

Energy dispersion studies using the smoothly broken powerlaw model

Introduction

This study is intended to address concerns raised by Stefan in his [energy dispersion studies and results for the region containing IC443 \(and W44\)](#).

The input simulations

The model includes Galactic diffuse, isotropic diffuse, and IC443:

- The "standard" Galactic diffuse model, `gal_2yearp7v6_v0.fits`, only extends down to 50 MeV, and in simulations, this is the minimum value of `MCENERGY` of the generated events. However, in the likelihood model `mapcube` representation, the model is power-law extrapolated (at each pixel) beyond the energy bounds of the map. So there will be a mis-match between the model use for simulation and that used for the likelihood analysis. To prevent this inconsistency, I've created version of the model that power-law extrapolates down to 3 MeV (I've also rebinned in sky coordinates to 0.5x0.5 deg pixels so that the simulation proceeds more quickly.) On slac afs, the file is `/afs/slac/g/glast/groups/scienceTools/bugs/Likelihood/energy_dispersion/Simulations/galdif_extended.fits`.
- Similarly, I've used a version of `iso_p7v6source.txt` (prepared by Josh) that extrapolates down to 10 MeV. For `emin=20 MeV` in `gtselect`, this should be fine. The file is `/afs/slac/g/glast/groups/scienceTools/bugs/Likelihood/energy_dispersion/Simulations/iso_p7v6source_extrapolated.txt`
- IC443: Here I use the standard `MapSource` template, `/afs/slac/g/glast/groups/catalog/2FGL/gll_psc_v05_templates/IC443.fits`, and a smoothly broken power-law with parameters:
 - `Index1 = -0.5`
 - `Scale = 100`
 - `Index2 = -1.9`
 - `BreakValue = 250`
 - `Beta = 0.1`

For simulation purposes, a `FileSpectrum` template was used.

High flux versions of these sources were simulated on a 1-day observation time using idealized +/- 50 degree rocking:

```
<source name="Galactic_Diffuse_ext">
  <spectrum escale="MeV">
    <SpectrumClass name="MapCube"
      params="1e3, galdif_extended.fits"/>
    <use_spectrum frame="galaxy"/>
  </spectrum>
</source>
<source name="Isotropic_Diffuse">
  <spectrum escale="MeV">
    <SpectrumClass name="IsotropicFileSpectrum"
      params="flux=800, specFile=iso_p7v6source_extrapolated.txt"/>
    <use_spectrum frame="galaxy"/>
  </spectrum>
</source>
<source name="IC443">
  <spectrum escale="MeV">
    <SpectrumClass name="FileSpectrumMap"
      params="flux=10., fitsFile=IC443.fits, specFile=IC443_sbpl.txt, emin=10, emax=1e6"/>
    <use_spectrum frame="galaxy"/>
  </spectrum>
</source>
```

This yields ratios of numbers of events within a nominal 14 degree radius cone about IC 443 of Galactic:Isotropic:IC443 = 10:1:10 for the energy range 20-5000 MeV.

Binned Analysis

Effects near ends of selected energy range with energy dispersion handling turned on

In order to account for events that are mixed from outside the selected energy range, the likelihood code extrapolates the model counts spectrum for each source beyond the `emin`, `emax` values specified in `gbin` when making the counts cube. Because the effective area is changing strongly as a function of energy below about 100 MeV, this sort of extrapolation can lead to problems modeling the measured spectrum at low energies. The recommended way to mitigate this is to create a counts cube (and corresponding binned exposure map) that extends beyond the desired energy range to be analyzed. The likelihood code will then use the actual exposure to compute the model counts as a function of true energy and the resulting spectra can then be used to compute accurately the model counts in measured energy space. In this analysis, the counts cube and binned exposure map extend from 20 to 5000 MeV, giving sufficient coverage at low and high energies to ensure accurate modeling for the desired analysis covering 60 to 2000 MeV.

The likelihood xml-model definition

```
<?xml version="1.0" standalone="no"?>
<source_library title="source library">
  <source name="IC443" type="DiffuseSource">
    <spectrum type="SmoothBrokenPowerLaw">
      <parameter error="0.4954398855" free="1" max="100" min="0.01" name="Prefactor" scale="1e-6" value="1" />
      <parameter error="0.1215327591" free="1" max="5" min="-5" name="Index1" scale="1" value="-0.5" />
      <parameter free="0" max="200" min="200" name="Scale" scale="1" value="200" />
      <parameter error="0.02281532475" free="1" max="5" min="-5" name="Index2" scale="1" value="-1.9" />
      <parameter error="21.72157285" free="1" max="1000" min="100" name="BreakValue" scale="1" value="250" />
      <parameter free="0" max="0.1" min="0.1" name="Beta" scale="1" value="0.1" />
    </spectrum>
    <spatialModel file="IC443.fits" type="SpatialMap">
      <parameter free="0" max="1000" min="0.001" name="Prefactor" scale="1" value="1" />
    </spatialModel>
  </source>
  <source name="Galactic Diffuse" type="DiffuseSource">
    <spectrum type="PowerLaw">
      <parameter error="0.002799883743" free="1" max="1e4" min="0." name="Prefactor" scale="1" value="50" />
      <parameter error="0.003039083563" free="1" max="1" min="-1" name="Index" scale="-1" value="0.0" />
      <parameter free="0" max="1000" min="1000" name="Scale" scale="1" value="1000" />
    </spectrum>
    <spatialModel file="galdif_extended.fits" type="MapCubeFunction">
      <parameter free="0" max="1000" min="0.001" name="Normalization" scale="1" value="1" />
    </spatialModel>
  </source>
  <source name="Isotropic Diffuse" type="DiffuseSource">
    <spectrum file="iso_p7v6source_extrapolated.txt" type="FileFunction">
      <parameter error="0.01269613352" free="1" max="1e4" min="0" name="Normalization" scale="1" value="10." />
    </spectrum>
    <spatialModel type="ConstantValue">
      <parameter free="0" max="10" min="0" name="Value" scale="1" value="1" />
    </spatialModel>
  </source>
</source_library>
```

The data were analyzed for five subselections, with counts cubes generated for `emin`, `emax` = 20, 5000 MeV (30 energy bands) for a 10x10 deg region centered on IC443:

1. IC443 events only
 2. IC443 + Galactic + Isotropic (at full simulated statistics)
 3. IC443 + Galactic using only events with `MCENERGY > 50` (=Gal(>50)) + Isotropic
 4. IC443 decimated by a factor of 10 (=IC443/10) + Galactic + Isotropic such that Galactic:Isotropic:IC443 = 10:1:1
 5. IC443/10 + Gal(>50) + Isotropic
- This is intended to mimic simulations where the Galactic diffuse model was truncated below 50 MeV.

The selected energy range for fitting was `emin`, `emax` = 60, 2000 MeV using

```
>>> like.setEnergyRange(60, 2000)
```

These five cases were analyzed both with energy dispersion handling turned off and turned on.

Results

ID	dataset	edisp handling	Index1	BreakValue	Index2
	MC values	...	-0.5	250	-1.9

1	IC443 only	no	-0.70 +/- 0.03	248 +/- 5	-1.88 +/- 0.01
1	IC443 only	yes	-0.43 +/- 0.07	249 +/- 10	-1.89 +/- 0.01
2	IC443+Gal+Iso	no	-0.80 +/- 0.04	253 +/- 7	-1.88 +/- 0.01
2	IC443+Gal+Iso	yes	-0.47 +/- 0.15	248 +/- 16	-1.89 +/- 0.01
2	IC443+Gal(>50)+Iso	no	-0.78 +/- 0.04	251 +/- 6	-1.88 +/- 0.01
2	IC443+Gal(>50)+Iso	yes	-0.47 +/- 0.05	249 +/- 6	-1.89 +/- 0.01
4	IC443/10+Gal+Iso	no	-1.05 +/- 0.66	282 +/- 93	-1.89 +/- 0.03
4	IC443/10+Gal+Iso	yes	-0.63 +/- 0.22	272 +/- 28	-1.92 +/- 0.04
5	IC443/10+Gal(>50)+Iso	no	-1.04 +/- 0.14	290 +/- 36	-1.90 +/- 0.04
5	IC443/10+Gal(>50)+Iso	yes	2.35 +/- 1.76	176 +/- 8	-1.82 +/- 0.04