Tenth International Fermi Symposium

9th-15th October 2022

Recent VERITAS Blazar Highlights

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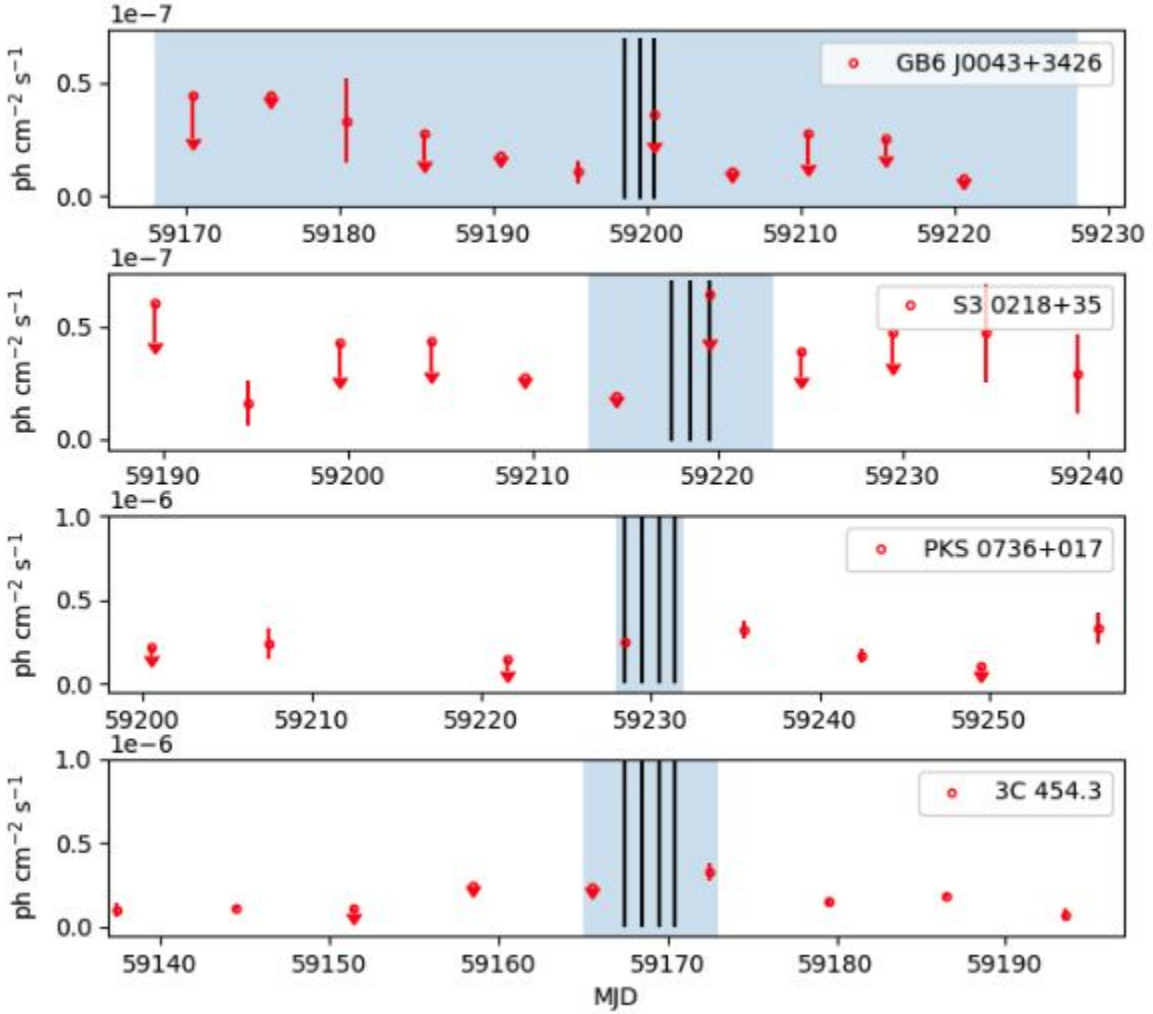
VERITAS

- VERITAS: Very Energetic Radiation Imaging Telescope Array System
- An array of four 12-meter imaging atmospheric Cherenkov telescopes (IACTs) at the Fred Lawrence Whipple Observatory in Arizona
- Sensitive to gamma-rays with energies between 85 GeV to 30 TeV
- Hundreds of hours of blazar and radio-galaxy observations each year

[https://veritas.sao.arizona.edu]

Unbiased survey of FSRQs

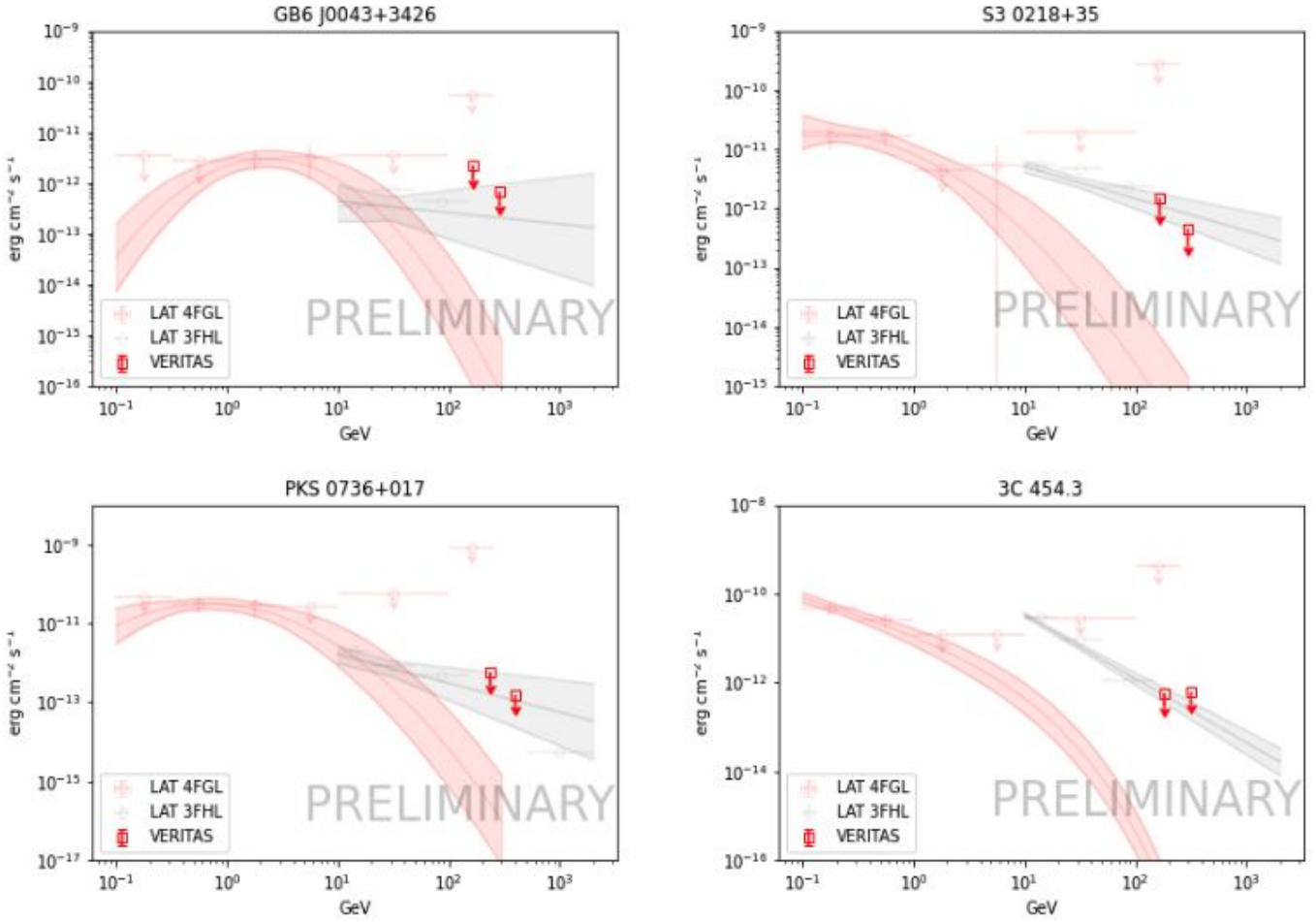
- FSRQs: flat spectrum radio quasars
- *8 of the 79 AGN* detected at *TeV* are FSRQs; *650 of 2863* detected by *Fermi-LAT* [Adams et al 2022]
- Unbiased survey of 12 FSRQs (not biased by high flux states) searching for TeV emission
- 8 of the 12 targets were selected using 3FHL (Third Fermi-LAT Catalog of High-Energy Sources) extrapolated spectra
- 4 of the 12 targets were already detected at TeV energies



Fermi-LAT light curves, 0.1-300 GeV. The vertical black lines represent VERITAS observation times. Shaded regions were used for the Fermi SED.

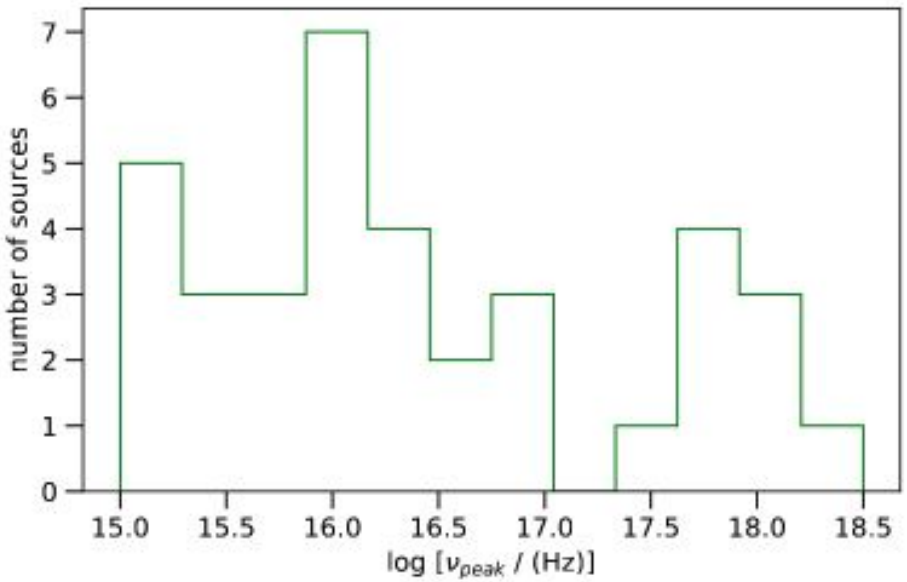
Unbiased survey of FSRQs

- VERITAS observed 4 of these FSRQs: *GB6 J0043+342, S3 0218+35, PKS 0736+017* and *3C 454.3*
  - ~30 hours observing these 4 (during 2020-2021) → Non-detections
- Non-detections constrain flux extrapolation from Fermi
- Goals: constrain duty cycle of TeV emission, characterize TeV emission from jets in FSRQs
- Additional VERITAS observations planned



Luminosity function of TeV HBLs

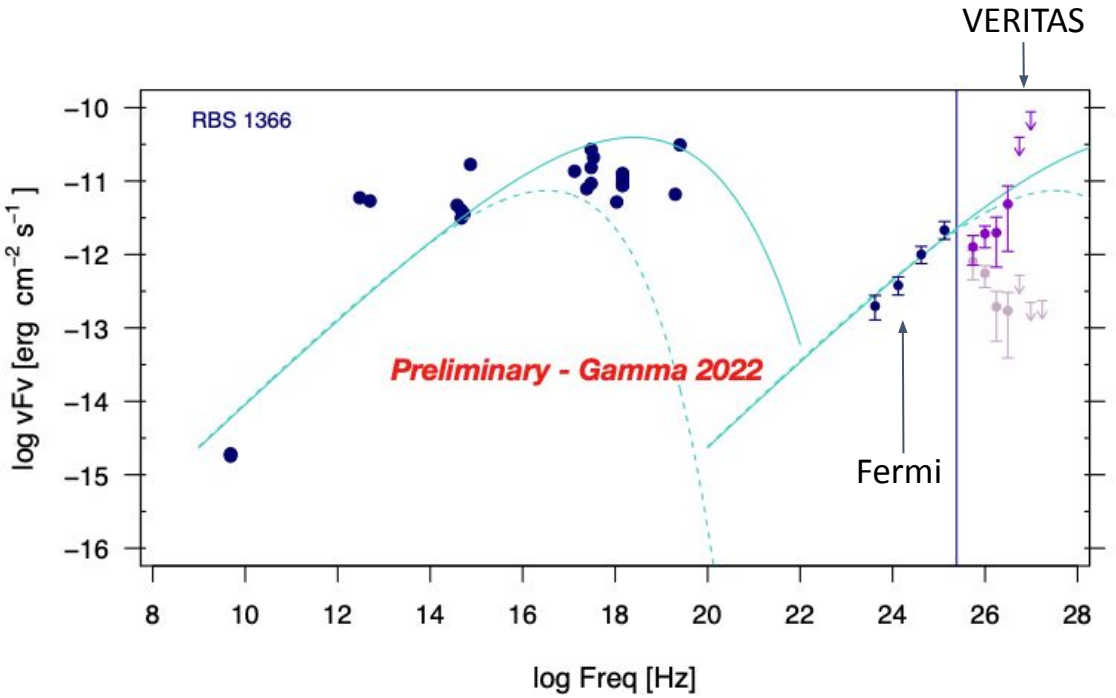
- HBLs: high-frequency-peaked BL Lacs
- Over 50 HBLs have been detected at TeV energies
- VERITAS: sample of 36 HBLs unbiased by high fluxes, selected from 3HSP catalog
- Redshifts 0.03 < z < 0.36 (& 4 unknown redshifts)
- Over 2,000 hours of exposure on these 36 sources since 2007
- Removed observation times triggered by high flux states to minimize bias → Exclude ~30% of the data
- Analysis in progress

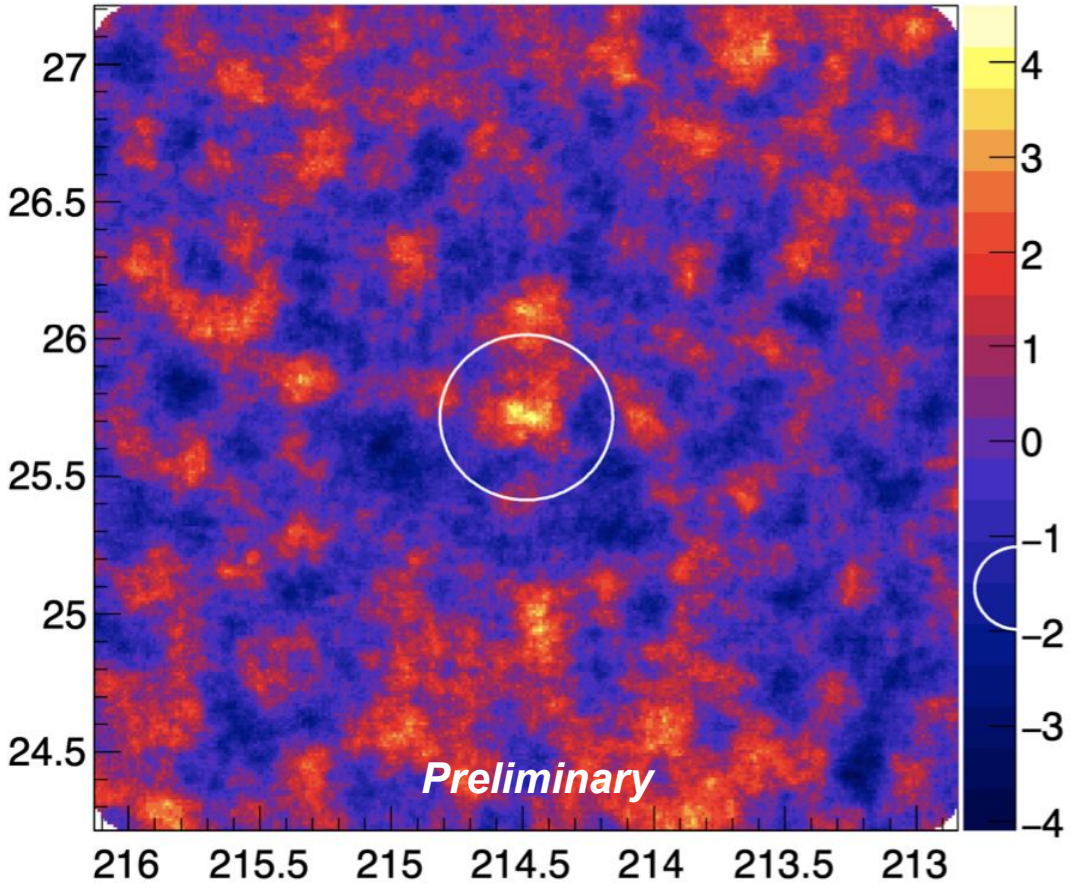


- Measure the luminosity function (# sources/volume/luminosity)
  - Constrain HBL contribution to extragalactic TeV background
  - How can particles accelerate to TeV energies?

RBS 1366 (RGB J1417+257)

- z = 0.237 [Ramazani et al 2017, via NED]
- VERITAS discovery in VHE
- Data: 60 hours, >5σ detection
- Classified as extreme HBL, log$\nu_{\text{sync, peak}}$[Hz]~ 17.2
- Flux: ~0.5% Crab



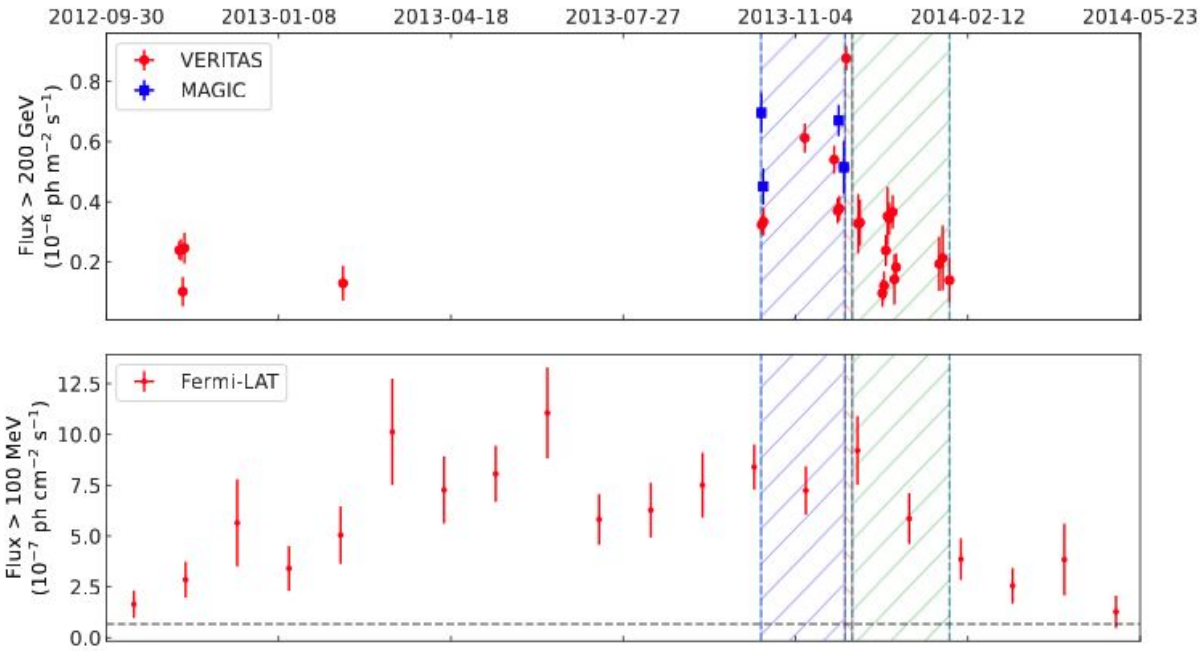


5.03σ detection

MWL data and SSC scaling courtesy of Eileen Meyer

VER J0521+211 flare

- Redshift: 0.18 < z < 0.34
- Discovery of VER J0521 + 211 in 2009 in the TeV gamma-ray band was made from VERITAS observations of RGB J0521.8 + 2112, motivated by a cluster of photons with energies > 30 GeV in Fermi-LAT data
  - State in 2009: HBL-like
- Long-lasting, elevated gamma-ray flux state observed by VERITAS, MAGIC, and Fermi-LAT in 2013 and 2014
- VERITAS total exposure time: 23.6 hours from 2012-2014



[C. B. Adams et al 2022 ApJ 932 129]

- No evidence of VHE spectral variability was observed between these flux states (hatched in the figure)
- SED described by one-zone SSC & is more typical of IBL
  - (Rare) shift in synchrotron peak

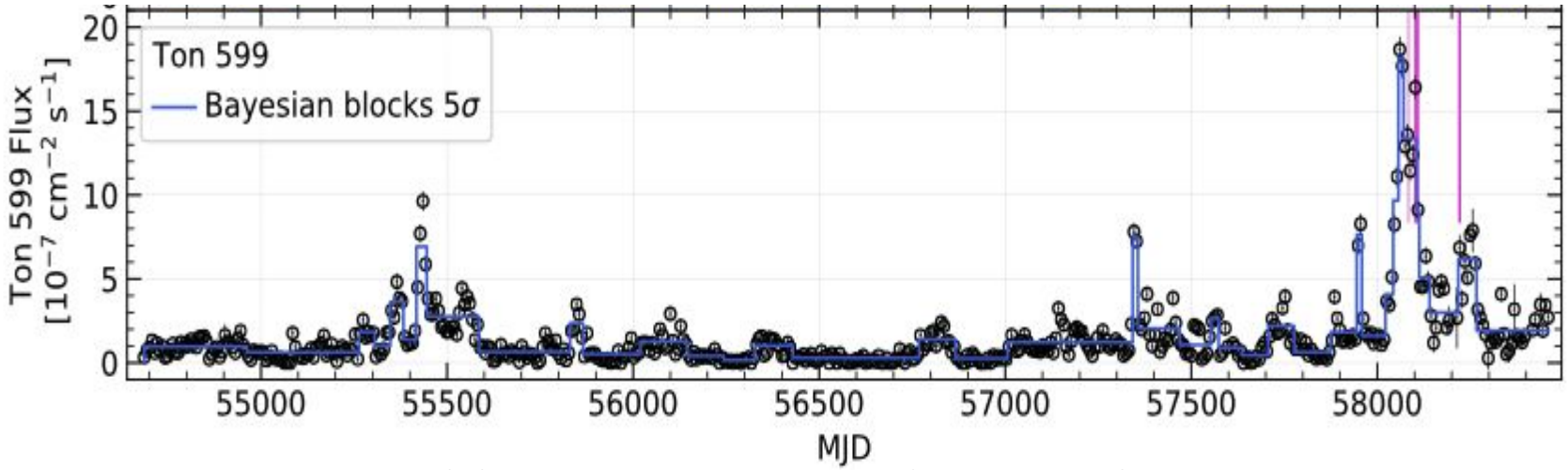
3C 279, PKS 1222+216, & Ton 599 flares

- 3C 279, PKS 1222+216, & Ton 599: all FSRQs
- 100 hours of VERITAS data over 10 years
- Daily to subdaily variability was observed by *Fermi-LAT* during the flaring states for all 3 sources 3C 279, PKS 1222+216, & Ton 599
- Multiwavelength SED modeling can shed light on the mechanisms of gamma-ray production during VHE flares
- Blazars have been observed to be variable at all wavelengths and at timescales down to several minutes in both the GeV and TeV bands (Aharonian et al. 2007; Ackermann et al. 2016). However, the *physical mechanisms that drive this variability are unclear*
- Timescale of variability → constrain emission region size
- No VHE activity was observed during multiple Fermi-LAT flares of 3C 279

[C. B. Adams et al 2022 ApJ 924 95]

PKS 1222+216 & Ton 599 flares

- For PKS 1222 + 216 and Ton 599, the variability timescales were of the order of days
  - The fastest Fermi-LAT variability did not occur during the detected VHE flares
- VERITAS detected flares of both PKS 1222+216 and Ton 599
- SEDs of the VHE flares of PKS 1222 + 216 and Ton 599 are described well by a purely leptonic emission model including an EIC (external inverse Compton) emission component

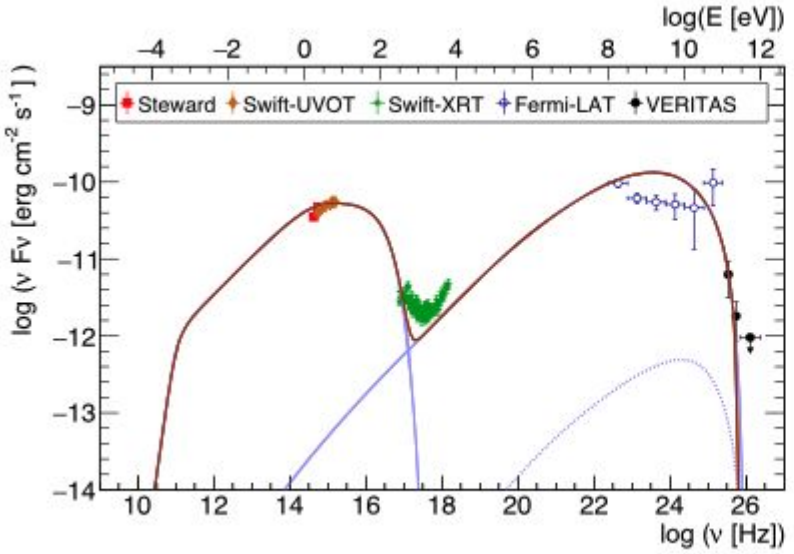


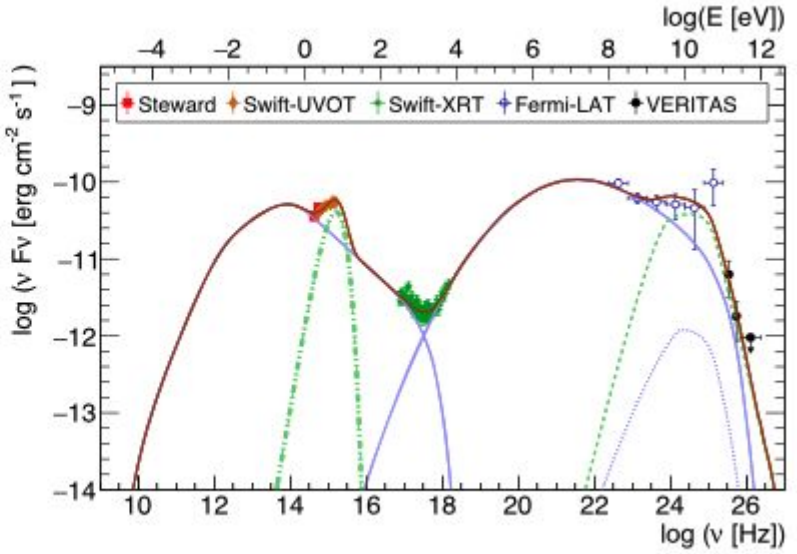
Fermi-LAT light curve. Magenta: corresponds to VERITAS observations

[C. B. Adams et al 2022 ApJ 924 95]

PKS 1222+216 flare

- FSRQ (flat spectrum radio quasar) at z = 0.432
- Timescales determined via Fermi light curve
  - The shortest variability timescale observed by Fermi-LAT during the VHE flare of PKS 1222+216 was 10.4 ± 6.2 days
- EIC region distance from core: 3.56pc (2.33pc for Ton 599)





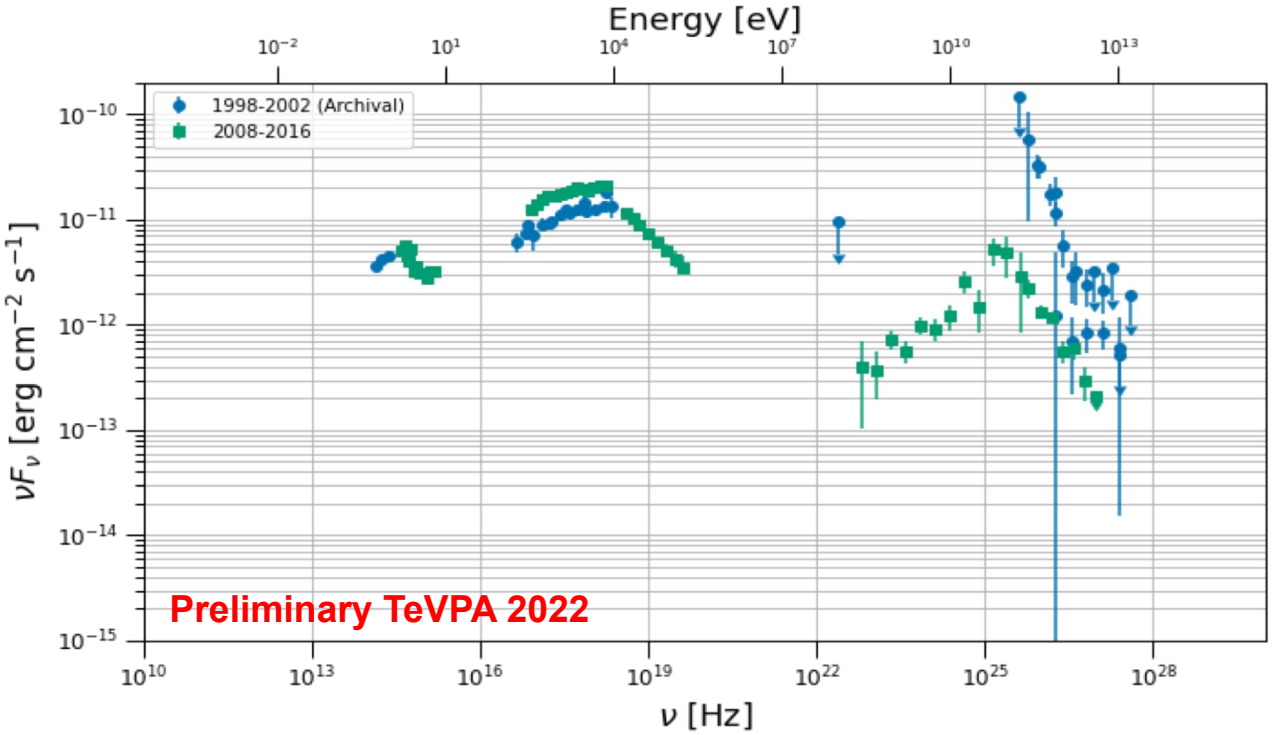
Left: Pure SSC model

Right: Includes EIC component

[C. B. Adams et al 2022 ApJ 924 95]

H 1426+428 flare

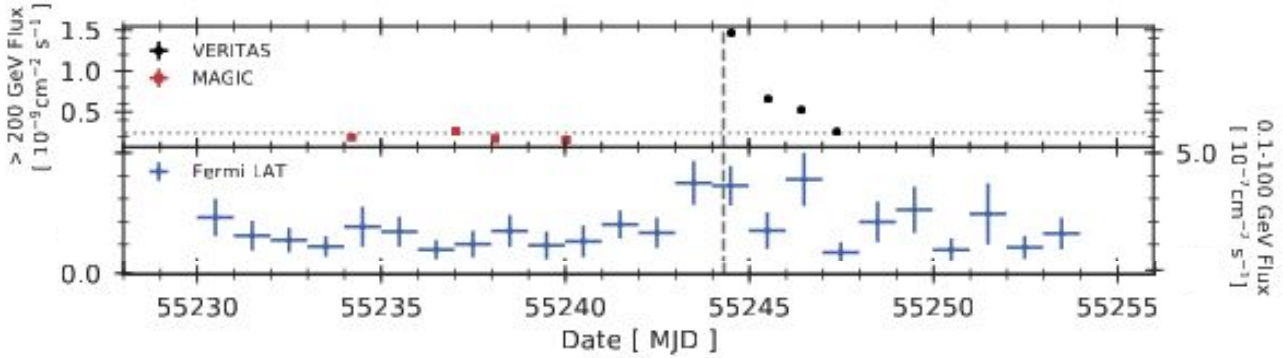
- Extreme high-frequency-peaked BL Lac at z = 0.129
- Not detected by any gamma-ray *satellites* until Fermi-LAT
- > 85 hours of VERITAS observations spanning 2008-2016: $\longrightarrow 14\sigma$ detection
- Moderate very high energy (VHE) flux variability
- Approximately constant high energy (HE) flux
- In 2021: increase in VHE & HE flux
- 2 papers planned



[O'Brien, *Multiwavelength observations of the extreme HBL H 1426+428*, TeVPa 2022]

Markarian 421 February 2010 flare

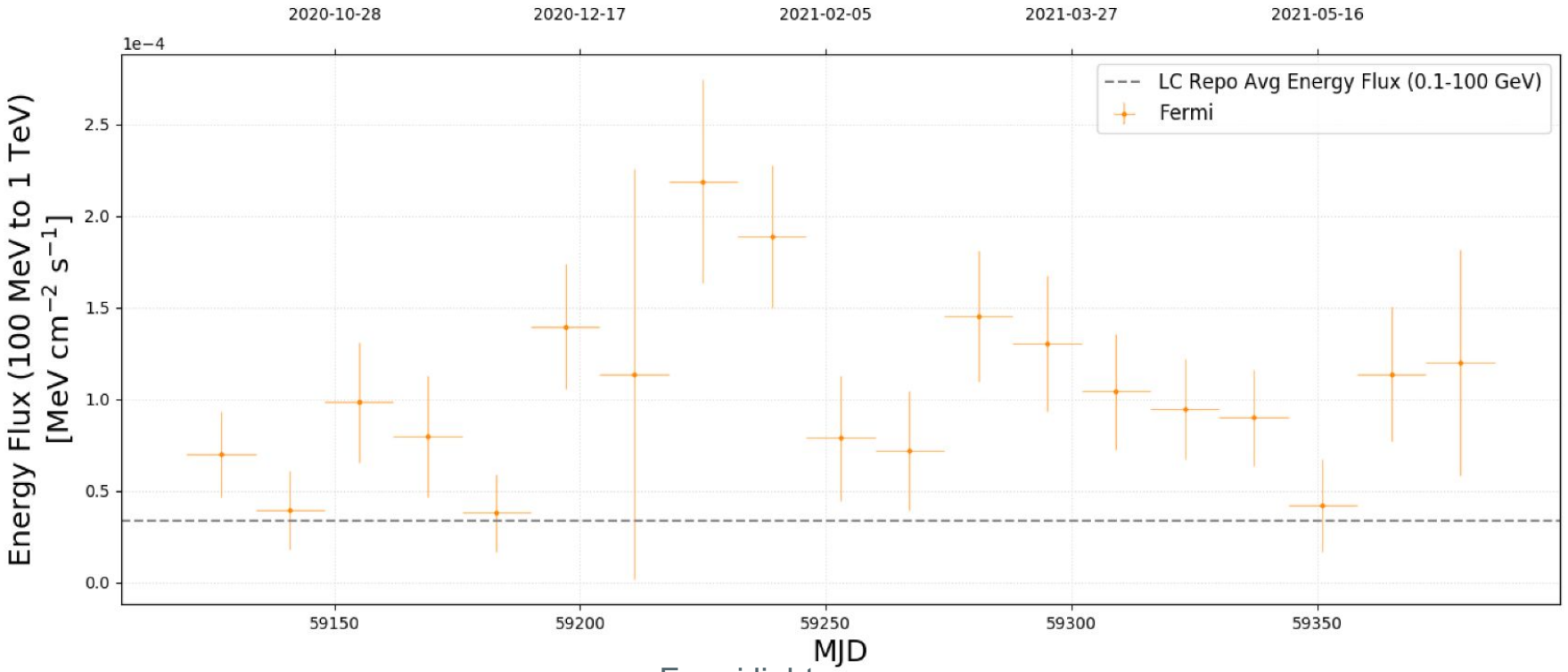
- HBL at z = 0.031 (closest BL Lac)
- VERITAS nightly monitoring of Markarian 421 (since 2018)
- Just prior to the observed TeV flare, a flare in both HE (*Fermi-LAT*, Abdo et al. 2011) and X-ray (MAXI, Isobe et al. 2010) was observed (without simultaneous VHE observations). This HE/X-ray flare triggered the VHE observations
- Unprecedented flare seen in Mrk 421 is difficult to explain by the classic single-zone synchrotron self-Compton model, in which variability in X-ray and VHE bands is expected to be correlated



[Abeysekara et al 2020]

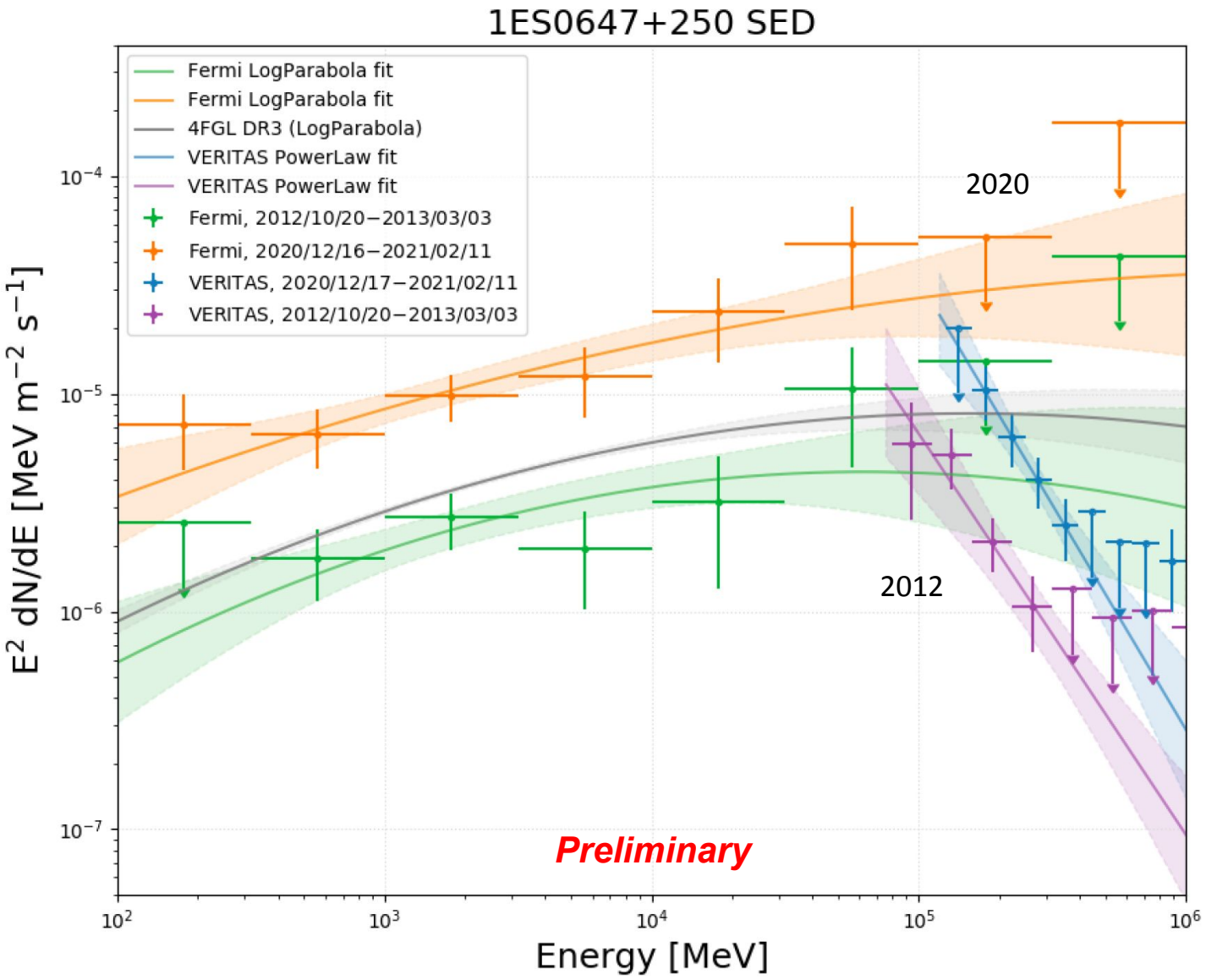
1ES 0647+250

- HBL, redshift unknown/uncertain
- VHE ATEL Dec 2020 (*MAGIC measures high flux state from the blazar 1ES0647+250*)
- LC Repo Average: 10 year average from the Fermi LAT Light Curve Repository, using a bin size of 1 month, and energy flux 0.1-100 GeV



Fermi light curve

1ES 0647+250



- Work in progress: building a multiwavelength SED
- Model SED with a synchrotron self-Compton model
- Possibly measure the redshift and constrain EBL

Summary

- VERITAS blazar program:
  - Unbiased surveys of blazars
    - FSRQs
    - HBLs → luminosity function
  - Expand the catalog of known VHE blazars
- Hundreds of hours of blazar observations per year
- Science drivers:
  - Understand high energy emission mechanisms, jet physics, blazar sequence, extragalactic background light
- VERITAS operations have been NSF funded through 2025
- We welcome collaboration!

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Thank you for your attention!

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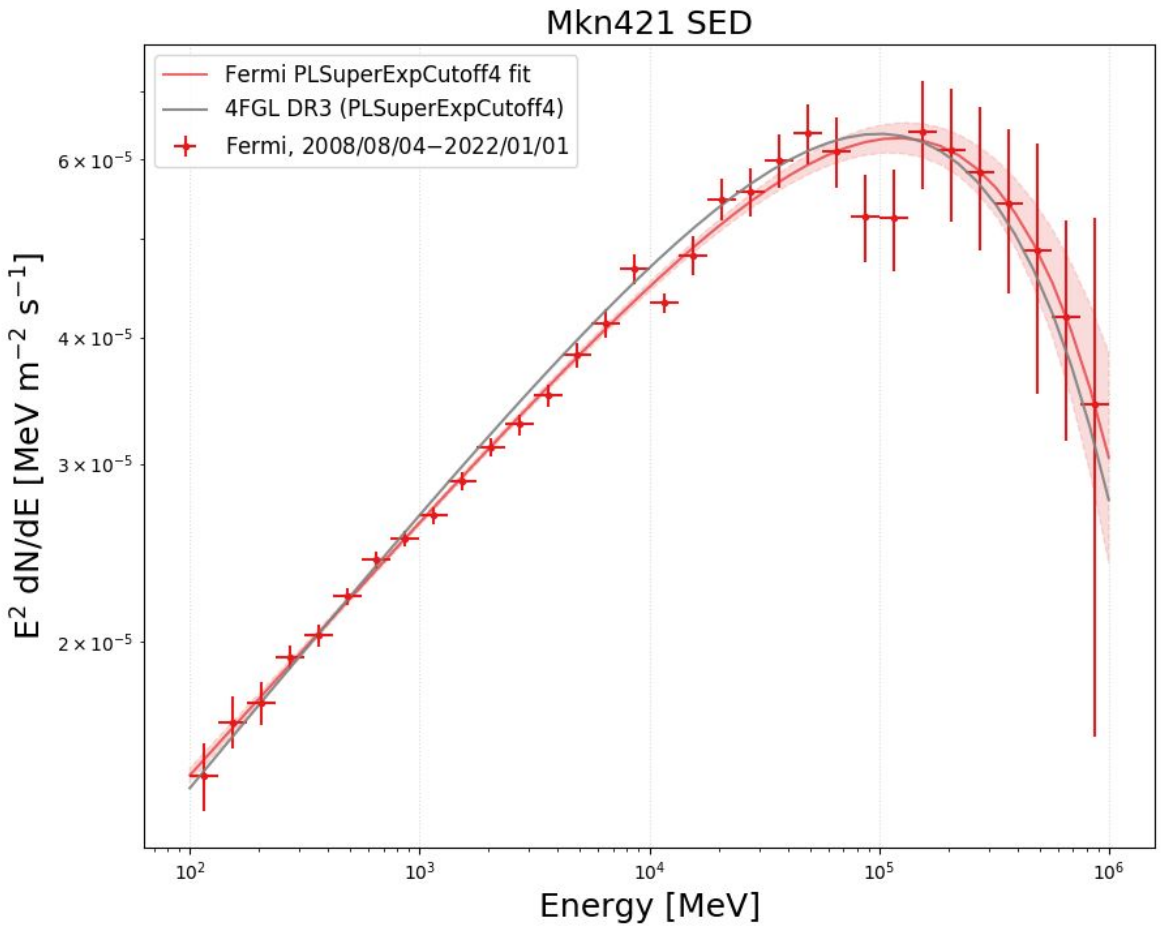
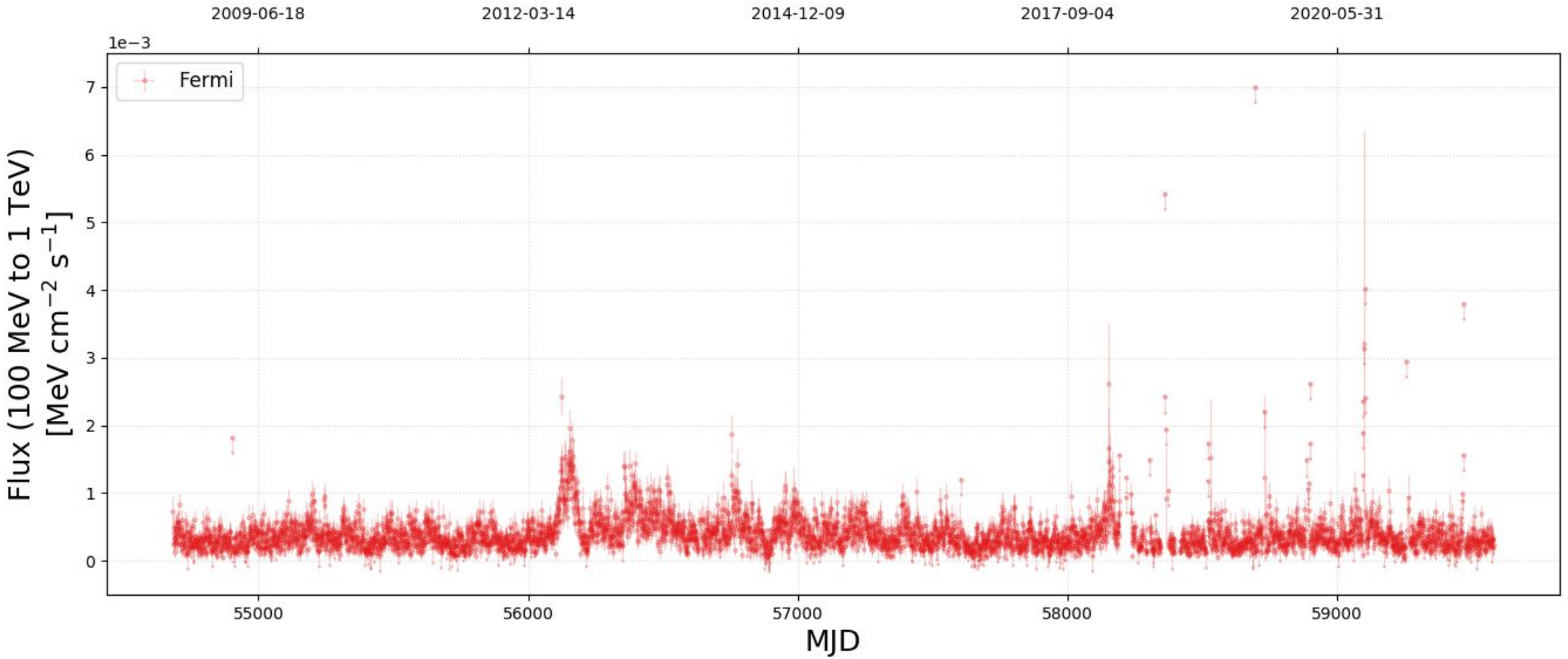
Extra slides

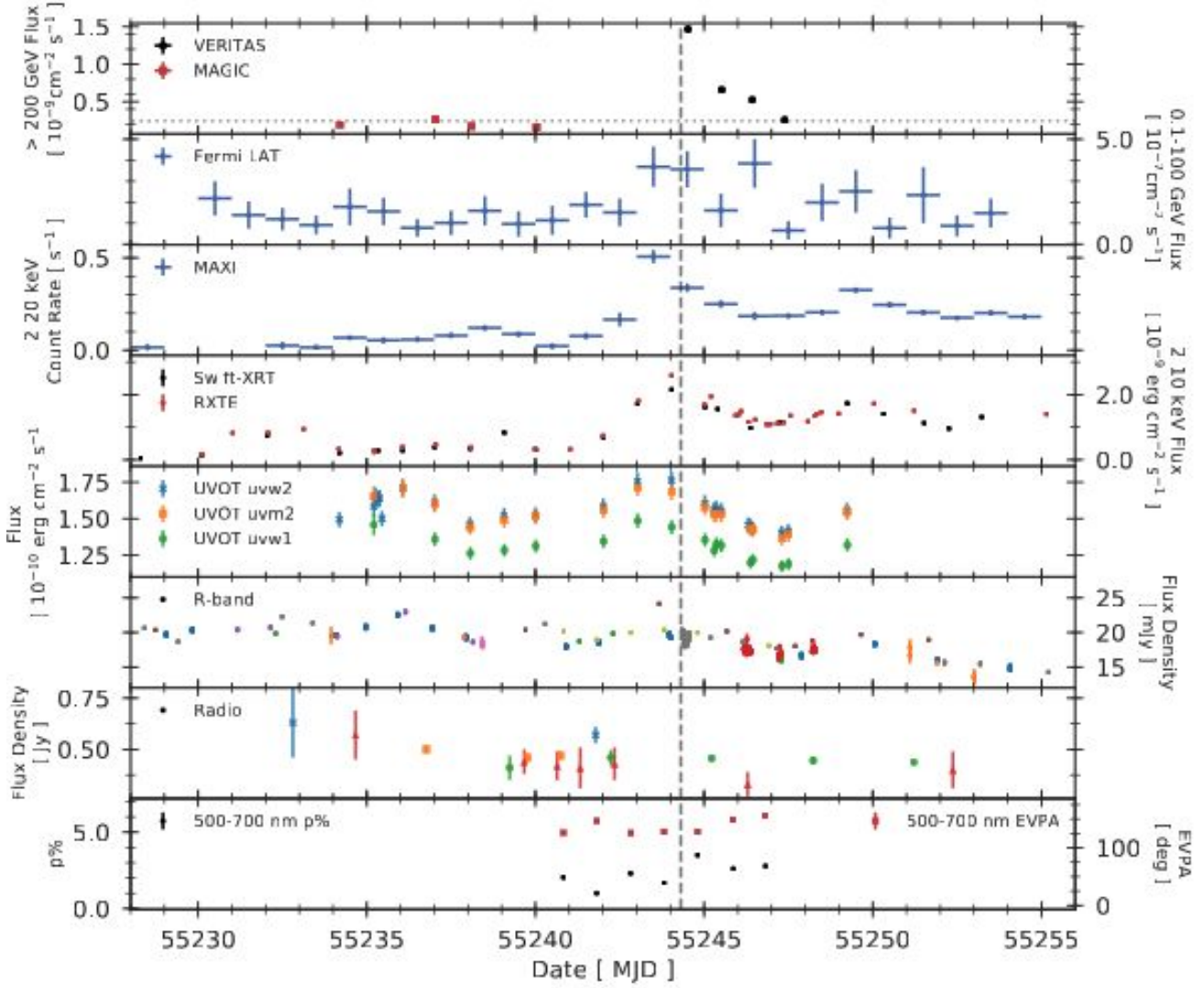
Markarian 421 SED



Markarian 421 light curve



Markarian 421 flare

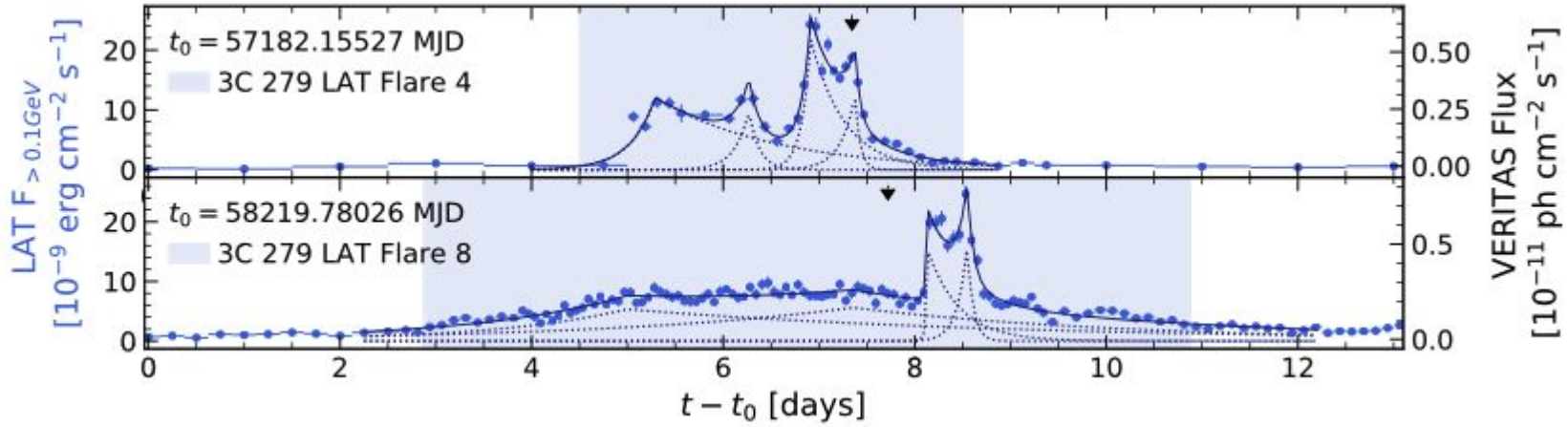


[Abeysekara et al 2020]

[Abeysekara et al 2020]

3C 279 flare

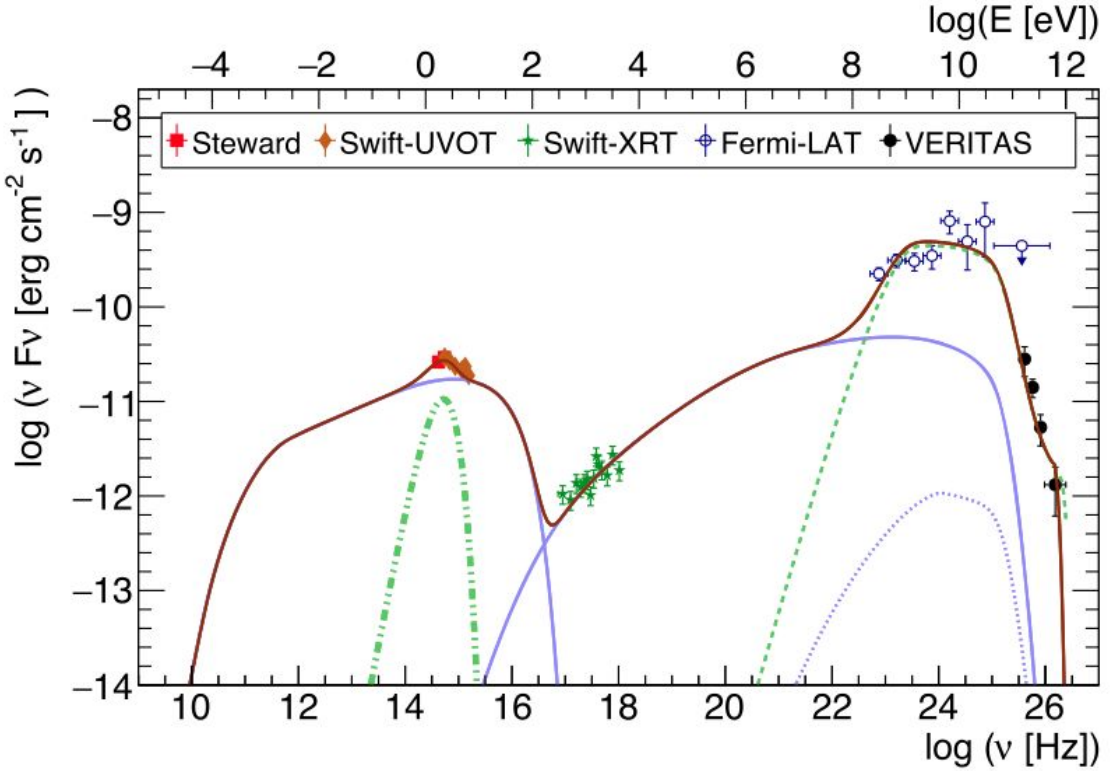
- FSRQ (flat spectrum radio quasar) at z = 0.536
- Fermi-LAT used to identify flares and variability timescale was determined
  - Each flare lasted between 1 and 11 days
  - Rise and decay times range from timescales of days to less than 1 hour
- *No* VHE activity was observed during multiple flares of 3C 279
- Using Fermi-LAT: find subhour-scale variability in 3C 279 → suggesting that extremely compact emission regions may be present within the jet



[C. B. Adams et al 2022 ApJ 924 95]

Ton 599 flare

- FSRQ (flat spectrum radio quasar), at z = 0.725
- Flare in 2017
- The shortest variability timescale of Ton 599 observed by LAT during its VHE fl are was 11.8 ±1.1 days
- SED is Compton dominated → EIC (external inverse Compton) component



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