
# Fermi

## Gamma-ray Space Telescope

## Advanced Likelihood

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# Goals

- Quality checks on spectral fitting of point sources
  - Major gotchas
  - Reminder of simple checks
  - Upper Limits
- Binned vs. Unbinned likelihood

# Major gotchas

- **Flux/Spectral analysis depends critically on calculating the proper exposure**

| selection | | livetime | response/exposure | minimization |
|---|---|---|---|---|
| **gtselect** | **gtmktime** | **gtltcube** | **gtexpmap** | **gtlike** |
| **(gtbin)** | | | **(gtsrcmaps)** | **(gtlike binned)** |

- **Examples of things that can screw this up**
  - **fselect, fcopy**
    - **these do not update the header keywords used in the exposure calculation**
  - **Mismatch of data selection and IRF set**
    - **Use the diffuse class IRFs with the diffuse class event selection**
  - **Mismatch of ROI selection (*gtselect*) and data cube (*gtbin*) in binned likelihood analysis**

# Major Gotchas II

- **Mismatch of calculated diffuse response and model diffuse components**
  - **Use the recommended diffuse models with the data (includes precalculated diffuse response values for each photon for those specific models)**
  - **Diffuse response for experts**
    - ***gtdiffrsp* calculates the diffuse response values**
    - **Use unique names in the input xml model for different diffuse model templates**
    - **Example: If you come up with a new version of the Galactic diffuse template, don't call it "GAL_v02"**
- **The currently recommended isotropic template is only appropriate for use with the diffuse event class**

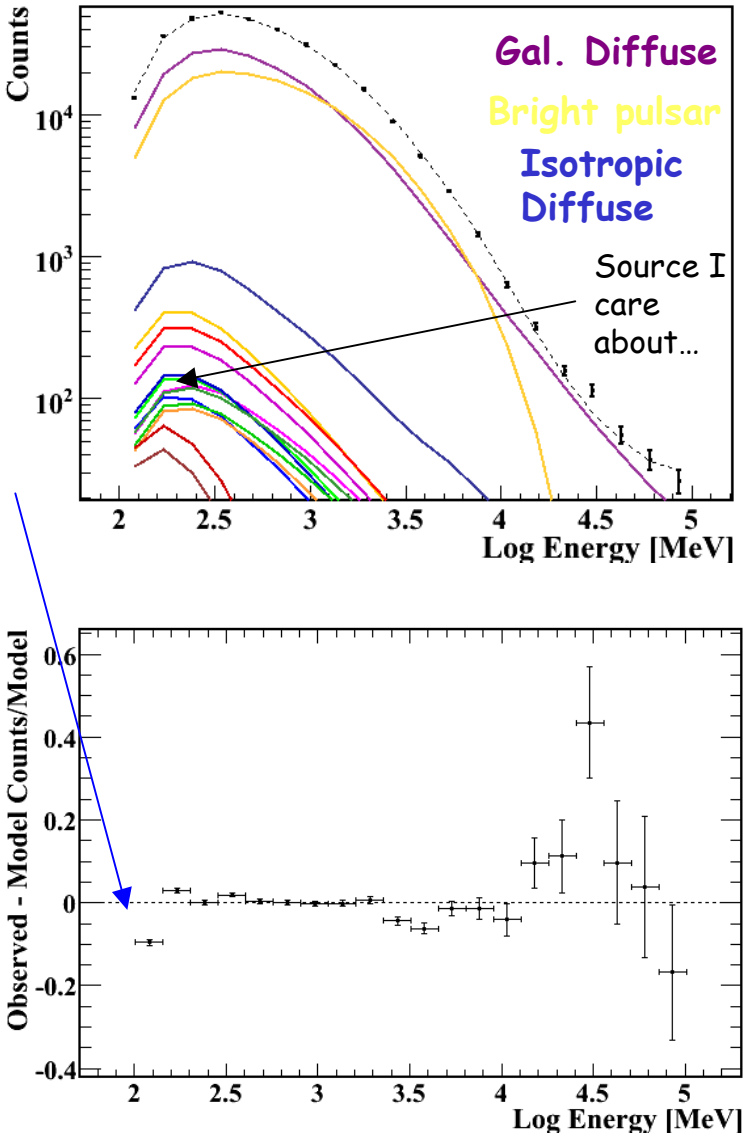
# Likelihood output - simple checks

***Did the fit work and does it make sense?***
***Reading the tea leaves of gtlike output***

- **Did the minimization converge?**
- **Are the number of predicted photons reasonable?**
- **Do the parameter values make sense?**
  - **Are values hitting limits?**
  - **Is there a source with an extremely soft spectrum or hard spectrum?**
- **Do the parameter errors make sense?**
  - **Too small? Were enough parameters left free?**
  - **Larger than the parameter values? Is the source significant?**
- **Consider the above for the target source and field sources**
- **All of the above become more critical for faint sources, complex regions, time-binned flux light curves…**

# Spectral Residuals

- **Unbinned analysis produces predicted counts and residuals as a function of energy.**
  - Example: a long integration near the Galactic plane and a bright pulsar
- **Discrepancy at low energy common**
  - **Likelihood uses true energy**
- **Discrepancies strongly tied to diffuse model for most analysis**
  - **Diffuse mediates cross talk between target source and nearby neighbors**
  - **Consider relative source strength**
  - **Test impact of model choices and selections on target source**



# Likelihood - ROI selection

*How big?*

- **Big enough to constrain model components - source of interest, diffuse emission, nearby sources**
- **Small enough to avoid significant zenith cut loss to livetime**
  - **Practical advantage! less photons and less sources => less calculations for unbinned analysis**
  - **Analysis disadvantage! likelihood is an inclusive modeling strategy**
- **Recommendations**
  - **~10 deg for isolated point source (E>100 MeV)**
  - **Larger regions (15-20 deg) benefit confused sources, aid in separating diffuse at low energy, improve error estimates**
- **Test it!**
  - **Are fit results reliable for different ROI radii?**
  - **What is the impact on GTIs?**

# Likelihood Model - sources

***What should be included?***

- **All sources that contribute photons to the selected region**
  - **Bright source list sources within ~10 deg of the ROI boundary - accommodates tail of low energy PSF**
  - **Same goes for 1FGL catalog sources**
- **Galactic diffuse model**
- **Isotropic diffuse model**
  - **Important for all parts of the sky…provides a home for residual instrument effects (cosmic rays)**

**This is a starting point. Adapt to find what works best for your region and source.**

# Likelihood Model - spectra

***What spectral shape?***

- **Power laws are simple and well defined**
  - **For faint sources, difficult to justify more parameters**
- **BUT lots of LAT sources are not simple power laws… some tips to help motivate other spectral forms**
  - **Bright pulsars?**
    - **Try simple exponentially cutoff power laws to improve fits for the pulsar itself *and for nearby sources***
  - **Visually inspect energy-dependent ROI selections**
  - **Do power-law fit parameters vary significantly for different minimum energy selections or fits in separate energy bins?**
- **Confirm: Most accurate and unbiased way to determine spectral parameters and errors is by testing the hypothesis using the likelihood analysis**

# Likelihood - reality checks

***Is anything missing?***

- **Visual inspection of count maps and residuals**
- **Test Statistic maps (for unbinned analysis)**
  - ***gttsmap* - Tests hypothesis of additional point source over a spatial grid**
  - **Very Calculation Intensive**
    - **try small regions (5 deg) and large grid spacing (0.5 deg)**
  - **Discrepancies may be additional source or component, or could be deficiencies in the diffuse model in some regions**
  - **Warning: *gttsmap* is not ideal for localization, use *gtfindsrc***
- **Predicted and residual count maps (for binned analysis)**
  - **Profiles, radial density, energy dependence**

# Likelihood - checking results

***Is the result consistent for a different analysis?***

- **Iteration**
  - **Consistent results for the best fit parameters?**
    - **Tip: *gtlike sfile=best_fit_model.xml***
- **Data selection tests**
  - **Minimum energy selection?**
  - **ROI selection? (Keep in mind this also effects good time selection in combination with zenith cut)**
  - **Consistency in distinct energy bins (catalog analysis)**
  - **Agreement using front or back events (requires use of appropriate IRFs, diffuse response, and isotropic model for each)**
  - **Time selections?**
- **Fit and Minimization choices**
  - **Impact of starting parameter values in the model?**
  - **Fit tolerence? (converging to true minimum?)**
  - **Effects of optimizer?**

# Binned vs. Unbinned Likelihood

- **Unbinned: Treats each photon independently (position, energy)**
  - **Best theoretical performance**
  - **More sensitive - important for faint sources**
  - **Best option for low statistics scenarios (e.g. flux light curves)**
  - **Drawbacks:**
    - **Not for use with spatially extended sources**
    - **Difficult to diagnose problems in individual source fit**
- **Binned: Treats the data in bins of position and energy. Minimal criteria - photons > bins**
  - **Less computationally intensive than unbinned**
  - **Handles templates for extended sources**
  - **Allows nice diagnostics of fit (source maps, spatial profiles, energy dependent comparisons of prediction and model)**
  - **Drawback: At highest energies, can run into low statistics even for long integrations**

**Use of both allows consistency check**
**(if both can be reasonably used)**

# Summary

- **Lots of ways to use the tools to evaluate spectral fitting and to validate results**
  - **Consistency is key**
  - **Analysis Cookbook provides basic starting points. Cicerone documentation provides deeper insight into into the likelihood technique**
  - **The First Catalog paper provides detailed examples of spectral fitting with the science tools**