Large Area Telescope (LAT) Update

Peter Michelson

Fermi Users Group Meeting, Sept 28, 2021

Fermi LAT Operations Updates

The LAT is working well

- LAT has 98.7% uptime for the science mission
- 794 billion triggers on the LAT
  - 3.84 billion LAT events available at the FSSC
    - 1.45 billion source photons available at the FSSC

LAT 10-year on-orbit performance paper published

- ApJS, 256, 12 (2021) arXiv:2106.12203

Technical/Operations Initiatives

- Augmented FT2 files in Level 1 processing
  - Added spacecraft velocity to FT2 files
  - Small corrections to geodetic coordinate calculations
- Improving Tracker bad-strip calibrations to better mask intermittent strips
- Improved trending of CAL and ACD performance calibrations
- Reducing polygon size that defines the South Atlantic Anomaly for LAT

4FGL-DR3

- **Fairly rapid update! 4FGL-DR2 (10 years) to 4FGL-DR3 (12 years)**
  - **Well established procedure now.**
- **Energy Range: 50 MeV – 1 TeV**
- **Same methodology and diffuse model as 4FGL (DR1), but with more data.**
- **5064 4FGL sources + 1607 new sources (c.f. 723 in DR2)**
- **Paper in internal review. (real paper this time.)**
- **Highlights are population of "Soft Galactic Unidentified" (SGU) sources.**
  - **Difficult to reproduce with systematic errors alone. Missing extended sources?**

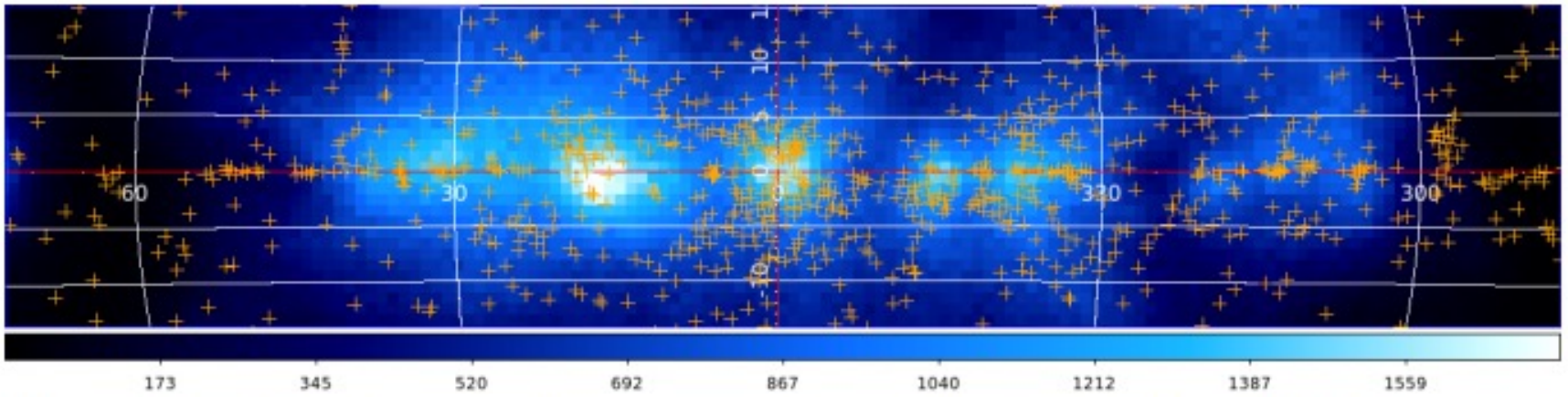
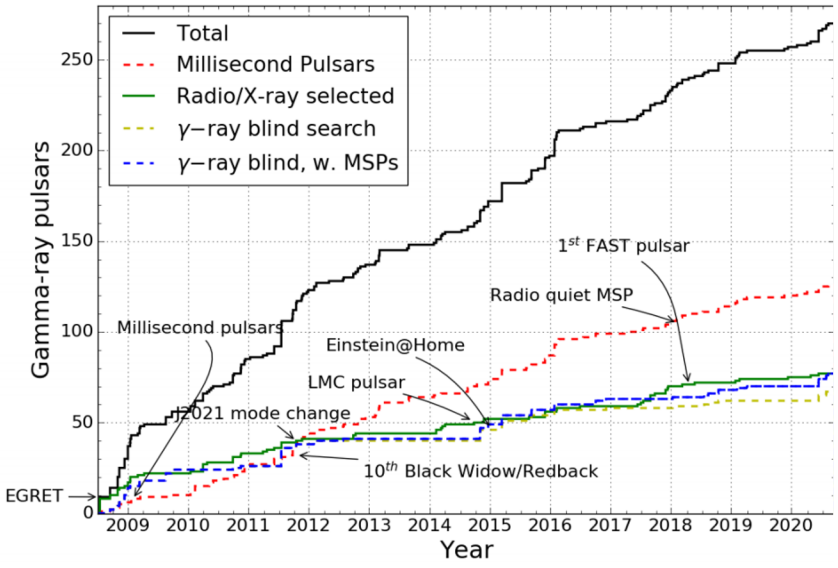
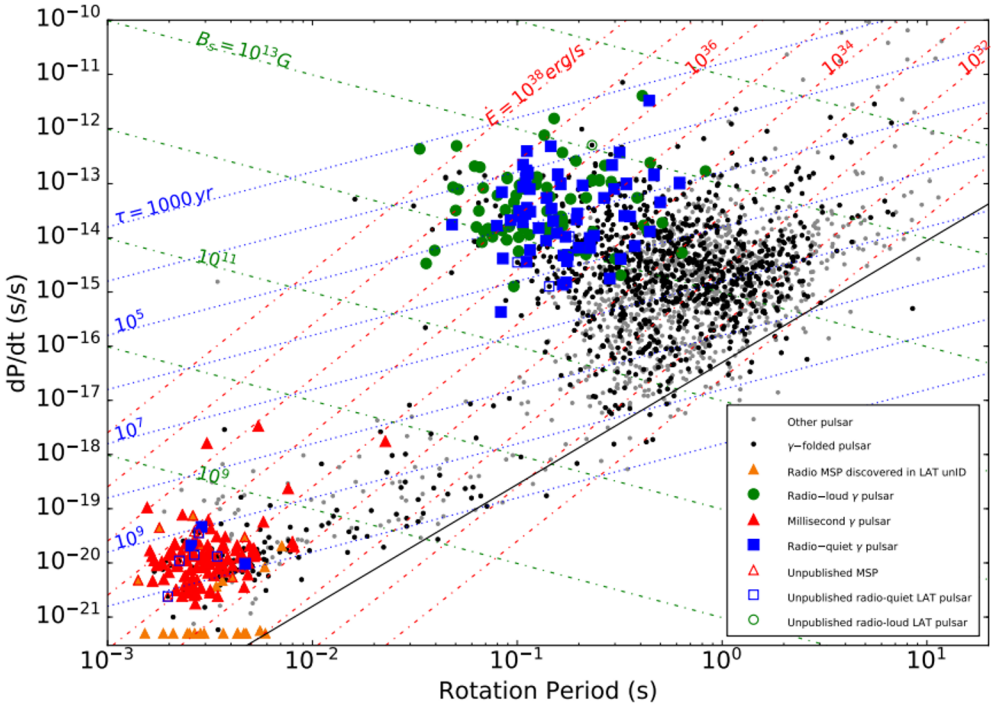


Figure 19. Positions of unassociated sources (crosses) around the Galactic Center. The background is a count map of 83-228 MeV "patch" photons simulated over 12 years.

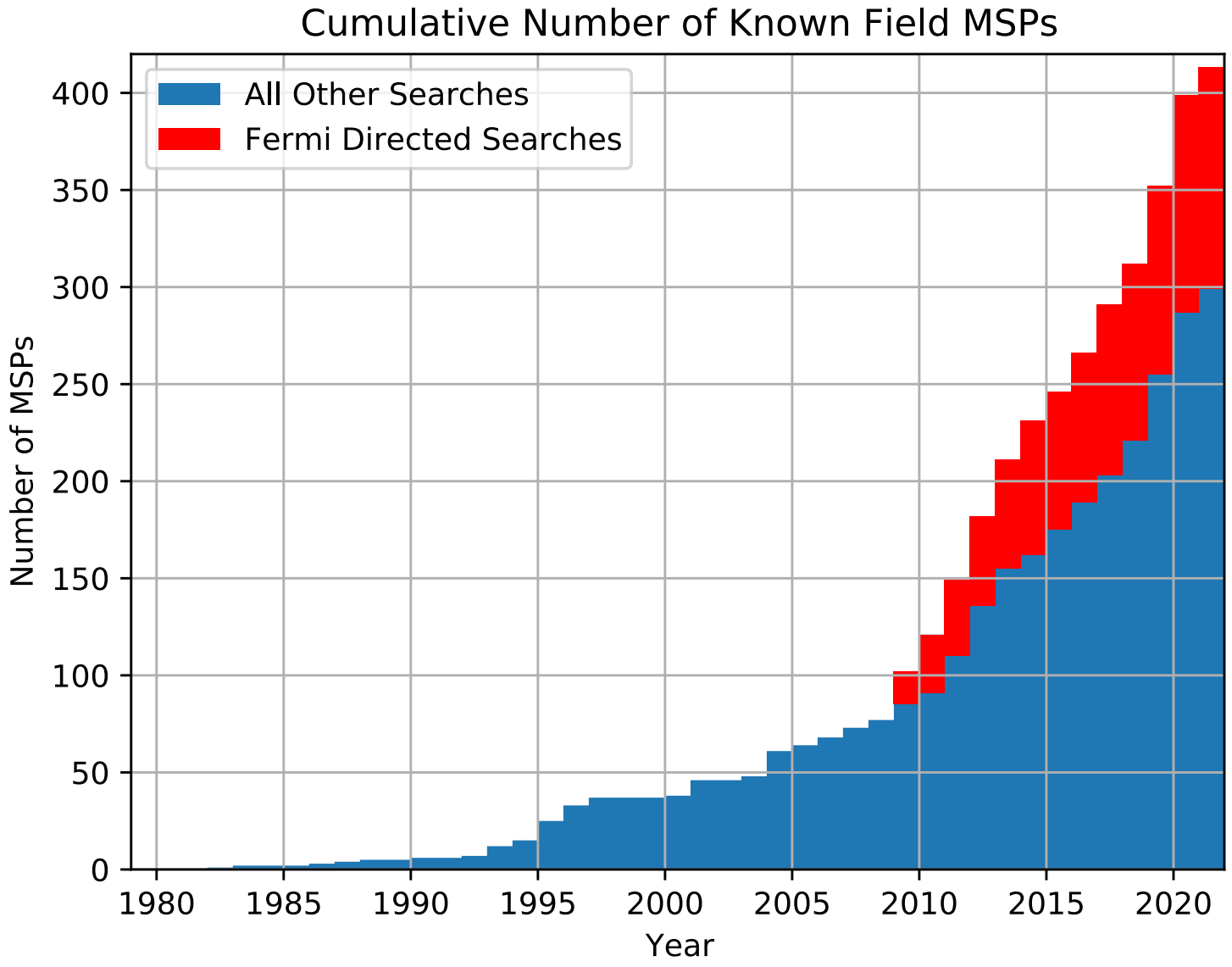
3rd Pulsar Catalog (3PC)

- **270 pulsars (144 young + 126 MSPs), c.f. 2PC (117)**
- **Included in catalog:**
  - **Ephemerides (up to MJD 58,000, longer as possible)**
  - **Use 4FGL-DR2 spectra**
  - **Updated distances**
  - **Pulsar light curves with classifications**
  - **Updated radio fluxes / upper limits**
- **Current main activities: drafting paper, finishing light curve analysis, collating distances**
- **Expect to submit later this year.**





Radio pulsar discoveries and Fermi



Searches for Low-frequency Gravitational Waves

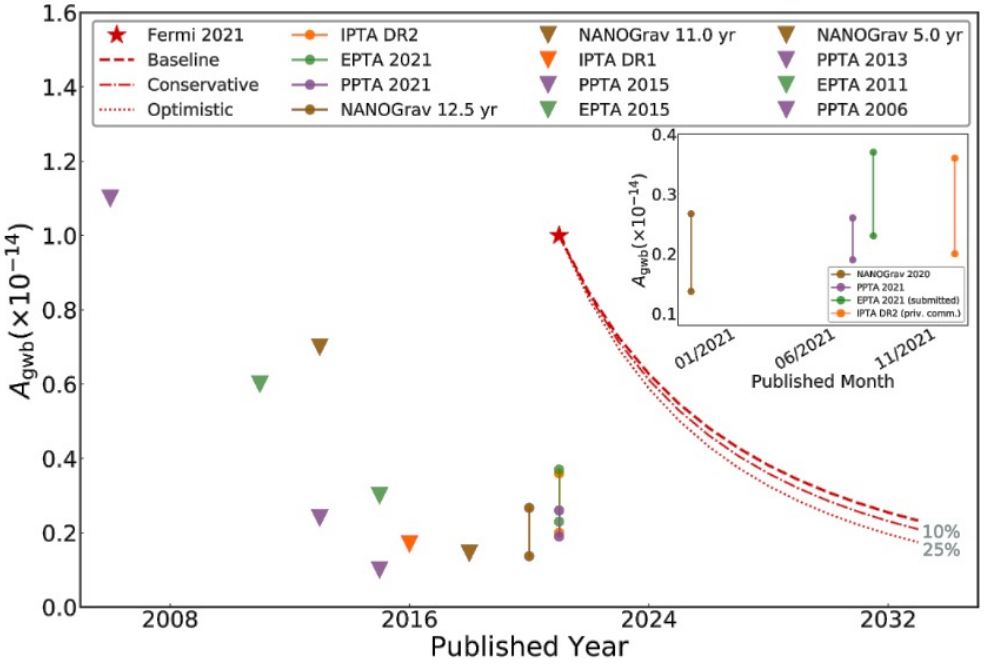
- **114 MSPs in Fermi-LAT sample.**
  - **Select the "best" according to sensitivity and brightness.**

- **Perform ensemble analysis to search for a nHz GWB expected to be generated by binary SMBHs.**

- **Limit is competitive with current radio results (factor of <5) and scales favorably with time.**
  - **In ten years will reach level of possible GWB signal pulsar timing arrays have detected.**

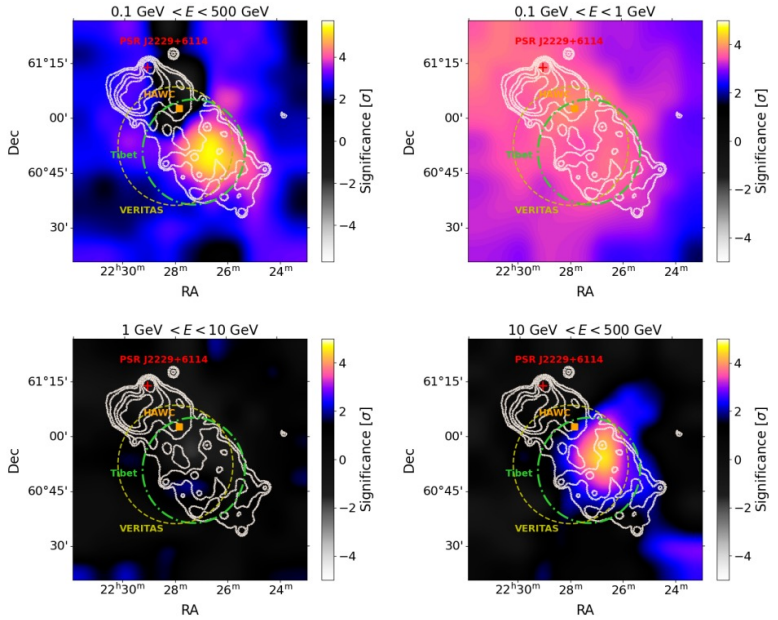
- **Already open up study of individual pulsars and compare intrinsic noise results to radio.**

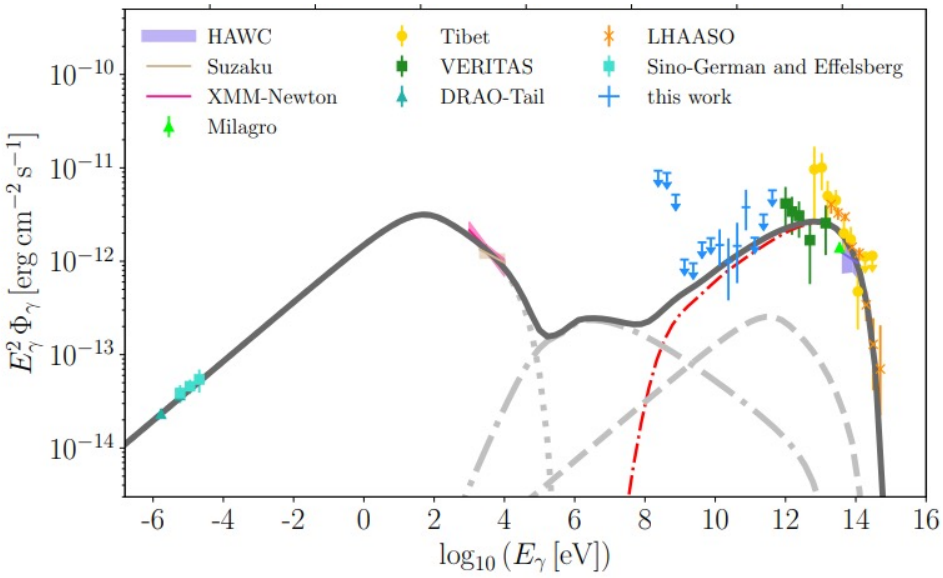
- **Submitting to *Science* soon.**



SNR G106.3+2.7: A PeVatron?

- **Recent detections at *very* high energy imply extreme particle acceleration.**
- **Fermi-LAT analysis of region reveals an extended source consistent with the VHE measurements.**
  - **Much better than other analyses in the literature! Properly accounts for emission from bright pulsar.**
- **Constraining "low" energy (<10 GeV) measurements along with radio and x-ray spectra, strongly constrain a leptonic acceleration scenario and suggests the presence of PeV protons.**
- **Submitted to *Nature Astronomy*.**





Neutrino Counterpart Searches

- ICECUBE/AMON issues Gold/Bronze alerts at a rate of ~25/year
- LAT Flare Advocates perform searches around neutrino positions on timescales
  - 1 day
  - 1 month
  - full mission
- Search for both known sources in a flaring state and new sources
- Issue GCN Circulars on all events, both GCN/ATels on candidate counterparts

Fermi-LAT Gamma-ray Observations of IceCube-200614A and detection of a new gamma-ray source, Fermi J0202.8+3132

ATel #13811; *S. Garrappa (DESY-Zeuthen) and S. Buson (Univ. of Wuerzburg) on behalf of the Fermi-LAT collaboration*
on 16 Jun 2020; 14:44 UT
Credential Certification: Sara Buson (sara.buson@gmail.com)

Subjects: Gamma Ray, >GeV, Neutrinos, Request for Observations, AGN, Blazar

Tweet

We report an analysis of observations of the vicinity of the high-energy IC200614A neutrino event (GCN 27941) with all-sky survey data from the Large Area Telescope (LAT), on board the Fermi Gamma-ray Space Telescope. The IceCube event was detected on 2020-06-14 at 12:41:21.41 UT (T0) with J2000 position RA =33.84 (+4.77 -6.39) deg, Decl. =31.61(+2.75 -2.28) deg 90% PSF containment. Five cataloged >100 MeV gamma-ray sources (The Fermi-LAT Collaboration 2019, arXiv:1902.10045) are located within the 90% IC200614A localization error. These are 4FGL J0159.0+3313, 4FGL J0202.4+2943, 4FGL J0203.7+3042, 4FGL J0205.2+3212 and 4FGL J0220.2+3246. Based on a preliminary analysis of the LAT data over the timescales of 1-day and 1-month prior to T0, these objects are not significantly detected (> 5 sigma).

We searched for intermediate (days to years) timescale emission from a new gamma-ray transient source. Preliminary analysis indicates no significant (> 5 sigma) new excess emission (> 100 MeV), at the IC200614A best-fit position. Assuming a power-law spectrum (photon index = 2.0 fixed) for a point source at the IceCube best-fit position, the >100 MeV flux upper limit (95% confidence) is < 8e-10 ph cm^-2 s^-1 for ~11-years (2008-08-04 / 2020-06-14 UTC), < 9e-9 (< 8e-8) ph cm^-2 s^-1 for a 1-month (1-day) integration time before T0.

Within the 90% confidence localization of the neutrino, ~2.7 deg offset from the best-fit IC200614A position, a >5 sigma excess of gamma rays, Fermi J0202.8+3132 was detected in an analysis of the integrated LAT data (> 100 MeV) between 2008-08-04 and 2020-06-14. Assuming a power-law spectrum, the best-fit localization is (J2000) RA: 30.71, Dec: 31.55 (0.16 deg 99% containment, 0.08 deg 68% containment), with best-fit spectral parameters flux = (5 +/- 3)e-10 ph cm^-2 s^-1 and index = 1.8 +/- 0.2. In a preliminary analysis of the LAT data over one day and one month prior T0, Fermi J0202.8+3132 is not significantly detected in the LAT data. A possible counterpart for Fermi J0202.8+3132 is the BL Lac candidate object NVSSJ020242+313212 (D'Abrusco et al. 2019, ApJS 242, 1), located 0.03 deg from the best-fit LAT localization.

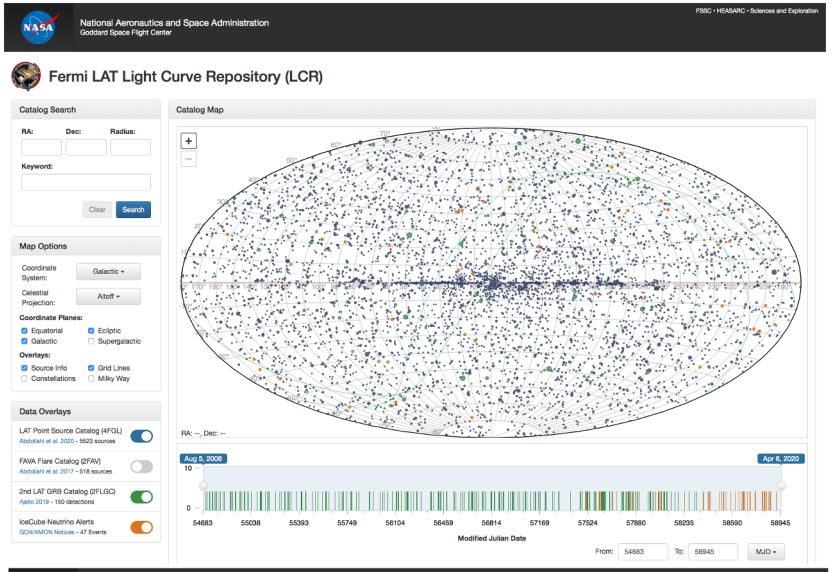
Two additional ~4 sigma excess of gamma rays are detected within the 90% confidence localization of IC200614A in an analysis of the LAT data (> 100 MeV) between 2008-08-04 and 2020-06-14. One is found at the best-fit localisation RA= 32.69, Dec= 30.97 (0.15 deg 99% containment), and has best-fit spectral parameters flux = (4 +/- 3)e-10 ph cm^-2 s^-1 and index = (1.8 +/- 0.2). The second one, at best-fit localisation RA= 35.91, Dec= 32.01 (0.2 deg 99% containment), has best-fit spectral parameters flux = (1.3 +/- 0.7)e-9 ph cm^-2 s^-1 and index = (2.2 +/- 0.2). These excesses are located ~1.2 deg and ~1.8 deg away from the best-fit IC200614A position, respectively. In a preliminary analysis of the LAT data over one day and one month prior to T0, they are not significantly detected in the LAT data.

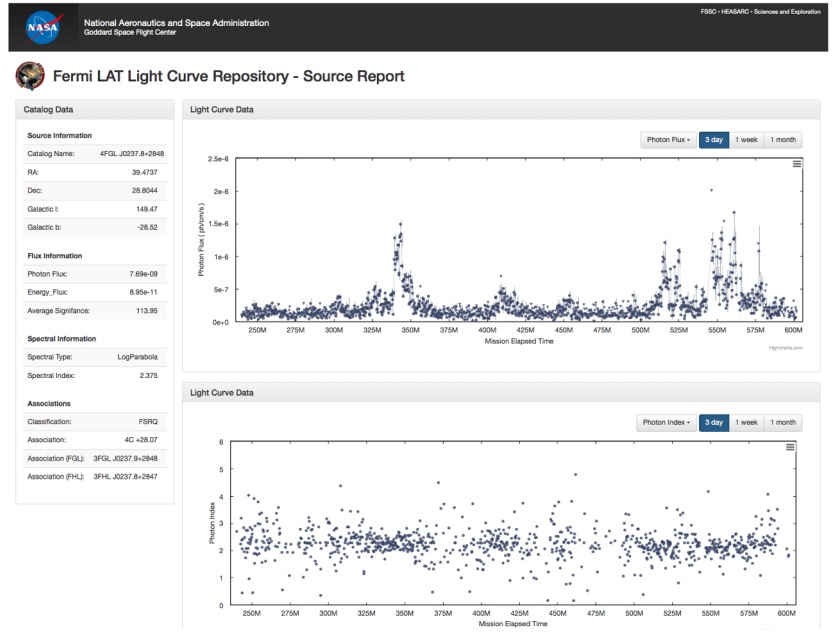
The Fermi-LAT Light Curve Repository (1)

- **Proposed as part of 2019 Senior Review**
  - **Establish and maintain a library of γ-ray source light curves (and spectra) on 3-day, 1-week, and 1-month time scales.**
  - **Constantly updated with new data.**
  - **Hosts both published variability results (like 4FGL, 1FLT) and results from a dedicated likelihood analysis.**

- **Preliminary results underwent validation analysis and procedure was refined. Major reprocessing (months of computing at SLAC) almost finished.**

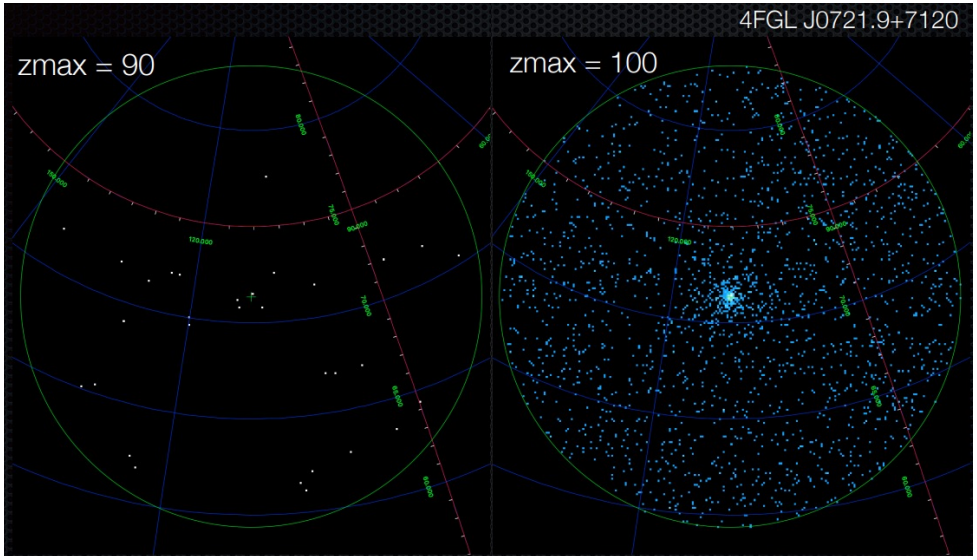
- **Public release "Soon" – well in advance of next Senior Review proposal submission!**
  - **Only remaining piece is completing interface between likelihood database at SLAC and GSFC webserver.**





The Fermi-LAT Light Curve Repository (2)

- **Implementation details:**
  - Includes 1525 variable sources in 4FGL-DR2; based on this sky model.
  - Power law modeling: includes index-fixed and index-free fits.
  - Constantly updated with new data.
  - Both flux points and upper limits available.
  - Loose zenith cut preserves many more photons but results in (very) small flux biases.



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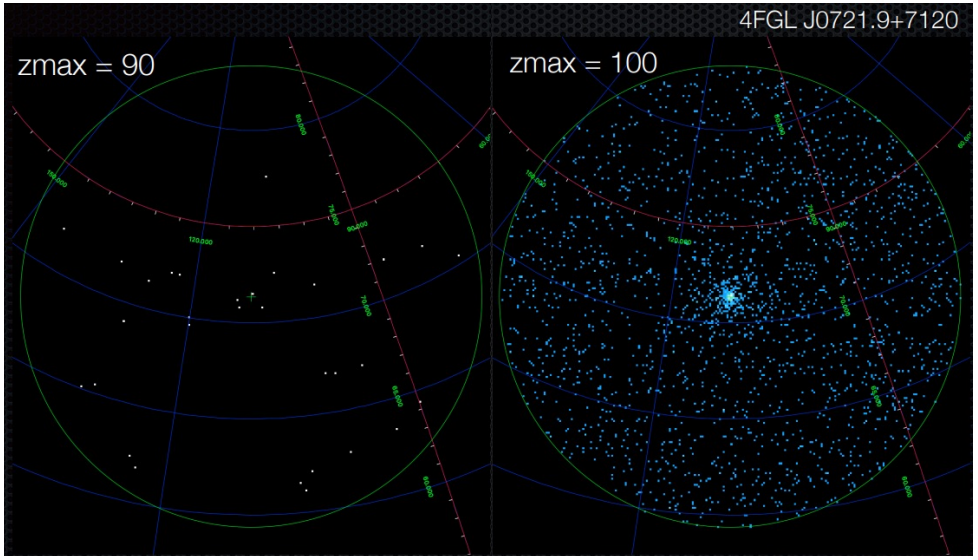

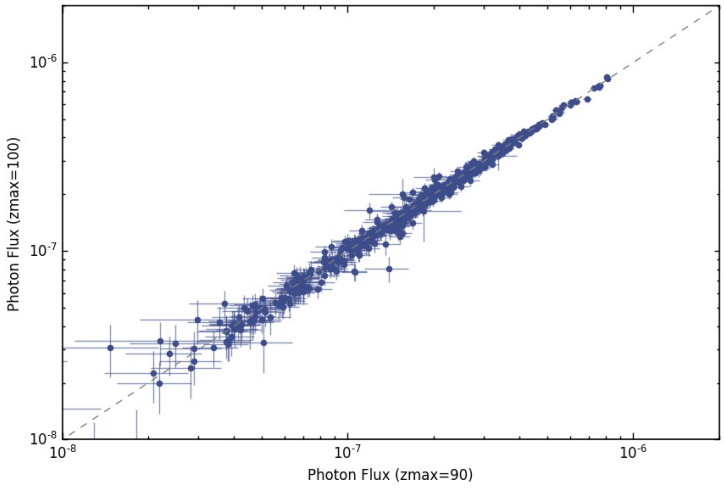

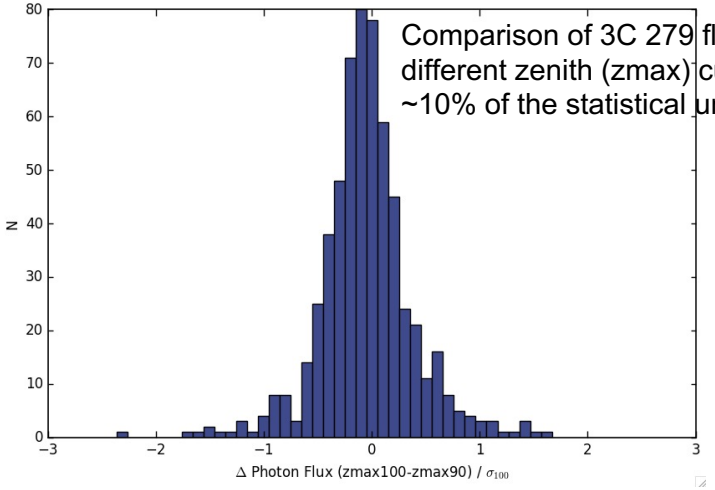

Comparison of 3C 279 flux estimates with different zenith (zmax) cuts, showing biases of ~10% of the statistical uncertainty.

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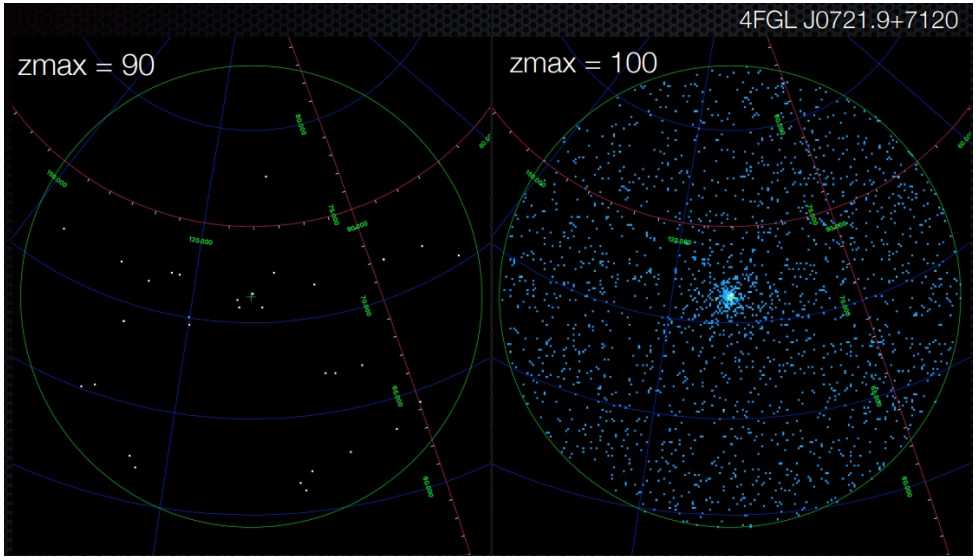

- **Extensions (for next SR proposal):**
  - New sky model + new variable sources.
  - Make likelihoods directly available (e.g. for Bayesian Block analysis)
  - Built-in post processing (like periodicity searches/analysis)
  - Other ideas!

First Cycle*:
# of interested students: ***10***
# of interested mentors: ***18***

- General mentees' satisfaction level and comments:
  a. Overall, heavily positive.
  b. 70% of the past mentees have expressed interest in continuing

Second Cycle*:
# of interested students: ***11***
# of interested mentors: ***15***

mentoring MP program

Mentor: PhD-holders within the LAT/GBM Collaboration (e.g. postdocs, faculty members, research scientists, etc.).

Mentee: Graduate students within the LAT & GBM Collaborations (e.g. masters' students, PhD students, etc.)

All mentors and mentees undergo a training workshop prior to their mentoring meetings.

Goals of the program:

- *Creating an effective mentoring structure*
- *Fostering strong and lasting relationships between mentors & mentees.*
- *Sharing resources and communicating advice in order to remove barriers to success, both personal and professional.*

Mentors do not supersede or interfere with the role of the research advisor, but rather serve as an additional resource.

*One cycle lasts six months and corresponds to the period between two LAT collaboration meetings.

- **BACKUP SLIDES**

Other Topics in Preparation

- PSR B1259-63 binary pulsar system passed through periastron, was active for an unusually long time. Paper in preparation.
- 4LAC-DR3 progressing.
- Nearing submission (Nature Astronomy) for a paper on gamma-ray eclipses (Colin Clark). Provides geometric constraints on neutron star masses.
- 1FGL (monthly time-scale transient catalog) was published and is updated quasi automatically.
- PWNe Catalog (Jordan Eagle) in preparation.
- Paper on ultra-fast AGN outflows recently accepted.
- Large-scale search for low-energy spectral breaks (Marianne) close to completion.
- Neutrino follow-up searches ongoing.
- LAT Light Curve Repository near completion. (Much more at Collaboration Meeting.)
- Rapid paper on nova RS Ophiuci.
- Recent acceptance of paper analyzing DM upper limits in irregular dwarf galaxies; progressing analysis of galaxy clusters.

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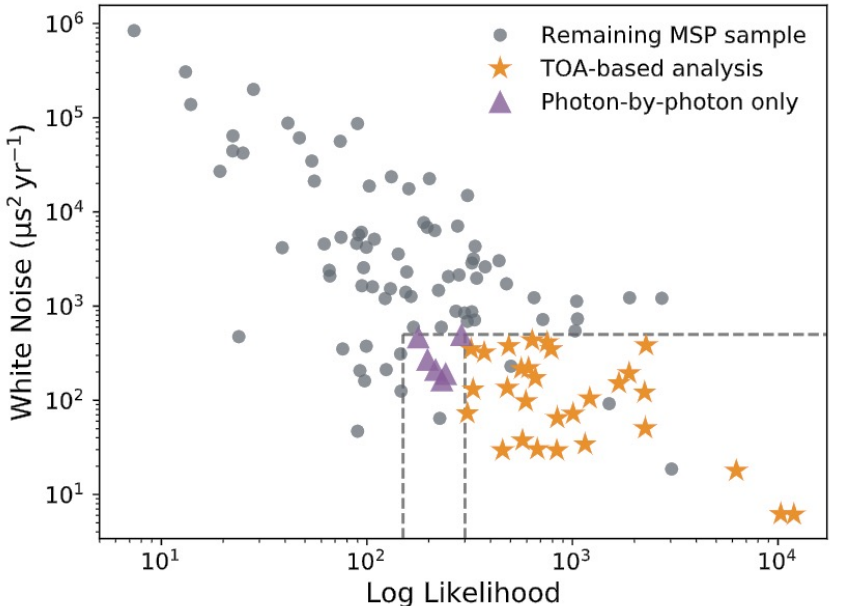
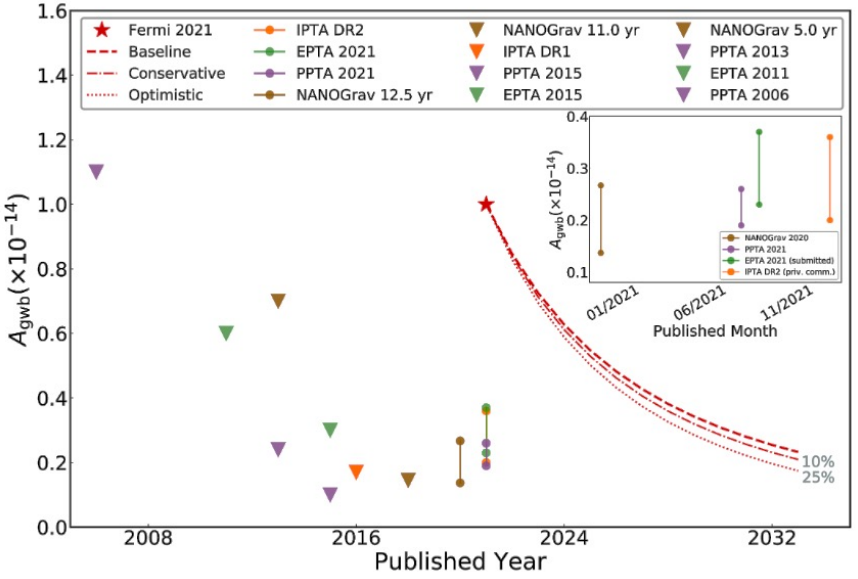
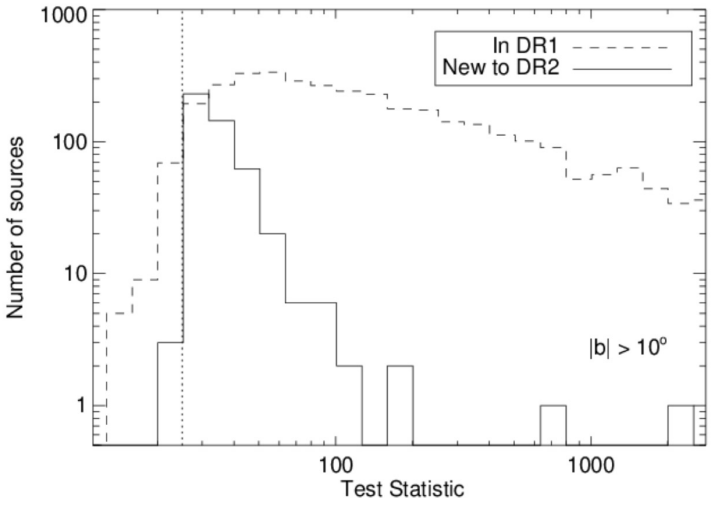
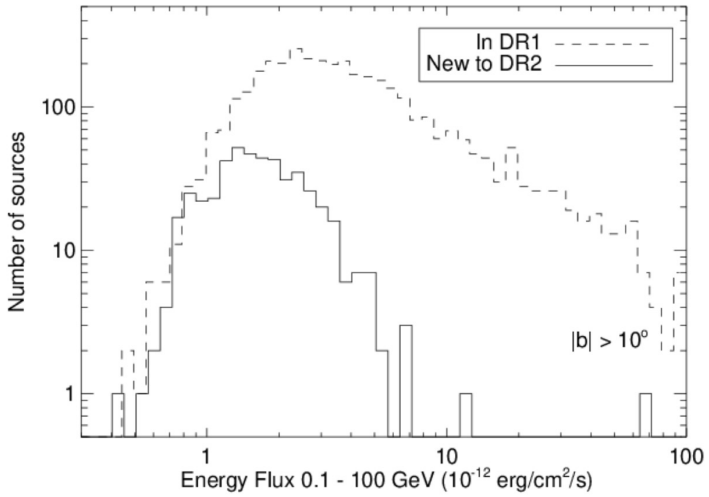




4FGL-DR2 and Future FGL Catalogs

- Updated 4FGL-DR1 (8 years) to 4FGL-DR2 (10 years)
- Energy Range: 50 MeV – 1 TeV
- Same methodology and diffuse model as 4FGL (DR1), but with more data
  - Plan on future incremental updates (DR3 – 12 years already in works)
- 5788 sources
  - 723 new sources just above detection threshold
  - 120 dropped below detection threshold, but kept for comparison
  - 40 newly associated
- Catalog: https://fermi.gsfc.nasa.gov/ssc/data/access/lat/10yr_catalog/
- ArXiv description: https://arxiv.org/abs/2005.11208





1st LAT Solar Flare Catalog

- LAT Collaboration et al., ApJ, about to be submitted
- 45 solar flare from 2010-2018
  - 37 show prompt impulsive emission – acceleration at flare site
  - 21 show delayed emission (>2 hours) - coronal mass ejection (CME)
  - 3 flares from behind the limb – associated with CME
- γ-ray spectra consistent with the decay of pions produced by >300 MeV protons
- Largest sample of high-energy gamma-ray flares provides a unique opportunity to perform population/correlation studies on the different phases of the flare opening a new window into solar physics