Accounting for uncertainties of the diffuse foreground model in GLAST likelihood analyses

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How large are the statistical uncertainties?

Diffuse emission from the inner galaxy:

$$I_{\ln E}(E) \approx (2 \cdot 10^{-4}\ \mathrm{ph.\,cm^{-2}\,s^{-1}\,sr^{-1}})\ \left(\frac{E}{100\ \mathrm{MeV}}\right)^{-1}$$

Resolution element as 68% single photon containment area

$$\Omega_{\mathrm{res}}(E) \approx (8 \cdot 10^{-3}\ \mathrm{sr})\ \left(\frac{E}{100\ \mathrm{MeV}}\right)^{-2}$$

The photon flux per resolution element therefore is

$$F_{\ln E}(E) \approx (1.6 \cdot 10^{-6}\ \mathrm{ph.\,cm^{-2}\,s^{-1}})\ \left(\frac{E}{100\ \mathrm{MeV}}\right)^{-3}$$

Then the detected number of photons per resolution element during the sky survey is

$$N(E,t) \approx 0.2\, A_{\rm eff}\, t\, F_{\ln E}(E) \approx 10^5 \ \left(\frac{E}{100\ \rm MeV}\right)^{-3} \left(\frac{t}{\rm yrs}\right)$$

and the relative statistical uncertainty is

$$\sigma \simeq \frac{1}{\sqrt{N}} \simeq \frac{1}{300} \left(\frac{E}{100\ \rm MeV}\right)^{1.5} \left(\frac{t}{\rm yrs}\right)^{-0.5} = \frac{1}{10} \left(\frac{E}{1\ \rm GeV}\right)^{1.5} \left(\frac{t}{\rm yrs}\right)^{-0.5}$$

At 1 GeV we have $\Omega_{\rm res} \simeq 0.3$ sq.deg.

$\longrightarrow$ **We can statistically detect small-scale structure!**

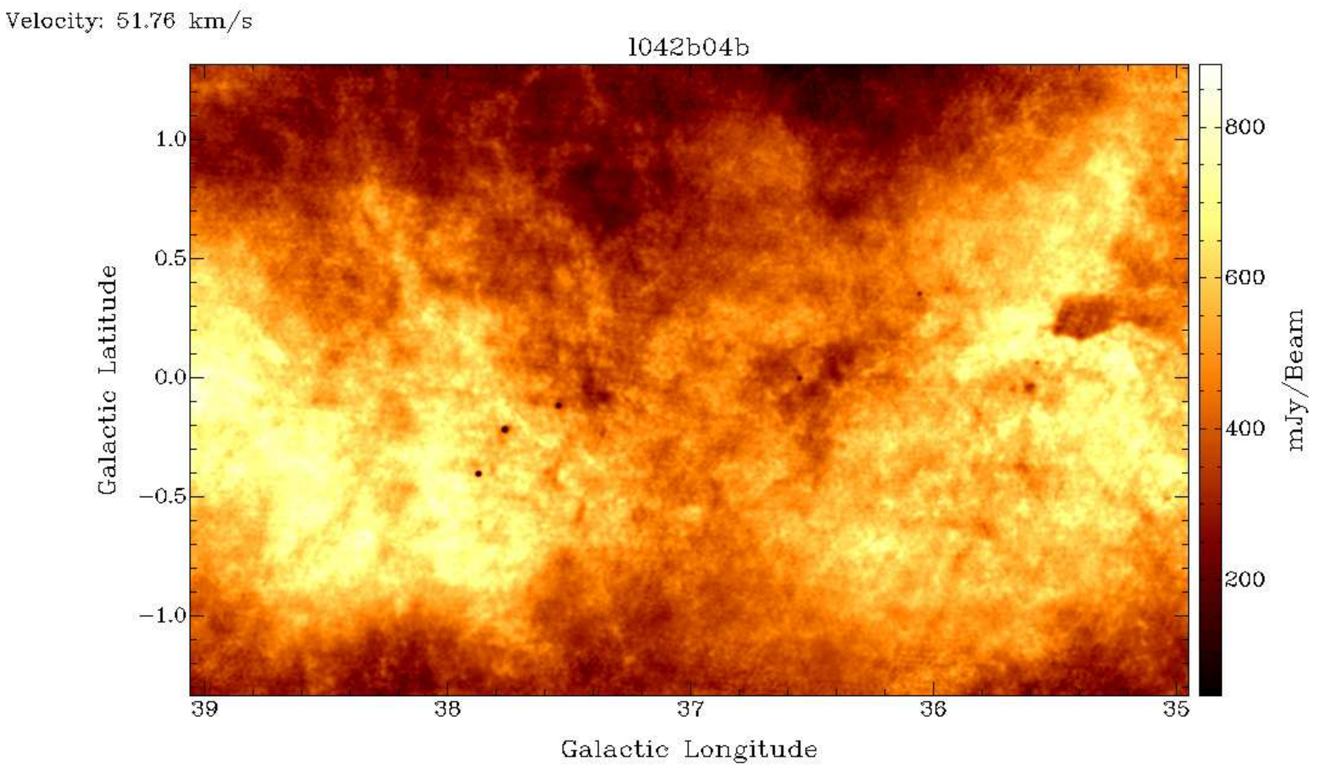
Technically the limit is the single photon resolution divided by the detection significance.

$$\Omega_{\rm limit} \approx \sigma\, \Omega_{\rm res} \simeq (0.1\ \text{sq.deg.}) \left(\frac{E}{1\ \rm GeV}\right)^{-0.5} \left(\frac{t}{\rm yrs}\right)^{-0.5}$$

True situation:

VGPS HI data

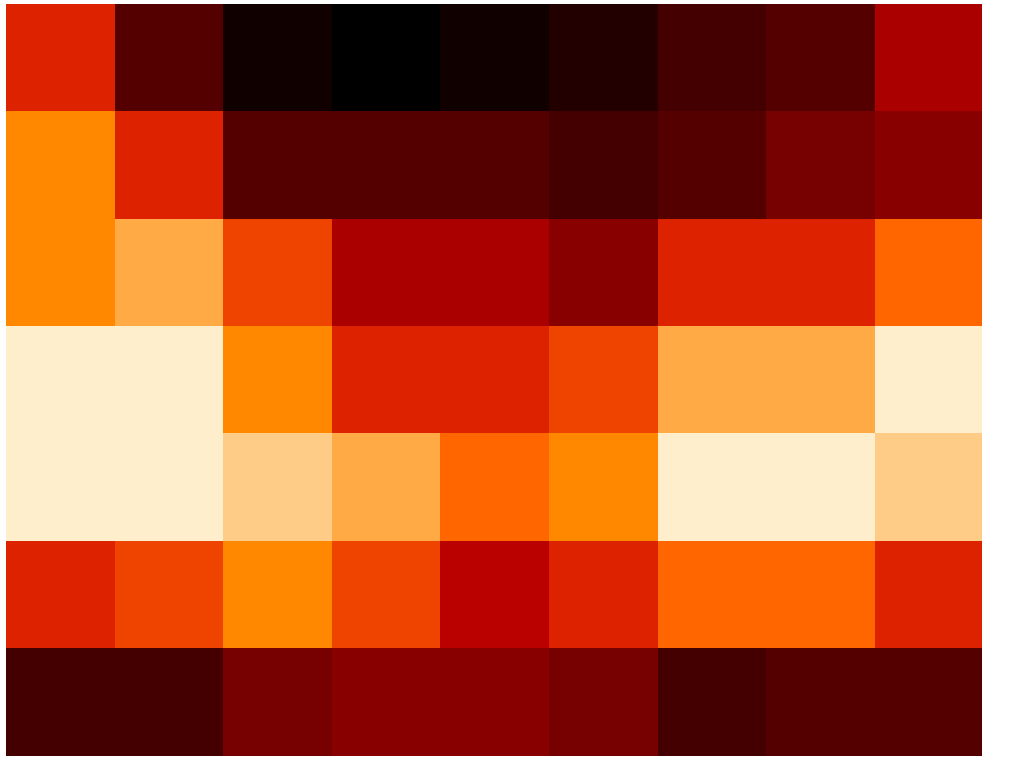
arcmin resolution



What we have:

Dwingeloo HI data

$\sim 0.6^\circ$ **resolution**



The low resolution of HI gas data gives problems:

- **foreground model can't contain substructure at $\theta \lesssim 0.6^\circ$**
- **we cannot correct for HI self-absorption and variable T_s.**

GLAST will resolve fine structure that is not in the foreground model.

How do we account for this in the likelihood analysis?

- **Location-dependent information on resolution?**
- **Angular-scale dependent uncertainty information?**

How do we derive the foreground model anyway?

We could derive the model on the data themselves!

- **Take out anything that looks like a point source.**
- **Use MaxEnt to find the mother distribution of the remainder.**

Benefits:

- **the model fits the data.**
- **have a single map to compare with propagation models.**

Disadvantages:

- **substantial effort required to find and analyze extended sources.**
- **difficult to find weak point sources in the galactic plane.**
- **don't use available information on ISM.**
- **small-scale ISM structure may also look point-like.**

Alternative: **fit a cosmic-ray/ISM model to the data!**

Problem:

40.000 square degrees are 40.000 independent data points at 500 MeV.

$\longrightarrow$ **2.000 square degrees are 2σ off**

$\longrightarrow$ **100 square degrees are 3σ off**

Additional regions where the model just doesn't fit!

What to do if you analyze a trouble region?

Angular structure may still be approximately right on certain scales ...

Angular-scale dependent uncertainty information?

How to incorporate uncertainty in foreground?

- **Have a few multipliers for the foreground model (total intensity, spectral skew)**
- **The multipliers operate on predefined angular scales**
- **The foreground model gives the expectation values (=1)**
- **The model also gives the allowed range of the multipliers**
- **The analysis tool includes these in the likelihood function**

$$\text{multiplier} \quad G_i(\theta, \phi) \quad \longrightarrow \quad \text{likelihood function} \quad \mathcal{L}' = \mathcal{L}\ \exp\left(-\frac{(G_i - 1)^2}{(\delta G_i)^2}\right)$$