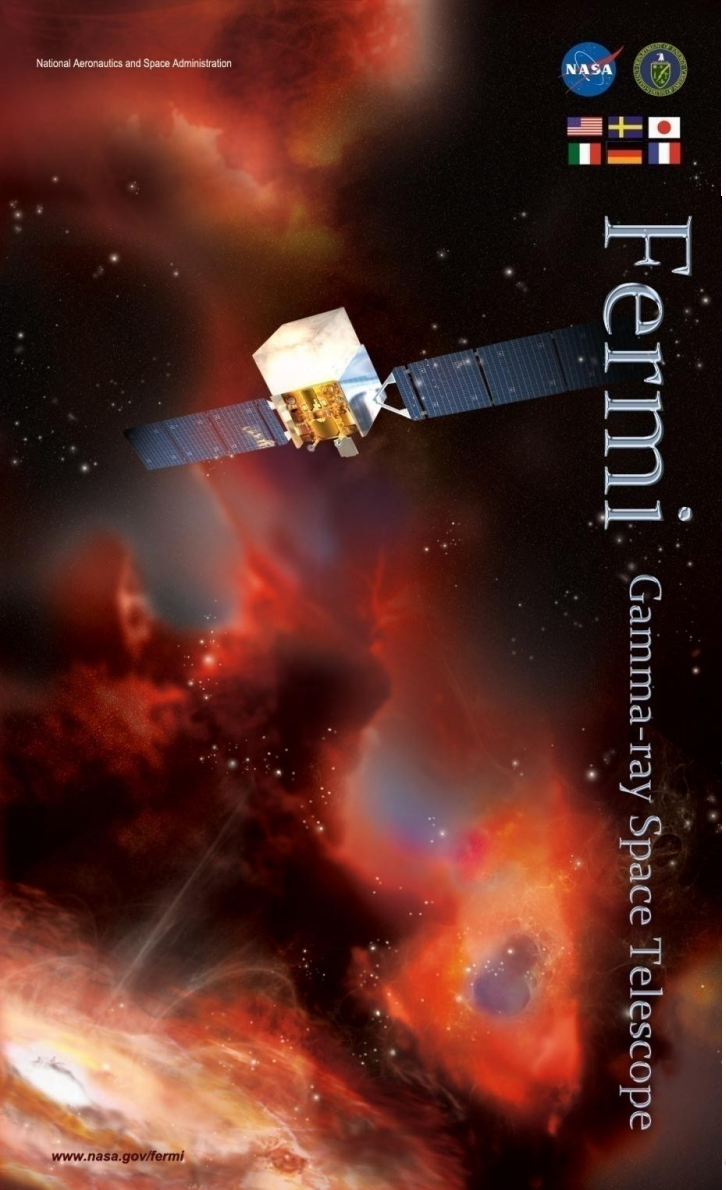

LCR
The Fermi Large Area Telescope
Light Curve Repository

Fermi
Gamma-ray
Space Telescope

The *Fermi*-LAT Light Curve Repository

Janeth Valverde (GSFC)

On behalf of the LCR Team:
D. Kocevski, S. Garrappa, M. Negro, A. Brill
and the *Fermi*-LAT Collaboration

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

LCR

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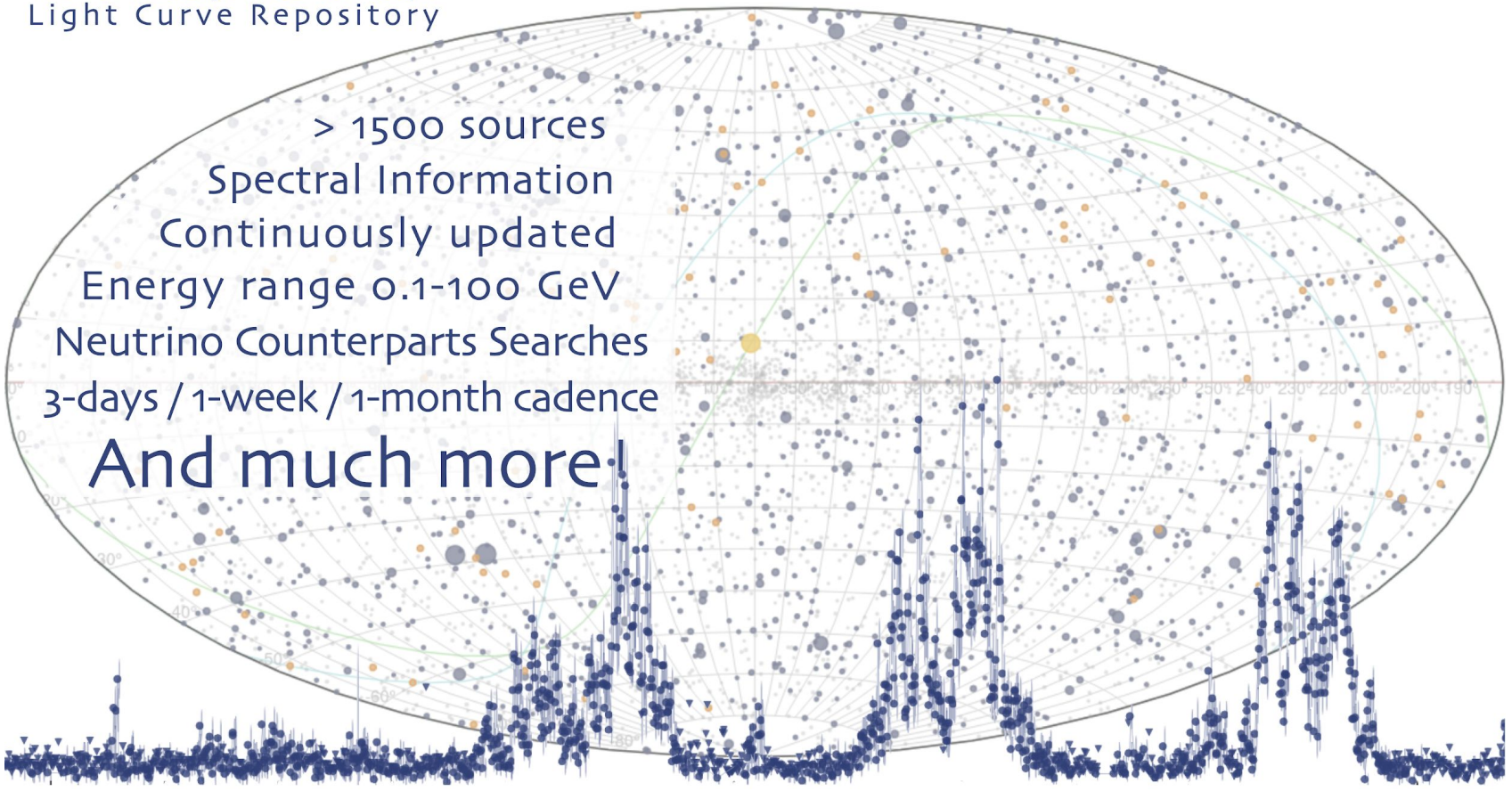


https://fermi.gsfc.nasa.gov/ssc/data/access/lat/lcr/

The Light Curve Repository (LCR)

Likelihood Analysis Summary:

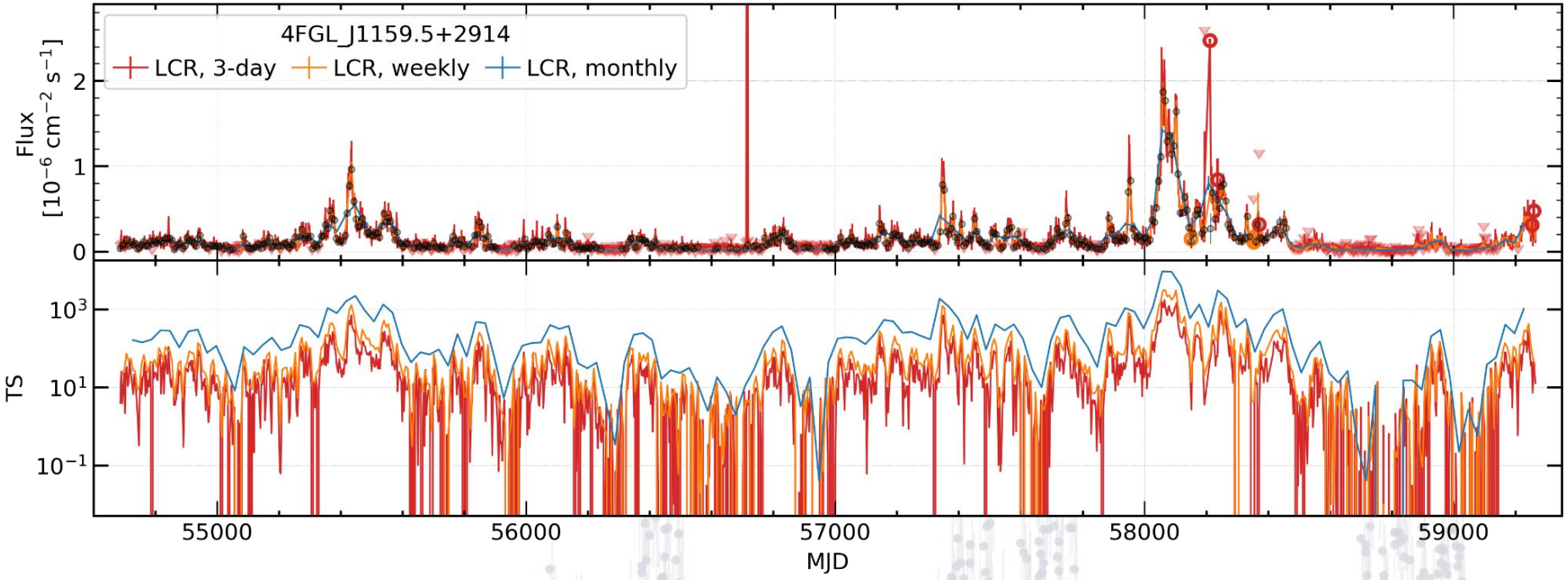
Time bins	3 day, 1 week, and 1 month
Energy bins	100 MeV - 100 GeV
Event selection	P8R3_SOURCE
Instrument response function	P8R3_SOURCE_V3
Acceptance cone (ROI)	12 deg (radius)
Zenith angle cut (zmax)	90 deg
Fit optimizer	MINUIT
Galactic interstellar emission model	gll_iem_v07.fits
Isotropic spectral template	iso_P8R3_SOURCE_V3_v1
4FGL-DR2 catalog	gll_psc_v27.fit
Upper limits confidence level	95% (Bayesian profile)
Minimum detection threshold	TS = 1-4 (~1-2σ)

- ★ Variability index cut > 21.67. This corresponds to a 99% confidence level for 10 points (one per year): 1525 sources, or 26.34% of the 4FGL-DR2.
- ★ GRBs episodes excluded.
- ★ Two methods:
  - Spectral parameter fixed.
  - Spectral parameter free.
- ★ Two step fit strategy.
  - 1st fit: only normalization set free and spectral index is fixed to catalog value.
  - 2nd fit: both normalization and spectral index are set free.
- ★ Iterative likelihood fit using tighter fit tolerances ranging from [1, 1-e4, 1e-8].
- ★ The spectral model used is that of the 4FGL-DR2, e.g. photon index (Γ) for power-law or α for logparabola (β is fixed).
- ★ Flux is extracted for all fits that yield TS > 1.
  - 95% Bayesian ULs for TS < 9.
  - Users can choose the minimum TS level for flux estimation.

Walk-through the webpage

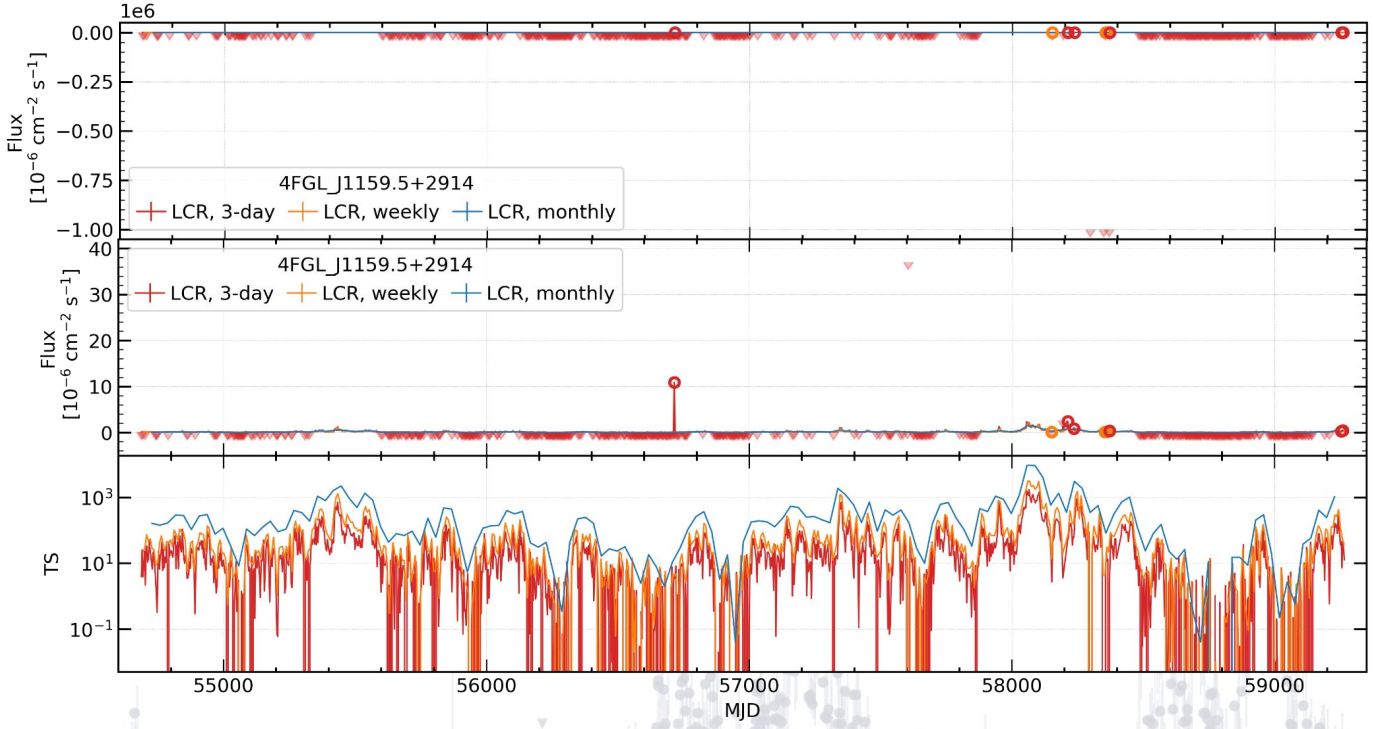
- ★ Review Usage Notes for analysis details, data modeling, fitting strategy & caveats.
- ★ Map:
  - Markers indicate relative variability index or TS (correlated), as selected by user.
  - "Gray Non-Variable Sources" allows to see sources with available LCR data.
  - Double click to fix the chart & select 4FGL/LCR/FAVA data products.
- ★ Table: Only sources with available light curves (LCs) provide embedded links.
- ★ Data overlays: GRB & IceCube neutrino alerts with arrival times and locations.
- ★ Catalog search: Keyword option
  - 3-, 7-, 30-day binned LCs.
  - Index free and fixed options. TS options.
  - You will download all data, including non-convergent, unconstrained and possibly TS<0. Data need to be cleaned before used.
  - Data in two formats: CSV, JSON. See Table and JSON File Description. When downloading the data, **label "cadence=daily" refers to 3-day binned LC**.
- ★ See the LCR FAQ.

Bright source: Ton 599, fixed index



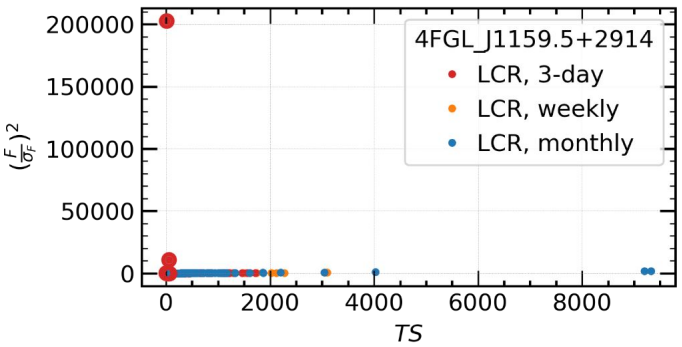
★ Empty circles indicate non-convergent analyses.
★ Black points are data from a dedicated analysis using a different pipeline.

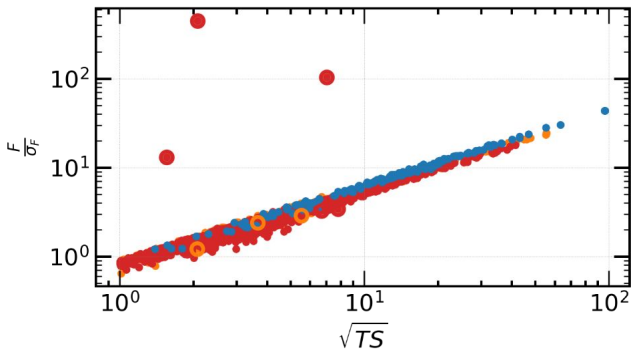
Bright source: Ton 599, fixed index



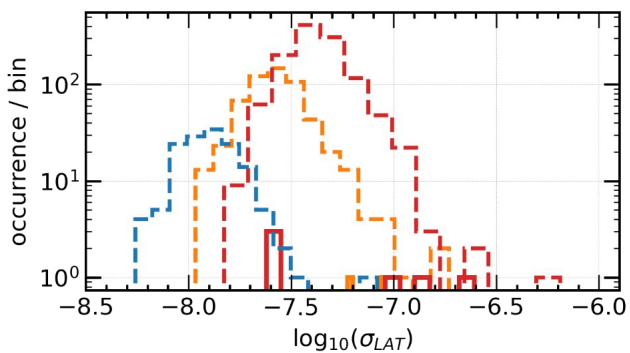
- ★ The LCR plotter does not show unconstraining results likely associated with non-convergent fits, including meaningless negative upper limits (ULS).
- ★ Empty circles indicate non-convergent analyses.

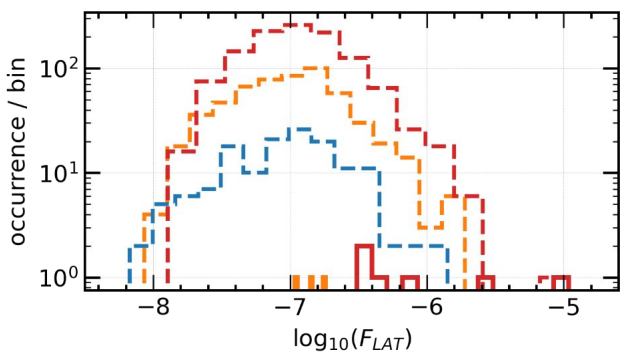
Bright source: Ton 599, fixed index

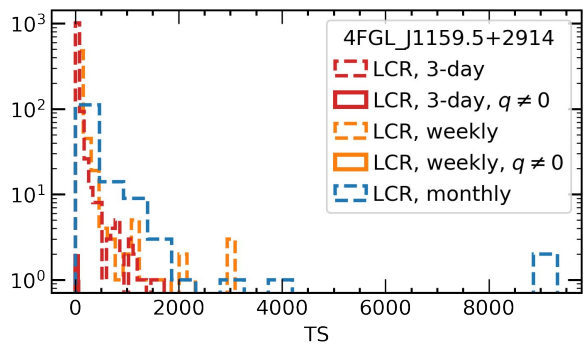




- ★ Monthly : 0 bins (out of 151) with UL<0 & 0 with q(fit quality) ≠ 0.
- ★ Weekly: 4 bins (out of 649) with q ≠ 0.
  - 3 provide flux measurements (circles).
  - 1 bin with UL=-1, it has q ≠ 0.
- ★ 3-day : 11 bins (out of 1511) with q ≠ 0.
  - 6 provide flux measurements.
  - 3 bins with UL=-1, all have q ≠ 0.

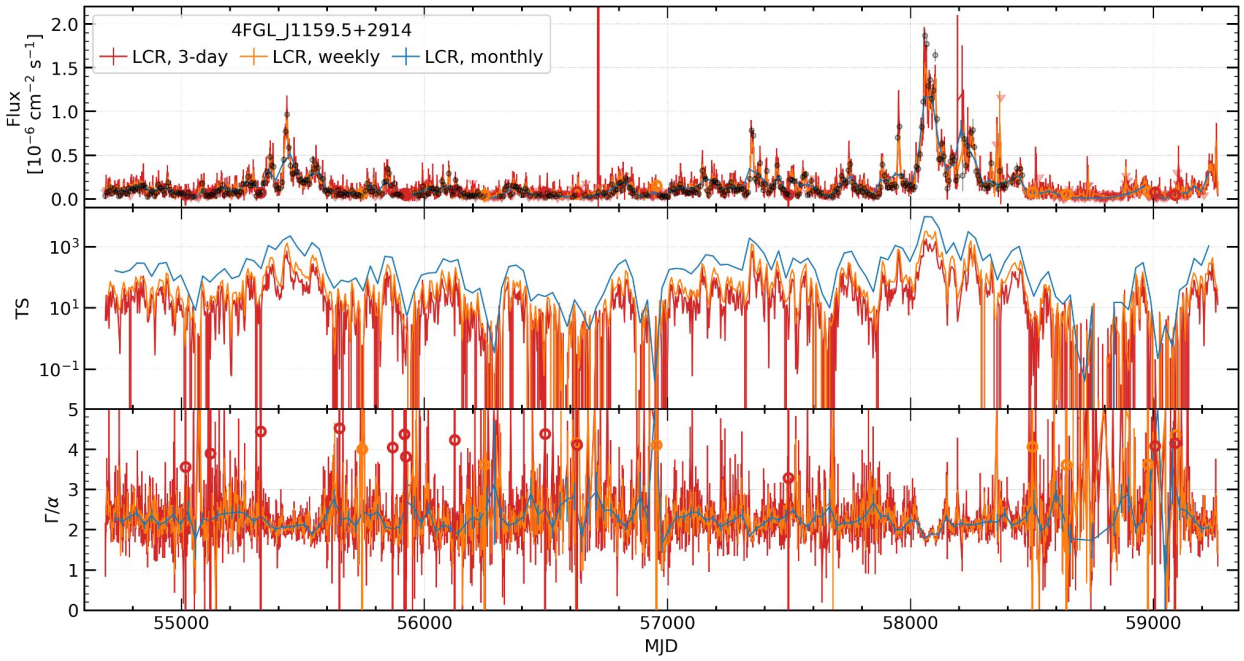






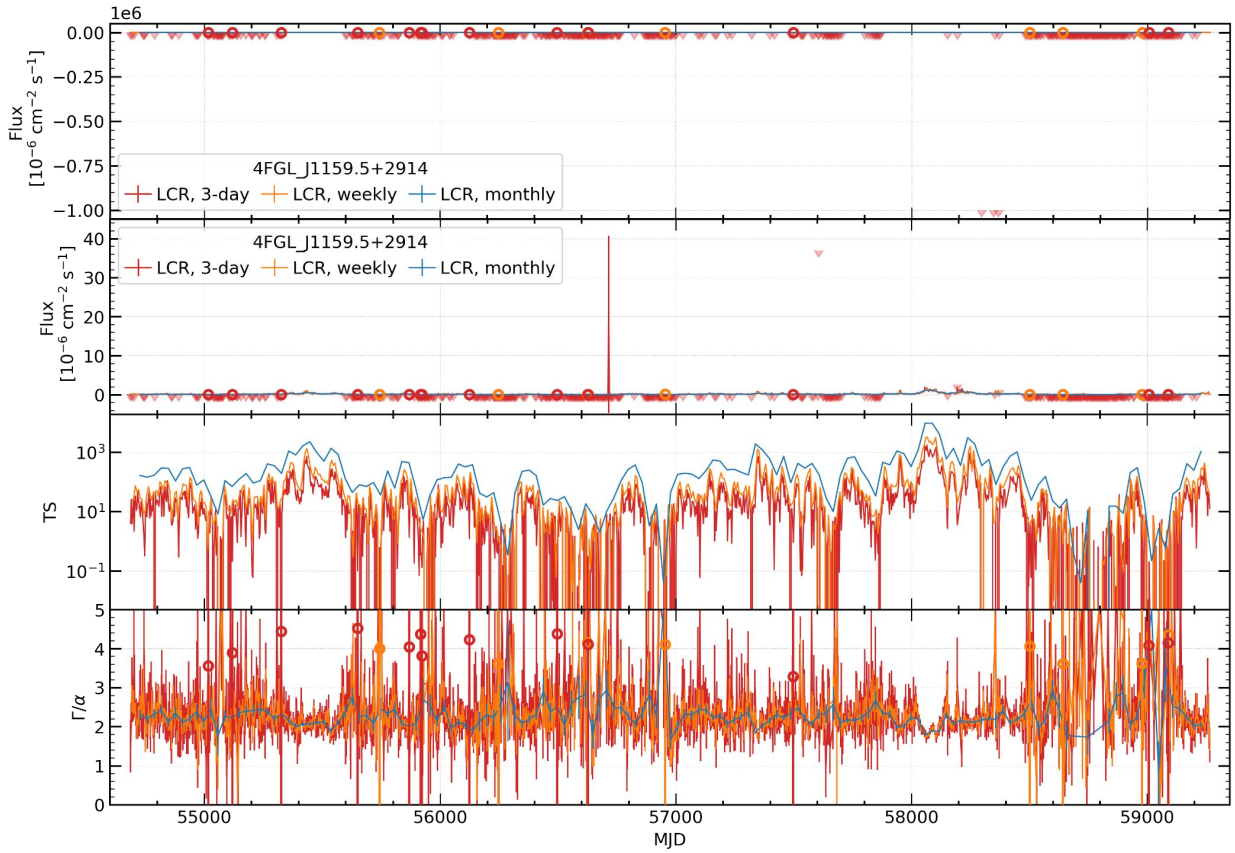
- ★ Empty circles indicate non-convergent analyses. In histograms, dashed lines represent results from all time bins. Solid lines represent bins that did not converge.
- ★ Fit quality q = 0 indicates a convergent analysis. Every other value indicates that the analysis did not converge.

Bright source: Ton 599, free index



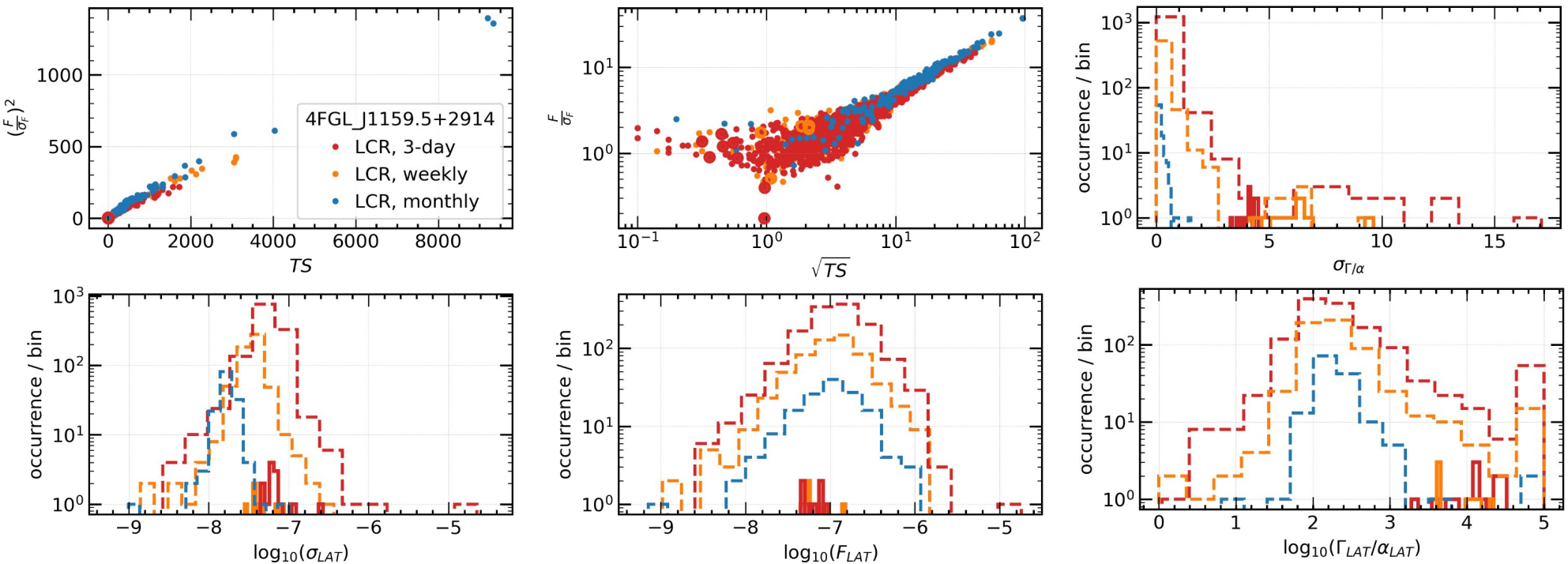
- ★ Monthly : 0 bins (out of 151) with UL<0 & 0 with q ≠ 0.
- ★ Weekly: 12 bins (out of 649) with q ≠ 0
  - 8 provide flux measurements.
  - 1 bin with UL=-1, it has q ≠ 0.
- ★ 3-day : 27 bins (out of 1511) with q ≠ 0.
  - 13 provide flux measurements.
  - 3 bins with UL=-1, all have q ≠ 0.
- ★ Empty circles indicate non-convergent analyses.

Bright source: Ton 599, free index



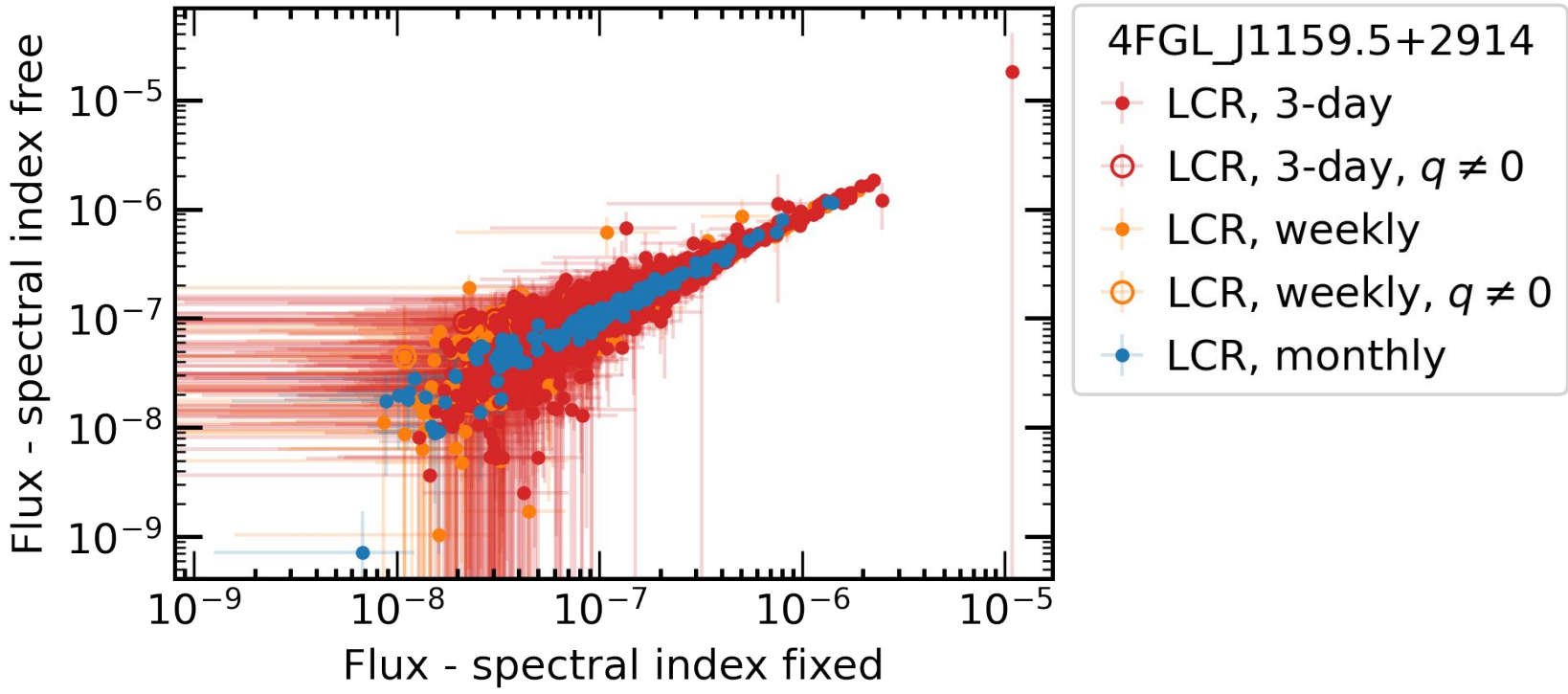
- ★ The LCR plotter might not show unconstraining results likely associated with non-convergent fits, including meaningless negative upper limits (ULS).
- ★ Empty circles indicate non-convergent analyses.

Bright source: Ton 599, free index



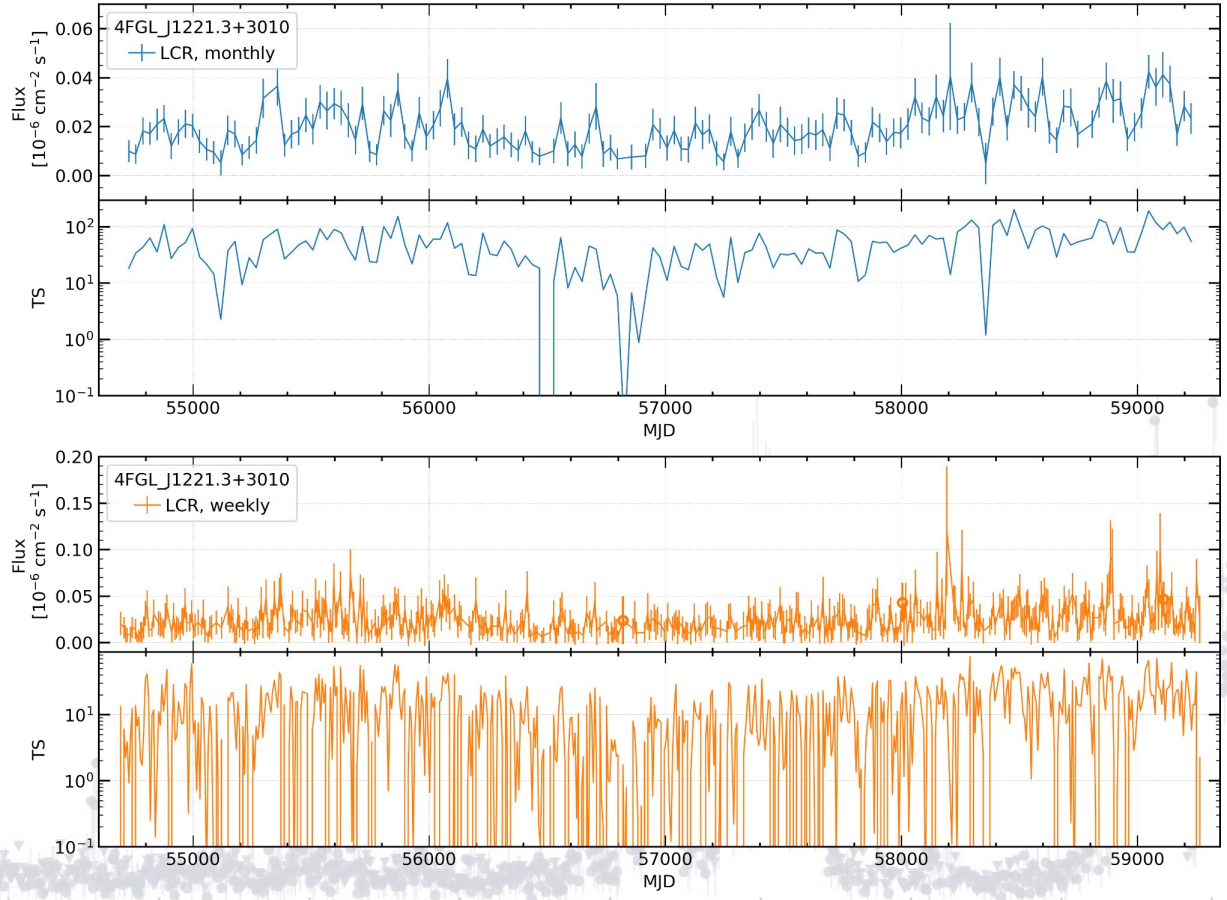
★ Empty circles indicate non-convergent analyses. In histograms, dashed lines represent results from all time bins. Solid lines represent bins that did not converge.

Bright source: Ton 599



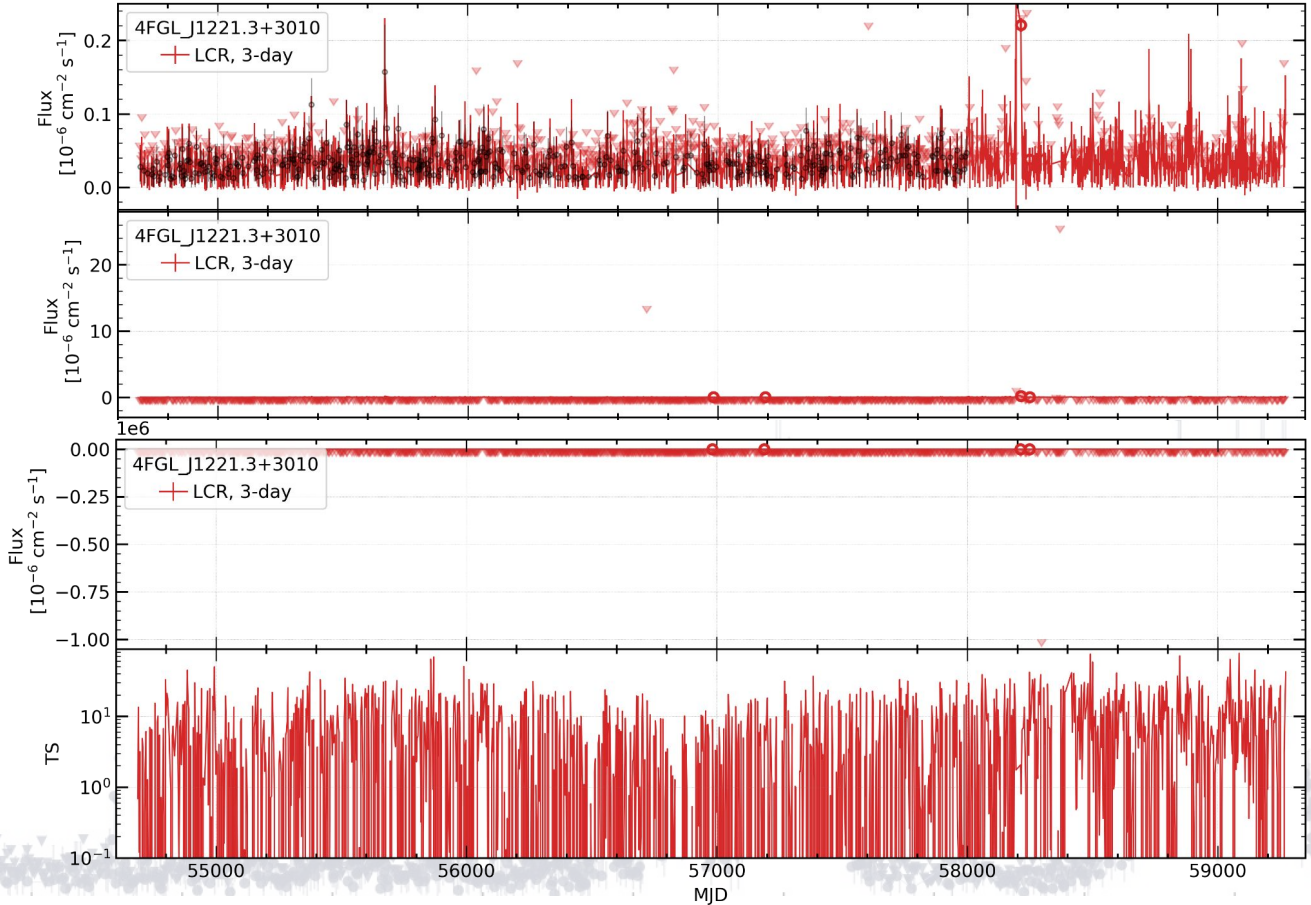
★ Empty circles indicate non-convergent analyses.

Dimmer source: 1ES 1218+304, fixed index



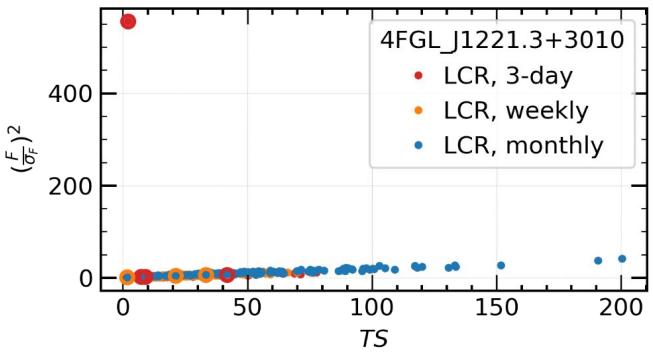
- ★ Monthly : 0 bins (out of 149) with UL<0 & 0 with $q \neq 0$.
- ★ Weekly: 5 with (out of 621) $q \neq 0$.
  - 3 bins provide flux measurements.
  - 1 bins with UL< 0.
- ★ Empty circles indicate non-convergent analyses.

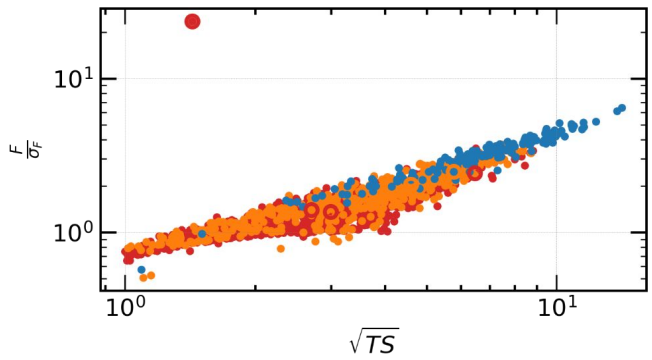
Dimmer source: 1ES 1218+304, fixed index



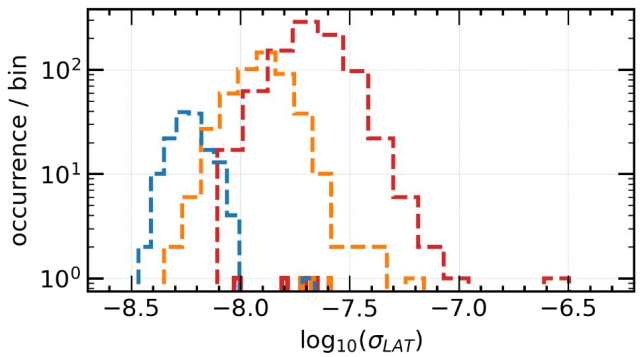
- ★ 3-day : 14 (out of 1485) with $q \neq 0$.
  - 4 bins provide flux measurements.
  - 1 bin with UL=-1, it has $q \neq 0$.
- ★ The LCR plotter might not show unconstraining results likely associated with non-convergent fits, including meaningless negative upper limits (ULS).
- ★ Empty circles indicate non-convergent analyses.
- ★ Black points are data from a dedicated analysis using a different pipeline.

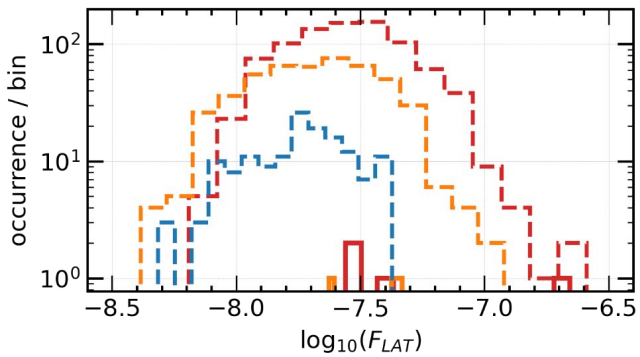
Dimmer source: 1ES 1218+304, fixed index

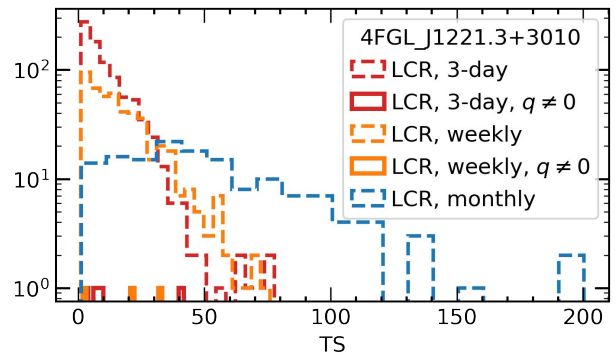




- ★ Monthly : 0 bins (out of 149) with UL<0 & 0 with q ≠ 0.
- ★ Weekly: 5 with (out of 621) q ≠ 0.
  - 3 bins provide flux measurements.
  - 1 bins with UL< 0.
- ★ 3-day : 14 (out of 1485) with q ≠ 0.
  - 4 bins provide flux measurements.
  - 1 bin with UL=-1, it has q ≠ 0.

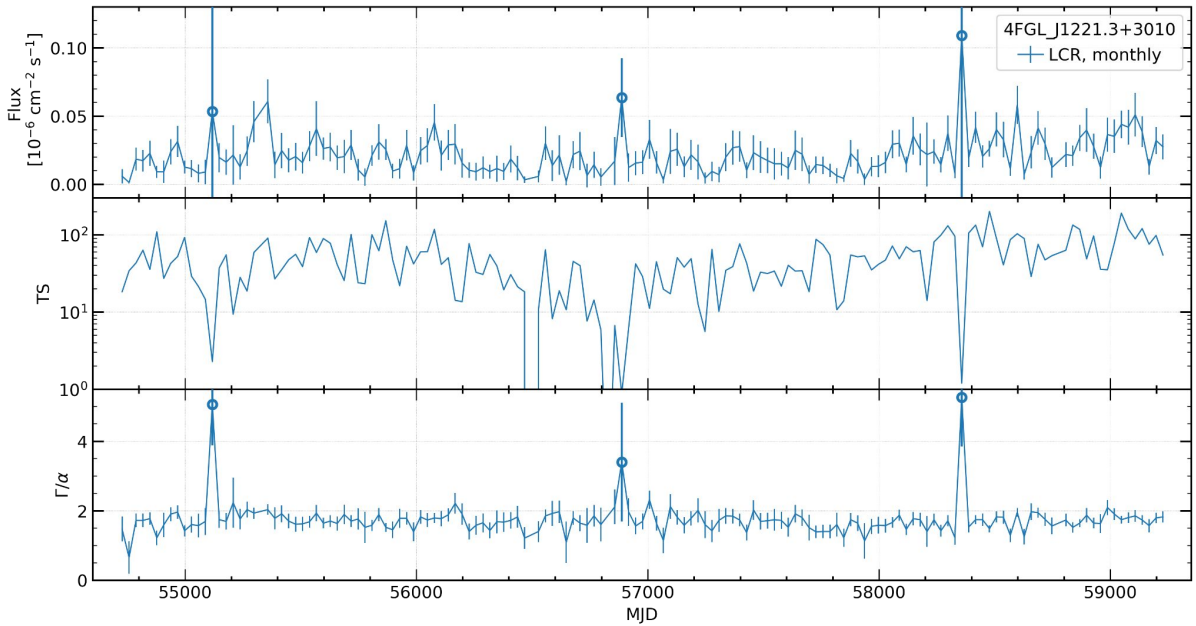






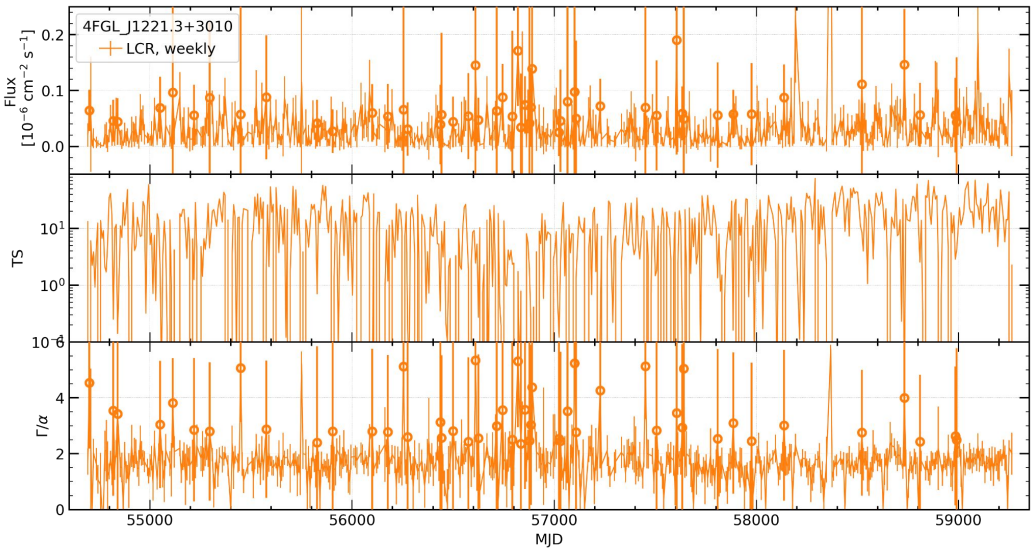
★ Empty circles indicate non-convergent analyses. In histograms, dashed lines represent results from all time bins. Solid lines represent bins that did not converge.

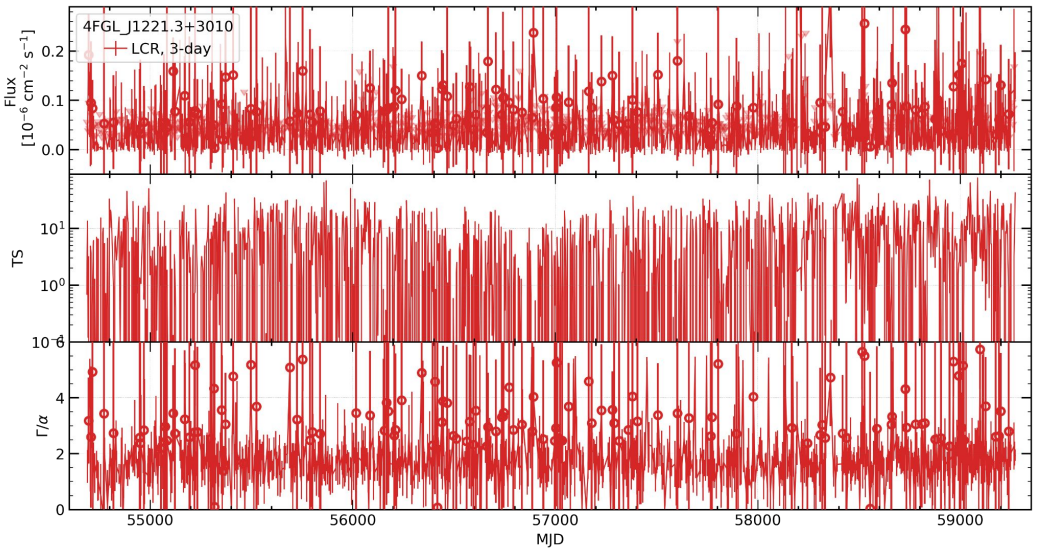
Dimmer source: 1ES 1218+304, free index



- ★ Monthly : 3 bins (out of 149) with q ≠ 0, all provide flux measurements.
- ★ Empty circles indicate non-convergent analyses.

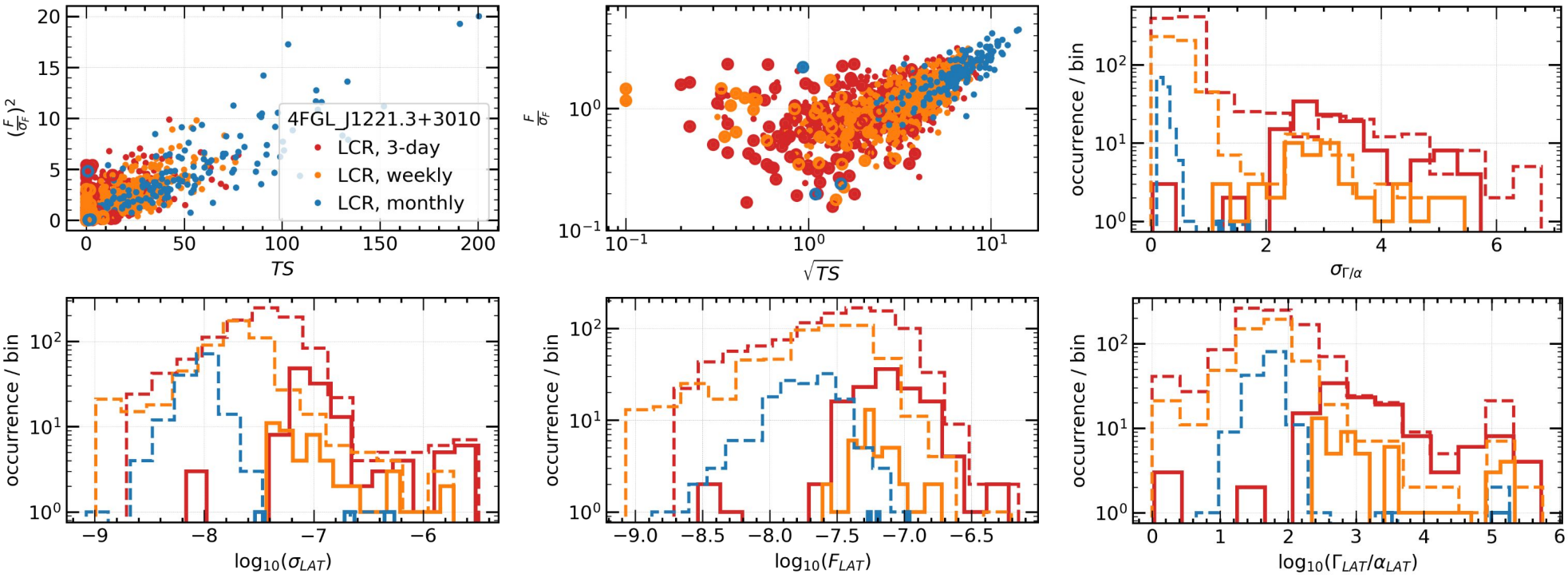
Dimmer source: 1ES 1218+304, free index





- ★ Weekly: 95 with (out of 621) q ≠ 0.
  - 50 bins provide flux measurements.
  - 1 bin with UL< 0.
- ★ 3-day : 461 (out of 1485) with q ≠ 0.
  - 125 bins provide flux measurements.
  - 1 bin with UL=-1, all have q ≠ 0.
- ★ Empty circles indicate non-convergent analyses.

Dimmer source: 1ES 1218+304, free index



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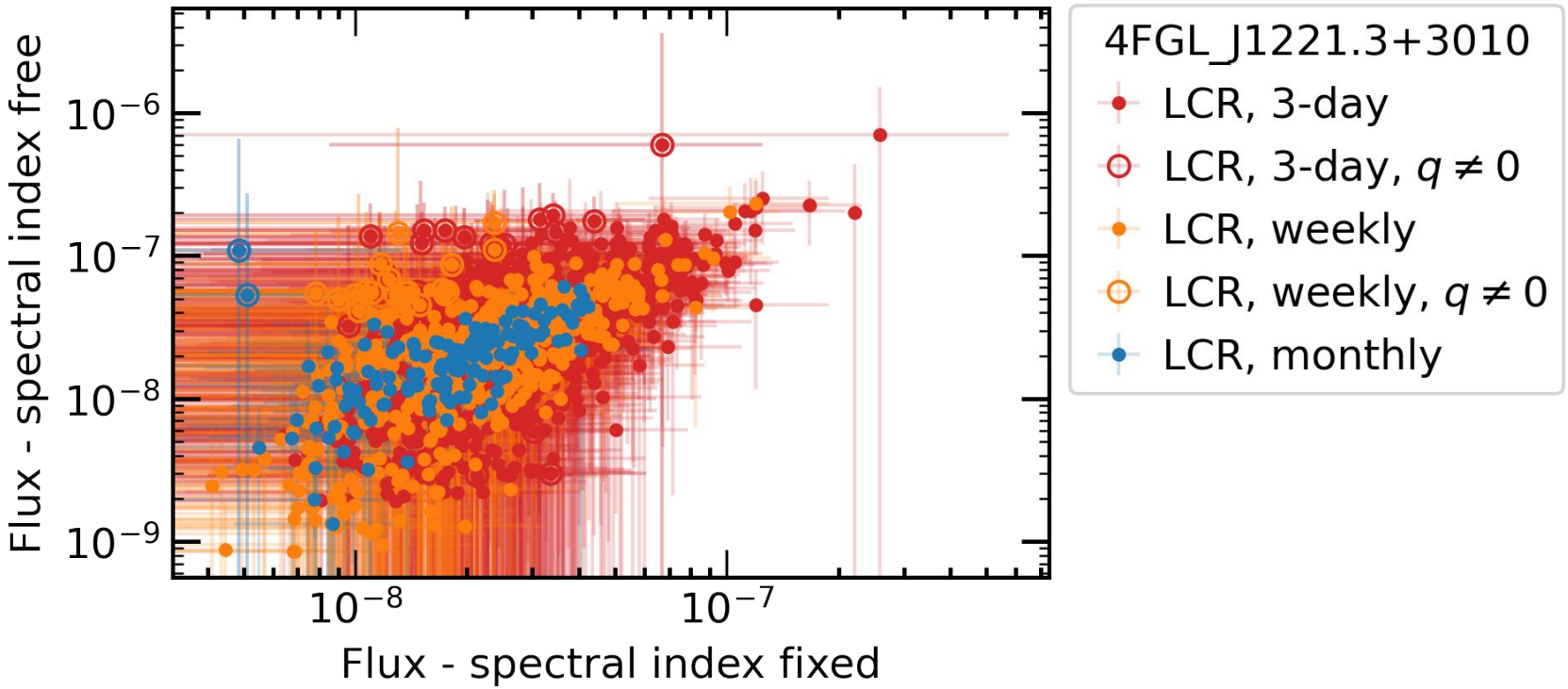
Dimmer source: 1ES 1218+304



★ Empty circles indicate non-convergent analyses.

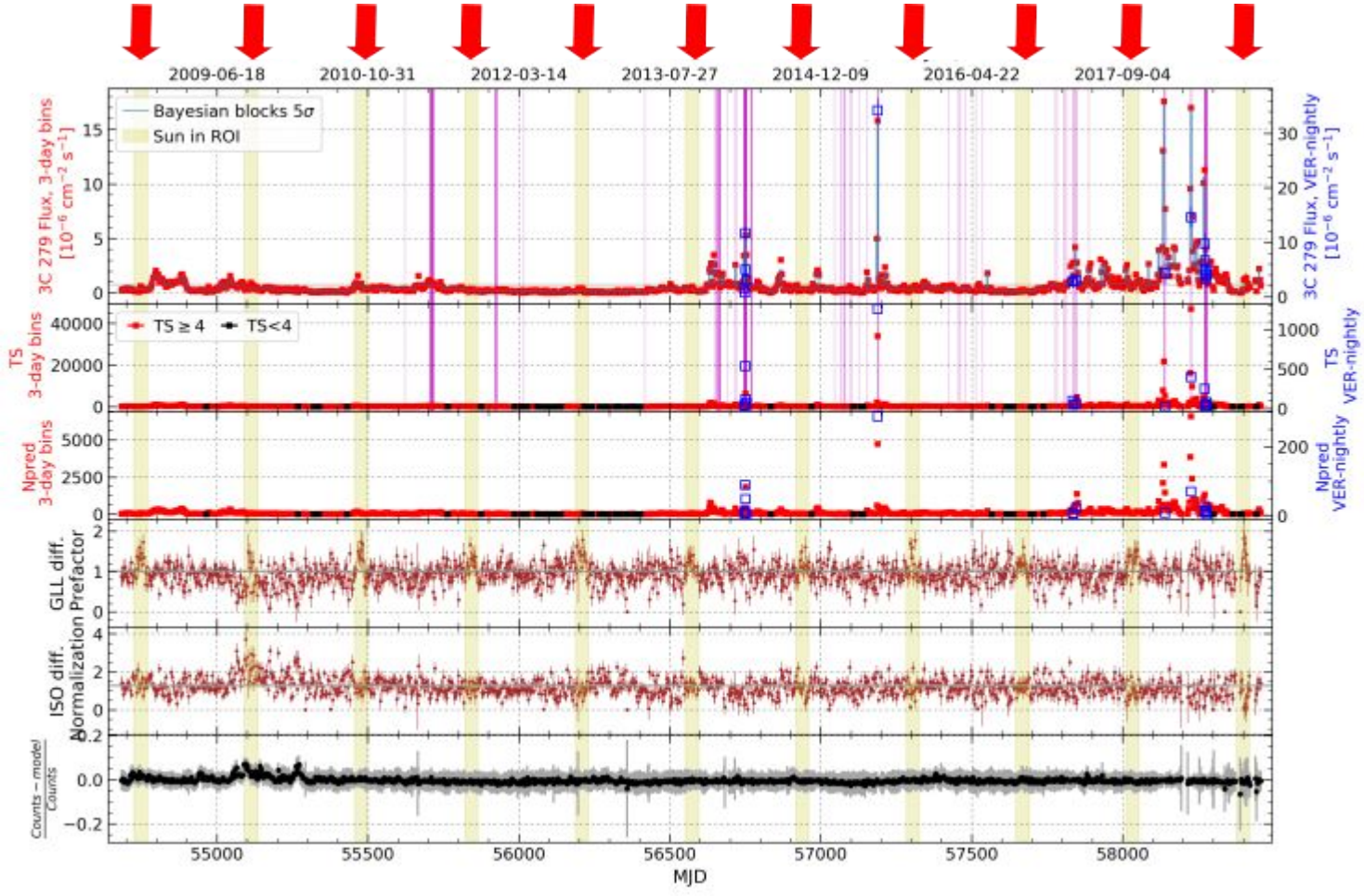
First look at a few sources

- From a look at the results of a sample of sources, 3C 279, Ton 599, PKS1222+216, 1ES 1215+303, 1ES 1218+304, 4C +28.07:
  - No negative TS values observed in test sample so far.
  - No non-convergent or UL<0 for monthly bins (except for a few bins for index free LC of a not so bright source such as 1ES 1218+304).
  - For other cadences, <3% non convergent bins and <1% UL<0 for index-fixed LCs or index-free LCs for bright sources.
  - For 1ES 1218+304, a dimmer source, ~30% non-convergent bins for the 3-day free-index LCs, because there is not enough data to constrain the spectral index. This is the main reason the LCR provides LCs from two fits, one with spectral index fixed and one with it free.
  - UL<0 seen so far come from non-convergent analyses, in which case these ULs are meaningless and should not be used.
  - Significance and flux-flux plots do not look so well for a dimmer source. This is also observed in LCs from other pipelines.

Caveats

- ★ The Fermi-LAT Collaboration does not have a recommended likelihood fit convergence strategy. The strategy adopted for the LCR generates reasonable results in most time bins, but the method does not represent an official strategy endorsed by the Fermi-LAT Collaboration.
- ★ The LCR provides fit results from both convergent and non-convergent likelihood analyses. Results from non-convergent analyses should be considered suspect and should not be used for higher level analyses (e.g. multifrequency cross-correlation, PSD, Bayesian blocks studies).
- ★ The likelihood test statistic (TS) is defined to be positive. Negative TS values can be obtained when parameters reach the limits of their allowed intervals without having maximized the likelihood profile. Fit results obtained from any interval that resulted in negative TS values should be considered suspect and should not be used in higher level analyses.
- ★ Because the LCR analysis is done automatically as soon as the data are available, the results are not validated by the LAT collaboration prior to release. Sanity checks are warranted by examining the flux to flux uncertainty ratio versus the square root of the TS, and the fit result distributions, e.g. flux, flux uncertainties, spectral indices mean values (Γ, α, etc) and their uncertainties, dedicated analyses.
- ★ The free-spectral-index light curves provided by the LCR were produced using a model of the pertinent region of the sky where only the spectral index of the target source is set free, while those of all the other sources were fixed to the catalog values. Therefore, contamination induced by possible changes in the spectral indices of the sources surrounding the target are not taken into account. For instance, sources undergoing bright flares have been seen to also experience dramatic changes in their spectral indices, including changes in the curvature, at the same time (e.g. harder-when-brighter behavior). Therefore, bright, variable sources in the region might be more likely to induce this type of contamination.
- ★ Read Usage Notes.

Caveats



- ★ Possible contamination by the proximity of the quiescent Sun or Moon has not been accounted for, nor have those time ranges been excluded.
- ★ Happens for sources close to the Ecliptic during epochs of solar or lunar proximity.
- ★ Yellow regions: Sun is $< 20°$ from 3C 279 (quiescent Sun flux ~5×10^{-7} ph/cm^2/s).

- To acknowledge this effort:
  - Add a link to the webpage.
  - Cite the ATel: Kocevski et al. (2021), ATel#15110.
- Contribute through: GitHub Repository
- Contact us: fermilcr@athena.gsfc.nasa.gov

Thank you!