



## The status of high-altitude Himalayan Gamma Ray Observatory at Hanle

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**Abstract:** A new  $\gamma$ -ray observatory comprising a large area imaging Cherenkov telescope and an array of wavefront sampling telescopes is being set up at the high altitude astronomical site at Hanle ( $32^{\circ}.8 N$ ,  $78^{\circ}.9 E$ , 4300 m amsl) in the Ladakh region of the Himalayas. The high altitude and low night sky background of the site plays an important role in lowering the energy threshold of both the imaging and wavefront sampling telescopes which is expected to be about 20 GeV and 60 GeV, respectively. In the first phase of operation, the 7 telescope array (named HAGAR) is being setup. This will be followed by 21 m diameter imaging telescope (MACE) in the second Phase. The details of the two telescope systems, the current status and the results of the preliminary simulation studies will be discussed in the paper.

## Introduction

Many celestial sources of Very High Energy (VHE)  $\gamma$ -rays have now been detected by exploiting the ground-based atmospheric Cherenkov technique [1]. Most of these detections have been made with systems operating at energy thresholds of a few hundred GeV. While, the satellite-based EGRET on board CGRO detected 7  $\gamma$ -ray pulsars[2] at MeV-GeV energies, there were no convincing detections of these by the ground based systems operating at much higher energies ( $> 100 GeV$ ), implying steepening of the energy spectrum or a spectral cutoff. Thus, the energy band between 10 GeV and 100 GeV, which still largely remains to be explored, is expected to shed light on spectral cutoffs in spectra of pulsars and AGNs and also expected to lead to astrophysical discoveries involving  $\gamma$ -ray bursts, Supernova remnants, plerions and unidentified EGRET sources.

The energy threshold of ground-based set ups could be lowered by installing them at higher altitudes where the photon density of atmospheric Cherenkov events is higher[3]. We<sup>1</sup> are setting up the Himalayan Gamma Ray Observatory (HIGRO)[4] at Hanle ( $32^{\circ}.8 N$ ,  $78^{\circ}.9 E$ , 4300 m

amsl) in the Ladakh region to address this important energy range using the two techniques of, “imaging” and “wavefront sampling”, of detecting atmospheric Cherenkov photon showers produced by cosmic  $\gamma$ -rays. This new observatory will have a large stereo imaging Cherenkov telescope (MACE) and an array of 7 non-imaging telescopes (HAGAR). The site offers an average of about 260 uniformly distributed spectroscopic nights per year which is a major advantage in terms of sky coverage for source observations. Located closer to the shower maximum, the Cherenkov photon density at Hanle is a factor of about 4 -5 more than at sea level[5]. Using the high altitude and low night sky background of the site to advantage, the two telescope systems will access the important region of very high energy  $\gamma$ -rays in the 10's of GeV energy range. This observatory will be located near a 2 m Himalayan Chandra Telescope (HCT) which can provide concurrent optical/IR monitoring of the objects of interest.

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1. A collaboration IIA, TIFR & BARC

## Design of HAGAR & MACE

The design of HAGAR & MACE telescope systems rely on our experiences gained by operating a non-imaging array (PACT) at Pachmarhi, imaging telescope system (TACTIC) at Mt. Abu and also the experiences of MAGIC and HESS groups.

### HAGAR telescope array

The HAGAR (High Altitude GAMMA Ray) telescope array[6] is based on wavefront sampling technique. It consists of 7 non-imaging telescopes deployed in the form of a hexagon as shown in figure 1. Each telescope has seven para-axially mounted mirrors (F/1 mirrors of 90 cm diameter) on a single platform. The mirrors are made by slumping 10mm thick float glass and coating their front surface by Al. An UV sensitive photo multiplier tube of Photonis make (XP2268B) is mounted at the focus of each mirror behind  $3^\circ$  diameter mask.

The telescope structure is based on Alt-azimuth design. Both its axes are driven by a stepper motor through a chain of gears with the reduction ratio of about 3000:1 for azimuth drive and 3200:1 for elevation drive. The telescope movement control system comprises of two 17 bit Rotary encoders (Heidenhain, ROC 417), two stepper motors with motor drives (Slo-Syn make) besides the Microcontroller-based Motion control interface Units(MCIU). This control system has been developed to achieve the steady-state pointing accuracy of the servo of  $\pm 10''$  with the maximum slew rate of  $30^\circ/\text{minute}$  for each axis. The resulting blind-spot size while tracking the stars near zenith is  $\sim 1^\circ.2$ . The telescopes' movement is maneuvered by the control software developed under Linux. The detailed point-run calibration by sighting large number of stars is being carried out to establish pointing model of the telescope to improve pointing accuracy further.

High voltages to individual PMTs are controlled using C.A.E.N. controller model SY1527. Pulses from individual PMTs are brought to the control room through coaxial cables of type LMR-ultraflex-400 and RG 213. The signals from the 7 PMTs in each element are added linearly before amplitude discrimination to yield a suitable count

rate and trigger pulse. A real time clock (based on 5 MHz crystal oscillator), synchronized to 1 Hz pulse from GPS clock, is used for recording absolute time with a resolution of  $1 \mu s$ . The PC based data acquisition (DAQ) and recording system employs CAMAC based instrumentation. The DAQ software is written in C under linux environment. Linux device drivers are developed to accomplish interrupt driven DAQ system. The trigger for data acquisition is obtained from a coincidence of any 4 out of 7 telescopes pulses. For each trigger informations regarding pulse height and arrival time of pulses from all PMTs are recorded along with other relevant information.

### MACE imaging telescope

The MACE (Major Atmospheric Cherenkov Experiment) telescope is planned to be a system of two high resolution imaging Cherenkov telescopes operating in a stereoscopic mode for  $\gamma$ -ray investigations in the sub TeV energy range. As depicted in 2 each telescope element will be based on the track and wheel design concept and will deploy an altitude-azimuth mounted parabolic tessellated light collector of 21 m diameter ( $f/d=1.2$ ). The drive control system of the telescope is being designed around electronically commutated motors using digital controllers, PC compatible hardware and software and Ethernet connectivity for remote monitoring and control.

The light collector will be made from 356 mirror panels of  $\sim 1 m \times 1 m$  size. Further, each panel consists of 4/9 diamond turned aluminium (Al-6063T6) spherical mirror facets of  $488 mm \times 488 mm / 323 mm \times 323 mm$  size. Various light collector configurations were simulated and a paraboloid basket with graded focal length mirror facets was determined to yield best possible timing and focusing characteristics[7]. All mirror panels will be equipped with motorized orientation controllers for aligning them to form a single parabolic light collector. Image processing algorithms for mirror alignment using "alignment lasers" and "star image" have been evolved[8].

The focal plane instrumentation will comprise 832 pixel imaging camera providing a field of view of  $4^\circ \times 4^\circ$ . The inner 576 pixels have a pixel-resolution of  $0^\circ.1$  and are used for generating the

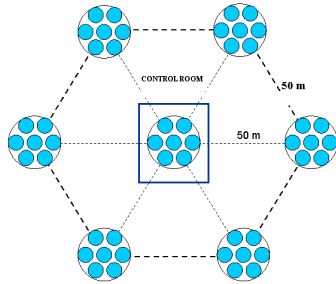


Figure 1: Layout of 7 telescope HAGAR array

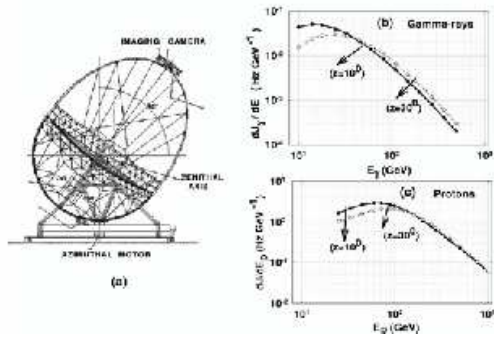


Figure 2: (a) A schematic of the MACE telescope to be set up at Hanle. (b) Differential detection rate for  $\gamma$ -rays as a function of the primary energy. (c) Differential detection rate for protons as a function of the primary energy.

event trigger. The surrounding 256 pixels will have a coarser resolution of  $0^\circ.2$ . The PMTs will be provided with acrylic front-aluminized light cones for enhancing the photo-sensitive area of the camera. The signal processing instrumentation will be housed within the camera and the digital data will be sent over optical fibers to the computer network in the control room for processing and archiving.

### Monte Carlo simulation studies

Monte Carlo simulation of Cherenkov showers have been carried out using the CORSIKA air shower simulation code [9]. Showers initiated by  $\gamma$ -rays, electrons, protons and  $\alpha$  particles incident

vertically at the top of the atmosphere were simulated using appropriate spectral shapes and the nature of Cherenkov light distribution at Hanle altitude was studied. For generating  $\gamma$ -ray showers the spectral shape of Crab as obtained from Whipple data [10] was used.

The atmospheric attenuation of Čerenkov photons at Hanle altitude is  $\sim 14\%$  as compared to  $\sim 50\%$  at sea-level. The lateral distribution of Čerenkov photon density for  $\gamma$ -ray primaries indicates presence of a "hump" at a core distance of about 90 m, due to effective focusing of Čerenkov photons from a range of altitudes. The  $\gamma$ /hadron segregation potential of various parameters along with their dependence on observation height has been investigated. Use of parameters based on Cherenkov photon density fluctuations, relative timing jitter, pulse decay time etc. have yielded promising results to discriminate  $\gamma$ -ray events from the more abundant cosmic rays [6].

### Performance of HAGAR & MACE

Taking into account various design details of HAGAR, energy thresholds and trigger rates are estimated for various PMT gains for  $\gamma$ -rays and cosmic rays [6]. The expected rate of events for a trigger based on 4 out of 7 telescope coincidence logic and for PMT gain of  $1.3 \times 10^7$  is about 55 Hz from protons, 16 Hz from  $\alpha$  particles, 1.3 Hz from electrons and 44/minute from  $\gamma$ -rays from crab. The peak of the differential  $\gamma$ -ray count rate distribution expected from the Crab nebula for a PMT gain of  $1.3 \times 10^7$  is at  $\sim 60$  GeV and this defines the energy threshold of the HAGAR system for vertically incident showers. At larger zenith angles the threshold energy would be proportionately higher.

Figure 3 shows the  $5\sigma$  sensitivity of HAGAR. Dotted line corresponds to the case without rejection of cosmic ray showers apart from the rejection obtained from 4 out of 7 telescope trigger logic. This sensitivity can be improved by rejecting off-axis cosmic ray showers and using several shower parameters based on density fluctuations and timing jitter in tandem [11, 12]. Sensitivity of HAGAR assuming 98% rejection of hadronic showers and retention of about 35% gamma ray showers is also shown in the figure as a solid line. This corresponds

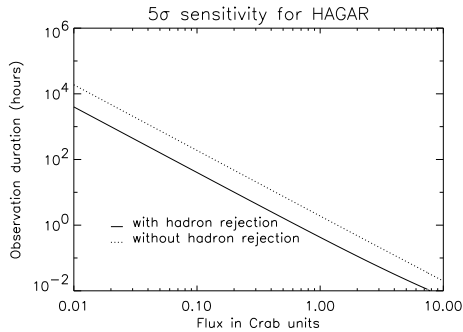


Figure 3: Sensitivity of HAGAR array ( $\approx 7.7\sigma/\sqrt{\text{hour}}$  for 1 Crab)

to the detection of Crab at  $5\sigma$  level within a duration of  $\sim 25$  minutes.

Preliminary simulation studies have been conducted to evaluate the expected performance parameters of the MACE telescope. Based on the measured value of the night sky background and a coincidence gate width of  $\sim 10$  ns, we have evaluated the single pixel threshold to be  $\sim 4$  pe at a single channel rate of  $\sim 26$  KHz using the Nearest Neighbour Quadruplet (NNQ) trigger. As shown in figure 2 (b) and (c), the  $\gamma$ -ray threshold energy of a single MACE element works out to  $\sim 15$  GeV and  $\sim 25$  GeV at zenith angles of  $10^\circ$  and  $30^\circ$  respectively while the proton threshold is  $\sim 60$  GeV and  $80$  GeV respectively [13]. Detailed simulation studies for stereo-mode operation of MACE and HAGAR + MACE system are in progress.

### Present status & Conclusions

The 7 element non-imaging telescope array, HAGAR, is being setup at Hanle in the Himalayas at an altitude of about 4200m above mean sea level. All the 7 telescopes and the data acquisition system are in place. The cabling work and the integration of all telescopes into the Data Acquisition system is going on. It is expected that, HAGAR will be operational for test and engineering data by September 2007. This system will have an energy threshold  $\sim 60$  GeV which has considerable overlap with the energy range of the satellite-based GLAST. Our initial emphasis will be on observations of pulsars including crab and geminga.

A conceptual Design report [14] for MACE is ready. The detailed engineering and structural design of the MACE telescope is going on. Fabrication of the mechanical structure, control system, focal plane instrumentation and Data acquisition system are all under active consideration. It is expected that the first telescope will be installed by the end of 2010 followed by additional telescopes for stereoscopic operation.

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