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Status of HAGAR, the High Altitude Gamma Ray Observatory at Hanle

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A 7 telescope array is planned to be constructed at Hanle in the Himalayas at an altitude of about 4200m above mean sea level for detecting celestial gamma-rays. The atmospheric Cerenkov light pool created by the primary gamma-rays is sampled through wave-front sampling technique to infer the direction and energy of the incident gamma-rays. Monte Carlo simulation calculations were performed to understand the energy threshold and event trigger rates. One telescope is fabricated and shifted to Hanle after extensive tests at CREST, Hosakote. The current schedule for the fabrication of remaining telescopes, experiment and the energy threshold will be discussed.

1. Introduction

Ground based atmospheric Čerenkov technique has been used extensively for the study of VHE γ-rays from astronomical objects. Energy thresholds of most of these experiments are typically about few hundred GeVs. There is a strong scientific motivation for lowering energy thresholds of ground based experiments to few tens of GeV and have overlap with satellite based detectors. This will enable the study of spectral cutoffs in AGN spectra and will also allow addressing various issues regarding pulsed emission from pulsars [1]. Thus there are several attempts to reduce energy thresholds of ground based experiments. Recently, based on stereoscopic technique, HESS has been able to achieve an energy threshold of about 100 GeV [2, 3]. MAGIC experiment using very large size light collector is expected to reach energy threshold of about 30 GeV [4, 5]. Similarly experiments like CELESTE, STACEE etc used large arrays of mirrors to achieve lower energy threshold. Alternatively it is possible to achieve lower energy threshold using modest size experiment carried out at high altitudes [6, 7]. One such experiment HAGAR (High Altitude GAmma Ray experiment) is under construction in Himalayas. This is a collaborative effort between Indian Institute of Astrophysics, Bangalore and Tata Institute of Fundamental Research, Mumbai.

2. HAGAR instrument details

HAGAR telescopes are being setup at Hanle ($32°46'46''$ N, $78°57'51''$ E) at an altitude of $\sim 4.2km$ amsl in the cold desert of Himalayas, which is a fine astronomical site. This array based on wavefront sampling technique will consist of 7 telescopes in the form of a hexagon with a spacing of 50 m and one telescope at the centre of the hexagon as shown in figure 1. Each telescope has seven para-axially mounted front coated mirrors of diameter 0.9 m with a Photonis phototube of type XP2268B at the focus of each mirror. f/d ratio for these mirrors is $\sim$1. Figure 2 shows the first telescope of HAGAR installed at Hanle.

Telescope structure is based on Alt-azimuth design. Each of the axes of the telescope is 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 ±10 arc-sec with the maximum slew rate of 30°/minute for each axis. 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 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 given to individual PMTs are controlled using C.A.E.N. controller model SY1527 so that PMT gains are constant. Pulses from individual PMTs are brought to the control room through coaxial cables of type LMR-ultraflex-400. PC based data acquisition and recording system employs CAMAC based instrumentation. DAQ software is written in C under linux environment. Linux device drivers are developed to accomplish interrupt driven DAQ system.

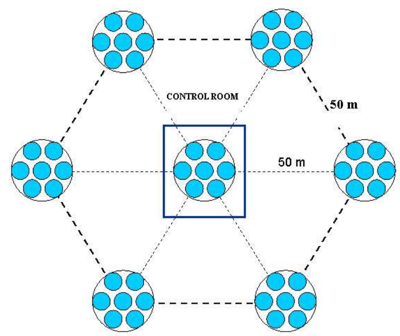

Figure 1. Layout of 7 telescope HAGAR array

Figure 2. First HAGAR telescope

3. Expected performance of HAGAR

Using CORSIKA package [8], Monte Carlo simulations of extensive air showers initiated by γ-rays, electrons, protons and α particles incident vertically at the top of the atmosphere were carried out and the nature of Čerenkov light distribution at Hanle altitude was studied. 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 γ-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 [9]. The Čerenkov photon density near the shower core at Hanle is higher by a factor of about 4-5 compared to that at the sea-level for showers of same energy. These features effectively reduce the energy threshold of the experiment operated at higher altitudes compared to the similar array operated at lower altitudes.

Taking into account various design details of HAGAR, energy thresholds and trigger rates are estimated for various PMT gains for γ-rays and cosmic rays. Results are given in Table 1. Showers of different cosmic ray species were generated using appropriate spectral shapes. For generating γ-ray showers the spectral shape of Crab as obtained from Whipple data [10] was used. Figure 3 shows the expected differential γ-ray count rate from Crab nebula for the PMT gain of 1.3×10^7. The energy threshold, defined as the peak of the differential trigger rate distribution, is $\sim 60\ GeV$ for vertically incident showers. At larger zenith angles the threshold energy would be proportionately higher. Main advantage of this experiment is the energy threshold which is considerably lower than that at sea level and overlaps with the energy range of future satellite based detectors.

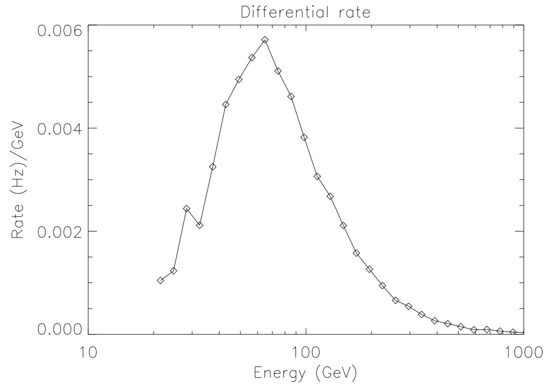

Figure 3. Expected differential γ-ray count rate spectrum from Crab nebula.

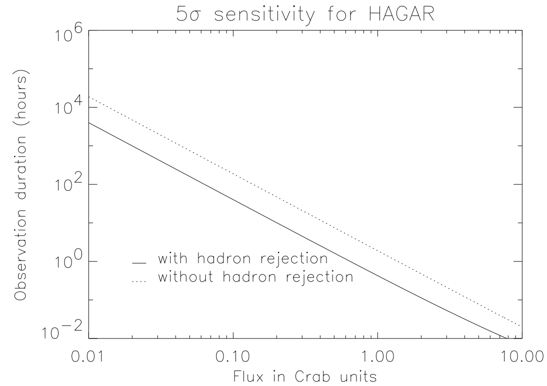

Figure 4. Sensitivity of HAGAR array ($\approx 7.7\sigma/\sqrt{hour}$ for 1 Crab)

The expected rate of events for a trigger based on 4 out of 7 telescope coincidence logic for PMT gain of 1.3×10^7 is about 55 Hz from protons, 16 Hz from α particles, 1.3 Hz from electrons and 44/minute from γ-rays from crab.

Figure 4 shows the 5σ 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]. It may be possible to reject about 98% of cosmic ray showers retaining about 35% of gamma ray showers. Sensitivity of HAGAR with this hadronic rejection is also shown in the figure as a sold line. This corresponds to the detection of Crab at 5σ level within a duration of $\sim$25 minutes.

Table 1. Trigger rates and energy thresholds for γ-rays and cosmic rays for different trigger conditions
The corresponding energy thresholds are given in brackets.

Trigger → PMT ↓ Gain	4/7 γ	6/7 γ	4/7 e	6/7 e	4/7 p	6/7 p	4/7 α	6/7 α
9.0×10^6	20.8/m 100 GeV	- -	31.9/m 115 GeV	- -	25.8 Hz 280 GeV	-	8.3 Hz 1130 GeV	-
1.3×10^7	43.8/m 60 GeV	19.2/m 80 GeV	79.4/m 90 GeV	28.4/m 110 GeV	55.2 Hz 250 GeV	20.2 Hz 310 GeV	15.8 Hz 600 GeV	7.3 Hz 1130 GeV
2.0×10^7	$>$ 131/m -	48.7/m 50 GeV	$>$ 272/m -	$>$ 89m -	$>$ 402 Hz -	53.3 Hz 180GeV	$>$ 85 Hz -	16.8 Hz 600 GeV

4. Present status and timeline

First telescope of HAGAR has been extensively tested at CREST, Hosakote near Bangalore and has been shifted to Hanle in June 2005. Some preliminary tests have been carried out on this telescope at Hanle site. Second telescope is installed at CREST and is ready for tests. In about one and half year from now, HAGAR is expected to be fully operational. Initial emphasis will be on observations of pulsars including crab and geminga. Pulsed emission has been detected from seven pulsars by EGRET below 10 GeV [13, 14, 15]. However, at energies above few hundred GeVs only non-pulsed emission from nebula is detected. Based on HEGRA data upper limit of 1-3% of unpulsed component has been quoted for pulsed component from Crab pulsar [16] in the energy range of $\sim$ 500 GeV to 10 TeV. EGRET measurement gives indication of steepening of pulsed emission for some pulsars. So it will be interesting to study spectrum of pulsed component at the energies accessible to HAGAR. We hope to have simultaneous observations with GLAST for pulsars. Detection of pulsed emission and its spectral cutoff in the energy range covered by GLAST and HAGAR would enable the differentiation between polar cap [17, 18] and outer gap [19, 20] models regarding the emission of γ-rays.

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