Ground Based Gamma Ray Astronomy with Cherenkov Telescopes

HAGAR Team

DHEP Annual Meeting, 7-8 April, 2016

Projects :

HAGAR Telescope System

Development of G-APD based imaging camera

Calibration device for LST of CTA and software development

Multi-waveband studies of TeV objects and simulations

Presentations :

HAGAR Telescope System - V. Chitnis

Multi-waveband studies of TeV objects and simulations : V. Chitnis

Development of G-APD based imaging camera

- **Introduction : V. Chitnis**
- **Characterisation of G-APDs : B. B. Singh**
- **Electronics details : S. Upadhya**

CTA :

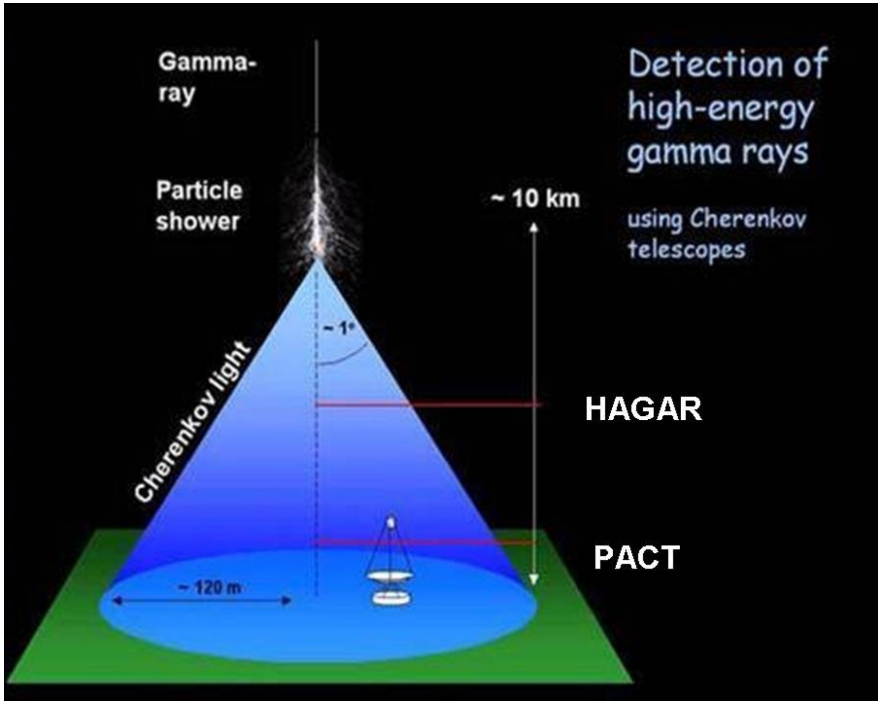
- **Calibration device for LST of CTA : B. B. Singh**
- **Software Development : K. S. Gothe**

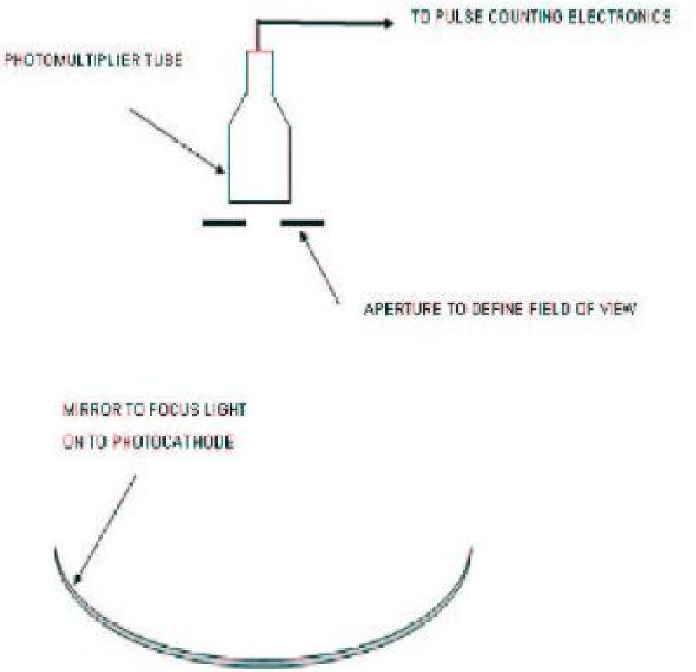
HAGAR Telescope System : Status and Recent Results

Atmospheric Cherenkov Technique

Indirect detection of VHE γ-rays from astronomical sources

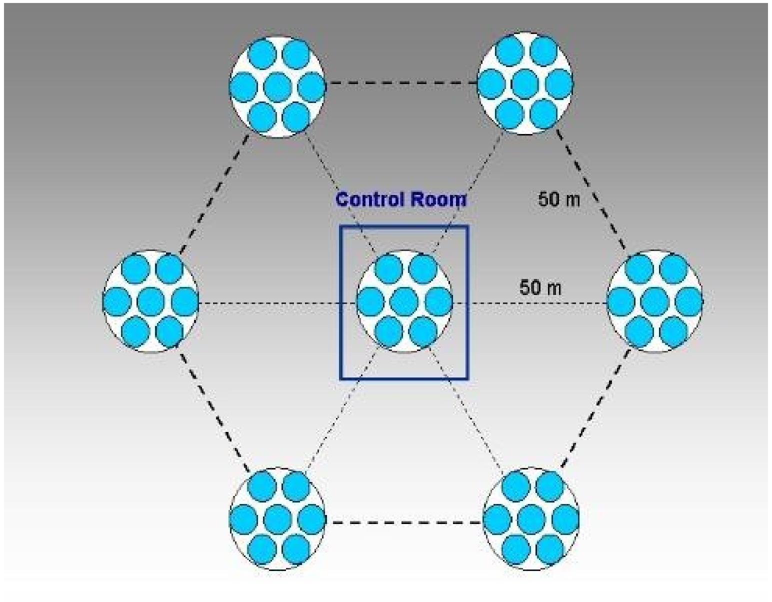
Energy range : few 10's GeV to ~ 100 TeV





Higher altitude location for lowering energy threshold

High Altitude GAmma Ray (HAGAR) Telescope



- Located at Hanle in Himalayas at an altitude of 4300 m
- Array of 7 atmospheric Cherenkov Telescopes based on wavefront sampling technique
- Each telescope consists of 7 para-axially Mounted parabolic mirrors of dia. 0.9 m
- Photonis UV sensitive phototube (XP2268B) At focus of each mirror.

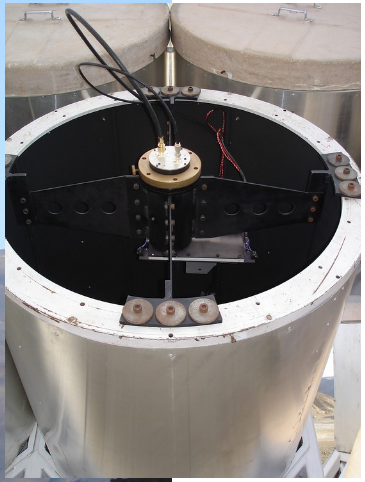
- Tracking system : Alt-azimuth design *(Gothe et al., Exp. Astr.,35, 489, 2013)*
- High voltages to PMTs given through CAEN controller
- Data Acquisition system : CAMAC based, interrupt driven

Data recorded on coincidence of at least 4 telescope pulses

Data : absolute arrival time of shower front (μs)
Cherenkov photon density (pulse height) at each telescope
Relative arrival time of shower front at each mirror (0.25 ns)

Parallel Daq consisting of Acqiris waveform digitizer with sampling rate of 1 GS/s to record telescope pulses

HAGAR Telescope Array



Installation during 2005-2008

Performance Parameters :

Energy threshold ~ 210 GeV

Cosmic ray trigger rate ~ 13 Hz

γ-ray rate from Crab nebula
= 6.3 /min

(L. Saha et al., Astroparticle Physics, 42,33,2013)

Modules Developed In-House

CAMAC controller

16 ch. CAMAC Latch

16 ch. CAMAC Scaler

CAMAC Real Time Clock

NIM to ECL Converter

ECL Delay Generator

Programmable Delay Generator

HAGAR Trigger Logic

Programmable Discriminator

VME RTC

HAGAR Observation Summary

- **Regular observational runs commenced in September, 2008**

Galactic sources

	ON (Hours)	OFF (Hours)
Crab	319.1	254.3
Geminga	200.0	107.9
Fermi pulsars	322.7	99.7
LSI+61 303	72.1	87.0
MGRO J2019+37	30.2	29.5

Extragalactic sources

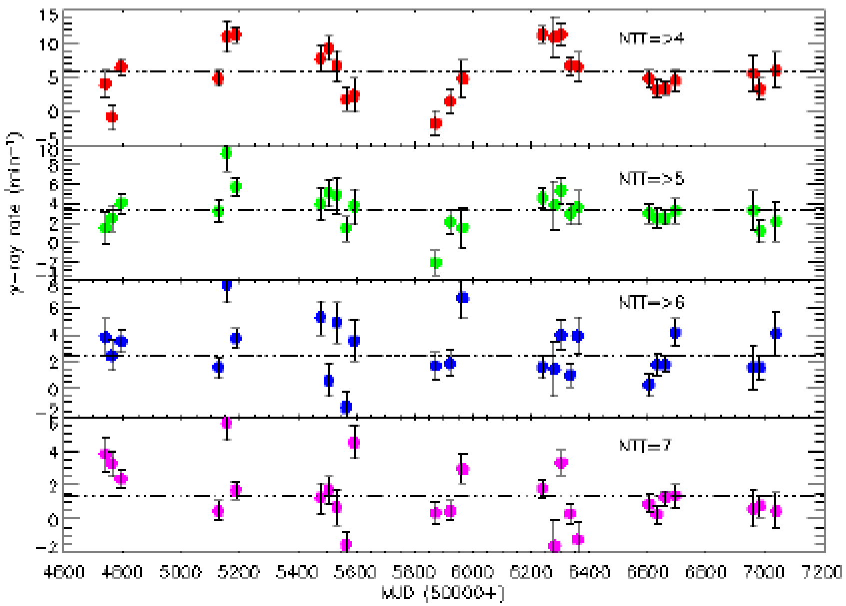
	ON (Hours)	OFF (Hours)
Mrk 421	262.8	314.4
Mrk 501	184.6	196.3
1ES2344+514	144.8	167.0
BL Lac	97.2	101.2
1ES1218+304	82.4	92.8
1ES1011+496	31.9	29.3
H1426+428	28.7	29.3
3C454.2	16.1	16.3
1ES1959+650	7.9	9.5

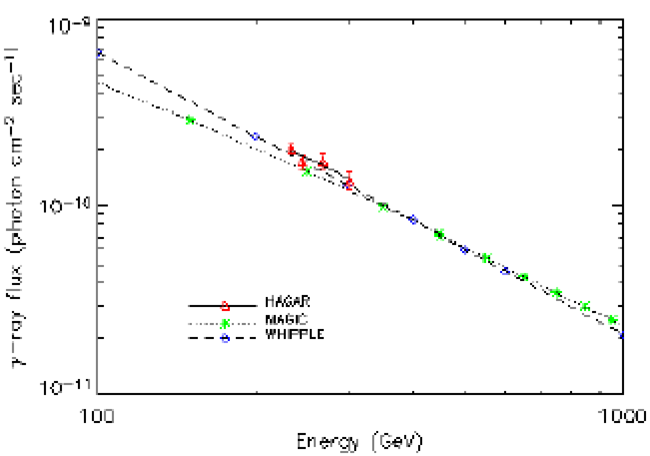
Calibration runs : 593 Hours

Total observation duration (during September, 2008 – March, 2015) :
3940 Hours

HAGAR Results : Crab Nebula

- **Steady source, used as standard candle**
- **Observation duration after applying data quality cuts for data collected in 2008-2014 = 103 hours**





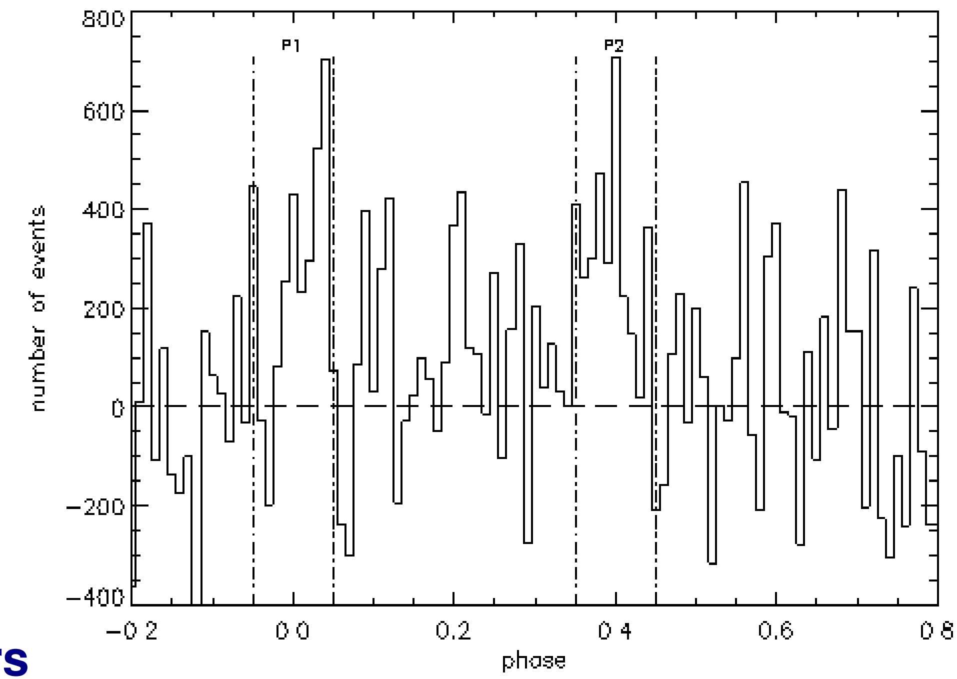
- **Using arrival time information shower axis direction reconstructed, space angle calculated and gamma ray rate estimated comparing ON-OFF run space angle distributions**

#triggering telescopes	γ-ray rate (per minute)	Significance σ
≥4	5.85±0.33	17.6
≥5	3.34±0.277	12.4
≥6	2.42±0.21	11.5
=7	1.37±0.15	9.3

Crab flux = $(2.01\pm0.11)\times10^{-10}$ ph/cm^2/s for threshold of 234 GeV

B. B. Singh et al. in preparation

Crab pulsar : Results



Data stretch : 260 hours

Pulsation period : 33 ms

P1 : 0.95-0.05
P2 : 0.35-0.45 } N_{on}
Bridge : 0.05-0.35
Background : 0.45-0.95 → N_{off}

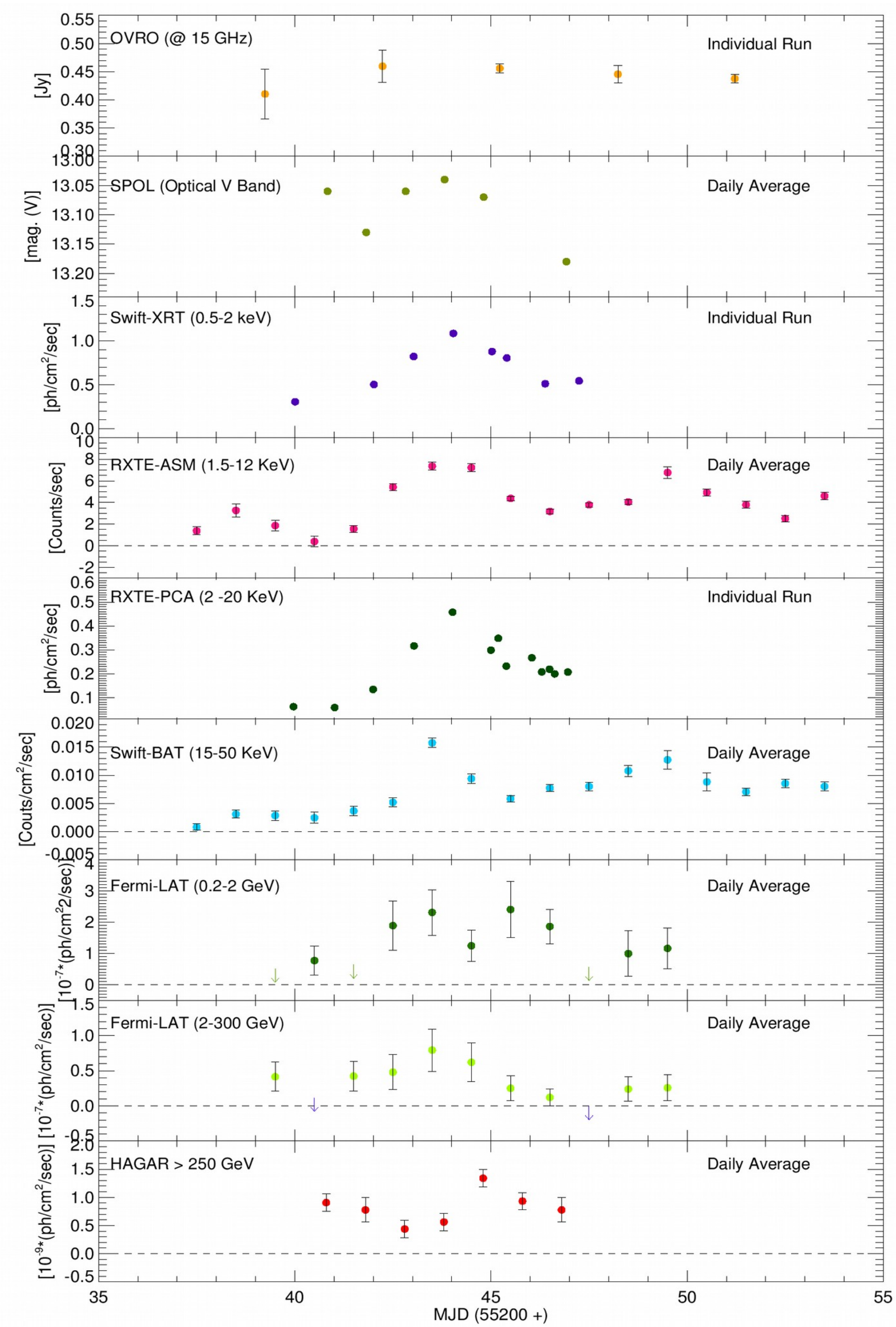
$$\sigma = \frac{N_{on} - R * N_{off}}{\sqrt{N_{on} + R^2 * N_{off}}}$$

Pulsed γ-ray rate :
0.54±0.09 counts /min (6σ)

Pulsed flux :
$(2.81\pm0.46) \times 10^{-11}$ ph/cm^2/s
(< 10% of unpulsed flux)

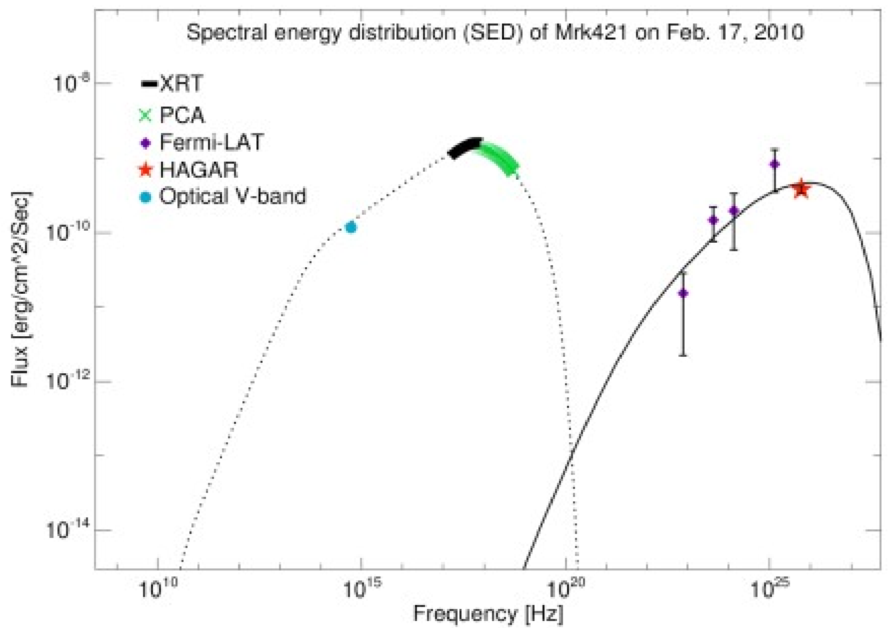
B. B. Singh et al., in preparation

Observations of Mkn 421 during February 2010 Flare



Maximum flux seen by HAGAR :
6-7 crab units on 17 February 2010

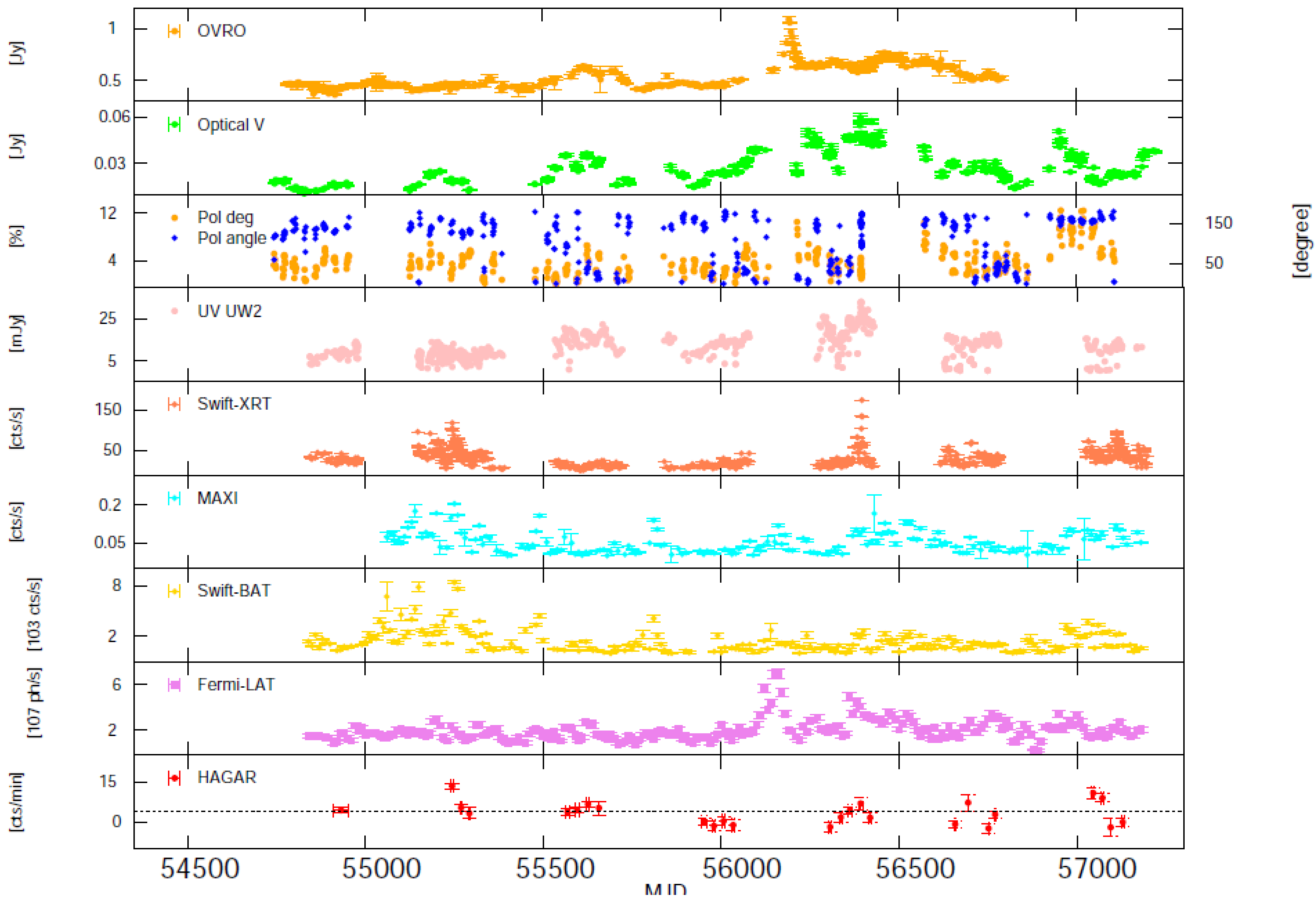
Average flux during February 2010 :
3 crab units (13.4 ± 1.05 counts/min
12.7σ significance)



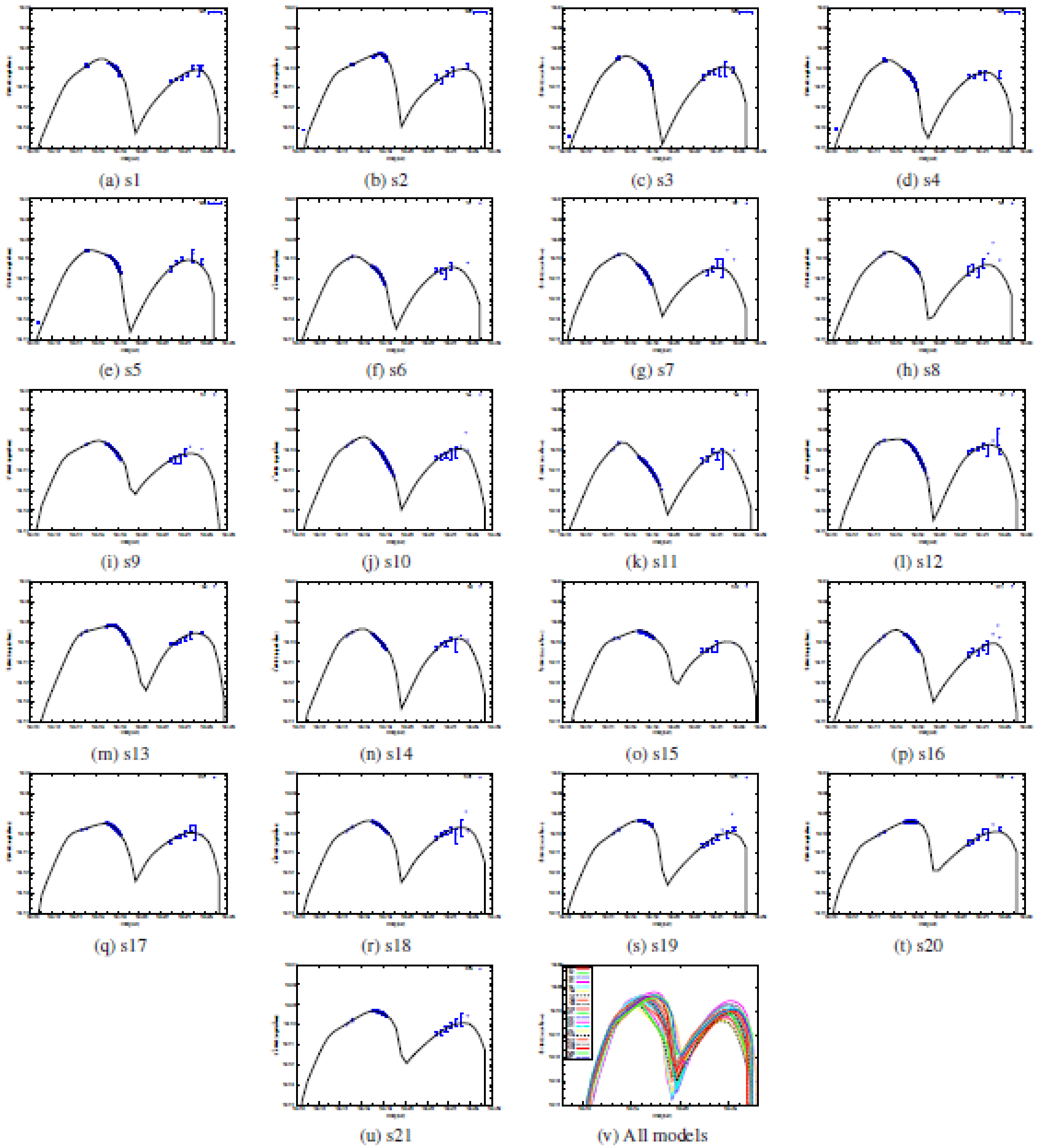
SEDs fitted with Synchrotron Self-Compton (SSC) model

A. Shukla et al., A&A, 541, A140, 2012

Long Term Study of Mkn 421 : Multiwaveband Picture

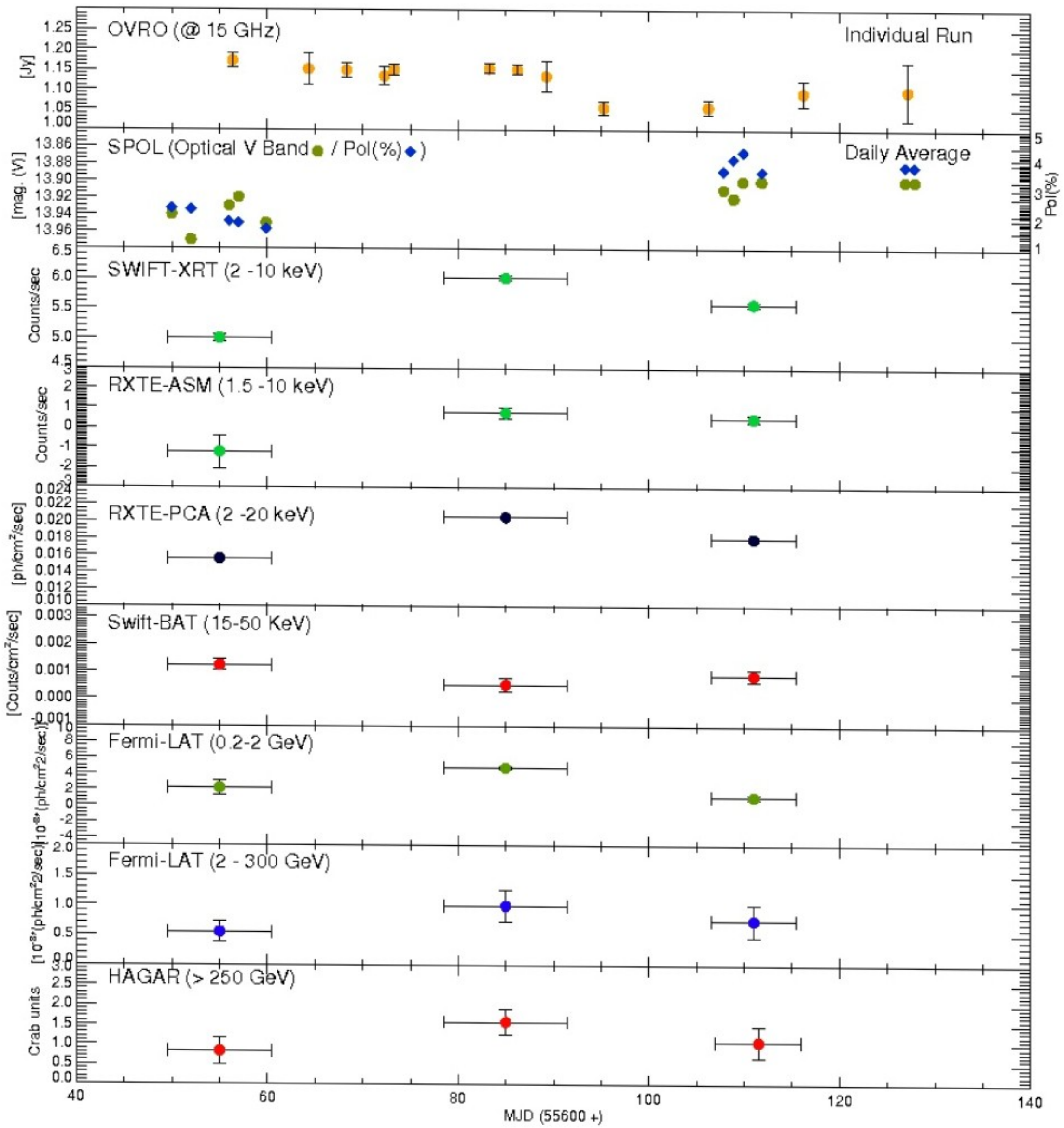


Multiwaveband SEDs of Mkn 421

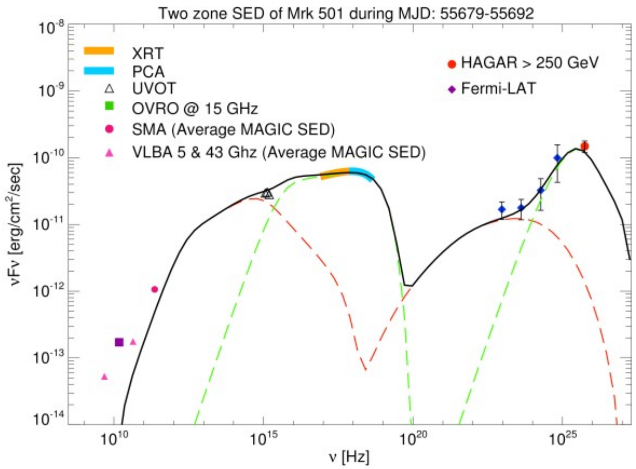


A.Sinha et al., to appear in A&A, 2016

Observations of Mkn 501 : March - June 2011



Detection at 5σ level in March-April 2011

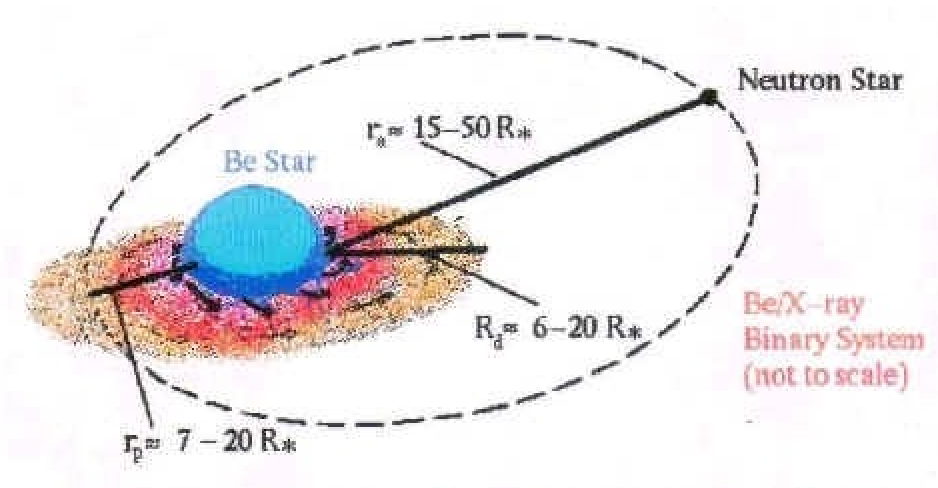


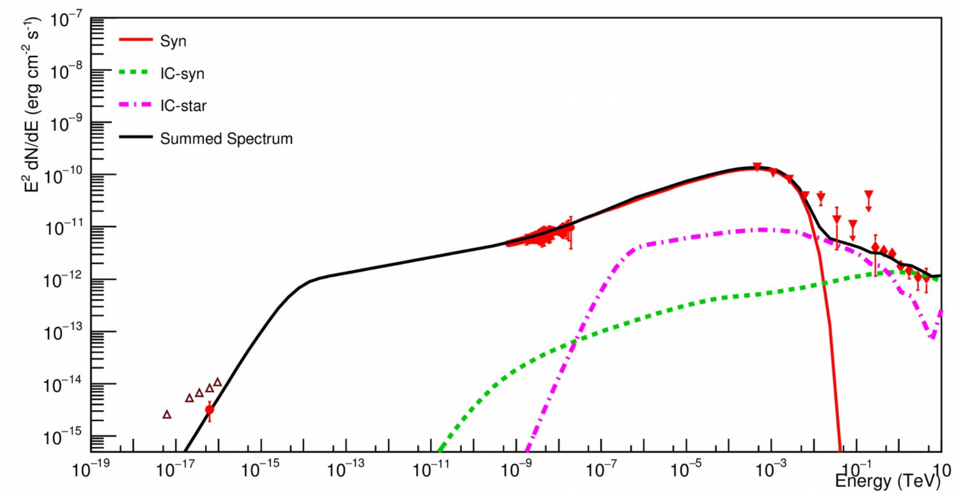
SEDs fitted with two zone SSC model

A. Shukla et al., ApJ, 798, 2, 2015

Multiwaveband studies of TeV objects and simulations

Multiwaveband Studies of TeV Binary LSI+61 303





SED fitted with one zone microquasar jet model

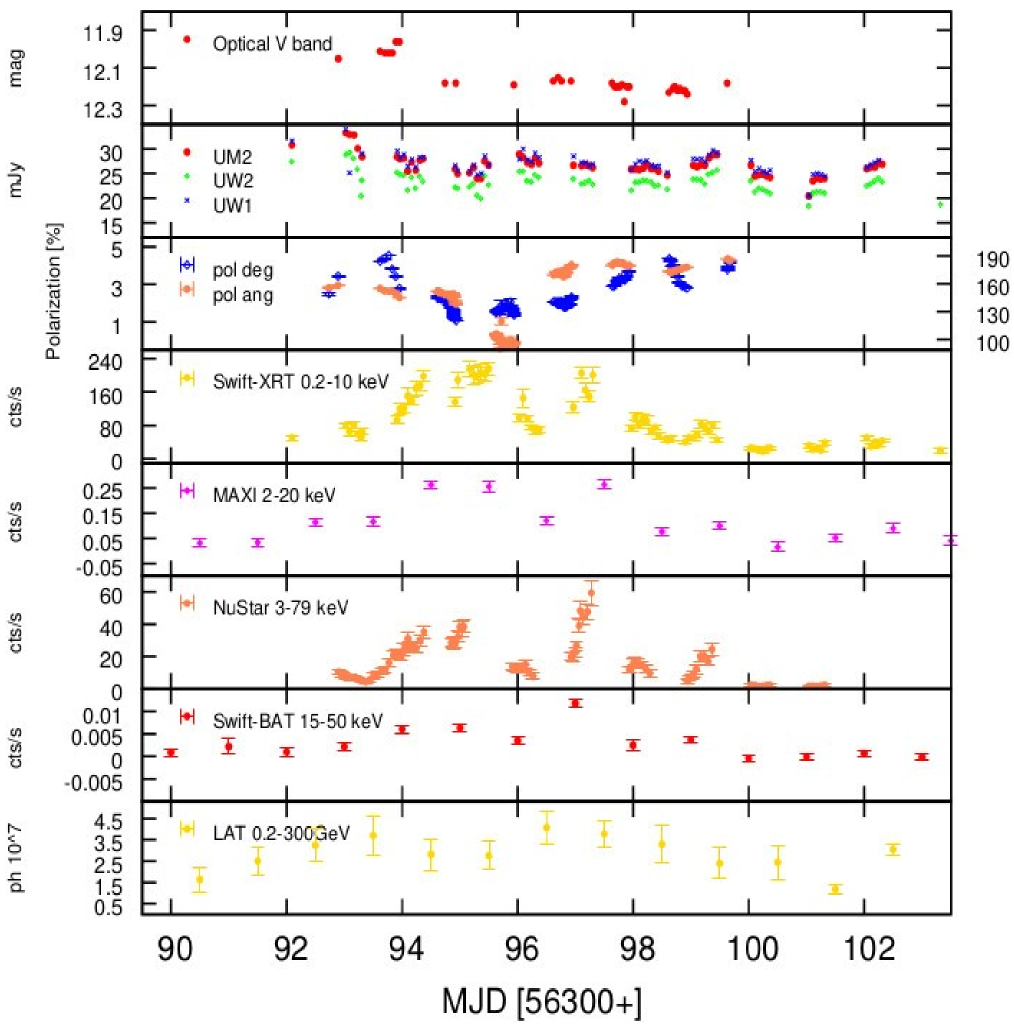
Be star + compact object
Orbital period : 26.496 days
Superorbital period : 1626 days

Study of superorbital modulation as a function of orbital phase in various wavebands

Components :
- Synchrotron
- Inverse Compton of Synchrotron
- Comptoniztion of external photons from companion star

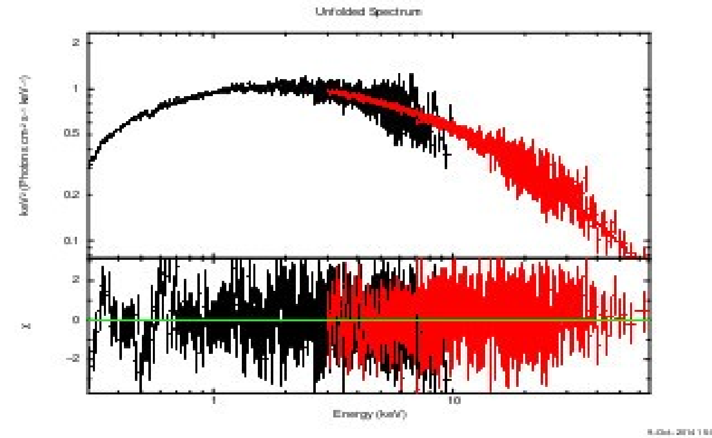
L. Saha et al. to appear in ApJ, 2016

Underlying Particle Distribution during X-ray Flare of Mkn 421



Doubling time scale in X-ray:
1.69+/-0.13 hours

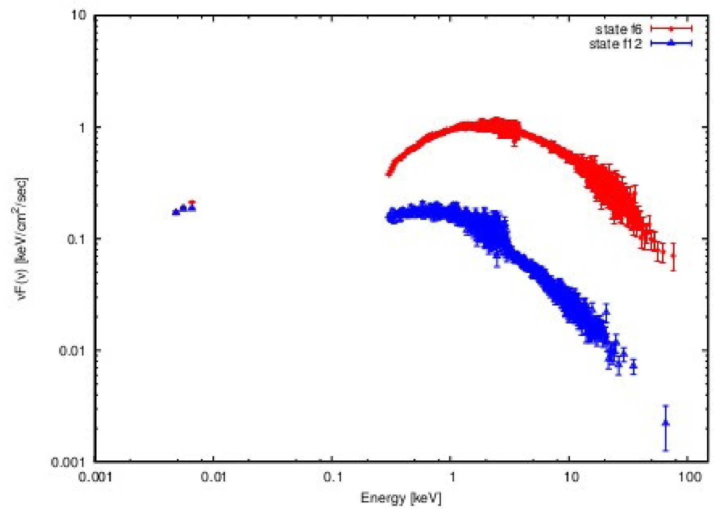
A.Sinha et al., A&A, 580, A100, 2015



(c) log parabola, LP

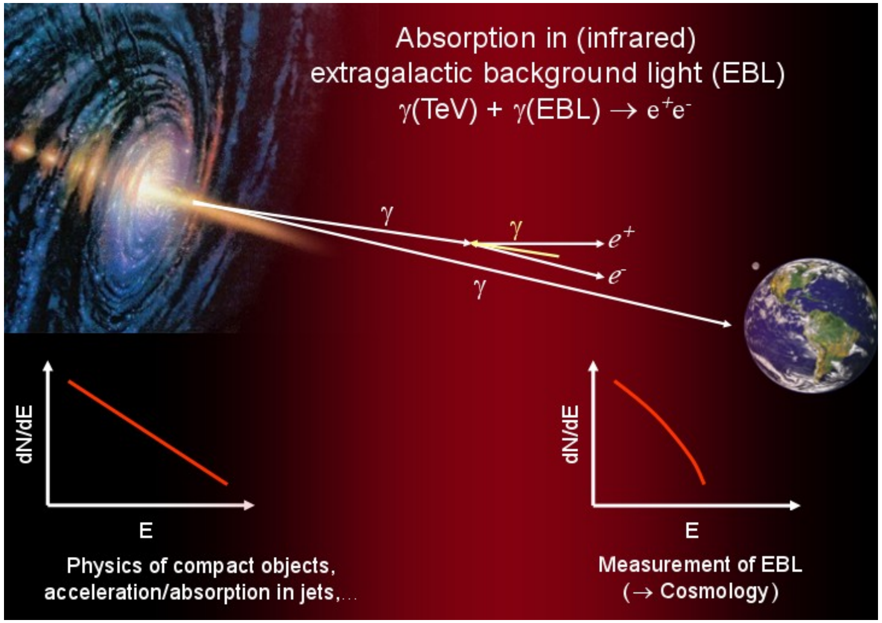
Synchrotron emission from logparabolic spectral distribution of electrons

Sinha et. al.: Study of Mkn 421 during huge X-ray flare in April 2013



X-ray flares plausibly caused by separate population

Estimation of Extragalactic Background Light using TeV Observations of Blazars



EBL causes redshift dependent attenuation and distortion of TeV spectrum

Correlation between spectral indices of TeV spectra with redishift -> estimate of EBL

A. Sinha et al., ApJ, 795, 91, 2014

Lateral density and arrival time distributions of Cherenkov photons in extensive air showers: A simulation study

Effect of various hadronic model components on Cherenkov photon density and arrival time distributions with core distance for various species

P. Hazarika et al., Astroparticle Physics, 68, 16, 2015

Development of G-APD based imaging camera

Imaging camera for small telescopes

Installation at Hanle

- 21m MACE is being installed at Hanle
- MACE will be mostly operated in discovery mode
- Need for smaller telescope for continuous monitoring Of known Blazars
- Imaging camera on 4m telescope (vertex element of TACTIC at Mt. Abu) will serve the purpose

Contribution to CTA camera

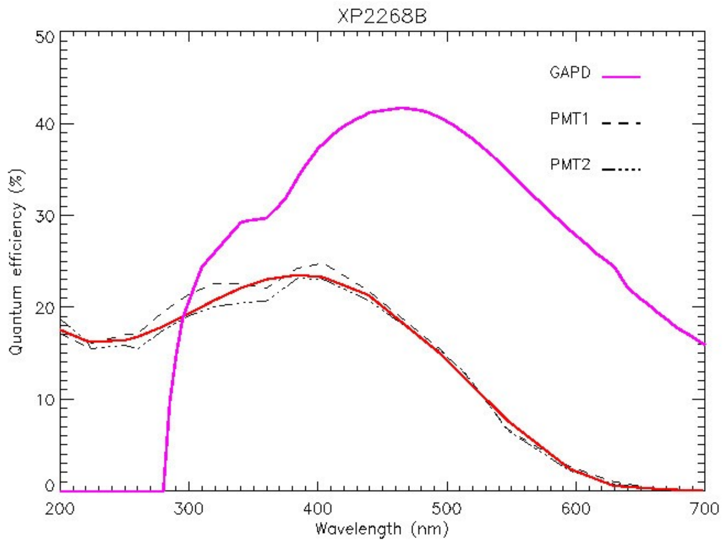
Imaging camera for small telescopes

Choice of photo-sensors

PMTs

high gain
fast response
low quantum efficiency

bulky
fragile
heavy
high bias voltage (~KV)
operation only during
dark night
magnetic sensitivity



G-PADs

high gain
fast response
high photon detection efficiency
well resolved photoelectron spectrum
compactness
ruggedness
low weight
low bias voltages (~70 V)
operation possible even
during moonlight and twilight
magnetic insensitivity
cross-talk
Saturation
Higher dark current
temperature dependence of gain

Design Parameters for Camera

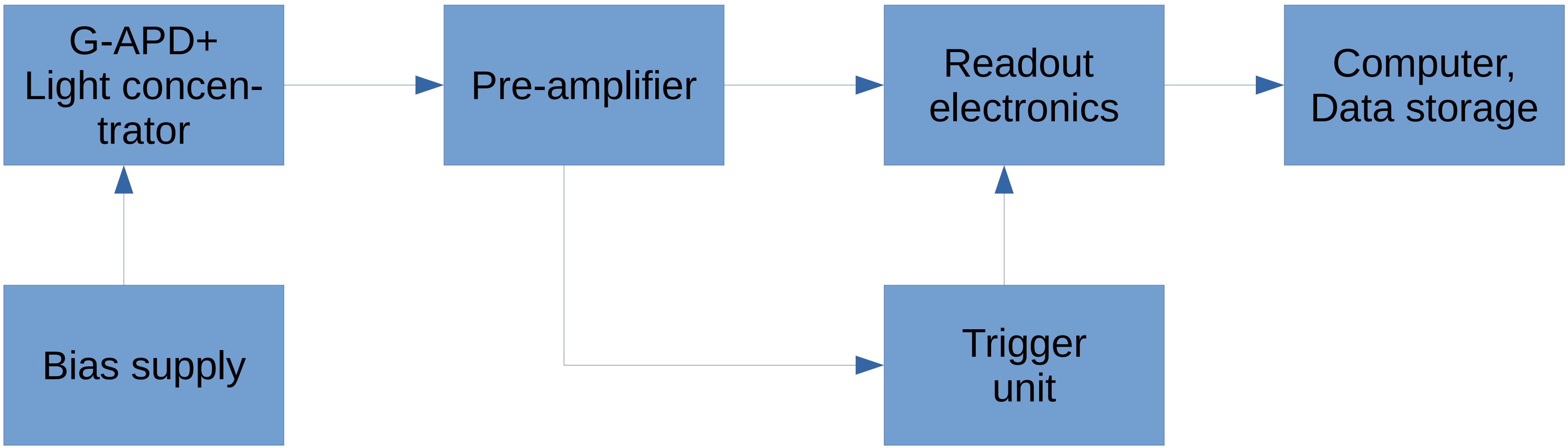
FOV : 4.8 deg X 4.8 deg
Physical size : 32 cm X 32 cm
Pixel size : 0.3 deg (21 mm)
no. of pixels : 256
Light concentrators : hollow

Photo-sensor : 16 channel (4x4) Array of MPPC from Hamamatsu S13361-3050AS-04
With size 12 mm X 12 mm

Design criteria for electronics :

Dynamic range : 0 to 2000 p.e./pixel
Resolution : 0.5 p.e. (for less than 10 p.e.)
Timing resolution : 1 ns
Double hit resolution : 10 ns
Operation to be carried on dark nights (background rate 90 MHz/pixel) as well as under twilight/moon (background rate upto 10 GHz/pixel)
Event rate : few 100's of Hz

Block diagram



Trigger criteria :

N photo-electrons in M neighbouring pixels

(Details in poster on G-APD performance parameters)

Data recording :

Sample mode : recording of pulse shape

Charge mode : recording of total charge in pulse

Other subsytems :

Calibration, temperature and humidity monitoring etc

Features of camera :

1. Entire electronics at the back of the camera
2. Thermal isolation of sensor and electronics compartments
3. Water cooling of electronics crates
4. Monitoring and maintaining temperature of sensor and electronics within tolerable limits
5. Calibration with LED pulser or pulsed Laser