Multiwavelength study of TeV Blazar Mrk421 during giant flare and observations of TeV AGNs with HAGAR.

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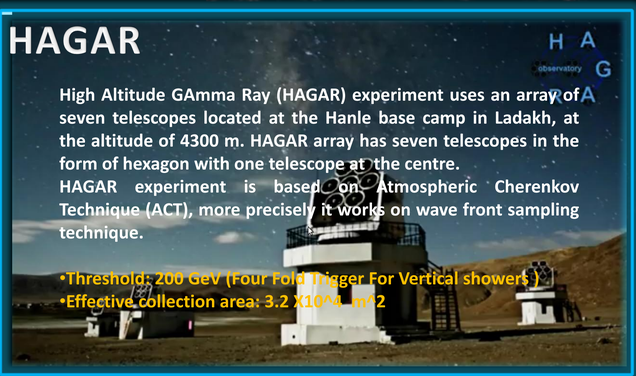
Instruments

HAGAR

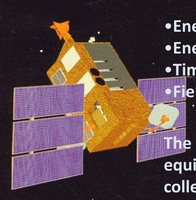
High Altitude GAmma Ray (HAGAR) experiment uses an array of seven telescopes located at the Hanle base camp in Ladakh, at the altitude of 4300 m. HAGAR array has seven telescopes in the form of hexagon with one telescope at the centre.
HAGAR experiment is based on Atmospheric Cherenkov Technique (ACT), more precisely it works on wave front sampling technique.



- Threshold: 200 GeV (Four Fold Trigger For Vertical showers)
- Effective collection area: 3.2 X10^4 m^2

RXTE

The PCA is an array of five proportional counters with a total collecting area of 6500 square cm.



- Energy range : 2 - 60 keV
- Energy resolution : < 18% at 6 keV
- Time resolution : 1 microsec
- Field of View : 1 degree FWHM

The ASM consists of three wide-angle shadow cameras equipped with proportional counters with a total collecting area of 90 cm^2

- Energy range : 2 - 10 keV
- Spatial resolution : 3' x 15'
- Field of View : 3 shadow cameras each with 6 X 90 degrees FOV
- Detector: Xenon proportional counter, position-sensitive
- scans 80% of the sky every 90 minutes.

SWIFT

Swift (BAT) : The Burst Alert Telescope (BAT) is a highly sensitive, large FOV instrument .

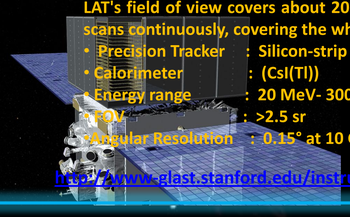
- Aperture : Coded mask
- Detecting Area : 5200 cm^2
- Detector : CdZnTe
- Detector Operation : Photon counting
- Energy Range : 15-150 ke

- Field of View :1.4 sr (partially-coded)
- Detector Size : 1.2 x 0.6 m (32,768 pieces of 4 x 4 x 2 mm CdZnTe)

http://swift.gsfc.nasa.gov/docs/swift/about_swift/bat_desc.html

FERMI-LAT

The LAT is an imaging high-energy gamma-ray telescope covering the energy range from about 20 MeV to more than 300 GeV. The LAT's field of view covers about 20% of the sky at any time, and it scans continuously, covering the whole sky every three hours.



- Precision Tracker : Silicon-strip detectors (direction)
- Calorimeter : (CsI(Tl)) (energy)
- Energy range : 20 MeV- 300 GeV
- FOV : >2.5 sr
- Angular Resolution : 0.15° at 10 GeV

http://www.glast.stanford.edu/instrument.html

Observations & Data Analysis

Source is observed in high state of activity during the 13 -19 February observation period by HAGAR, FERMI, SWIFT & RXTE .

- HAGAR: Direction and energy of gamma rays are estimated by relative time delays and densities of photons at the each telescope [1,2].
- ASM: ASM light curve is obtained by the method discussed in [3].
- PCA: Data reduction and analysis is done by FTOOLS & XSPEC packages distributed as a part of HEASOFT.
- BAT: Standard light curves are downloaded from http://heasarc.nasa.gov/docs/swift/results/transients/
- Fermi: Likelihood analysis (unbinned gtlike) is used to determine the flux, spectrum and location of a source.

References

[1]Amit Shukla; et al. Poster in ASI 2011 on Blazar observation with HAGAR,2011.
[2]Bose et al. 2007 PhD thesis TIFR, Mumbai
[3]Chitnis, V.R. et.al; 2009 Apj.698.1207C.
[4] Krawczynski, H., Hughes, S. B., Horan, D., et al., 2004, ApJ, 601, 151

Abstract

The radiation mechanism of very high energy gamma ray emission from blazars and crucial parameters like magnetic field, size of the emitting region are not well understood yet. To understand the above mentioned properties of blazars, we observed five nearby TeV gamma ray emitting blazars (Mrk421,Mrk501,1ES2344+514,1ES1218+304 and 3C454.3) and one radio galaxy (M87) using the High Altitude GAmma Ray (HAGAR) telescope. HAGAR is an array of seven telescopes located at Hanle, India to detect Cherenkov light caused by extensive air showers initiated by gamma rays. Mrk421 was observed to undergo one of its brightest flaring episodes on 2010 February 17, and detected by various experiments in X-rays and gamma rays. HAGAR observations of this source during 2010 February 13 - 19, in the energies above 250 GeV show an enhancement in the flux level, with a flux of 6 Crab units being detected on 2010 February 17. We present the spectral energy distribution of the source during this flaring episode and investigate the correlation of the variability in X-ray and gamma ray bands. In addition to this, analysis procedure to extract gamma ray signal from HAGAR data will be discussed and preliminary results on all the AGNs will be presented.

Scientific motivation for AGN Studies in VHE gamma rays

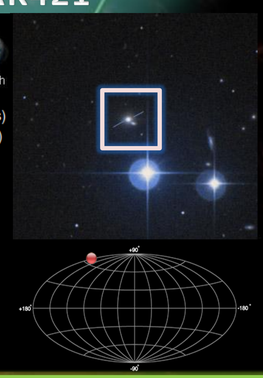
- Emission mechanisms (especially for high energy component)
  - Leptonic (IC of synchrotron or external photons)
  - Hadronic (proton synchrotron, $p+\gamma \rightarrow \pi^0 \rightarrow 2\gamma$)
- Location of Emission Blob
- Particle acceleration mechanisms
  - Shocks, Blandford-Znajek
- Jet composition
  - Poynting flux, leptonic, ions
- Jet confinement
  - External pressure, magnetic stresses

- Extragalactic Background Light (EBL)
- Origin of Cosmic Rays
- New Physics

➢ Lorentz Invariance

MRK421

Source Type:	HBL
R.A.:	11 04 27.3 (hh mm ss)
Dec.:	+38 12 32 (dd mm ss)
Gal Long:	179.83 (deg)
Gal Lat:	65.03 (deg)
Distance:	z=0.031
Flux:	0.3 (Crab Units)
Energy Threshold:	500 GeV
Spectral Index:	2.2
Extended:	No
Discovery Date:	1992-08
Discovered By:	Whipple



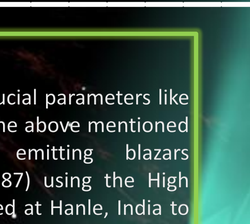
Results

We obtained a quasi-simultaneous light curve of Mrk421 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 (>250 GeV) data for month of February 2010 with one day binning in X-ray and gamma ray bands.
Correlated variability in x-rays and gamma rays is also investigated by using several instruments. We found *Correlation Coefficient* 0.87 with 1 day lag in Hard X-rays band and VHE gamma rays by using BAT data and HAGAR data .

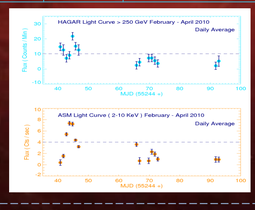
HAGAR Observations During High State of Activity

Total duration	550 Minutes
Excess number of on source events	6684
Mean gamma ray rate	~ 12 +/- 1 /Minute
Significance (Sigma)	~ 12

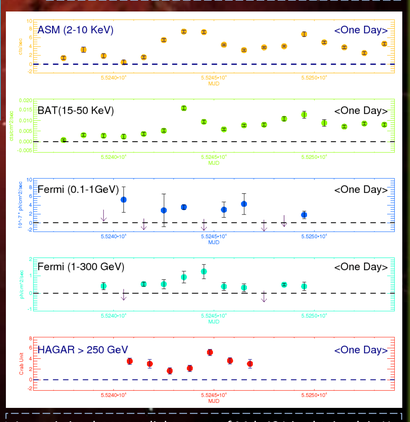
Instruments	Lag (Days)	Correlation coefficient
ASM vs BAT	0	0.8
ASM vs FERMI	0	0.81
ASM vs HAGAR	1 , 2	0.61 , 0.64
BAT vs FERMI	0,1	0.67 , 0.56
BAT vs HAGAR	1	0.87
HAGAR vs FERMI	-1,0	0.5,0.4



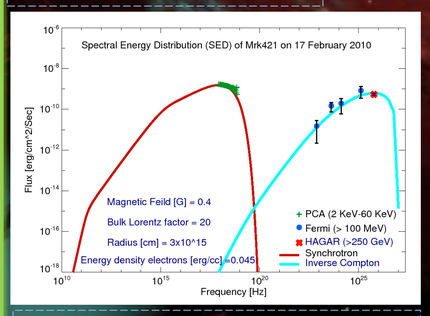
Above plot shows Light Curve of source on 17 February 2010. Intra night variability is detected by HAGAR as well as Fermi(LAT).
- HAGAR: 30 minutes Scale
- Fermi:3Hours Scale



Above Figure contains daily light curve of mrk421 during the high state of the X-ray and gamma ray from February to April 2010. The top panel has HAGAR data points (>250 GeV) and ASM data points are plotted ig bottom panel. It's clearly seen in the HAGAR as well as ASM light curve that source was in brightest state in the month of February in both Gamma rays and X-rays. Activity of the source has reduced in the months of March and April but it was still brighter than it's quiescent level flux.



A quasi-simultaneous light curve of Mrk 421 is obtained in X-ray and gamma ray bands 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 as well as observed HAGAR (>250 GeV) data for month of February 2010 with one day binning (daily average) in the above figure. The top 4 panels correspond to ASM, BAT, Fermi (100 MeV -1 GeV) and Fermi (1-300 Gev) respectively. The bottom panel in the plot corresponds to HAGAR data.



One zone homogeneous SSC model (Krawczynski et al. 2004) is fitted to the X-ray & gamma 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 delta which is filled with a homogeneous non-thermal electron population. Best fit SED is obtained for the parameters given above.

Discussion & Conclusions

HAGAR telescope has detected a VHE gamma ray flare from Mrk421 on 17 February 2010, above 200 GeV with 5 sigma confidence in less than 40 minutes of observation. Intra night flux variations were seen by HAGAR and Fermi-LAT during this flare. The maximum flux above 250 GeV is found to be between 6-7 Crab unites by HAGAR.
Correlation between Hard X-rays and VHE Gamma rays suggest that electrons are accelerated to higher energies and these electrons are responsible for producing VHE gamma rays via Inverse Compton by interacting with hard X-ray photons.
The X-ray data from RXTE (PCA) and Gamma ray data from Fermi-LAT and HAGAR corresponding to the February 17,2010 flare of Mrk421 is successfully modeled with one zone Synchrotron Self Compton (SSC) (Krawczynski et al. 2004). A hint of correlated variability at X-rays and gamma rays is seen, which strengthens the belief that gamma rays are produced via SSC in Mrk421.
HAGAR has also detected Mrk421 during March – May 2009 above 250 GeV with average flux of 1.5 Crab unit and Mrk501 during March – June 2010 at 250 GeV with average flux of 1 Crab unit .

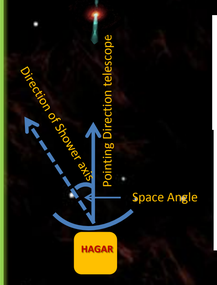
Observations

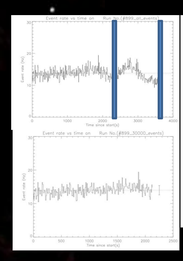
A typical on/off source observation run span is around 40 minutes. Background runs were taken either immediately before or after (sometimes both before and after) the source run by aligning all telescopes to a dark region (a region with the same declination as that of the source but with different RA). Background region is chosen in such a way that it covers same zenith angle range as that of the source. The observation log is given in table below:

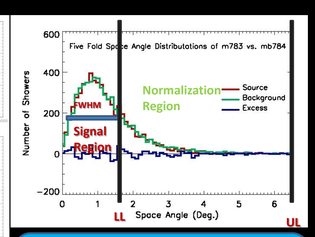
Object	Type	On (Hrs)	Off (Hrs)
Mrk421	HBL	86	101
Mrk501	HBL	49	53
3C 454.3	HBL	15	15
1ES1218+304	HBL	10	12
M87	RG	2	2
1ES2344+514	HBL	80	93

Analysis Method

Most of the Cherenkov emission of the air shower originates from shower maximum region which is at height of about 5 km from Hanle and follows a spherical wavefront with a large radius of curvature and thickness of around 1 meter at observation level. This wavefront can be approximated by a plane front at the observation level.
The arrival direction of each shower in Cherenkov light pool could be computed by measuring the relative arrival times of shower front at different telescopes by using TDC module. **A plane front is fitted to the shower, which is a good approximation at observation level. 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 called Space angle. Space angle between this arrival direction and the pointing direction of the telescope axis is constructed for every event.







Rate Plots of a data file

No. of γ-rays $= \sum_{i=0}^{LL^{\circ}} (S_i - CB_i)$

Results

Object	Observation Period	Exposure time (hr)	Mean Gamma Ray Rate (per min)	Error	significance
Mrk421	March – May 2009	12	7.3	1.6	7.9
Mrk421	March –April 2010	11.2	4.3	0.85	5.1
Mrk501	June 09	2.8	-5.2	2.0	U.L.
Mrk501	March-June10	10.5	4.3	1.6	4.85
1es2344+514	Sep –Dec.08	4.4	-6.6	1.6	U.L.
Crab	Sept-Dec 2008	12.2	7.1	0.8	9.8

MACE Telescope

➢HiGRO (Himalayan Gamma-Ray Observatory) collaboration also setting up a 21 meter diameter MACE (Major Atmospheric Cerenkov Experiment) Cerenkov imaging telescope at HANLE.