# Status of HAGAR telescope array at Hanle in the Himalayas

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***Abstract*. Recently, an array of 7 wavefront sampling Atmospheric Cherenkov telescopes has been commissioned at the high altitude (4270 m amsl) station Hanle in the Ladakh region of the Himalayas for the detection of high energy gamma rays from celestial objects. Data on Crab nebula and few other sources were also collected. The test data are used to fine tune some of the detector response parameters used in the Monte Carlo simulation of the experiment. In this paper we shall explain the salient features of the HAGAR telescope setup, its performance parameters like the energy threshold, collection area, sensitivity etc and future plans.**

***Keywords*: HAGAR, Gamma-rays, Atmospheric Cherenkov Technique**

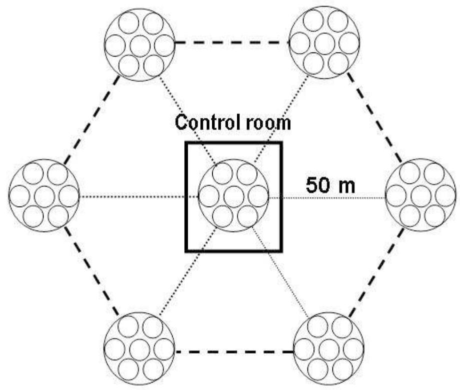


Fig. 1. Schematic layout of HAGAR array

## I. Introduction

Study of VHE gamma rays from celestial sources is carried out using ground-based atmospheric Cherenkov technique. Energy thresholds of previous generation atmospheric Cherenkov telescopes were of the order of few hundred GeVs or higher. There are strong astrophysical motivations for lowering energy thresholds of such setups to below 100 GeV and have overlap in energy with satellite based detectors. This will enable the study of cutoffs in the spectra of AGNs as well as pulsars [1].

There are several ways of reducing energy threshold of atmospheric Cherenkov Telescopes. For example, MAGIC experiment has used very large mirror area to reduce energy threshold to about 25 GeV [2]. Also earlier experiments like CELESTE, STACEE etc. have used large arrays of mirrors to achieve lower energy thresholds. Another way of reducing energy threshold is to set up these telescopes at higher altitudes, so that even modest size telescopes can achieve lower energy threshold [3], [4].

High Altitude GAmma Ray (HAGAR) experiment is one such effort in setting up an array of small telescopes at very high altitude. This array is located at Hanle (32° 46' 46" N, 78° 57' 51" E) at an altitude of 4270 m in Ladakh mountain range of Himalayas [3]. From the Monte Carlo simulation of extensive air showers, it is seen that the Cherenkov photon density in a shower at the altitude of Hanle is a factor of 4-5 higher than that at sea level. Also, atmospheric attenuation of Cherenkov photons is much lower at high altitude. These factors result in considerable reduction in energy threshold of an experiment at Hanle compared to similar experiment carried out at lower altitudes.

HAGAR experiment is the first phase of a grand Himalayan Gamma Ray Observatory (HIGRO) project [5] It is an array of non-imaging telescopes and based on wavefront sampling technique. This array has been commissioned recently. In this paper we shall describe the details of the set-up and discuss the present status.

## II. Details of HAGAR Telescope array

The HAGAR array consists of seven telescopes with six of them deployed in the form of a hexagon. The seventh telescope is located at the centre of the array. The spacing between neighbouring telescopes is 50 m. A schematic layout of the array is shown in figure 1.

Each telescope consists of seven mirrors of diameter 0.9 m each. They are made by forming 10 mm thick float glass sheets into parabolic shapes of f/d ratio unity. At the focus of each mirror one fast UV sensitive phototube of the type Photonis XP2268B is mounted [6]. These 7 mirrors of a telescope are mounted para-axially on a single platform. The telescopes have alt-azimuth mounts. Each axis of the telescope is driven by a stepper motor. The telescope movement control system consists of two 17 bit Rotary encoders, two stepper motors and Micro-controller-based Motion Control Interface Unit

(MCIU). Steady state pointing accuracy of the servo is ± 10 arc-sec with maximum slew rate of 30°/minute. The resulting blind-spot size while tracking the stars near zenith is ∼ 1.2°. The telescopes' movement is maneuvered by the control software developed under Linux. The telescope pointing is continuously monitored and corrected in real time during tracking.

High voltages fed to photo-tubes are controlled and monitored using C.A.E.N.controller (model SY1527). Pulses from photo-tubes are brought to the control room situated below the central telescope via coaxial cables of length 85 m and of types LMR-ultraflex-400 (30 m) and RG 213 (55 m). For generating trigger, the pulses from 7 photo-tubes of a telescope are added linearly to form a telescope pulse. Event trigger is generated on coincidence of at least 4 out of 7 telescope pulses above a preset threshold within a resolving time of 150 ns.

CAMAC based instrumentation system is used for acquiring data. An interrupt driven software is used for recording data. The rates of 49 photo-tube's and 7 telescope's pulses are monitored continuously and recorded at regular intervals using monitoring interrupts of frequency 1 Hz. Event interrupt due to the presence of Event trigger initiates data recording and is given the highest priority. The event data consists of relative arrival time of Cherenkov shower front at each mirror accurate to 0.25 ns as measured by TDCs, Cherenkov photon density at each mirror using 12 bit QDC, absolute arrival time of event accurate to $\mu s$ as given by Real Time Clock (RTC) module synchronized with GPS and other informations like the triggered telescopes in an event.

## III. Pointing Model

An important issues in the pointing of HAGAR telescope system is co-alignment of 7 mirrors mounted para-axially with the guiding telescope and the telescope axes. The following procedure was developed to attain good accuracy in the pointing of telescopes as well as all mirrors in each telescope.

Alignment of guiding telescope with the telescope axes was done by sighting large number of bight stars. A CCD camera (ST-4) was used to obtain the pointing data and pointing models for the guide telescopes were worked out. All mirrors in a telescope were initially co-aligned with the guide telescope by sighting a distant stationary light source. There after, several scans in RA-DEC space were performed by pointing the telescopes to isolated bright stars. In these scans, the direction of telescopes are offset from the direction of star in RA and DEC in steps of 0.5 deg and the photo-tube count rates are recorded. Profiles of count rate as a function of offset was generated for each mirror. The centroid of these profiles give the pointing direction of mirror, or rather offsets in the pointing of each mirror with respect to the telescope direction. Based on these offsets the mirror alignments were fine tuned and checked by repeated RA-DEC scans. These scans also provide data on the pointing of mirrors as a function of altitude and azimuth. They are used for fine tuning pointing models of all telescopes as well.

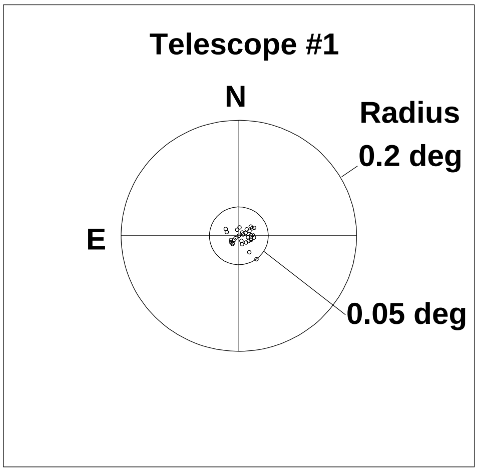


Fig. 2. A typical spread in the position of star images as seen in a guide telescope after applying pointing model. The stars are selected such that various elevation and azimuth angles are covered.

The azimuth and altitude corrections in pointing models are given by following expressions :

$$\Delta A = -AN \times sin\ \mathbf{A} \times tan\ \mathbf{E} - AW \times cos\ \mathbf{A} \times tan\ \mathbf{E} + NPAE \times tan\ \mathbf{E} + IA + ACEC \times cos\ \mathbf{A} + ACES \times sin\ \mathbf{A} \quad (1)$$

and

$$\Delta E = AN \times cos\ \mathbf{A} - AW \times sin\ \mathbf{A} + IE + CTC \times sin\ \mathbf{E} + CTT \times tan\ \mathbf{E} \quad (2)$$

where A and E are Azimuth and Elevation angle of the star respectively, AN, AW, NPAE, IA, IE, ACEC and ACES are coefficients corresponding to real physical misalignments and other mechanical distortions in the telescope [7], CTC and CTT are empirically found coefficients.

The figure 2 shows the position of star images in the the guiding telescope of one of the 7 telescopes after application of pointing model. The stars are selected such that various elevation and azimuth angles are covered in this plot. The figure 3 shows the position of star images at the foci of 7 mirrors of the same telescope after fine tuning mechanical alignment of mirrors and also pointing model. The overall pointing accuracy of all 49 HAGAR telescope mirrors achieved by this method is 0.20±0.12 deg.

## IV. Performance Parameters

Extensive Monte Carlo simulations have been carried out in order to understand performance of HAGAR experimental setup. Extensive air showers due to protons, alpha particles, electrons, and gamma primaries impinging on the atmosphere were simulated using the CORSIKA code [8], [9]. following appropriate energy spectrum. For gamma ray showers vertical incidence

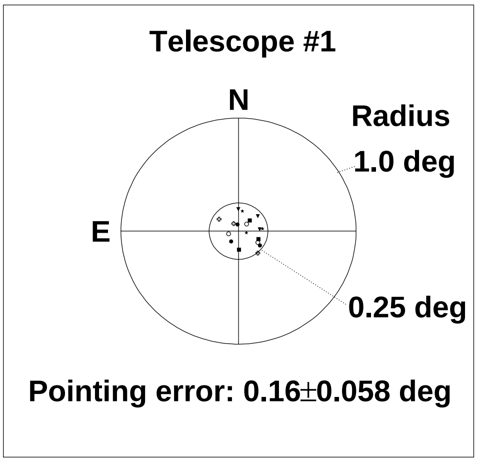


Fig. 3. Position of star images at the foci of 7 mirrors of the same telescope, Telescope # 1.

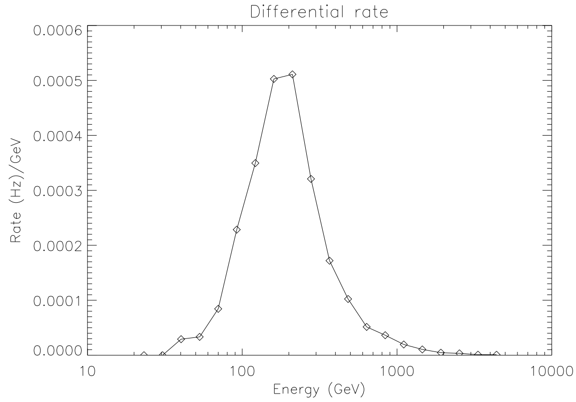


Fig. 4. Expected differential $\gamma$-ray count rate spectrum from Crab nebula. The peak of the distribution is around 185 GeV.

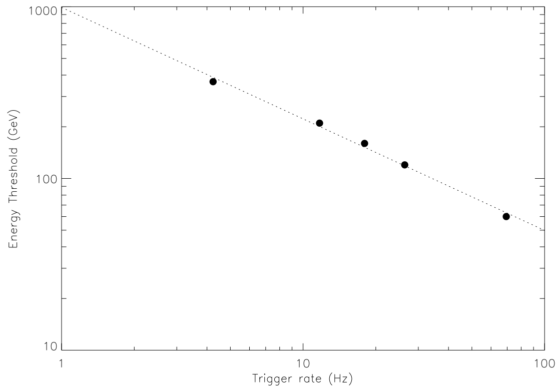


Fig. 5. Trigger rate vs energy threshold for photo-tube gains of 1, 2, 2.5, 3 and 5 $\times$ $10^6$. Energy threshold decreases and trigger rate increases with increase in photo-tube gain.

is assumed, whereas cosmic ray showers are incident within 3° around vertical. Cherenkov light distribution from these showers was then passed through detector simulation program specific to HAGAR, developed in-house. This program takes into account various site and instrument related parameters like Atmospheric attenuation of Cherenkov photons at Hanle ($\sim$ 14%); field of view of the experiment (3° FWHM); reflectivity of the mirrors ($\sim$ 80%); night sky background light at Hanle ($\sim$ $1.5 \times 10^8$ ph/s/sr/cm$^2$); photo-tube parameters including gain, quantum efficiency (Peak efficiency of 24% at 400 nm) , and pulse rise time of 2 ns; attenuation in coaxial cables; amplification of pulse by $\times$10 amplifier module and various discriminator thresholds. Finally the trigger criteria of coincidence of at least 4 pulses out of 7 crossing discriminator threshold of 180 mV in narrow coincidence window of 150 ns is applied. Total trigger rate obtained from simulations, which is sum of trigger rates from protons, alpha particles and electrons is 13.7 Hz, which is consistent with the observed trigger rate of about 14 Hz. The threshold energy defined as the energy corresponding to the peak of the differential rate curve for gamma ray initiated showers, is about 185 GeV and is shown in figure 4. Expected trigger rate from Crab like source is about 9.6 counts/min when the source is at zenith. The effective collection area is estimated to be about $4 \times 10^4$ m$^2$. The 5$\sigma$ sensitivity of HAGAR for 50 hours of observation is estimated to be $1.68 \times 10^{-10}$ erg/cm$^2$/s.

The observed trigger rate and the corresponding energy threshold are different than our earlier estimates [10]. The present trigger rate is lower and hence energy threshold is higher. The earlier estimates were obtained before the installation of the setup. There are certain issues to be addressed regarding fine tuning of mirror alignment and possible weathering of mirrors. Also at present, photo-tubes are operated at somewhat lower gain. In order to have an idea about variation of trigger rate (and energy threshold) with photo-tube gain, simulations were repeated varying gains in the range of $1 \times 10^6$ to $5 \times 10^6$. The energy threshold as a function of trigger rate is shown in figure 5. The energy threshold decreases and trigger rate increases with increase in photo tube gain. For photo-tube gain of $5 \times 10^6$ the energy threshold is about 60 GeV. The sensitivity of HAGAR is estimated for various conditions and is shown in figure 6. At present, the raw sensitivity of HAGAR is $1.8\sigma/\sqrt{hour}$ (solid line). With highest photo-tube gain considered here, sensitivity will be $3.6\sigma/\sqrt{hour}$ (dash line). We are planning to use gamma-hadron separation parameters based on density fluctuations, timing jitter and pulse shape for rejection of cosmic ray background. Assuming 98% rejection of cosmic ray showers and 35% acceptance for gamma ray showers sensitivity of HAGAR is estimate to be $7.6\sigma/\sqrt{hour}$ (dash-dot line). This is the limiting sensitivity for HAGAR.

## V. PRESENT STATUS AND FUTURE OUTLOOK

HAGAR is fully operational now. Several engineering and test runs have been conducted and science observations commenced in September, 2008. Sources observed so far include Crab nebula, Geminga pulsar, and blazars (Mkn 421 and 1ES 2344+514). Results of preliminary

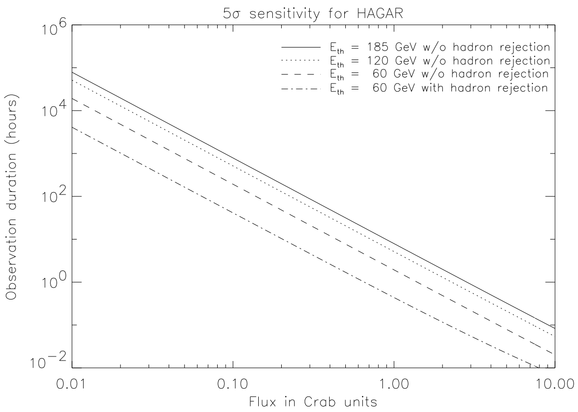


Fig. 6. Sensitivity of HAGAR array for a source of strength 1 Crab for various conditions

analysis are described in accompanying papers [11], [12].

We have further upgraded the data acquisition system recently (April 2009). we have re-designed and replaced the existing trigger circuit with a new and efficient trigger logic module. Also we have incorporated a parallel data acquisition system using two 4 channel modules of Acqiris flash ADC or digitizer model DC271A. This is 8 bit compact PCI digitizer with 1 GHz bandwidth with 50 Ω resistance and sampling rate of 1 GS/s. Seven telescope pulses are input to this module. This will enable us to study pulse shape, use gamma-hadron separation parameters based on pulse shape, reduce night sky background contribution by restricting window around Cherenkov pulse and also incorporate technique of software padding besides providing redundancy in data acquisition. All these upgrades are expected to improve the sensitivity of HAGAR and lower the energy threshold further.

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