Fermi Gamma-ray Space Telescope

Effects of Biases of the Interstellar Emission Models on Point Source Finding and Characterization with the Fermi-LAT

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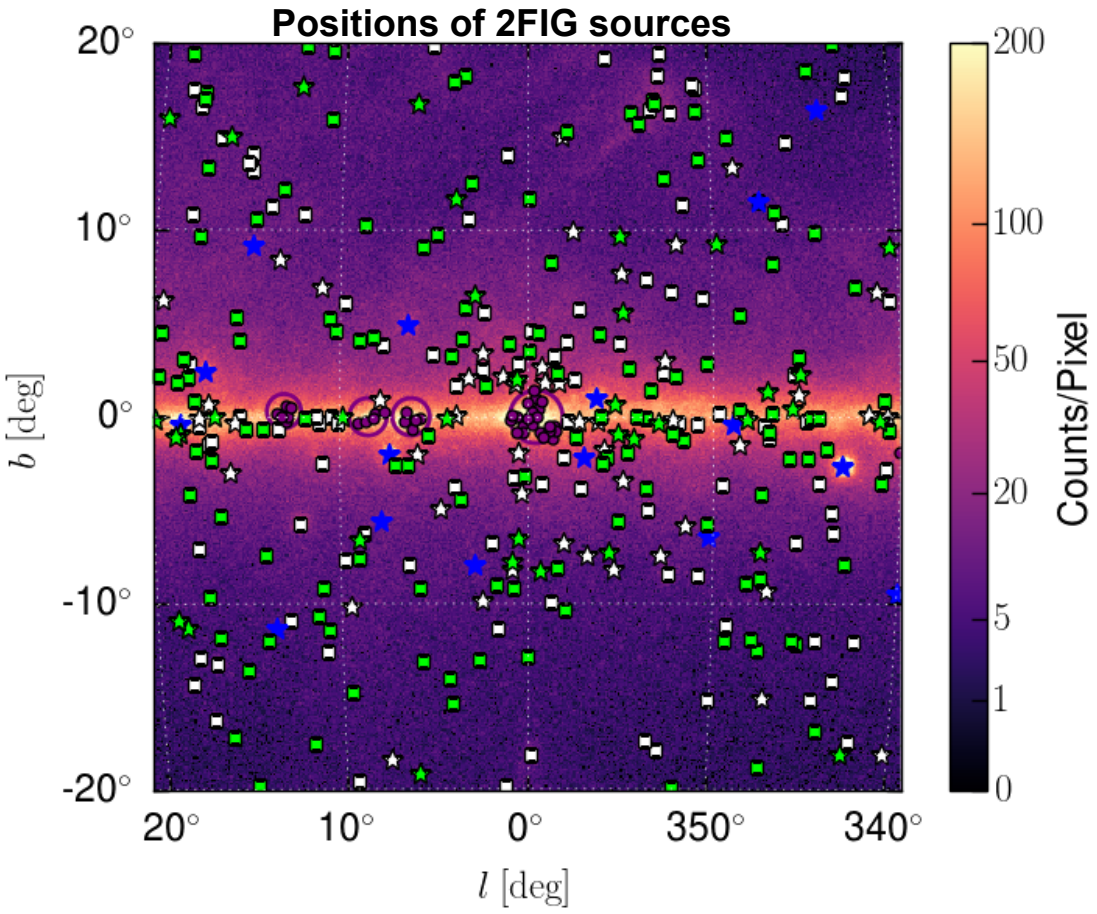
7th Fermi Symposium

Garmisch-Partenkirchen, Germany Oct. 19, 2017

Outline

- Questions:
  - How much do uncertainties of the interstellar emission models (IEMs) affect point source detection?
  - How much do they affect our characterization of the spectra of the detected sources?
  - How can we account for these uncertainties in data analysis?
- Results & Discussion:
  - Comparison of data analysis pipeline using two different IEMs.
  - Quantifying the level of the systematic errors in the IEMs.
  - Applying likelihood de-weighting to account for systematic errors.

2FIG Analysis Pipeline and Results



Off. IEM 374 srcs
Alt. IEM 385 srcs

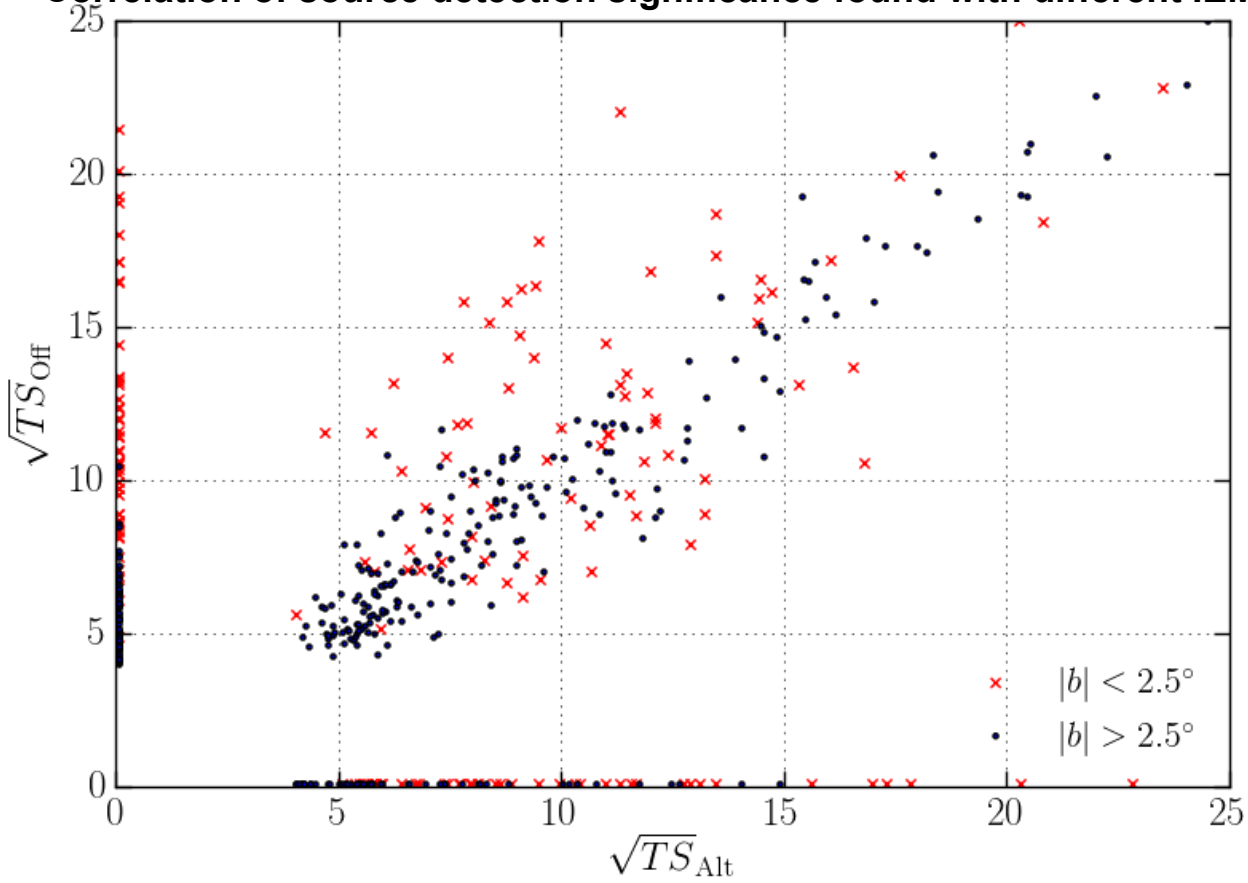
Merged: 290

3FGL Sources
New Sources
★ PSR Cand.
■ Non-Cand.

- 2FIG source list: *Fermipy*-based source-finding pipeline in the inner 40°x40° of the Galaxy
  - Run twice, using different IEMs: Official (Off., 374 srcs) and Alternate (Alt., 385)
  - See arXiv:1705.00009 for details of analysis pipeline
  - Detection criteria TS = -2 Δ log L > 25

Effect of IEM on Source Detection Significance

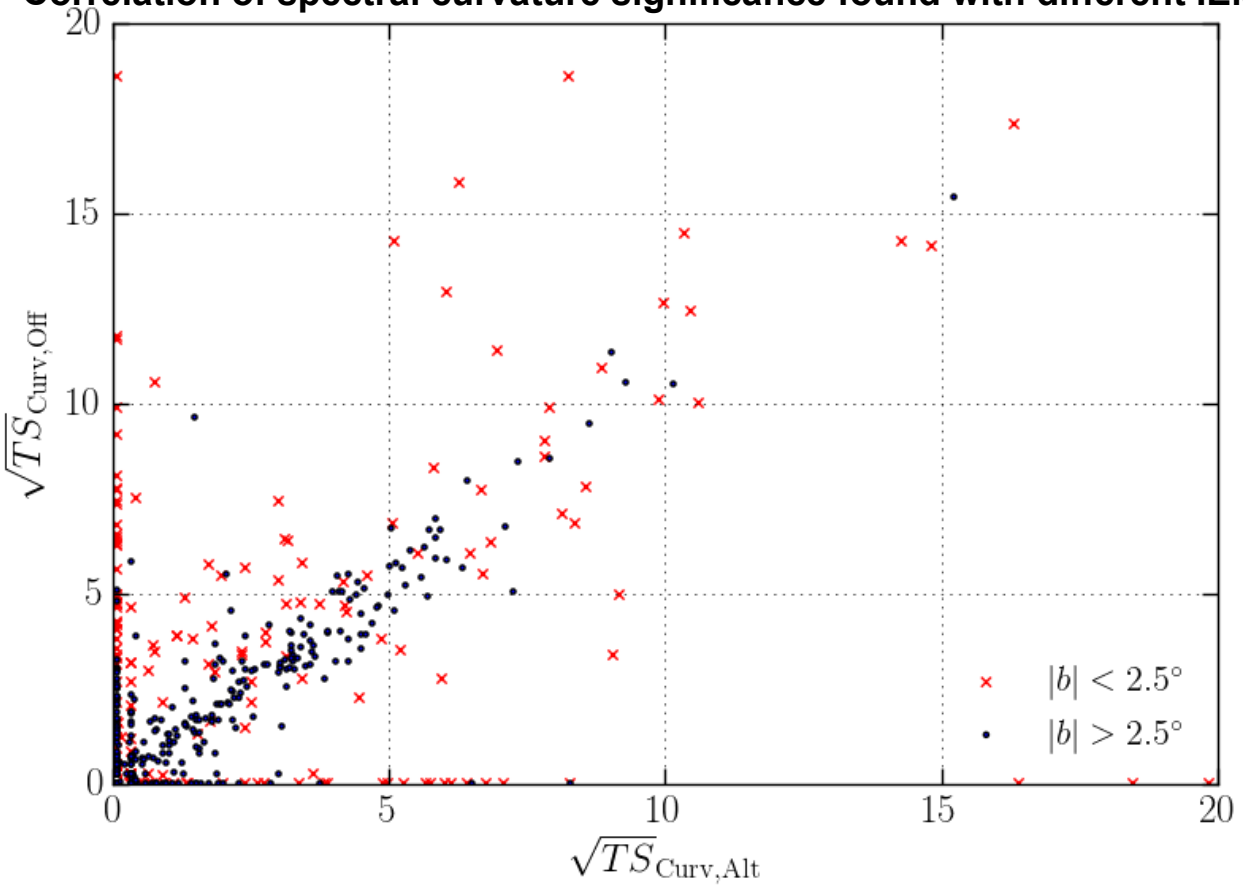
Correlation of source detection significance found with different IEMs



- Away from the Galactic plane (|b| > 2.5°) we observe good correlation between the source detection significance seen with the two IEMs
- Along the galactic plane the correlation is poor (rms ~ 5σ)

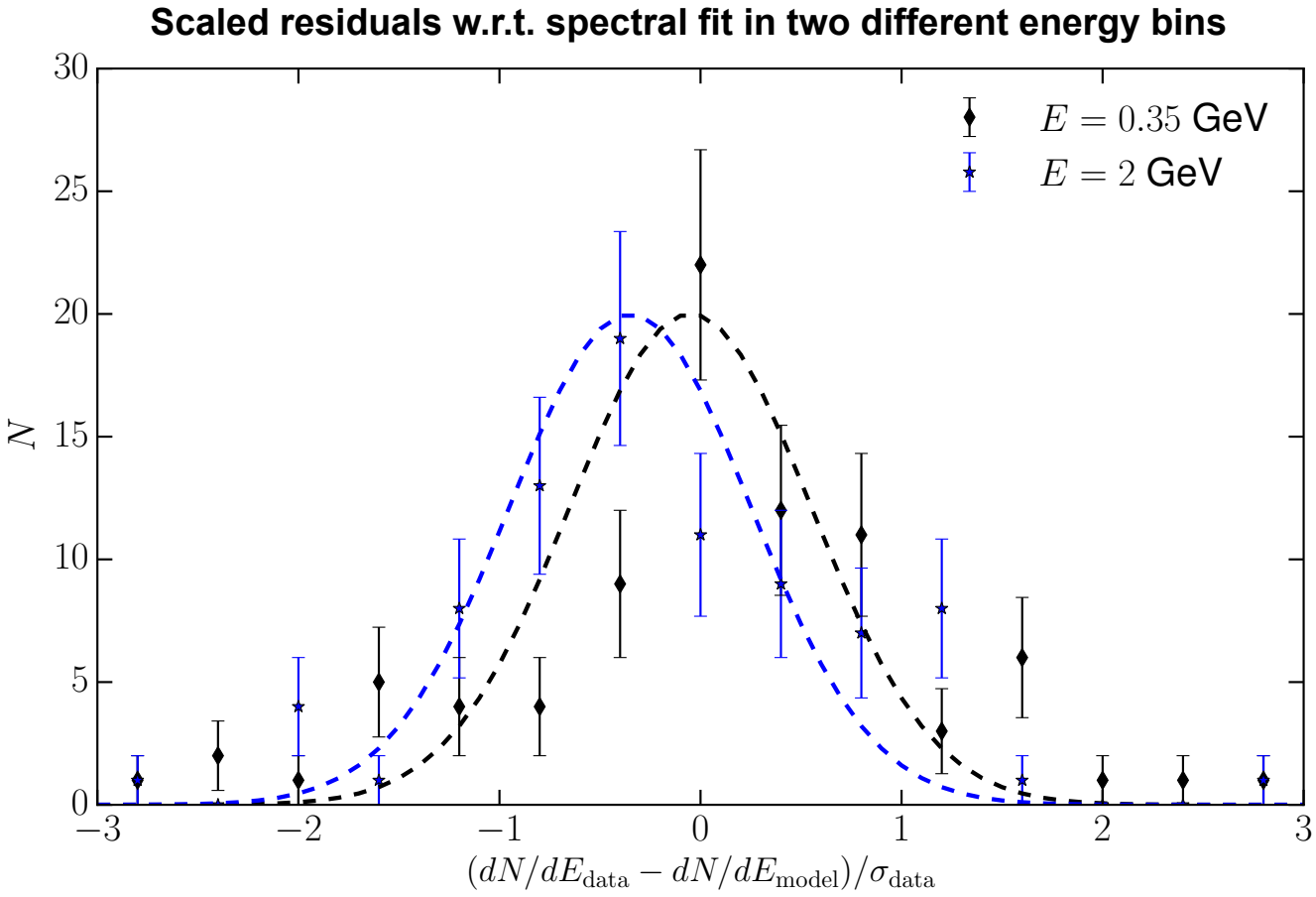
Effect of IEM on Spectral Curvature Significance

Correlation of spectral curvature significance found with different IEMs



- Away from the Galactic plane (|b| > 2.5°) we observe good correlation between the spectral curvature significance seen with the two IEMs
- Again, along the galactic plane the correlation is poor

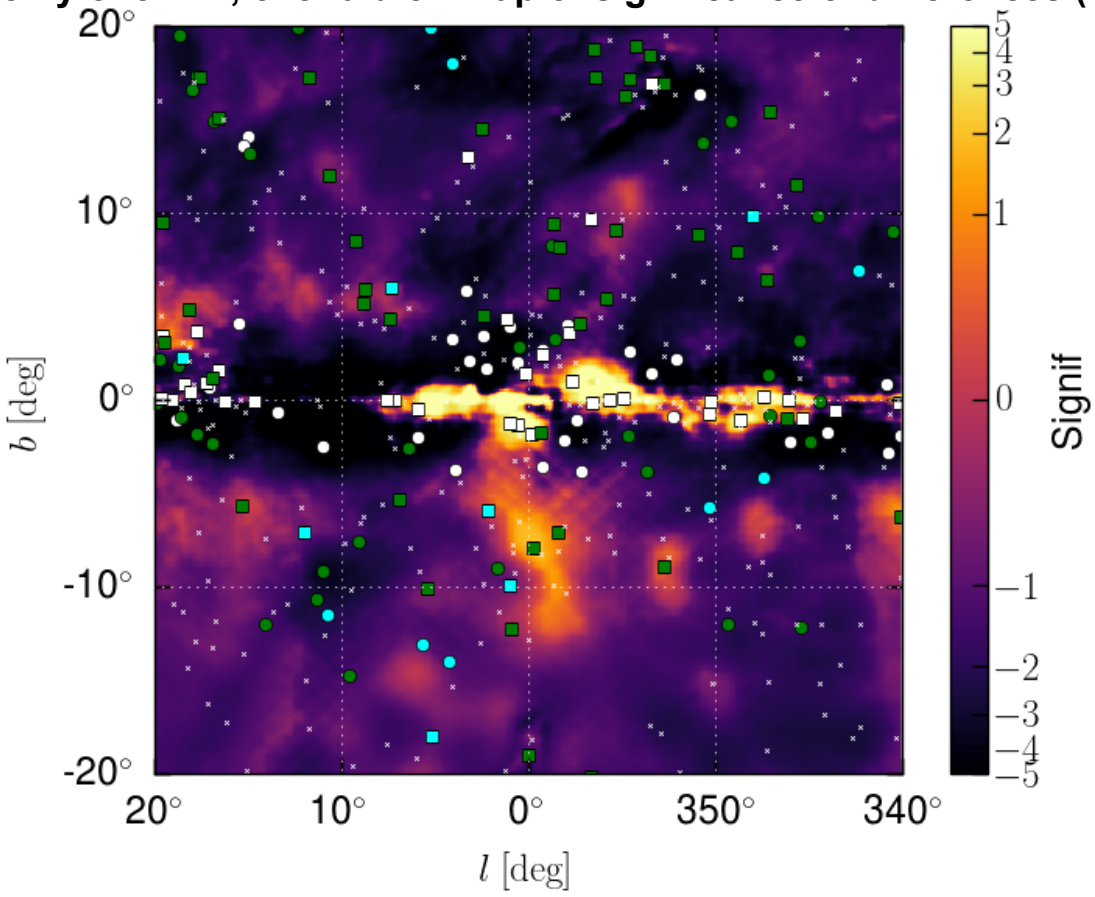
Test for Spectral Biases



- The flux value in individual energy bins agrees reasonable well with the broadband spectral models
- No evidence of strong biases, but a few outliers, both positive and negative

Unmatched Sources Along the Plane

Sources found in only one IEM, overlaid on map of significance of differences (Off-Alt) between IEMs



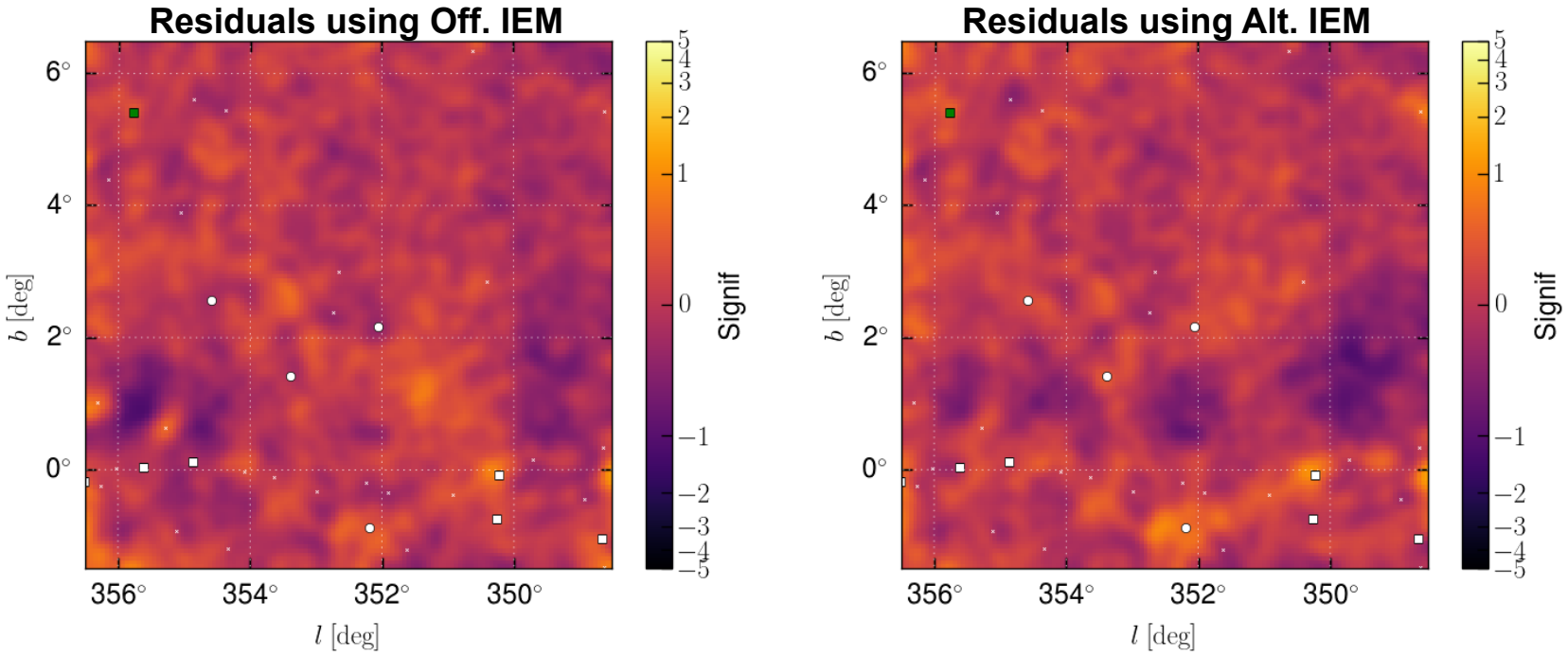
Large markers show sources found only with one IEM

TS 16-25 w/ other Model TS < 49

■Off. and not Alt.
O Alt. and not Off.

- Most source found with only one IEM are either low-significance or found at sub-threshold significance with the other IEM (cyan and green markers)
- Sources found with high-significance with only one IEM (large white markers) occur in regions where the two IEMs differ significantly (color scale)

Unmatched Sources and Residual Maps

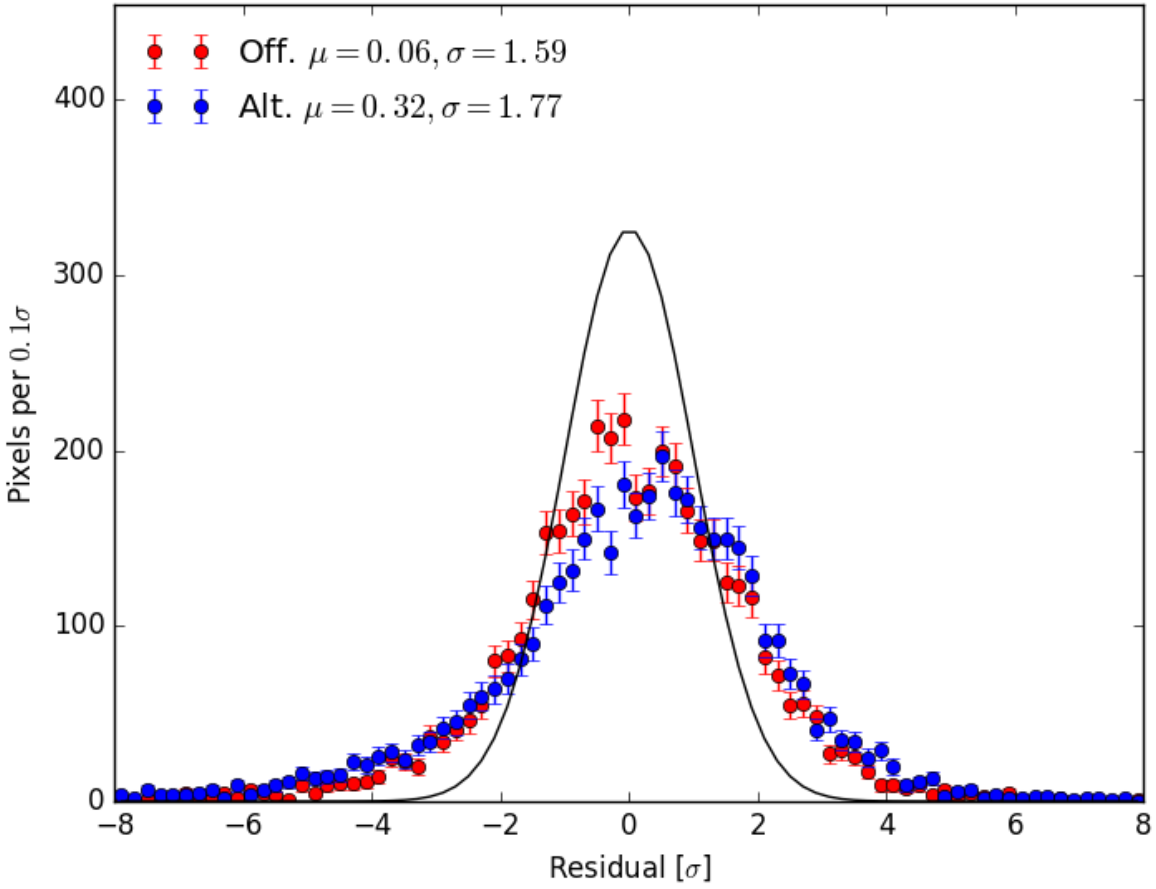


■Off. and not Alt.
○ Alt. and not Off.

- Examination of 8°x8° fit regions along Galactic plane shows structured residuals, we consider two cases
  - Regions where both IEMs under-fit the data: potential spurious sources
  - Regions where both IEMs over-fit the data: potential lost sources
    - Equivalently: modeled point-source sensitivity is too good

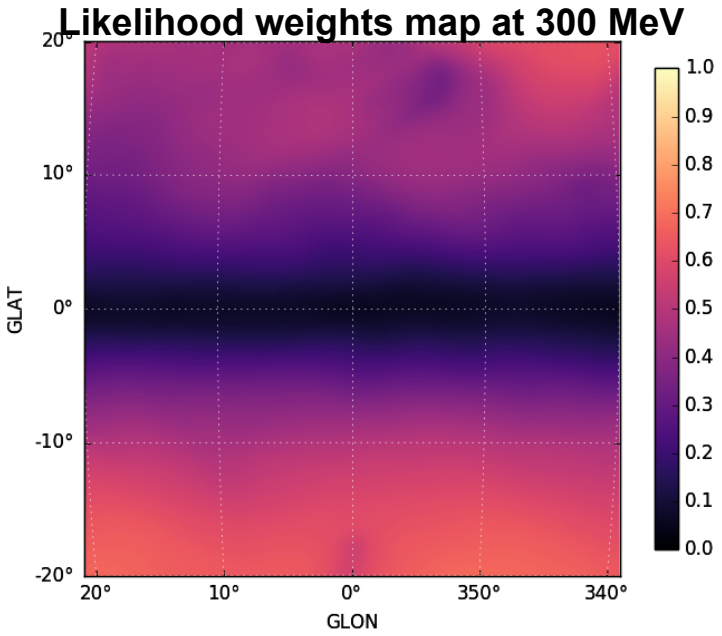
Scaled Residuals

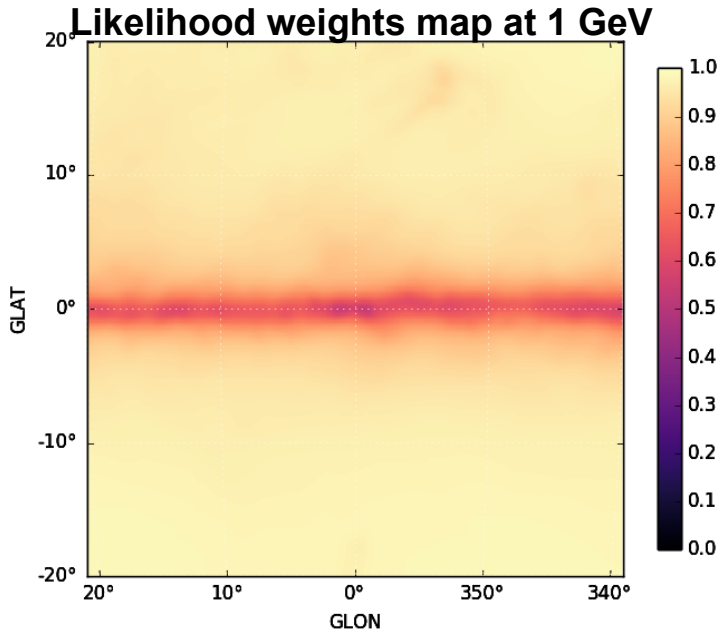
Histogram of scaled residuals for 0.48° x 0.48° pixels for regions along Galactic plane



- With both models, scaled residuals are significantly wider than Normal distribution, this implies systematic uncertainties that are, on average, slightly large than statistical uncertainties.
- Low-end tail out to ~6σ: some regions where models badly overfit the data

Likelihood Weights Maps

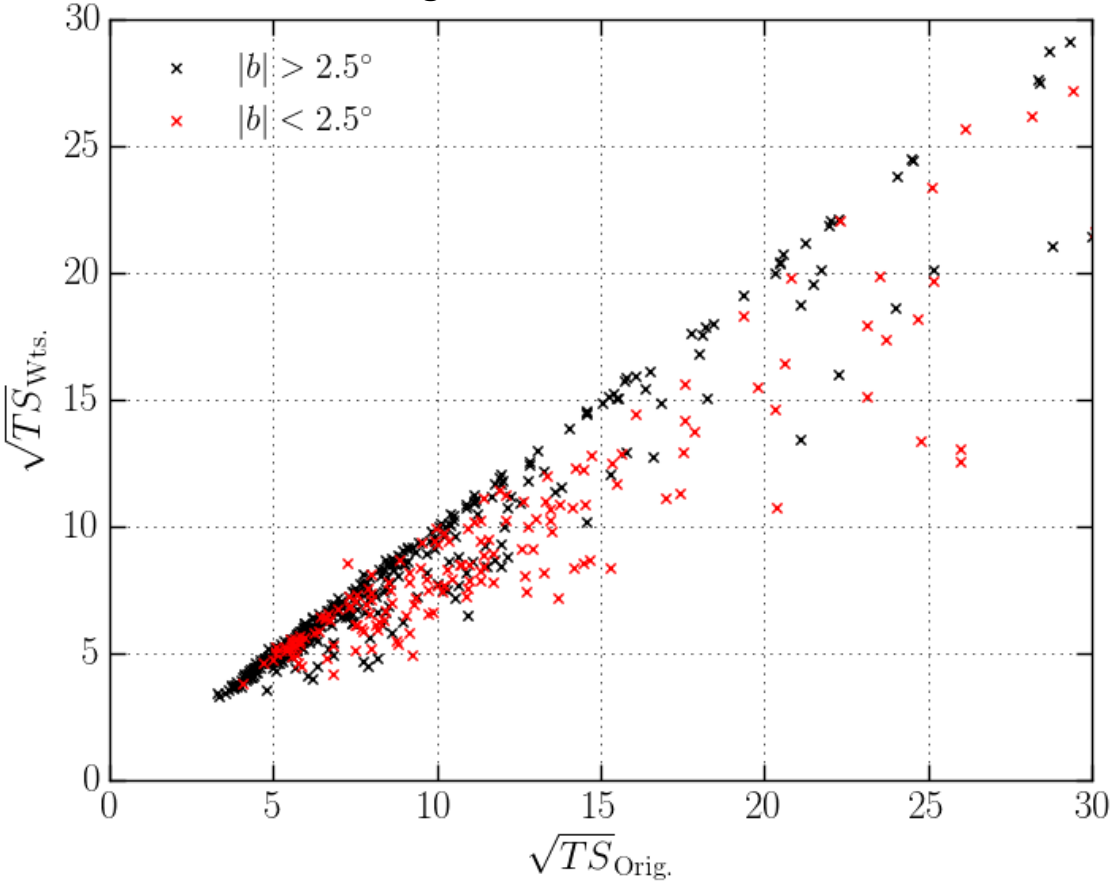




- We are developing method of de-weighting likelihood to account for systematic uncertainties (see e.g., **2015ICRC...34..848B** for additional details)
  - For now, we assume systematic uncertainties are a fixed fraction of total counts. These maps were generated with $\varepsilon = 0.02$

Likelihood De-weighting Decreases Source Detection Significance

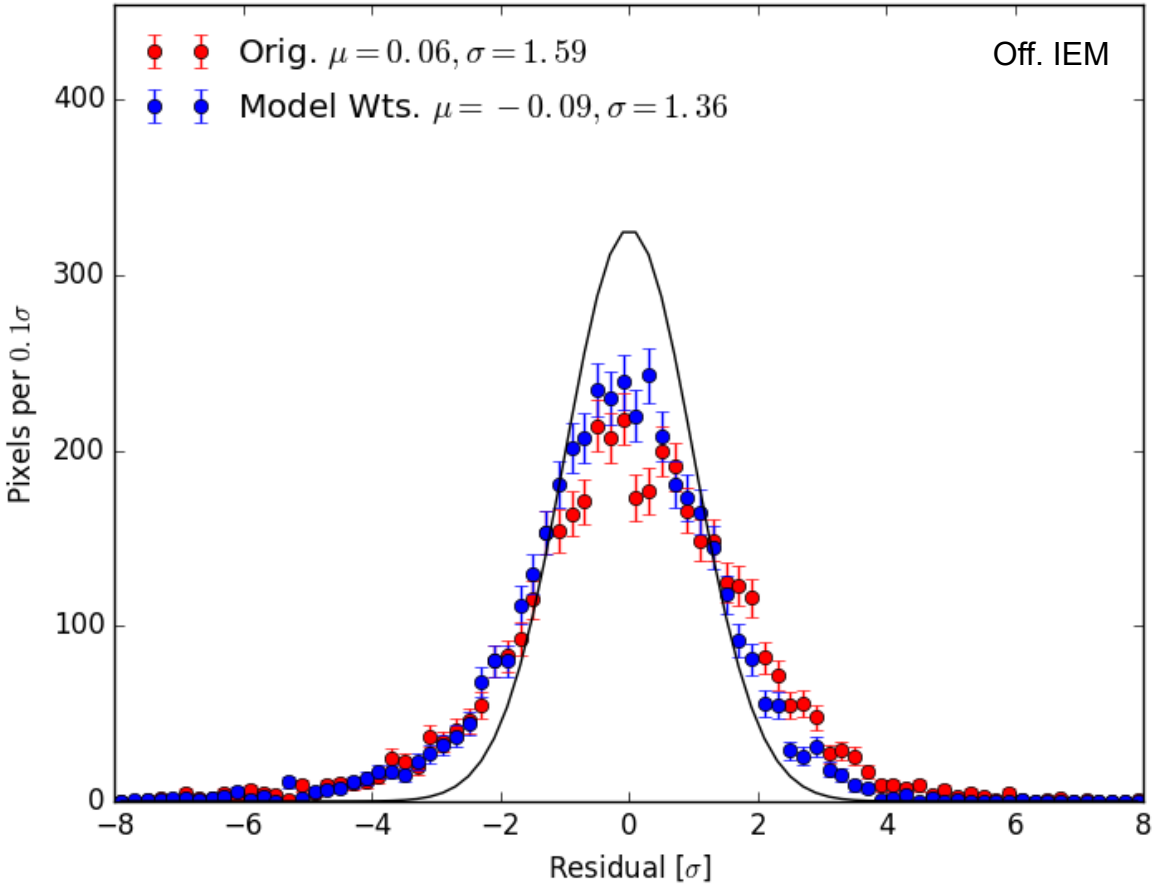
Correlation between detection significance with and without likelihood de-weighting



- As expected, apply de-weighting almost always reduces source detection significance
- Amount of reduction depends on source spectrum, local background, confusion with nearby sources

Likelihood De-weighting Narrows Scaled Residual Distribution

Comparison of scaled residuals with and without likelihood de-weighting for Off. IEM



- It appears that these likelihood weights under-estimate systematic uncertainties close to the plane
- In other regions/ or with different IEMs this is less the case (see extra slides)

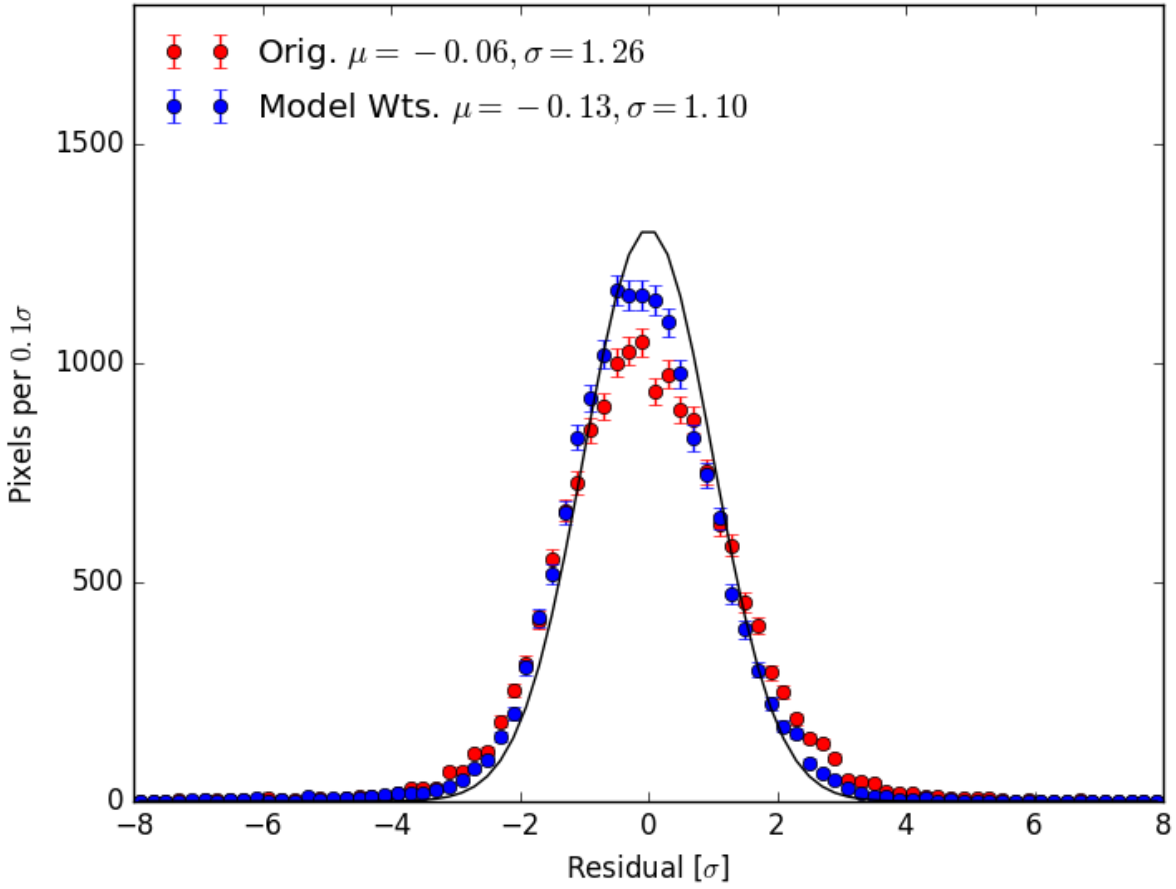
Summary

- Source detection and spectral parameter estimation are biased by errors in the IEMs
  - Away from the Galactic plane (|b| > 2.5°) , on average the effect is roughly similar in magnitude to the statistical uncertainties
  - Along the Galactic plane (|b| > 2.5°) the effect can be several times the statistical uncertainties
    - Large enough to create spurious sources or significantly degrade sensitivity for real sources
- Likelihood de-weighting scheme performs as expected, reduces source detection significance and narrows scaled residual distribution
  - Some additional tuning of weighting scheme is still warranted

EXTRA SLIDES

Scaled Residuals for 40°x40° Region

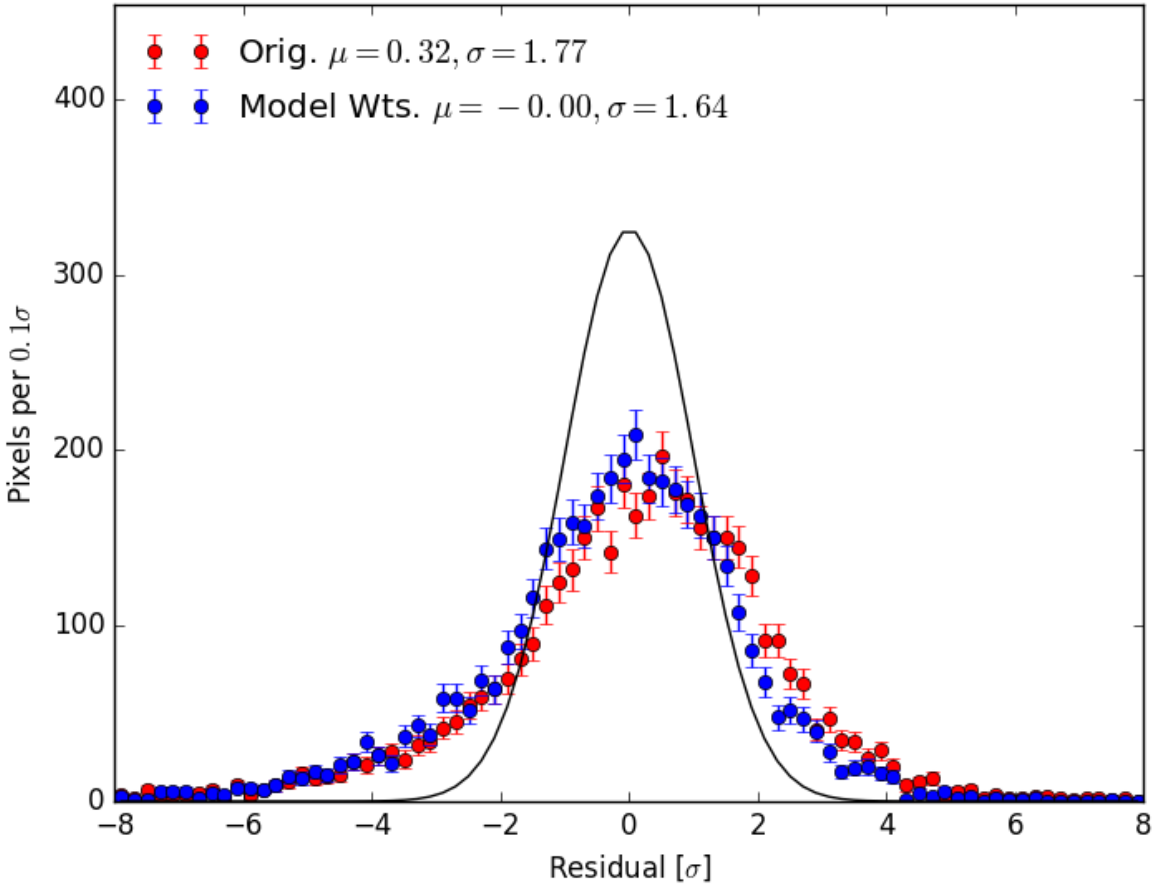
Comparison of scaled residuals with and without likelihood de-weighting for entire 40x40 Region



- Over the entire 40°x40° region the weights come closer to estimating level of systematic uncertainty (which is lower)

Scaled Residuals for Alt. IEM

Comparison of scaled residuals with and without likelihood de-weighting for Alt. IEM



- Using the weights derived for the Off. IEM with the Alt. IEM analysis we are underestimating the systematic uncertainties substantially
- This suggests that the Alt. IEM may have biases in regions where the weights are closer to 1, i.e., away from the highest statistics areas