2FGL: The Second Fermi LAT Catalog

Construction and Content

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The Basic task: find sources in the photon data

Data: 28 M

Exposure: 52 Ms

Two years (excluding 3 GRBs) "Pass7 processing"

[1FGL: 11 months]

2FGL Table 1888 entries [1FGL: 1451]

2FGL Table

Light curves, SED plots, associations
Strong source high latitude example: SED plots

Circles are 3°, 100 MeV PSF (‘front’ section) (varies by a factor of 30 with energy!)

Pulsars fit with exponential cutoff

Use log parabola if better fit
Measuring point source properties: maximize likelihood

- Model of the sky must account for all photons:
  - PSF (poster by Roth, Rando, Wood)
  - Aeff (poster by Ackermann, Atwood, Rando)
  - Galactic, isotropic diffuse including CR (talk by J-M Casandjian) 1/8 degree grid, pixels centered on plane
  - Earth limb

- An important issue: how to measure significance?

  Test Statistic: \( TS = -2 \log(\frac{L_{\text{fit}}}{L_{\text{null}}}) \)  

  We conservatively choose only sources with \( TS > 25 \).
Detecting sources

- Initial list: use 1FGL supplemented with:
  - PGWave, MRfilter: image based
  - MST (minimal spanning tree): pattern of high energy photons

- Likelihood, using current model
  - Test each of 3.1 M 0.1° deg pixels with a trial point source, (index 2), record the corresponding TS.
  - Look for clusters with max TS>10, use as seed for new iteration

- Efficiency checks:
  - Test with Monte Carlo – generated sources
  - Recheck by applying PGWave
The 2FGL process: Stage I

Use the *pointlike* tool applied between 100 MeV and 300 GeV.

- Initial list: use 1FGL as seeds supplemented with:
  - PGWave, MRfilter: image based
  - MST (minimal spanning tree): pattern of high energy photons

- Create model with point and extended sources, galactic, isotropic and limb diffuse
  - Require exponential cutoff for all LAT pulsars, use log parabola if improves fit

- Fit the entire sky including updating positions (procedure detailed below)

- Create 'residual TS' map:
  - TS for new point source (index 2) at each of 3.1M 0.1° pixels
  - Look for clusters with max TS>10, use as seeds in new model

- Provide all with TS>10 to stage II
Details about the sky model

- Tessellate sky using HEALPix: 1728 regions
- Each ~5° square pixel defines:
  - Center of circular regions for:
    - data (5 deg)
    - sources (10 deg)
  - sources inside are varied; those outside fixed to results of previous iteration
  - Note ~x3 overlap of data: not independent
- Diffuse component normalizations free
- Iteration procedure:
  - Each region fit (full likelihood maximized) independently
  - Each fit remeasures point source positions: Apply updates between cycles.
  - Check changes in log(L): iterate until none changes by more than 10 (8-10 iterations required)
Localization

Basic principle: the likelihood function, as a function of the position of a source, is an estimator of the position, with the curvature defining the resolution.

Demo with 3C 273.

Error ellipse defined by 95% contour (2.45σ). Plot shows contours, and results of fit to quadratic surface.

PSF: 3° @ 100 MeV (front)

PSF: 0.1° for E>10 GeV (front)

‘TS plot’
Source confusion

Example of overlapping sources resolved by PGWave: missed source close (0.65°) to a stronger source

Analysis of nearest neighbor distribution (for high latitudes) indicates missing fraction of 5.5%, vs. 7.6% for 1FGL

Yellow: intermediate iteration
Red: added in final iteration
Localization assessment

- Since localization errors are determined by the PSF, itself defined by data, a consistency check is to compare the distribution of deviations of associated sources with the expected

  - Preliminary indications are that in fact we need to scale the error ellipse dimensions by a factor of 1.1, as in 1FGL.

- Some apparent associations, or pulsar identifications, are far off due to diffuse confusion; the final catalog positions for 2 such LAT-identified pulsars will be fixed to the radio locations.
Stage I Summary

Consistency mostly good

Example consistency check:
all photons in 5° radius circle
(Approx. 12 d.o.f.)

Contributions for all energies, full sky

<table>
<thead>
<tr>
<th>Free parameters</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectra</td>
<td>7603</td>
</tr>
<tr>
<td>Diffuse normalization</td>
<td>3456</td>
</tr>
<tr>
<td>Location</td>
<td>5096</td>
</tr>
<tr>
<td>(2 per TS&gt;16 source)</td>
<td></td>
</tr>
</tbody>
</table>
Most sources apparently associated with diffuse structures probably result from inadequate representation of the diffuse itself.

Galactic center is complicated!
See talk by T. Porter

Orion molecular cloud: poster
by S. Digel & F. Giordano

Sources: TS>10 seeds for 2FGL
Use the standard tool *gtlike* in binned mode

- Accept all 3499 TS>10 sources from stage I
- Similar iterative scheme, but with 933 overlapping regions chosen to equalize number of sources
- Refit spectra and diffuse normalization
- Fit pulsars with exponential cutoff
  - Everything else with power law: try log parabola
  - Retain all with *gtlike* TS>25 when generating model
    - The *pointlike* fit and TS generally agree well, but some scatter for low values.

- Generate:
  - Table
  - Spectral plots
  - Light curves
  - Associations
277 1FGL sources are not represented. Recall that they were only used as seeds at the start of the new process.

- Some reasons:
  - New requirements for localization
  - Extended sources were represented by more than one point source
  - Improved galactic diffuse model
  - There, but not significant enough (flared during first 11 months)

- Dominant effect is new fitting procedure: application of current procedure (especially now using binned vs. unbinned `gtlike`) to 1FGL accounts for nearly all.

The 5 LAT pulsars that are not (DC) detected are put in ‘by hand’
Summary

2FGL almost ready to go, with following features

- Much improved diffuse representation, new limb component
- ~1888 sources, vs. 1451  1134 for (revised)1FGL
- 12 extended sources
- Pulsars fit with exponential cutoff, others log parabola if appropriate
  - better characterization of sources, improved fits to nearby weaker sources
- Better source finding efficiency: both detecting faint sources and resolving nearby sources

But: is not perfect, D. Thompson will next discuss caveats
Backup, or discarded for now
Checking for missing sources: PGWave

PGWave determines that this is two close sources.

TS map is rather distorted.

An overview of the territory.

Blowup, showing before (yellow) and after (red).

After split.
Gamma rays from Earth limb in tails of PSF

Required at celestial poles, low energies only