EGRET Source Variability: The State of the Paper

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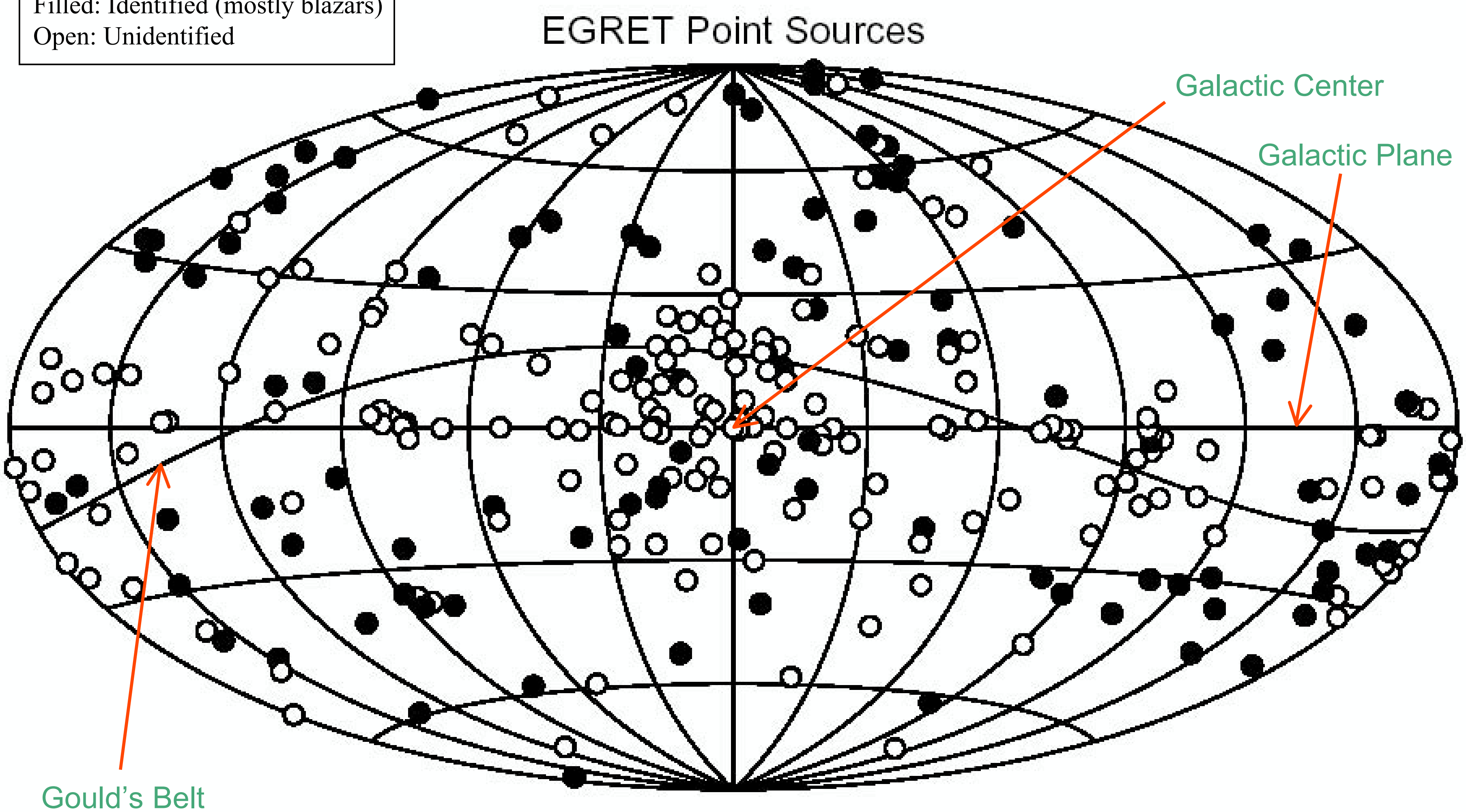
Introduction

- Variation in the emitted gamma-ray flux is an important clue to the nature of the source.
- Most of the 270+ EGRET point sources are not far above the detection threshold. Often it's not clear if they are variable. Statistical analysis is needed to clarify the effects of measurement error.
- That situation won't change with GLAST, although the total number of "bright" sources will increase.
- The statistical treatment of upper limits is still problematic. The results reported by the standard EGRET program are not easy to use.
- In spite of this, several people have analyzed the 2nd and 3rd EGRET catalogs, most notably McLaughlin et al.
- Bill Tompkins tried to do it right, with better statistical methods and analysis of the original data, in his 1999 Ph.D. dissertation.
- I am currently re-working Bill's results into a publishable paper.

Obligatory Map of the 3rd EGRET Catalog

Filled: Identified (mostly blazars)
Open: Unidentified



The Method

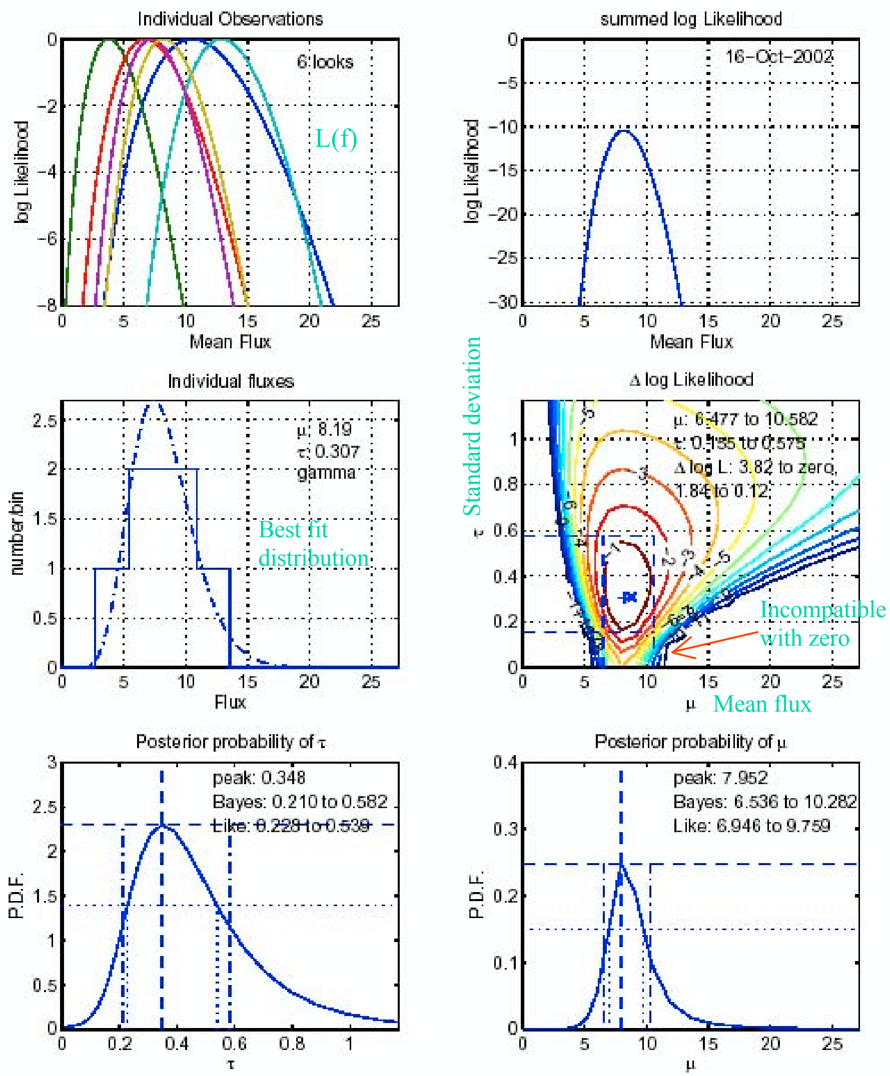
- The basic unit of data is the flux of photons with E > 100 MeV from a point source in a Viewing Period (1-3 weeks). Short viewing periods within one month are combined.
- Beyond this, the ordering and spacing of the observations are ignored. They are assumed to be drawn from an uncorrelated, stationary random process, whose distribution we wish to study. Thus very long and very short time scales are ignored.
- For each observation, a likelihood function L(flux) is determined. Empirically it can be represented by a 3-parameter function. Bill wrote his own likelihood program to do this.
- To combine these functions, a form must be assumed for the probability distribution. Bill used a lognormal. I find that a gamma distribution causes fewer numerical difficulties.
- The parameters of the distribution (mean and standard deviation) are optimized to agree with the joint likelihood of all the observations. The mean is a nuisance parameter for our purposes.

The Nature of the Results

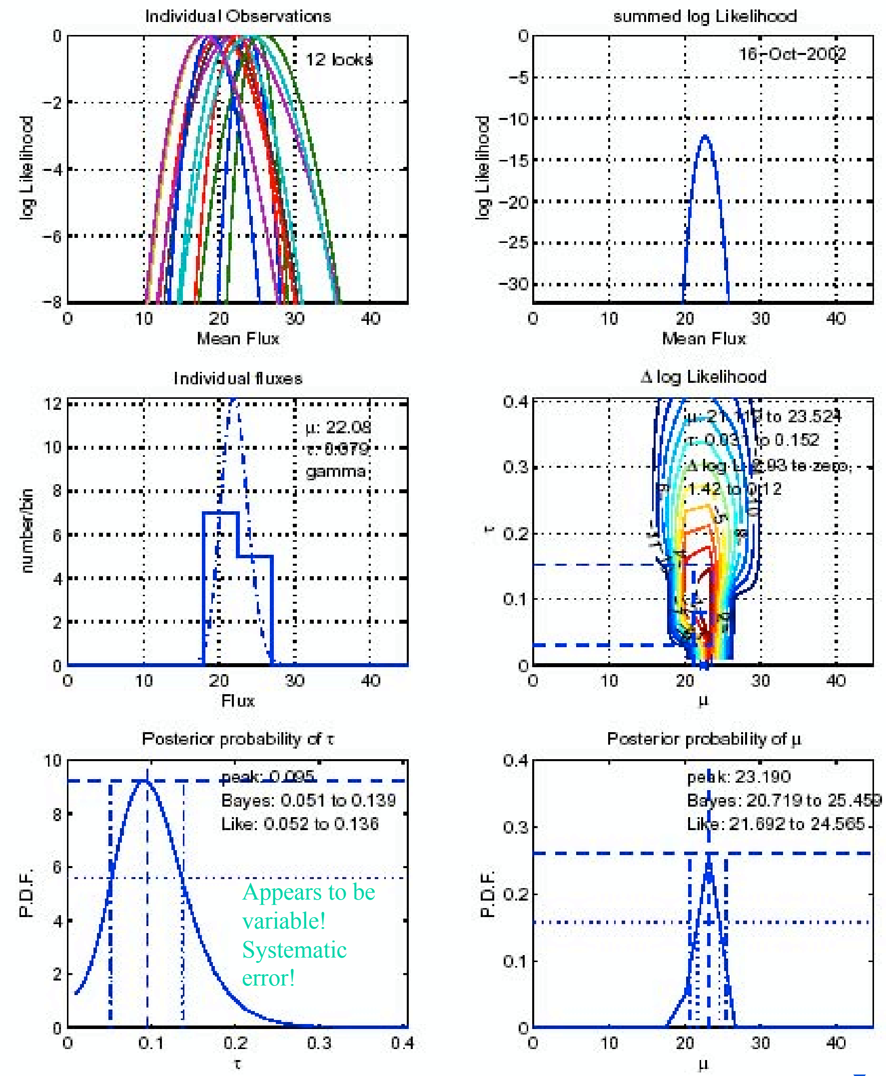
- Previous analyses ask the question, “Is it variable?” McLaughlin et al. do a χ^2 test. Strong sources, with small error bars, always appear highly variable.
- We ask, “How variable is it, and how well do we know that?” We estimate the standard deviation of the flux distribution and set confidence limits on it by Bayesian or frequentist methods. We want to separate the intrinsic flux variation from statistical errors.
- For most sources, the results are ambiguous. The error bars are just too big. We can combine individual sources to determine the properties of identified source classes.

Sample Results

J0210−5055
(Moderately bright, probably variable)



J0534+2200
(The Crab)

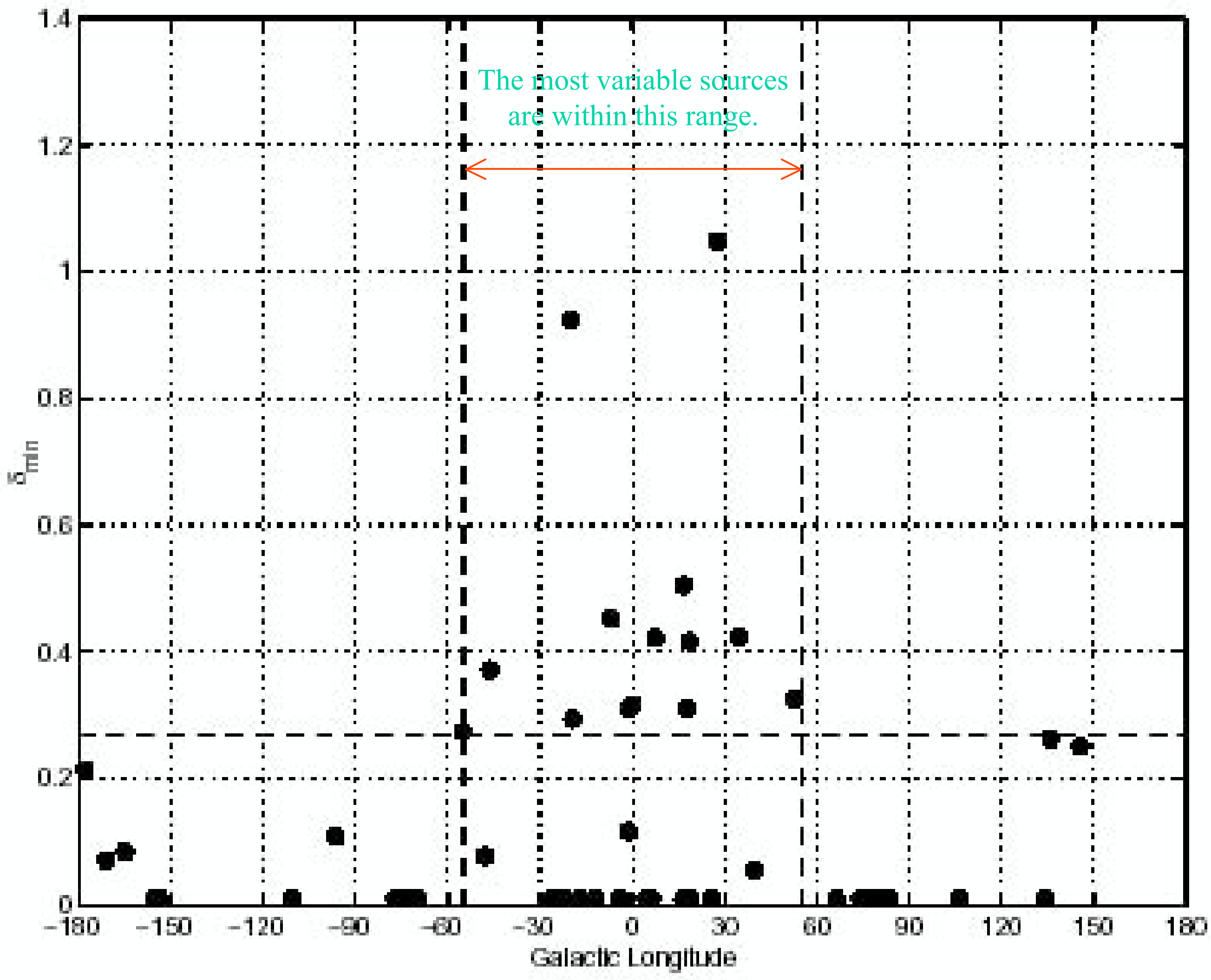


Individual Sources

- The bright pulsars are believed to be steady emitters, but we find an intrinsic standard deviation of 10-12%. This is attributed to systematic error, and there are some plausible culprits. We assume that all sources are subject to the same errors.
- Other sources which clearly have low variability include some pulsar candidates and one BL Lac object (0716+714).
- There are 18 sources which are certainly highly variable (> 0.7). Eleven are identified blazars, 4 are at high latitude, and 3 along the galactic plane.
- There are 17 variable, unidentified sources along the galactic plane, mostly concentrated within 55° of the galactic center.

Minimum Variability of Sources Within 6° of the Galactic Plane

Lower bound on standard deviation



Variability of Select Classes of Sources

- Once a group of sources has been identified, it is easy to calculate the mean variability δ and its scatter.
- Unidentified source are more variable at high latitude, showing a mixed population of galactic and extragalactic objects.
- We verify some previous results: Gould's belt, Gehrels steady sources, Grenier persistent sources, pulsars & candidates, AGN.

Table 1. Variability of selected classes of sources

Source Class	Members	$< \delta >$	RMS(δ)
Unidentified	158	0.50	0.16
Pulsars	6	0.12	...
AGN	94	0.79	0.24
SNR	10	0.35	0.09
a AGN	27	0.67	0.36
A AGN	67	0.81	0.23
Unidentified, $\|b\| > 15°$	74	0.61	0.14
Unidentified, $5° < \|b\| < 15°$	37	0.58	0.19
Unidentified, $\|b\| < 5°$	47	0.43	0.12
Unidentified, $\|b\| > 30°$	29	0.84	...
Gould's Belt, unidentified	58	0.39	0.27
Persistent, unidentified	88	0.37	...
Gehrels steady	120	0.47	0.11
Romero's SNR	17	0.33	0.10
Pulsar wind nebulae	9	0.47	0.17
Pulsar candidates	6	0.20	0.03
Romero's WR stars	6	0.38	...
Romero's Of stars	4	0.30	...
Romero's OB associations	22	0.39	0.12

Current State of the Paper

- The serious number-crunching is done.
- It has gone through several drafts.
- The science needs to be strengthened.
  - The literature survey is out of date.
  - We need to choose a set of source classes.
  - Conclusions need to be clarified.