



## Observations of Blazars using HAGAR Telescope Array

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**Abstract:** Several AGNs of Blazar class, including Mkn421, Mkn501, 1ES2344+514, 1ES1218+304 and 3C454.3, have been observed at energies above 200 GeV with High Altitude GAMMA Ray (HAGAR) telescope array located in Himalayas in India, over past two years. We had very long coverage of Mkn421 and have observed it in one of the brightest flaring episodes in February, 2010. HAGAR observations of this blazar during this flare have shown enhancement of flux level with a maximum flux of about 6 Crab units on 17th February. We present multi-waveband spectral energy distribution of this source during this flaring episode and investigate the correlation of variability in X-ray and gamma ray bands. Preliminary results on other blazars will also be presented.

**Keywords:** TeV Blazars, HAGAR, Fermi-LAT,  $\gamma$ -ray astronomy

## 1 Introduction

Blazars are AGN with a relativistic jet that is pointing in the direction of the Earth. They belong to the radio-loud Active Galactic Nuclei (AGNs) and characterized by a non thermal spectrum extending up to high energies. Spectral energy distributions (SEDs) of high energy peaked TeV blazars show two broad peaks, one from infrared to X-ray energies and the other at X-ray to  $\gamma$ -ray energies. It is believed that first peak of the SED originates due to synchrotron radiation by relativistic electrons gyrating in the magnetic field of the jet plasma. The origin of high energy GeV/TeV peak is still under debate. This high energy peak could originate due to either inverse Compton scattering of synchrotron photons by same population of electrons which produces the synchrotron radiation (for a recent review of observations and models, see [1]) or extremely energetic protons gyrating in strong magnetic field via synchrotron radiation [2] or as inverse Compton and synchrotron emission from a proton-induced cascade [3]. The blazar, Mark421 ( $z=0.031$ ), has been the first extragalactic source detected at gamma ray energy  $E > 500$  GeV [4]. Using the newly commissioned High Altitude GAMMA Ray (HAGAR) telescope system we have observed several TeV blazars in last three years. Here, we report observations of Mrk421 in its high state of activity during February to April 2010 and Mrk501 during March-June 2010. We have detected a very bright flare above 250 GeV on February 17, 2010 from Mrk421. In this paper we present a flaring state SED of MRK421 derived by HAGAR, FERMI-LAT and PCA-RXTE data by

using one zone SSC model. We have also investigated a correlated variability in X-rays and gamma rays in this work. Also, we present preliminary results on Mrk501 in this paper.

## 2 HAGAR

HAGAR, an array of atmospheric Cherenkov telescopes using wave front sampling technique, is located at the Hanle base camp in Ladakh, at an altitude of 4300 meters. The main motivation is behind the setting up the experiment at high altitude is to exploit the higher Cherenkov photon density and thus achieve lower energy threshold. HAGAR experiment uses an array of seven telescopes in the form of hexagon with one telescope at center. Each telescope has seven para-axially mounted front coated mirrors of diameter 0.9 with a UV sensitive photo-tube at the focus of each mirror. Each telescope is separated by 50 meters distance from neighboring telescope. HAGAR Data Acquisition (DAQ) system consists of CAMAC based DAQ system. In addition a parallel DAQ using commercial waveform digitizer (ACQIRIS make) is also used. Direction and energy of gamma rays are estimated by relative time delays and densities of photons at each telescope. The performance of the HAGAR array has been studied by simulations, which are done in two steps; first step is generate of gamma and cosmic rays induced showers in atmosphere by using Monte Carlo simulation package CORSIKA, developed by KASKADE group [5]. Second step is to study

the response of the array towards the Cherenkov radiation in the simulated showers. The performance parameters like energy threshold, collection area and sensitivity of the experiment are obtained by detector simulation package indigenously developed by HAGAR collaboration. Energy threshold of the HAGAR telescope is estimated for  $\geq 4$  Fold trigger condition to be 204 GeV for vertically incident showers initiated by gamma rays and the corresponding collection area is  $3.2 \times 10^8 \text{ cm}^2$ . HAGAR sensitivity is such that Crab nebula could be detected with  $5\sigma$  confidence in 15 hours of exposure time. [10]. Cherenkov wavefront is spherical in shape and it is approximated by a plane front in our analysis procedure, which is a good approximation at observation level. The arrival direction of each shower in Cherenkov light pool is computed by measuring the relative arrival times of shower front at different telescopes. Normal to this plane front gives the arrival direction of the incident shower. The angle between direction of the shower axis and pointing direction of the telescope is defined as Space Angle. These Space Angles are reconstructed for every event by measuring relative arrival time difference at each telescope [11]. The observations were carried out pointing all seven telescopes towards the source or background direction. Each source run is followed by a background run with same exposure time (typically 40 minutes) and covered same zenith angle range as of source observation to observe at same energy thresholds. Data selection is done by using some parameters which characterize good quality data, in order to reduce systematic errors. Extraction of gamma ray signal is done by comparing on-source vs off-source space angle distribution taken during same night. Space angle distribution of background is normalized with source space angle distribution by comparing the tail of the distribution since we do not expect any gamma ray event in this region. The excess of gamma ray events is computed by comparing ON-OFF sources runs of same night of same thresholds. To reduce the systematic errors in our data we have analyzed only events with signals in at least 5 telescope ( $\geq 5$  fold), which correspond to 250 GeV energy threshold.

### 3 Observations

#### 3.1 HAGAR

Observations of Mrk421 in an active state were carried out with HAGAR for three months, during February-April 2010 in moonless nights. The source was observed with a mean zenith angle of  $6^\circ$ . Observation log of Mrk421 of year 2010 is given in table 1. Observations of Mrk501 were also made during March-June, 2010 in moonless nights. The maximum zenith angle for Mrk501 observation during these months was  $25^\circ$ .

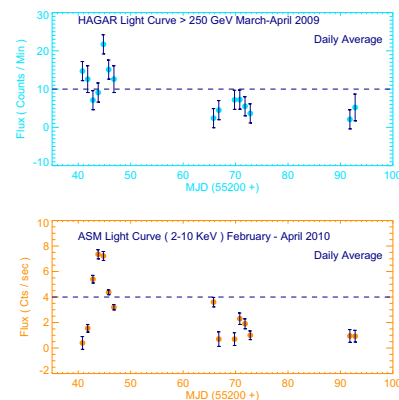


Figure 1: The top panel shows daily average light curve of Mrk421 during the period of February - April 2010 in VHE Gamma ray by HAGAR above 250 GeV and bottom panel shows the same in 2-10 KeV X-rays by ASM. The X-axis should be read as 55200+.

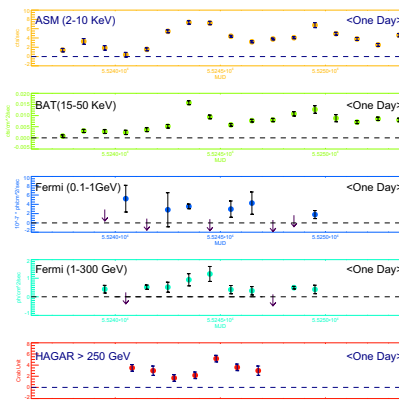


Figure 2: The top four panels are daily average of ASM, BAT, Fermi (100 MeV -1GeV) and Fermi (1-300 GeV) respectively and bottom panel in the plot corresponds to HAGAR data above 250 GeV during the month of February 2010

#### 3.2 Fermi

The Large Area Telescope (LAT) is a pair production telescope [6] on board Fermi spacecraft. LAT covers energy range from 20 MeV to more than 300 GeV with field of view  $\geq 2.5$  sr. Fermi-Lat data<sup>1</sup> from 13-19 February 2010 of the Mrk421 above 100 MeV is analyzed with the standard analysis procedure (ScienceTools provided by Fermi-Lat collaboration). A 10 degree region of interest (ROI) is chosen around the source for event reconstruction from the so-called “diffuse” event class data. To avoid the background of earth albedo we only retained events having a

1. <http://fermi.gsfc.nasa.gov/>

Feb2010	13-19	8
March2010	10-18	8
April2010	05-06	2

Table 1: Observation log of Mrk421 during 2010

Month	Total duration	Excess number of on source events	Mean $\gamma$ ray rate	Significance
Feb	479 Min	6418.22	$13.4 \pm 1.05$	12.7
March	478 Min	2524.23	$5.3 \pm 1.1$	4.8
April	116 Min	414	$3.5 \pm 2.1$	1.7

Table 2: HAGAR Observations of Mrk421 during High State of Activity.

zenith angle  $< 105^\circ$ . To determine the flux, spectrum and location of a source, the resulting data set is analyzed including Galactic and isotropic backgrounds with instrumental response function P6V3 DIFFUSE by using likelihood analysis (unbinned glike). We used a power law spectrum to model the source spectrum above the 100 MeV with integral flux and photon index as free parameters.

### 3.3 PCA,ASM and BAT

Proportional Counters Array (PCA) is an array of five identical filled xenon proportional counter units (PCUs). The PCUs cover energy range from 2-60 KeV with a total collecting area of 6500 cm<sup>2</sup>. The archival X-ray data from PCA on board RXTE is analyzed for 17 February 2010 to obtained X-ray spectrum and light curve. We have analyzed Standard 2 PCA data which has a time resolution of 16s with energy information in 128 channels. Data reduction is done with FTOOLS (version 5.3.1) distributed as part of HEASOFT (version 5.3). Data were filtered using standard procedure given in the RXTE Cook Book 4 for each of the observations. The background models were generated with the tool ‘‘pcabackest’’, based on RXTE GOF calibration files for a ‘bright’ source (more than 40 ct/sec/PCU). The ‘‘Dwell’’ data from RXTE-ASM were obtained using ASM website<sup>2</sup> and these data are analyzed by the method discussed in [7]. A daily average flux between 15-50 KeV from swift BAT is obtained from BAT website<sup>3</sup>.

## 4 Results

### 4.1 Mrk421

We have analyzed data from Mrk421 collected by using HAGAR telescope during February - April,2010. This was found to be in the high sate of activity during the entire period of observations and source was in the brightest sate in the month of February fluxes of gamma rays and X-

rays have decreased in later months but the fluxes was still higher than the quiescent state. Figure 1 contains daily light curve of the X-ray and gamma ray of Mrk421 during the high state of activity. The upper panel of this shows the daily average of gamma ray flux above in Crab units. Bottom panel of the figure shows daily average of 2-10 KeV from ASM on-board RXTE. It’s clearly seen in the HAGAR as well as ASM light curve that source was in brightest state in month of February in both gamma rays and X-rays. All details of the HAGAR results is given in table 2. We have further investigated flaring behavior in the month of February 2010. HAGAR telescope has detected Mrk421 in high state of VHE Gamma ray flux above 250 GeV, during the observations of 13-19 February,2011. One of the brightest flaring episodes of this source was observed by various experiments on 17th February 2010. The maximum flux above 250 GeV is found to be between 6-7 Crab units by HAGAR on February,17. Source was detcted above 250 GeV with 5 sigma confidence in less than 40 minutes of observation by HAGAR.

#### 4.1.1 Variability

A quasi-simultaneous light curve is obtained of Mrk421 in X-rays and gamma rays band by using archived data of soft X-ray by ASM on board RXTE, hard X-ray data from BAT on board Swift and gamma ray data from LAT on board Fermi with observed HAGAR ( $>230$  GeV) data for month of February 2010 with one day binning in figure 2. The top 4 panels correspond to ASM, BAT, Fermi (100 MeV -1GeV) and Fermi (1-300 GeV) respectively. The bottom panel in the plot corresponds to HAGAR data above 250 GeV. We see a clear variation in flux over a period of seven days in X-ray as well as gamma rays. Source had shown a peak flux in X-rays and low energy gamma rays by ASM,BAT and Fermi on 16 February,2010 but GeV/TeV gamma ray flux reached peak with a lag of one day on 17 February,2011, shown by Fermi and HAGAR.

#### 4.1.2 Intra-Day vaiability

Source has also shown a intra-day flux as well as spectral variation in 17 February. HAGAR detected change in flux with in three hours of time figure 3 contains HAGAR and LAT fluxes during the 2010, February 17. Source had shown a flaring behaviour in first 10 hours of LAT observations and then become quiescent for next few hours and start flaring up again later. A similar trend is also seen by VERITAS collaboration [12]. The later part of the night HAGAR also observed Mrk421 and detected a continious decrease in the flux over a period of  $\sim 4$ hrs. LAT observations also shows a similar trend in their observations, which are simultaneous with HAGAR. Intra night flux variations

2. <http://xte.mit.edu/>

3. <http://heasarc.nasa.gov/docs/swift/results/transients/>

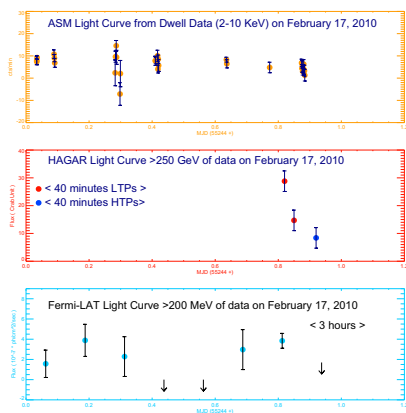


Figure 3: Intranight Light curve of Mrk421 on 17 February, 2010. Top panel ASM 2-10 KeV “Dwell” data, middle panel is HAGAR light curve above 250 GeV. The bottom panel presents light curve of LAT above 200 MeV for 17 February. The X-axis should be read as 55244+.

by HAGAR and spectral index (photon index) and flux variation in Fermi-LAT data during this flare on 17 February were seen. Spectral variation were detected by LAT during this active state. The hardest photon index of 1.39 obtained by the Fermi-LAT ( $> 100\text{ MeV}$ ) correspond to data of 17 February, 2010.

#### 4.1.3 SED

We attempted to obtain a flaring state SED of Mrk421 during the flare of 17 February 2011 by using soft X-ray data from PCA on board RXTE, gamma ray data from LAT on board Fermi and HAGAR data. Spectral analysis of X-ray data was done by using xspec, PCA spectral data of 17 February was fitted with a cutoff powerlaw with line of sight absorption. the line of sight absorption was fixed to neutral hydrogen column density at  $1.38 \times 10^{22}\text{ cm}^{-2}$  [8]. The Fermi-LAT data is divided in four bins (0.1-1 GeV, 1-3 GeV, 3-10 GeV and 10-300 GeV) to obtain spectrum of Mrk421 on 17 February by freezing photon index to 1.39 which is obtained by taking 100 MeV-300 GeV data. We have observed Mrk421 with HAGAR on 17 February and detected a giant flare. The maximum flux had reached 6-7 Crab units with a average flux of 5 Crab units. We have taken integral flux above 250 GeV to fit SED. A one zone homogeneous SSC model [9] is fitted to the data to obtain the SED. This model assumes a spherical blob of radius  $R$  and uniform magnetic field  $B$ , moving with respect to the observer with the Lorentz Factor  $\Gamma$  and is filled with a homogeneous non-thermal electron population. We used equipartition of the field to compute the best fit parameters. A best fit of SED is obtained for the parameters given below:

Bulk Lorentz factor of emitting blob ( $\Gamma$ ) : 20

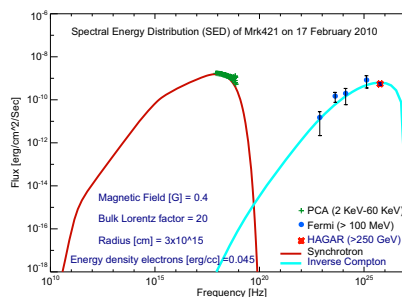


Figure 4: Spectral Energy Distribution of Mrk421 of 17 February, 2010.

Month	Total duration	Excess number of on source events	Mean $\gamma$ ray rate	Significance
March-June	499 Min	2691.65	$5.4 \pm 1.1$	4.85

Table 3: Data table at a single column.

Strength of tangled magnetic field in the jet frame ( $B$ ) : 0.4 Gauss

Radius of emission volume :  $3 \times 10^{15}\text{ cm}$

Jet-frame energy density of the electrons ( $U$ ) : 0.045 erg/cc

#### 4.2 Mrk501 and other Blazars

HAGAR detected TeV blazar Mrk501 in relatively high state of activity during March-June 2010. The average flux of the source during this period of time was detected 1.1 Crab units with 4.9 sigma. Details of the observations are given in table 3. Data analysis is going on for other TeV blazars.

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