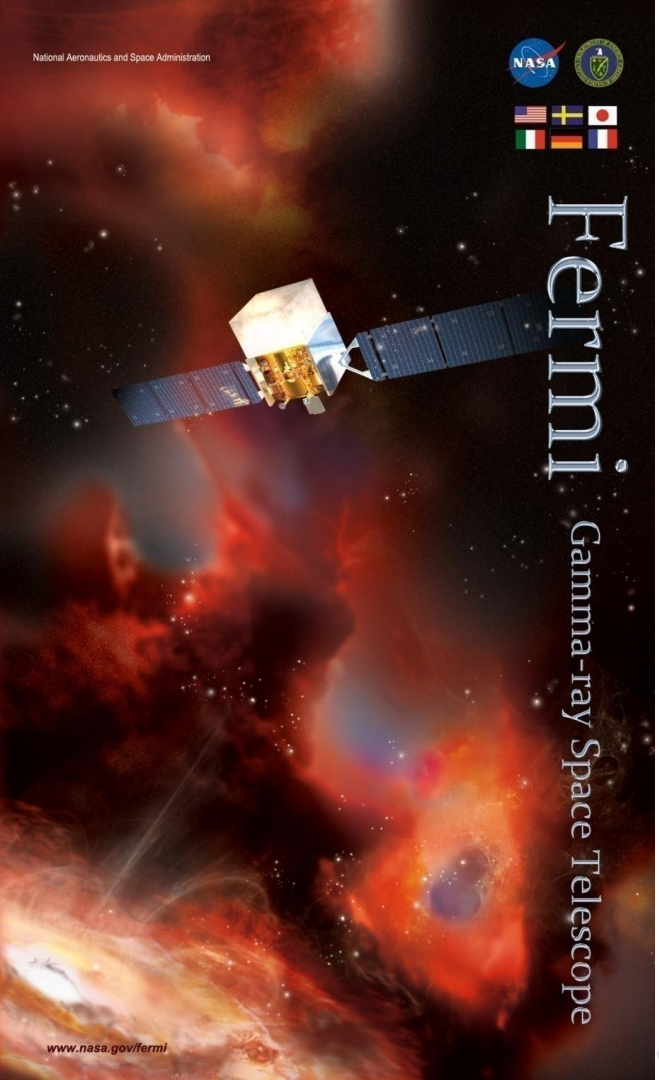


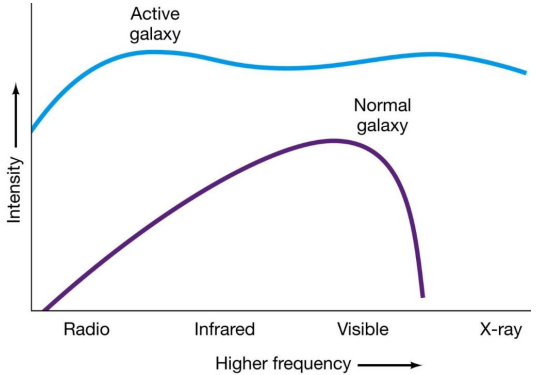
Towards building a history of extreme explosions

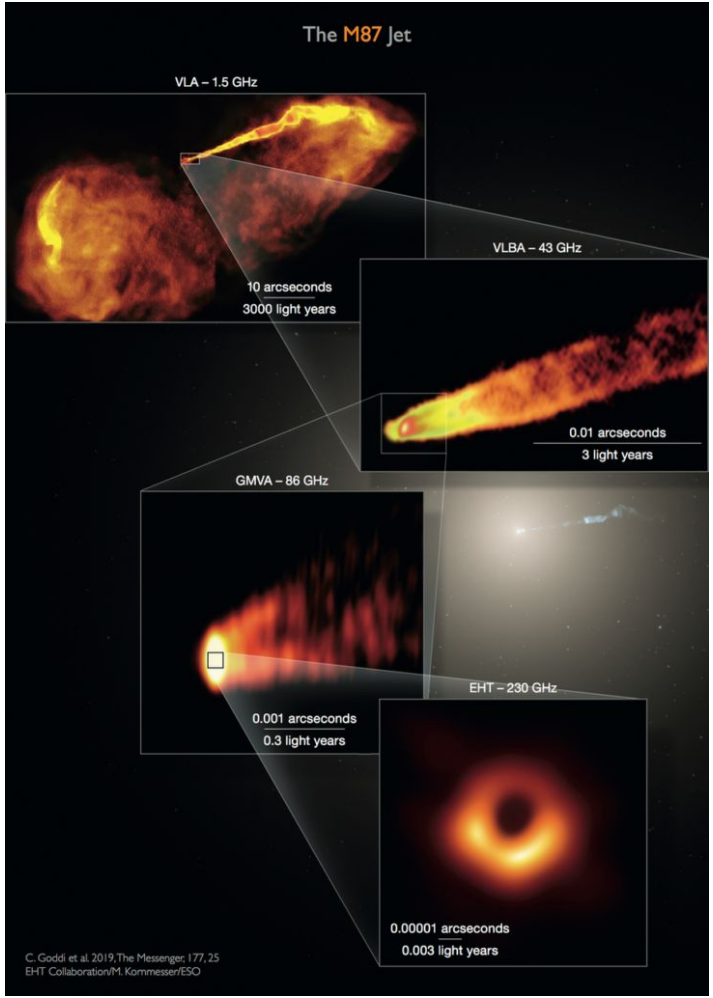
GeV flare characteristics in blazars

Janeth Valverde
UMBC / NASA GSFC

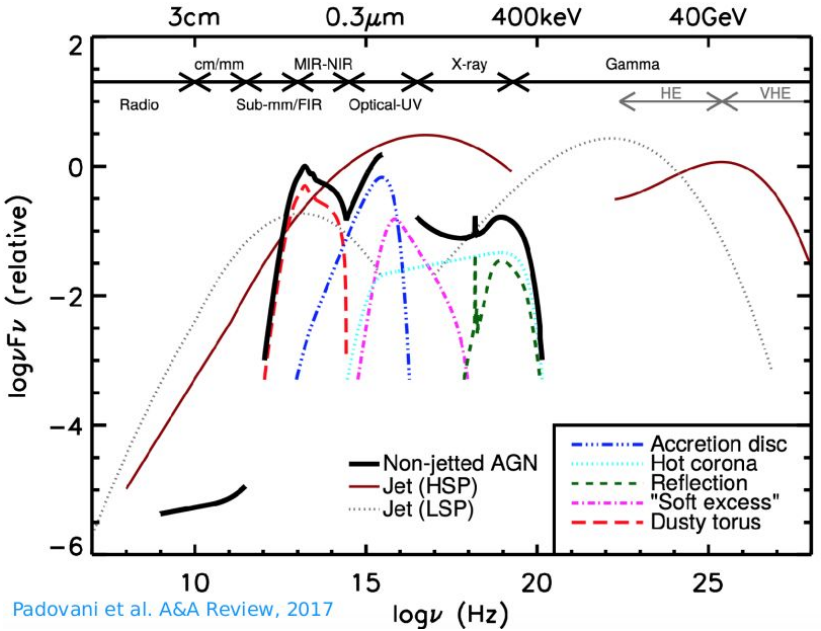
What is an AGN?

- A few % of galaxies.
- Activity centered in the galactic nucleus.
- Rapid variations => extremely compact source.
- Central supermassive black hole (SMBH) $\gtrsim 10^9$ solar masses, surrounded by accretion disk.
- Strong twisted magnetic fields (B), possibly confine particles in the jet (Blandford & Znajek 1977, Blandford & Payne 1982).
- Billions of light years away => possibly an early stage in development.

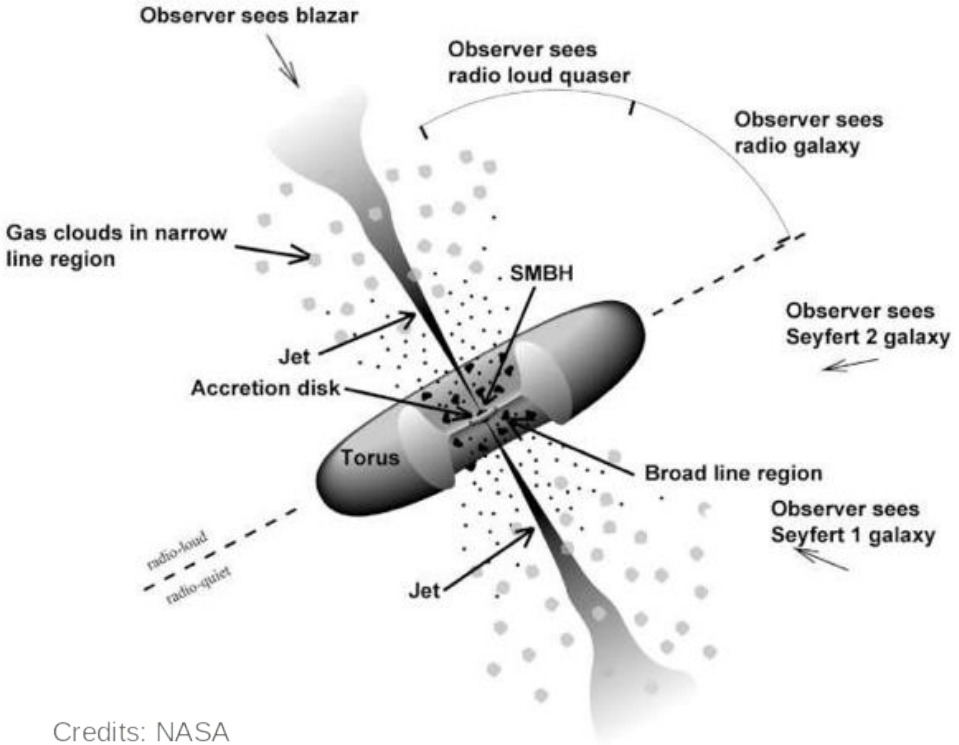




What we see depends on how we see it



Padovani et al. A&A Review, 2017



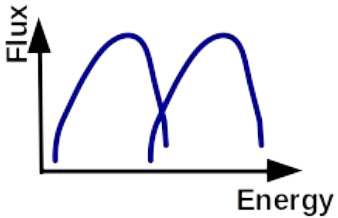
Credits: NASA

Blazars

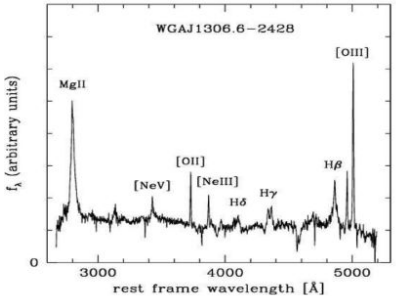
- A few % of AGNs, radio loud.
- Jet points at us (animation).
- Can be flat spectrum radio quasars (FSRQs, broad emission lines) or BL Lac objects with weak or no emission or absorption lines.
- Large amplitude variability.
- Polarization.
- Relativistic beaming, Doppler factor:

$$\delta = \frac{1}{\gamma(1 - \beta\ \cos(\theta))}, \qquad \gamma = (1 - \beta^2)^{-1/2}$$

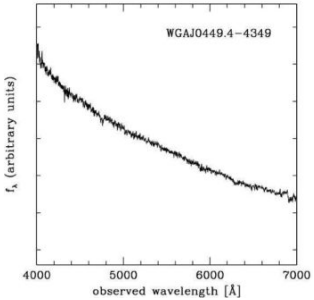
- Characteristic spectral energy distribution (SED).

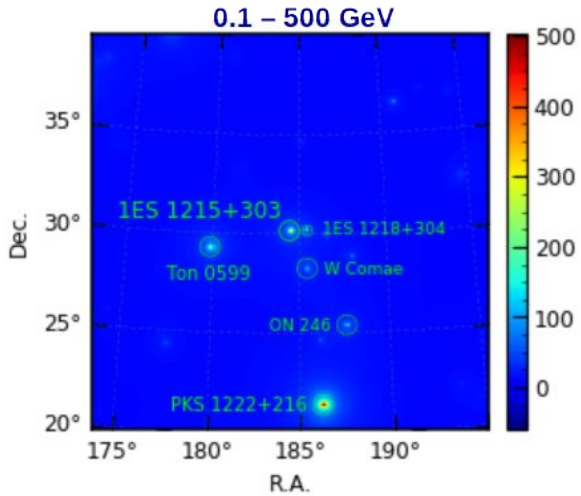


FSRQs

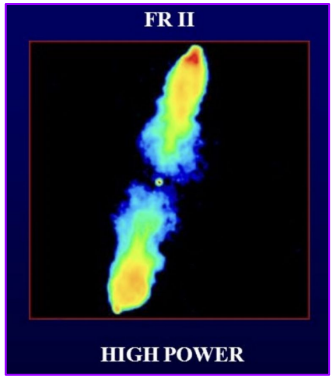


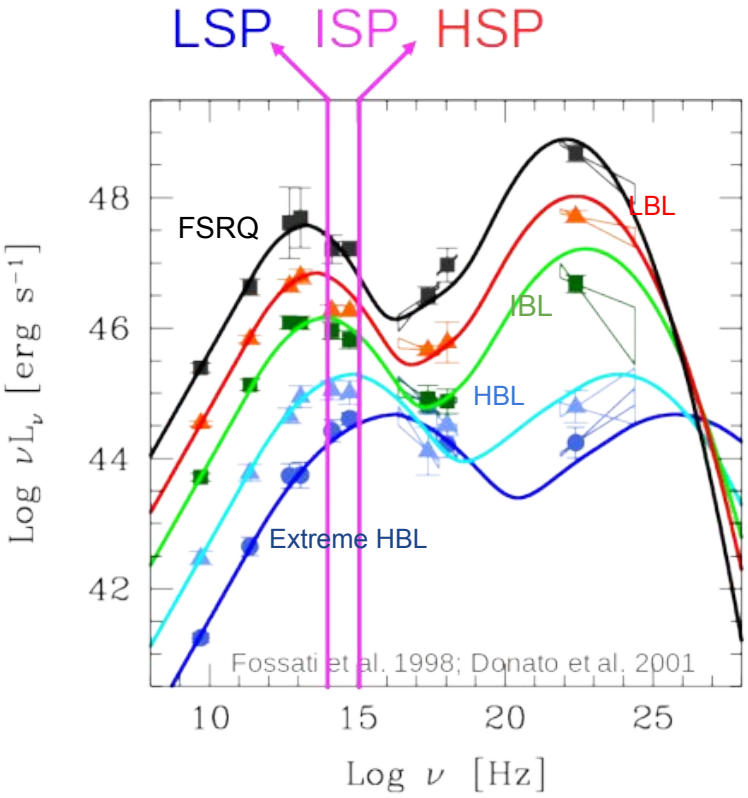
BL Lacs



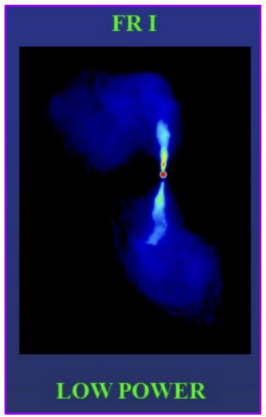


Blazar classification

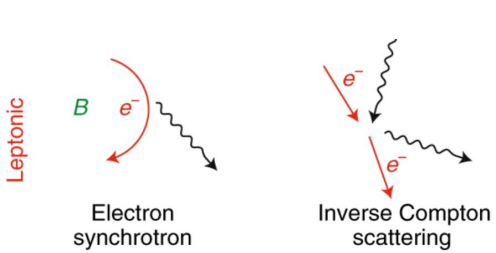


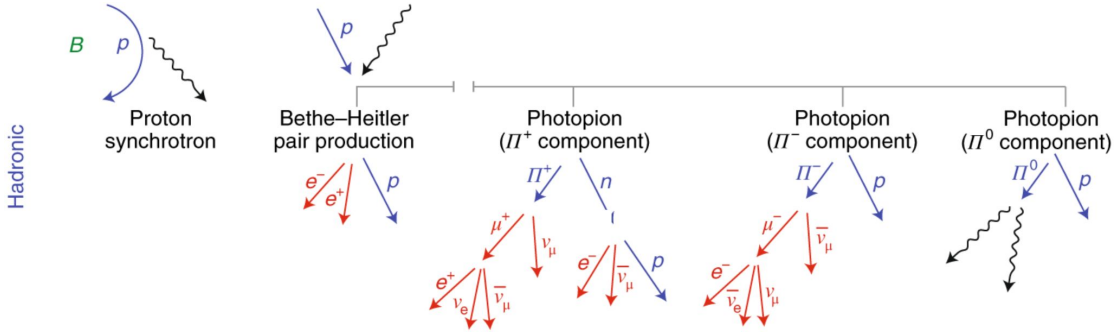


- BL Lacs subtypes: Low-, intermediate- or high-synchrotron-peaked (LSP, ISP, HSP; Abdo et al. 2010).
- Based in Padovani & Giommi (1995; ratio 5 GHz/1 keV flux) for BL Lac objects: LBL, IBL, HBL.



Models of blazar emission



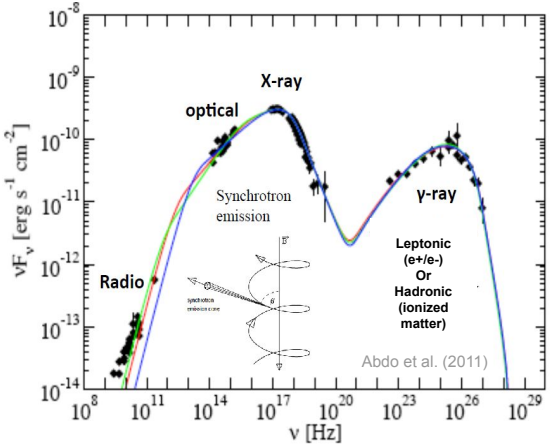


Leptonic

- HE emission likely from inverse Compton scattering by same e-/e+ that emitted synch: synchrotron self-Compton (SSC).
- Upscatter of low-energy photons from broad-line region, disk or torus: external inverse Compton (EIC).
- Synch. & Compton variations correlated.

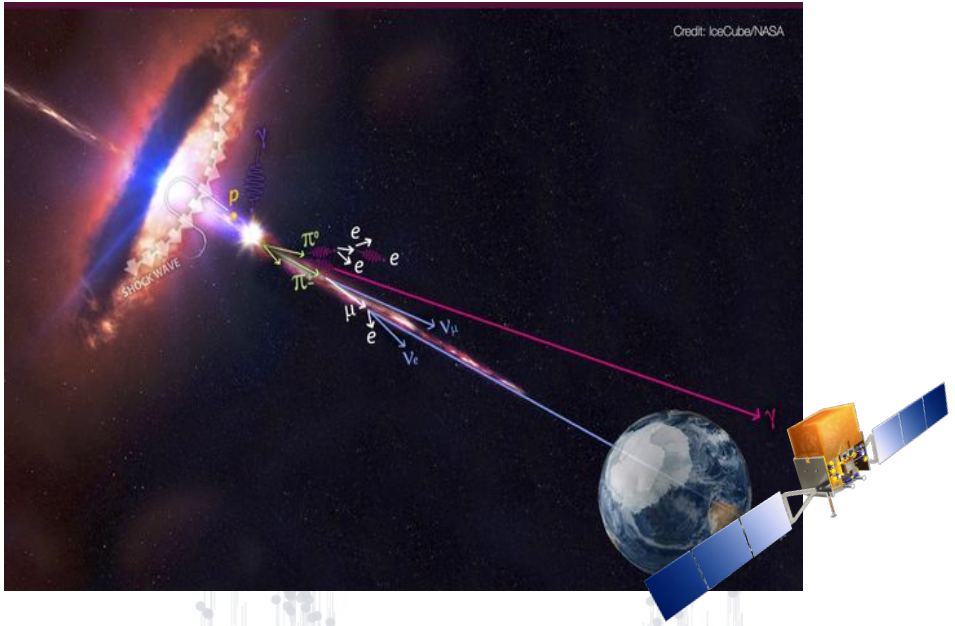
Hadronic

- HE emission from ultra-relativistic e-/e+ & protons.
- γ-ray emission via e.g. proton synchrotron or photo-pion prod.
- Synch. & Compton emission from secondary products of π±.
- Production of neutrinos.



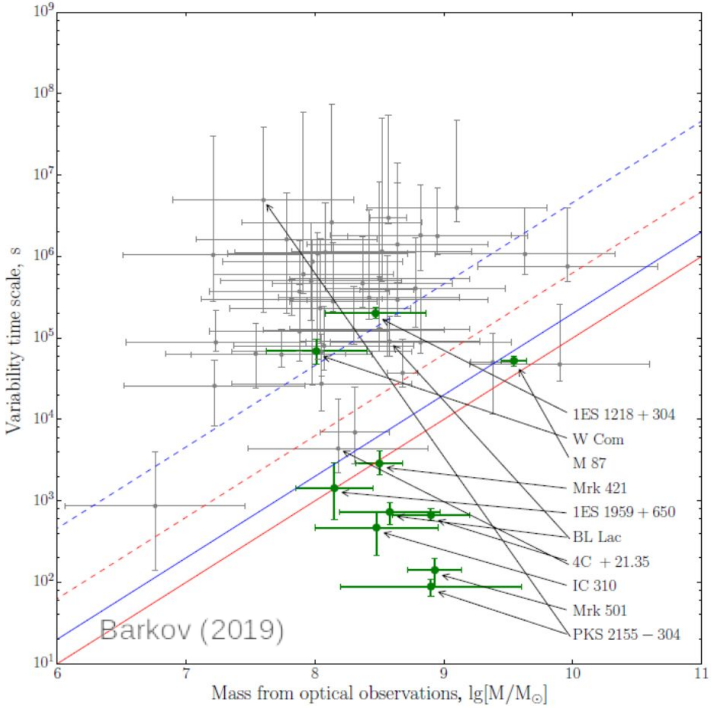
Motivation

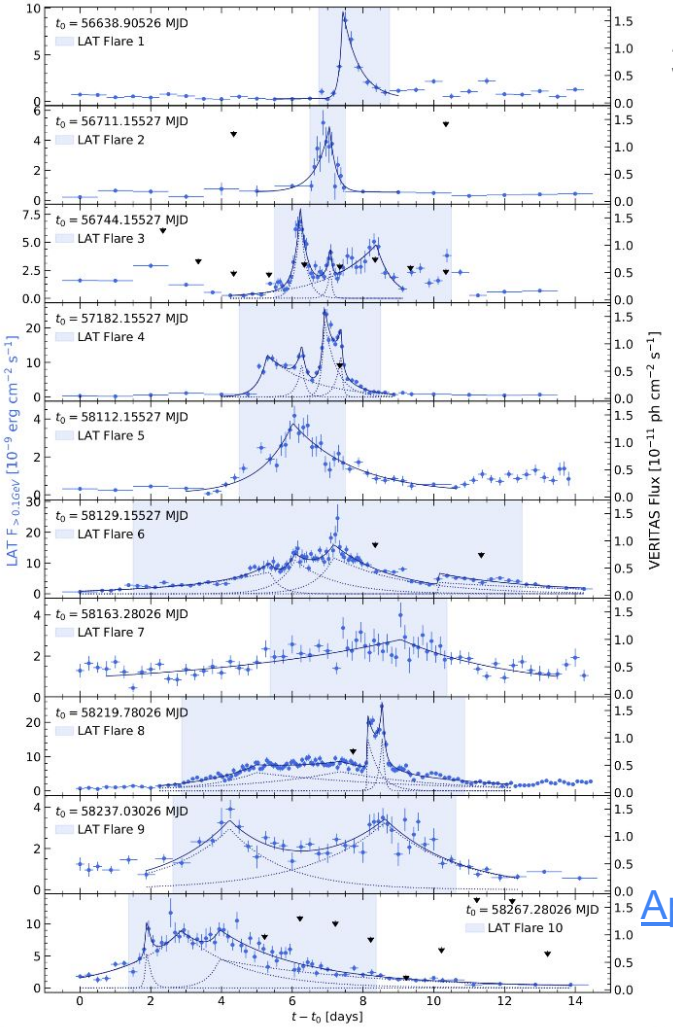
- To understand the physics that underlies variations:
  - Unobservable activity in accreting objects.
  - Precession of collimated relativistic plasma.
  - Nature of the parent particle population.
  - Changes in the field strength.
  - Particle acceleration in the emission zone.
  - Characteristics per source class
- Time-domain and multi-messenger (MM) astrophysics:
  - Correlations with gamma-rays.
  - Real time alerts in different timescales and levels of activity.
  - Duty cycles.



Generating mission-long well-sampled Fermi-LAT light curves of steady sources is computationally expensive
➥ Use of the publication-quality, mission-long, continuously updated Fermi-LAT Light Curve Repository (LCR) data.

Gamma Flare Timescales



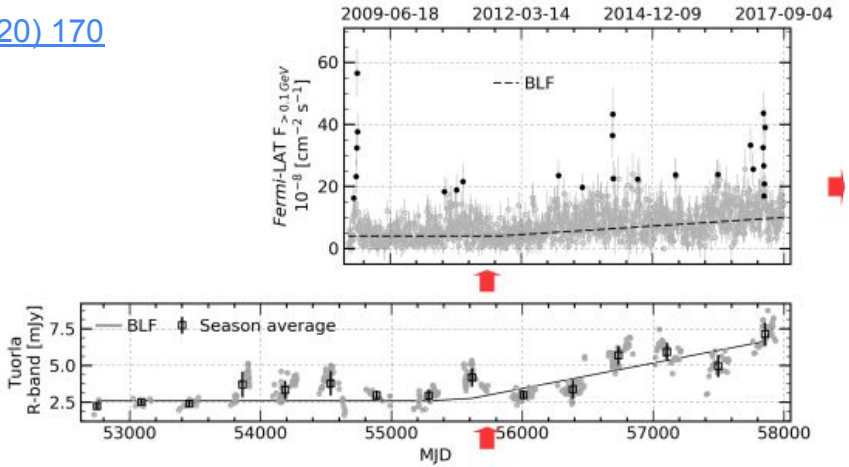


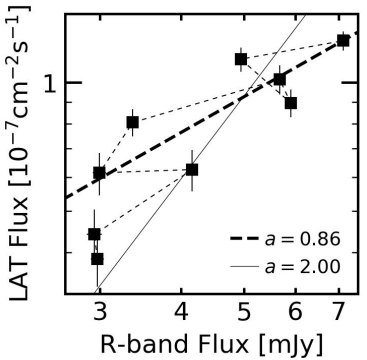
3C 279

[ApJ 924 (2022) 95]

Long-term GeV-optical flux increase: Flare?

ApJ 891 (2020) 170





LAT: linear increasing trend
inconsistent with stochastic modeling
@ ≈ 3.3σ (from simulated LCs).

Continuous increase since 2011

Jet precession: X

No strong radio-knot oscillation/ shift
No clear increase of radio luminosity
No jet broadening from stacked VLBI images

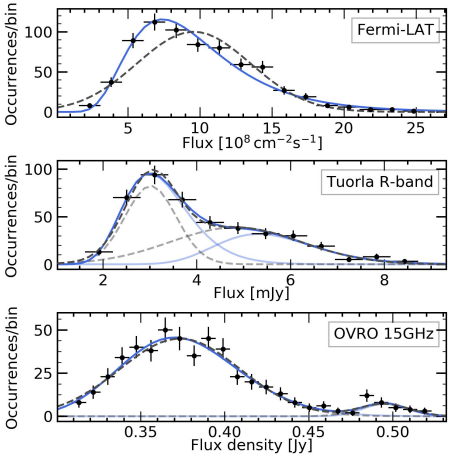
Accretion process: ~ V

Timescale consistent with the falling time considering the SMBH mass and an ADAF disk

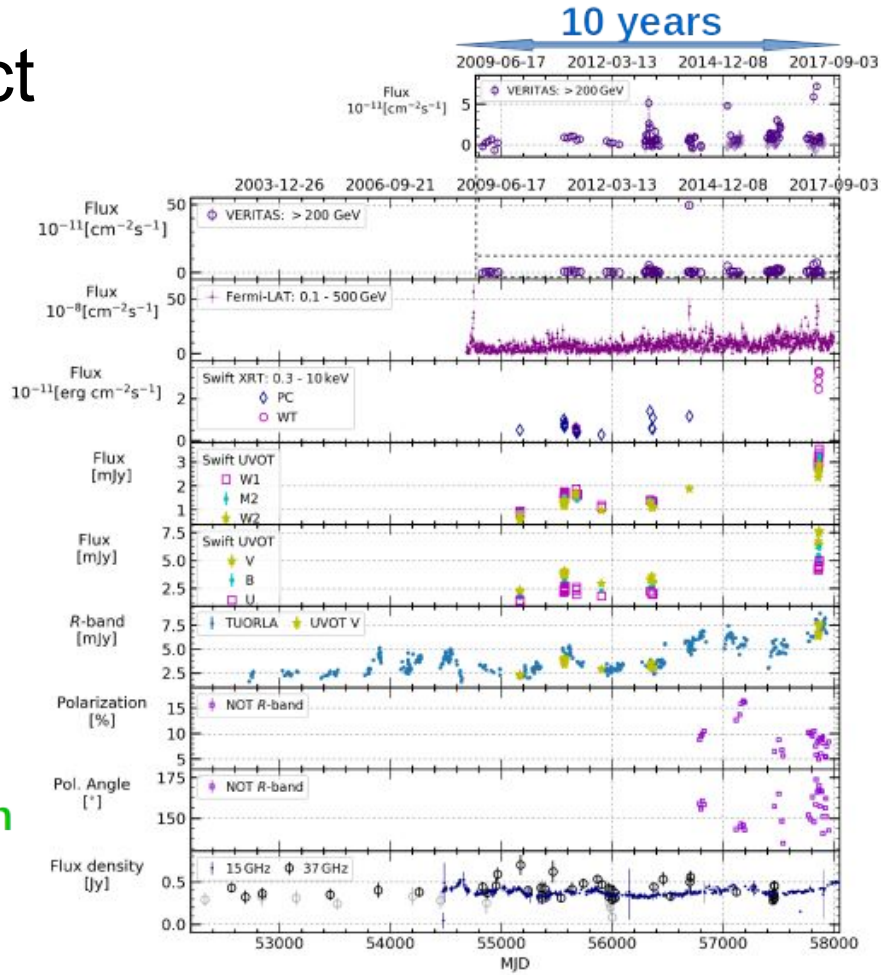
$$\tau_{ff} = 4.63\times10^{-5}\left(\frac{r}{1.0\times10^{3}r_g}\right)^{3/2}\left(\frac{M_{\rm BH}}{10M_\odot}\right)\text{days} \simeq 8.7\ \text{years}$$

Duty cycle: BL Lac object

ApJ 891 (2020) 170

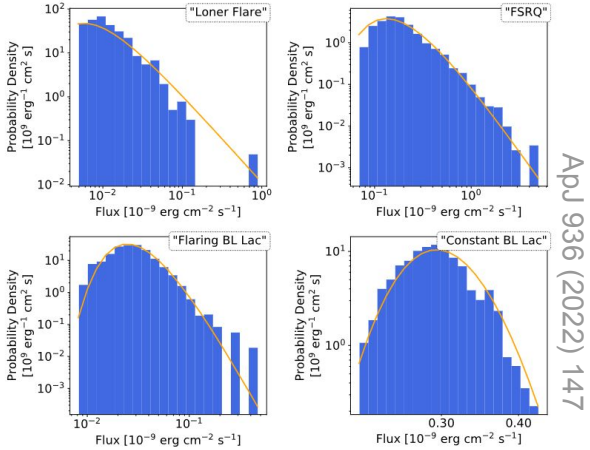


- TeV γ-rays
- GeV γ-rays
- X-ray
- UV-Optical
- Optical
- Optical polarization
- Radio

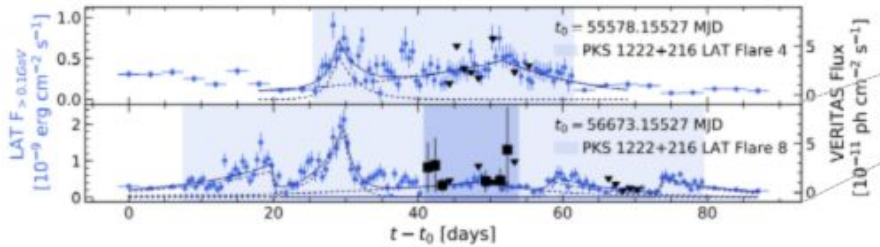


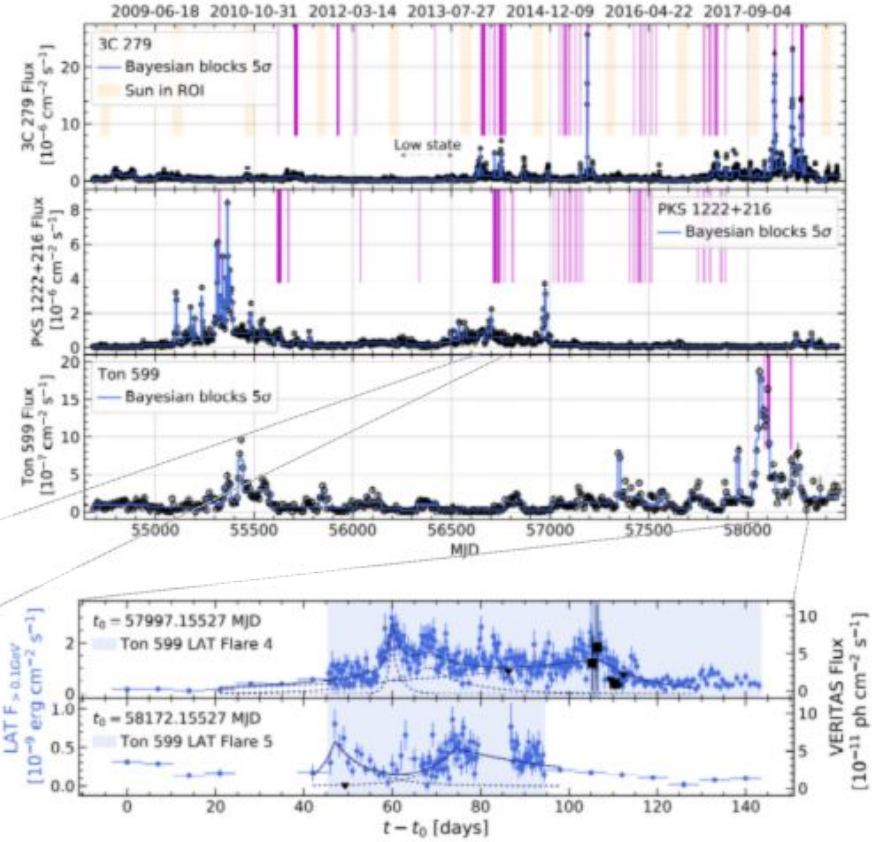
Duty cycle: FSRQs

[ApJ 924 (2022) 95]



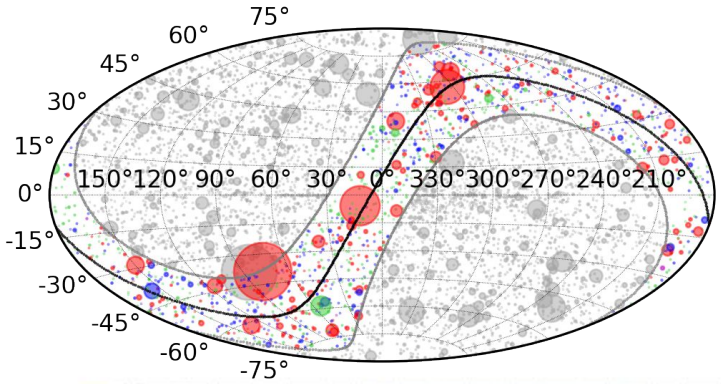
ApJ 936 (2022) 147

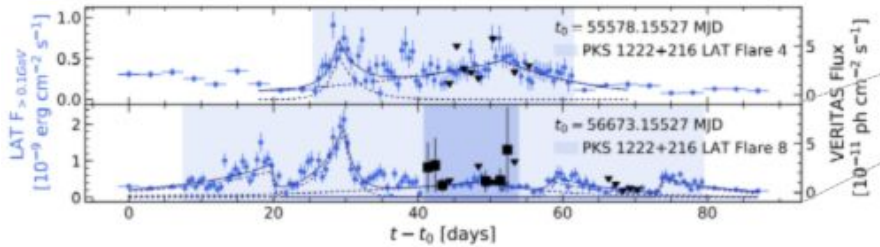


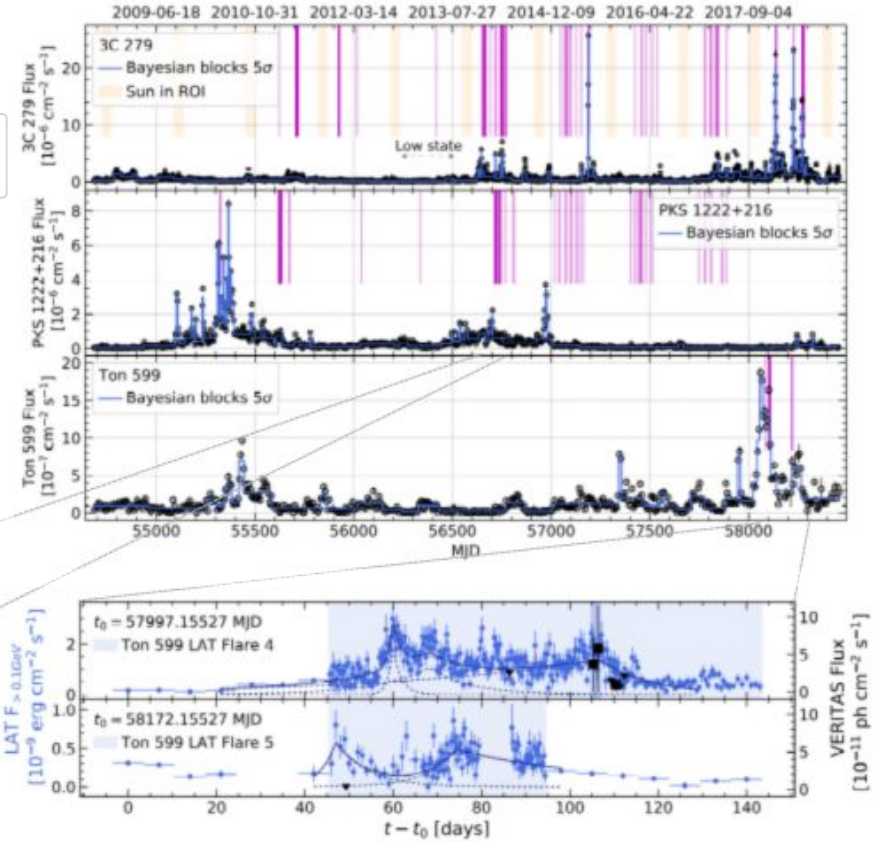


Watch out for the Sun & Moon in the ROI!

[ApJ 924 (2022) 95]



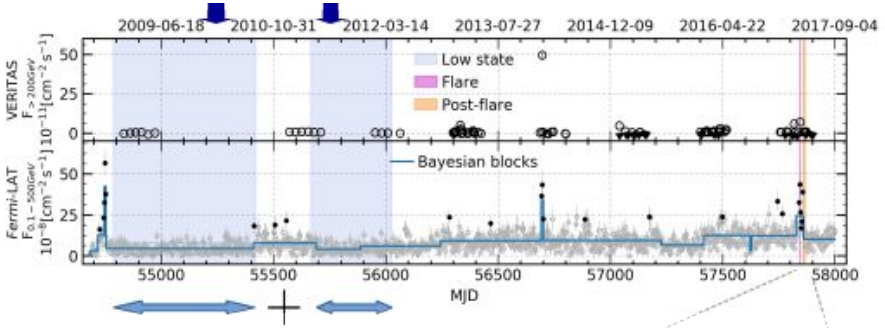


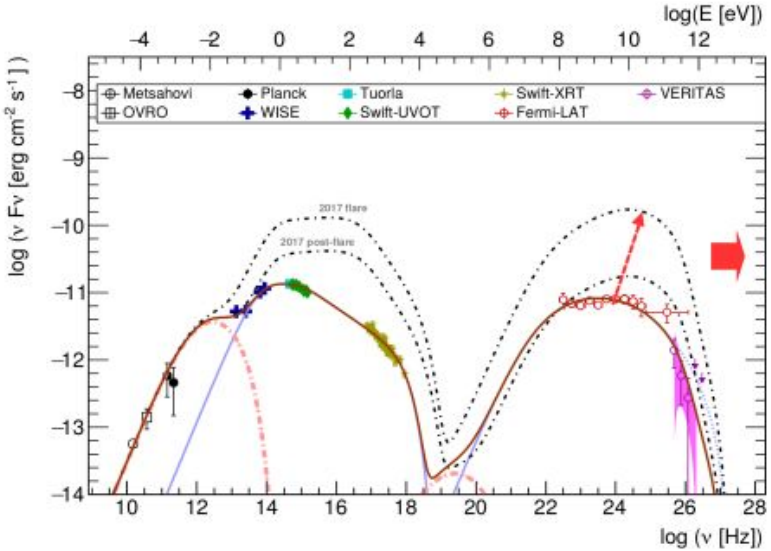


Careful with Solar and Lunar contamination!
3C 279 is 0.2 front the ecliptic.

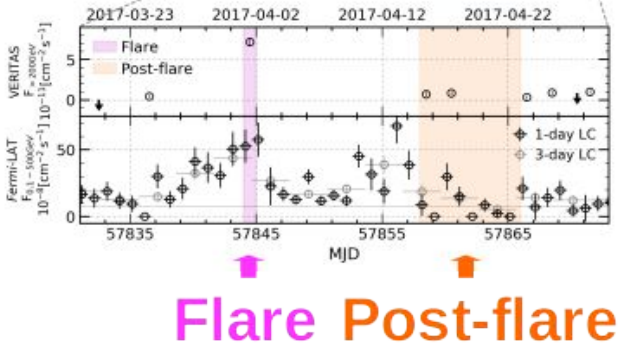
Low vs flaring states: Spectral characteristics ➥ Acceleration mechanisms

[ApJ 891 (2020) 170]





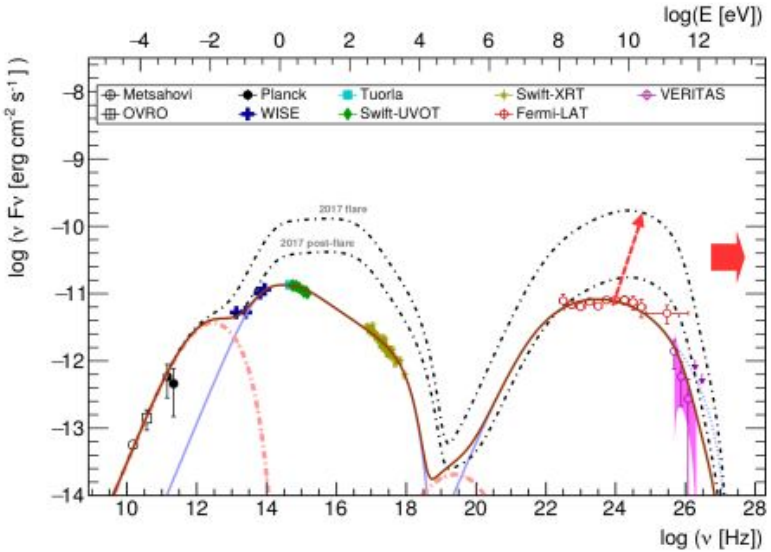
$$K_1 \times 3$$
$$B \times 2.4$$
$$\gamma_{brk} \times 4.5$$
$$n_2 \times 1.2$$



Flare **Post-flare**

Low vs flaring states: Spectral characteristics ➥ Acceleration mechanisms

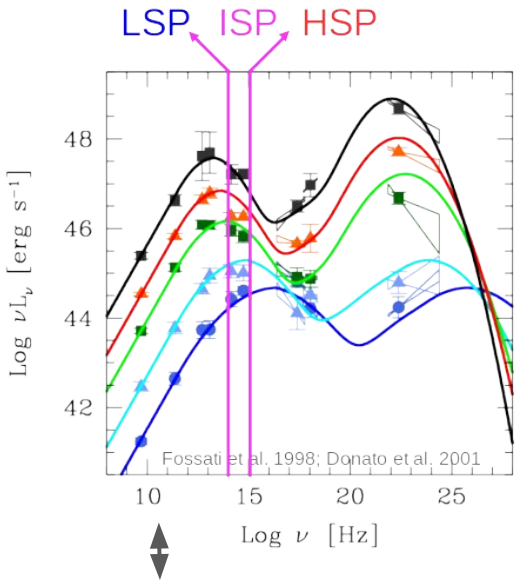
[ApJ 891 (2020) 170]

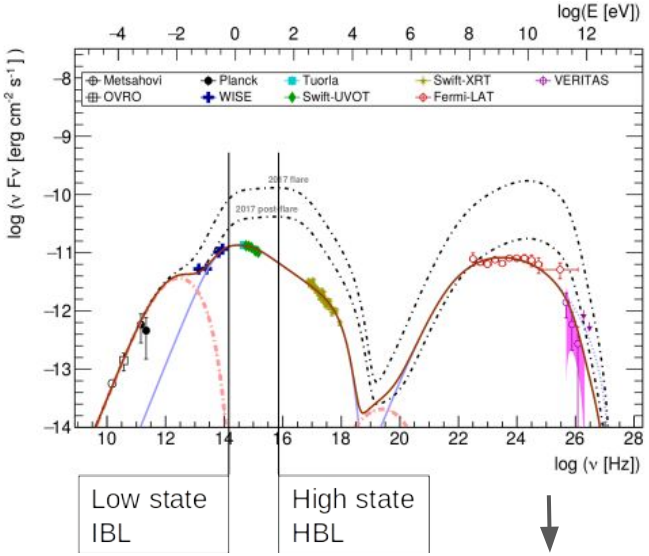


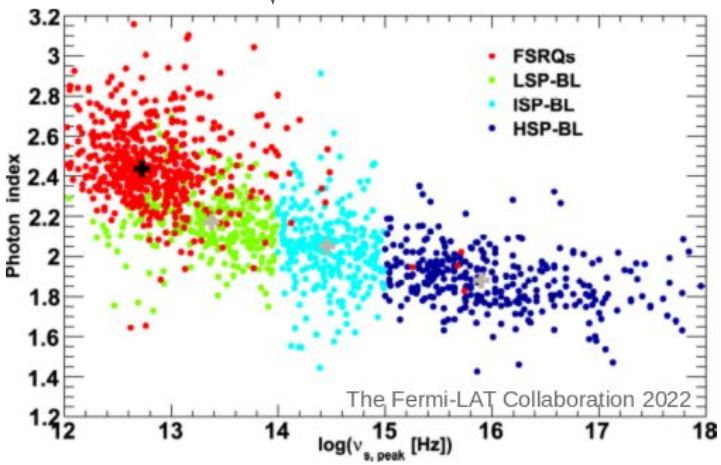
$K_1 \times 3$
$B \times 2.4$
$\gamma_{brk} \times 4.5$
$n_2 \times 1.2$

Want to learn more about SED modeling?

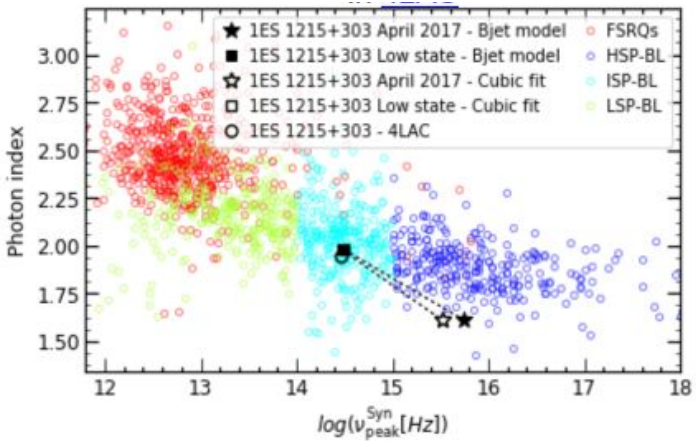
Check out Josh Rolfe's & Daniel Barr's Posters 13 & 15!







ApJ 891 (2020) 170

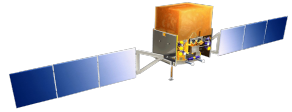


LCR
The Fermi Large Area Telescope
Light Curve Repository

https://fermi.gsfc.nasa.gov/ssc/data/access/lat/lcr/

ApJS (2023), 265, 31

Fermi
Gamma-ray
Space Telescope



Fermi-LAT LCs.

Public database since Dec 2021.

Publication ready.

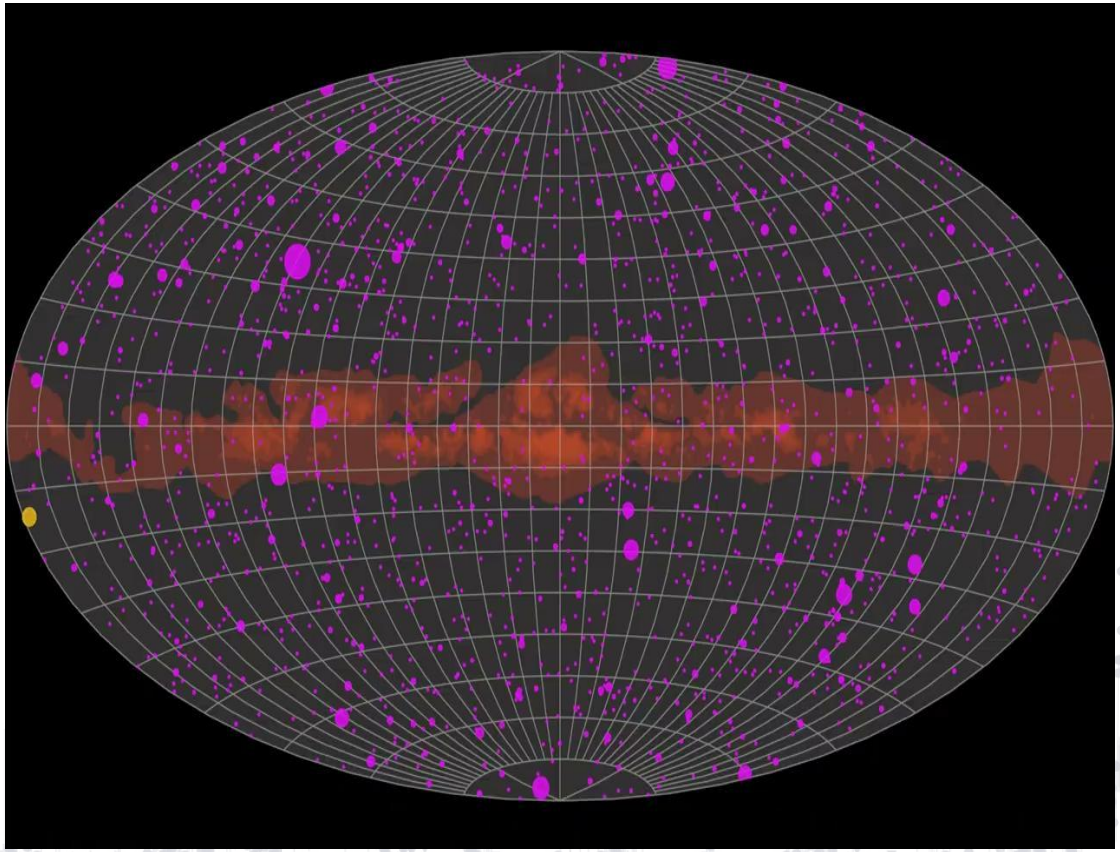
1525 sources (26% of 4FGL-DR2).

3-, 7- & 30-day cadence.

Spectral information.

Entire mission (> 16 years).

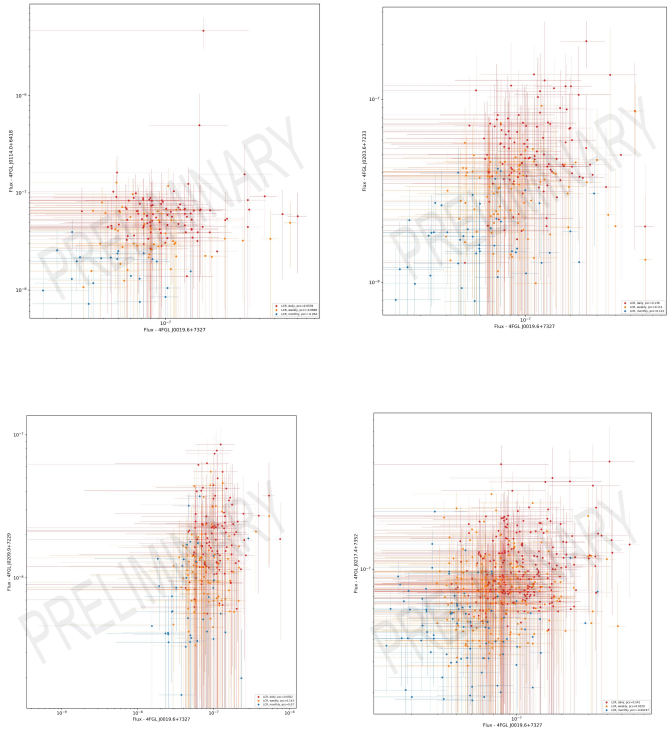
Continuously updated.

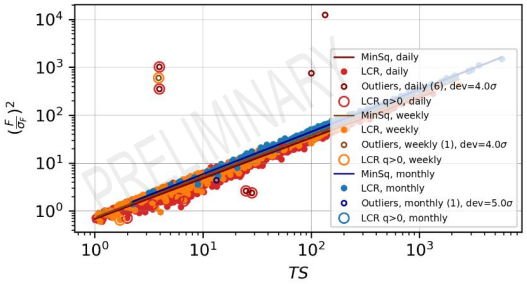


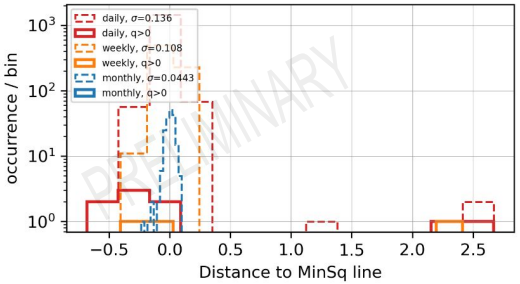
~90% AGN

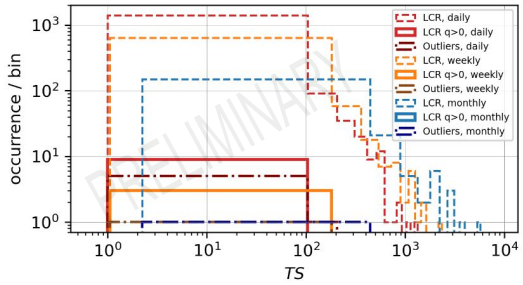
Mostly blazars.

Automating the validation process

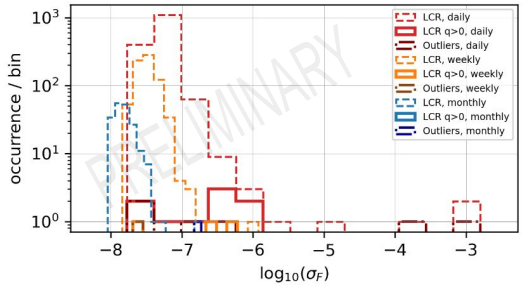


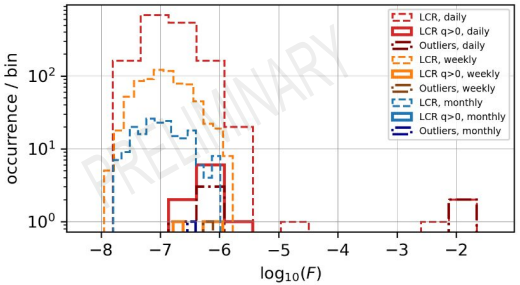






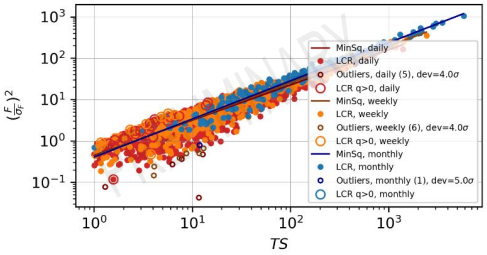
FSRQ 4C +28.07
4FGL J0237.8+2848
Index fixed

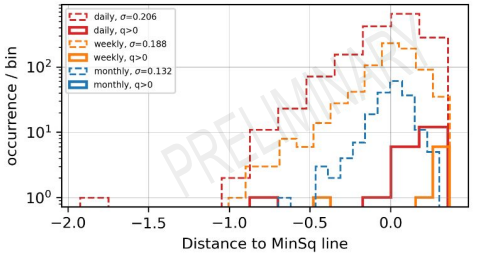


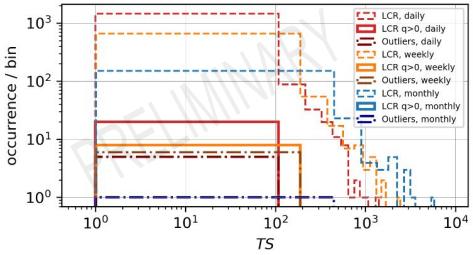


Automating the validation process

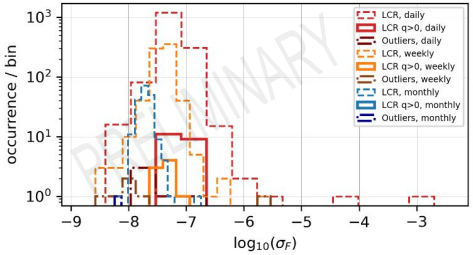
- Removes undesired data upfront:
  - With absent TS, flux, flux error, index or index error.
  - TS < 0.
  - Flux error or index error == 0.
- Excludes data from analyses that did not converge).
- Excludes outliers from significance proxies according to desired deviation thresholds.
- Prints distances to the Sun and Moon when closer than 12 deg.
- Examines possible correlations with light curves of variables sources within 12 deg from the target.

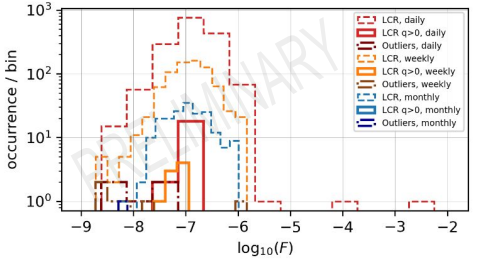


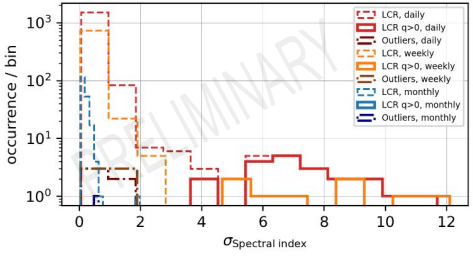


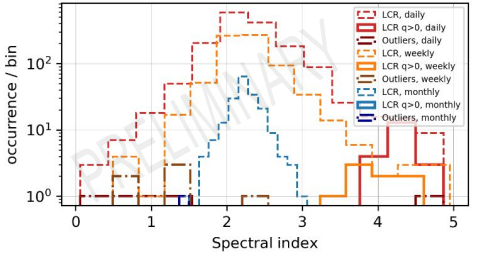


FSRQ 4C +28.07
4FGL J0237.8+2848
Index free









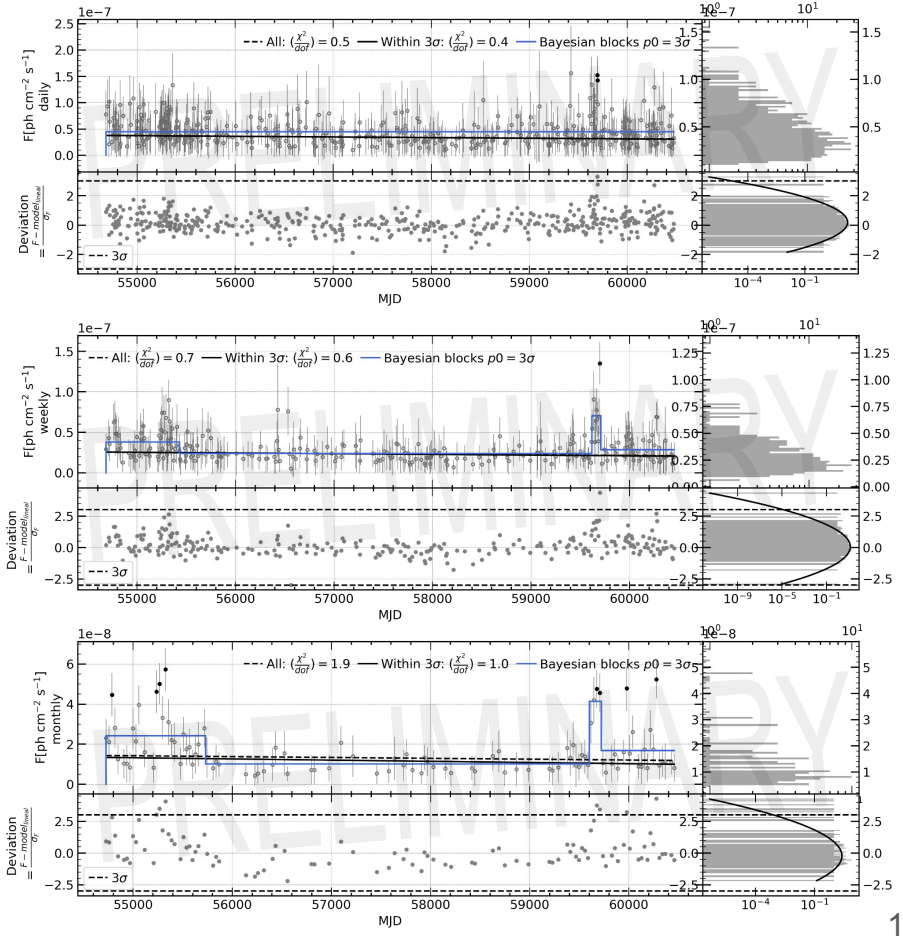
Duty cycle

Important to guide multi-wavelength observations. Exploits unique ability of the Fermi-LAT to scan the entire sky.

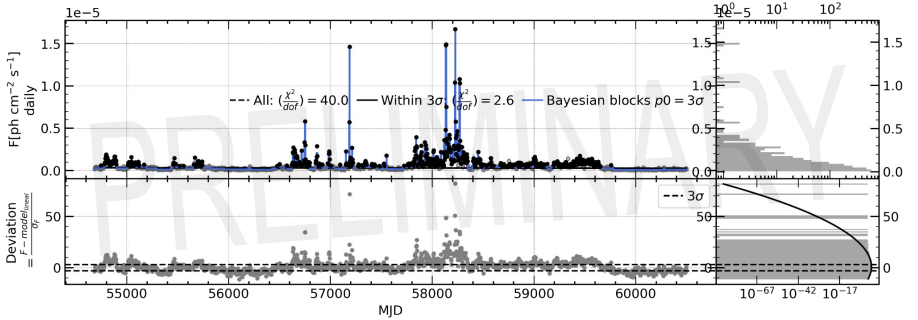
Procedure:

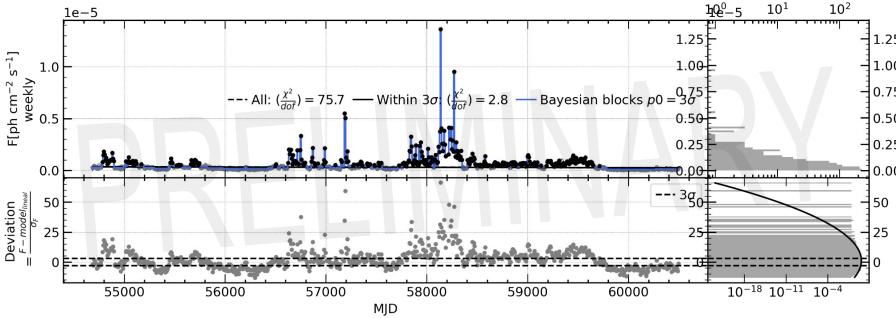
- Validate LCR light curves.
- Select light curves with >100 data points:
  - Daily: 1519 sources
  - Weekly: 1506 sources
  - Monthly: 775 sources
- Recursively fit a linear baseline.
- Select the threshold of activity. At >3 sigma:
  - Daily: 775 (out of 1519) sources
  - Weekly: 833 (out of 1506) sources
  - Monthly: 637 (out of 775) sources

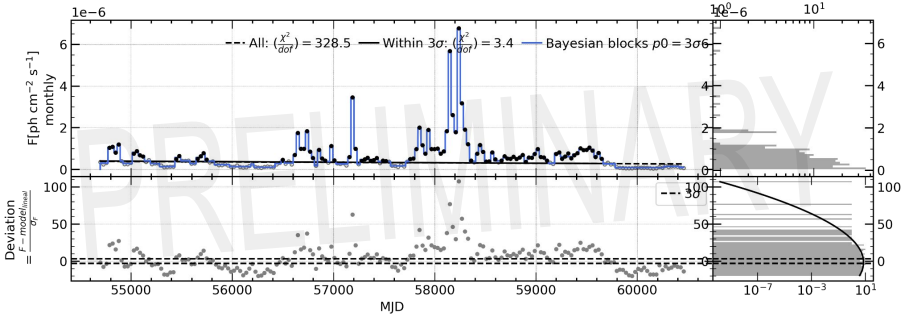
Faint FSRQ: 4FGL J0004.4-4737



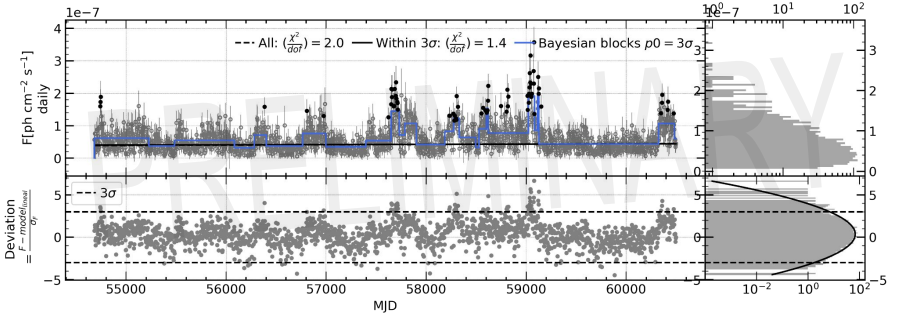
FSRQ 3C 279

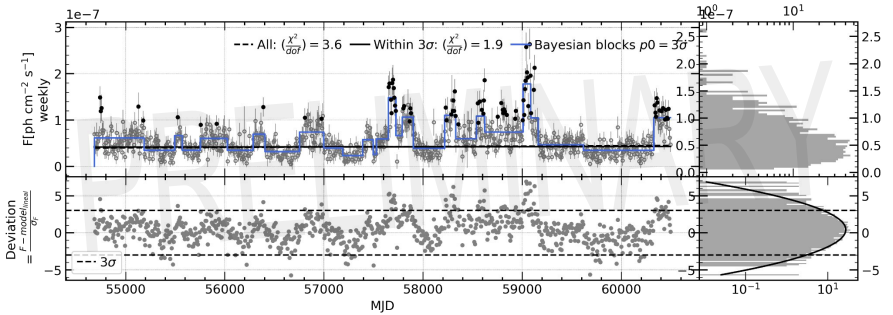


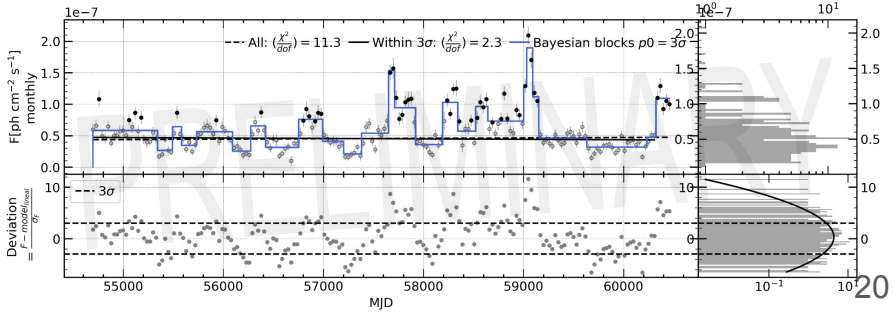




BLL PKS 0447-439 (HSP)



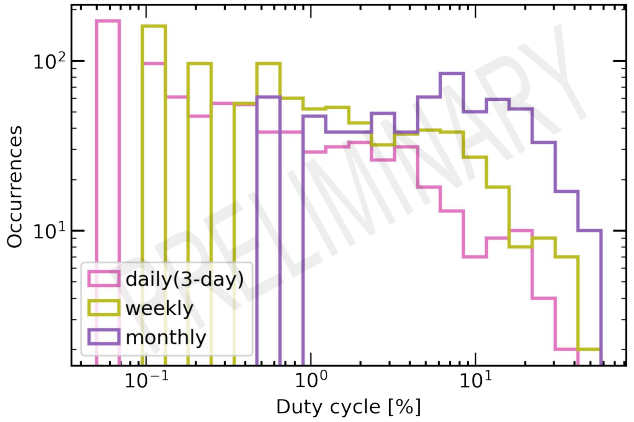




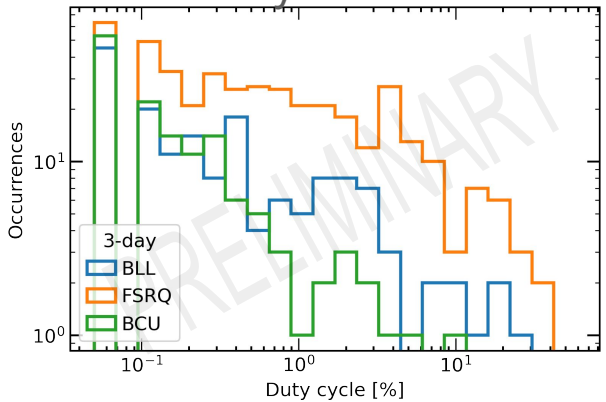
Blazar duty cycle

- 3-day: ~92% of LCR sources with >100 light curve data points. Of these, roughly 35% BLL, 41% FSRQ, 24% BCU.
- Weekly: ~92% of LCR sources with >100 light curve data points. Of these, roughly 34% BLL, 41% FSRQ, 24% BCU.
- Monthly: ~94% of LCR sources with >100 light curve data points. Of these, roughly 46% BLL, 46% FSRQ, 8% BCU.
- Blazars show activity at all timescales.
- ~100 sources flared only a few times during the mission at all cadences.
- Short timescale flares wash out at longer timescales.
- A baseline is less representative at longer timescales.
- FSRQs tend to reach longer duty cycles than BL Lacs.

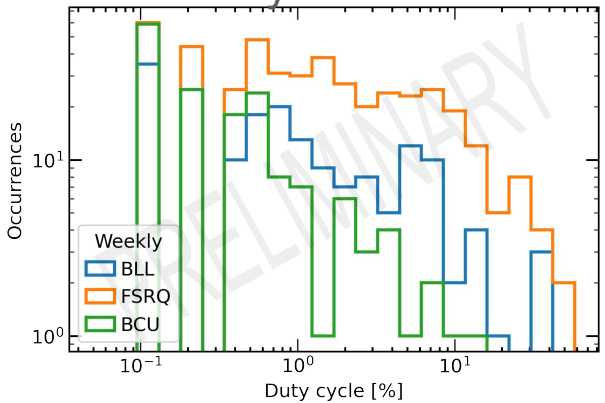
LCR sources



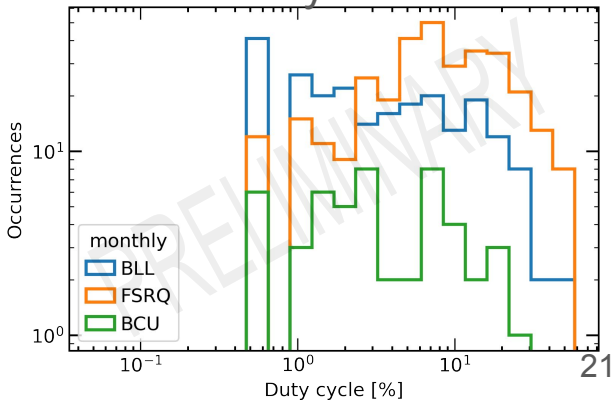
3-day blazars



7-day blazars



30-day blazars



Ongoing & future work

- Fairly automated data validation.
- Duty cycle.
- Selection of flares.
  - Extract features.
  - Examine characteristics of flares according to the source type.
  - Can the selection be automated? ➥ Alerts!
- Flux distributions.
- Spectral analysis.
  - Can we extract significant changes in the spectral slope and correlated with other spectral characteristics?

Contact: janeth@umbc.edu

Thank you!