

Indian Astronomical Observatory, Leh-Hanle

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Indian Astronomical Observatory (IAO), Hanle, was set up by the Indian Institute of Astrophysics (IIA), in the year 1997 in Changthang region of Leh district of Jammu & Kashmir at an altitude of 4500 m above mean sea level. Though the primary interest was to undertake astronomical studies from the high altitude cold desert site that provides the largest number of clear and highly transparent skies in India, the presence of IIA in the pristine, geographically unique site has spurred development of many experiments in several branches of science. Since the activities of the observatory now span the entire area of Leh district, the office and laboratories of the observatory are being set up in Leh, the district headquarters. Site characterization of Hanle began in 1994 and the infrastructure development in 1996. The first phase of development ended in 2000 with the commissioning of 2-m Himalayan Chandra Telescope. The telescope was remotely controlled and equipped with instruments for regular use since 2003. Utilizing this infrastructure, very high energy gamma ray astronomy was initiated with the commissioning of HAGAR in 2007 and MACE to be installed beginning 2015 summer. Different institutions have utilized the infrastructure for various experiments in earth sciences.

Key Words: Astronomy – Optical; Infrared; Gamma Rays; Astronomical Observatories; High Altitude Science – Astrophysics; Geophysics; Atmospheric Studies

Introduction

In an attempt to establish a large optical/NIR telescope facility in the country, the Indian Institute of Astrophysics (IIA) undertook the exercise of identifying a high altitude astronomical site, following the recommendations of a committee chaired by Prof. B.V. Sreekantan, on behalf of the Department of Science and Technology, Government of India in 1986. Based on a study of the available topographical maps, weather data and satellite imagery, carried out during 1992-93, six potential sites were identified in the Himalayan and trans-Himalayan regions, all more than 4000 m altitude above mean sea level. Simultaneous reconnaissance survey of all the six sites indicated the trans-Himalayan sites, located in the rain shadow of the Himalayan Mountains, to be more favourable. Of these, Digpa-ratsa Ri, Hanle, was chosen for further

detailed studies. A continuous monitoring of the weather and cloud coverage, which began in 1995, together with seeing measurements made in campaign mode, indicated Hanle to be a world-class astronomical site for the national large optical telescope (Cowsik *et al.*, 2002). Following the identification and characterization of the site, a committee chaired by Dr K. Kasturirangan suggested the development of the site in two steps: (1) installation of a 2-m class telescope and development of infrastructure and remote operation capability; (2) development of the large infrared-optical telescope utilizing this infrastructure and experience gained.

The foundation stone for the Indian Astronomical Observatory (IAO), Hanle, was laid by Lt. Gen. (Retd) M.V. Krishna Rao, the then Governor of Jammu & Kashmir state in October 1997. The first step was executed with the installation of the 2-m

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diameter Himalayan Chandra Telescope (HCT) at Mt. Saraswati (longitude $75^{\circ} 57' 51''$ E, latitude $32^{\circ} 46' 46''$ N, altitude 4500 m above mean sea level). It was installed in August 2000, and was dedicated to the astronomical community in August 2001 when the telescope and dome were fully automated and remotely operated from Bangalore using a dedicated satellite communication link. It was equipped with state-of-the-art instruments for optical and near-infrared imaging, and optical spectroscopy during 2002-03 and the regular allotment of telescope time began in May 2003.

The development of infrastructure at Hanle has attracted other scientific projects in astronomy such as High-Altitude Gamma Ray (HAGAR) telescope and Major Atmospheric Cerenkov Experiment (MACE) in the Very High Energy (VHE) Gamma Ray region, and seeded many experiments in earth sciences at Hanle as well as other locations in Leh district. New initiatives undertaken by IIA in the area of Solar Astronomy (National Large Solar Telescope: NLST) has led to the identification of the lake site of Merak, Pangong Tso region where the daytime observing conditions are excellent due to the stabilizing effect of a large water body. Preparations for the National Large Optical Telescope (NLOT) have continued and site characterization activities are expanded in the region around Hanle. The scientific activities at all these locations are coordinated from the headquarters of Indian Astronomical Observatory situated in Leh, the headquarters of the district of the same name.

The idea of development of the high altitude observatory is even older. "The suggestion to look for an astronomical site in Ladakh region located more than 3,000 metres above mean sea level was mooted in November 1981 at a meeting organized by ADCOS held under the Chairmanship of the late Prof. MK Vainu Bappu. At this meeting, it was pointed out that the Ladhak (*sic*) region remains relatively clear during the monsoon period, when rest of the country experiences cloudy sky due to monsoon conditions. It was also noted that only at such high altitudes, precipitable atmospheric water vapour will be low enough for high quality infrared observations"

(Bhatnagar and Gandhi, 1991). This led to a DST project on site survey in Leh (1984-89), a national project headed by Dr. A Bhatnagar, Udaipur Solar Observatory. The survey concentrated on a region near Nimmu (4100 m above msl) on Leh-Kargil road northwest of Leh and concluded the following: "From a detailed analysis of the data and comparing with established high quality observatory sites in the world, it is concluded that the Mt. Nimmu site is acceptable as regards the following parameters:

- (i) Zenith Precipitable Water Vapour (ZPWV),
- (ii) temperature variation (AT) during night time,
- (iii) wind speed and direction,
- (iv) relative humidity,
- (v) astronomical "seeing",
- (vi) day sky brightness (marginally acceptable),
- (vii) night dark sky brightness (marginally acceptable),
- (viii) extinction coefficient in UBV_IJH bands, and
- (ix) microthermal temperature fluctuations.

Due to the low percentage of the available clear weather, this site may not be acceptable for optical observational astronomy.

While the survey was in progress, following the advice of Dr Vasant Gowarikar, the then Secretary, DST, Prof. JC Bhattacharyya, the then director of IIA, prepared a Concept Report for a High Altitude Observing Facility (Bhattacharyya, 1987). Bhattacharyya observed in this report: "I would like to extend our dreams towards creation of world-class high altitude observatory in our country. Even if the site at Mt Nimmu does not appear to be so suitable, the Ladakh area still offers some of the highest accessible sites in the world.... But for such a venture, we may have to try some new ideas in technology.... The telescope will have to be totally remote-operated. Considering giant strides we have made in our space programs, development of such a system appears well within our reach."

This thread was followed up by IIA in 1992 under the leadership of Prof. R. Cowsik, the then director of the institute. Through a detailed study of meteorological, topographic, and satellite imagery data, sites were identified at altitudes higher than Mt Nimmu. Site reconnaissance trips were conducted simultaneously to six high altitude sites in July 1992 cutting across the Himalayas in the states of Uttar Pradesh (current Uttarakhand), Himachal Pradesh and Jammu & Kashmir (southeast Ladakh). It was apparent from this study that the Monsoon clouds are weakened as they cross the Himalayas, especially over the regions of eastern Himachal Pradesh and Uttarakhand, while the westerly disturbances that affect northwest India are weakened as one moves towards southeast of Nimmu. The Hanle region surrounded by high mountains separating it from Tibet, Himachal Pradesh and northwestern Ladakh appeared the most prospective region comparing well with international high altitude sites for astronomy. Further reconnaissance trips were made to Hanle in the following winter (January 1994) and summer (July 1994) and a permanent site characterization camp was established in December 1994.

Science at High Altitudes

A year of site characterization proved that Hanle stands well above all other astronomical sites south of Himalayas, and compares well with the best international sites. The development of the site as an astronomical observatory site was hence initiated.

Researchers in several other scientific fields began to take advantage of the presence of IIA in the area, and started experiments right from the time of site characterization phase. The earliest among these were the two high-accuracy GPS stations set up collaboratively by the Centre for Mathematical Modeling and Advanced Computer Simulations (CMMACS), Bangalore, with Leh and Hanle serving as hubs for GPS campaigns in other sites in Ladakh. These measurements, together with campaigns and permanent stations in the sub-Himalayan regions, have provided accurate information on the geodynamic deformation of Indian sub-continent consequent to collision of Indian crustal plate with

the Eurasian one. This was followed by the installation of broad-band seismographs by Wadia Institute of Himalayan Geology (WIHG), Dehradun, at Hanle and other sites in Ladakh as a part of national network.

The experiments in atmospheric physics were conducted in campaign mode by National Physical Laboratory (NPL), New Delhi and Indian Institute of Tropical Meteorology (IITM), Pune. The latter institute collaborated with IIA in collecting aerosol samples for a few years subsequently. Space Physics Laboratory (SPL), Trivandrum has initiated more detailed study of aerosols, establishing a high altitude aerosol observatory. Indian Institute of Geomagnetism has conducted a study of feasibility of measuring the effect of solar storms on earth's magnetic field.

In the field of astronomy, Hanle has attracted investment in the area of Very High Energy Gamma Ray astronomy, and a site is identified for solar astronomy at Merak, on the bank of Pangong Tso (Lake). The University of Tokyo and Raman Research Institute (RRI), Bangalore, collaborated with IIA in characterizing Hanle for sub-mm wave astronomy. Harvard-Smithsonian Centre for Astrophysics collaborated with IIA to identify another high altitude site (5200 m above msl) to the west of Hanle for astronomy at tera-hertz frequencies. Hanle region appears to be the best for the NLOT, and hence more sites are being characterized and compared around this region. Some initiatives have been taken in the area of astroparticle physics as well.

IIA is developing its IAO Leh campus, which acts as a hub for all these activities in the district of Leh.

The Location of Hanle

The Indian Astronomical Observatory is located on the Digpa-ratsa Ri mountain range and Nilamkhul Plains at its foot in the Hanle region of Leh district of Jammu & Kashmir state in India. The highest peak in Digpa-ratsa Ri is at an altitude of 4517 meters. The surrounding Nilamkhul Plain is at an altitude of 4240 meters above msl. The range measures 2 km

east-west and 1 km north-south with the top providing about half square km of flat area. The peak contains a few rocky mounds which have been levelled by a few meters. An area of 600 acres, including the mountain top and the plains at its base constitute the IAO.

Hanle (pronounced *an-lay*) region is known by a Buddhist monastery and a small tributary of Indus originating in a nearby glacier. The monastery was built as a fort in the 16th century when the Ladakhi rulers defined the border with Tibet beyond this region. The distance between Leh and Hanle is 260 km of which 200 km is along Indus and 60 km along the Hanle River. Leh is the largest district in Jammu & Kashmir, but has a very sparse population. The district headquarters, Leh, has a population of 15000. Locations of Leh and Hanle are shown in Fig. 1 with respect to Jammu, Srinagar and Kargil. About 180 km of travel from Leh upstream of Indus brings one to Nyoma, the subdivisional town in which Hanle region lies. There is some public infrastructure in Nyoma, with limited generation of electric power for local needs, a high school, a public hospital, a branch of J&K bank, and a police station. After another 20 km along Indus, one crosses it and drives due south along Hanle River for the next 60 km. This road was just a drive on sand desert until a few years ago. The surfaced road has come up in stages during the last five years.

Hanle river valley is home to many migratory birds including the rare black-necked crane, and animals such as Tibetan wild ass and Tibetan gazelle. The river cuts across a large tract of flat sandy desert surrounded by high mountains. The Hanle monastery is near the centre of the desert. Since clouds traveling from south and from west lose most of their water on their way, what remains precipitates over the high mountains. The mountain peaks are a couple of km above the altitude of the desert and at a distance of tens of km; consequently, they do not obstruct more than 3° over the horizon as seen from the peak of the observatory.

There are several hamlets scattered along the

Hanle river and in the Nilamkhul Plains surrounding the observatory. The size of each hamlet is limited by the availability of agricultural and pastoral land for sustenance. There is no electric power, but most houses have solar powered lamps. Buses ply from Leh once a week and there are no telephone lines. The observatory had to set up all infrastructure required for its operation.

Astronomical Site Characteristics

One year of monitoring of the sky from the region on the northern edge of the Nilamkhul Plain — where paramilitary forces had provided some infrastructure support — showed that the number of clear skies at Hanle meets the expectations for an international quality site (Hirotsu Team 1996). Additional site survey experiments conducted initially from this location and soon from the mountain peak showed that the site surpasses Mt Nimmu in all aspects that were acceptable there as well. The site characterization has continued at Hanle for nearly two decades. We describe the characteristics in some detail here since they have a bearing on suitability of the site for astronomical purposes, and also provide valuable data for climatological studies.

Cloud-Free Skies

The number of nights a telescope can be used from a given site is one of the most important data required before significant investments are made on development of the site and establishing an astronomical observatory. Hence, manual monitoring of skies at hourly intervals was initiated at Hanle during the last week of 1994, and it has continued ever since. The amount of cloud cover in the sky is measured in octas. Nights with 0 octa clouds continuously for 6 hours or more are the best nights for astronomy and are called Photometric Nights. Nights with not more than 3 octa clouds for at least five hours of the night are usable with somewhat reduced accuracy. These nights, added to the Photometric nights, are called Spectroscopic Nights. The photometric nights thus have the best quality, and spectroscopic nights are the nights during which the telescope is usable. The number of photometric

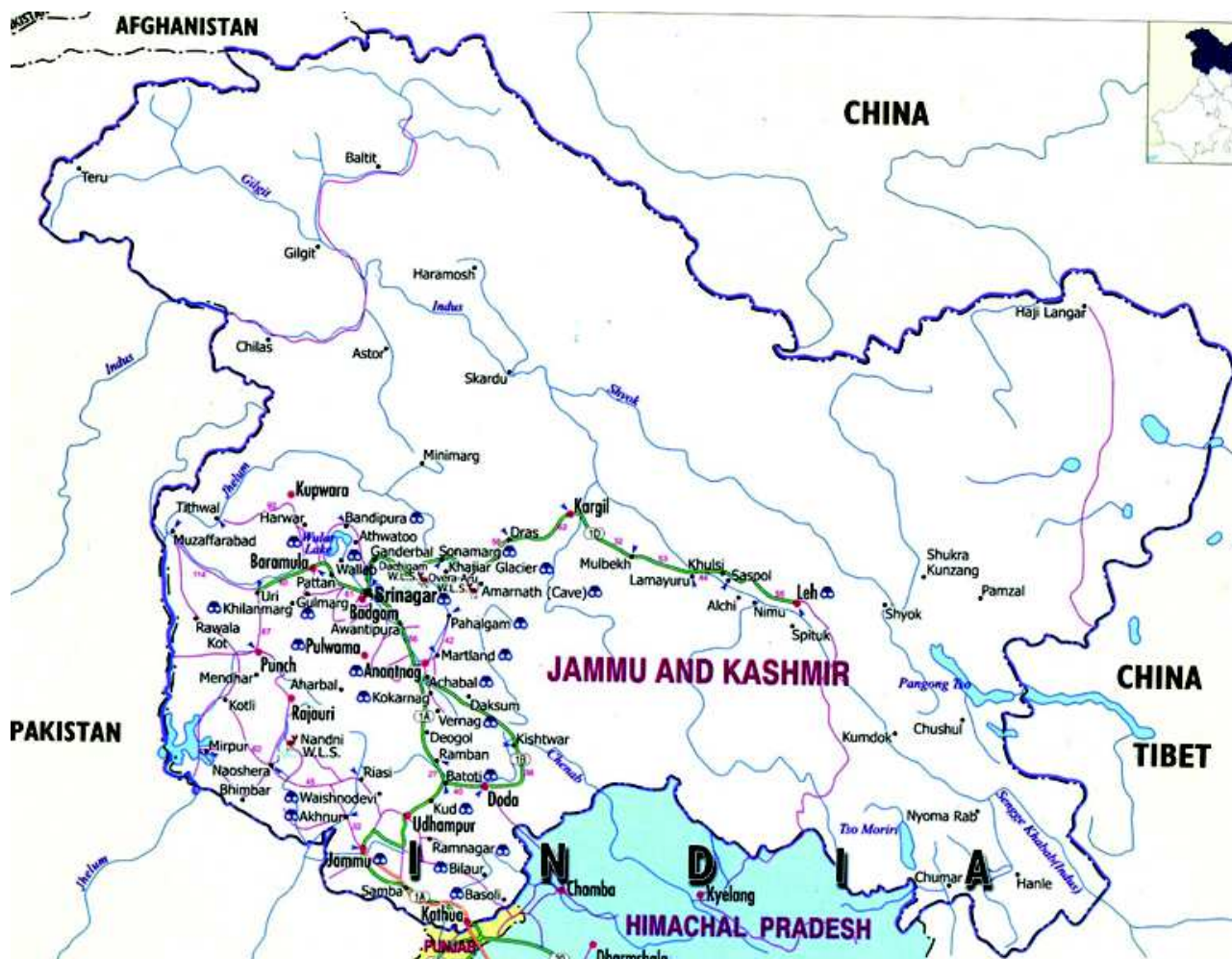


Fig. 1: Outline of Jammu & Kashmir state showing the location of Hanle in the extreme southeast. http://www.aaryavansotravel.com/images/map/jammu_kashmir_map.jpg

and spectroscopic nights available is estimated using the cloud cover data. The percentages of such nights during different years between 1995 and 2011 are shown in Fig. 2. One would notice that the annual averages are very stable over the years, though there is some spread in a given month over different years. The seasonal averages over 17 years are compared in Table 1 with corresponding values for Nimmu during 1986 winter-1988 summer. Hanle site stands out significantly above Nimmu. The worst year of Hanle (1997) is much clearer than Nimmu during parts of 1986-88 when data is available, though 1997 summer and autumn values are approaching the Nimmu values 11 years earlier. Both these observations are at solar minima, and similar effect

is also noticeable during the solar minimum of 2008, though only in summer.

An additional aspect brought out by Fig. 2 is the fact that the effect of monsoon is minimal at Hanle compared to sites to the south of Himalayas that do not permit observations during several monsoon months. This helps in uniform coverage of entire sky from Hanle while some parts of sky have limited observability from south of Himalayas.

The Weather

An automated weather station was installed at Mt Saraswati in July 1996. New sensors and weather servers were procured in the year 2000 as a part of 2-

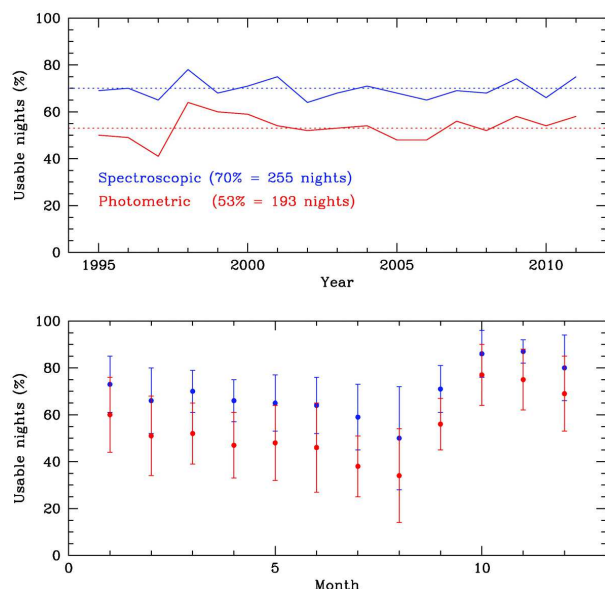


Fig. 2: Percentage of Photometric and Spectroscopic nights at Hanle during 1995-2011

Table 1: Comparison of seasonal values of Photometric and Spectroscopic nights at Hanle with Nimmu

Season	Hanle 1995-2011		Hanle 1997		Nimmu 1986-88	
	P %	S %	P %	S %	P %	S %
Winter	62	73	67	76	22	39
Spring	51	67	39	60	23	48
Summer	41	58	30	51	23	46
Autumn	71	81	45	74	43	65

m telescope automation support. The old weather station was then moved to different locations in Ladakh. Additional weather stations have functioned at Hanle, Merak (by the Pangong Tso), Kalaktartar (south of Hanle) and Rendong (north of Hanle) starting between 2007 and 2012 as a part of NLST and NLOT site characterization. With these weather stations, data is procured continuously with regard to ambient air temperature and relative humidity, wind speed and direction.

The weather station data clearly demonstrates that Hanle is a cold and dry site (Fig. 3). The weather is never hot and humid. The temperature at the

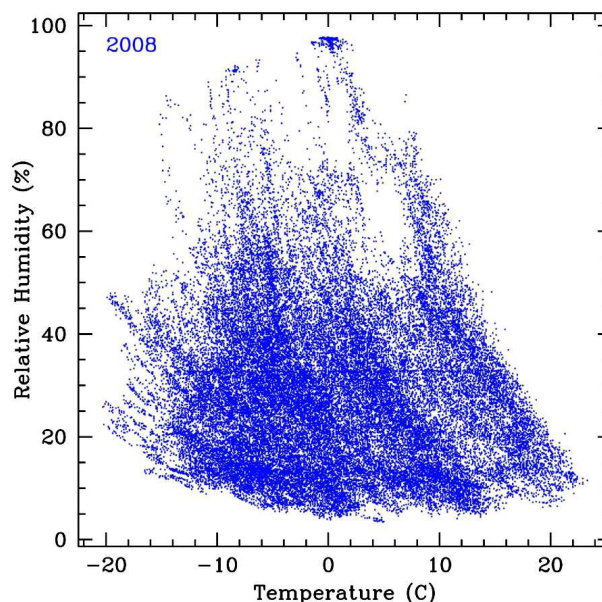


Fig. 3: Climatograph of Mt Saraswati, Hanle, over the year 2009. Observed values are plotted for every 10 min interval

telescope site varies between $+25^{\circ}\text{C}$ during summer afternoon and -25°C during winter early mornings. The extremes have reached a little beyond these values during a few years. Humidity can rise in summer when some clouds bring in moisture and cool the weather. Average annual relative humidity is 30% with less than 10% for significant time. The relative humidity does not correlate strongly with pressure or wind speed, but shows some indication of correlation with wind direction with higher humidity when the monsoon wind blows from due south (Fig. 4).

The rainguage in the first weather station worked trouble free for only three complete calendar years at Mt Saraswati and measured rainfall in mm was 52 (1997), 57 (1998), 79 (1999). It was later refurbished and installed near base at an altitude of 4340 m. A new weather station was co-located at this site in 2005. Both the weather stations showed rainfall of 116 mm in 2006. The new weather station was later transferred to Merak for the NLST site characterization and the old one was shifted to a higher altitude site Kalak Tartar to the south of Hanle. The rainfall at Kalak Tartar was 120 mm in 2008. It appears likely that there has been a steady increase in rainfall by a factor of two between 1997 and 2008.

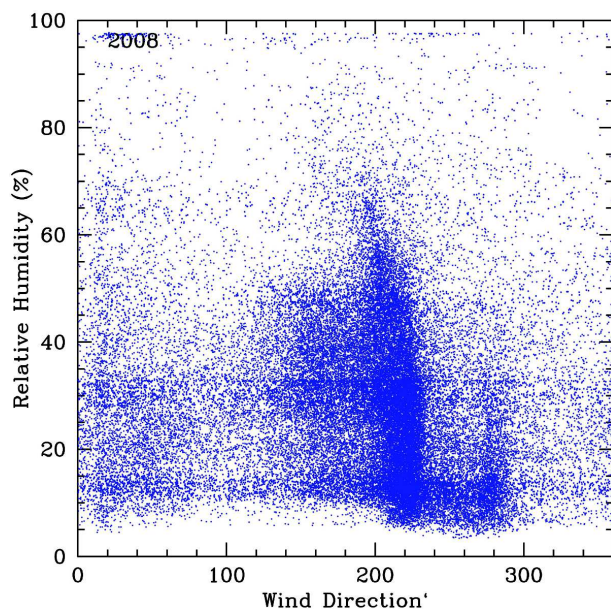


Fig. 4: Variation of relative humidity with wind direction. Here and in Figure 5, one notices the prevailing wind direction of between 200° and 220° with occasional westerly disturbance (280°) and northerly winds (20°). North is 0° , East is 90° , South is 180° and West 270°

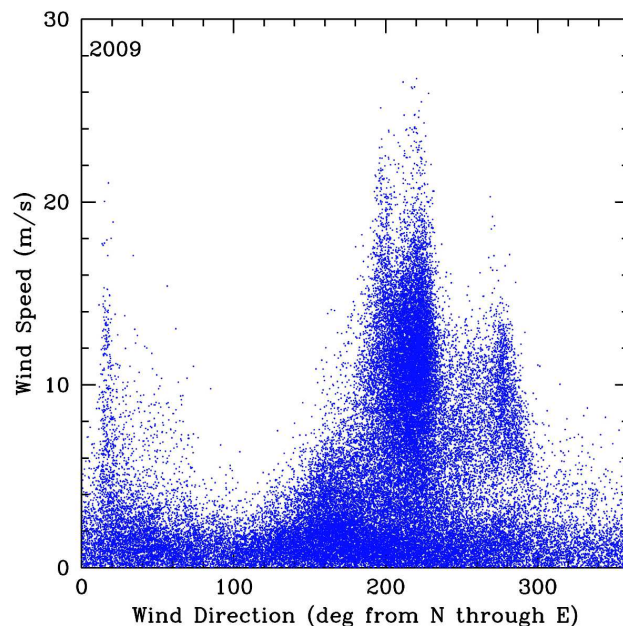


Fig. 5: Plot of wind speed against wind direction showing major directions of prevailing wind. One notices the prevailing wind direction of between 200° and 220° with occasional westerly disturbance (280°) and northerly winds (20°). North is 0° , East is 90° , South is 180° and West 270°

This trend needs to be confirmed with more continuous data.

Average atmospheric pressure at Mt Saraswati is 590 hectopascals with occasional low or high in the range of 570-600 hectopascals. The prevailing wind is south-southeasterly, and becomes more southerly during the southwest monsoon. Westerly disturbances are often seen bringing westerly winds. Occasionally northerly winds are also noticed (Figs. 4 and 5).

Atmospheric Extinction and Sky Brightness

Hanle is above approximately 40% of atmosphere and has very low atmospheric water vapour and aerosols. The transparency of sky is hence very high and the brightness of night sky is low. Due to a lack of urban and industrial development, the light pollution is also non-existent except for some outdoor lights installed by the government in villages and government units outside the observatory. These and other outdoor lights that may come up in future are required to be provided with appropriate shades to protect the dark sky as also the wild life from

disturbance to the circadian rhythm. The low extinction and sky brightness was noticed during the early experiments (Hirots Team 1996; Bhatt *et al.*, 2002), and are characterized better later with better equipment including the 2-m HCT (Parihar *et al.*, 2003; Stalin *et al.*, 2008). An automated extinction monitor is in the final stage of development (Sharma *et al.*, 2011).

Table 2 gives the average values of extinction and sky brightness in the optical region as observed during 2000-2008. Astronomical magnitude system is logarithmic with the brightest stars visible to the naked eye on an average of magnitude 1 and the faintest visible of magnitude 6 (1% brightness compared to magnitude 1) from a dark site near sea level. Extinction values in the magnitude system imply absorption of starlight at zenith by 28% in the ultraviolet and 5% in the near-infrared bands at Hanle. These values are about half compared to lower altitude observatories in India. The absorption is primarily due to Rayleigh scattering by atmospheric molecules with some contribution due to aerosol scattering and absorption by ozone. The observed

values of extinction and sky brightness are similar to the values at the established high altitude astronomy site of Mauna Kea in Hawaii. The sky brightness is mostly due to scattered starlight, with contribution from auroral emission especially in the *R*- and *I*-bands.

The *I*-band used here is just longward of the red band at the beginning of infrared band of electromagnetic radiation. As we move to longward wavelengths, the water vapour in the atmosphere absorbs increasingly reaching its peak at tera-hertz frequencies. A 220-GHz (1.36 mm wavelength) radiometer is in operation in Hanle since 1999, installed collaboratively by IIA, RRI and the University of Tokyo. The measurements with this instrument show that the absorption at this frequency is less than 0.1 for 70% of the winter months. While this is better than at Mauna Kea, the annual average is similar at both sites (Ananthasubramanian *et al.*, 2002; Ananthasubramanian *et al.*, 2004). Water vapour column and aerosol optical depth are being measured near 1 μm wavelength as well, using sun photometer during daytime. There is good correlation between the measurements made in both these bands with wavelengths differing by a factor of 1000 in wavelength.

The sky background in the infrared region is due to thermal emission of the atmosphere. Low ambient temperature and low aerosols reduce the sky brightness beyond 2 μm wavelength, whereas the emission between 0.7 and 2 μm wavelength is dominated by emission bands of OH and water vapour in the atmosphere.

Table 2: Atmospheric extinction and sky brightness at Hanle (Stalin *et al.*, 2008)

Band	Wavelength (Å)	Extinction (mag)	Sky Brightness (mag/arcsec ²)
<i>U</i>	3650	0.36	22.14
<i>B</i>	4400	0.21	22.42
<i>V</i>	5500	0.12	21.28
<i>R</i>	7000	0.09	20.54
<i>I</i>	8800	0.05	18.86

Astronomical Seeing

Atmospheric turbulence smears the image of a point source which is measured by astronomical seeing. A good site should have a mean value of seeing less than 1 arcsec. Mt Saraswati rises 200 m above the surrounding Nilamkhul plain of mean radius of 5 km. This results in a stabilizing of atmosphere after sunset, reducing the ground layer turbulence. The seeing at peak was thus expected to be low. Measurements of seeing were conducted with a 12-inch Differential Image Motion Monitor (DIMM) during 1997-98 which confirmed that the mean seeing is a little below 1 arcsec. Further observations have been made with a 10-inch DIMM attached to the 2-m HCT (see e.g. Fig. 6). A 14-inch robotic DIMM has been recently deployed for continuous monitoring of seeing (P S Parihar, personal communication).

The observations of DIMM attached to HCT were conducted to test the effect of dome on seeing. Quite often, the enclosure of a telescope interferes with the thermal equilibrium of the site and also alters the wind flow causing a degradation of seeing. HCT dome was designed to minimize its influence on the environment and the observations bear this out. Fig. 6 shows that the median seeing inside the dome was 0.9 arcsec in November 2006.

Himalayan Chandra Telescope

As the competitiveness of the site was confirmed, the proposal for Himalayan InfraRed-Optical Telescope (HIROT) of 4-6 m aperture was submitted to the Government. The expert committee chaired by Dr. K. Kasturirangan, which reviewed the proposal, opined that the logistics at the site are very poor and conditions for living and working are very difficult. Hence, the committee suggested that the development of national large telescope be undertaken in a 2-step process: (i) develop the infrastructure at the site and remote operation capability by procuring and installing a modern 2-m class telescope; (ii) plan the national large telescope at the site using the infrastructure developed and experience gained.

The 2-m telescope project was accepted and

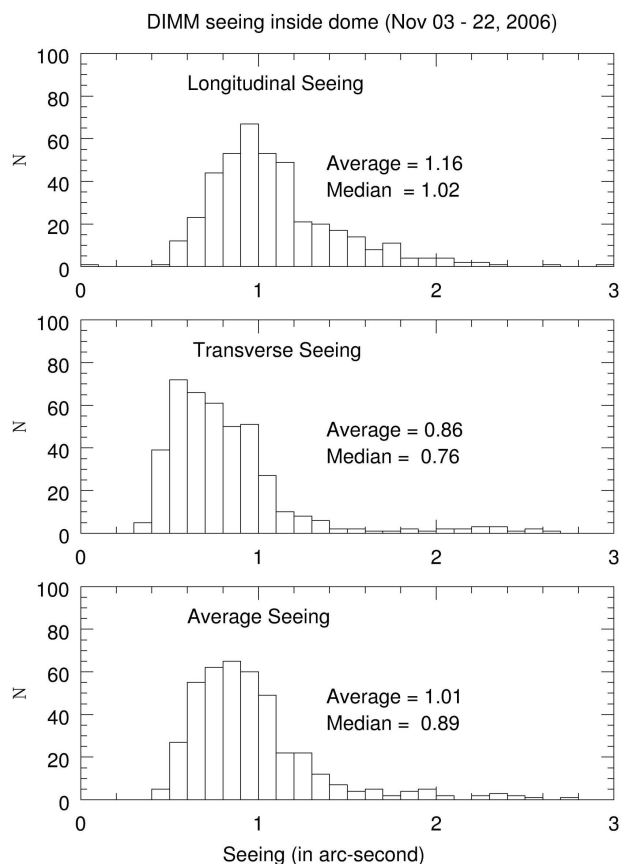


Fig. 6: A sample histogram of astronomical seeing observed through the dome of 2-m Himalayan Chandra Telescope (P S Parihar, personal communication)

funded by the DST in 1997. The telescope was custom built by M/s EOS Technologies Inc., Tucson, USA following the specifications of IIA. In the meantime, IIA developed the required infrastructure that included solar photovoltaic electric power plants, a liquid nitrogen plant to cool the focal plane detectors of the telescope, satellite-based communication link for remote operation, necessary buildings including the enclosure for the telescope itself. The telescope was transported and installed at the site in August 2000.

The Telescope

HCT (Fig. 7) is of Ritchey-Chrétien design with an $f/1.75$ primary and infrared-optimized secondary. The Cassegrain focal ratio is $f/9$ providing an image scale of 11 arcsec/mm. The primary is made of Corning ultra-low expansion (ULE) coefficient glass ceramic

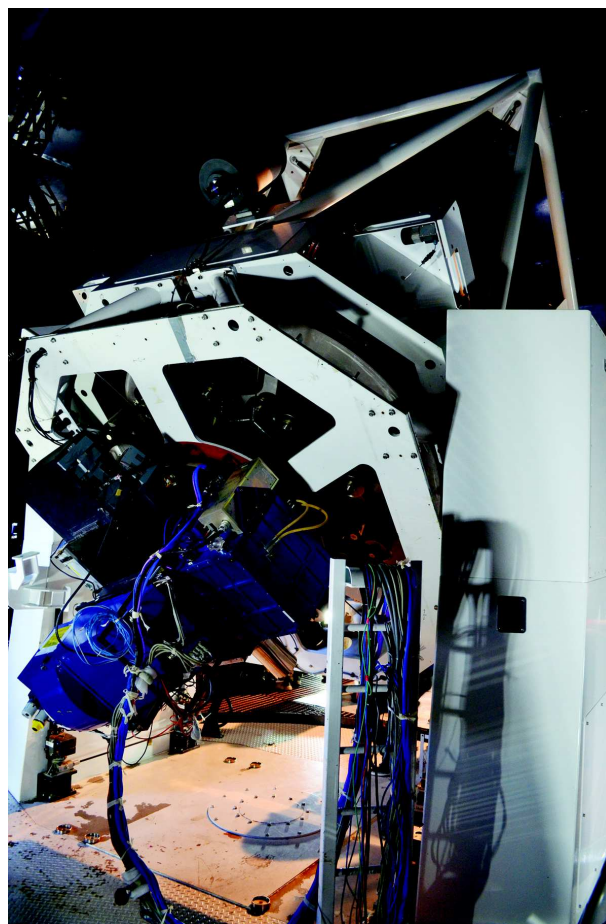


Fig. 7: The 2-m aperture Himalayan Chandra Telescope with the main focal plane instruments in blue: HFOSC on the axial port at the bottom, and TIRSPEC on the side port

with an aspect ratio of 1:20. The secondary focus and tip-tilt are computer controlled to keep the optical alignment fixed at all orientations and temperatures. Pointing model corrections made online provide a blind pointing accuracy of 3 arcsec (rms) and good open-loop tracking. An autoguider developed in collaboration with the Copenhagen University Observatory, Denmark, provides accurate tracking of the telescope for long integrations.

The focal plane instruments are mounted on the Cassegrain instrument-mounting cube fixed to the instrument rotator that corrects for image rotation in the alt-azimuth telescope. A mirror turret reflects the light to the desired side port of the cube, or permits the light path to the axial port. The autoguider assembly is fixed to one of the side ports, and the Shack-Hartmann wavefront sensor used for fine-

tuning of the primary mirror warping harness is fixed to another. Thus, two side ports and one axial port are available for focal plane instruments. The Cassegrain mirror turret is computer controlled and permits a choice of instruments in about one minute of time.

The telescope and instruments are controlled remotely via a dedicated satellite link. The HCT remote control facility is located at IIA's campus at Hosakote, the Centre for Research & Education in Science & Technology (CREST), at about 35 km from Bangalore. Regular observations are undertaken from this centre.

The Focal Plane Instruments

The Himalaya Faint Object Spectrograph (HFOSC), designed and fabricated in collaboration with the Copenhagen University Observatory, is mounted on the axial port. This is used for optical imaging and spectroscopy. An autoguider was developed as a part of this collaboration. A standby CCD imager is mounted on one of the side ports. An NIR Camera for broad and narrow band imaging in the 1-2.5 μm wavelength region, fabricated by the Infrared Laboratories Tucson, USA, and the control system developed by IIA, was used on the side port till 2013. This was replaced in 2013 by the TIFR infrared spectrograph-camera (TIRSPEC) which can be used in imaging as well as spectroscopy mode. TIRSPEC belongs to the Infrared Astronomy Group of Tata Institute of Fundamental Research, Mumbai, and it was designed in collaboration with M/s Mauna Kea Infrared, LLC, Hawaii (Ninan *et al.*, 2014). Specifications of HFOSC and TIRSPEC are given in Table 3 and 4 respectively. IIA is developing a fiber-fed high-resolution Echelle Spectrograph to be commissioned in 2015.

Automation Support System

An automated weather station with weather server software provides online information of ambient temperature, relative humidity, pressure, wind speed, wind direction and detection of precipitation. This information, together with an all-sky night-viewing camera (CONCAM) provided by the Michigan

Technological University, USA, supports the remote observer through the weather related information. Videoconference facility over the satellite communication link provides support to remote maintenance when some manual intervention by the technical staff at site is necessary.

Science with the Himalayan Chandra Telescope

Beginning with May 2003, HCT time is allocated to astronomers in cycles of 4 months each. About 25 proposals are received for each cycle. The astronomical community that has utilized the HCT consists of over 60 Indian astronomers and 60 astronomers from abroad. The fields of investigation cover a wide range of topics from the solar system objects to cosmology. Due to its location in the high-altitude, cold desert in the trans-Himalayan Changthang Ladakh region with a large number of clear nights, and ease of operation from near Bangalore, the 2m HCT has been extremely productive, with over 130 refereed publications and an average 7 citations per paper, which is comparable to some of the older, well established, international 2m class telescopes. More than 20 Ph.D. theses based on the HCT data have been completed by students at IIA or other national institutions and universities and several students are currently obtaining data. Some of the results obtained are described in the following.

Star Formation Processes and Young Stellar Objects

Star formation occurs in the denser regions of the interstellar medium comprising mainly of molecular gas and dust components. A study of star forming regions enables an understanding of the many details of the complex processes of formation of stars. The HCT is being used to study Galactic star forming regions, as well as regions of star formation in external galaxies. Fig. 8 shows an example of star forming region observed in the near infrared.

In a study of Galactic star forming regions, bright rimmed clouds (BRC) are being studied to quantitatively testify the 'small-scale sequential star formation' hypothesis around these regions (Ogura *et al.*, 2007; Chauhan *et al.*, 2009, 2011). Quantitative age gradients have been found in all the BRCs studied.

Table 3: Specifications of Himalaya Faint Object Spectrograph

Wavelength range	350-900 nm
Detector	2048 X 4096 pixels CCD with pixel size 15 X 15 microns (0.3 arcsec X 0.3 arcsec in the image plane)
Collimator focal length	252 mm
Camera focal length	147 mm
Reduction factor	0.58
Spectral resolutions	R~150 to R~4500 using a set of 11 grisms
FOV	10 X 10 arcmin; (unvignetted)
Filters	Bessell UBVR _I 372.7(10), 486.1(10), 500.7(10), 656.3(10), 672.4(10)
Performance (not necessarily limiting)	Imaging: R=22.2, err=0.18 mag, exp time=1200s 2-sigma detection of ~23.0 mag/arcsec ² in 40 minutes (H-alpha filter) Spectroscopy: V=18.5, Resln =300; S/N=22 for 20min exposure time

Table 4: Specifications of TIRSPEC

Wavelength range	1-2.5 microns
Detector	18 micron pixel, 1024 X 1024 format Hawaii-1 array
Image Scale	0.3 arcsec/pixel
FOV	307 arcsec X 307 arcsec
Filters (imaging)	JHK, Ks, H2(1-0), CO(2-0), Br-gamma Methane on/off, K-continuum
Spectroscopy (single order)	Y (1.02-1.20), J(1.21-1.48), H(1.49-1.78), K(2.04-22.35)
Spectroscopy (cross-dispersed)	YJ (1.02-1.49), HK (1.50 - 1.84 & 1.95 - 2.45)

There is evidence that a series of radiation-driven implosion processes proceeded in the past from near the central O star(s) towards the peripheries of the H II region.

A long-term programme to monitor young stellar objects in the Orion Nebula Cluster was initiated in 2004, with an aim to address various phenomena associated with young stars. The prime motivations of this project are (a) to explore various manifestations of stellar magnetic activity in very young, low-mass stars, (b) to search for new pre-main sequence eclipsing binaries, and (c) to look for EX Or and FU Or like transient activities associated with young stellar objects (YSOs). Several new variables have been detected in the region, and this work clearly demonstrates the need for a systematic, long term

monitoring to detect variability in YSOs (Parihar *et al.*, 2009; Rodríguez-Ledesma, 2012). YSOs have been identified and characterized in several other starforming regions as well (e.g. Ojha *et al.*, 2011). A detailed multi-coloured monitoring of the interesting object V982 Ori over several years has established this object as a UX Or type, a rare class YSO. A detailed study of the post-outburst phase of McNeil's nebula (illuminated by the young stellar object V1647 Orionis) confirmed that V1647 Ori is a pre-main-sequence star of the EX Or type (Ojha *et al.*, 2006). The object is continuously observed for understanding the evolution of the system (Ninan *et al.*, 2013).

A study of star forming regions in blue compact dwarf galaxies Mkn 104 and I Zw 97 (Ramya *et al.*,

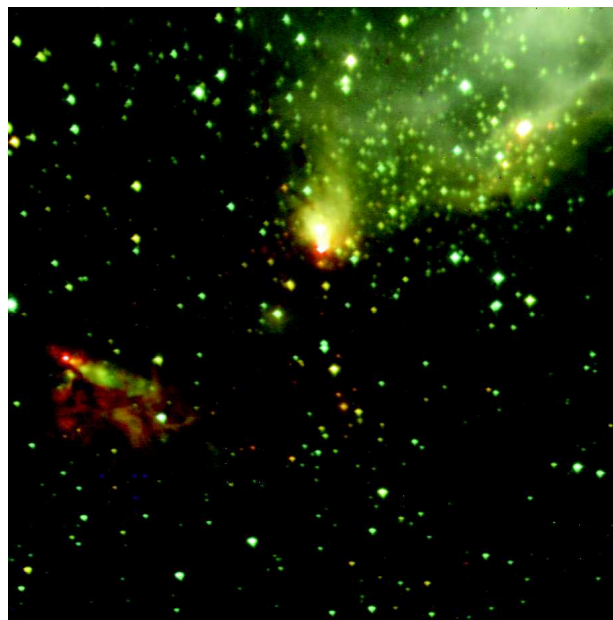


Fig. 8: JHK_s colour-composite image of the NGC 7538, star-forming region (J: blue; H: green; K_s: red) obtained with the TIRSPEC mounted on the 2 m Himalayan Chandra Telescope. The field-of-view is ~5 arcmin x 5 arcmin. North is up, and east is to the left

2009) indicated that neither of these galaxies is a young system; instead they are undergoing episodic star formation superposed on a faint older component. Both galaxies are very similar in their stellar content, showing an older 4-Gyr population, an intermediate 500-Myr population and the current burst of star formation of age 5-13 Myr. A study of the infrared bright galaxy NGC 1084 indicates that star formation in NGC 1084 has taken place in a series of short bursts over the last 40 Myr or so (Ramya *et al.*, 2007). Clues to the evolution of bulgeless late-type galaxies were obtained through a study of their star formation by Das *et al.* (2012).

Young Open Clusters

Several groups are studying open clusters with a view to obtain accurate photometry of clusters that are not well studied so far (Sujatha and Babu, 2006; Sujatha *et al.*, 2006; Carraro *et al.*, 2006; Subramaniam *et al.*, 2010). Star formation and study of young stars in open clusters is another active area of research undertaken with the HCT (Sharma *et al.*, 2007, 2012; Pandey *et al.*, 2008; Jose *et al.*, 2008; Jose *et al.*,

2011; Jose *et al.*, 2012; Ojha *et al.*, 2010).

Variable stars are being identified and followed up in order to understand the evolutionary stage of the cluster. Subramaniam *et al.* (2005) studied the young open cluster NGC 146 and discovered several pre-main sequence stars (PMS) and one Herbig Be star, while NGC 7419 was found to be a young open cluster with a number of very young intermediate mass PMS stars (Subramaniam *et al.*, 2006). Mathew *et al.* (2008) performed a survey of 207 young open star clusters to identify emission-line stars by using slitless spectroscopy. 157 emission-line stars were identified in 42 clusters. Of these, 54 emission-line stars in 24 open clusters were new discoveries. Emission-line stars were discovered for the first time in 19 clusters. These authors have continued to study emission-line stars in more clusters (Mathew and Subramaniam, 2008; Mathew *et al.*, 2010; Mathew *et al.*, 2012a; Mathew *et al.*, 2012b).

Evolved Stars

Carbon-rich, metal-poor stars can provide information on the role of low and intermediate mass stars in early galactic chemical evolution. New candidate CH-stars were identified through a spectroscopic survey with the HCT for higher resolution observations with larger telescopes (Goswami, 2005; Goswami *et al.*, 2007). The latter observations were used in determining abundances of elements in the atmospheres of these stars and understanding them in the context of slow and rapid neutron capture processes (Goswami *et al.*, 2006; Goswami and Aoki, 2010). The increased sample has led to a better estimate of the fraction of CH stars in the galactic halo (Goswami *et al.*, 2010). Similarly, a search for lithium-rich K giants has increased the sample by a factor of two, which helps the study of mixing processes in the red giant phase of stellar evolution (Kumar *et al.*, 2011).

HCT is also used to study variable stars in globular clusters. Of these, RR Lyrae stars are standard candles for distance measurements but their absolute magnitude depends on their metallicity. HCT has led to discovery of a large number of RR Lyrae

stars in clusters, determination of their metallicity and calibration of their absolute magnitudes apart from measurement of long period modulations of these oscillations termed Blazhko effect (Ferro *et al.*, 2004, Ferro *et al.*, 2008; Ferro *et al.*, 2012; Ferro *et al.*, 2013; Lázaro *et al.*, 2006; Bramich *et al.*, 2011; Figuera Jaimes *et al.*, 2013). Several blue stragglers and XX Phoenicis stars were also discovered in this process (Ferro *et al.*, 2010; Ferro *et al.*, 2011).

HCT was also used to support HST observations of pulsations in accreting white dwarfs in cataclysmic variables (Szkody *et al.*, 2007).

Variability in brown dwarfs, the missing link between stars and gas-rich giant planets like Jupiter, has also been studied with the HCT (Maiti *et al.*, 2005; Maiti, 2007). The observed variability is ascribed to formation and evolution of dust in the atmospheres of these cool objects.

Stellar Explosions

The most energetic stellar explosions, the supernovae (SNe) and gamma-ray burst sources (GRBs) are caused by the death of massive stars. The nature and evolution of the explosion and its remnant are determined by parameters such as the mass, metallicity and environment of the progenitor star. The high luminosity of these objects enables their observations at cosmological distances and makes them excellent probes to study the universe at various redshifts. Supernovae of Type Ia have been traditionally used as cosmological standard candles. This requires good calibrations, which can be obtained only through a detailed study from the early to the late phases of the outburst. An important goal of studying core-collapse supernovae (CCSNe) is to deepen our understanding of their progenitors and explosion mechanisms. The diversity of supernovae also excites an interest in the study of the phenomenon itself and the nature of the progenitors. With these motivating factors, low redshift supernovae are being monitored with the HCT as a Target of Opportunity programme. While the type Ia are observed to study the diversity in this class, the CCSNe (Type II and Ib/c) are observed with an aim to understand the

explosion mechanism and the progenitors as also phenomenology involved in the late stages of evolution of massive stars.

The first objects to be observed during the science verification phase were the Type Ic SN 2002ap (Pandey *et al.*, 2003b), Type Ia SN 2002hu (Sahu *et al.*, 2006) and SN 2003du (Anupama *et al.*, 2005a). Several other supernovae have been observed and studied in detail since then. Some of the most interesting studies have been those of the type Ib SN 2005bf which showed the presence of a thin hydrogen envelope (Anupama *et al.*, 2005b; Tominaga *et al.*, 2005), the underluminous, peculiar type Ia SN 2005hk (Sahu *et al.*, 2008), the highly reddened type Ia SN 2003hx (Misra *et al.*, 2008), the type Ibn SN 2006jc – a type Ib supernova with narrow He emission lines (Anupama *et al.*, 2009), the broad line type Ic SN 2007ru that showed a high kinetic energy to ejected mass ratio (Sahu *et al.*, 2009), the extremely slow type Ib SN 2009jf that showed signs of asphericity (Sahu *et al.*, 2011) and the transitional type Ia event SN 2009an (Sahu *et al.*, 2013). Figure 9 shows one of the recent supernovae in the nearby galaxy M82 obtained with TIRSPEC.

The optical afterglows of several GRBs have been observed with the HCT. The afterglows monitored in detail include GRB 010222 (Cowsik *et al.*, 2001a), GRB 021004 (Pandey *et al.*, 2003a), GRB 021211 (Pandey *et al.*, 2003c), GRB 030226 (Pandey *et al.*, 2004) and GRB 030329 (Resmi *et al.*, 2005), all observed during the science verification phase. Subsequent to regular allotment of time, monitoring the GRB afterglows is being conducted as a Target of Opportunity programme and the data is published. Some detailed studies are conducted collaboratively by national and international groups; see e.g. Misra *et al.* (2007), Resmi *et al.* (2012).

Of a very modest and lesser nature of stellar explosions are those of novae in which accretion on a white dwarf from the companion star leads to thermonuclear explosions on its surface. The HCT has been used to study the outbursts of classical and recurrent novae (Kamath *et al.*, 2008; Anupama *et al.*, 2013). An optical and radio study of the nebular

remnant of the classical nova GK Persei indicated the remnant to be very similar to supernova remnants, in particular, Cassiopeia A (Anupama and Kantharia, 2005). A faint bipolar nebula, probably associated with an older planetary nebula that is associated with GK Persei was detected in the lines of [N II] and H α . It was found that the novalike variable V4332 Sagittarii did not conform to the known class of novae (Banerjee and Ashok, 2004). Galactic microquasars and X-ray binaries are other kinds of interacting binaries that are studied with HCT (Kaur *et al.*, 2008).

Galaxies and Cosmology

Apart from the studies of extragalactic supernovae, gamma-ray burst sources and star forming regions, all of which are already described, HCT is also being used for several other studies in the area of galaxies which include the study of dust formation in early type galaxies (Patil *et al.*, 2007).

Significant contributions of HCT are in the area of active galactic nuclei (AGN). There were several studies on the variability of different types of AGN over different timescales (Raiteri *et al.*, 2005; Goyal *et al.*, 2007; Goyal *et al.*, 2009; Goyal *et al.*, 2010; Goyal *et al.*, 2013; Gopal-Krishna *et al.*, 2011). Masses of black holes in some AGN are estimated by using different techniques (Stalin *et al.*, 2011; Ramya *et al.*, 2011). The telescope has also been used for deep *J* band imaging of high redshift QSOs (Goto and Ojha 2006).

In the area of observational cosmology, HCT is used for multi-site monitoring of selected gravitationally lensed QSOs with a view to estimating the Hubble constant at all epochs without the need for standard candles (Eulaers *et al.*, 2013; Rathna Kumar *et al.*, 2013).

Solar System Objects

HCT is also used for studies of solar system objects such as asteroids, comets and planets. Images of comet Tempel were obtained before and after Deep Impact collision as a part of an international campaign (Meech *et al.*, 2005). Internationally coordinated multisite observational programme to characterize the

nuclei of comets is continuing in order to support future space missions (Meech *et al.*, 2011a; Meech *et al.*, 2011b; Belton *et al.*, 2011). Similarly, HCT also participated in the internationally coordinated follow-up observations of the main belt comet P/2006 VW₁₃₉ (Hsieh *et al.*, 2012) and C/2012 S1 (ISON) (Meech *et al.*, 2013).

Observations of night side of Venus were made in the near-infrared 2.3 μ m *K* band, in a coordinated multisite campaign. Clouds were detected at 53 km altitude above the surface of Venus and their evolution and zonal velocities determined (Limaye *et al.*, 2006).

Other Scientific Experiments

Though the second step of development of a large infrared-optical telescope at Hanle is yet to be initiated, there has been some progress in this direction. The National Large Optical Telescope Group at IIA has been looking at other, still higher altitude sites in the surrounding region, and has established weather stations in the surrounding regions, and developed robotic site testing experiments in the laboratories of IIA. Indian astronomers have also proposed participation in one of the planned, current generation, international Giant Segmented Mirror Telescopes (specifically the Thirty Meter Telescope Project); the India-TMT Group plans to utilize the experience and technology developed in this process to build its own large telescope in the country and install it in the best site identified through ongoing site characterization experiments.

In the meantime, the infrastructure developed with HCT has been attracting many experiments in astronomy as well as other sciences. The scope of IAO with its administrative headquarters at Leh has thus expanded over a larger area of Changthang (highlands) Ladakh region of Leh district.

Gamma Ray Astronomy

The advantage of high altitude for ground-based gamma-ray studies using atmospheric Cerenkov technique inspired collaboration between IIA and TIFR to develop the High Altitude GAMMA Ray (HAGAR) experiment at Hanle (Cowsik *et al.*,

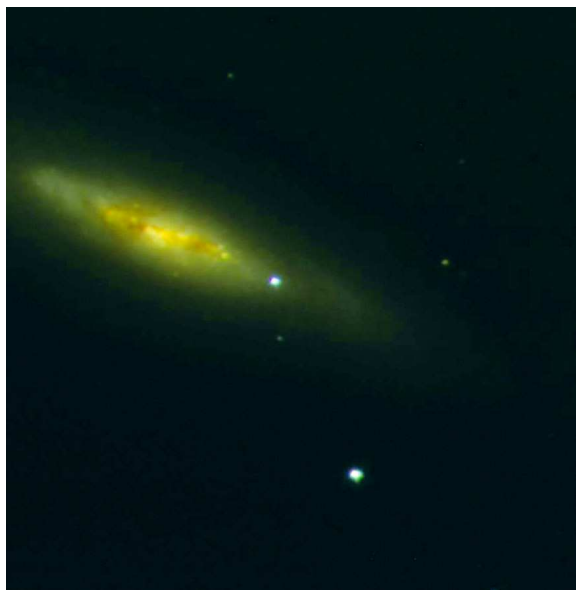


Fig. 9: JHKs colour-composite image of the SN2014J, Supernova in M82 (*J*: blue; *H*: green; *K_s*: red) obtained with the TIRSPEC mounted on the 2 m Himalayan Chandra Telescope. The field-of-view is ~ 5 arcmin \times 5 arcmin. North is up, and east is to the left

2001b). The facility built totally indigenously has begun operations since 2008 (Fig. 10). This has paved way to the development of Major Atmospheric Cerenkov Experiment (MACE), a world-class experiment initiated by BARC in collaboration with IIA and TIFR.

The HAGAR array is based on wavefront sampling technique of atmospheric Cherenkov events, and it consists of seven telescopes in the form of a hexagon with a spacing of 50 m including one telescope at the centre of the hexagon. Each telescope has seven paraxially mounted front coated mirrors of diameter 0.9 m with a Photonis phototube at the focus of each mirror (Gothe *et al.*, 2013). Sources monitored regularly include the Crab Pulsar, Geminga and the active galactic nuclei 1ES2344+514, Mkn 421 and Mkn 501. The energy threshold of the array is 208 GeV and it can observe a Crab-like source at 5-sigma significance in 17 hours (Saha *et al.*, 2013). Mrk 421 was observed at one of its brightest flaring episodes during February 2010 at energies above 250 GeV showing an enhancement in the flux level, with a maximum flux of ~ 7 Crab units detected on February 17, 2010. Spectral energy distributions



Fig. 10: The HAGAR array at the base of Mt Saraswati

during this flaring episode were constructed using data available at different energies including HAGAR to infer that the flaring occurred due to a passing shock in the jet (Shukla *et al.*, 2012). Mkn 501 was found in moderately high state in 2010-11 reaching a peak activity in May 2011 (Shukla *et al.*, 2014).

The MACE telescope is a high resolution imaging Cherenkov telescope consisting of a parabolic light collector of 21 m diameter. The light collector will be made of 356 panels of approx 1 m \times 1 m size with each panel consisting of 4/9 aluminium alloy spherical mirror facets of smaller dimensions. Each mirror panel will be equipped with motorized orientation controllers for aligning them to form a single parabolic light collector. The focal plane instrumentation will comprise 832 pixels imaging camera providing a field of view of $4^\circ \times 4^\circ$. The γ -ray threshold energy of MACE is expected to be ~ 15 GeV and ~ 25 GeV at zenith angles of 10° and 30° respectively. The telescope is fabricated and tested at ECIL, Hyderabad and site preparations at Hanle are progressing. The facility is scheduled to be fully assembled at Hanle in 2015 and commissioned in 2016.

Bhabha Atomic Research Centre (BARC), Mumbai, IIA, Saha Institute of Nuclear Physics and TIFR, Mumbai, are collaborating on the development of gamma ray astronomy from Hanle, under the banner of Himalayan Gamma Ray Observatory (HiGRO). The group has proposed participation in the next generation international mega-project in

gamma ray astronomy – the Cherenkov Telescope Array.

Solar Astronomy

Hanle was investigated for its suitability for the National Large Solar Telescope. An alternate lake site at Merak by the Pangong Tso in the neighbouring region appeared more advantageous due to better stabilization of daytime atmosphere as confirmed through detailed studies at three candidate sites. A 2-m aperture telescope that would be the one of the world's largest solar telescopes is proposed at Merak, with Hanle as a backup site.

Sub-mm and Terahertz Astronomy

Raman Research Institute, Bangalore, and University of Tokyo collaborated with IIA to characterize Hanle for sub-mm astronomy. The results from 220 GHz radiometer are described already in Section 2 above. The Harvard-Smithsonian Centre for Astrophysics, USA, collaborated with IIA to identify a possible site for Terahertz astronomy at Polakongka La, at an altitude of 5200 m, near Sumdo, to the west of Hanle. IIA operated a small station at this site for a few years.

Earth Sciences

Hanle is a part of western tracts of the largest high altitude plateau of the world which holds the clue to the mechanics of deformation and flow of continental collision zones. A GPS Geodesy program was initiated in Ladakh in 1997 with V K Gaur as the Principal Investigator. GPS measurement campaigns were undertaken at around six and more pre-identified locations in Ladakh from Nubra valley — Chushul to Hanle along the Karakoram fault annually. Two permanent GPS stations forming a part of the national network of GPS stations are operated continuously by IIA at Leh and Hanle and the data is regularly sent by the HCT support staff to the national GPS data Centre at SOI Dehradun. Two other permanent stations are situated in Indian Institute of Science, Bangalore, and Indian Institute of Astrophysics, Kodaikanal. Analysis of these data sets together with those from 10 campaign sites in the region, have helped resolve some critical questions about the

deformation of the Tibetan plateau (Jade *et al.*, 2004). Further, GPS data from Hanle has also been analysed for estimation of zenith integrated water vapour in the atmosphere over Hanle (Jade *et al.*, 2005).

Two broadband seismic stations are also collocated with the Leh and Hanle GPS stations to image the deep structure of the site (elastic parameters with depth up to 400 km in the earth). These are also a part of a national network funded by the Department of Science & Technology.

Ladakh provides highest latitude site in India for studies of geomagnetism. IIGM, Mumbai has established a small temporary station to study the effect of sun-earth interaction on the magnetic field.

IIA is collaborating with CMMACS, Bangalore, and LSCE, France, towards studying atmospheric constituents of Hanle which are uncluttered by greenhouse gas emissions. The study began with transporting air samples in bottles to France for a detailed laboratory analysis. Subsequently, a continuously monitoring system for ultra-high precision measurement of atmospheric CO₂ concentration has been set up at Hanle. The collaboration also operates another site in coastal Puducherry, in southern India. The ultra-high precision CO₂ measuring system, CARIBOU (100 ppb) was developed by LSCE and DAPANIA (Department d'Astrophysique, de physique des Particle, de physique Nucleaire et de l'Instrumentation Associee), France, adhering to the WMO standard. The CARIBOU system was replaced by an upgraded version PICARRO in 2012, which measures methane and water vapour concentrations in addition to CO₂.

SPL/ISRO, Trivandrum, has established in 2009 an aerosol observatory at Hanle in collaboration with IIA under its project on Aerosol Radiative Forcing over India (ARFI) as a part of Geosphere-Biosphere Program. The objectives include:

1. Long-term, continuous measurements of optical and physical properties (such as spectral AOD, number size distribution, BC concentration) of columnar and ambient aerosols from the pristine

environment at Hanle.

2. Continuous measurements of short wave and long wave incoming broadband solar flux and assessing the impact of aerosols on the radiation budget.
3. Develop a regional (Himalayan) aerosol model (by synthesizing with other existing Himalayan station) that could be incorporated into Regional Transport (RT) models.
4. Provide background aerosol data for ARFI project, for estimating the regional and global climate impact of aerosols, and to delineate the anthropogenic share to it.
5. Investigate the process of new (nanometer sized) particle formation from precursors, and their dynamics including interaction with clouds, in the unique environment provided by the high altitude, the meteorology and abundant UV available at this station.
6. Develop local (Hanle) model for aerosol column, size distribution, and its annual variation, to help understand the extinction of star light, brightness of night sky, and scattering processes around the solar limb. Planning astronomical research programmes including future major projects in the near-ultraviolet, optical and gamma-ray wavebands on night sky objects as well as the Sun.

The instruments deployed at present include (i) a Multi Wavelength Radiometer for aerosol and water vapour monitoring, (ii) a specially configured Aethelometer for measuring the amount of absorbing Black Carbon aerosol particles which heat the atmosphere, (iii) a Scanning Mobility Particle Sizer + Counter for aerosol number size distribution measurements in the nanometre size range, which are important in aerosol-cloud interaction at this altitude, and (iv) a radiation instrument to characterize the incoming short-wave and long-wave radiations.

It was deduced from the data that the aerosol number-size distributions at Hanle exhibit two prominent modes: a nucleation mode with mode

diameter at ~16 nm and a consistent accumulation mode with the mode diameter ranging between 115 and 150 nm. The number concentration increased, and the accumulation mode broadened when west Asian air mass prevailed. In summer (during August), the number concentrations tended to higher values associated with air mass from the Indian origin. The ratio of the Aitken to accumulation mode concentration indicated that the aerosol particles existing over the site are aged (Moorthy *et al.*, 2011). It was also found that the mean black carbon concentrations at Hanle are significantly lower than the corresponding values reported for other Himalayan stations, while they were higher than those reported from the South Pole and pristine Antarctic environments. Variation within the day as well as from day to day are highly subdued during winter season (December to February) while they are the highest in spring (March to May). In general, the less frequently occurring high BC values contributed more to the annual and seasonal means, while 64% of the values were below the annual mean. Seasonally, highest BC concentration ($109 \pm 78 \text{ ng m}^{-3}$) occurred during Spring and lowest ($66 \pm 42 / 66 \pm 62 \text{ ng m}^{-3}$) during summer/winter season (June to August/December to February). Diurnal variations in general were very weak, except during spring and summer when the effects of convective boundary layer dynamics are discernible. Most of the time Hanle is influenced by the advection from West and Southwest Asia, while the contribution from the Indo-Gangetic Plains (IGP) remained very low during spring and summer (Babu *et al.*, 2011).

Search for Strange Quark Matter

The quark structure of hadrons suggest the existence of Strange Quark Matter (SQM), containing a large amount of strangeness as postulated by various authors quite a few years ago. The occurrence of stable (or metastable) lumps of SQM, would lead to many rich consequences; for example, the SQM, which may exist as relics of early universe cosmic quark-hadron phase transition, could give a viable explanation for the dark matter as well as the large amount of dark energy found by WMAP observation. The final proof of SQM will be its experimental

detection. Bose Institute, Calcutta, experimented to find the suitability of a particular type of OHP as a solid-state nuclear track detector (SSNTD) for strangelet detection at very high mountain altitudes and to standardize it.

A pilot study was initiated by Bose Institute, Calcutta, in 2008. Two A4 size PET detectors were placed at the roof the guest-house. Two small pieces of standard SSNTD CR-39 were attached to the PET detectors. The objective was to find out the level of degradation with long-term exposure and if it detects any particle track and its nature. These were recovered after 360 days. Small parts of PET and CR-39 were etched and it was found that tracks could be detected with possible origins in heavy ions as well as protons and alpha particles.

Infrastructure

Since there is essentially no public infrastructure available at Hanle, the observatory had to develop all the required facilities. The presence of scattered population in the Nilamkhul Plain, and the paramilitary forces nearby provided considerable moral strength and support.

The first team to visit Hanle for site reconnaissance (August 1993), stayed in tents at the northwestern base of Digpa-ratsa Ri. The winter reconnaissance was conducted with the facilities offered by Indo-Tibetan Border Police (ITBP). During the summer of 1994, a team pitched tents at the peak of Mt Saraswati and attempted some observations through a telescope. During the following winter, a permanent camp was set up in a hut made available by ITBP, which also provided boarding facility. An 18-inch telescope was set up in the front of the hut, the enclosure for which was made of wood and tarpaulin by the site characterization team with its own hands. A kitchen was built hiring a mason from Leh the following year in an attempt to become less dependent on the hospitality of ITBP. IIA's own camp at the base of the mountain was set up in November 1996.

Since Hanle is 260 km from Leh, the nearest town with significant infrastructure, and also the

location where acclimatization to high altitude could be undertaken before proceeding to Hanle, it was apparent that a transit camp is required in Leh. ITBP had provided support for the first few weeks of the visit of the first site characterization team. A contract was negotiated with a hotel for arrangements of boarding and lodging during winter when the hotel was normally closed. A house was rented in May 1995 and used as office-cum-guest house until 2007 when a bigger and more modern house could be rented. IIA has subsequently procured land from J & K Government to set up Raman Science Centre, which will house the observatory headquarters. The construction has been initiated in 2012.

Land

The observatory area comprises of nearly 600 acres of land including the entire range of Digpa-ratsa Ri (Fig. 11 shows the area near the peak) and some flat land at the eastern side (part of which is seen in Fig. 10). The land is provided on long lease by the J & K Government and foundation stone for the observatory was laid by the then Governor, Lt. Gen. (Retd) M. V. Krishna Rao in October 1997. About half acre of land was also provided by the State Government for the Raman Science Centre in Leh and the foundation stone was laid by the then Chief Minister, Dr Farooq Abdullah in May 2003.

Accommodation

The site development of IAO began with the plywood and glass hut fabricated and assembled by IIA in 1996. Subsequently FRP-based huts and other prefabricated shelters were erected at base as well as summit. These huts continue to serve as accommodation for persons posted at Hanle and also those visiting from Leh and Bangalore. A permanent building, Megh Nad Saha Astronomical Archives was built in 2000-01 with laboratory rooms and a few bedrooms and dining area. This is used primarily for accommodating visiting scientists and technical staff. A shelter made of bamboo composite material was provided by the National Mission on Bamboo Applications. Permanent buildings are planned for accommodating the staff of IAO as well as additional visiting staff.



Fig. 11: Peak of Mt Saraswati with area reserved for future development at the right and 2-m HCT in the centre

A new house was rented in Leh during 2006 to serve as transit accommodation for visiting scientists and technicians. The Leh office of the observatory is situated in an adjacent rented building. Construction of Raman Science Centre has been initiated in 2012.

The Road

Hanle can be reached from Leh by a road built and maintained by the Border Roads Organization (BRO). When the site was identified, about 180 km of road was black-topped and the remaining 80 km was unpaved. BRO has progressively completed black-topping the remaining 80 km of road. BRO was earlier commissioned by IIA to design the alignment of road from Hanle Monastery to the summit. Cutting of this road was entrusted to it in 1996 and was completed in three seasons. A Bailey bridge was built across Hanle River as a part of this road. All the infrastructure development and installation of 2-m HCT were completed utilizing this unpaved road. BRO was commissioned for the black-topping of the road between the base camp and summit in 2005 and the works were completed in 2007.

Electric Power

IAO uses clean power for most of its requirements. Two 30 kWp solar photovoltaic (SPV) electric generators were installed for the operation of 2-m HCT and auxiliary equipment. The battery capacity is sufficient to draw 8 kW power from each of these

units for 30 hours. The HCT and focal plane instruments and their control computers, dome, etc. operate on one of these units. The second unit is used as spare for HCT, and it supplies power to non-critical areas of the observatory. A third similar unit has been added at the base to cater to the gamma-ray telescope (HAGAR). Except for the generation of liquid Nitrogen, the observatory could boast of a completely solar-powered observatory. BARC has recently commissioned an SPV plant for the operation of the proposed MACE facility.

Two diesel generators of 62.5 kVA are available at the summit area when demand for power is larger - for example, for welding during construction phase and for coating the primary mirror during the operation phase. Two similar units were installed at the accommodation for liquid nitrogen generator and heating of rooms and water, etc. They have been replaced recently by two 100 kVA diesel generators which were decommissioned at Bangalore. The diesel generator capacity reduces nearly to 50% at the altitude of Hanle compared to sea level, due to reduced air density.

Communication

A terminal-to-terminal satellite based communication link was established in 1985 between the site survey camp, office-cum-guest house at Leh, and IIA, Bangalore, by India Satcom Limited, Bangalore. This was the only means of communication between the

site, Leh office and Bangalore headquarters until the installation of the telescope. It was found that it could be connected to e-mail though with very low efficiency since the original bandwidth was 4 kbps increased to 8 kbps after a few years of operation. An application was made for a 64 kbps point-to-point satellite communication link, which could be commissioned only after the 2-m telescope was installed.

The 64 kbps communication link was far from commissioning when the 2-m telescope was ready to be transported to the site. At this juncture, the Indian Space Research Organization (ISRO) offered help with temporary bandwidth. This communication link was the lifeline for installation of the 2-m telescope and later for its remote operation since 2001 until the migration to the enhanced bandwidth specifically allotted to IIA.

The communication links are also used for voice connectivity between IAO and CREST. However, there was no telephone facility between IAO, Hanle and rest of the world for a long time. A DSPT terminal has been procured from BSNL in 2009, which has made telephone connectivity possible. BSNL has recently provided mobile connectivity to the Hanle region by installing a tower atop Mt Saraswati.

Vacuum Coating Plant

A vacuum coating plant supplied by M/s HindHivac Pvt Ltd has been installed at the site in a building about 150 m to the east of HCT. It has been tested periodically and some mirrors of HAGAR were coated. The HCT optics has not been coated yet since the dry conditions and low suspended particulate matter keep the optics in good condition. The primary mirror is washed with distilled water once a year.

Liquid Nitrogen Plant

The astronomical detectors such as charge coupled devices and infrared detector arrays require to be cooled to reduce the thermal noise well below the expected signal from celestial sources. Liquid nitrogen is the most widely used coolant in the temperature ranges of -100° to -170° C. Liquid nitrogen is available as a by-product of oxygen gas

production and is available cheaply where such commercial sources are available. Observatories are generally remote from industrial areas and the transportation costs may not always be trivial. Since Hanle is too remote for transportation across Himalayas, IAO generates its own liquid nitrogen. An 8-litres/hour capacity plant was installed before the installation of the telescope.

Observatory Staff

Though the 2-m HCT is remotely operated, there is a need for manpower at site to maintain the observatory in a highly reliable state since it provides high quality observing conditions. There is also some need for remote operation support. The presence of local population around the observatory area has been of great strength for IAO, compared to other high-altitude sites in the American and Antarctic continents. It was apparent during early stages of site development that the local populace is not well-educated due to lack of facilities, and otherwise has the similar intelligence quotient as other demographic constituents of the country. Most of local population around Hanle has obtained primary education in local schools, and a few venture to stay in hostels at Nyoma, 60 km away, or even at Leh 260 km away for secondary education. It was apparent that persons born and brought up at this altitude perform better than those who travel to high altitudes even after due acclimatization.

Population around Leh is exposed to the world better due to many non-government agencies working in the area, and also because of contact with tourists from around the world. A larger cross section of persons from Leh obtains higher education at far off centres in the country compared to the population around Hanle.

Early activities at Hanle had benefitted greatly from persons hired locally on daily wages and from Leh as Engineer Trainees. When the 2-m HCT was commissioned, a few recruitments could be made utilizing the backlog of vacant reserved positions as majority of local population belongs to the Scheduled Tribes. Currently, the observatory operates with the help of six support staff recruited from regions

surrounding Hanle, and ten persons including four engineers recruited from Leh and surrounding regions. The total staff strength is 16 recruited for the HCT, and a similar number of temporary staff (project appointments, daily wagers and trainees) supports all activities of IAO at Leh, Hanle and Merak. This is a small number for a full-fledged observatory operating in such a large tract. Collaborating institutions have been progressively providing some additional staff for the operation of gamma-ray astronomy facilities. A few astronomers and engineers from Bangalore and CREST coordinate with the observatory staff in the maintenance and operation of HCT.

Remote Control Station at CREST, Bangalore

The HCT is operated remotely from the Centre for Research and Education in Science and Technology (CREST) campus of IIA in Bangalore. The national and international astronomers utilizing the HCT as Guest Observers do not need to travel to high altitude. A few astronomers in Bangalore, and a smaller number of engineers, coordinate, in collaboration with the IAO staff, periodic preventive maintenance, performance tests and calibration of the instrument. Unlike other observatories, HCT is operated without assistance to guest observers except for some temporary trainees occasionally available. Some of the astrophysicists of the Institute who have gained experience in operation have often supported the novice astronomers.

Human Resource Development

HCT has contributed significantly to human resource development in the field of optical-infrared astronomy. Several students have obtained their Ph.D. degree using the HCT data and several are currently working. Some students are working for their Ph.D. degree in astronomical instrumentation in projects related to IAO. One student has been awarded Ph.D. degree utilizing HAGAR data and another has made extensive simulations to help data analysis strategy and obtain estimates of accuracies. One student has completed his Ph.D. using the geodynamical data. A large number of students have undertaken short-term projects related to site characterization,

instrumentation, and astronomical studies using the telescopes.

The facilities created at IAO have provided job opportunities to scientists in various disciplines. The Research Trainee program at HCT remote control station has been highly successful in training several individuals towards obtaining a Ph.D. position in observational astronomy or astronomical instrumentation. Engineer Trainee program at IAO has likewise provided opportunities to engineering graduates to expose themselves to front-ranking instrumentation and provided them with better job opportunities.

The Future

IAO was set up for the task of installing the national large infrared-optical telescope. With the 2-m Himalayan Chandra Telescope, it has demonstrated that infrastructure can be developed at the remote site in the high altitude cold desert, and observations can be carried out remotely from the lower altitude comforts at Bangalore. The size of the large facility proposed in the 1980s was a 4-m class second generation telescope, while a 6.5 m telescope at the lower end of third generation facilities was considered in the 1990s. It now appears appropriate to construct a front-ranked third generation telescope of 10-m or larger aperture. The astronomical community in India proposes to leapfrog into the fourth generation through participation in an international 30-m aperture telescope and build its own 10-m class telescope utilizing this experience. The environments of Hanle provide excellent host for such an endeavour. A telescope of such an aperture at Hanle or higher altitudes in the neighbourhood will have the sensitivities required for generating scientific programmes for the 30-m telescope. IIA has been conducting additional site characterization programmes at Hanle since 2010, specifically designed for the National Large Optical Telescope.

The advantages of Hanle region are maximal in the infrared to mm-wave bands and very high energy gamma ray domain. The large optical telescope would naturally be optimized for the infrared region. In addition, world-class facilities can

be planned for sub-mm and tera-hertz bands. HAGAR has lowered the gamma-ray detection threshold, and has successfully detected several gamma-ray sources in observations lasting only a few hours. MACE will soon achieve sensitivities comparable to current international standards. IAO has also attracted a proposal to build one of the largest aperture solar telescopes in the world.

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