



Fermi
Gamma-ray Space Telescope

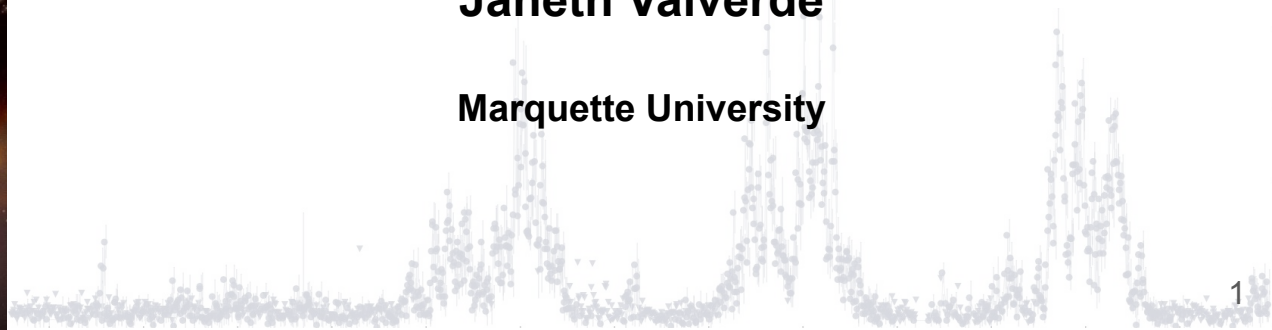


Towards building a history of extreme explosions

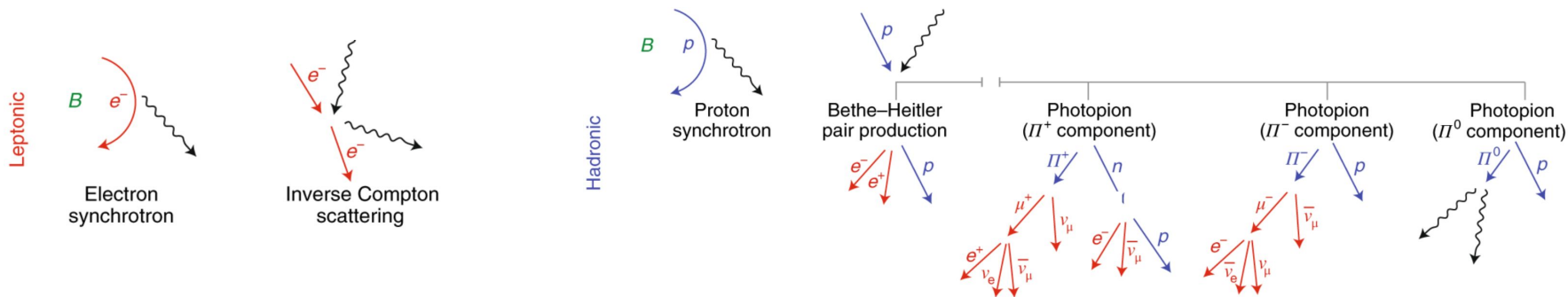
GeV flare characteristics in blazars

Janeth Valverde

Marquette University



Models of blazar emission

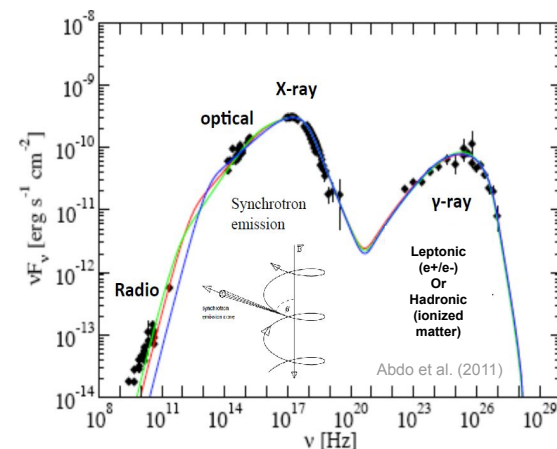


Leptonic

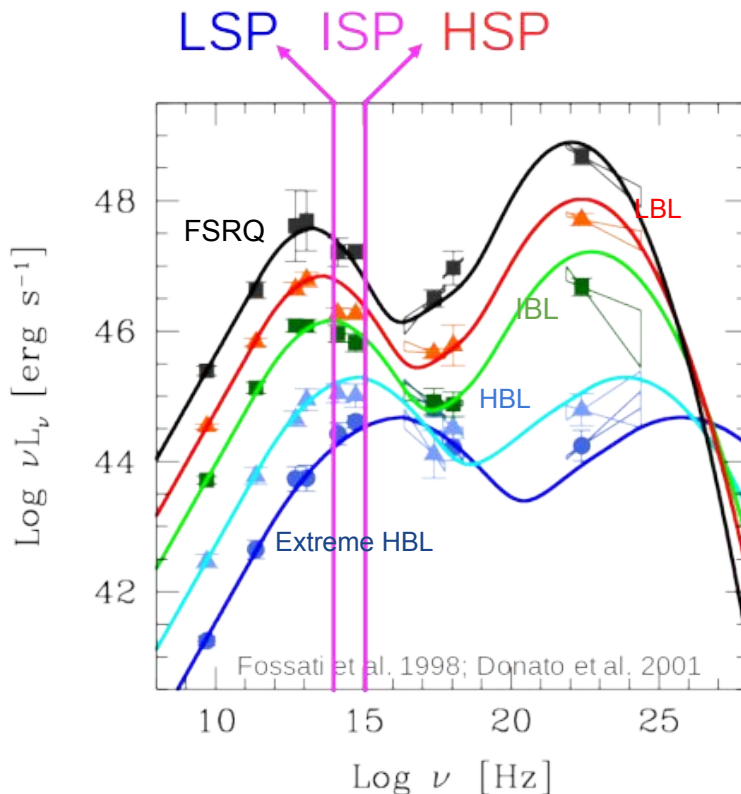
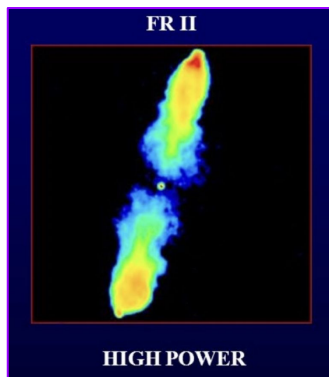
- HE emission likely from inverse Compton scattering by same e^-/e^+ that emitted synch: synchrotron self-Compton (SSC).
- Upscatter of low-energy photons from broad-line region, disk or torus: external inverse Compton (EIC).
- Synch. & Compton variations correlated.

Hadronic

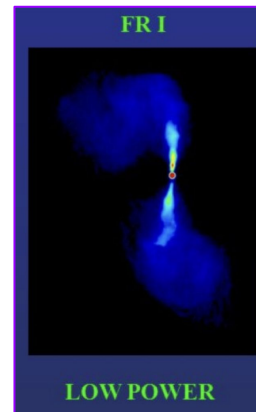
- HE emission from ultra-relativistic e^-/e^+ & protons.
- γ -ray emission via e.g. proton synchrotron or photo-pion prod.
- Synch. & Compton emission from secondary products of $\pi^\pm$.
- Production of neutrinos.



Blazar classification

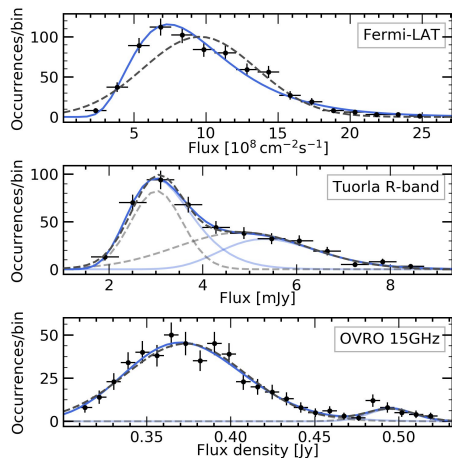


- BL Lacs subtypes: Low-, intermediate- or high-synchrotron-peaked (LSP, ISP, HSP; Abdo et al. 2010).
- Based in Padovani & Giommi (1995; ratio 5 GHz/1 keV flux) for BL Lac objects: LBL, IBL, HBL.

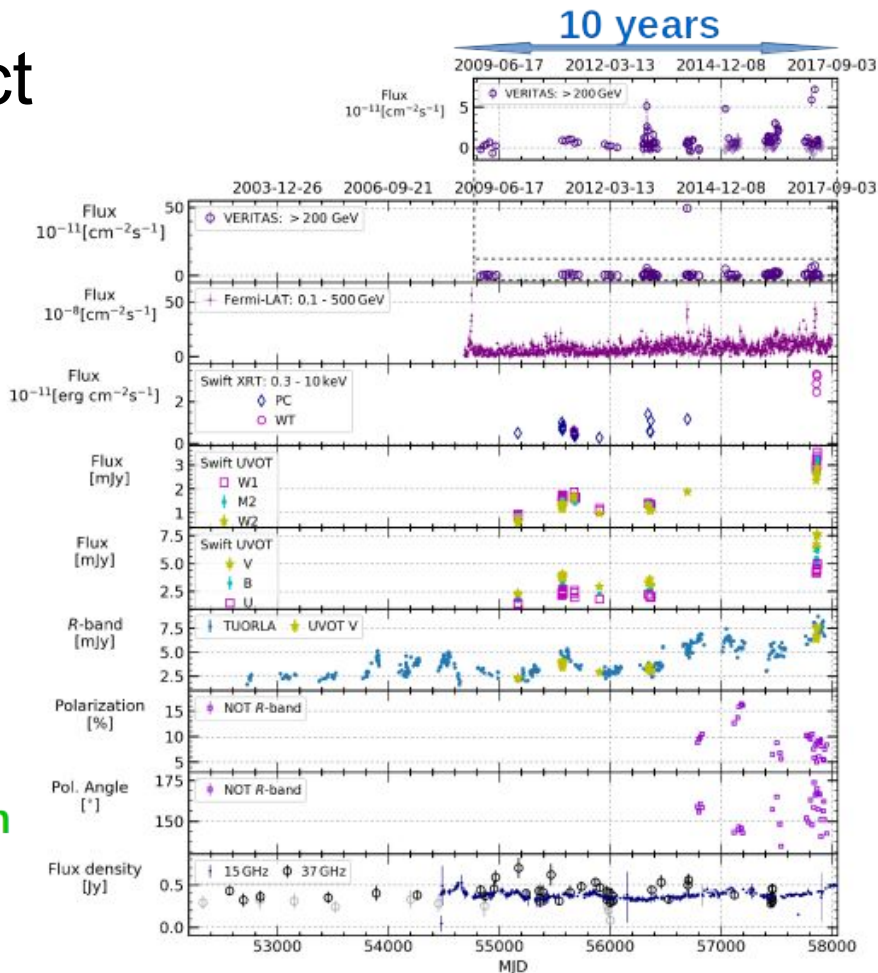


Duty cycle: BL Lac object

[ApJ 891 \(2020\) 170](#)

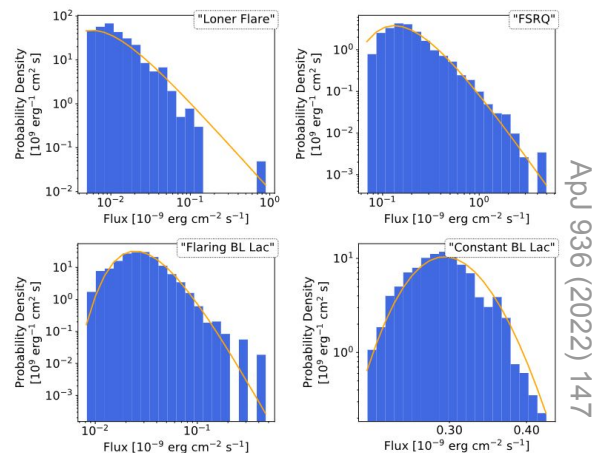


- **TeV γ -rays**
- **GeV γ -rays**
- **X-ray**
- **UV-Optical**
- **Optical**
- **Optical polarization**
- **Radio**

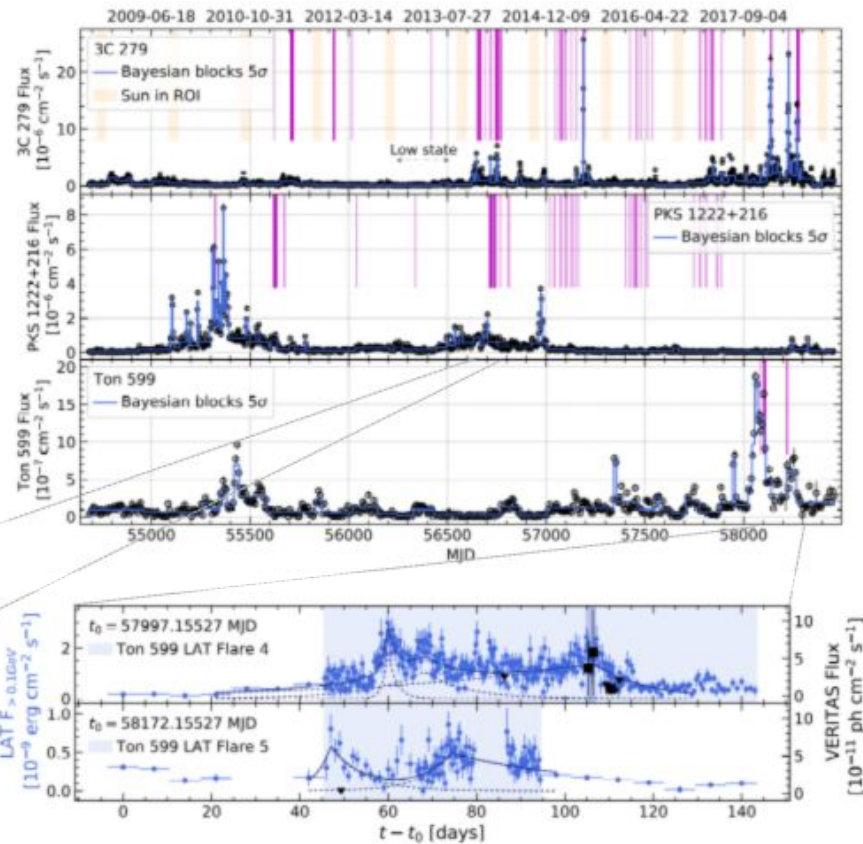
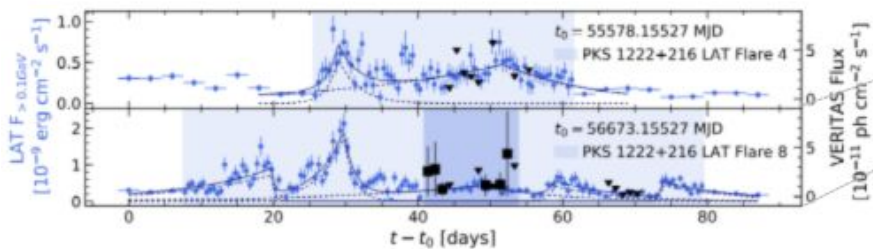


Duty cycle: FSRQs

[ApJ 924 \(2022\) 95](#)

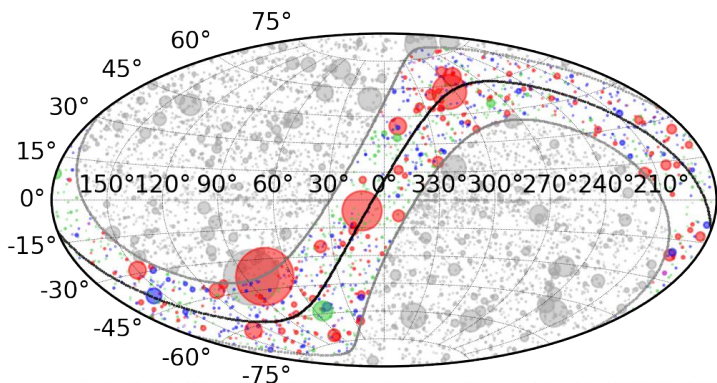


ApJ 936 (2022) 147

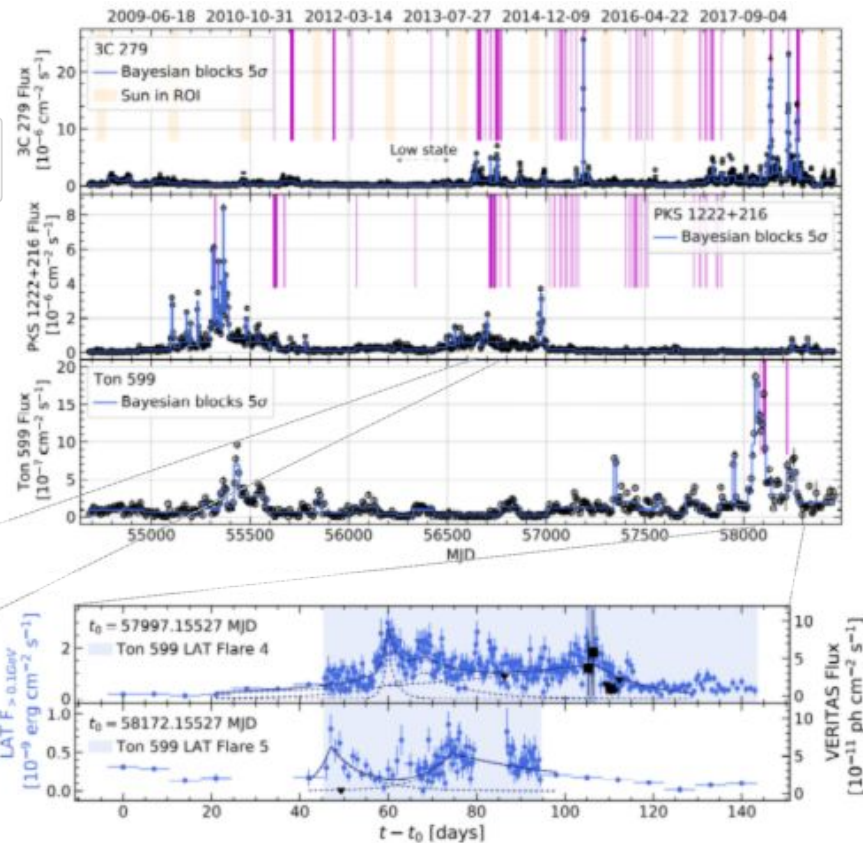
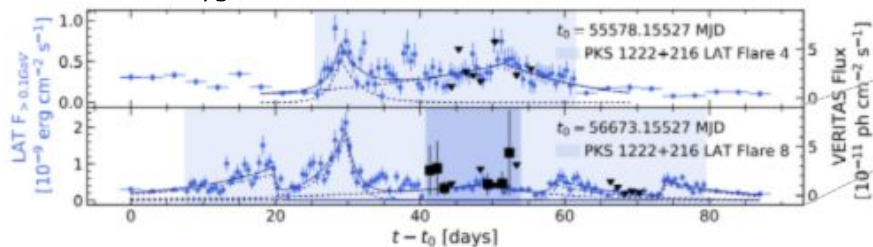


Watch out for the Sun & Moon in the ROI!

[ApJ 924 \(2022\) 95](#)



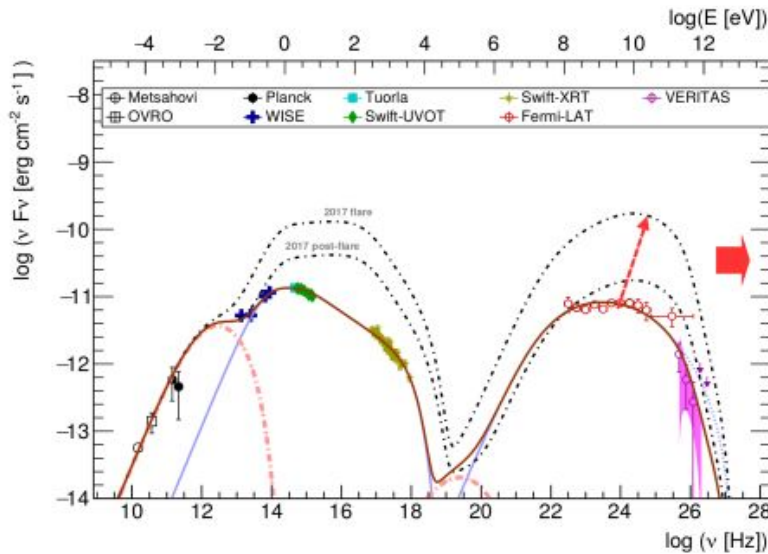
- Ecliptic
- $|b_{\text{Ecliptic}}| = 20^\circ$



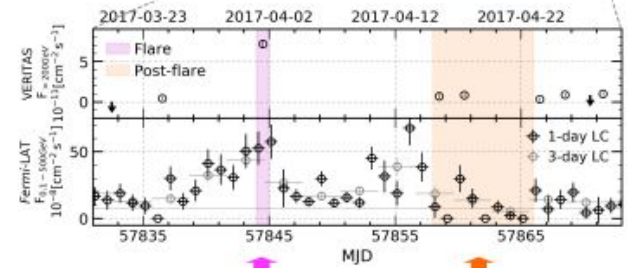
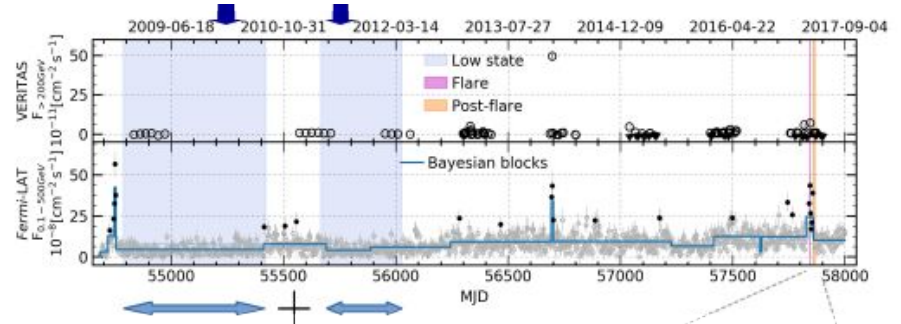
Careful with Solar and Lunar contamination!
3C 279 is 0.2 front the ecliptic.

Low vs flaring states: Spectral characteristics → Acceleration mechanisms

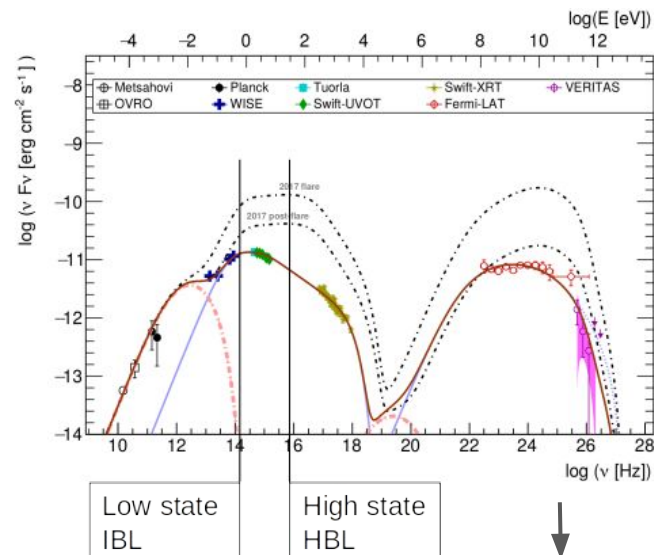
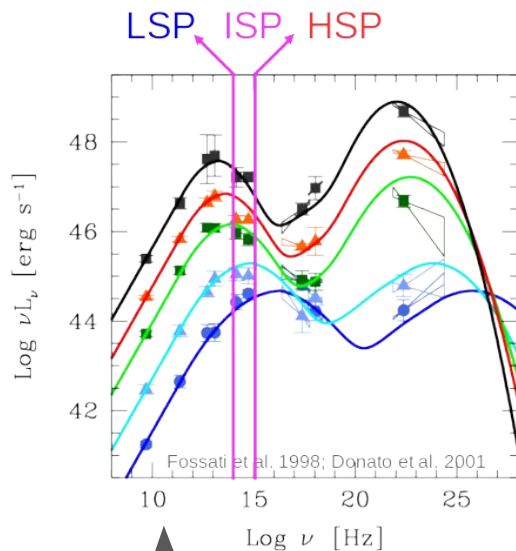
[ApJ 891 \(2020\) 170](#)



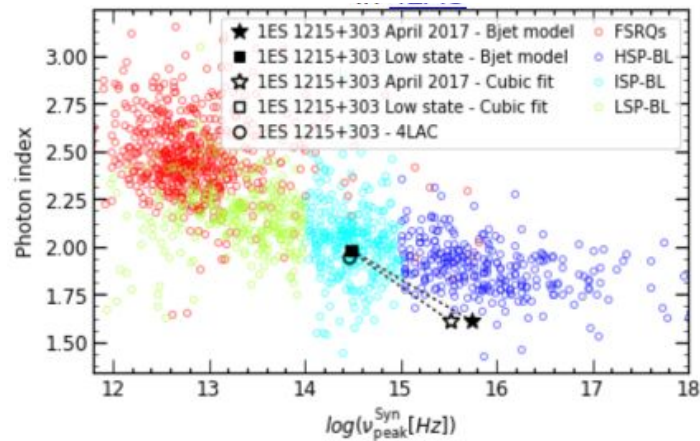
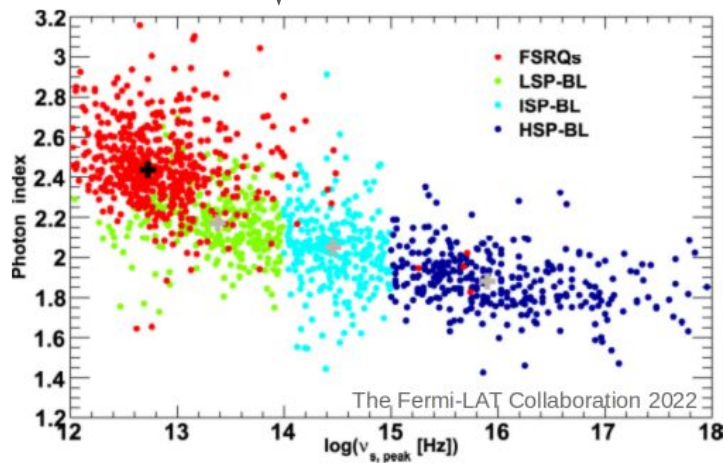
$$\begin{aligned}
 K_1 &\times 3 \\
 B &\times 2.4 \\
 \gamma_{brk} &\times 4.5 \\
 n_2 &\times 1.2
 \end{aligned}$$



Flare Post-flare

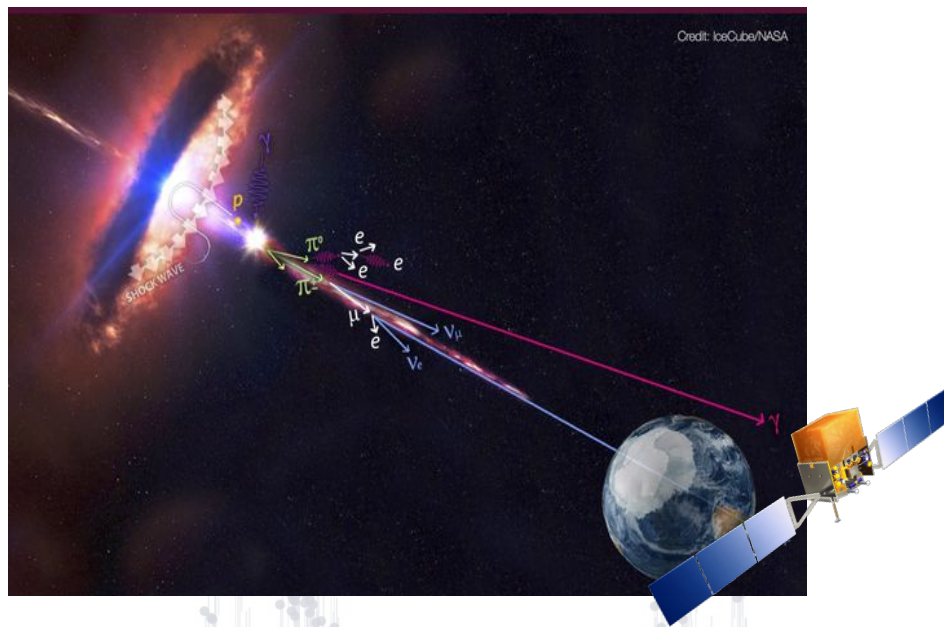


[ApJ 891 \(2020\) 170](#)

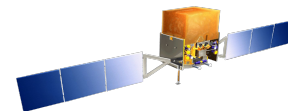


Motivation

- 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.



Fermi-LAT LCs.

Public database
since Dec 2021.

Publication ready.

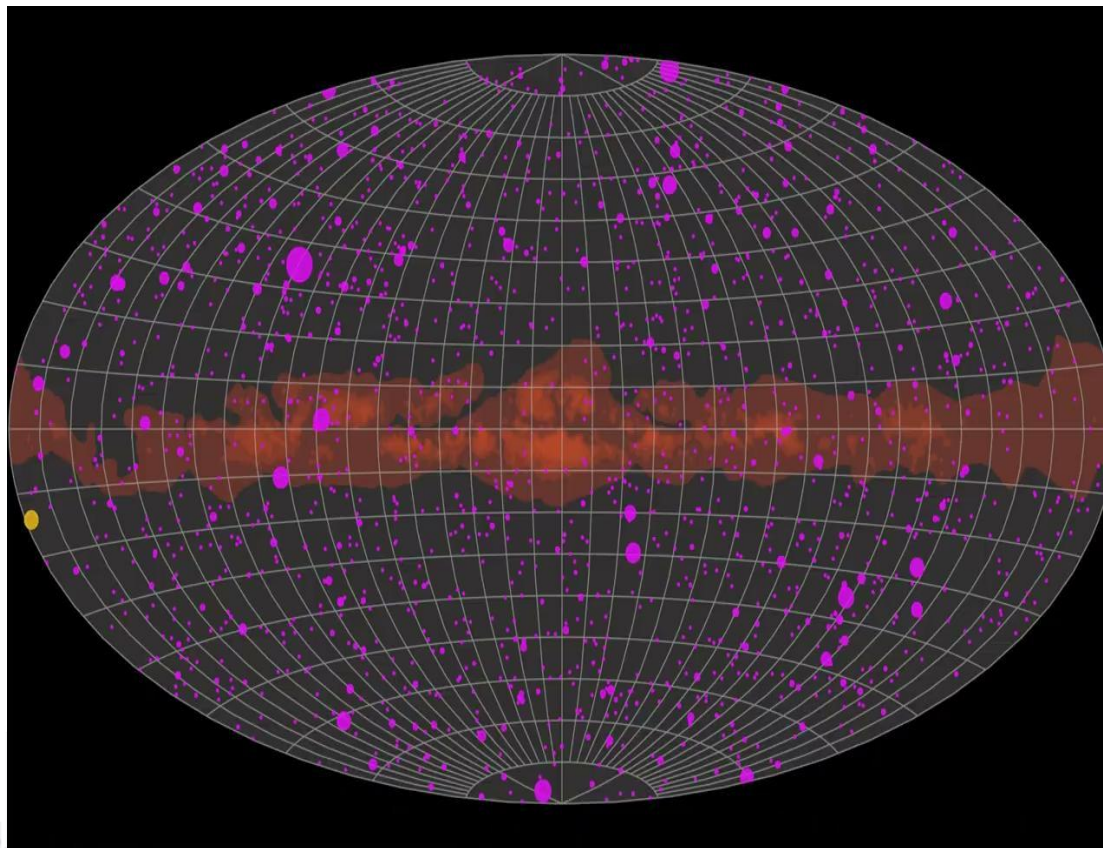
1525 sources
(26% of 4FGL-DR2).

3-, 7- & 30-day
cadence.

Spectral information.

Entire mission
(> 16 years).

Continuously
updated.



~90% AGN

Mostly blazars.



Scientific impact: Cited by >100 papers ([ADS](#))

- [IXPE and Multiwavelength Observations of Blazar PG 1553+113 Reveal an Orphan Optical Polarization Swing.](#)
- [X-Ray Polarization of BL Lacertae in Outburst.](#)
- [Discovery of X-ray polarization angle rotation in the jet from blazar Mrk 421](#)
- [Microquasar Cyg X-3 - a unique jet-wind neutrino factory?](#)
- [The spectra of IceCube Neutrino \(SIN\) candidate sources - IV. Spectral energy distributions and multiwavelength variability](#)
- [Repeated patterns of gamma-ray flares suggest structured jets of blazars as likely neutrino sources](#) (jets composed of fast spine & slower sheath)
- [Hunting Gamma-Ray-emitting FR0 Radio Galaxies in Wide-field Sky Surveys](#)
- [Comprehensive Study of the Blazars from Fermi-LAT LCR: The Log-Normal Flux Distribution and Linear rms-Flux Relation](#)
- [Modeling weekly-timescale gamma-ray variability in blazars with self-supervised deep learning](#)
- [Spectroscopic reverberation mapping of Quasar PKS 0736 + 017: broad-line region and black-hole mass](#)

Polarization

Neutrinos

Population search

Lognormality

AI training

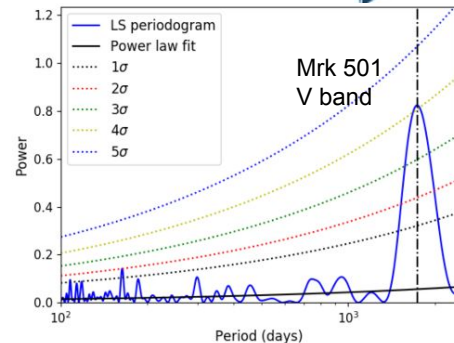
Classification

Correlations

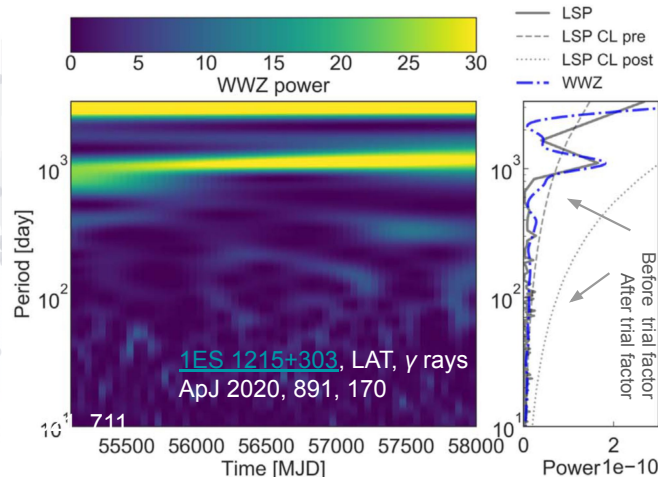
Reverberation map.

Scientific impact: Search for periodicity

- Quasi periodic oscillations (QPO) in AGN might indicate, e.g., the presence of supermassive black hole binary systems or a precessing jet.
- Possible QPOs in optical data. Possible jet precession in radio observations. No conclusive QPO detection in γ -rays.
- Analysis must include trial factors (look-elsewhere effect).
- QPO studies with LCR data:
 - MWL periodicity search in a sample of γ -ray bright blazars ([MNRAS 2023, 518, 57880](#)).
 - Detection of possible transient QPOs in the γ -ray LC of PKS 0244-470 & 4C+38.41 ([ApJ 2023, 950, 173](#)).
 - A 31.3 day Transient QPO in γ -ray emission from blazar S5 0716+714 ([ApJ 2022, 938, 8](#)).

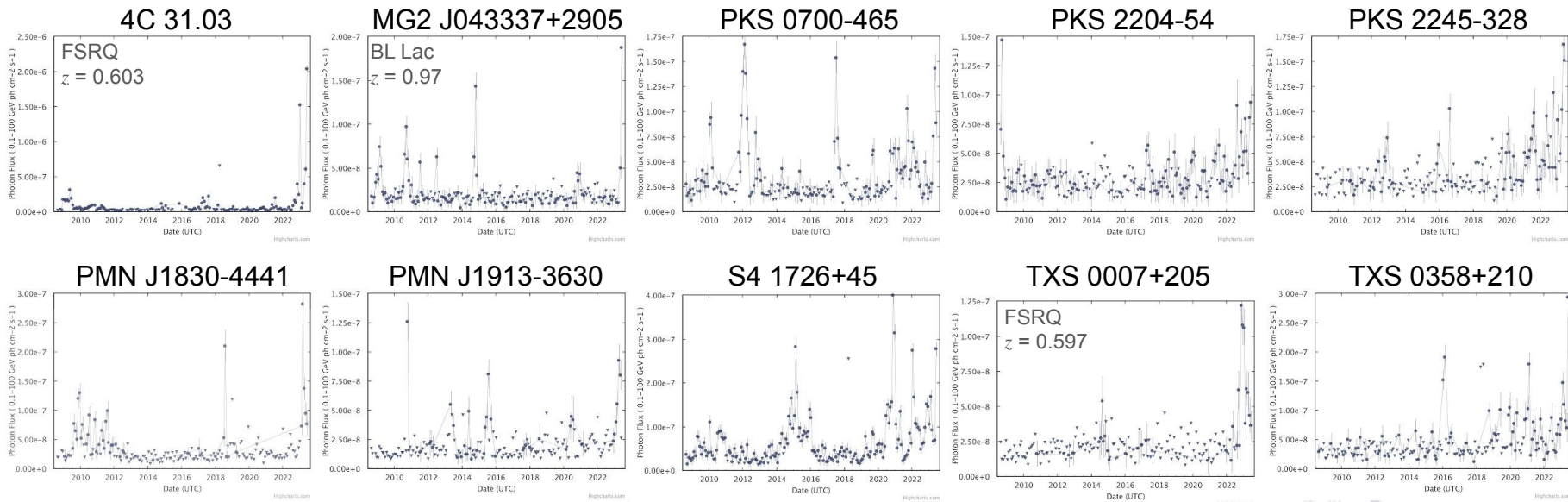


MNRAS 2023, 518, 57880



M 87

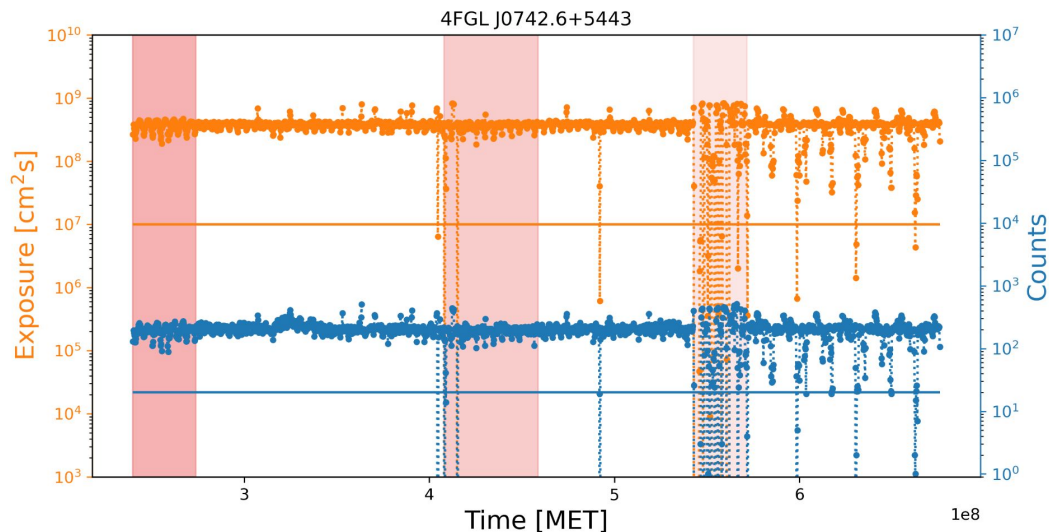
Enabling science: Community alerts



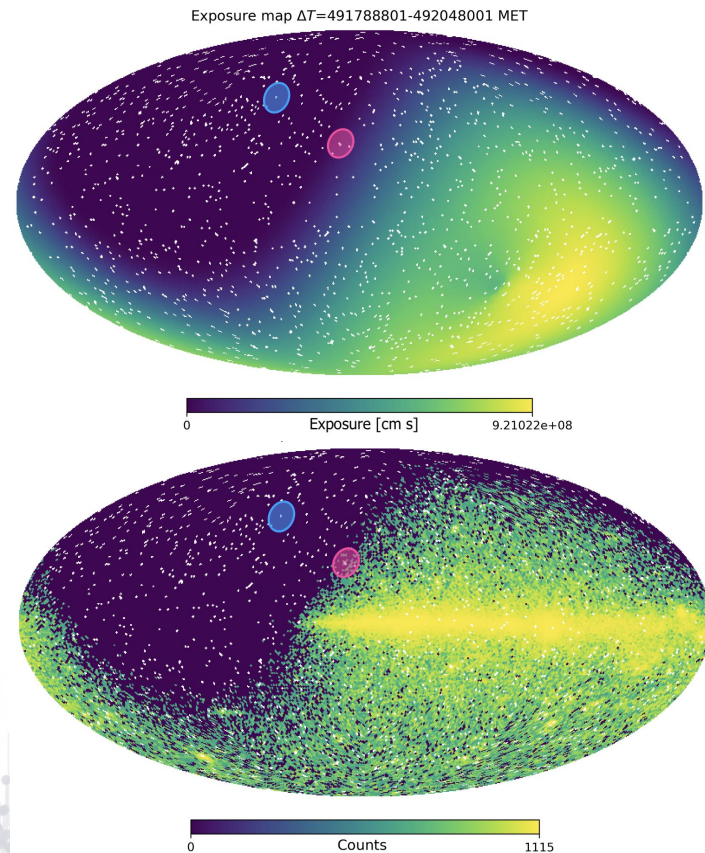
LCR LCs

- > 100 Astronomer's Telegrams & Gamma-ray Circular Notices:
https://www-glast.stanford.edu/cgi-bin/pub_rapid.
- Now in [astro-colibri.com](https://astro.colibri.com) and later CTAO.

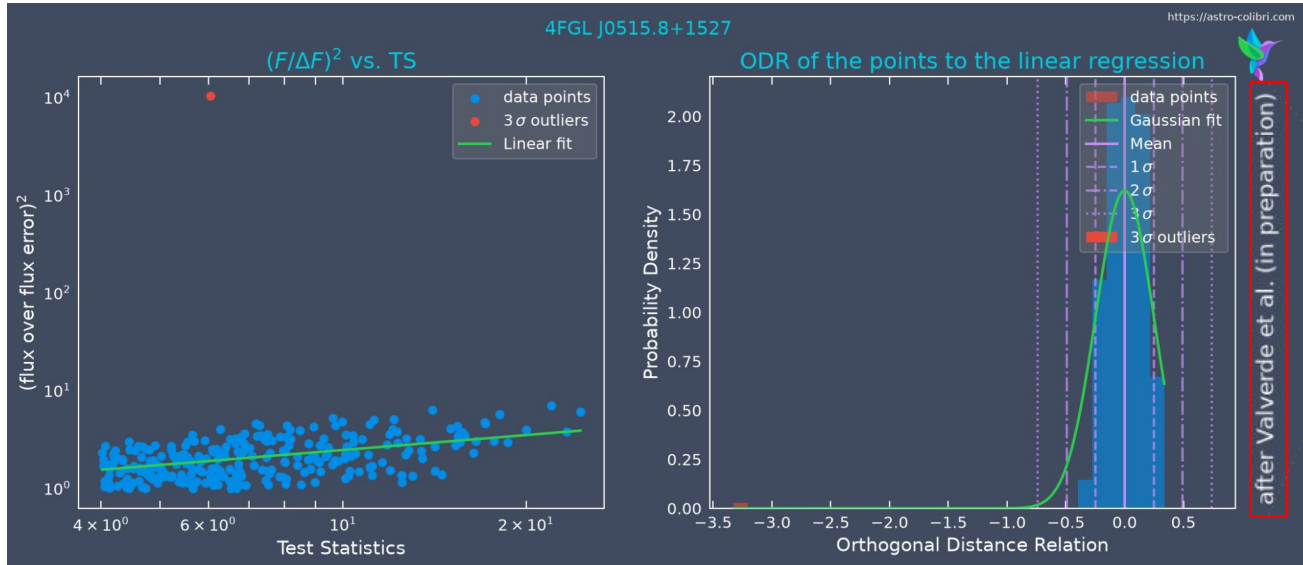
LCR paper: Exposure - Caveats



LCR pipeline does not save exposure files: Independent analysis to obtain all-sky exposure maps for each time range & estimate exposure for each LCR source ROI (i.e. 2.6K instead of 4M analyses). FSRQ GB6 J0742+5444 In the example above.

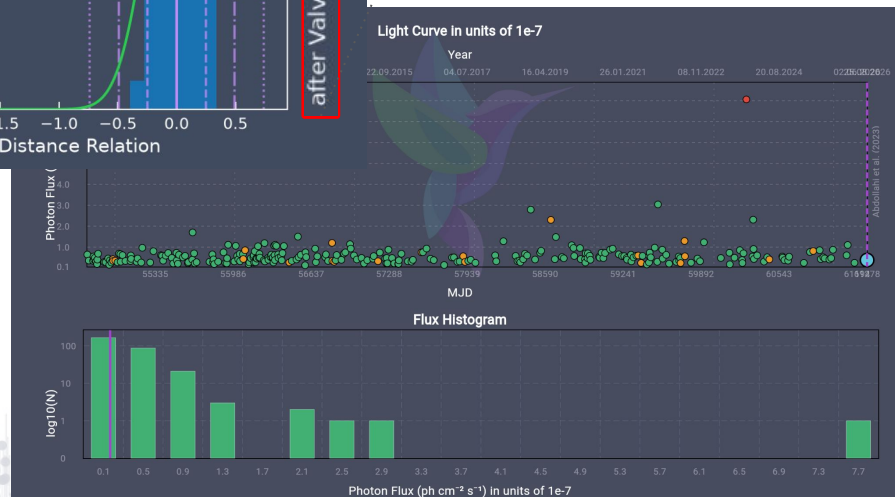


Enabling science: Astro-COLIBRI

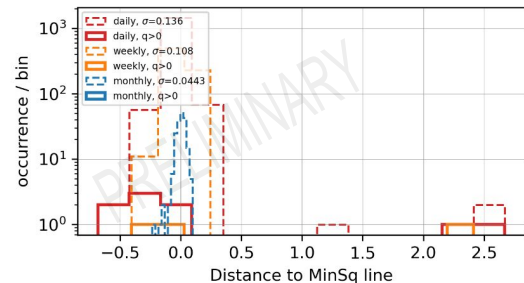
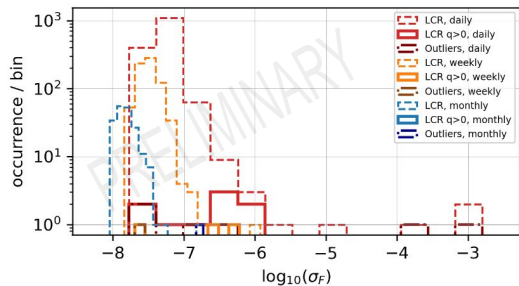
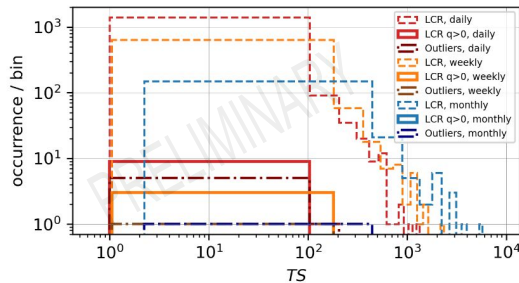
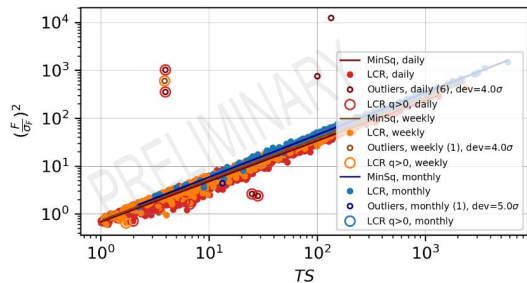
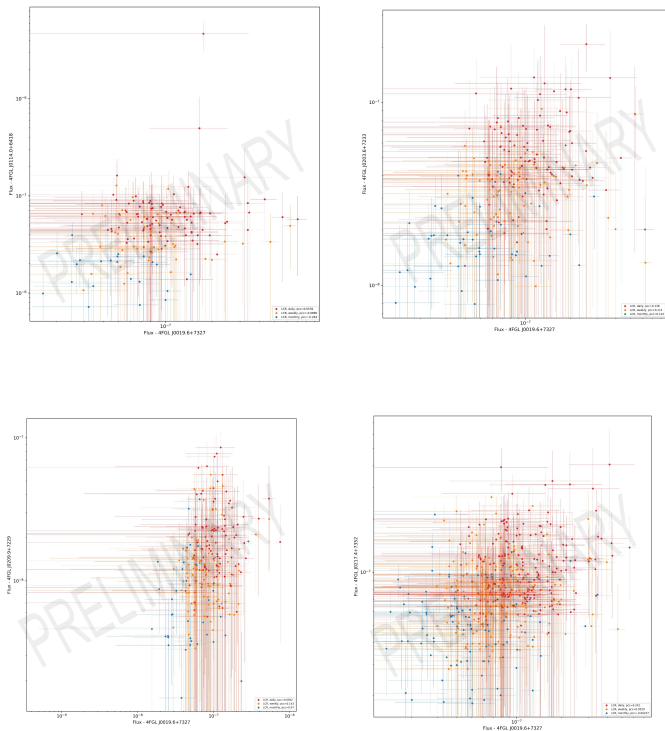


after Valverde et al. (in preparation)

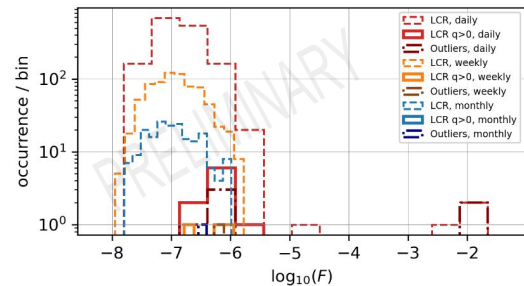
Stay tuned for the light curve guidelines paper!



Automating the validation process

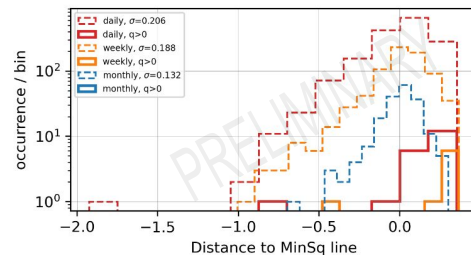
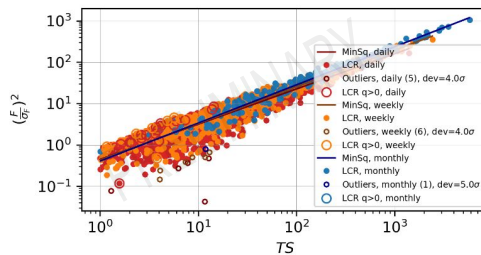


FSRQ 4C +28.07
4FGL J0237.8+2848
Index fixed

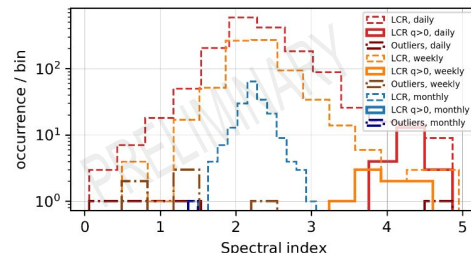
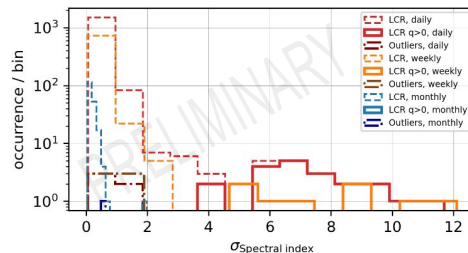
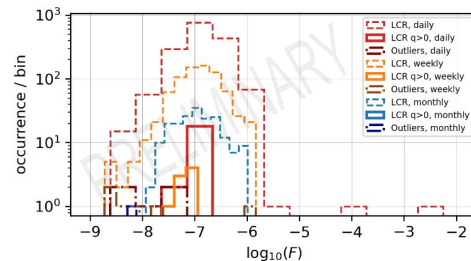
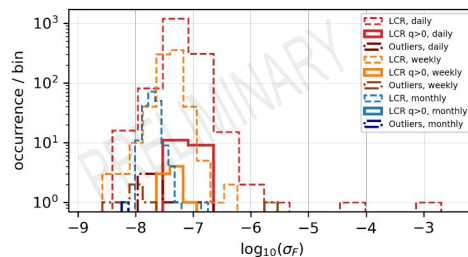
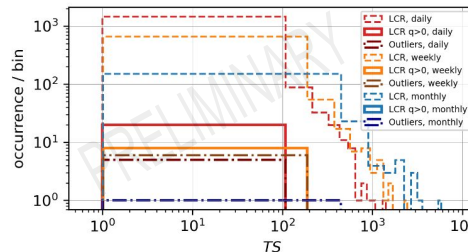


Automating the validation process

- 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



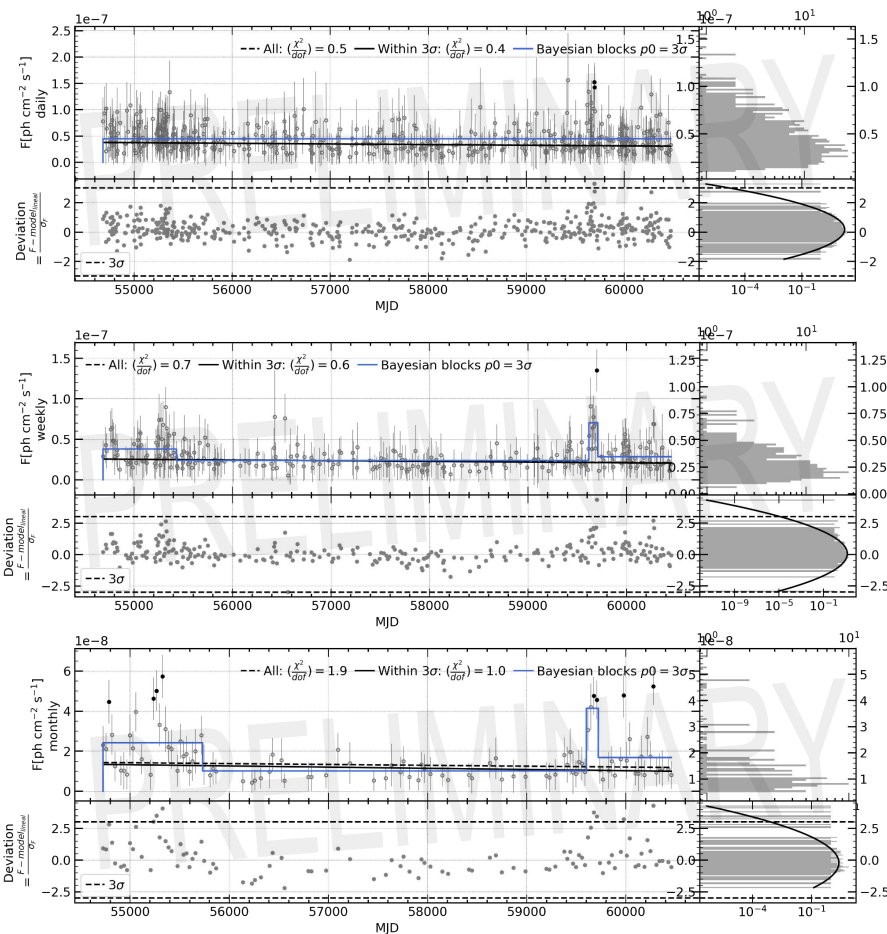
Duty cycle

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

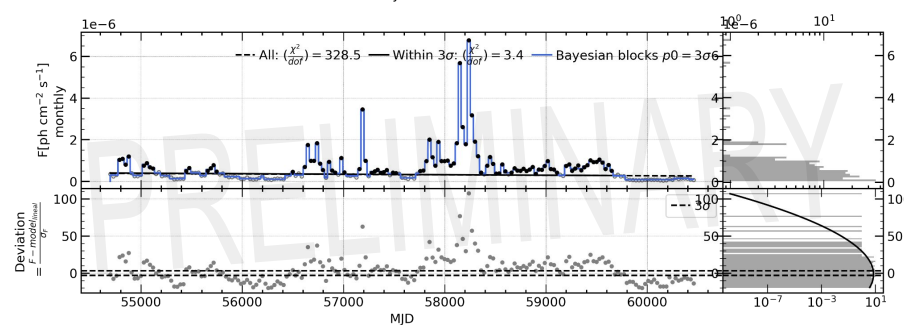
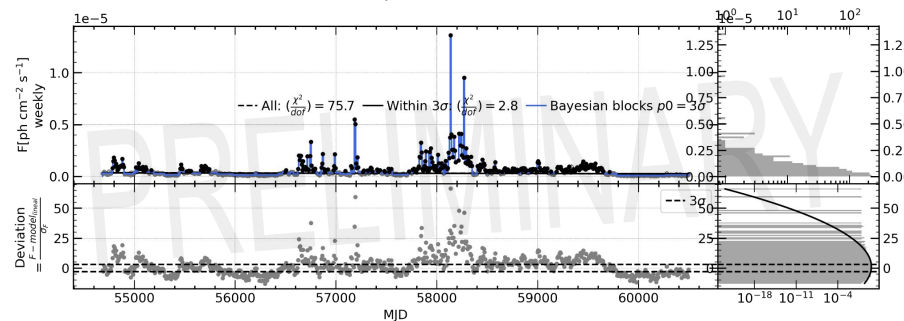
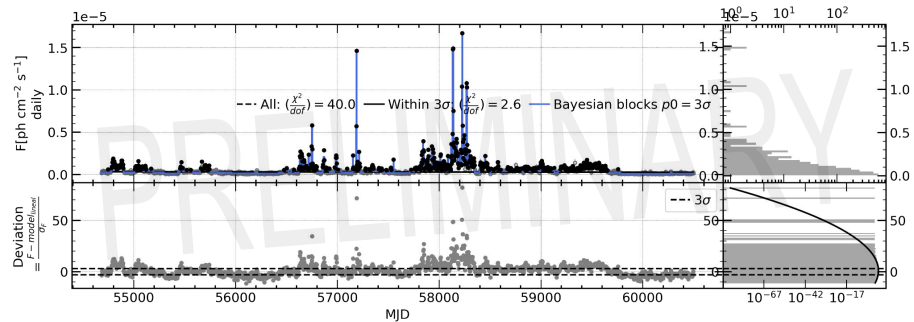
Procedure:

- 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

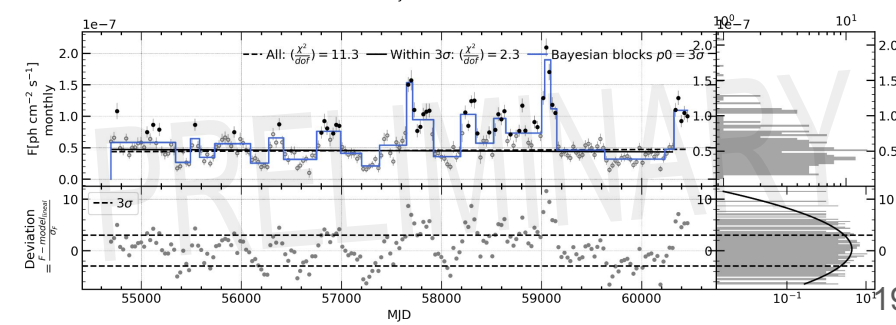
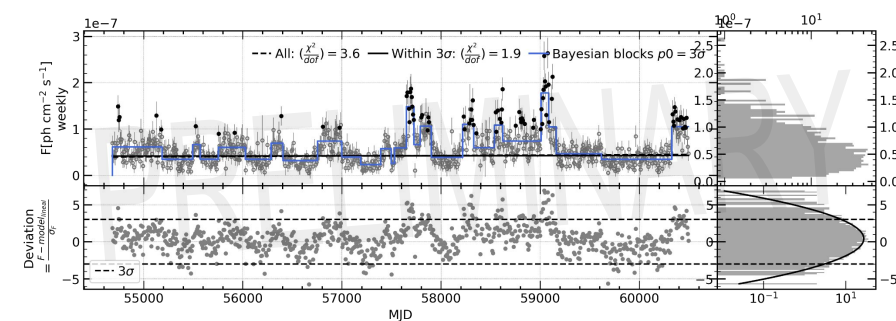
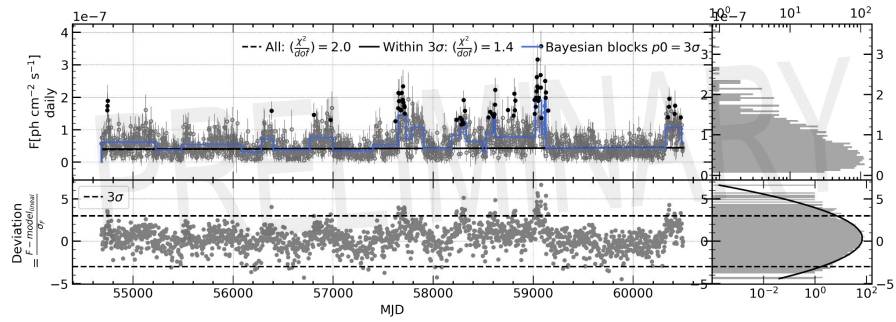
Faint FSRQ: 4FGL J0004.4-4737



FSRQ 3C 279



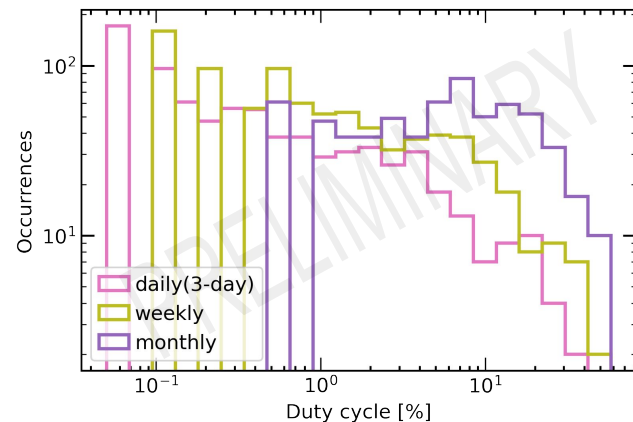
BLL PKS 0447-439 (HSP)



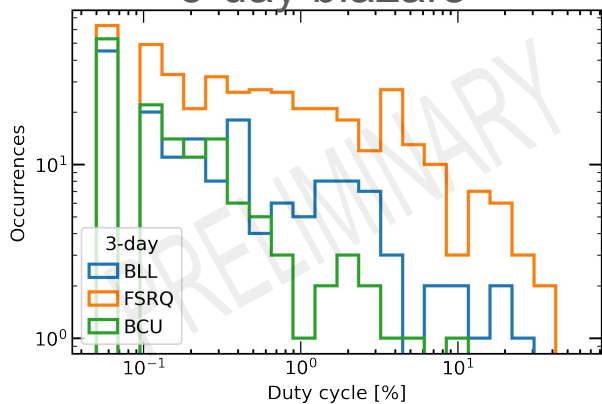
Blazar duty cycle

- 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.

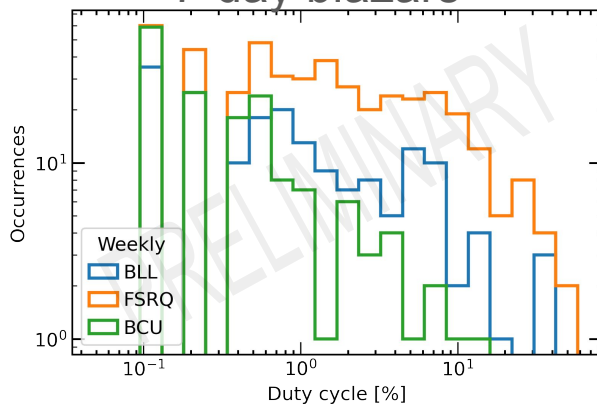
LCR sources



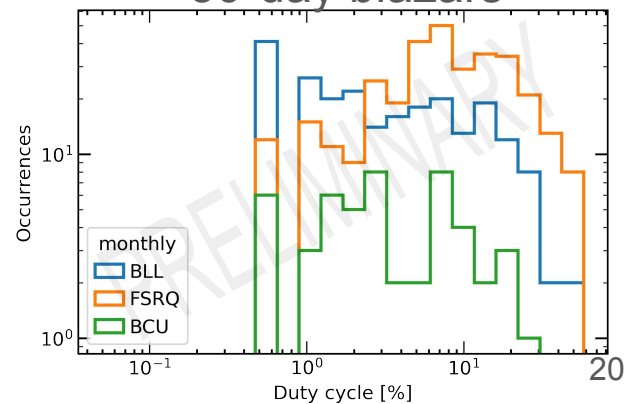
3-day blazars



7-day blazars



30-day blazars



Ongoing & future work

- Fairly automated data validation: Coming public release w/paper.
- 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?

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Thank you!