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Science with Indian Astronomical Observatory, Hanle

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Abstract. Indian Astronomical Observatory, Hanle, is the high altitude (4500 m above msl) observatory operated by the Indian Institute of Astrophysics, Bangalore. The 2-m Himalayan Chandra Telescope (HCT) installed in the autumn of 2000 as a first step towards a national large telescope is operated remotely from Bangalore. HCT data has resulted in 70 research publications till date, with average citations of 9.2 per paper. Some of the results are described in this brief review. The development of this high altitude site has also attracted other facilities in the area of Very High Energy gamma ray astronomy using atmospheric Čerenkov technique, and also in earth sciences.

Keywords : Observatories – high altitude – optical astronomy – infrared astronomy – gamma ray astronomy

1. The Site

In an attempt to establish a large optical/NIR telescope facility in the country, the Indian Institute of Astrophysics undertook the exercise of identifying a high altitude astronomical site. Based on a study of the available topographical maps, weather data and satellite imagery in 1992-93, six potential sites were identified in the Himalayan and trans-Himalayan regions, all above 4000m. Simultaneous reconnaissance 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 studies. A continuous

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monitoring of the weather and cloud coverage, which began in the 1995 winter season, together with occasional seeing measurements, indicated Hanle to be a world-class astronomical site for the national large optical telescope (Cowsik, Srinivasan & Prabhu 2002). The development of the Indian Astronomical Observatory was taken up at the site as a two step process: (1) development of infrastructure and remote operation capability with a 2-m class telescope; (2) development of the large infrared-optical telescope utilizing this infrastructure and the experience gained.

Indian Astronomical Observatory (IAO) is located in the Digpa-ratsa Ri mountain range with its peak at an altitude of 4517 m, in the general area of Hanle. Hanle region marks the border of Ladakh with Tibet and is known for a Buddhist Monastery and river of the same name apart from several mountain ranges and scattered villages. Nilamkhul Plain surrounding Digpa-ratsa Ri is at an altitude of 4240 meters above msl and extends several kilometres in all directions. The central range measures 2 km east-west and 1 km north-south. An area of 600 acres, including the mountain and a part of the plains at its base constitute the Observatory. Hanle provides ~ 190 photometric and ~ 260 spectroscopic nights annually. Average night sky brightness is $V = 21.3$ mag arcsec^{-2}, with low extinction ($V = 0.12$ mag: Parihar *et al.* 2003; Stalin *et al.* 2008). The median seeing at the site is estimated to be 0.9–1 arcsec 3 metres above ground near the HCT location.

2. The Himalayan Chandra Telescope

The 2-m diameter Himalayan Chandra Telescope (HCT: longitude $78^\circ 57' 51''$ E; latitude $32^\circ 46' 46''$ N; altitude 4500 m) is situated near the top of the mountain range. It was installed in August 2000, and dedicated to the nation in August 2001 when the telescope and dome were fully automated and remotely operated 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.

HCT is of Ritchey-Chrètien design with a $f/1.75$ primary and infrared-optimized secondary, fabricated by M/s EOS Technologies Inc, Tucson, USA, on behalf of their principals, M/s Electro-Optics Systems Pte Ltd, Canberra, Australia. The Cassegrain focal ratio is $f/9$ providing an image scale of 11 arcsec mm^{-}1. The primary is made of Corning ultra-low expansion (ULE) coefficient glass ceramic 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 2.5 arcsec (rms) and good open-loop tracking of 0.08 arcsec/min median over the entire sky above 20° elevation. An autoguider built by the Copenhagen University Observatory, Denmark, tracks the telescope with 0.1 arcsec accuracy over 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 kms from Bangalore.

The Himalaya Faint Object Spectrograph (HFOSC), built by the Copenhagen University Observatory, is mounted on the axial port. This is used for optical imaging and spectroscopy. An optical CCD imager is mounted on one of the side ports. The NIR Camera used for broad and narrow band imaging in the 1–2.5 μm wavelength region is mounted on another side port. This instrument was fabricated by the Infrared Laboratories Tucson, USA, and the control software as well as the user interface were developed by IIA.

3. Science with the Himalayan Chandra Telescope

The HCT was released for regular science observations in May 2003. The astronomical community that has utilized the HCT consists of over 60 Indian astronomers and 60 astronomers abroad. The fields of investigation cover a wide range of topics from 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 $\sim$ 70 refereed publications and an average citation of 9.2 per paper, which is at par with some of the older, well established, international 2m class telescopes. Some of the results obtained are described below.

Interstellar Medium, Star Formation, Young Star Clusters: This is the topic of this workshop and several talks and posters report results from HCT. 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). Quantitative age gradients have been found in all the BRCs studied. 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. Also, in general, weak-line T-Tauri stars are somewhat older than classical T-Tauri stars.

A long term programme to monitor young stellar objects in the Orion Nebula Cluster was initiated in 2004, with the aim of addressing 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 EXOr and FUOr like transient activities associated with YSOs. Several new variables have been detected in the region, and this work clearly demonstrates the need for systematic, long term monitoring to detect variablility in YSOs (Parihar *et al.* 2009). A detailed multi-coloured monitoring of the interesting object V982 Ori over several years has established this oject as a UXOr type, a rare class YSO. A detailed study of the post-outburst phase of McNeil's nebula – V1647 Orionis (Ojha *et al.* 2006), confirmed that V1647 Ori is a pre-main-sequence star of the EXOr type.

A study of star forming regions in blue compact dwarf galaxies Mkn 104 and I Zw 97 (Ramya, Sahu & Prabhu 2009) indicates 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, Sahu & Prabhu 2007).

Several groups are studying open clusters with a view to obtaining accurate photometry of clusters that are not well-studied so far (Sujatha & Babu 2006; Sujatha, Babu & Ananthamurthy 2006; Carraro, Subaramaniam & Janes 2006; Sharma *et al.* 2007). Star formation and study of young stars in open clusters is another active area of research undertaken with the HCT.

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 and one Herbig Be star, while NGC 7419 was found to be a young open cluster with a number of very young intermediate mass pre-MS stars (Subramaniam *et al.* 2006). Based on a survey of emission line stars in open clusters, Mathew, Subramaniam & Bhatt (2008) have studied the Be phenomenon in clusters.

Evolved Stars: Stars that are somewhat more massive than the sun often show peculiarities as they evolve beyond the main sequence. A dredge up can mix the matter enriched by nucleosynthesis in the inner regions into the outer envelope. Carbon-rich stars resulting from such mixing are studied by Goswami

(2005). A survey of lithium rich stars has also been undertaken. HCT is also used to study stellar oscillations in stages such as RR Lyrae stars (Ferro *et al.* 2004, 2008), white dwarfs (Szkody *et al.* 2007), and subluminous B type stars. Variability in brown dwarfs, the missing links between stars and gas-rich giant planets like Jupiter, have been studied with the HCT (Maiti *et al.* 2005; Maiti 2007).

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 is determined by parameters such as the mass, metallicity and environment of the progenitor star. This area is also highly relevant to the topic of the ISM workshop since these stars die while the less massive stars born in their vicinity are still young, the explosion adds significantly to the interstellar matter in their surroundings, and the ejected matter can lead to induced star formation. The high luminosity of supernovae enable their observations at cosmological distances and make them excellent probes to study the universe at various redshifts. Supernovae of Type Ia (resulting from accreting or coalescing white dwarfs formed in intermediate mass stars) have been traditionally used as cosmological standard candles. This requires good calibration, 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 the progenitors and explosion mechanisms of CCSNe. 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 core collapse supenovae are observed with the aim of understanding the explosion mechanism and the progenitors.

The first objects to be observed during the science verification phase were the Type Ic SN 2002ap (Pandey *et al.* 2003a), and Type Ia SN 2002hu (Sahu, Anupama & Prabhu 2006) and SN 2003du (Anupama, Sahu & Jose 2005). 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 (Anupama *et al.* 2005; Tominaga *et al.* 2005), which showed the presence of a thin hydrogen envelope, 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 (Anupama *et al.* 2009) a type Ib supernova with narrow He emission lines, and the broad line type Ic SN 2007ru that showed a high kinetic energy to ejected mass ratio (Sahu *et al.* 2009).

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.* 2003b), 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.

Of a very modest and lesser nature of stellar explosions are those of novae. The HCT has been used to study the outburst of several classical novae and the recent 2006 outburst of the recurrent nova RS Ophiuchi (Anupama 2008; Anupama *et al.* 2008). An optical and radio study of the nebular remnant of the classical nova GK Persei (Anupama & Kantharia 2005) indicated the remnant to be very similar to supernova remnants, in particular, Cas A. A faint bipolar nebula, probably associated with an older planetary nebula that is associated with GK Per was detected in the lines of [N II] and Hα. Banerjee & Ashok (2004) used HCT to study the novalike variable V4332 Sagittarii and found that it did not conform to the known class of novae. Galactic microquasars and X-ray binaries (Kaur *et al.* 2008) are other kinds of interactive binaries that are studied with HCT.

Galaxies and Cosmology: HCT is being used for several studies in the area of galaxies and cosmology. Notable amongst these studies are the study of dust formation in early type galaxies (Patil *et al.* 2007), the study of Wolf-Rayet galaxies and low surface brightness galaxies (Das *et al.* 2007). The study of variability over various timescales in the Active Galactic Nuclei forms another important component of extragalactic astronomy pursued with the HCT (Raiteri *et al.* 2005; Goyal *et al.* 2008). The telescope has been used for deep J band imaging of high redshift QSOs (Goto & Ojha 2006) and is also used for multi-site monitoring of selected gravitationally lensed objects with a view to estimating the Hubble constant at all epochs.

Solar System Objects: HCT is also used for studies of solar system objects such as asteroids, comets, clouds in the atmosphere of Venus, and space debris in our immediate environment. Images of comet Tempel were obtained before and after Deep Impact collision as a part of an international campaign (Meech *et al.* 2005). The outburst of comet 17P/Holmes was studied. Images obtained 1-2 days after the outburst clearly showed the ejected debris, and also indicated the debris was ejected with a projected velocity of ~ 0.45 km s^{-1} (Vasundhara *et al.* 2010). Observations of night side of Venus were made in the 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).

4. Very High Gamma Ray Astronomy

The advantage of high altitude for studies of Very High Energy (VHE) γ-rays using atmospheric Čerenkov technique was brought out by Cowsik *et al.*

(2001b). Subsequently, a High Altitude Gamma Ray (HAGAR) observatory was established at IAO at the base of Digpa-ratsa Ri (longitude $78°57'1''$ E, Latitude $32°46'46''$ N, 4270 m above msl). The HAGAR array is based on wavefront sampling technique and consists of seven telescopes in the form of a hexagon with a spacing of 50 m and 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. This facility, a joint project of IIA and TIFR was commissioned in 2008 and science observations commenced in September 2008. Sources being monitored include the Crab and Geminga pulsars, and blazars 1ES2344+514 and Mkn 421. Preliminary results indicate that Crab pulsar is detected at 5.9σ at a threshold energy of about 200-220 GeV (Brito *et al.* 2009).

BARC, in collaboration with IIA and TIFR, is taking the next step of installing a 21-m imaging Čerenkov Telescope at Hanle, termed Major Atmospheric Cerenkov Experiment (MACE).

5. Other Science from IAO

The infrastructure developed at IAO has attracted many other groups to conduct their scientific experiments at this geographically unique site. The experiments include GPS geodesy for studying geodynamic deformation of the Indian subcontinent due to its collision with the Eurasian plate, broadband seismography, in-situ measurements of atmospheric CO_2 concentration, measurement of atmospheric aerosols. This is apart from the site characterization interests of astronomy for which atmospheric water vapour and aerosols are monitored routinely. The latter activity is recently extended to other sites such as Kalak Tartar (5400 m) a few km south of Hanle, and Merak (4200 m) on the bank of Pangong lake identified for solar astronomy. The participating institutions in earth science experiments are CMMACS, Bangalore, SPL/ISRO, Trivandrum and international collaborators in some cases.

Acknowledgments

A small team of astronomers at Bangalore and engineers at Leh maintain HCT with a high degree of reliability and ensure trouble-free operation with the help of a small team of support staff at Hanle and the remote control station at CREST. A larger team was involved with the development of the observatory and continues to support new developments at Hanle. HAGAR was similarly developed by a large group at IIA and TIFR, and science observations are carried out by a smaller group of astronomers from IIA, TIFR and SINP, Kolkata. The HCT team has extended support to all other scientific experiments at IAO.

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