope. The telescope and dome automation can be controlled from the CREST at Hoskote. The dome tracks the telescope to within  $0.2''$  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/he was operating from Hanle itself.

### *The Focal Plane Instruments*

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 CCD imager, a medium-resolution optical spectrograph camera and an infrared imager in the range  $1.0\text{-}2.5\mu$ .

The first light optical imager was designed by IIA and it uses a SITE  $2k \times 4k$  thinned VISAR-coated ST-002AB CCD of pixel size  $15\mu$ . The filter wheel unit was also designed and fabricated by the Institute.



The HFOSC.

The Near-Infra Red Imager is built around a 512 x 512 HgCdTe array of 0.8 $\mu$  pixel size so as to be sensitive to the wavelength range 0.8-2.5 $\mu$ . This contains the K band enabling the astronomer to fully utilize the high altitude advantage when much fainter limits can be reached. The instrument has 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), built in collaboration with the Copenhagen University Observatory, is designed to operate in the range 300-900 nm. It is highly efficient because in an exposure of 10 minutes, it can allow a  $3\sigma$  detection of a point source of  $m_v \approx 25.5$  and an extended source of  $m_v \approx 21.5$  mag arcsec<sup>2</sup>. A 30 minute exposure can give a spectrum of a point source of  $m_v=18$  at  $R \approx 150$  and  $m_v = 14$  at  $R \approx 3000$  with  $S/N = 50$ . The instrument has been in use for observations since October 2002.

***Harvesting the data*** : 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 from the telescope has been going on, and this has testified the fine quality of the telescope.

The second generation instruments for the 2 m telescope will be:

(a) a high resolution optical spectropolarimeter, (b) 1-5 micron infrared imager-spectrograph and (c) a wide field mosaic CCD camera.

**A high resolution spectropolarimeter** : An efficient high resolution spectrograph on the 2-m Hanle telescope can obtain high resolution spectra of stars up to 12th magnitude, perhaps even fainter. The bright-moon period on the 2-m telescope can be best utilized with a high resolution spectrograph. For the study of chemical composition of evolved stars, very metal-poor stars, stellar atmospheres and to detect planets around bright stars by radial velocity monitoring, an efficient and state of the art high resolution spectropolarimeter can come handy. From Hanle the spectral region of stars from 3000 Å to 4000 Å can be well explored in high resolution mode. At an  $R$  of 50,000, and a spectral coverage from 3400 to 1 micron, such an instrument can cater to the needs of a large variety of astronomical programs e.g. radial velocity measurements, abundances of various elements, measuring Isotopic ratios, Doppler imaging etc. Interesting objects identified from the medium resolution spectral surveys can be investigated in detail with the help of high resolution spectroscopy.

The HCT since 2003 has been used to observe the monitoring of low redshift supernovae, gamma ray burst (GRB) sources, brown dwarfs- very low mass stellar objects and variable stars, to name a few.

**A 1.5 micron IR Spectrograph camera** : IR spectroscopy is essential for the comprehensive studies of pre-mainsequence as well as highly evolved objects. An IR spectrograph giving a resolution



of 10,000, and a spectral coverage of 1 to 5 micron would be ideal for detecting important atomic and molecular lines formed in the extended geometries of highly evolved stars.

### *Antipodal Transient Observatory*



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 $\mu$  pixel size. The telescopes and instruments are designed to be controlled by a single computer at each station and are to be used predominantly for the continuous photoelectric monitoring of the active galactic nuclei and some other objects.

### *Into The High Energy Zone*

Hanle as an active observatory offers an opportunity for any scientific activity that may have been limited by environment, pollution or low altitudes. The site is well suited for studies of cosmic rays, atmospheric Cerenkov detection of high and ultra high energy gamma rays, ionosphere and stratosphere.

### *High Altitude Gamma Ray Telescope*

The gamma ray energy region in between that of the satellite experiments (10GeV) and of the traditional atmospheric Cerenkov experiments (~250 GeV) has not yet been explored. While there

are about 100 astrophysical sources (like the active galactic nuclei, pulsars etc) at  $\sim 10$  GeV, 100, those at  $\sim 250$  GeV count less than 10. This is the energy region where photon generating processes seem to cease and thus interesting information is expected about these sources. There are essentially two methods for atmospheric Cerenkov experiments to reach lower energy thresholds. The first is to use very large size telescopes to collect the meager number of Cerenkov photons at these energies. The second method is to conduct experiments at very high altitudes where the number of Cerenkov photons is high enough to still allow the use of smaller telescopes. Our Institute, in collaboration with TIFR, has taken up the second approach and has started work on a gamma ray experiment, the high energy gamma ray telescope (HAGAR) to be conducted at Hanle which will address this exciting energy range.

Monte Carlo simulations have been done on the generation of Cerenkov photons at the desired altitude for gamma ray and cosmic ray primaries for various energies and for the geometry of the particular experiment. These calculations for the proposed setup show that a threshold energy of 50 GeV is achievable with atmospheric Cerenkov technique at the altitude of Hanle. These simulations are undergoing further refinements.



**The first telescope of the 7-Unit Himalayan Gamma Ray (HAGAR) Telescope.**

An Atmospheric Cerenkov experiment with 7 telescopes, each with 7 mirrors of total area of 4.4 sq.mtrs (the total light gathering area of 7 telescopes is thus 31 sq.mtrs) was proposed for HAGAR. The telescopes will be deployed on the periphery of a circle of radius 50 meters with one telescope at the centre. Each telescope will have an alt-azimuth mounting. Each of the 7 mirrors in each telescope will be looked at by a UV sensitive PhotoMultiplier Tube. Two prototype telescopes have been fabricated in a workshop near Hosakote. The first unit was installed at Hanle in May 2005 and post-installation tests have been conducted. The other telescopes are in progress.

## *The Earth and its atmosphere*

Nearer home, the subjects of interest include 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 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 from the infrared studies point of view,ph.

## *CREST*

The CREST, short for Centre for Research and Education in Science and Technology is located at Hosakote, about 40 km from the Koramangala Campus of the Institute in Bangalore. The centre is host to the remote controls of the HCT, the Test and Calibration Facility (TCF) for the UVIT payload project as a part of the MGK Menon Laboratory for Space Sciences. In addition, some activities have been initiated in laboratory physics which include laser



**The M.G.K. Menon Laboratory for Space Sciences**

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, cavity QED and gravitation. These experiments have a bearing on understanding the foundational aspects of basic laws of physics, especially general relativity, quantum electrodynamics and quantum mechanics. The laboratory has different state-of the art lasers and other sophisticated equipment. Research program to develop optical switches and three- dimensional holographic memories using photorefractive crystals (lithium niobate, barium titanate etc.) and biological molecules (bacteriorhodopsin and its mutants) has been initiated. The interest in these systems stems from the fact that it is possible to store hundreds of billions of bits of data in a cubic centimetre volume and transfer them at the rate of billion or more bits per second The compact size and faster data processing rate make these devices extremely useful in parallel processing computers, three-dimensional memories and associative memories for neural network.

### *The 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



## *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 collisions. This apart the data on galaxies obtained through the 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 pursuing 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.

## *Laboratory Physics*

The Institute is well into experimental physics for which a specialized laboratory is being developed at the CREST campus. At present interest is focussed in areas like high-contrast, all-optical switching in bacteriorhodopsin and study of refractive index variations with temperature using automated interferometric techniques. Some details are as under:

**High-contrast, all-optical switching in bacteriorhodopsin :** High speed photonic switching, which forms an essential component of optics based communication networks and data processing systems, can be achieved with electro-optic, opto-mechanical, magneto-optic, and acousto-optic devices.

The current rapid development of high data-rate fiber-optic communication and real-time information processing system has created a need for all-optical, ultrahigh-speed photonic switches, which will eliminate the need to convert the photonic signal to an electrical signal and vice-versa. An all-optical switching action can be accomplished by use of one optical pulse (pump beam) to control the transmission of a second optical pulse (signal or probe beam) by virtue of their interaction in a nonlinear medium. In this project, experiments were carried out with the nonlinear-absorption-based, high-contrast, all-optical switching in the photochromic bacteriorhodopsin (bR) films. The switching action is accomplished by control of the transmission of a weak probe beam through a bR sample with the help of strong pump beam illumination at 532nm wavelength. It was found that the switching properties of bR films depend on several experimentally controllable parameters such as probe wavelength, pump-beam intensity and excitation rate. A comparative study of the switching behaviour and other parameters were carried out at three different probe wavelengths (543, 594 and 633nm) and various beam powers and excitation rates. The experiments were carried out on commercially available D85N and D96N mutants.

**Study of refractive index variations with temperature using automated interferometric techniques:**

Refractive index is the most important parameter of a material. It helps in determining its application for optical devices, or for a material being studied via optical method. This can be measured very precisely by using interferometric techniques. It is possible to measure the change in index of refraction of a material as a function of temperature by interferometric methods. Because of their high sensitivity, interferometers have been used to measure very small displacements, small surface roughness, quality of optical components indices of refraction wavelengths of waves interfering etc. Temperature dependent refractive index changes have been measured in alkali halide filters like  $BaF_2$  and  $MgF_2$  which are widely used in FUV and NUV. They have extremely sharp transmission cutoff edges in the ultraviolet region. These filters are good for solar observations and the study of variation refractive index with temperature is very important for the same. An effort has been made to incorporate advanced control and data acquisition techniques with interferometry, which enabled high degree of accuracy in measurements. The entire experimental set-up including motion stages, detectors, temperature control etc is implemented on Lab VIEW platform.

### *The Library*

The library of the Indian Institute of Astrophysics at Bangalore is a modern library and is equipped with the state of the art technology. It is more than 200 years old and over the years it has accumulated a large collection of books in astronomy, astrophysics, physics, mathematics, geophysics, electronics and computer sciences. Today it can boast of housing the largest and most comprehensive collection in astronomy and astrophysics in the country.

The library collection is distributed among the main library at Bangalore and the branch libraries in Kodaikanal, Kavalur and Hosakote. The Kodaikanal library is 107 years old and is equipped with old volumes of several journals and a small collection of books and current journals in solar physics and geophysics. The Kavalur library has a fairly large collection of atlases, catalogues and a small collection of books for the use of observers and resident scientists. The Hosakote library has been recently set up and has books and journals in broader areas of science and technology.





**Prof. K.R. Sreenivasan, Director, The Abdus Salam International Center for Theoretical Physics, Trieste, visited the Institute 25-10-2006. With him in the Library are Profs. Siraj Hasan and Vinod Krishan and Dr. Christina Birdie**

The main library at Bangalore has about 18000 books and subscribes to 243 journals. It can access 134 journals electronically (<http://www.iiap.res.in/library/journals.html>). IIA has a functional web page (<http://www.iiap.res.in/lib.html>), which accommodates the essential information about the library in addition to the various e-journals and databases. The library catalogue can be accessed over the internet with a web-based OPAC. The library is an important nodal center for lending and reference service in astronomy in the country. It is also a part of FORSA ( Forum for Resource Sharing in Astronomy and Astrophysics) consortium and has access to several journals as a member. The library recently created an Open Access Repository using Dspace software. This digital repository is developed to capture, disseminate and preserve publications of the Institute. The IIA Open Access Digital Repository is accessible on the Internet from 'http://prints.iiap.res.in'. The repository currently hosts full-text of 82 PhD theses, 451 research papers in IAP Publication community, 66 newspaper clippings and 477 research papers published in the Bulletin of the Astronomical Society of India community. It also has 88 archival publications, which have rare contents and photographs to make it a more unique repository.

**Historical Collections :** Since the library is more than 200 years old it boasts of a valuable archival collection. 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 Transaction' of 1794 and the oldest almanac available is that for the year 1767. The Place of pride however goes to the hand-written "Annual Report" of the Madras Observatory for the year 1792.

During the last two years, special efforts have been made to digitize the archival collection. These include books, manuscripts, photographs and maps published before 20th century. There is also a programme for preserving the old documents so as to arrest any further deterioration.

IIA library is a member of the Digital library of India (DLI) project, which is a collaborative project between Carnegie Mellon University, USA, Indian Institute of Science, Bangalore and Ministry of Communication and Information Technology, Government of India. Under this project the number of pages scanned cropped and OCR'd at IIA library run to more than 4,00,000 pages, and the full-text access to these pages is available in the public domain.

### *The Cyberspace*

The Computer Centre 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 systems, one Sun fire system, one 8 node Sunfire system for high end computing. The email server, webserver and firewall are also present in the Computer Centre. Two Pentium IV PC's with Windows XP OS are available for general use. IIA is a part of the high speed computational project Garuda of C-DAC. A Pentium IV PC running Red Hat Enterprise Linux OS connects to the Garuda network. The IIA campus is connected to the Internet by a 5 Mbps link from Sify.

### *Technology development*

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

The Institute has mechanical engineering workshops at its headquarters in Bangalore, Vainu Bappu Observatory, Kodaikanal Observatory, Indian Astronomical Observatory as also in the CREST campus. 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 mosaic CCD cameras both for astronomy and other usages. Some recent works carried out at the workshops include the manufacture of CCD dewars, camera for the HCT at IAO, coelostats for solar astronomy- specifically for solar eclipses and the Antartica expedition etc. The mechanical workshops at the CREST campus and IAO have provided necessary support during the installation and testing of the HAGAR telescopes.

### *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 the distinction of



building the 2.34M Vainu Bappu Telescope optics in the country in the early 1980s. It has since been continuously carrying out works on different aspects of optical technology.



#### The Long Trace Profilometer

The Division has contributed substantially to other sister organizations in the country such as BARC, ISRO, VSSC, LASTEC etc. for the development of indigenous optical instrumentation and technology. The Division has contributed significantly for the development of Very High Resolution Radiometer (VHRR) passive coolers for the Indian satellite programmes.

The Division has the rare distinction of building a Long Trace Profilometer, for testing Synchrotron Beam Line Optics, for the first time in the sub-continent. This has given the country a distinctive place among the handful LTP builders. This instrument is developed under a contract from the Board of Research for Nuclear Sciences. A second one in the line has also been developed and built, and delivered to CAT, Indore.

The activity in the Division at present is focused on conducting research on Adaptive optics, thin film coatings etc., which have wide spread application in astronomy, space sciences, defence and atomic energy.

## *Graduate studies programme*

A significant part of the Institute's activity is the graduate studies programme managed by the Board of Graduate Studies (BGS). The programme 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 twenty and in the last decade twenty Ph.D.theses in research areas ranging from instrumentation to cosmology have been awarded. The BGS runs a summer project students programme which is completed in two months during the student's summer vacation. The Institute is also a major partner in the Joint Astronomy Program conducted by the Indian Institute of Science.

## *Looking Ahead*

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 Theoretician's Mind*

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. In high energy astrophysics, the interest will be in radiative processes around compact objects like neutron stars, pulsars, black holes, gamma ray bursts and x-ray binaries etc. Spectral line formation in solar and stellar atmospheres is an extensively studied field but a lot is sought to be done. 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 experiments.

## *Solar astronomy*

The Institute is working towards creating facilities for the study of the sun. The Hanle site offers the advantage of low water vapour, a large number of clear days in a year and several hours in a day to allow coronagraphic 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. A detailed site characterization is underway from this point of view that will enable focussing on proper solar instrumentation.

## *National Large Solar Telescope*

The existing facilities for solar research in India are grossly inadequate for high resolution observations of the Sun. The solar tower telescope at Kodaikanal, with its high dispersion spectrograph installed in 1960, is still the only major solar facility in the country. A large and versatile telescope can facilitate simultaneous measurements of the solar atmospheric

parameters and of the magnitude and direction of magnetic fields with high accuracy. With this in view, a two metre class high technology equipment, the National Large Solar Telescope (NLST), has been proposed as a national facility. The NLST will be a major effort of Prof. S.S. Hasan from the Institute, with solar astronomers from ISAC Bangalore, Udaipur solar Observatory, ARIES, Nainital and IUCAA, Pune. It will incorporate most of the technological innovations in the field of optics by the use of active and adaptive mirrors and will be one of the best telescopes in the world of its category. In fact, this will be the largest till the four meter Advanced Technology Solar Telescope in USA comes into existence.

NLST will be complementary to space missions like SOLAR-B and SDO. While the space mission will provide uninterrupted coverage of the Sun, the NLST will provide high spectral, temporal and spatial resolution observations.

### *Some first steps for the NLST*

The diffraction limit of a 2 metre telescope at 500 nanometers wavelength is 0.06 arcsec which corresponds to ~ 35 km on the solar surface. With the use of adaptive optics, features of the Sun can be resolved to this order, provided the 'seeing' conditions of the site where the telescope is located are very good. So, where can we establish the NLST ?

Site selection for establishment of sophisticated equipments is an arduous process. The number of annual sunshine hours, the number of hours providing a certain range of values of the Fried's parameter for the seeing measurements, the isoplanatic angle provided by the site, and the year round meteorological conditions such as wind speeds and direction, the precipitable amount of water vapor, the microthermal fluctuations, etc. are all to be studied, and at different locations. Some of these measurements are routinely carried out at Hanle.

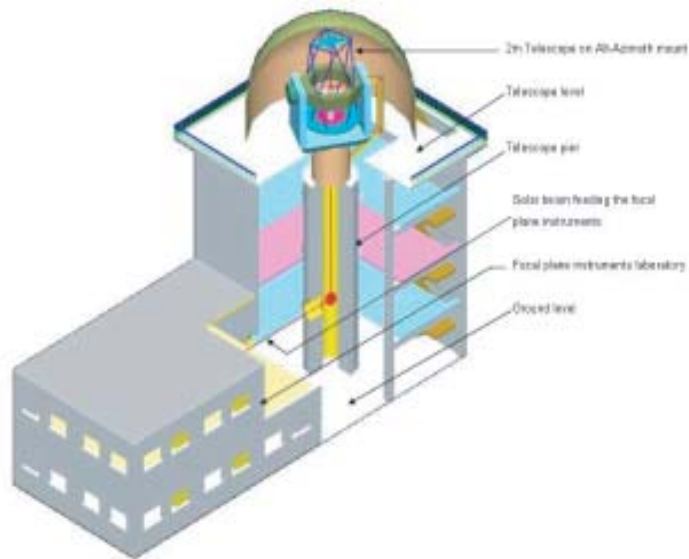
The standard equipments which have been developed in the recent times for solar site characterization are the Solar Differential Image Motion Monitor and an array of scintillometers called the SHABAR. These are being fabricated and refurbished with the help of the National Solar Observatory, USA. It is important to install the equipment on a specially designed tower in order to avoid the thermal stratification by near-ground layers of the atmosphere. One set of equipment and the tower are expected to be ready for operation at Hanle by Sept/Oct 2006. In the meantime, identical equipment will be installed at another two or possibly three other sites and the site characterization work will continue during the years 2007-08 to arrive at a final choice of the best of the sites for locating the NLST.

Further work on the preparation of the site chosen for the telescope installation will be governed by the fabrication and delivery schedules of the NLST.

**NLST: The instrumental side :** To be able to follow the dynamical events that propagate upwards in the atmosphere, observations at different heights within the solar atmosphere are most essential. For this, the telescope with auxiliary instrumentation should operate efficiently over the visible as well as

in the near Infra red region of the solar spectrum, i.e., in the wavelength range from 3800 Å to 2.5 microns. One of the primary goals is to measure the vector magnetic fields in the small scale features accurately by measuring the polarization. To achieve an accuracy of one part in 10,000, in the polarization measurements, the telescope polarization itself must be lower than this. An aperture of 2 m for the primary mirror is the minimum size that would be required to collect enough photons for reliable measurements by the instruments. It is estimated that with a coarser resolution, about 30,000 photons/sec would reach each pixel of the CCD detector of the measuring instrument. This will enable to build a final signal with a signal to noise ratio of ~ 100 in an integration time of 60 msec. In the case of polarization measurements, a signal to noise ratio of 1000 would be needed as the polarization signals are sometimes weak.

The image correcting system for the NLST will depend on the site characteristics. The image correcting system should have at least two different sub-systems (apart from the main telescope pointing and tracking system). The first being the tip-tilt correcting element to correct for the first order aberrations and the second being the adaptive optics(AO) which then corrects for other higher order aberrations. The tip-tilt system will work with a granulation/solar feature correlation tracking method and is well established. In fact, all solar observatories will have a tip-tilt system as one of their image stabilization method.



**Telescope Dome and Dome Building**

The above requirements when translated into system specifications by using the available existing system for the smaller telescope will lead to the following :

- sub-aperture sizes of the Shack-Hartmann system ~ 6cm (of the order of  $r_0$ ).
- a correlation tracker working on the full FOV of the telescope (which is about 5~arcmin).
- number of lenses in the Shack-Hartmann ~ 1000.
- number of actuators in the deformable mirror ~ 1000.
- CCD chip size for the wave front sensor ~ 1024X1024.
- frame rate of the CCD ~ 2000Hz.
- CCDs with large wells are preferred (in order to reduce the photon noise).
- a system band width of 100-200Hz is necessary.
- a fiber based interferometric setup may be required to quickly calibrate the flatness of the deformable mirror.

In order to develop such a complex system, a two step approach is planned. In the first phase, collaboration with the Udaipur Solar Observatory (USO) will be established to get involved with their low-order AO system and with the knowhow gained a low-order system would be developed with about 100 actuators and tested in the laboratory and in the field. The technical expertise acquired in this process would be used to upgrade low order system to a high order system.

**NLST: The scientific side Polarimetry :** Most of the physical processes that take place on the Sun involve magnetic field. Magnetic fields on the Sun have sizes ranging from small-scale features to large-scale complexes of activities. Polarimetry is the only available way to quantitatively study the magnetic fields. Polarimetry is a study of the polarization nature of the source under consideration (in our case the Sun within the field-of-view (FOV) of interest).

Polarimetry is done with either a spectro-polarimeter or a filter based system. The NLST will include the polarization and analyzing optics in its optical train.

The scientific requirements of the NLST will warrant a very accurate polarization modulation and analyzing unit. The requirements for the polarimeter are:

- 1) Preferably cover the whole wavelength range (3500A to 2.5micron). It is possible with two or three modulators covering a set of wavelength range.
- 2) Preferably a fixed one (no movable parts).
- 3) Highly stable over at least a day (so that a single calibration for the whole day will be sufficient).
- 4) Polarization accuracy of  $10^{-5}$  and a precision of few times  $10^{-4}$ .
- 5) Good optical quality (since it is being kept at the Gregorian focus).
- 6) A calibration unit located in front of the modulator in the optical path.
- 7) Preferably the balanced modulation scheme need to be used in order to avoid seeing induced spurious polarization.
- 8) Modulator should have good transmission over all wavelengths from 3500A to

2.5 micron since it is kept way up in the optical path.

**NLST: The technology side :** The Institute will be collaborating with Astronomy Technology Centre (ATC) in Edinburgh which has considerable expertise in the field of optical, infrared (1 - 27 microns) and sub-mm astronomical instrumentation and in developing conceptual designs for optical telescopes and instruments.

Specific areas where expertise will be sought through are - for the design of the optical configuration, choice of suitable material for the mirrors etc., setting up an adaptive optics laboratory within the Institute and design and development of the spectro-polarimeter through collaboration with the Institute for Astronomy, Hawaii and High Altitude Observatory, Boulder, U.S.A. It is proposed to acquire technical know-how in the design of heat trap at the prime focus of the 2m telescope.

### *Vainu Bappu Observatory*

The science sought to be done from Kavalur will be spectroscopy intensive, focussing on (a) chemical evolution of the Galaxy - study 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. Metal-poor stars are very important tools to study early Galactic history. The small-scale, medium resolution spectral survey of field stars started on VBT Kavalur has proved to be quite rewarding. There are proposals to carry out large-scale spectral survey using OMR spectrograph at VBT Kavalur, as well as the HFOSC at IAO Hanle.

**The 1.3 meter Telescope :** A modern 1.3 meter telescope is in the process of being acquired to be installed at the VBO.

As complementary programmes the observations of southern objects not accessible from Hanle and also programmes requiring optical spectroscopy will continue to be undertaken from Kavalur. The activities are expected to peak in the near future.

### *Indian Astronomical Observatory*

The scientists at the Institute have ambitious programmes for doing astronomy with the 2m HCT and other facilities from Hanle in the coming years. A solar vacuum telescope is being planned to be established at Hanle. The HCT will shortly be equipped with a high resolution spectropolarimeter.

A peep into the research activities proposed to be pursued from IAO in the future is as follows:

- a) Galactic Astronomy: star formation, star clusters, extra-solar planets, binary stars, evolved stars and chemical abundances, Interstellar UV radiation field.
- b) Extra-galactic astronomy and observational cosmology: starburst galaxies, Active Galactic Nuclei, Type Ia Supernovae as standard candles, gravitational lenses.
- c) Targets of opportunity: multi-site observations and monitoring of gamma ray burst sources, supernovae, novae, rapidly varying young stellar objects and occultation events.

What scientific returns does one expect from such ventures? Astronomers visualize making

observations that will enable them to throw light on cosmology and large scale structure of the universe. This is possible because by taking the short exposure limit to 25 B magnitude, we can image galaxies that are just being formed when the age of the universe was only a billion 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.

### *An 8-10 meter Infrared-Optical Telescope*

With infrastructure improving by the day, Hanle as one of the best high-altitude sites for astronomy, has evoked considerable interest nationally and internationally in developing a major facility, namely, an 8-10 meter Infrared-Optical Telescope. The Trans-Himalayan region of Ladakh provides a large number of clear nights evenly spread over the seasons.

Changthang Ladakh is above a mean altitude of 4000 m (13000 ft) above sea level, and many sites are possible in the altitude range of 4500-5500 m (15000-18000 ft). It is a cold, dry, high altitude desert similar to Atacama desert (Chile) in the southern hemisphere.

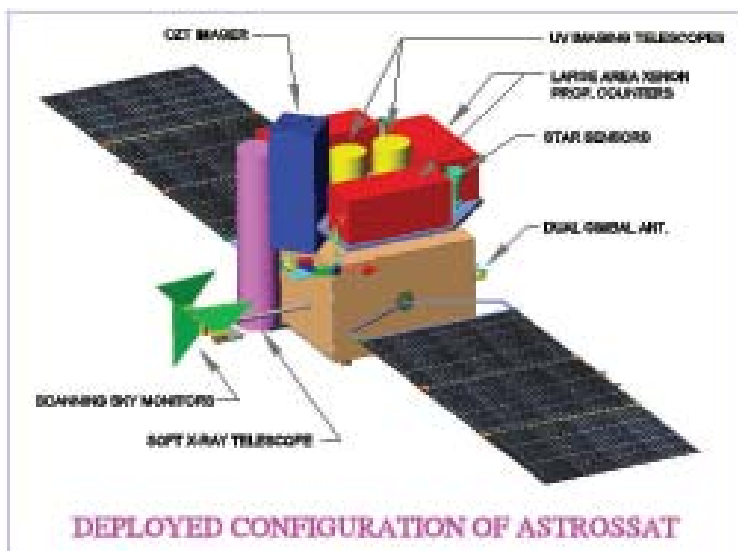
The sites will have advantages to other low altitude sites from near-UV to mm-wave astronomy and the ultra-high energy gamma-ray astronomy using atmospheric Cerenkov technique. India has felt the need to develop a large infrared-optical telescope. IIA and University of Arizona have informally discussed projects involving two 6.5 m mirrors on a mount similar to the Large Binocular Telescope (effective aperture of 9m diameter) and seven 6.5 m mirrors on a single mount similar to the Giant Magellan Telescope. Collaborations with other institutions in India, and US and Europe and east Asia are likely.

In fact, the groundwork towards achieving this objective in a reasonable period for the telescopes to be fabricated and erected is underwa

### *A Leap Into Space*

The Institute is already a serious participant in space astronomy ventures in the country, in the oven and on the anvil.

**ULTRA VIOLET IMAGING TELESCOPE (UVIT) :** The Ultra Violet Imaging Telescope is one of the payloads in ASTROSAT, the first Indian satellite entirely devoted to astronomy. The satellite is designed for simultaneous multiwavelength observations, covering a very wide range from hard X-gamma rays to the visible band. Such simultaneous observations have a special role to play in understanding the location and nature of physical processes of emission in variable sources. The satellite is expected to be launched near the end of 2007. The UVIT would be making images of the sky simultaneously in three channels : 320 nm to 550 nm (visible), 180-300 nm (Near Ultra Violet), and 130-180 nm (Far Ultra Violet).



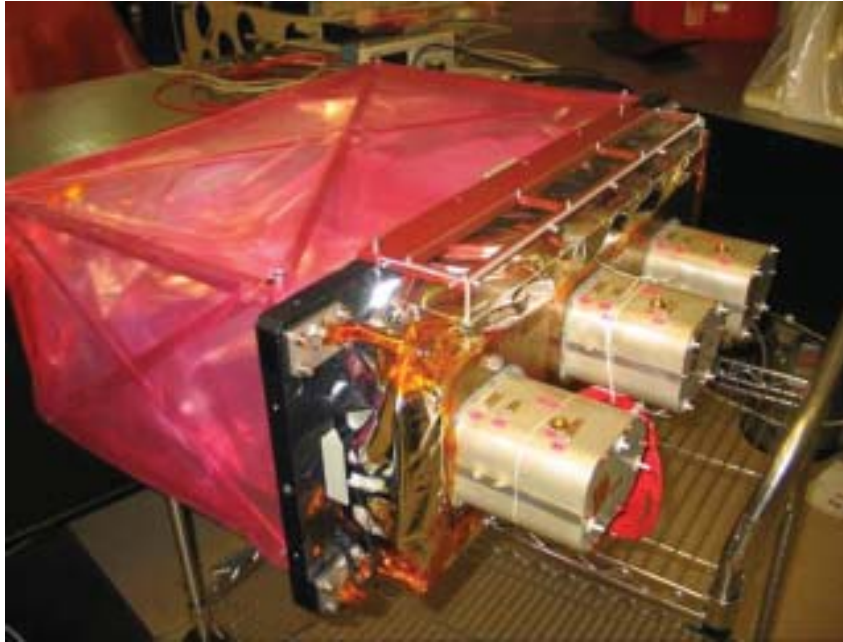
The science goals of the mission are diverse - galaxy evolution, pulsars, supernova remnants, Star formation rate, stellar populations in other galaxies, sky survey, dust properties, polarization and time variability, just to name a few.

The instrument is being jointly developed by Indian Institute of Astrophysics (IIA), Inter University Centre for Astronomy and Astrophysics (IUCAA), Physical Research Laboratory (PRL), Tata Institute of Fundamental Research (TIFR), several laboratories of ISRO and the Canadian Space Agency. The payload would be assembled and tested at IIA. The structure and thermal control of the instrument are being designed at IIA with active support of ISAC of ISRO. The main optics (mirrors of the telescopes) has been designed and spherical mirrors for a half size model have been made at IIA. A small clean room is already functional at IIA and instruments are being assembled for testing of components etc., including tests in vacuum. For assembly and testing of the telescopes, a special purpose clean laboratory is being developed at the CREST campus having an area more than 500 sq. mt. It has three sections with different levels of cleanliness: Class 100,000 for testing of mechanical parts, Class 10,000 for assembly of mechanical parts and Class 1000 (with a Class 100 optical table



and access to a vacuum chamber for testing the assembled telescope) for assembly and testing of the telescopes.

**The TAUVEX mission :** TAUVEX is an Indo-Israeli Ultraviolet Imaging Experiment that will image large parts of the sky in the wavelength region between 1400 and 3200 Å. The TAUVEX hardware is built by EL-Op, Israel whereas the software for data acquisition and reduction is developed by IIA. The payload is scheduled to be launched into a geosynchronous orbit by a GSLV launcher as part of ISRO's GSAT-4 satellite in early 2007



TAUVEX will use a set of 3 ultraviolet (UV) telescopes to observe much of the UV sky. The UV sky is still not fully explored and TAUVEX will obtain a unique data set which will be used for many years into the future. The instrument consists of 3 telescopes optimized for use between 140 and 320 nm. With almost a degree sized field of view and 6 - 10 arcsecond resolution, TAUVEX is well-suited for surveys of the sky to a magnitude limit of close to 20. TAUVEX was built in Israel and is undergoing final fabrication and qualification at the site of the Prime Contractor (ELOP Industries Ltd.). The instrument will be delivered to ISRO in 2006 and will then be integrated with the GSAT-4 spacecraft in preparation for the launch.

The prime responsibilities of the Institute include the mission planning, development of the pipeline software, dissemination of the data products to the general Indian science community and, of course, the actual scientific analysis of the data and publication of the results. It is to be noted that, uniquely amongst Indian satellites, the data will be released to the entire Indian community immediately on processing. Further information including sky simulations may be found at <http://tauvex.iiap.res.in>.

Space coronagraph : The solar astronomers at the Institute are taking a plunge into space, away from the hassles of frequent weather changes on ground and the scattered light, to be able to study high frequency oscillations caused by coronal waves and magnetic fields in the solar corona. Based on the joint recommendations of astronomers as also the Space Weather panels for carrying out intensive studies of solar coronal emissions and magnetic fields, ADCOS constituted a working group of scientists from Indian Institutions including two from IIA. This group is working on to make a detailed proposal for design and fabrication of a solar coronagraph which is proposed to be launched aboard an Indian satellite in the time frame 2010 - 12. The group has proposed a simple experiment to fabricate a 20 cm coronagraph. It will enable taking simultaneously 530.3 nm and 637.4 nm coronal emission line images of the solar corona, at a rate of about 3-5 Hz. There is scope to add a spectrograph that will help determine velocity structure of the transients.

The scientific objective is 1. to determine the existence and nature of waves in the solar corona by studying the intensity oscillations using emission lines Fe xiv at 530.3 nm and Fe x at 637.4 nm in different types of coronal structures, 2. the simultaneously obtained images of the active regions in the 530.3 nm and 637.4 nm coronal emission lines, representing plasma at about 1.8 MK and 1.0 MK respectively, will yield clues to the cooling processes involved in the coronal and post flare loops, 3. the high cadence observations will allow to determine the velocity pattern of coronal mass ejections (CMEs) and possibly the origin of solar wind.

### *Sub-mm Astronomy*

The altitude advantage of Hanle makes it one of the best sites in the world for astronomy in the sub-mm range. Astronomers at IIA also plan to develop a sub-mm observing facility at Hanle which may help to exploit the excellent qualities of the site for mm and sub-mm observations. They have been conducting some site characterisation in this area with national and international collaborations and these activities will escalate with time. It is expected that other national and international institutions would desire to place a sub-mm telescope of significant size at this site, with the Institute as a significant partner.

### *Raman Science Centre*

A science centre at Leh is also a part of the IAO which is aimed at taking science to the common person in the region which will be equipped with a small telescope, computers, lecture hall and guest house facilities.

In the next decade the IAO will create a strong base for optical astronomy. As of now there are not many young people coming forward to pursue research in the field of optical astronomy. In order to fully use the existing optical telescopes and ensure the growth of the optical astronomy in India we need the above mentioned to be carried through in a planned way.

The cover of the oldest printed book in the possession of the Library, IIA.

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.

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

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

Vainu Bappu Telescope building, Kavalur.

The solar tower tunnel telescope.

An aerial view of the E-W arm of GEETEE.

A close up view of 135 deg and 45 deg oriented antennas

The M.G.K. Menon Laboratory for Space Sciences, work in progress.

Telescope Dome and Dome Building

## *Reaching for the Stars*

### **Indian Institute of Astrophysics**

[www.iiap.res.in](http://www.iiap.res.in)

#### **NGC 6819, taken through the Himalayan Chandra Telescope**

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Crab Nebula, taken through the Himalayan Chandra Telescope