Fermi-LAT Lightcurve Analysis

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What I learned this week

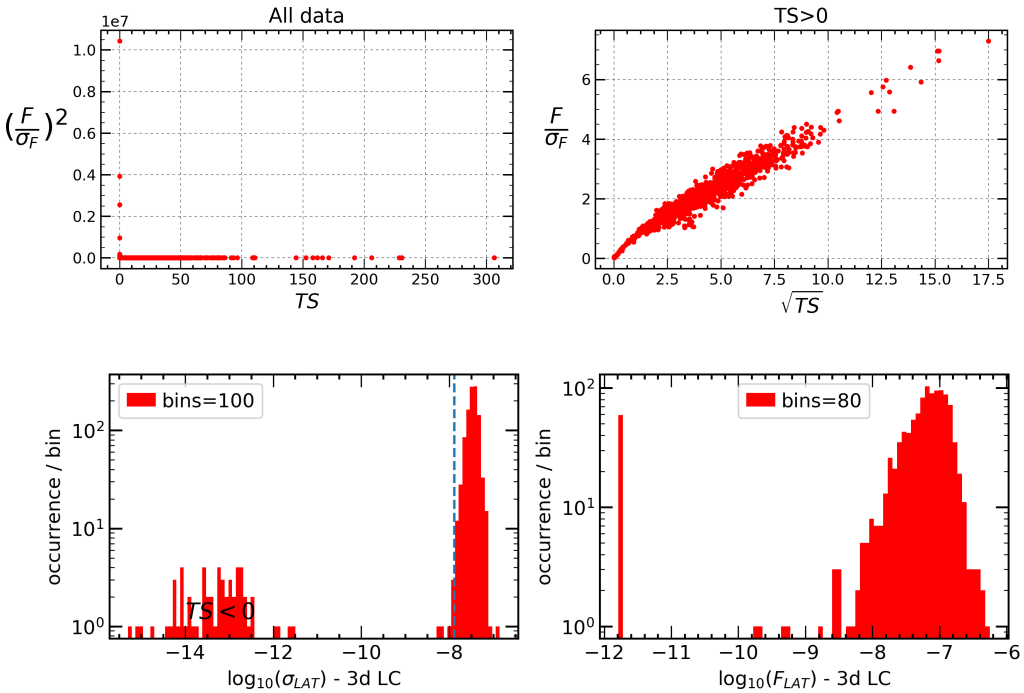
- ★ Fermipy is meant to be built & maintained by the community for the community.
- ★ From the discussions, possible areas to contribute to `lightcurve.py`:
  - Save/provide a log of the step where the fit converged.
  - Save/provide the fit results of other (free) sources in the ROI, including the diffuse backgrounds.
  - Make convergence strategy flexible or so that the criteria can be chosen by the user.
  - Double check the allowed range of parameter values for spectral indices?

Convergence strategies

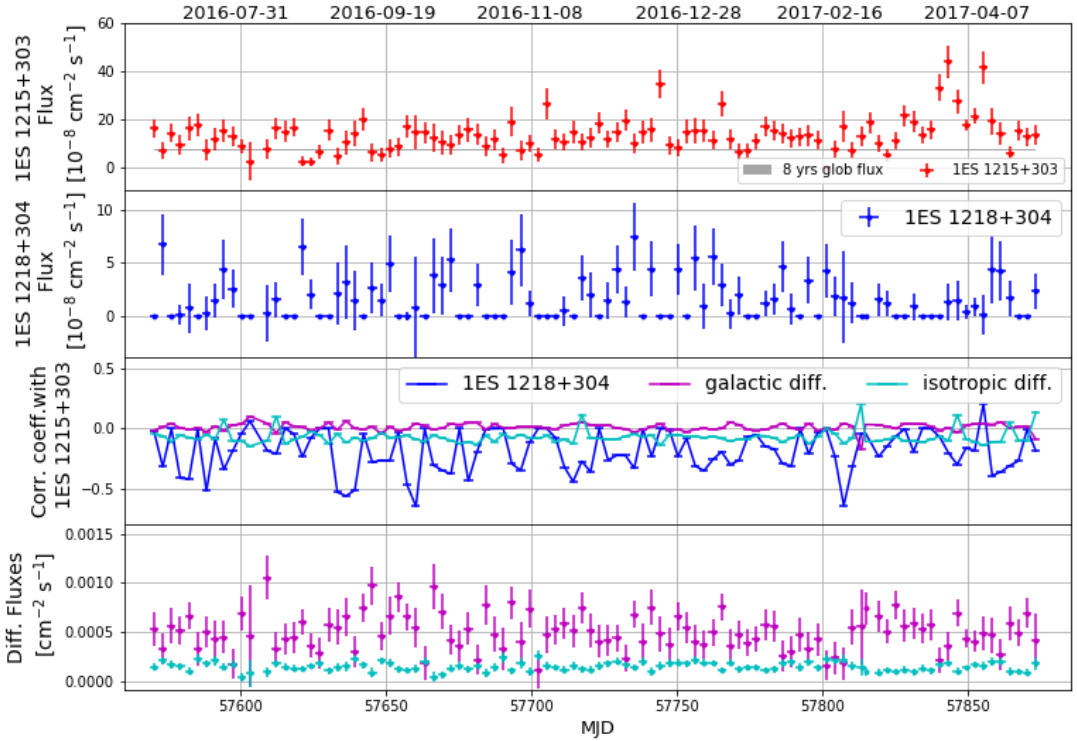
- ★ The collaboration does not recommend a specific strategy, but has endorsed various through the papers.
- ★ Most strategies include:
  - Removing sources in the ROI that have TS below a value that is chosen depending on how bright the target is.
  - Fix unlikely spectral indices values (e.g. α=5.0 +/-0.0). Happens for sources with low TS.
  - Running a series of fits where we fix sources with TS below a value that increase at each step until the analysis converges.
  - Before fixing parameters, letting the analysis run from where it left the last time can get the fit to converge.
  - Light curve repository strategy is based on changing the fit tolerance.

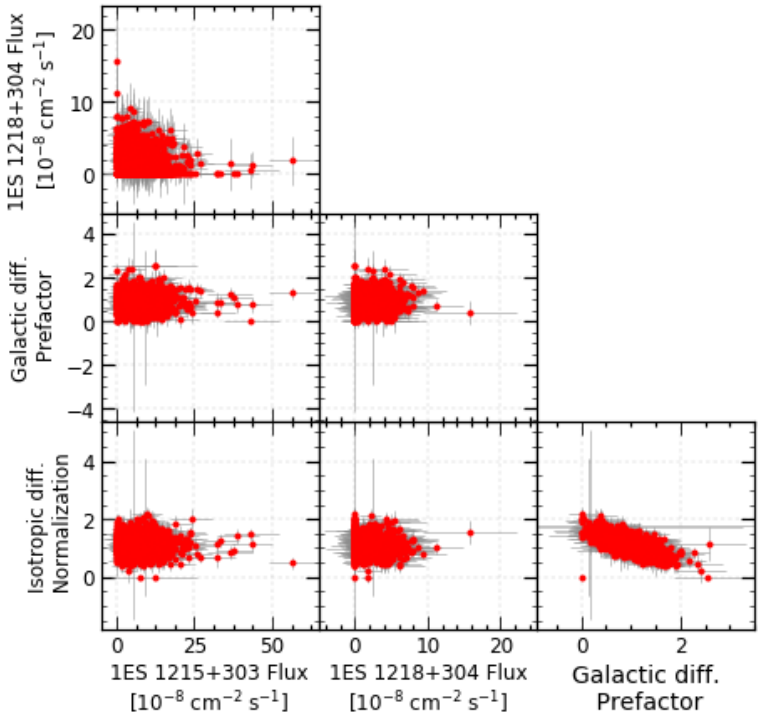
Good practices

- ★ Avoid fixing sources close to the target or variable sources so that correlated effects between them and the target can be investigated.
- ★ Perform sanity checks: Convergence, correlation parameters, parameter distributions, flux-flux correlations.



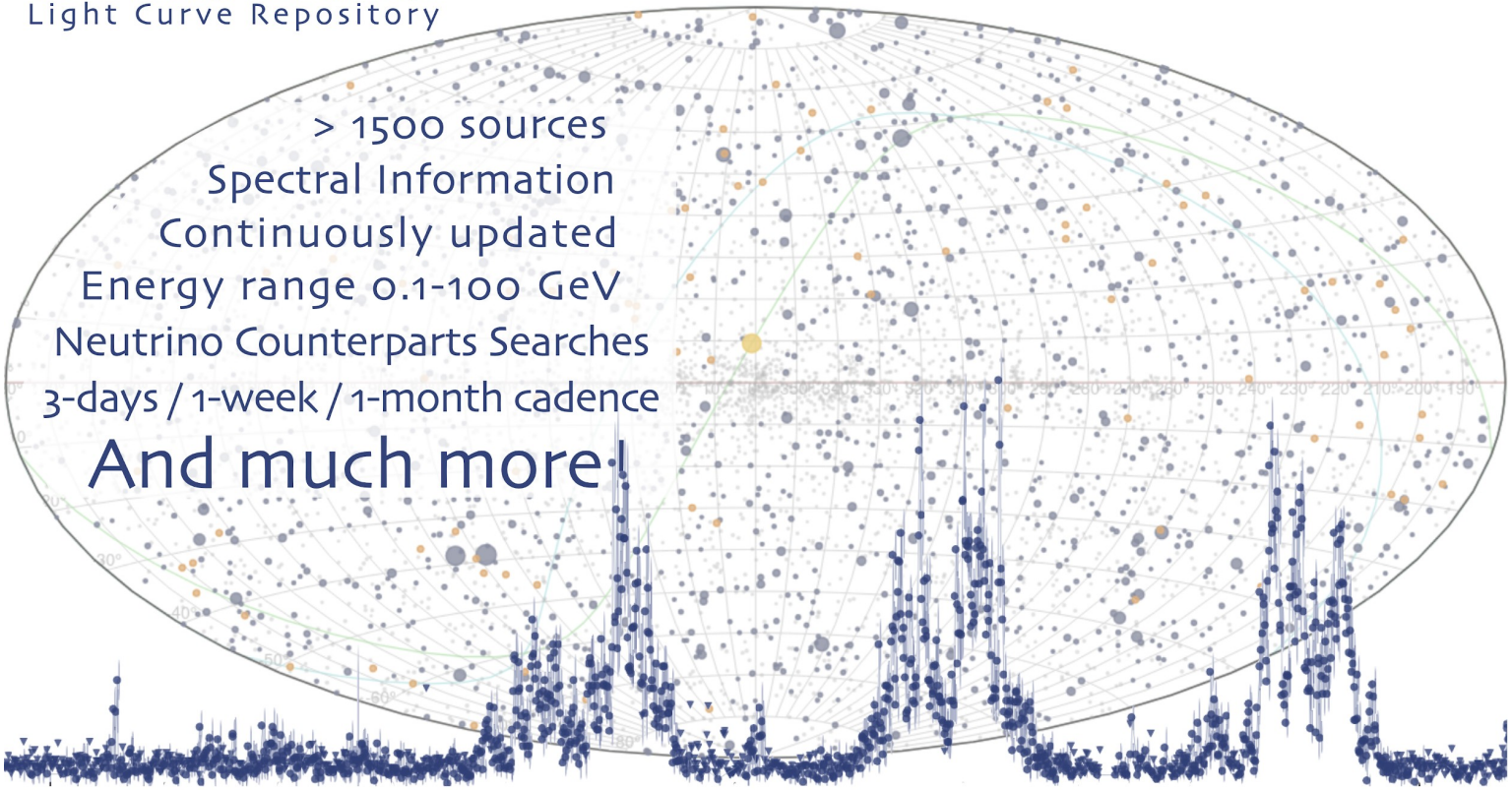
Good practices





LCR
The Fermi Large Area Telescope
Light Curve Repository

Fermi Gamma-ray Space Telescope



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

LCR: Automated likelihood analysis

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)

★**Unbinned** likelihood analysis.

★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.

★Only variable sources free in ROI. 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, between 1 and 4, for flux estimation.

LCR: Continuously updated

★Review paper for details & caveats.

★Three cadences: 3-day (~1700 time bins in 14 years), 7-day, 30-day.

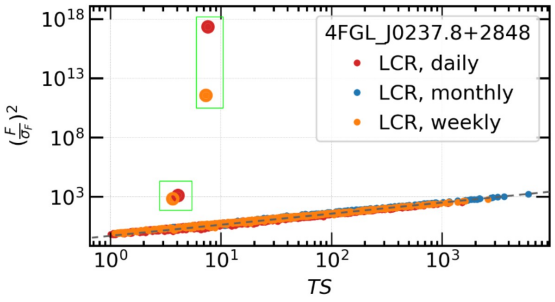
★Complex analysis: Data included non-convergent, unconstrained, with TS<0. Data need to be cleaned before used.

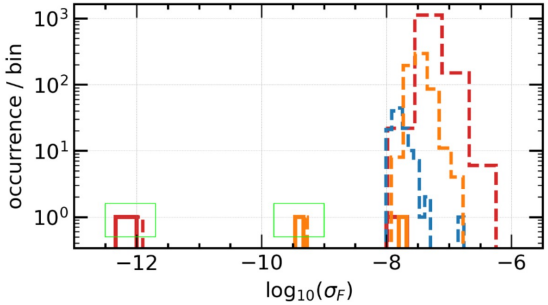
- Index fixed and free options. Index fixed: ~0.7% of time bins did not converge. Index free: ~35% of time bins did not converge.
- A few bins with TS<0 per cadence, for both fixed and free fits.
- 175 GRBs & 266 solar flares affected $\lesssim$0.01% time bins for all LCR sources per cadence.
- Unconstrained values can happen during time periods with low or zero exposure. Seems to affect < few% of total time bins.

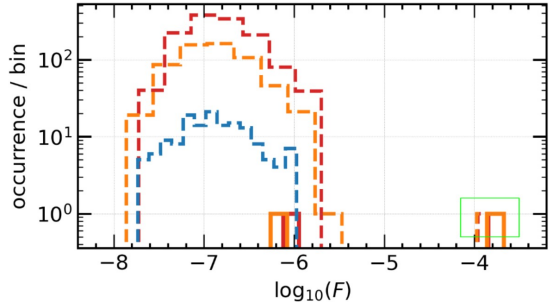
★Data in two formats: CSV, JSON. See Table and JSON File Description.

LCR: 4FGL J0237.8+2848

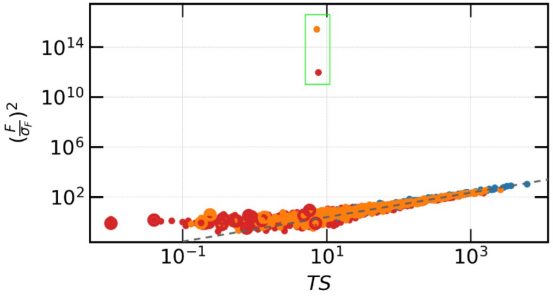
Index fixed

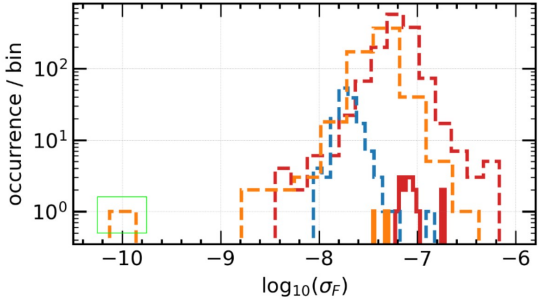


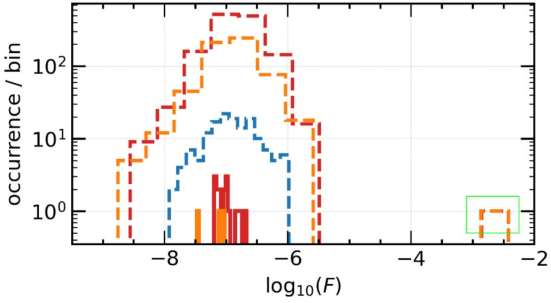




Index free







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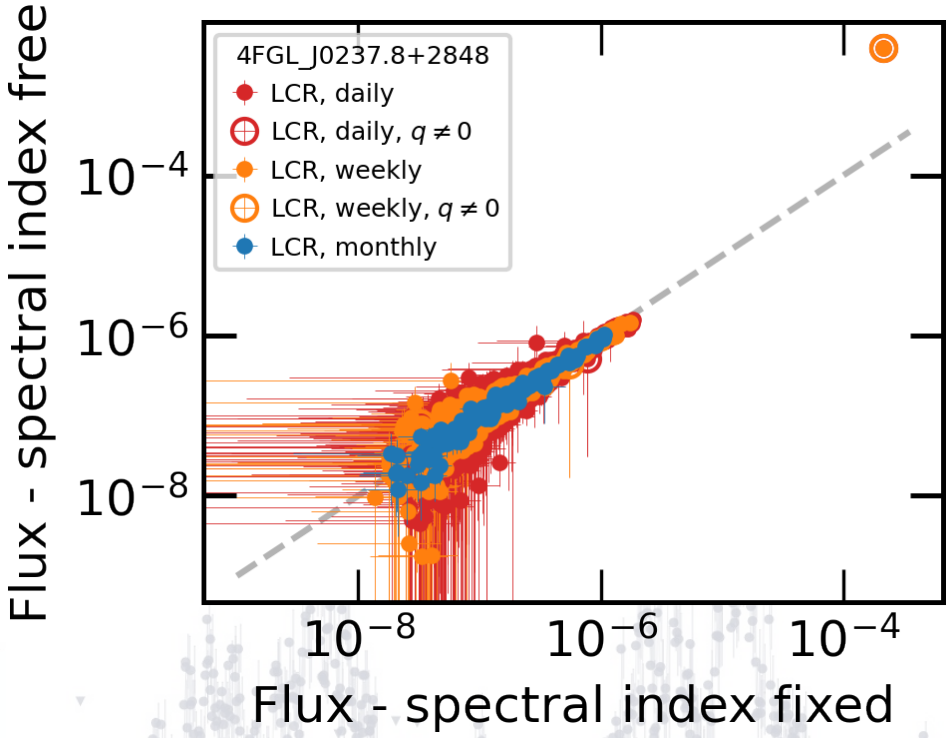


Use LCR results in model files?

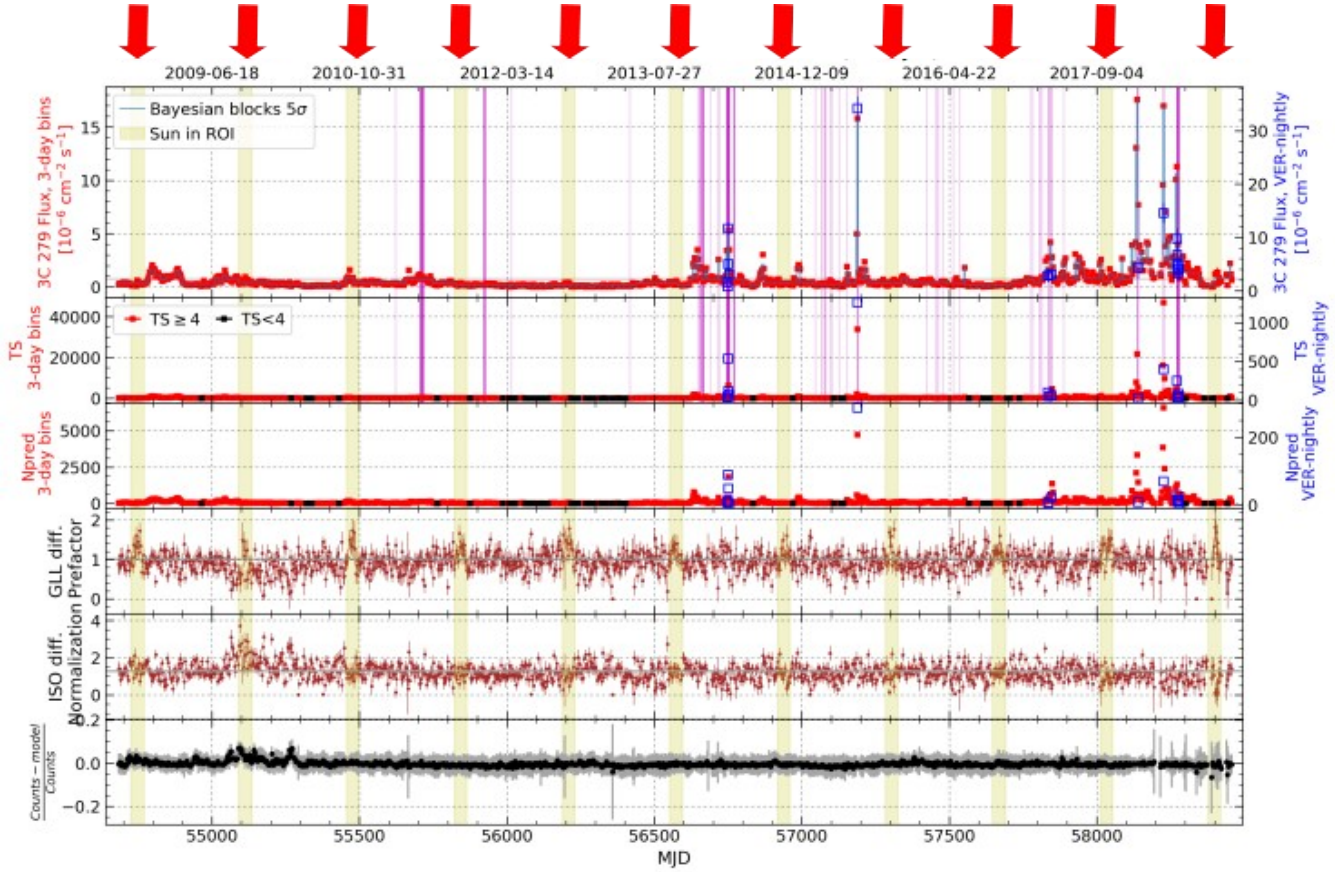
- ★LAT CM input: Use LCR results to build model files with values that better discribe the source activity in the corresponding time bin. This file can be used in detailed analyses of smaller timescales included in the concerned time range.
- ★If we wanted to make this possible for Fermipy users, what is the best way to do it? Something needed from LCR folks?

- ★ Paper on best practices when performing LAT (AGN) variability analyses in preparation.
- ★ To get in touch with LCR folks:
  - Email: fermilcr@athena.gsfc.nasa.gov
  - Contribute through: GitHub Repository

Thank you!

Backup slides

Solar contamination



★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 (see e.g. Adams et al. 2022).

★Yellow regions: Sun is < 20° from 3C 279 (quiescent Sun flux ~5×10^{-7} ph/cm^2/s).

Lunar contamination

★ The Sun moves about 1°/day and is in or close to the ROI of sources once a year. The Moon moves ~13°/day and is in or close to the ROI of sources 13 times a year.