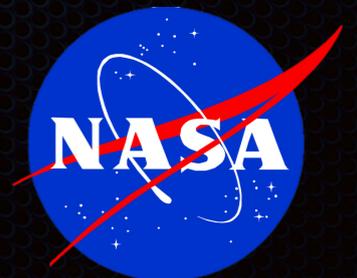


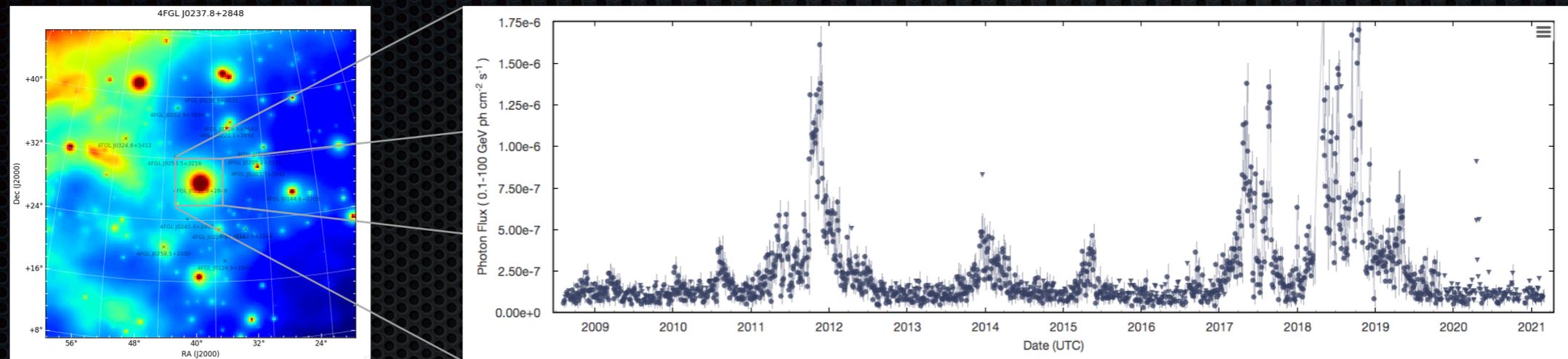
# The Fermi LAT Light Curve Repository

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# Fermi Light Curve Repository



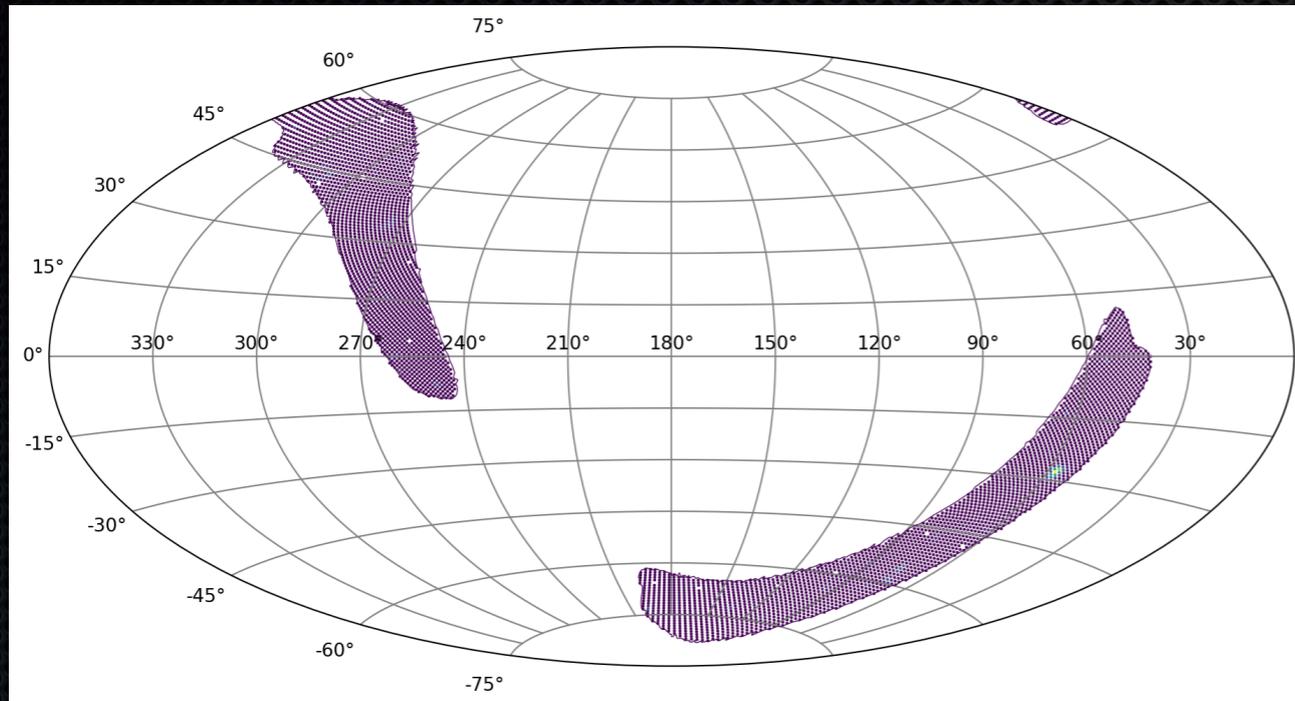
- ✦ A public library of light curves on time scales of days, weeks, and months for all LAT sources deemed variable in the 4FGL
- ✦ Hosted at the FSSC, this library will serve as a general purpose repository for publication ready light curve data
  - ✦ Consist of a full likelihood modeling of the source and surrounding region
  - ✦ The repository will provide flux and spectral index history for these sources over the lifetime of the mission
- ✦ Serve as a resource to the time-domain and multi-messenger communities by helping scientists monitor interesting LAT sources and alerting them of new gamma-ray flares

# Motivation

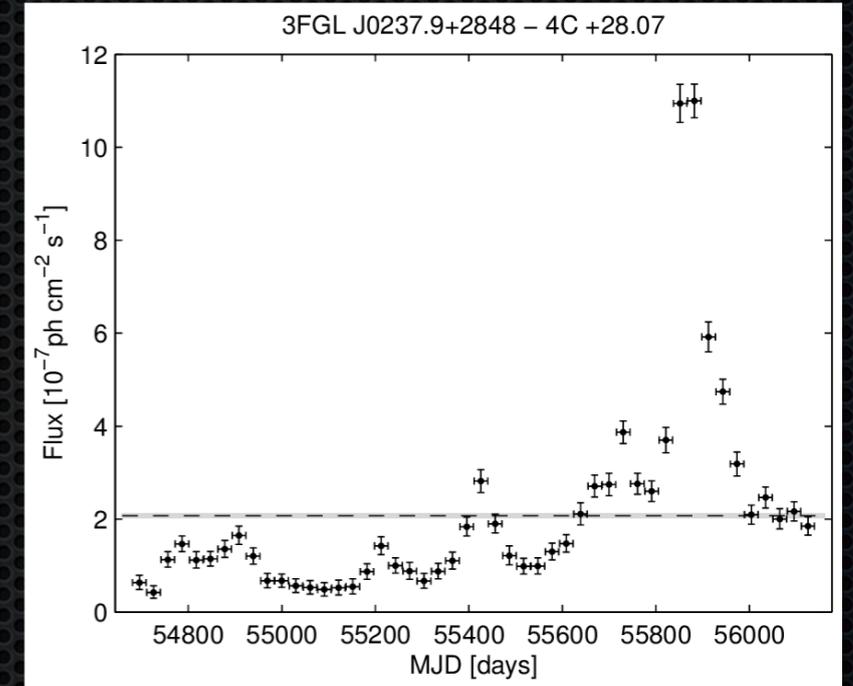
- The long baseline monitoring of the gamma-ray sky provided by the LAT has been critical to time-domain and multi-messenger discoveries
- Constraints on neutrino emission from bright gamma-ray blazars have largely disfavored steady-state AGN as the primary source of the observed astrophysical neutrino flux
  - The TXS 0506+056 association suggested that astrophysical neutrinos detected by IceCube could be attributed to high fluence AGN that undergo intense flaring activity
- Long baseline monitoring has also long been indispensable to study of AGN variability
  - e.g. Lags in 3C 279, quasi-periodic variations in PG 1553+113, rate of orphan flares
- The Fermi All-sky Variability Analysis (FAVA) is extremely effective at source detection/discovery, but the relative flux light curve are not ideal for source characterization
  - FAVA has been extremely useful in identifying long term variability of sources, but relative photometric light curves are easily contaminated by nearby variable sources
- Characterization requires a full likelihood analysis of the source and surrounding region

# Analysis Logistics

Distributed TS Map

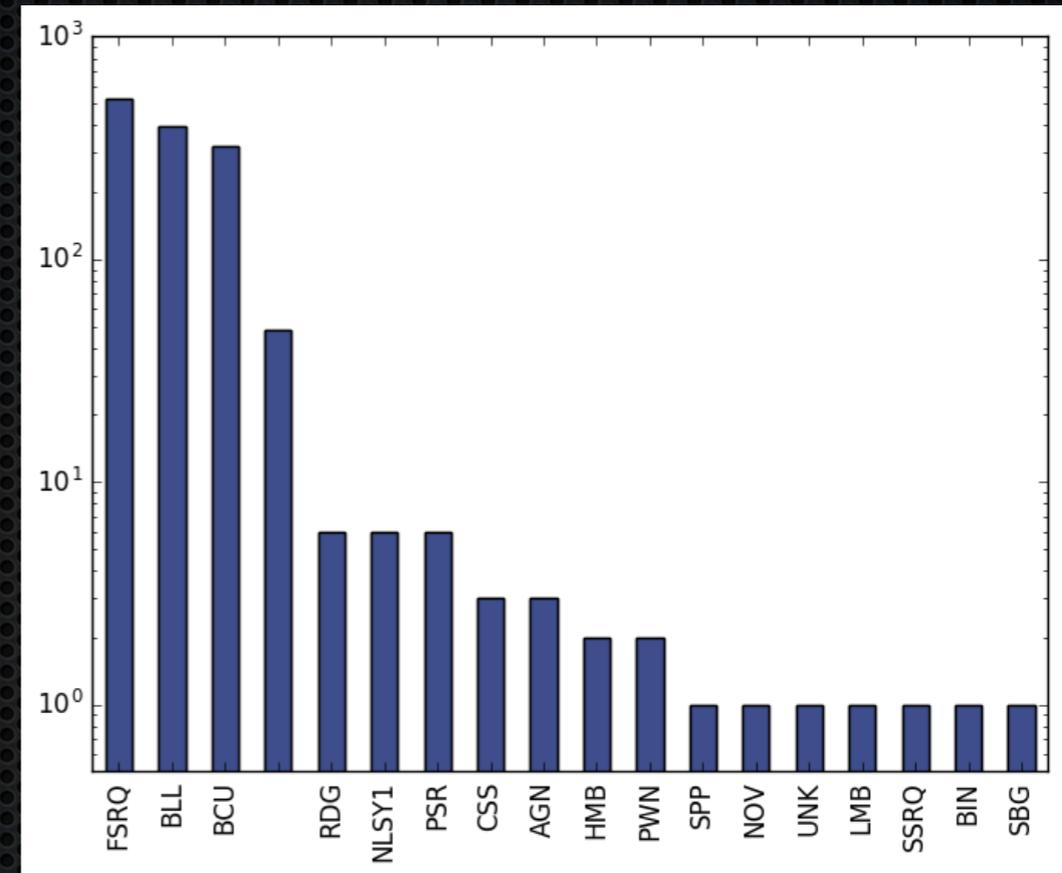
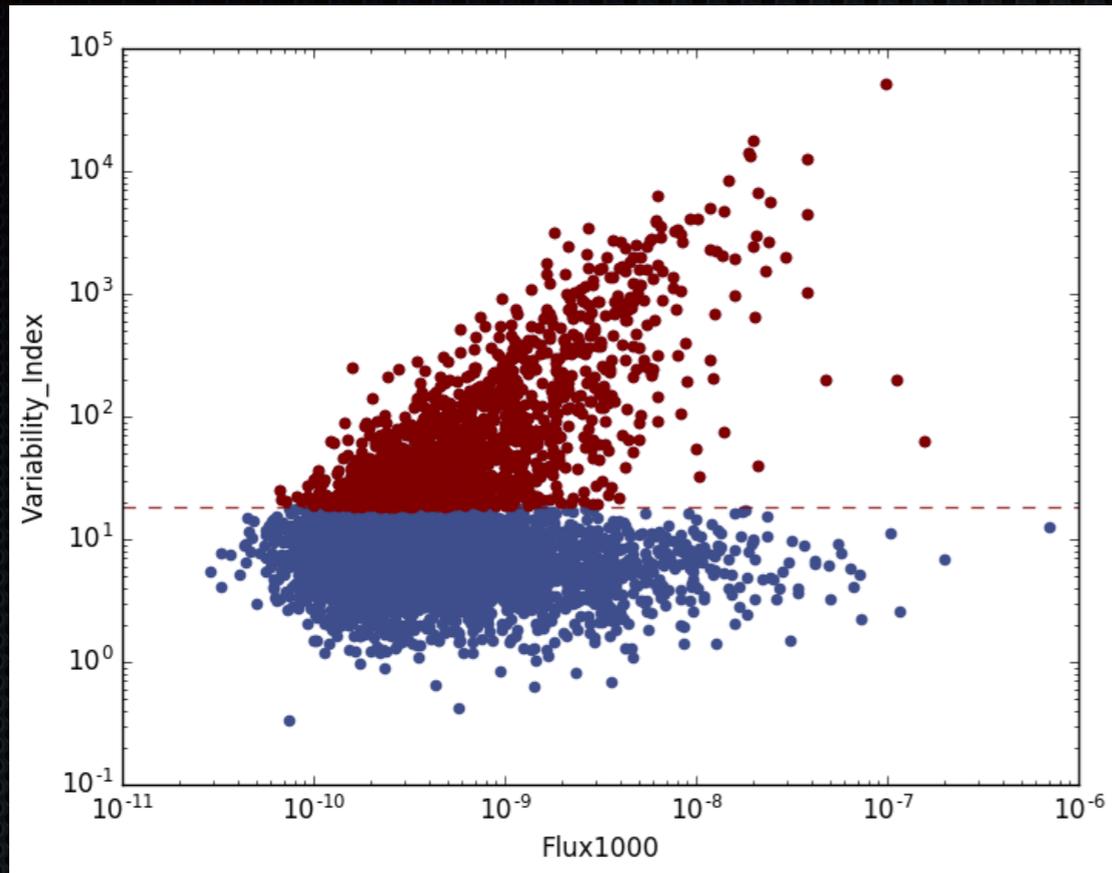


Distributed Light Curve



- A major challenge of producing likelihood light curves is the computational expensive
- The computational overhead is tackled by parallelizing the full unbinned likelihood analysis with a computer cluster at SLAC National Accelerator Laboratory using a distributed likelihood analysis code developed for LIGO followup
  - Each sky bin is analyzed on a separate node, same can be done for individual time bins
- The 3-day distributed unbinned likelihood light curves can then be generated in ~15 minutes

# Sample Selection



- Start with the newly released 4FGL-DR2 catalog
- Select all sources with Variability\_Index > 21.67 (with no additional cuts on TS)
  - A variability index of >21.67 over 12 intervals indicates <1% chance of being a steady source
- Results in 1525 sources (26% of the 4FGL-DR2 catalog)
- Majority of sources are AGN (FSRQs, BL Lacs, BCU)

# Data Selection & Model Generation

- Data Selection

- data = P8\_P305

- IRFS = P8R3\_SOURCE\_V2

- ROI = 12

- Zenith angle = 100

- Model Generation

- Model all sources within ROI + 10 deg

- Fix all sources non-variable sources to their catalog values

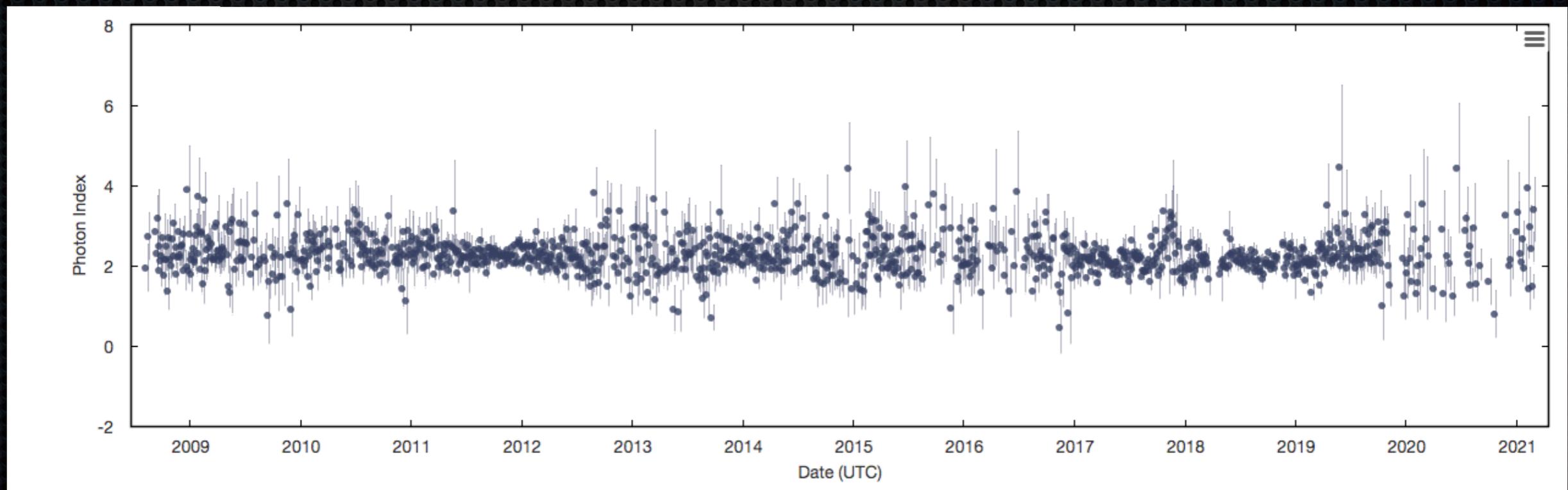
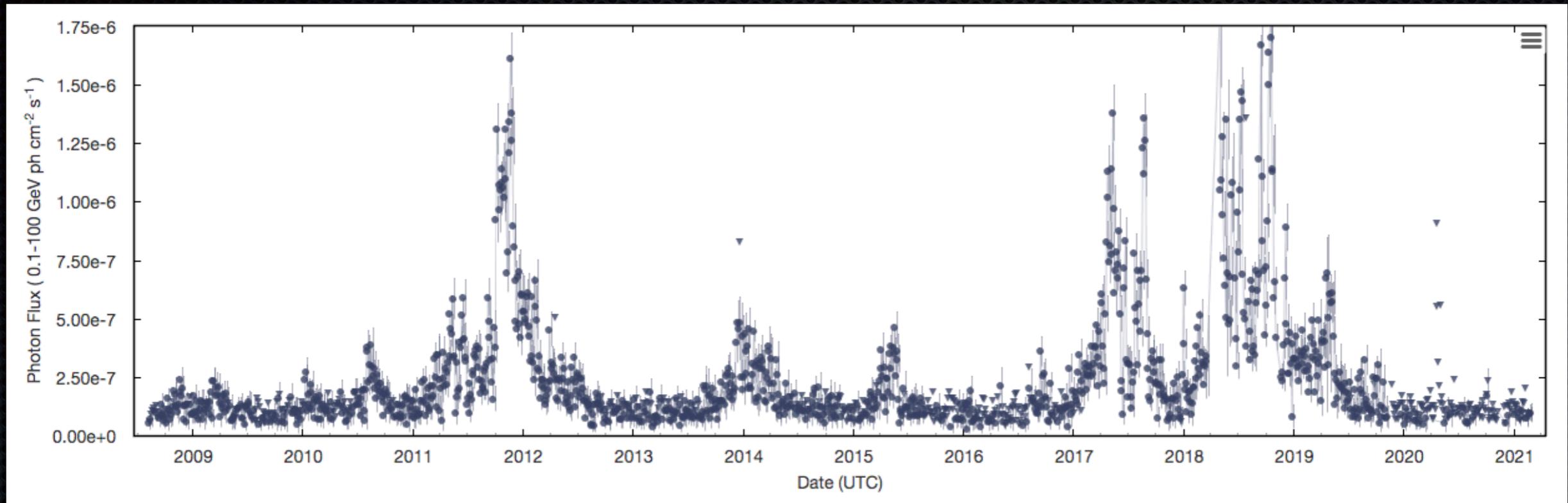
- Leave all variables sources free

- All variables sources outside ROI > 12 deg are fixed to their catalog values

# Likelihood Fitting Strategy

- Use pylikelihood to perform unbinned analysis using MINUIT
- Perform a nested fixed and free spectral index fit
  - First fit: only normalization set free and spectral index is fixed to catalog value
  - Second fit: both normalization and spectral index are set free
- Iterative likelihood fit using increasingly tighter fit tolerances
  - Perform multiple fits using fit tolerances ranging from [1, 1-e4, 1e-8]
  - Implemented to minimize fit non-convergence
- Flux extraction occurs for both fixed and free index fits
  - Flux is extracted for all fits that yield  $TS > 1$
  - 95% Bayesian upper limits are also calculated whenever  $TS < 4$  (~2 sigma)
  - Users can then choose the minimum TS level for flux estimation

# 12 Year Light Curve @ 3 day binning





# Fermi LAT Light Curve Repository (LCR)

## Catalog Search

RA:  Dec:  Radius:

Keyword:

## Map Options

Coordinate System:

Celestial Projection:

Coordinate Planes:

Equatorial  Ecliptic

Galactic  Supergalactic

Overlays:

Source Info  Grid Lines

Constellations  Milky Way

Sun  Moon

4FGL Marker Size:

Variability Index  Significance

4FGL Marker Label:

4FGL Name  Association

3FGL Assoc  Classification

4FGL Marker Color:

Gray Non-Variable Sources

## Data Overlays

LAT Point Source Catalog (4FGL)   
Abdollahi et al. 2020 - 5523 Sources

FAVA Flare Catalog (2FAV)   
Abdollahi et al. 2017 - 4309 Flares

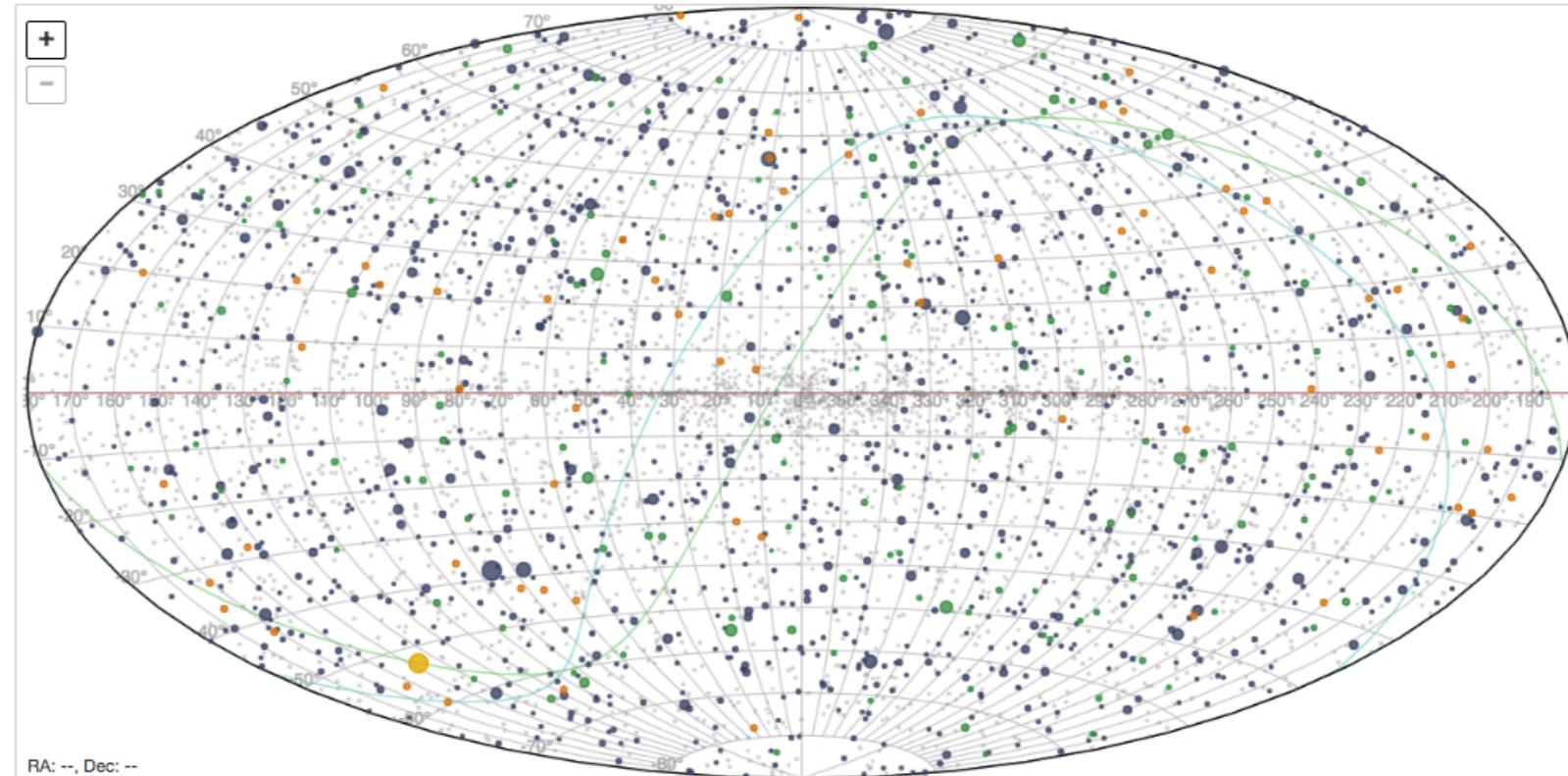
2nd LAT GRB Catalog (2FLGC)   
Ajello 2019/GCN - 207 Detections

IceCube Neutrino Alerts   
GCN/AMON Notices - 68 Events

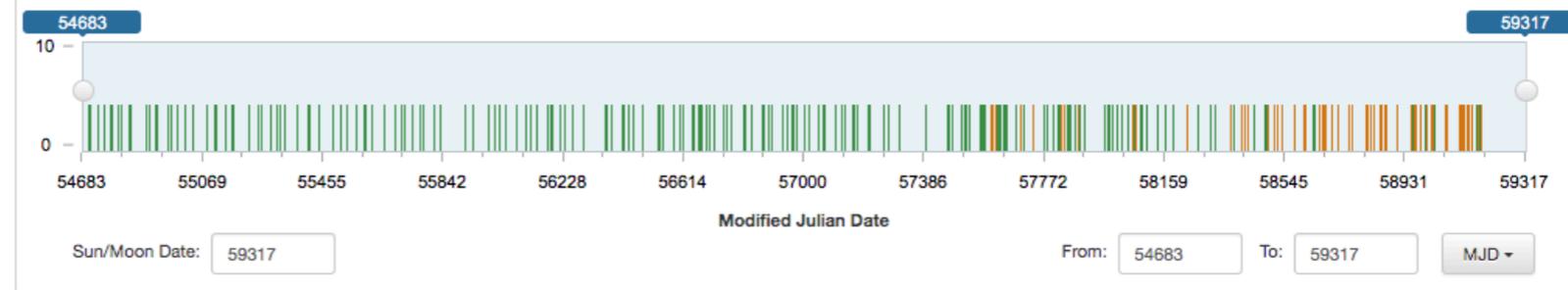
## Related Resources

- [The Fermi Science Support Center](#)
- [Fermi All-Sky Variability Analysis \(FAVA\)](#)
- [Fermi LAT & GBM Analysis Tutorials](#)

## Catalog Map



RA: --, Dec: --



## Catalog Sources

4FGL  2FLGC  IceCube

Source ID	RA	Dec	Gal l	Gal b	Association	Class	Variability Index	Photon Flux 1-100 GeV	Energy Flux 1-100 GeV	Average Significance	Spectrum Type	Spectral Index
4FGL J0000.3-7355	0.098	-73.922	307.709	-42.730			8.665	1.719e-10	1.920e-12	7.400	PowerLaw	2.119
4FGL J0001.2+4741	0.313	47.686	114.250	-14.338	B3 2358+474	bcb	17.289	1.425e-10	1.631e-12	4.197	PowerLaw	2.198
4FGL J0001.2-0747	0.315	-7.797	89.033	-67.305	PMN J0001-0746	bl	16.869	8.397e-10	9.440e-12	22.748	PowerLaw	2.148
4FGL J0001.5+2113	0.382	21.218	107.649	-40.168	TXS 2358+209	fsrq	920.677	9.679e-10	1.926e-11	30.666	LogParabola	2.598



## Fermi LAT Light Curve Repository - Source Report

### Light Curve Options

#### Data Cadence:

**3 day** 1 week 1 month

#### Analysis Options:

Minimum Detection Significance: **TS = 4 (2 $\sigma$ )**

Spectral Fitting: **Free Index**

#### Plotting Options:

- Upper Limits
- Connector Line
- Error Bars
- Data Tooltips
- Show Non-Convergent Fits
- Show Unconstrained Fits



### 4FGL Catalog Data

#### Source Information

Catalog Name: 4FGL J0237.8+2848

RA: 39.474°

Dec: 28.804°

Galactic l: 149.470°

Galactic b: -28.524°

Variability Index: 3219.99

#### Flux Information

Photon Flux: 7.7e-9 ph cm<sup>-2</sup> s<sup>-1</sup>

Energy Flux: 9.0e-11 MeV cm<sup>-2</sup> s<sup>-1</sup>

Average Significance: 113.95

#### Spectral Information

Spectral Type: LogParabola

Photon Index  $\alpha$ : 2.27  $\pm$  0.018

Photon Index  $\beta$ : 0.090  $\pm$  0.0091

#### Associations

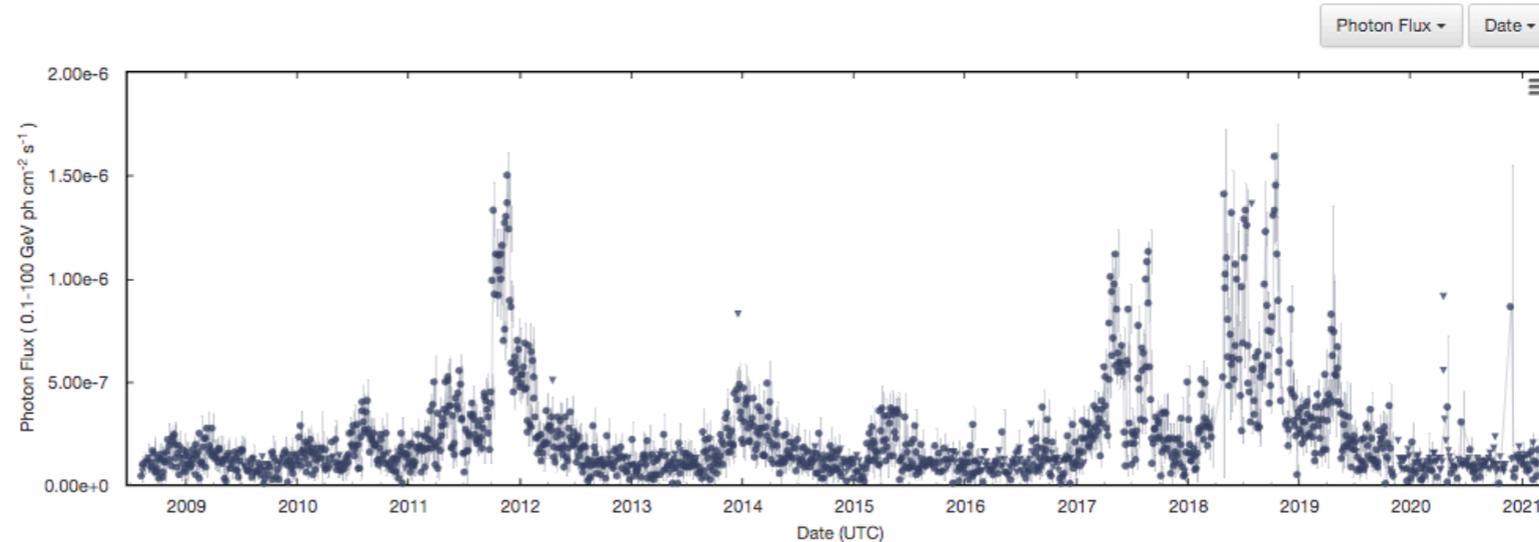
Classification: FSRQ

Association: 4C +28.07

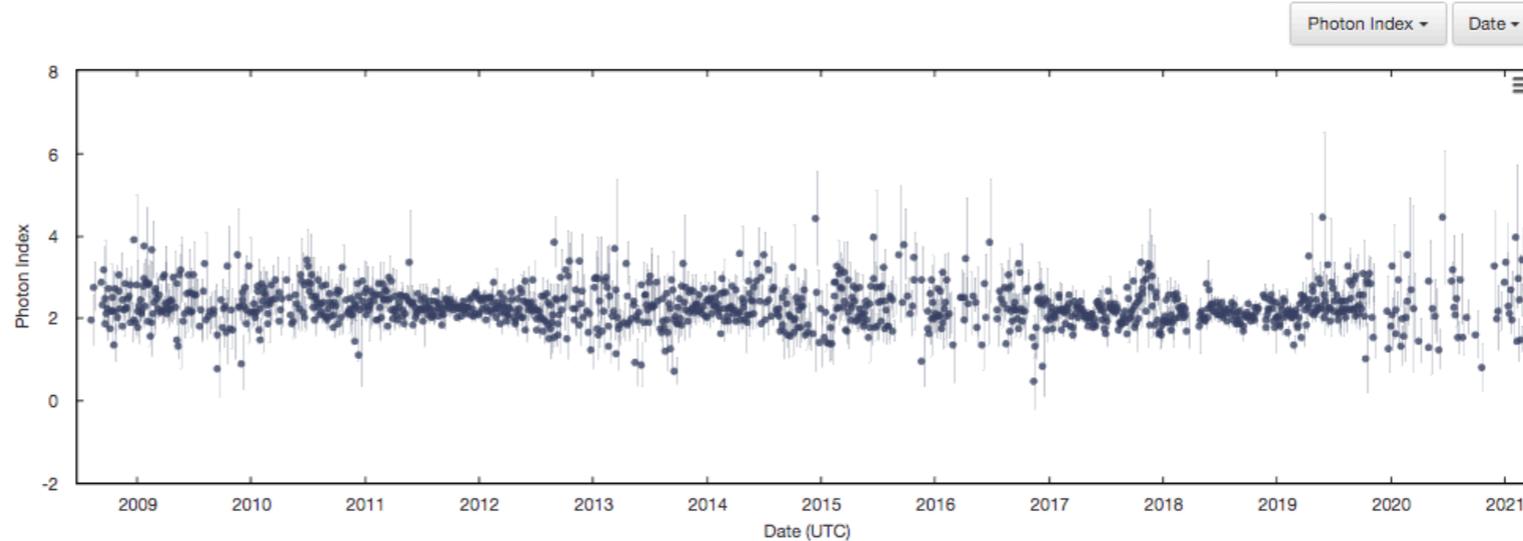
Association (FGL): 3FGL J0237.9+2848

Association (FHL): 3FHL J0237.8+2847

### Light Curve Data



### Ancillary Data



### Fit Convergence

MINUIT Return Code Distribution



### Fit Tolerance

PyLikelihood Fit Tolerance Distribution



### Detection Ratio

Detection Distribution



# Current Status

- A beta version of the data portal has been published to the FSSC and posted to GitHub
  - <https://github.com/dankocevski/LightCurveRepository>
  - Feedback from the community is welcomed!
- We are currently re-running the light curve generation using suggested analysis revisions
- A python API to directly access the light curve results is also underway
  - Should allow for direct access to the LCR database
- Automated secondary analysis is also planned
  - Bayesian block analysis, periodicity analysis, etc
- An announcement will be made to the community once the light curve analysis is complete
- The light curves for the 1525 sources in the repository will be continually kept up to date