Ground Based Gamma Ray Astronomy and Multiwaveband Studies of Blazars

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DHEP Annual Meeting, 4-6 May, 2022

Projects :

HAGAR Telescope Array

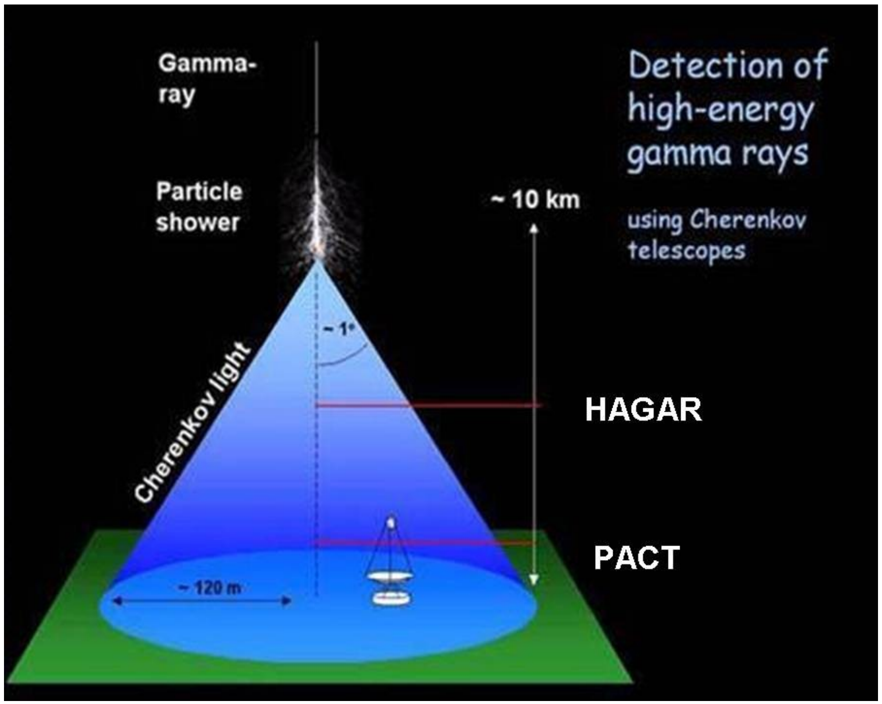
Development of SiPM based imaging camera

Multiwaveband Studies of Blazars

Atmospheric Cherenkov Technique

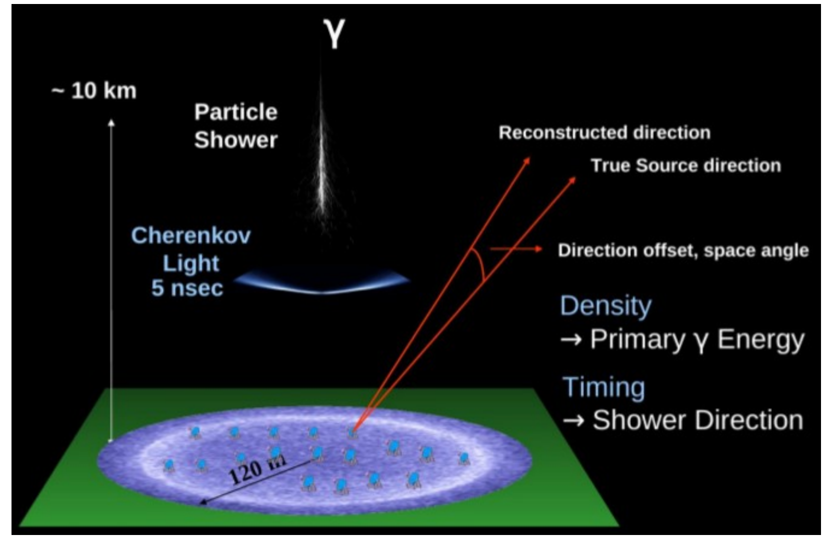
Indirect detection of VHE γ-rays from astronomical sources

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

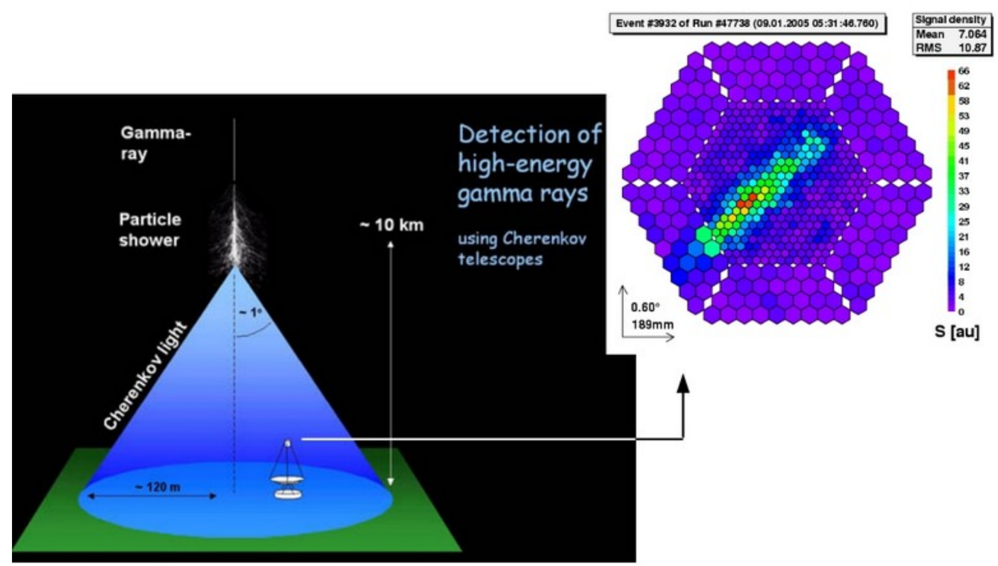


Higher altitude location for lowering energy threshold

Wavefront sampling technique

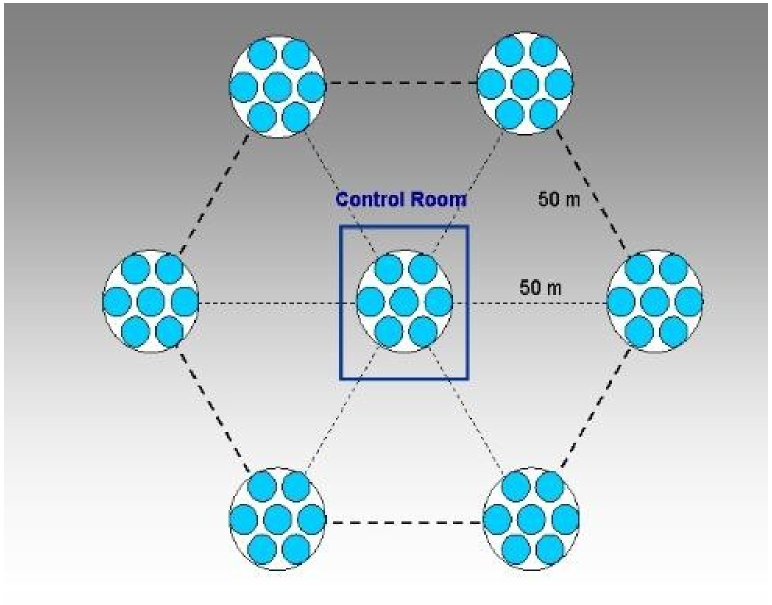


Imaging technique



HAGAR Telescope Array : Status and Recent Results

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 PMT (XP2268B) at focus of each mirror.

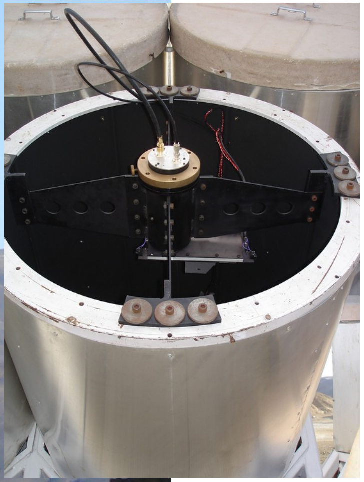
- Tracking system : Alt-azimuth design *(Gothe et al., Exp. Astr.,35, 489, 2013)*
- High voltages to PMTs given through CAEN controller
- Data Acquisition system : CAMAC based, interrupt driven

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)
Telescope pulses stored using waveform digitizer with 1GS/s

VME based DAQ has been installed

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)

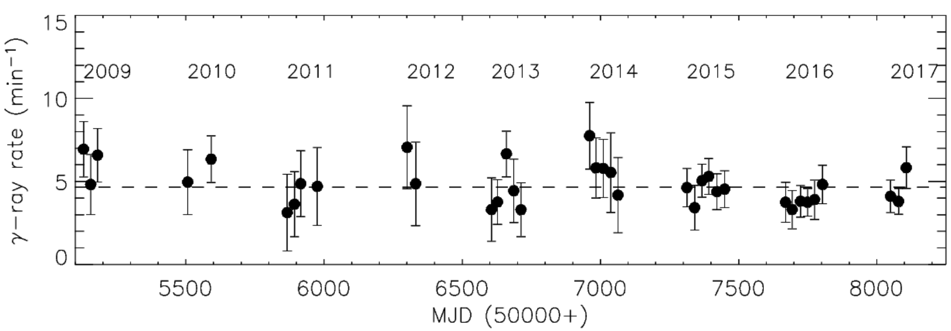
Results from HAGAR

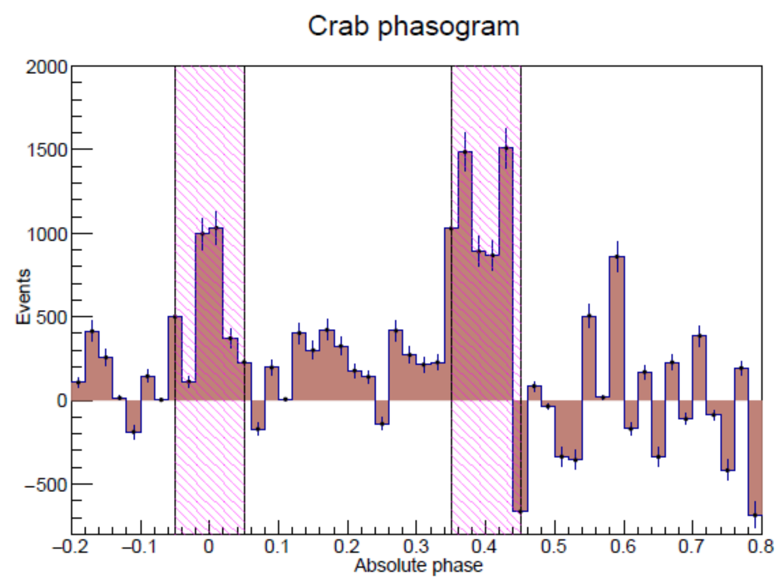
Detection of blazars Mkn 421 and Mkn 501 in flare and moderate state of activity

Detection of standard candle source Crab nebula with significance level of 20σ

Detection of pulsations from Crab pulsar at a period of 33 ms with 6.3σ significance level

Crab nebula light curve





(Further details in talk by Bharat Singh)

SiPM based imaging camera for 4-m class telescope

SiPM based camera : Design Features

SiPMs as alternative to PMTS
-> higher photon detection efficiency
-> longer observation duty cycle

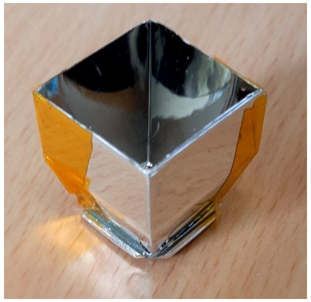
TACTIC Telescope at Mt Abu

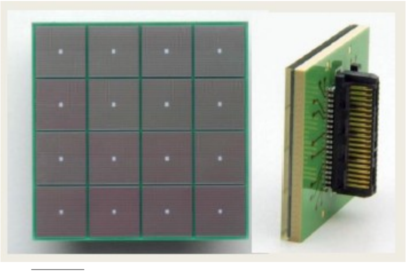
Vertex Element Specifications :
Focal length : 4m, f/D ~ 1.1
34 spherical mirror facets

Final installation site : Hanle

Camera Specifications

No. of pixels : 256
Physical size : 36 cm X 36 cm
Field of view : 5 ^{o}X 5^{o}
Pixel size : 0.3^{o} X 0.3^{o}
Light concentrators :
Square entry - Square exit
Photo-sensor :
Hamamatsu 4 X 4 SiPM array
of 3 mm X 3 mm subpixels





3 mm

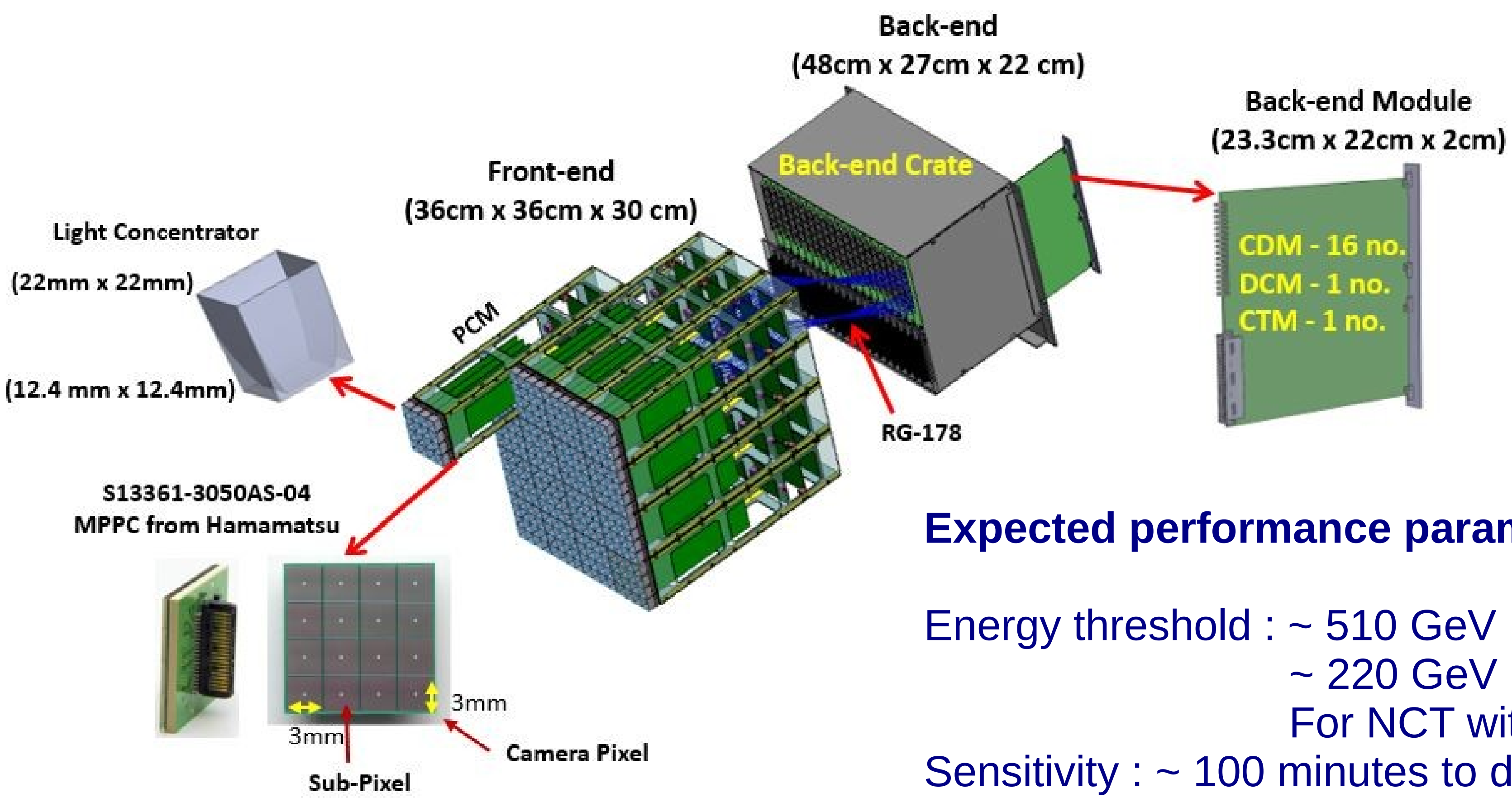
Breakdown voltage V_{BR} : 53±5 V
Temperature coefficient of V_{BR} : 54 mV/^{o}C
Operating temperature : -20 ^{o}C to +60 ^{o}C

(Ref : Chitnis et al., Proceedings of Science, ICRC2021, 719, 2021)

Design Requirements for Camera

Dynamic range : 1 to 1500 pe/pixel with single pe resolution upto few pe
Timing resolution for pulse profile : 1 ns
Event rate : upto 100 Hz
Electronics mounted at the back of the camera
Weight   < 100 kg

Imaging Camera View

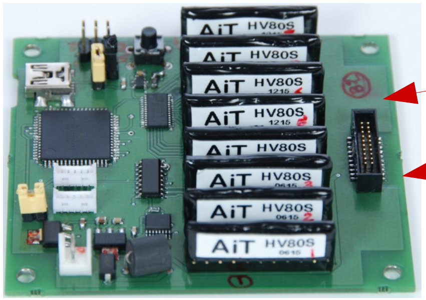


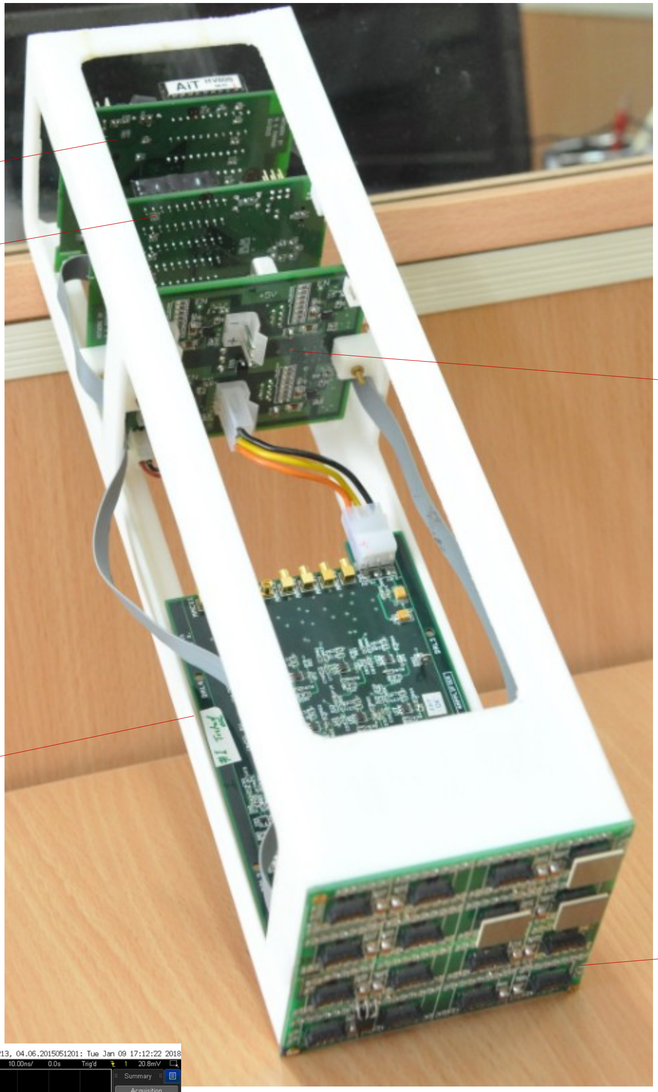
Expected performance parameters :

Energy threshold : ~ 510 GeV @ Mt Abu
~ 220 GeV @ Hanle
For NCT with 10 pe
Sensitivity : ~ 100 minutes to detect Crab
Like sources at 5σ

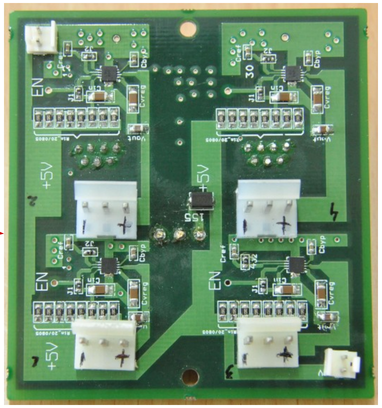
16-Pixel Cluster Module

8 ch. Bias Supply Card

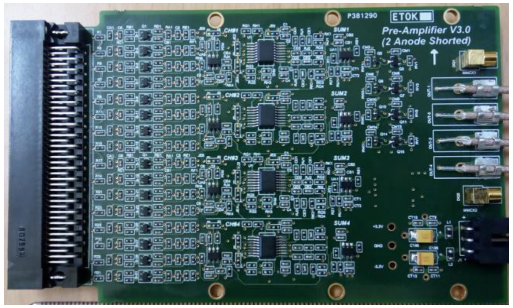




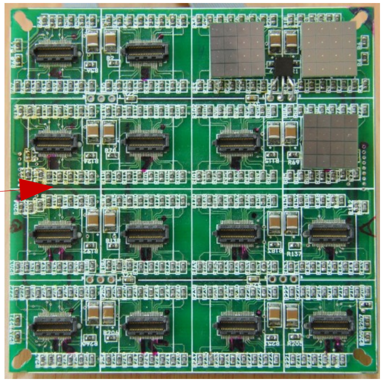
Low Voltage Power Supply Card

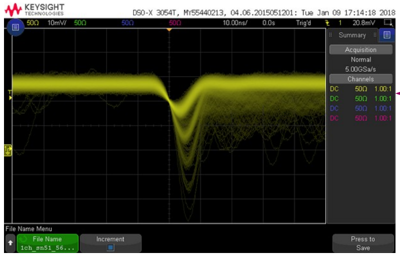


4 Pixel Pre-Amplifier

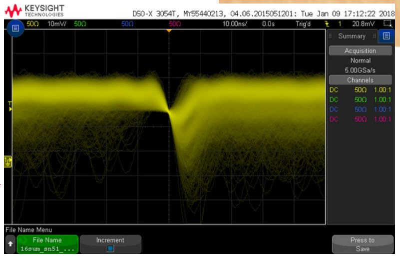


SiPM Mount PCB





1 sub -pixel

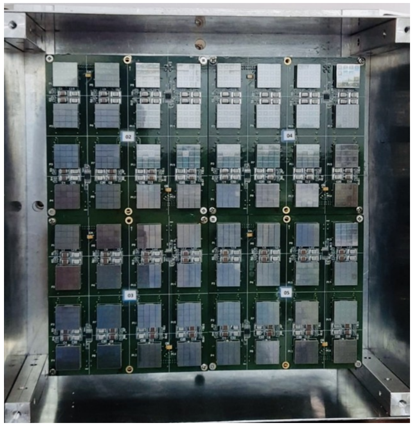


Pixel pulses

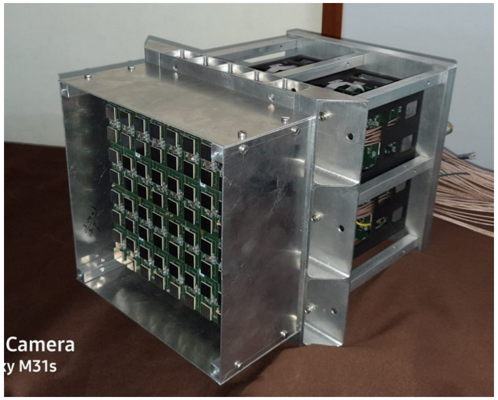
Pixel Cluster Module (PCM) Dimensions:
280mm (H) x 88mm (B) x 88mm (W)

64-Pixel Mini-Camera

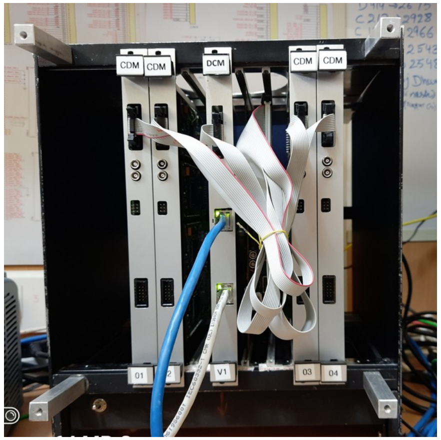
Front view of mini-camera



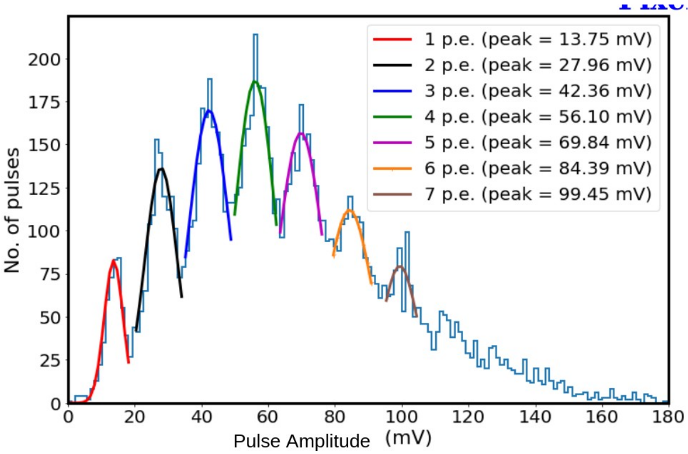
Front end electronics



Back end electronics



Photoelectron spectrum



Mini-camera mounted in focal plane of vertex element

Plan :

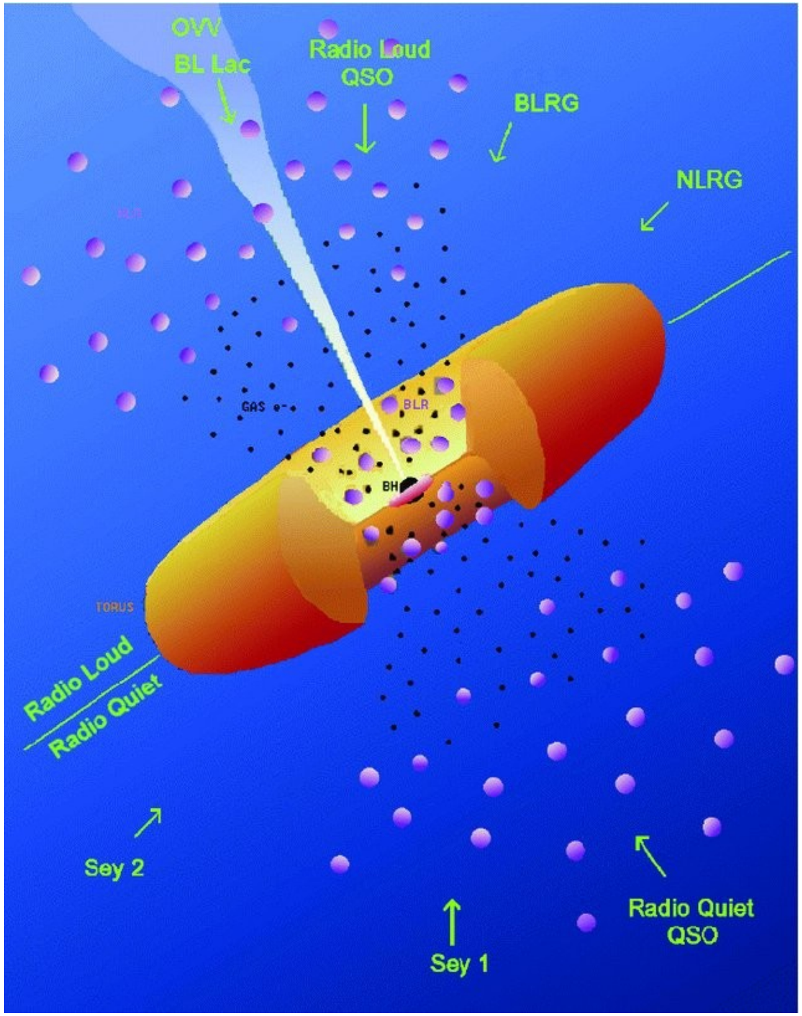
Testing of mini-camera at Mt Abu in 2022
Work on remaining camera modules : 2022-23
Testing of entire camera at Mt Abu 2023

Installation at Hanle for monitoring blazars

(Further details in talk by Kiran Gothe)

Multiwaveband Studies of Blazars

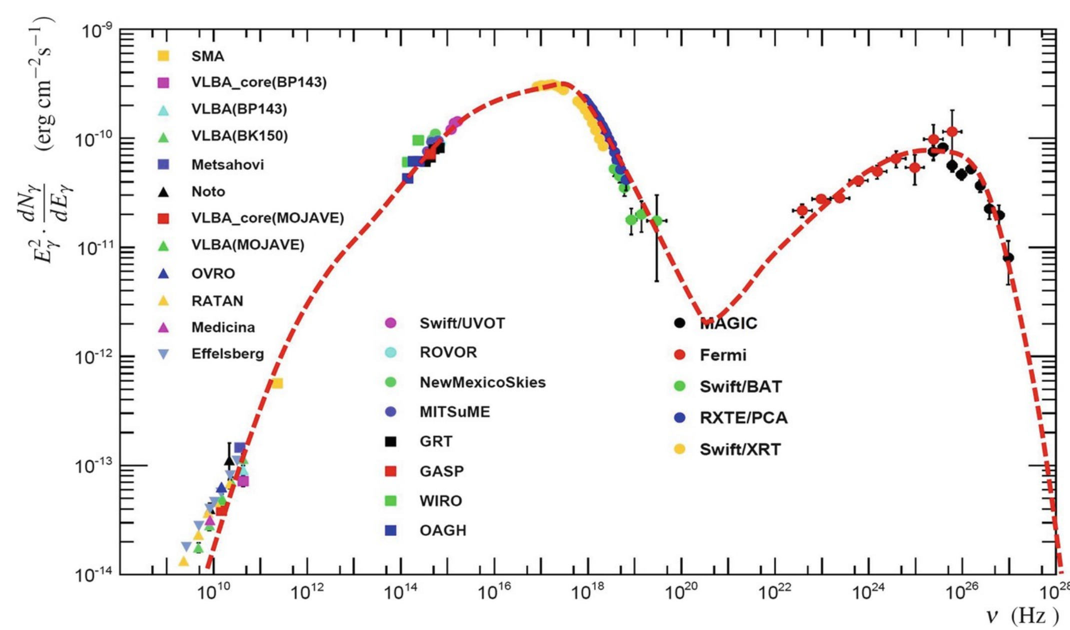
Blazars



Blazars : Active Galactic Nuclei with jets directed towards Earth

Variability in all wavebands on timescales from minutes to years

Double peaked spectral energy distribution explained using leptonic/hadronic models

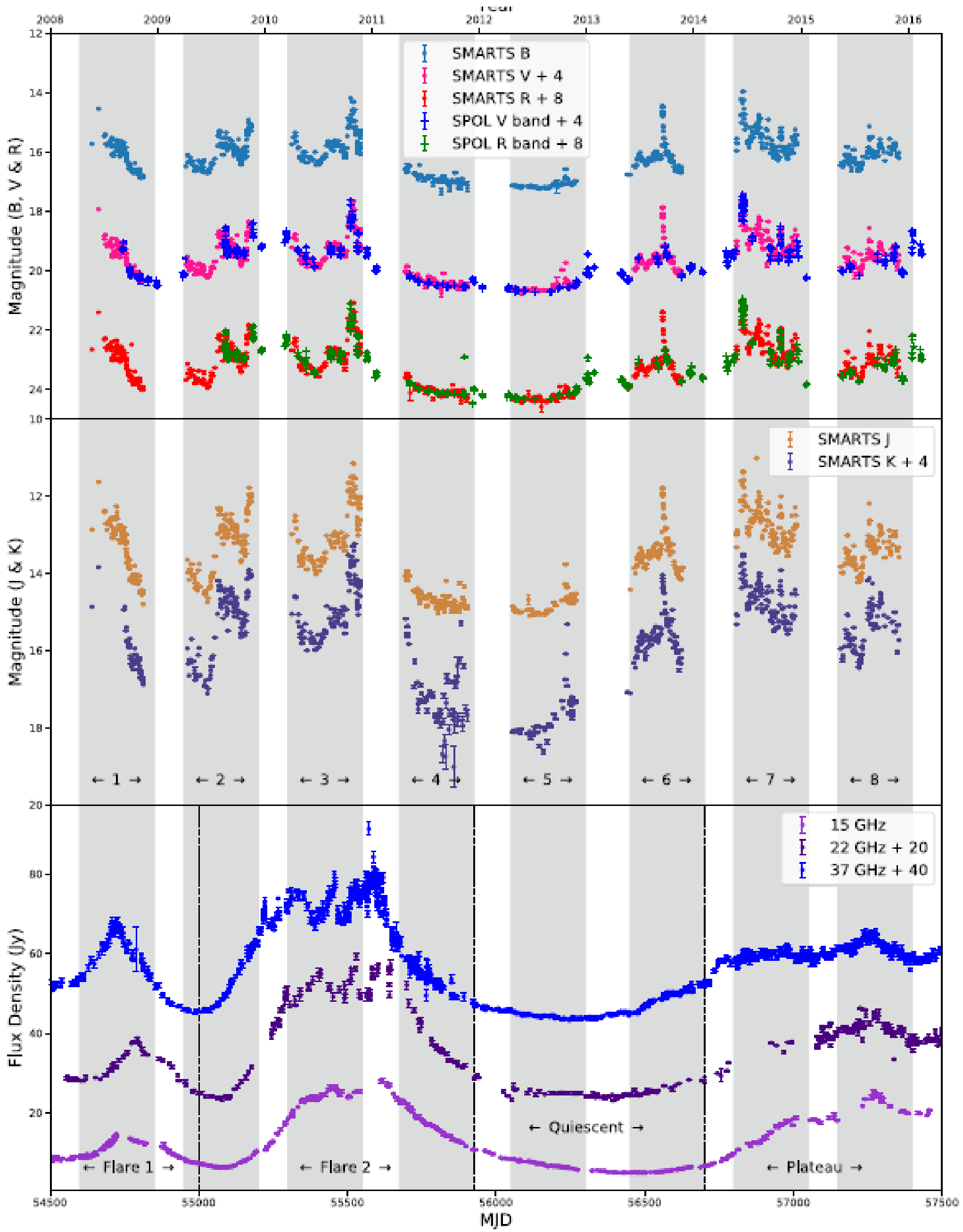


Multiwaveband studies :

Temporal studies : MW light curves, correlations, variability, QPO

Spectral studies : Spectral shape, MW SED

3C 454.3 : Variability Studies

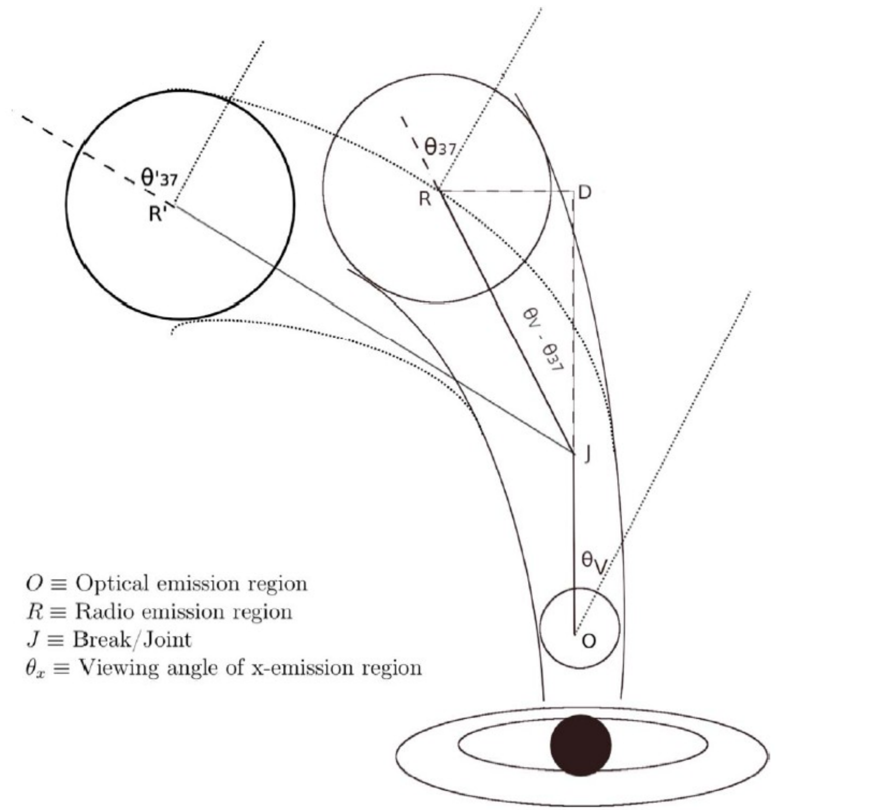


(Sarkar et al., ApJ, 887, 185, 2019)

Optical, IR and radio band light curve spanning 8 years data

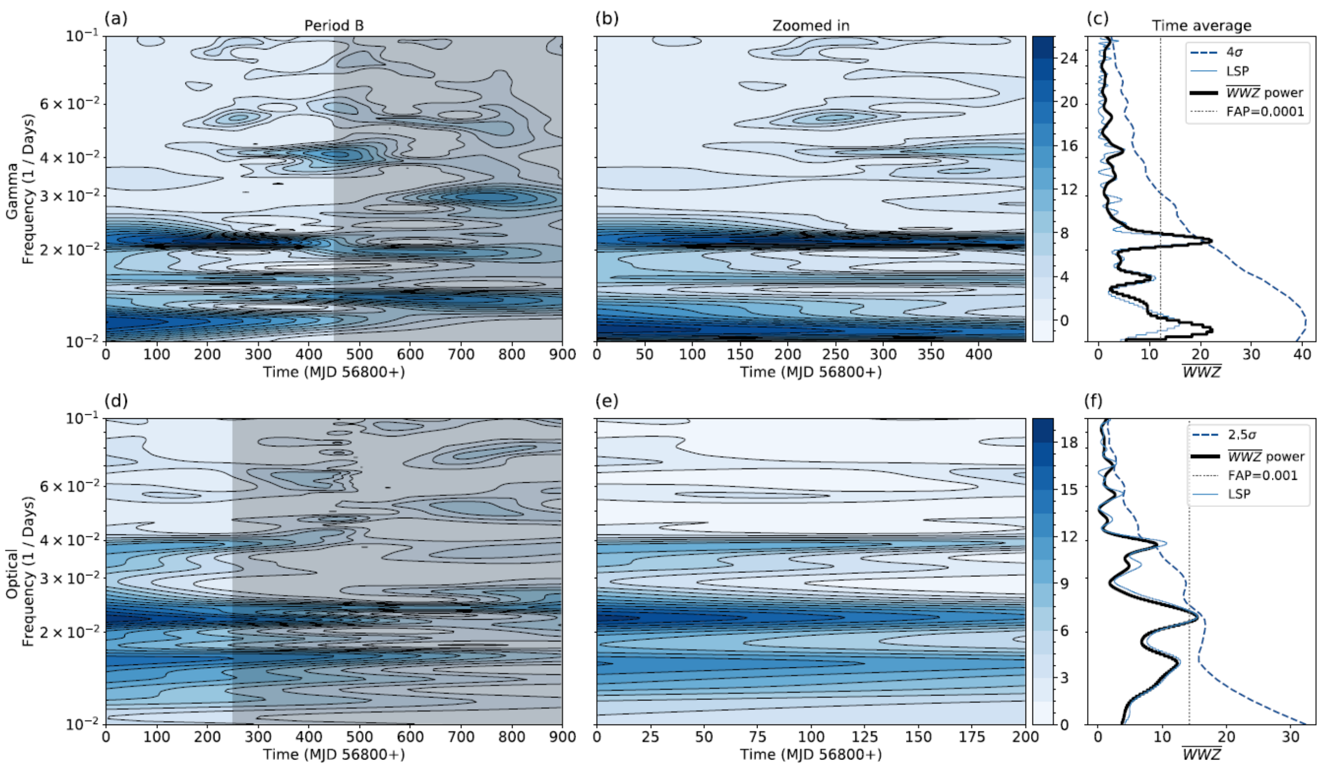
Variability, correlation and spectral studies

Lag of 10-100 days between radio and optical/IR data



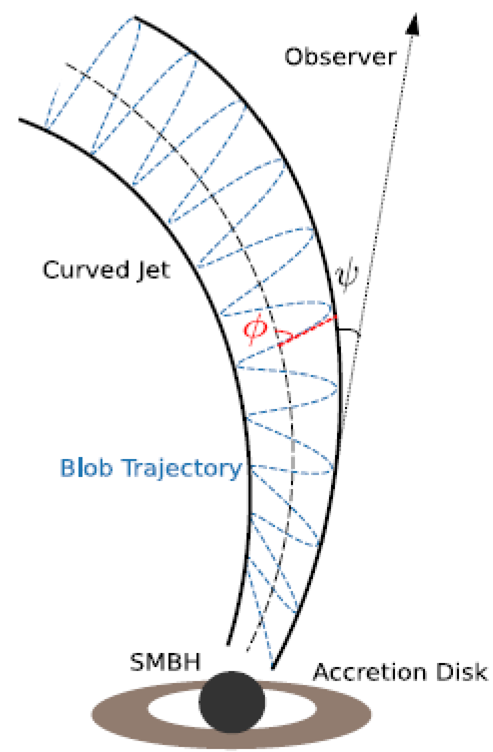
Curved jet model

Quasi-Periodic Oscillations in 3C 454.3



QPO search with various techniques :
Lomb-Scargle periodogram,
Weighted wavelet z-transform,
REDFIT

QPO detected at a period of ~ 47 days with > 4σ in gamma rays and > 2.5 σ in optical

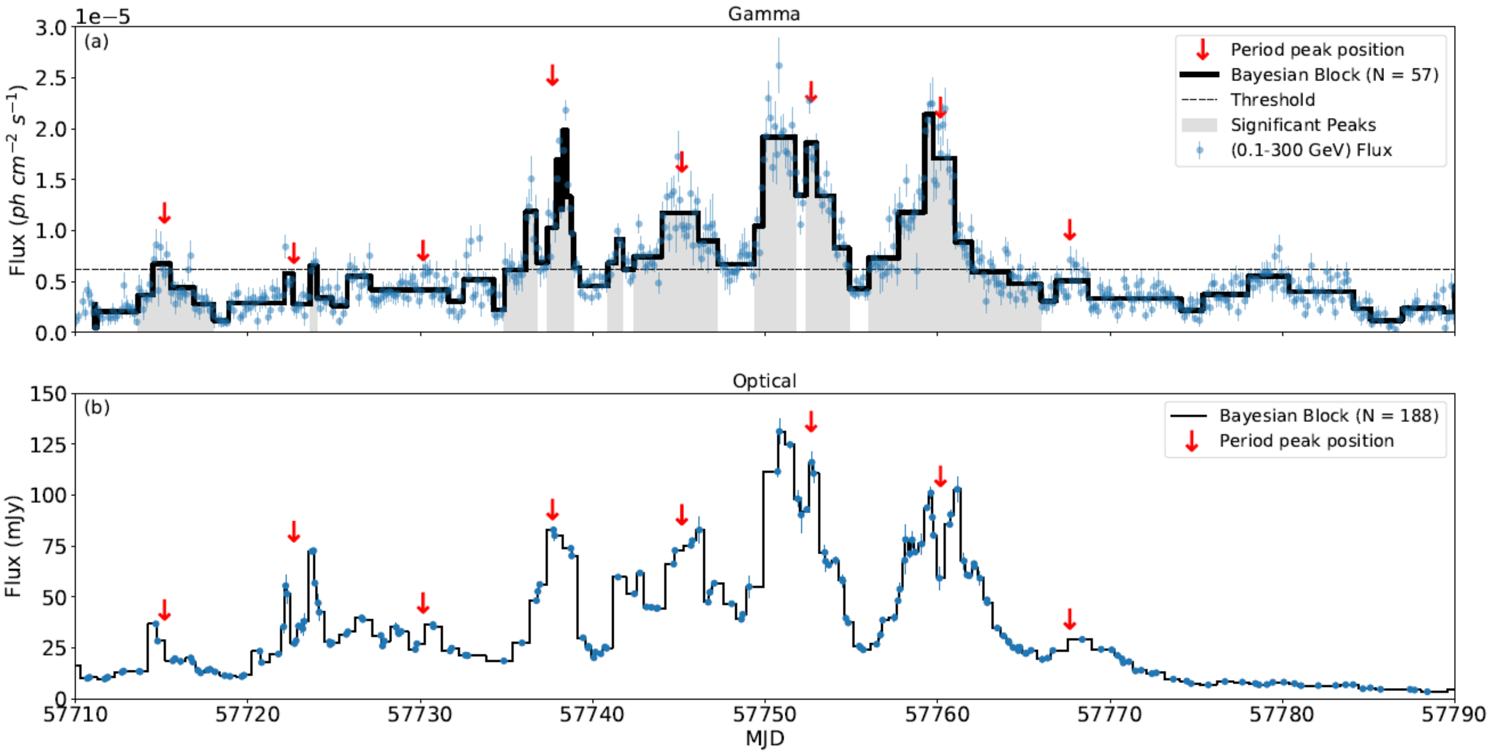


Possible scenario : emission from blob moving helically inside curved jet

Jet curvature : ~ 0.05°/pc

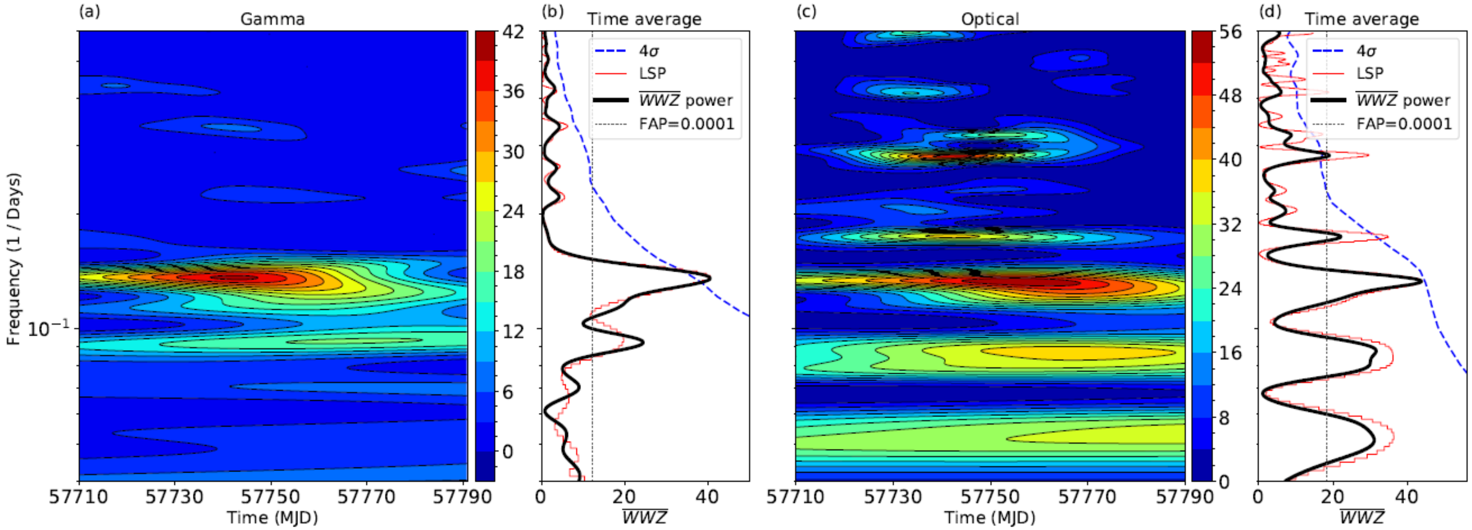
(Sarkar et al., MNRAS, 501, 50, 2021)

QPO in CTA 102



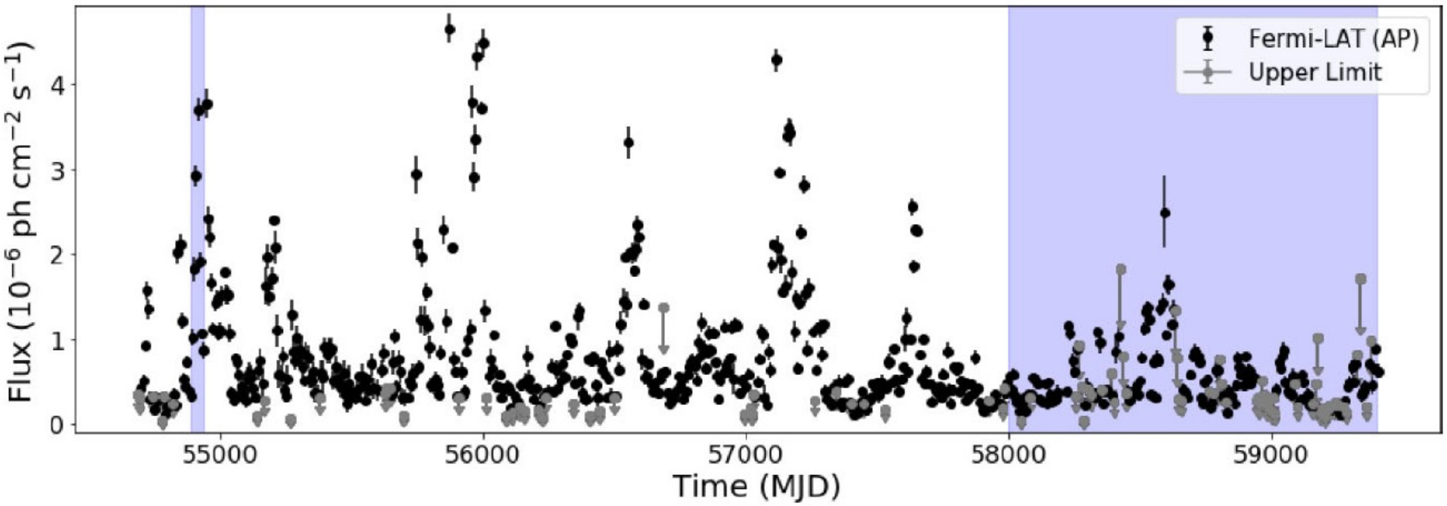
~ 7.6 days QPO seen during flaring episode in 2016-2017 with > 4σ significance

Possible scenario : Blob moving helically in curved jet



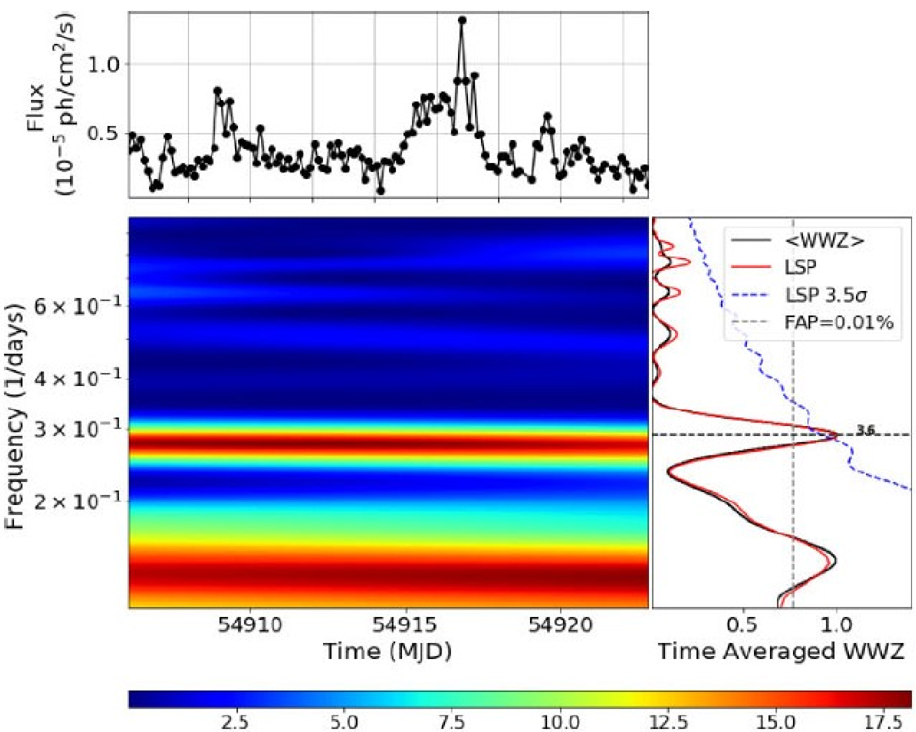
(Sarkar et al, A&A, 642, A129, 2020)

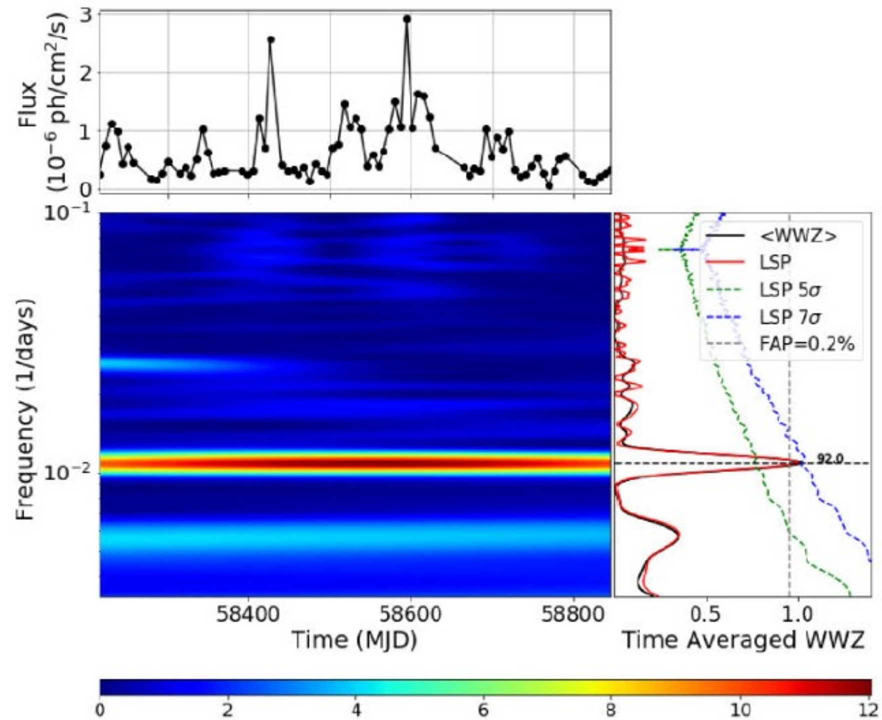
QPO in PKS 1510-089



3.6 day QPO in 2009 with ~ 3.5σ, shortest QPO in gamma rays so far

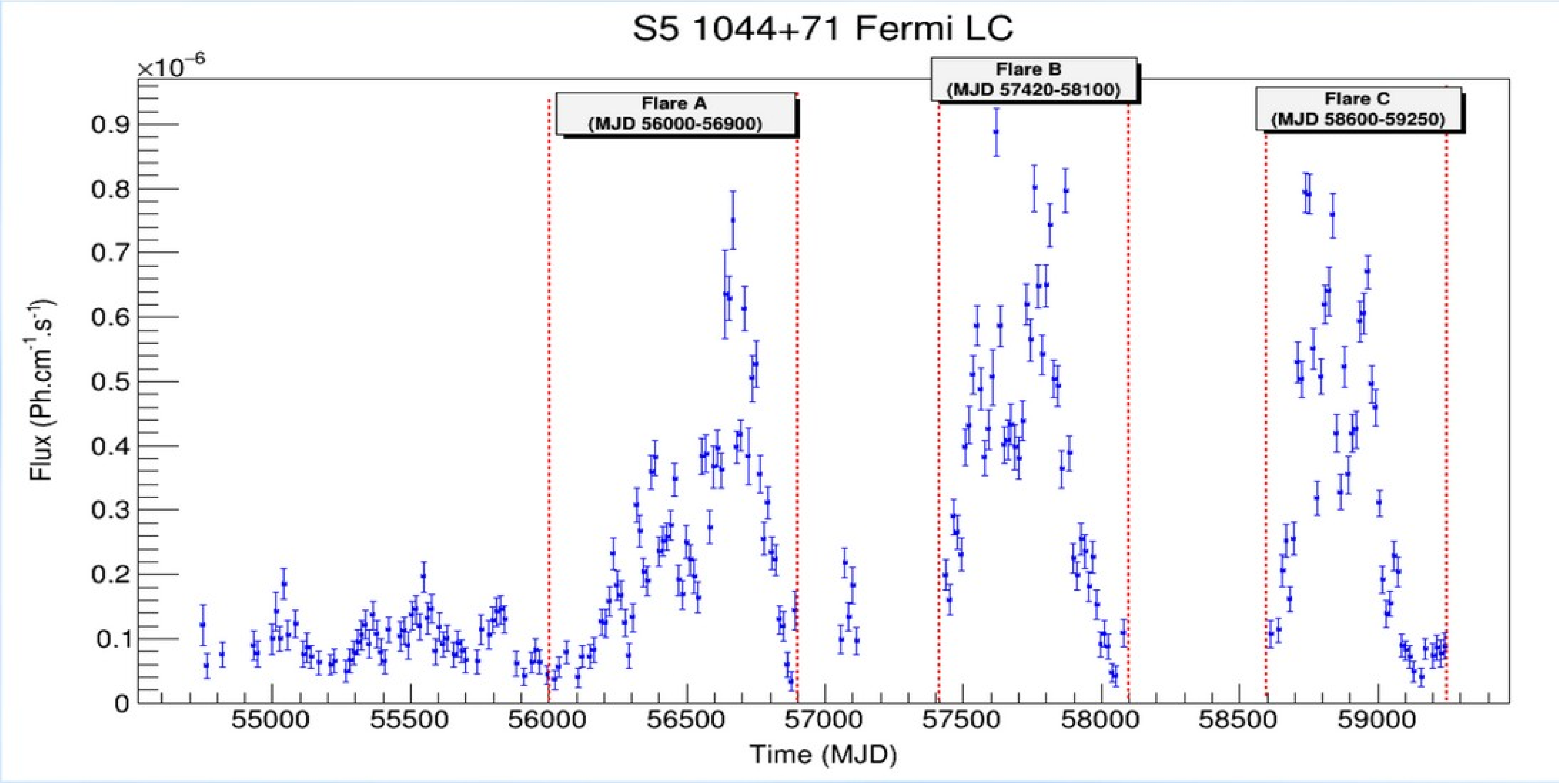
92 days QPO in 2018-2020 with ~ 7σ, most significant Blazar QPO so far





(Roy et al., MNRAS, 510, 3641, 2022)

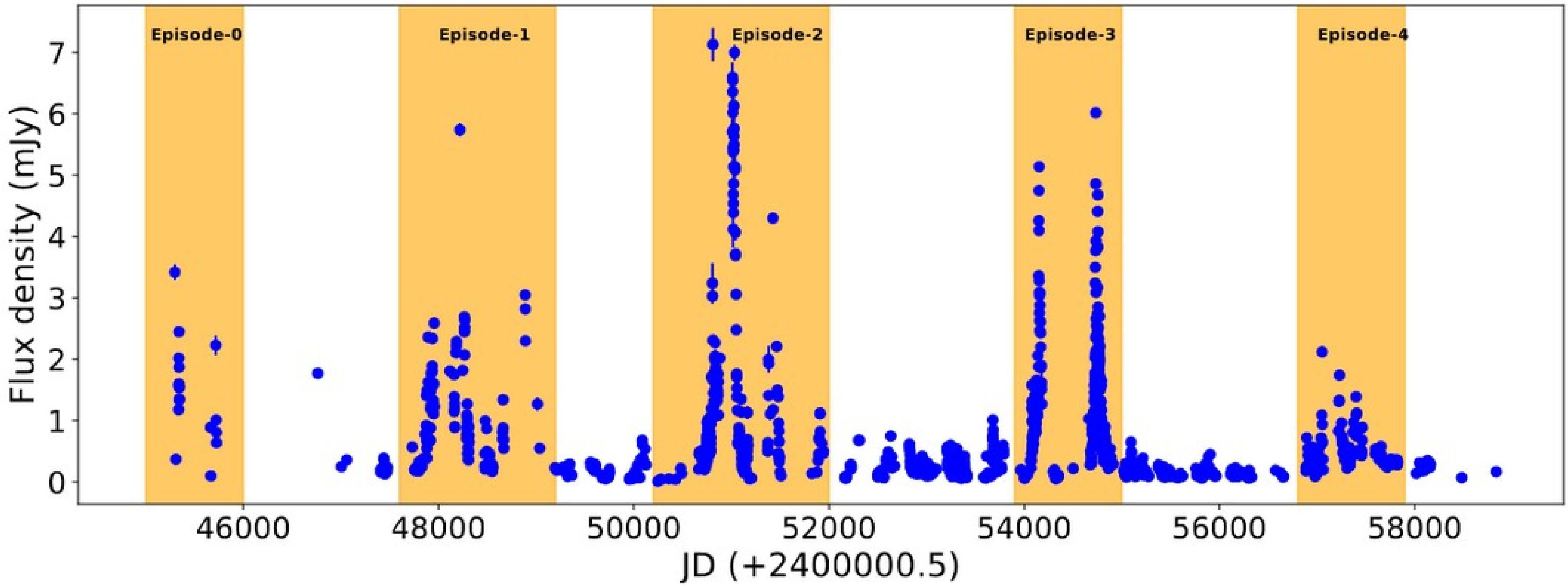
Long Term QPO in S5 1044+71

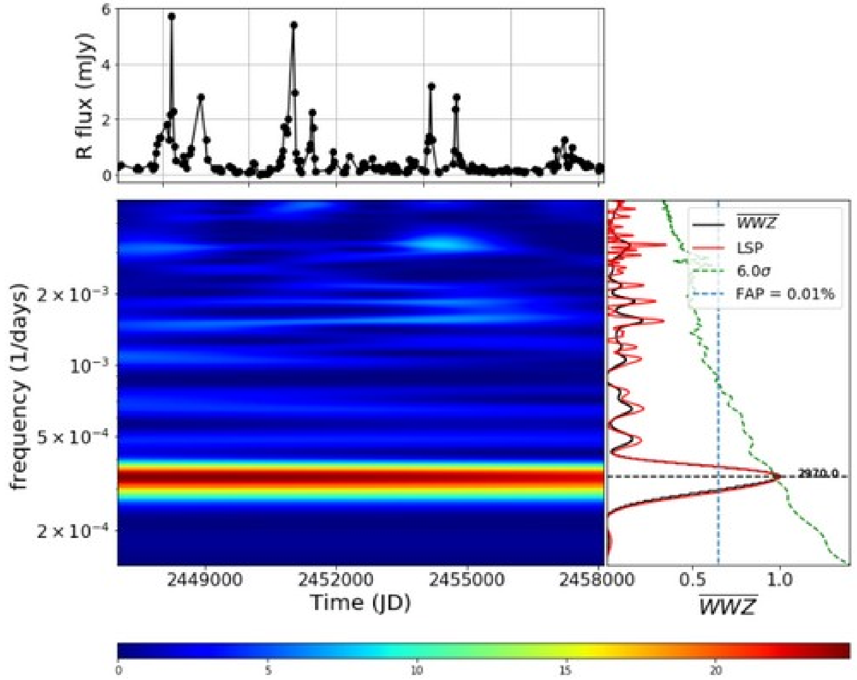


Period ~ 1093 days

(Chatterjee et al., in preparation)

Long Term QPO in AO 0235+164



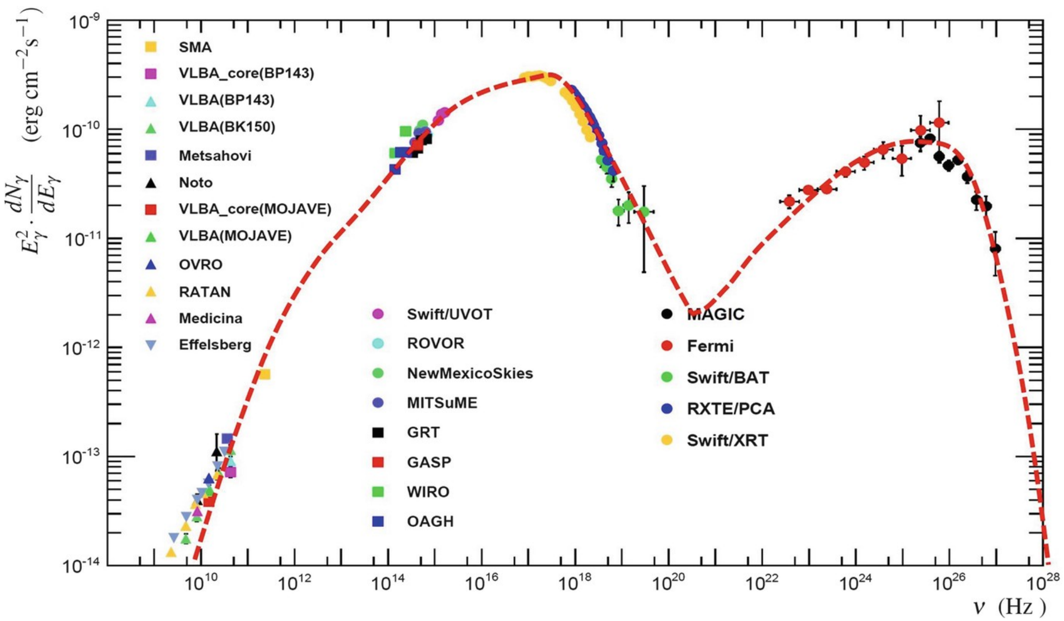


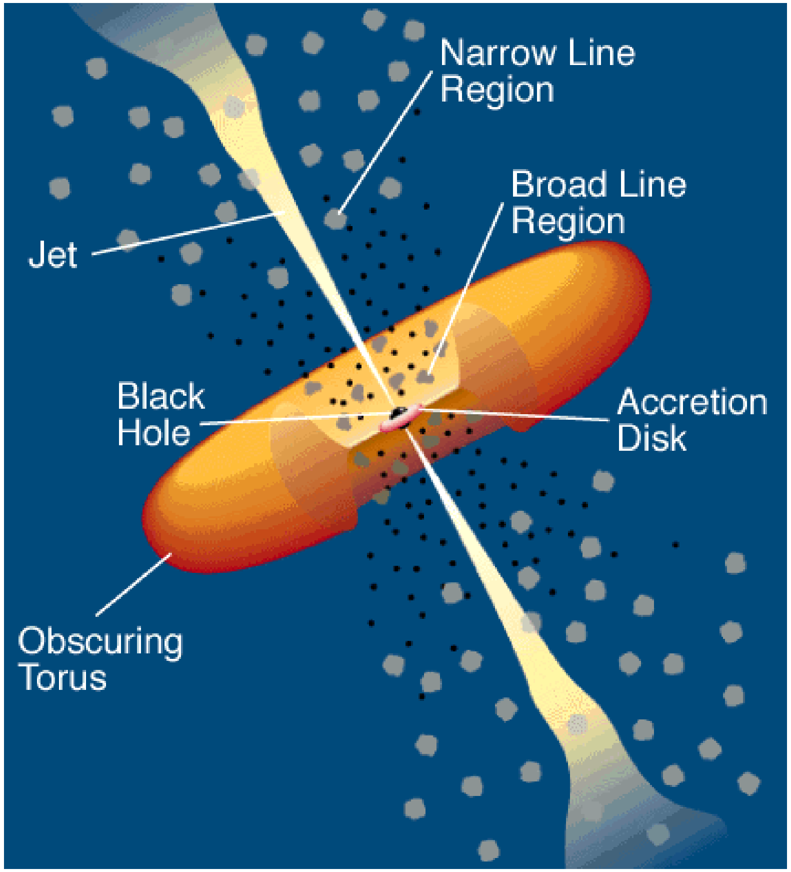
~ 8.13 years periodicity in optical R band data

Possibly binary supermassive black hole

(Roy et al. Under review with MNRAS)

Multiwaveband SED

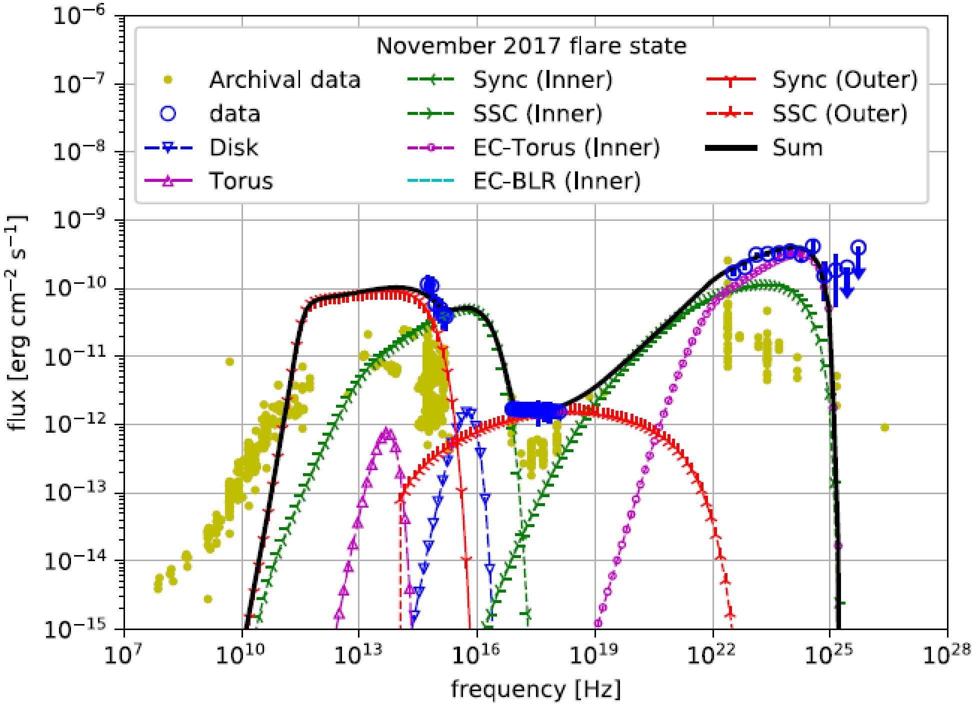


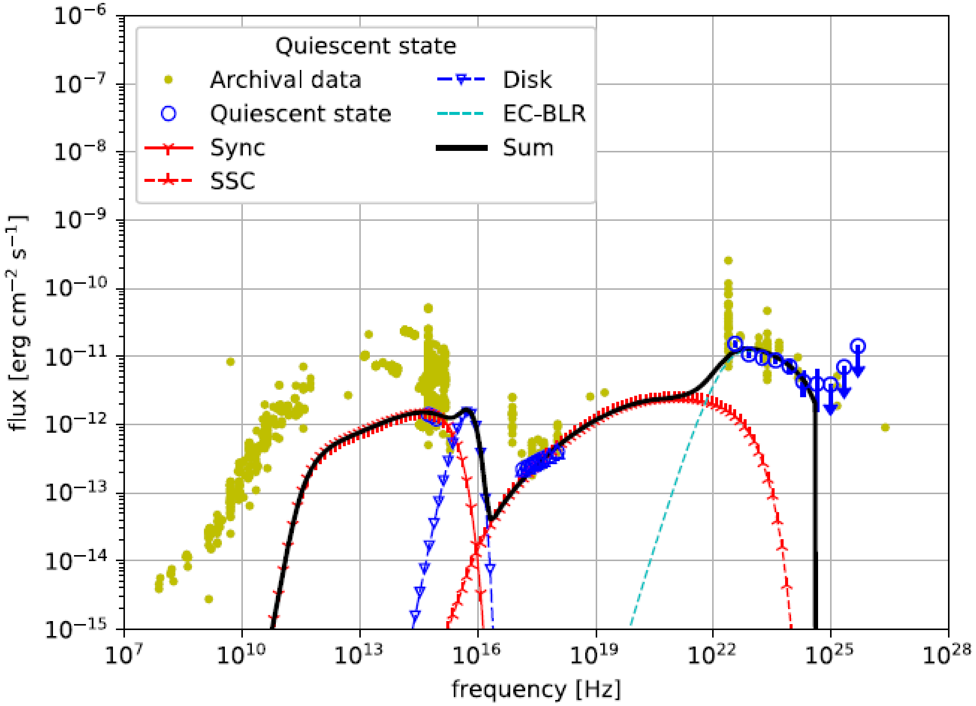


First peak : Synchrotron emission from energetic electrons
Second peak : leptonic/hadronic scenarios

Leptonic : Inverse-Compton scattering of Synchrotron photons (SSC)
Or External photons (EC) from BLR, dusty torus

SED of Ton 599

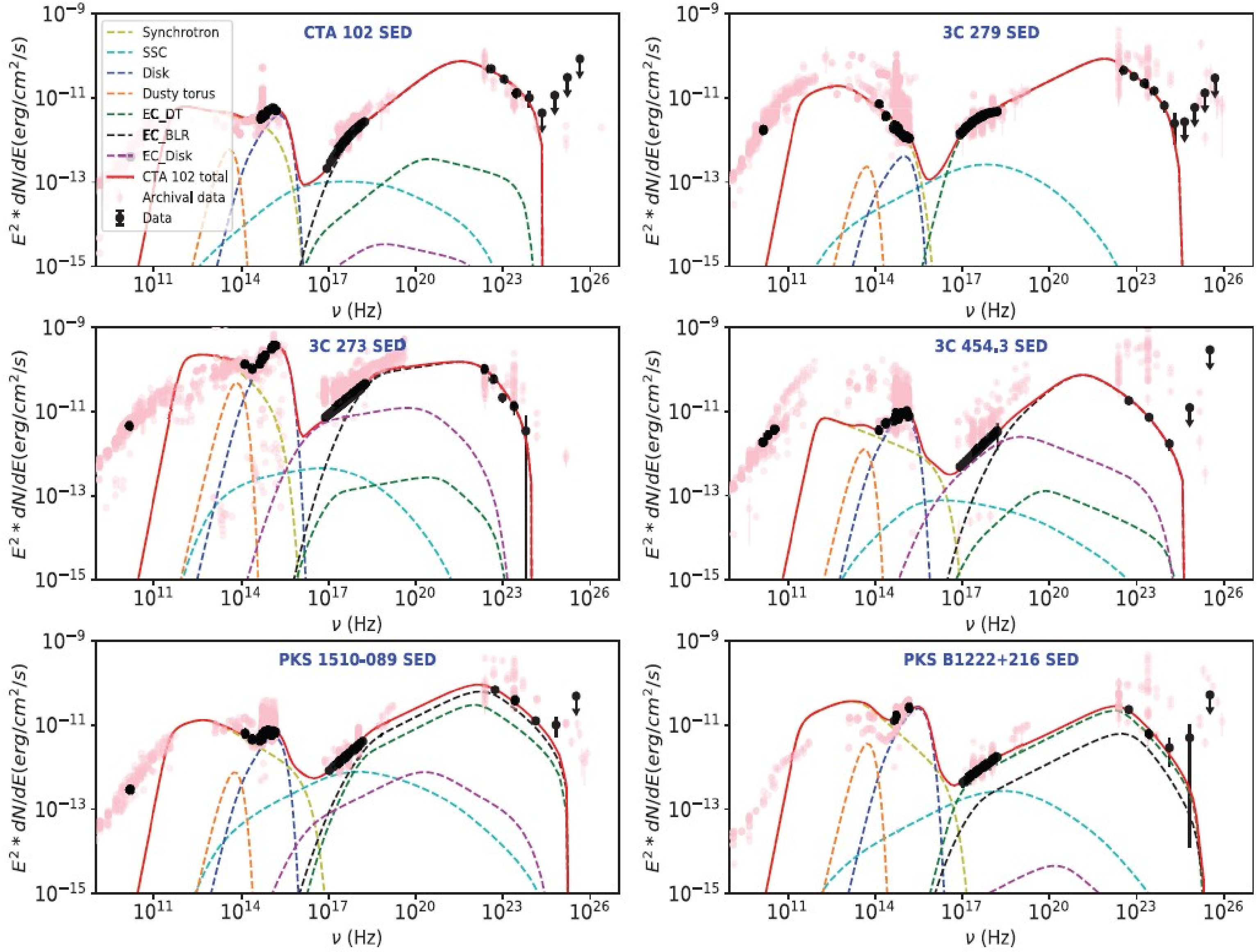




Flare and quiescent state SEDs fitted with a combination of SSC and EC

(Patel and Chitnis, MNRAS, 492, 72, 2020)

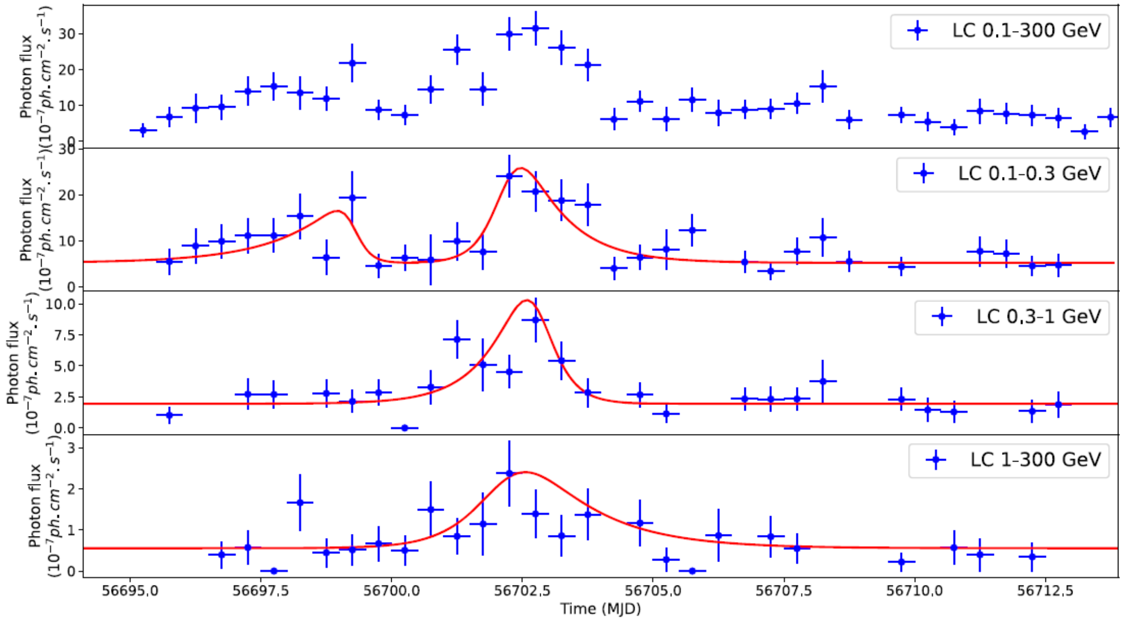
Quiescent state SEDs of six brightest FSRQs



Aim : To study baseline emission, correlations between model parameters etc

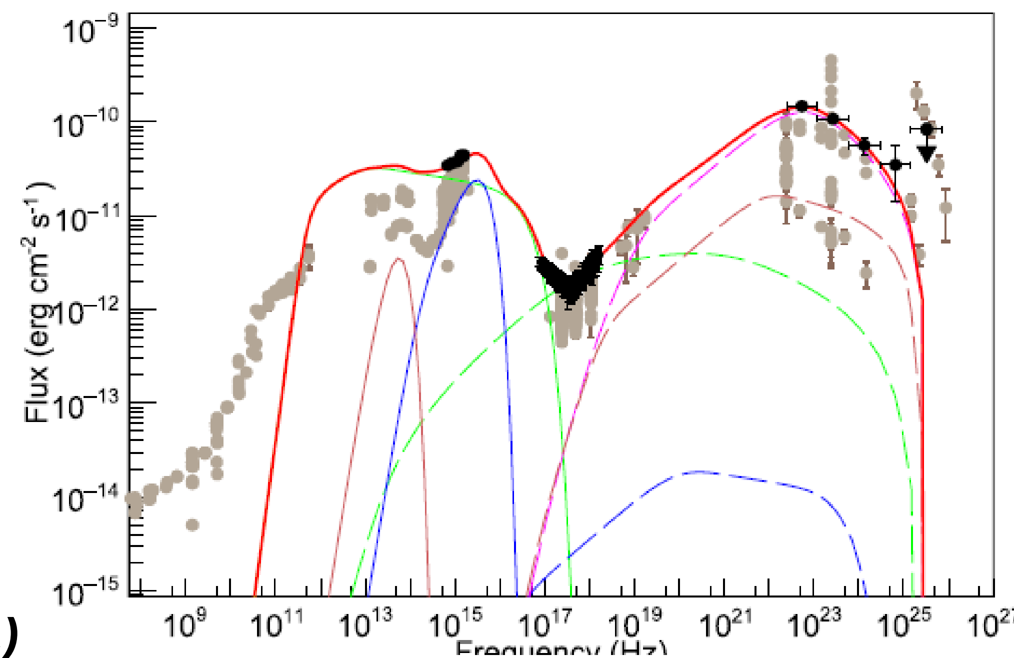
(Roy et al. MNRAS, 504, 1103, 2021)

Temporal and Spectral Study of PKS B1222+216



Energy dependence of gamma Ray light curve during flare

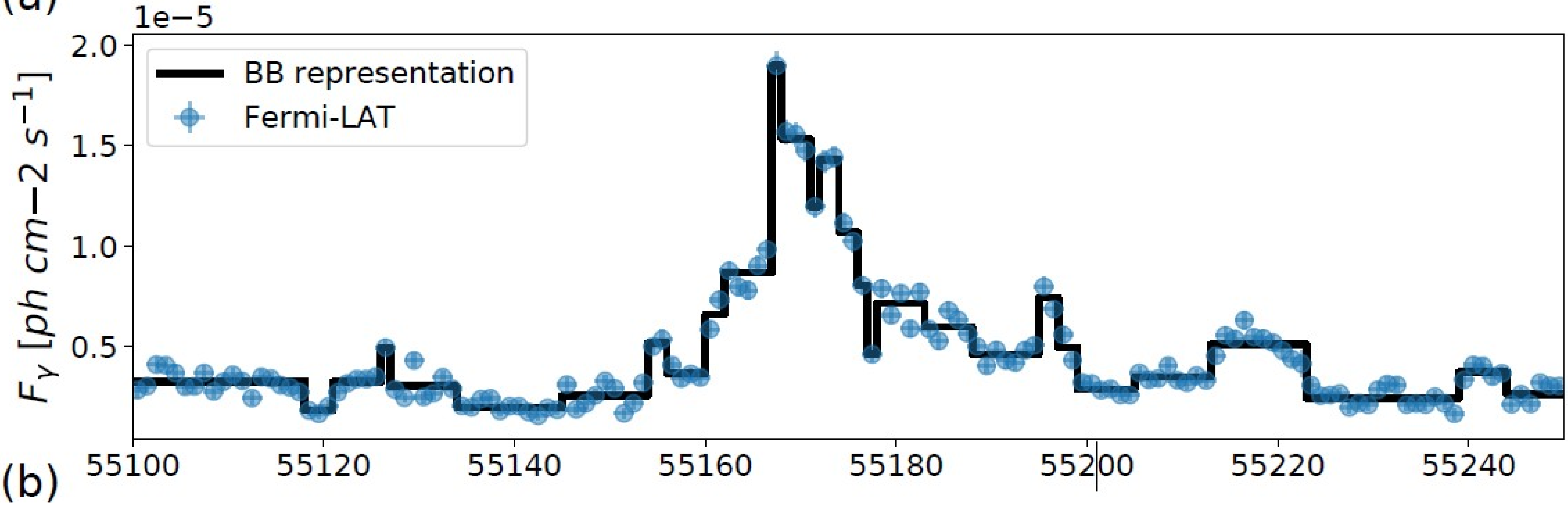
SED fit using SSC+EC



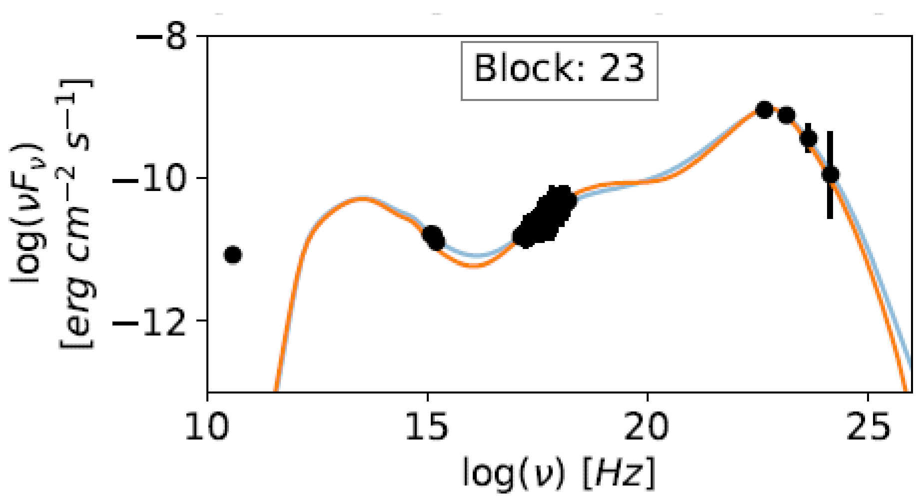
(Chatterjee et al., MNRAS, 508, 1986, 2021)

Evolution of 3C 454.3 SED during flare

(a)



(b)



One typical SED : fit with EC

Explanation of flare in terms of Doppler factor change due to helical motion of emission region

(Sarkar et al., in preparation)

Team Members

Present members :

Anshu Chatterjee, Ramdas Deshmukh, Phunchok Dorjey, Nawang Dorji, Sandeep Duhan, Kiran Gothe, Varsha Nikam, Nandkishor Parmar, Mano Ranjan, Shobha Krishna Rao, Abhradeep Roy, Bharat B. Singh

Santosh Chavan, Ganesh Ghodke, A. P. Krishnan Kutty, Mandar Saraf, Piyush Verma

Past members :

B. S. Acharya, Anthony D'Souza, Nagesh Krishnamurthy, Sonal Patel, Arkadipta Sarkar, Suresh Upadhya

Thanks