

National Aeronautics and Space Administration



Fermi  
Gamma-ray Space Telescope

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# The Fermi LAT First Source Catalog & Using the Catalog for Analysis

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*Catalog slides are modified from Jean Ballet's presentation at the 2009 Fermi Symposium*

# The First LAT Catalog (1FGL)

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## Features:

- 11 months of data 100 MeV to 100 GeV, 23.3 Ms livetime
- 10.6 M events over the whole sky (Pass 6 v3 Diffuse class)
- Improved diffuse model and calibration with respect to 0FGL
- Detection based on integrated data (not on flares)
- Precise localization

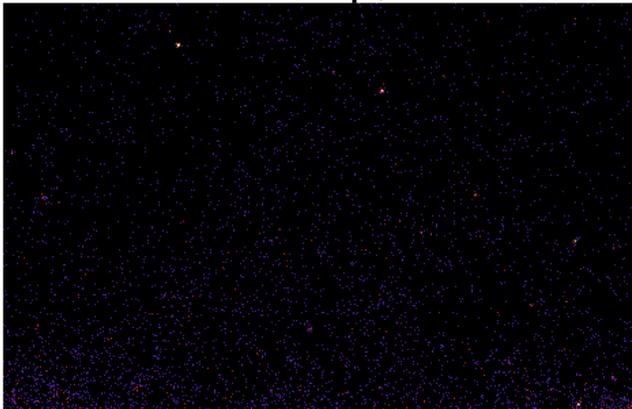
## Contents:

- Source coordinates and error ellipse at 95% confidence
- Source significance and overall spectral index
- Average flux in 5 energy bands 0.1 – 0.3 – 1 – 3 – 10 – 100 GeV, plus spectral index and total flux
- Flux per month, variability index
- Quality flags: sensitivity to diffuse model, low source to bkg ratio, confusion, error ellipse not well defined, etc.
- Associations with known sources

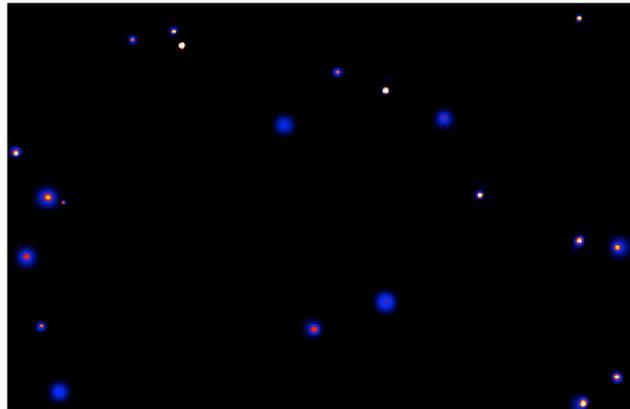
# Source detection

- **Difficulty is that point spread function improves enormously from  $5^\circ$  at 100 MeV to nearly  $0.1^\circ$  above 10 GeV.**
- **Combine several energy bands, merge seeds from several detection methods.**

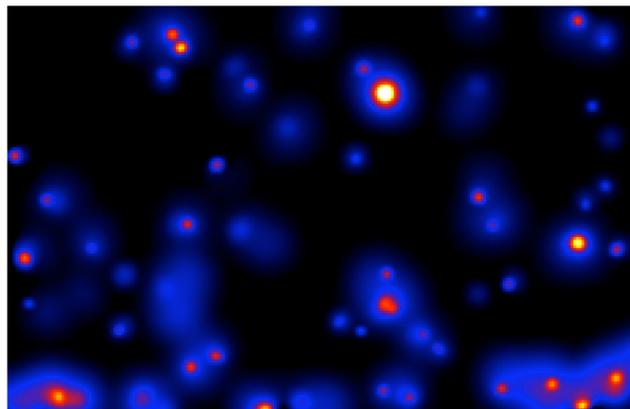
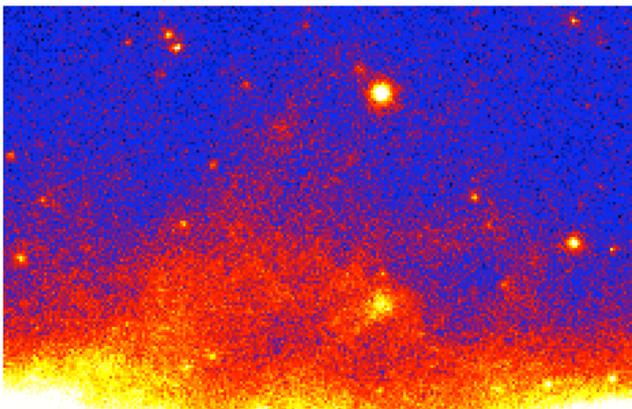
Raw counts map,  $75 \times 45^\circ$



Wavelet filtered



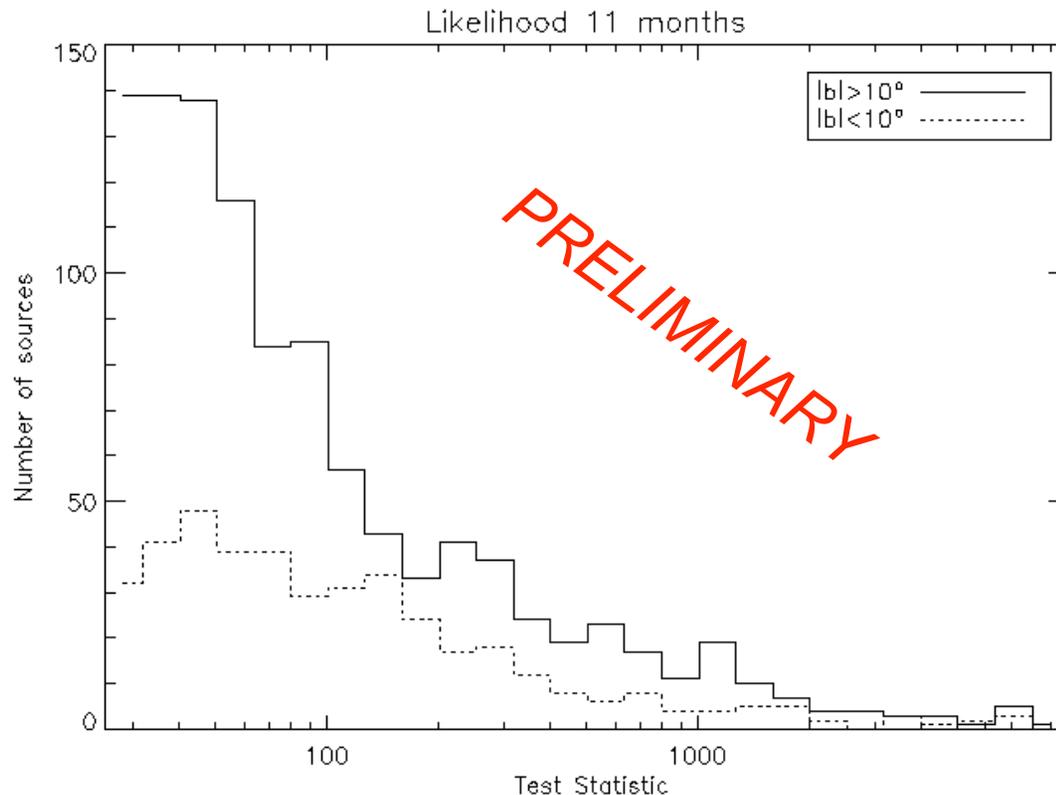
Front > 5 GeV  
Back > 10 GeV  
Very few events,  
very well localized



Front > 200 MeV  
Back > 400 MeV  
Many events, not so  
well localized

# Source significance

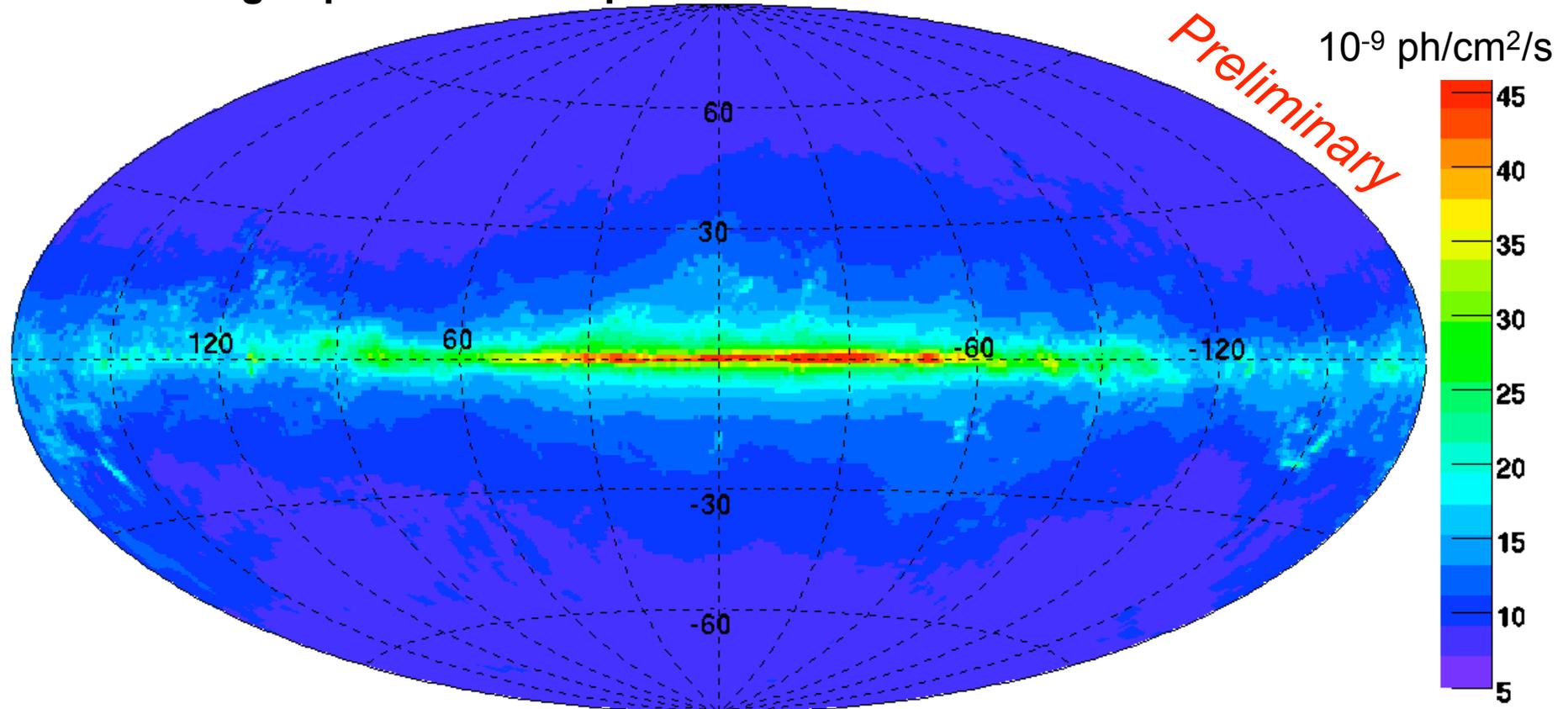
- **3D maximum likelihood analysis (position and energy) was used to determine source significance assuming power-law spectra on top of standard diffuse model**
- **Define  $TS = 2 \Delta \log(\text{likelihood})$  comparing models with and without the source. Cut at  $TS = 25$ , corresponding to about  $4 \sigma$  or  $2.5E-5$  probability (4 degrees of freedom including source position).**



Works well at high latitudes.  
Peak in TS distribution at threshold.  
TS distribution flatter close to Galactic plane. Faint sources are not detected.

# Sensitivity map

- Structure is mostly that of the interstellar medium
- Below  $10^{-8}$  ph/cm<sup>2</sup>/s outside the Galaxy ( $|b| > 30^\circ$ )
- Strong dependence on spectral index

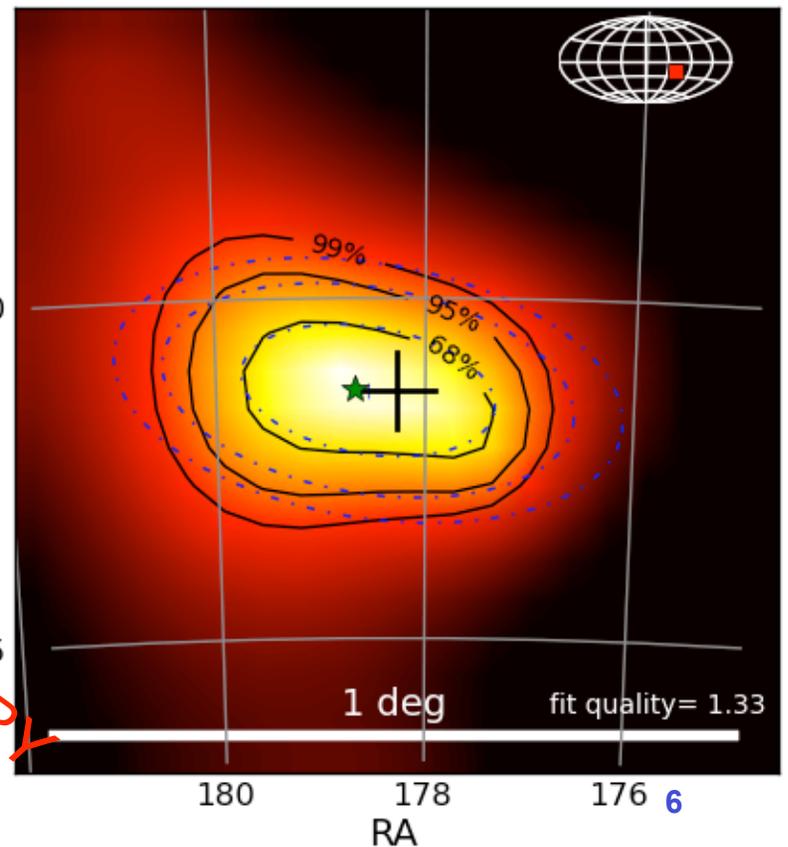
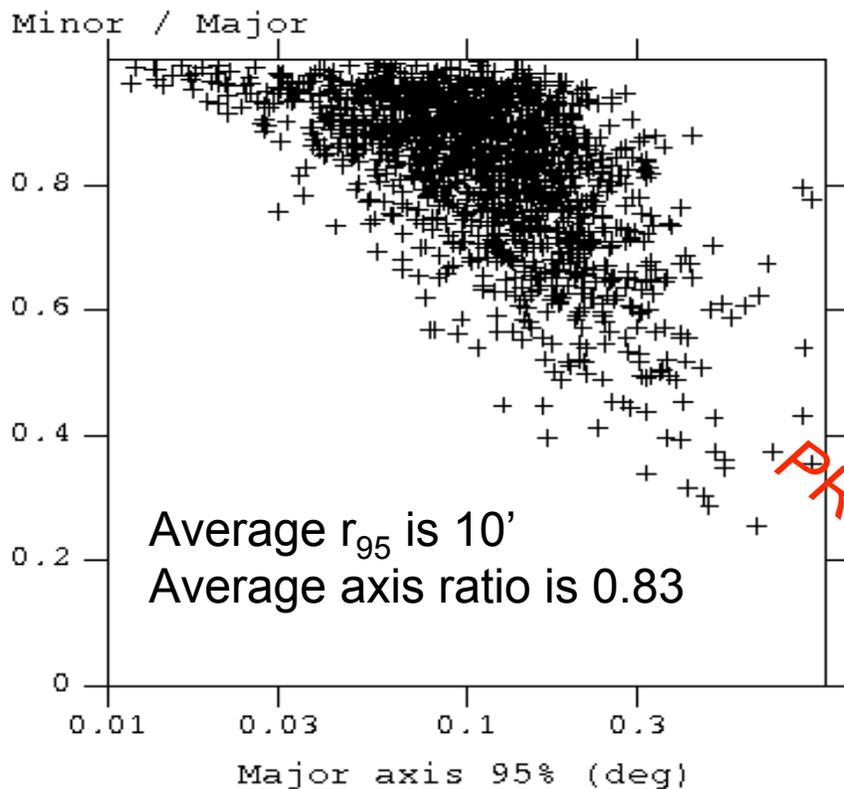


Flux  $> 100$  MeV required to reach TS=25 for average  $E^{-2.2}$  spectrum

Galactic coordinates, Aitoff projection

# Source localization

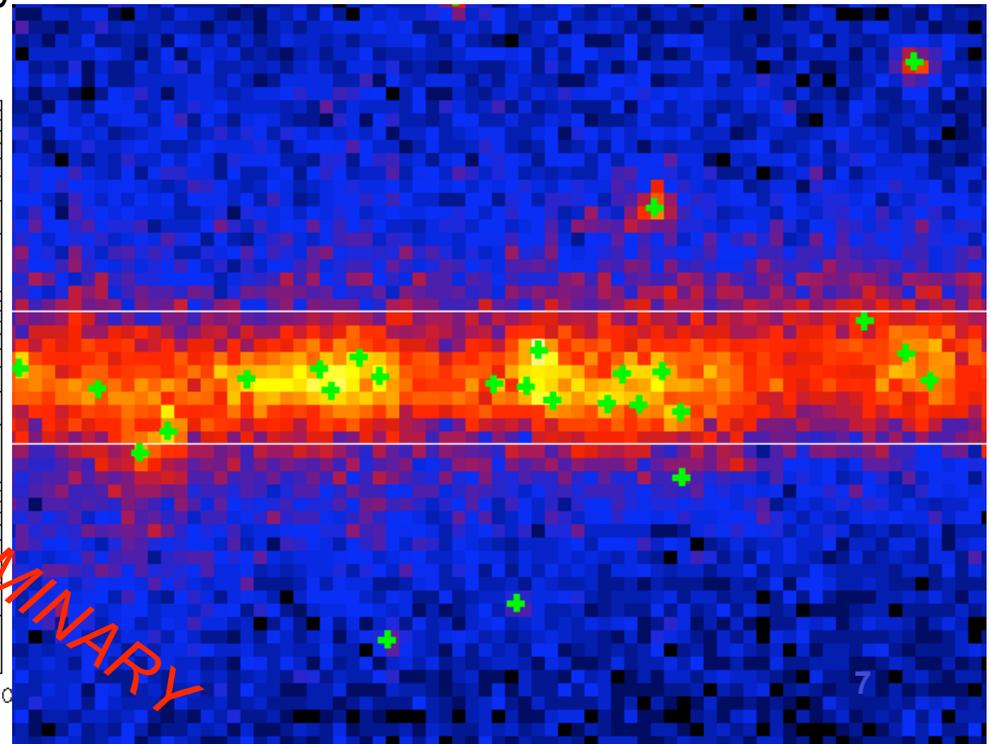
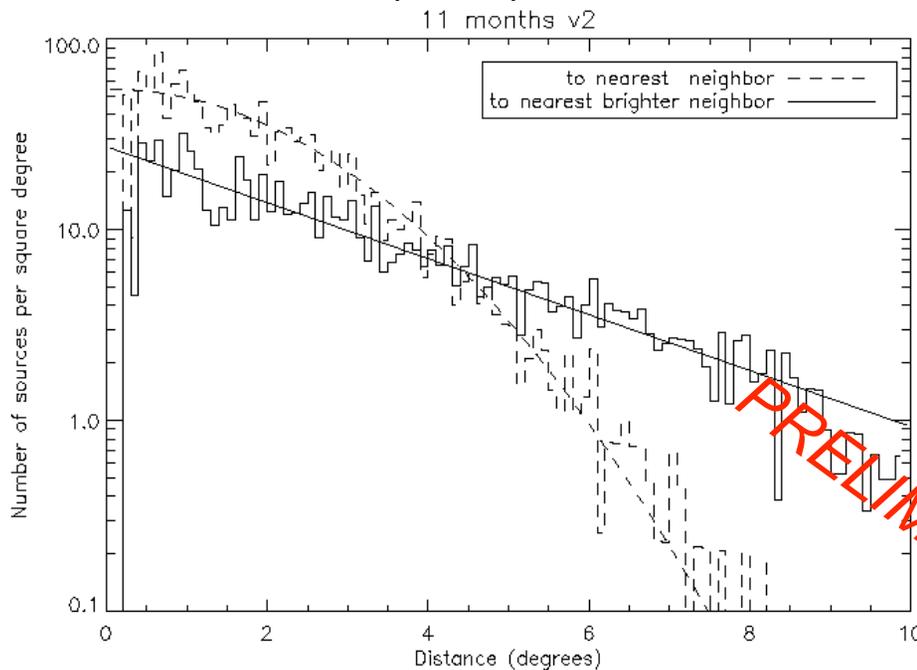
- Conservative error radii adjusted on known associations
- Conservative  $0.012^\circ$  absolute limit based on bright pulsars
- Elliptical parameters whenever can be extracted, mostly round.
- A difficult example is below. Cross is  $1\sigma$  1D error from other localization method for comparison



PRELIMINARY

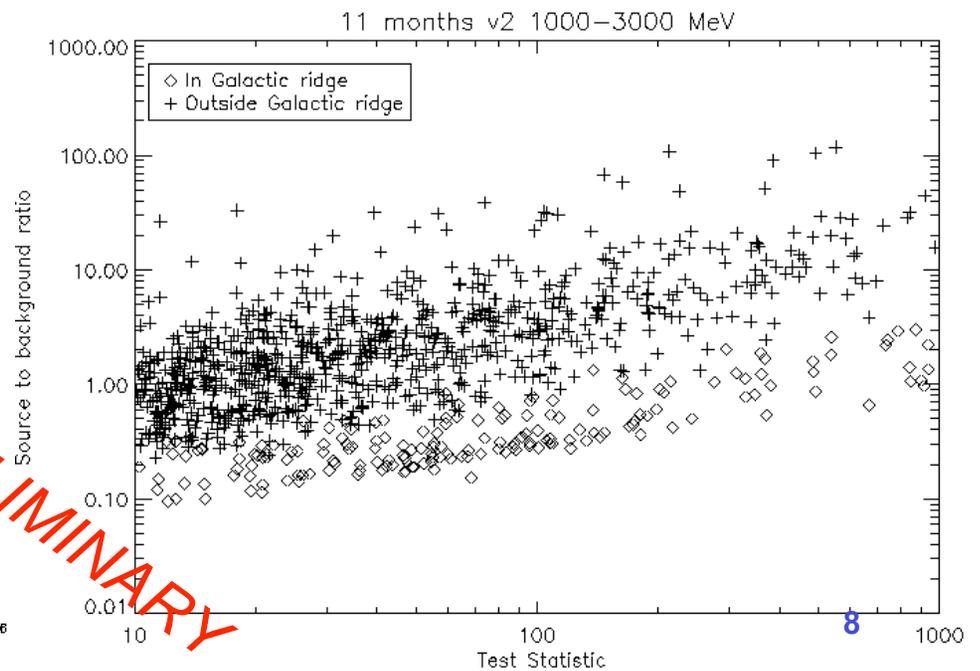
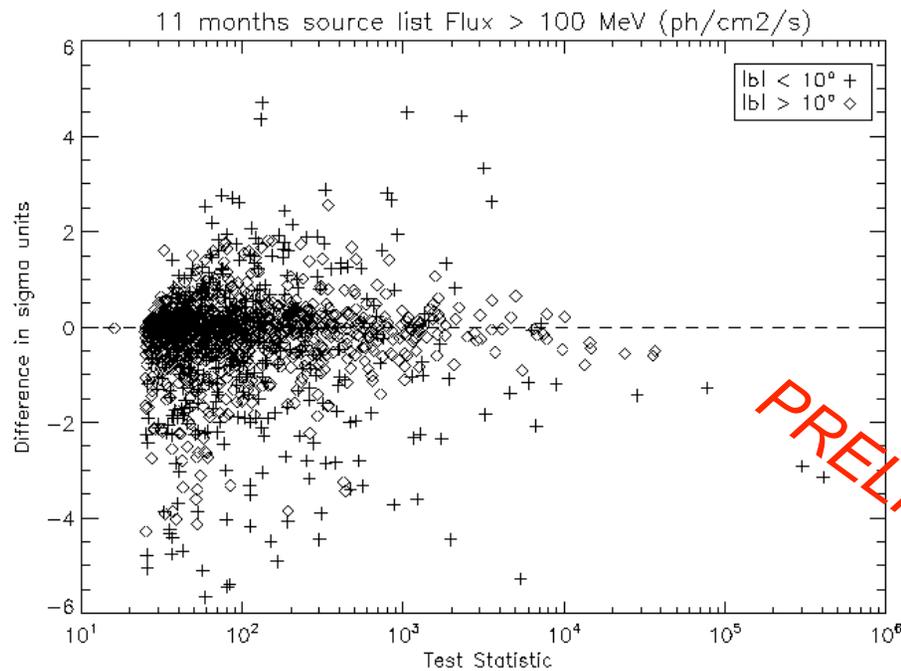
# Source confusion

- Average distance between sources outside the plane is about  $3^\circ$
- Much more than  $r_{68}$  at typical detection energy ( $0.8^\circ$  at 1 GeV)
- Extrapolation to 0 distance indicates that only 6 sources or so are confused outside the plane
- Introduces additional bias against very soft sources ( $\Gamma \geq 3$ )
- **15° region of the Galactic ridge above 1 GeV**
- **Crosses are sources, pixel is  $0.2^\circ$**
- **Sources not clearly separated**
- **Could be unmodeled diffuse emission**



# Diffuse emission uncertainties

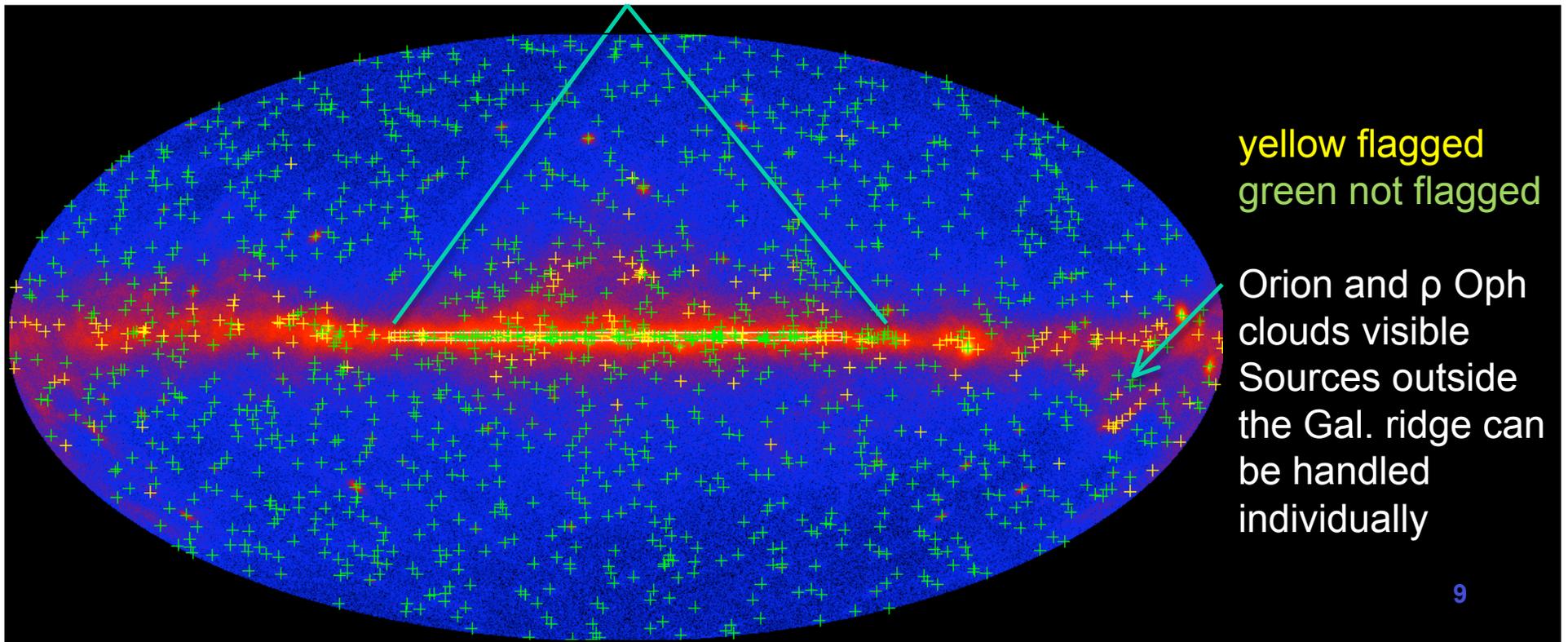
- Use two different diffuse models to assess sensitivity of sources
- With good statistics, 10% of the background can be significant
- Inside Galactic plane, dispersion due to diffuse model is 1.8 sigma
- Outside plane, dispersion is 0.7 sigma
- **Source to background ratio within  $r_{68}$  is not very large in the Galactic plane even above 1 GeV.**
- **Has to go above 3 GeV to be above 50%**



PRELIMINARY

## First LAT source catalog: 1451 sources

- The Galactic ridge ( $|\text{lat}| < 1^\circ$ ,  $|\text{lon}| < 60^\circ$ ) has serious difficulties: sources are close to each other, are not high above the background below 3 GeV, and the Galactic diffuse model is very uncertain there. This even affects sources statistically very significant ( $\text{TS} > 100$ ).
- We plan to flag Galactic ridge sources to warn against using them without detailed analysis. Of course there are still many true sources in there, including pulsars and SNRs.



# First LAT Source Catalog Conclusions

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- Typical 95% error radius is **10 arcmin**
- About 250 sources show evidence of **variability**
- About half the sources are **associated** positionally, mostly with blazars and pulsars
- **Other classes** of sources exist in small numbers (XRB, PWN, SNR, starbursts, globular clusters, radio galaxies, narrow-line Seyferts)
- Uncertainties due to the diffuse model, particularly in the **Galactic ridge**, should be kept in mind for low-latitude and local cloud studies
- The Catalog is an **analysis product** but also a **useful input** for many other studies with LAT data

## On using the Catalog for Analysis

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- **The 1FGL Catalog will be distributed via the FSSC as:**
  - **FITS table**
  - **XML input file for gtlite/ModelEditor**
  - **ds9 region file**
- **Useful for selecting specific sources for further study**
  - **More or less data**
  - **Different spectral models**
  - **Different diffuse emission models**
- **Useful for defining an initial point-source model for any ROI**
- **Additional items to note:**
  - 1) **The gamma-ray sky (blazars in particular) is highly variable. Flux and spectral information in the 1FGL are only time averages for the 11 months of the data set.**
  - 2) **For studies of diffuse emission at low latitudes and toward prominent local clouds, be aware that some 1FGL sources may be unresolved diffuse emission – whether they should be in the source model is a case-by-case decision.**

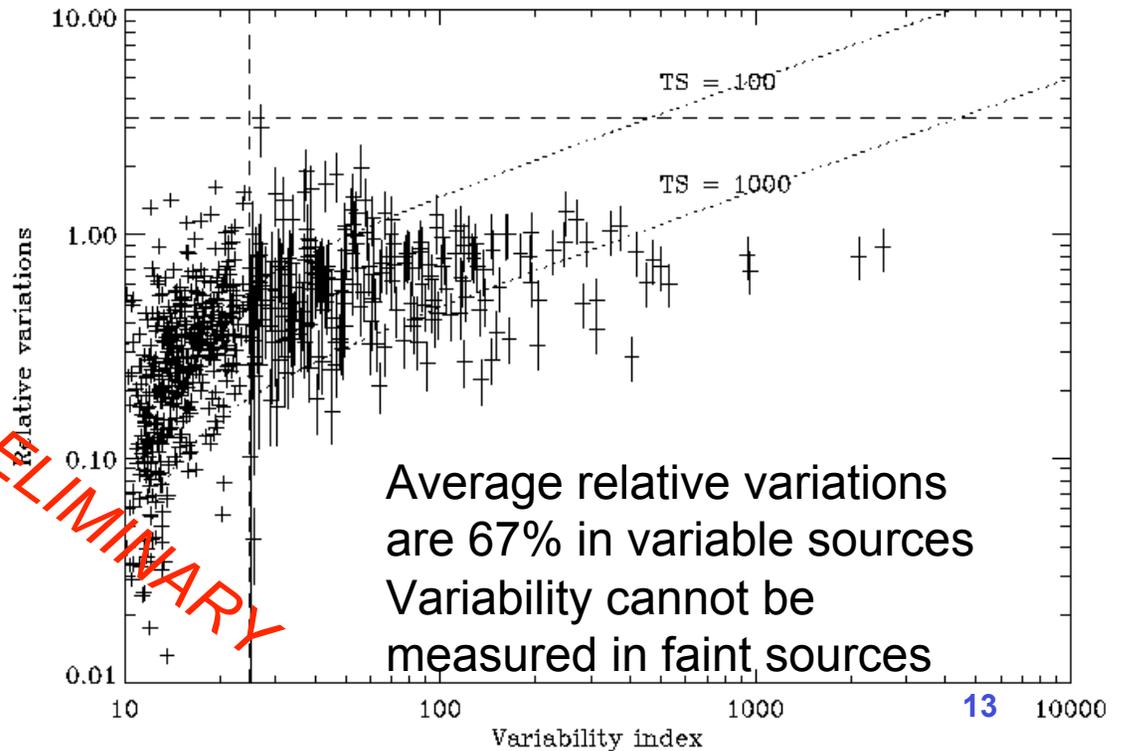
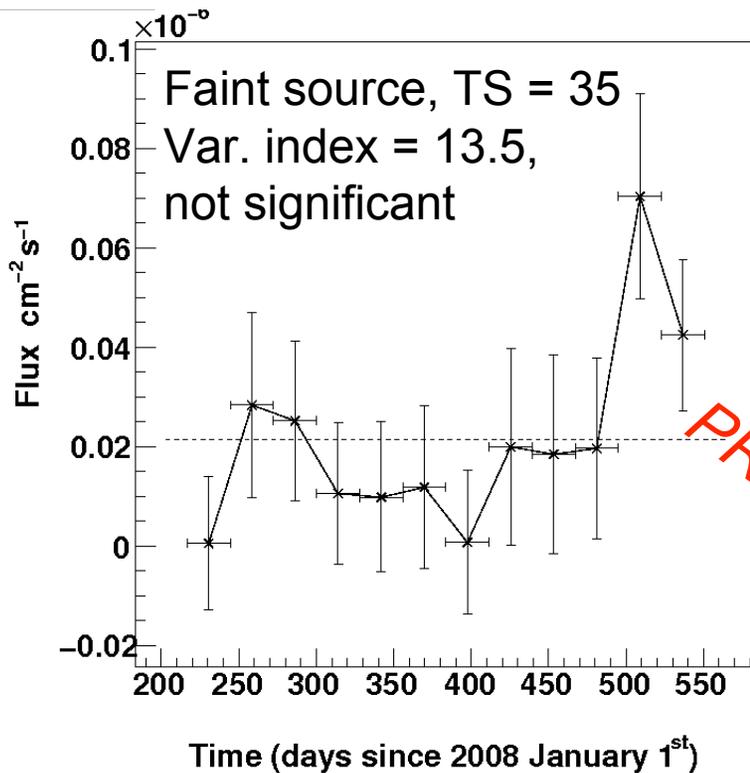


# Backup Slides

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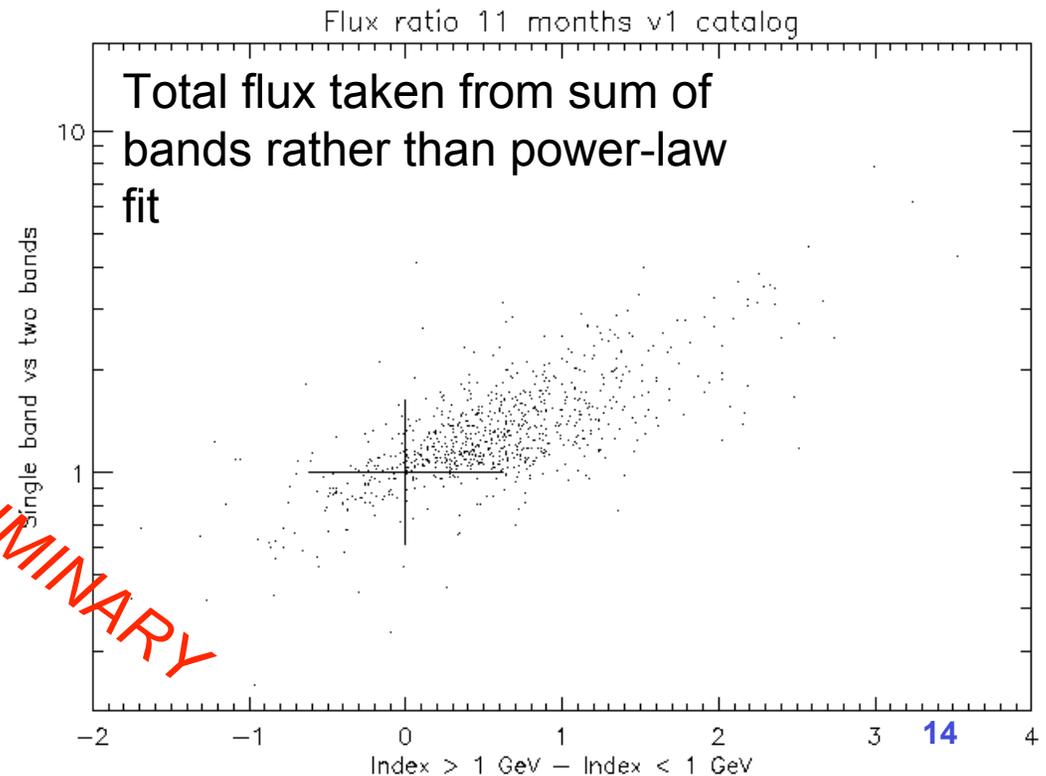
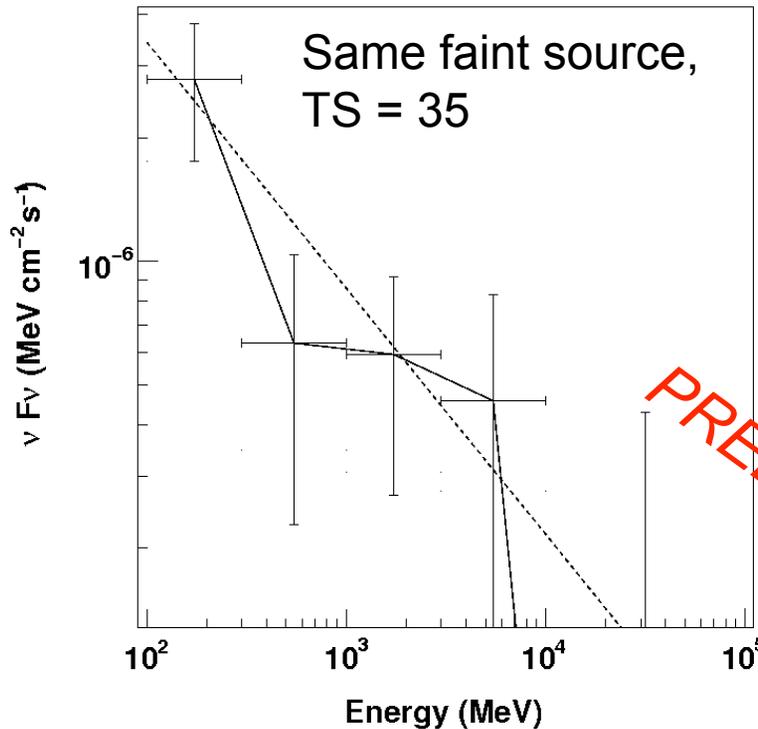
# Source variability

- Build light curves of all sources on one-month time scale
- Pulsars are stable within 3%
- Bright blazars are very clearly variable
- Variability index:  $\chi^2$  against constant hypothesis. 250 variable sources
- Relative variations:  $\Delta F/F$  where  $\Delta F^2 = \text{measured variance minus Poisson variance}$



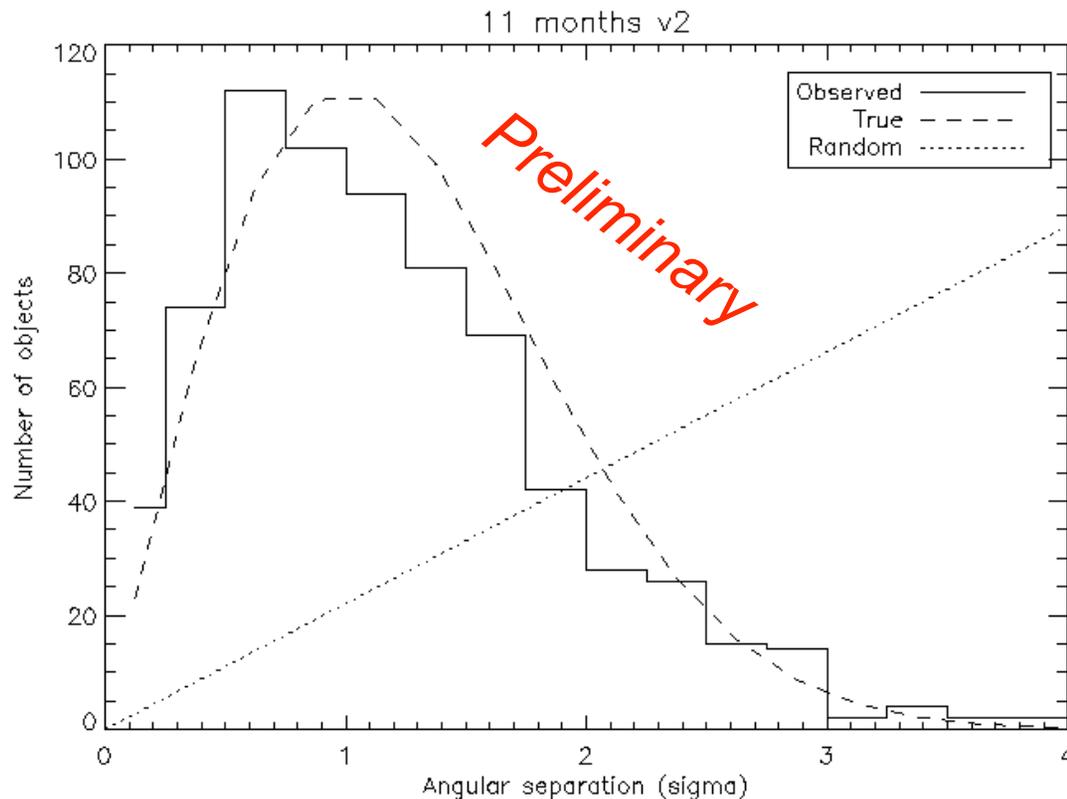
# Source spectra

- Extract flux of all sources in 5 bands from 100 MeV to 100 GeV
- Upper limit in bands in which sources are not significant
- Average spectrum is broken, power-law estimate is too high
- Sources not significant in all bands, total flux not well measured (strong detection does not imply well measured  $F_{>100 \text{ MeV}}$ )



# Source association

- Likelihood ratio between true association (gaussian distribution with width defined from  $r_{95}$ ) and random association (flat at counterpart density)
- Typically one half of the sources are associated to a plausible counterpart (radio blazar, pulsar, PWN, SNR, XRB), down from 2/3 at 0FGL (brighter)



Point sources only  
No doubt that most of these associations are true.  
 $r_{95}$  was multiplied by 1.2 to cover the tail.  
The distance distribution may be more complex than a simple gaussian

## Other LAT catalogs

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- **The AGN catalog, drawn from sources above  $10^\circ$  latitude, excluding known non AGN. Goes with the full source catalog, which adopts the AGN associations. Similar to LBAS (ApJ 700, 597) vs BSL (ApJS 183, 46)**
- **The pulsar catalog, drawn from all pulsed detections of both radio and  $\gamma$ -ray pulsars. First version (6 months of data) submitted to ApJ (arXiv:0910.1608)**
- **The gamma-ray burst catalog, drawn from all GRB detections. Completely separate (bright GRBs are actually excluded for the LAT source catalog). Available in quasi real time at Fermi SSC**