Status of HAGAR Telescope Array in Himalayas

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Abstract: High Altitude GAmma Ray (HAGAR) telescope array, which is the first stage of Himalayan Gamma Ray Observatory (HiGRO), has been successfully installed at Hanle in Himalayas and has been collecting science data since September, 2008. In last two and half years, we have observed several sources including galactic objects like Crab nebula, Geminga pulsar, LSI+61 303 and some of the pulsars detected by Fermi as well as extragalactic objects including Mkn 421, Mkn 501, 1ES2344+514, 3C454.3 etc. Analysis of the data on all these sources is underway. Preliminary results include detection of Crab nebula at a significance level of 7.8σ in 10.4 hours. Search for pulsations is being carried out for all the pulsars observed by HAGAR. Amongst the AGNs, Mkn 421 is detected in flare state in February, 2010. Details of these results as well as plans for upgrade of HAGAR will be presented. In the second phase of HiGRO, Major Atmospheric Cherenkov Experiment (MACE) will be installed at Hanle, next to HAGAR. Update on our activities at Hanle will be given.

Keywords: VHE gamma ray astronomy, Atmospheric Cherenkov Technique

1 Introduction

High Altitude GAmma Ray (HAGAR) telescope array is an atmospheric Cherenkov experiment located in Himalayas. This experiment was conceived as an attempt to lower energy threshold of small size telescopes by installing them at high altitude location. This is an economic approach of reducing energy threshold compared to the other method involving very large mirrors. HAGAR, installed in 2008, is an experiment based on wavefront sampling technique. In this paper, status of HAGAR will be discussed alongwith the overview of results and future outlook.

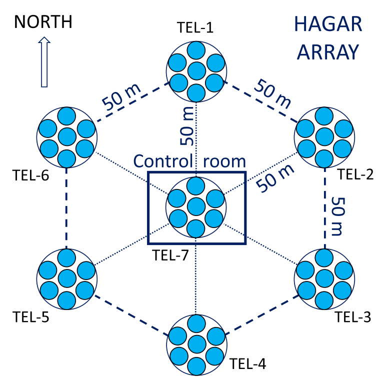

Figure 1: Schematic layout of HAGAR array

2 HAGAR details

The HAGAR telescope 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. It was set up to exploite the advantage of higher altitude location and lower atmospheric attenuation of Cherenkov photons [1].

HAGAR is an array of seven telescopes with six of them deployed in the form of a hexagon and one telescope at the centre [2]. The spacing between the neighbouring telescopes is 50 m. A schematic layout of the array is shown in figure 1. Each telescope consists of seven para-axially mounted parabolic mirrors of diameter 0.9 m each. At the focus of each mirror a UV sensitive photo-tube of the type Photonis XP2268B is mounted. The telescopes have alt-azimuth mounts and their 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 servo is ±10 arc-sec with maximum slew rate of 30°/minute. 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. Pointing model worked out for each telescope sighting several stars has been incorporated in tracking program and overall pointing accuracy of 12'±7' is achieved [3].

High voltages of 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). In control room, the pulses from 7 photo-tubes of each 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 200 ns.

Data acquisition system is CAMAC based and interrupt driven. The rates of 49 photo-tubes and 7 telescope pulses are monitored continuously and recorded at regular inetrvals using monitoring interrupts of frequency 1 Hz. Event interrupt produced by 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 μs as given by Real Time Clock (RTC) module synchronized with GPS and other informations like the triggered telescopes in an event.

In addition to CAMAC based system, another parallel data acquisition system consisting of flash ADCs (ACQIRIS make DC271A, bandwidth : 1 GHz, sampling rate : 1 GS/s) is also installed. Two modules of flash ADCs, each with 4 channels, are used for recording pulses from 7 telescopes.

3 Performance Parameters of HAGAR

Extensive Monte Carlo simulations have been carried out to understand performance of HAGAR experimental setup. Extensive air showers due to protons, alpha particles, electrons and gamma primaries impinging on the atmosphere are simulated using CORSIKA code [4, 5], following appropriate energy spectra. Cherenkov photon distributions from these showers are passed through detector simulation program developed in-house to take into account various parameters related to HAGAR system. Performance parameters of HAGAR are estimated using output from detector simulation program [6].

Cosmic ray trigger rate obtained from simulations as a sum of trigger rates from protons, alpha particles and electrons is estimated to be 13.2 Hz, which is close to the observed rate. Energy threshold of HAGAR is estimated to be 204 GeV for vertically incident gamma ray showers (see Fig. 2). Threshold increases with the angle of incidence of gamma rays and approaches value of about 500 GeV for an inclination angle of 45°. Effective collection area is estimated to be about 3.2×10^4 m^2 for vertically incident showers and increases to 1×10^5 m^2 for showers incident at 45°.

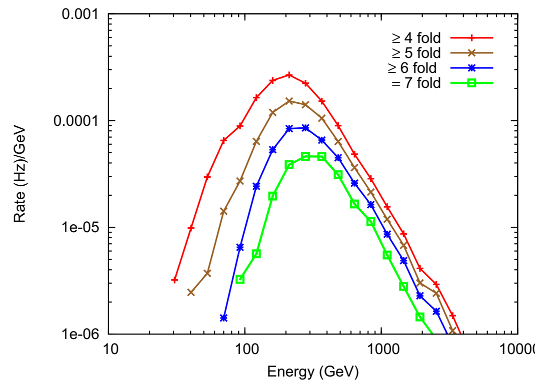

Figure 2: Differential rate as a function of energy as obtained from simulations for various trigger conditions

Gamma ray rate for Crab like source is estimated to be 6.6 /min for source near zenith. Sensitivity of HAGAR is estimated to be $1.3/\sqrt{hour}$. Details of performance parameters and comparison of simulations with observations has been given by Saha et al. [6].

4 Observation methodology and data analysis method

Science observations with HAGAR commenced in September, 2008. Sources observed inlcude galactic objects like Crab nebula, X-ray binary LSI+61 303, MGRO 2019+37, Geminga pulsar and some pulsars detected by LAT onboard Fermi as well as extragalactic objects like Mkn 421, Mkn 501, 1ES2344+514, 1ES1218+304, 3C454.3 and M87. Observation durations for these sources are listed in Table 1. In addition to this, several runs were conducted tracking dark regions for estimation of systematics in data.

HAGAR observations are generally conducted in pairs, tracking source region and background region for 40 minutes each. Background region is selected such that same angular region of the sky is covered in ON-OFF pair. Recorded data includes arrival time of Cherenkov shower front at each telescope, for each event, given by the TDC. By fitting a plane front to this data, direction of the shower axis is obtained as a normal to the fitted front. For each event, space angle i.e. the angle between the pointing direction and the direction of shower axis, is estimated. Space angle distributions from ON and OFF runs are compared and excess of events is attributed to the gamma ray signal. Details of data analysis method are given by Britto et al. [7].

Source name	Type	Observation Duration	
		ON (hours)	OFF (hours)
Crab	PWN	121.9	117.4
LSI+61 303	XRB	25.6	28.3
MGRO 2019+37	PWN	16.4	15.3
Geminga	Pulsar	76.1	48.1
J0007+7303	Pulsar	2.4	2.8
J0357+32	Pulsar	3.6	1.0
J0633+0632	Pulsar	14.1	4.5
J2055+2539	Pulsar	5.9	2.3
Mkn 421	HBL	86.5	100.7
MKn 501	HBL	48.8	52.5
1ES2344+514	HBL	75.5	86.9
1ES1218+304	HBL	4.7	6.0
3C454.3	Quasar	15.3	15.3
M87	FRI	2.0	2.7

Table 1: HAGAR observation log

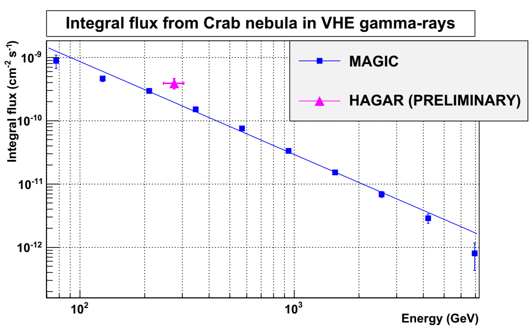

Figure 3: Comparison of Crab flux from HAGAR with MAGIC

5 Results

In the last three years, we had a very long coverage of about 120 hours for Crab nebula, which is a standard candle source for VHE gamma ray experiments. After selecting the best quality data, 10.4 hours of data was retained for further analysis. In view of systematics caused by the bright star Zeta Taurus in the field of view of HAGAR during Crab observations, only events with $\geq$6 telescopes participating in trigger were seleccted. Gamma ray rate from Crab nebula was estimated to be 5.1$\pm$0.7 $counts\ min^{-1}$, corresponding to detection at a significance level of 7.8σ. Flux from Crab nebula is estimated to be $(3.9\pm0.7)\times10^{-10}$ ph cm^{-2} s^{-1} with threshold energy of 275 GeV [7] and is shown in Fig. 3 along with energy spectrum obtained from MAGIC [8].

Search for pulsed emission at the known periods has been carried out for Crab and Geminga pulsars as well as for three Fermi detected pulsars, viz. J0357+32, J0633+0632 and J2055+2539 [9]. Phase histogram for Crab pulsar is shown in fig. 4 folded over rotation period ($\sim$33 ms) for

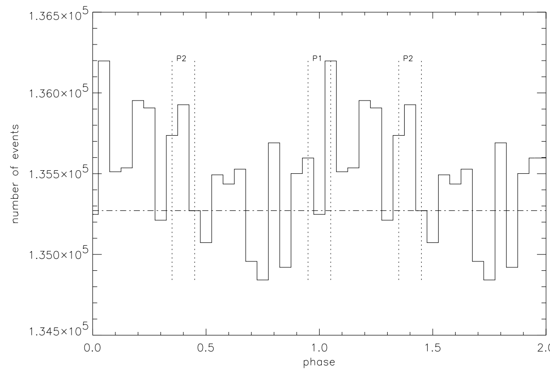

Figure 4: Phase histogram of Crab pulsar

two cycles. The monthly timing ephemeris of the Crab pulsar were extracted from Jodrel Bank crabtime data base [10]. From HAGAR data, no evidence for pulsed emission was seen in any of these sources at energies above 200 GeV. Time averaged 3σ upper limits on pulsed component of gamma ray flux are estimated for all these pulsars. For Crab pulsar estimated upper limit is 1.5×10^{-11} ph cm^{-2} s^{-1}.

Amongst the blazars, Mkn 421 is observed extensively by HAGAR and a flare from this source has been detected in February, 2010 (see Shukla et al. [11] for details). HAGAR detected flux reached a maximum value of about 6.9 Crab units on 17 February, 2010. Average flux observed during 13-19 February 2010 was about 3.2 Crab units. The flux from this source decreased in March and April seasons. Similar behaviour was seen in the soft X-ray data from ASM onboard RXTE. Hint of correlated activity between X-ray and gamma ray bands is seen [11]. The multiwaveband SED of Mkn 421 corresponding to 17 February 2010, obtained using X-ray data (from PCA onboard RXTE), lower energy gamma ray data (from LAT onboard Fermi) and VHE gamma ray data (from HAGAR), is shown in Fig. 5. This SED is fitted with one zone Synchrotron Self Compton (SSC) model given by Krawczynski et al. [12]. Parameters of fitted model are discussed in [11] and also listed in the figure. On this day, intra-day variability was also detected by HAGAR. Fig. 6 shows light curves from ASM, HAGAR and Fermi-LAT for 17 February 2010. LAT light curve shows two flares during this day and decrease from second peak seen by LAT is also apparent in near simultaneous HAGAR data.

Amongst other blazars, data from Mkn 501 taken during March-June 2010 is analysed. This source is detected at a significance level of 4.9σ in 8.3 hours. Flux above threshold energy of 260 GeV is estimated to be 2.89×10^{-10} ph cm^{-2} s^{-1}, which corresponds to about a Crab unit. Analysis of data from other sources is underway.

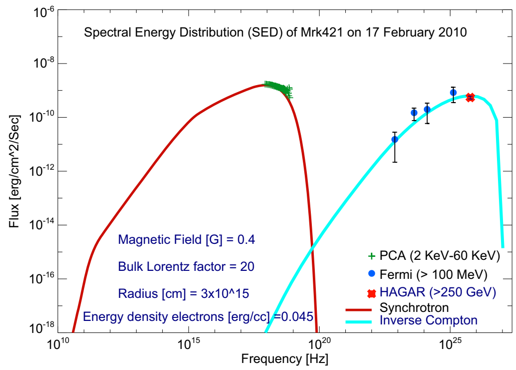

Figure 5: Multiwaveband spectral energy distribution of Mkn 421 during 17 February 2010 flare. Data is fitted with one zone SSC model. Model parameters are listed in the figure.

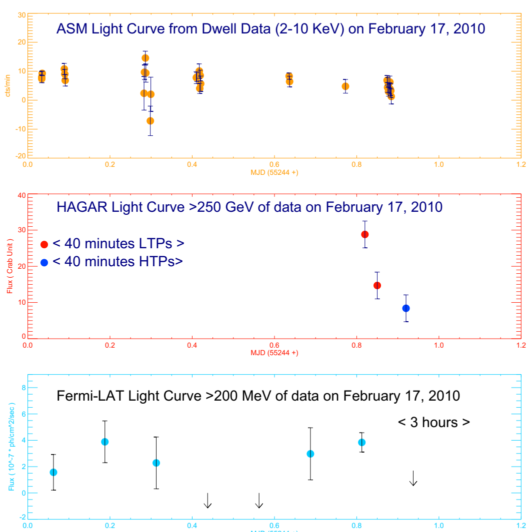

Figure 6: Intra-day light curves of Mkn 421 on 17 February 2010 from X-ray (ASM), VHE gamma ray (HAGAR) and lower energy gamma ray (Fermi-LAT) observations

6 Future Outlook

Some improvements in HAGAR data acquisition system are planned. These include introduction of digital delays for telescope pulses to reduce coincidence width. At present, coincidence width is kept 200 ns for zenith angles within 30° and 300 ns for higher zenith angles. With digital delays, this width can be reduced, which will result in reduction in chance coincidence and enable operation of photo-tubes at higher gain. Digital delay module is ready and will be soon augmented with HAGAR DAQ. Also there is a plan for triggering HAGAR with another type of trigger, called grand sum trigger. Grand sum pulse is analog addition of telescope pulses. For coherent addition of these pulses for various pointing directions, analog delays are required. Work on analog delays is underway. Use of grand sum trigger will enable reduction in energy threshold at trigger level.

In case of data analysis, efficient use of FADC data is planned. Using this data software padding can be done for better balancing between ON-OFF regions. Also work on GHS parameters based on pulse shape, density fluctuations, timing jitter etc will be taken up to improve sensitivity of HAGAR.

Next stage will be augmentation of HAGAR with MACE (Major Atmospheric Cherenkov Experiment) which will be coming up near HAGAR as a next phase of HiGRO (Himalayan Gamma Ray Observatory) [13]. Installation of MACE is expected to take place in 2012. HAGAR and MACE are expected to have common triggers which will improve sensitivity of HAGAR and this is also expected to improve rejection of muon triggers for MACE.

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