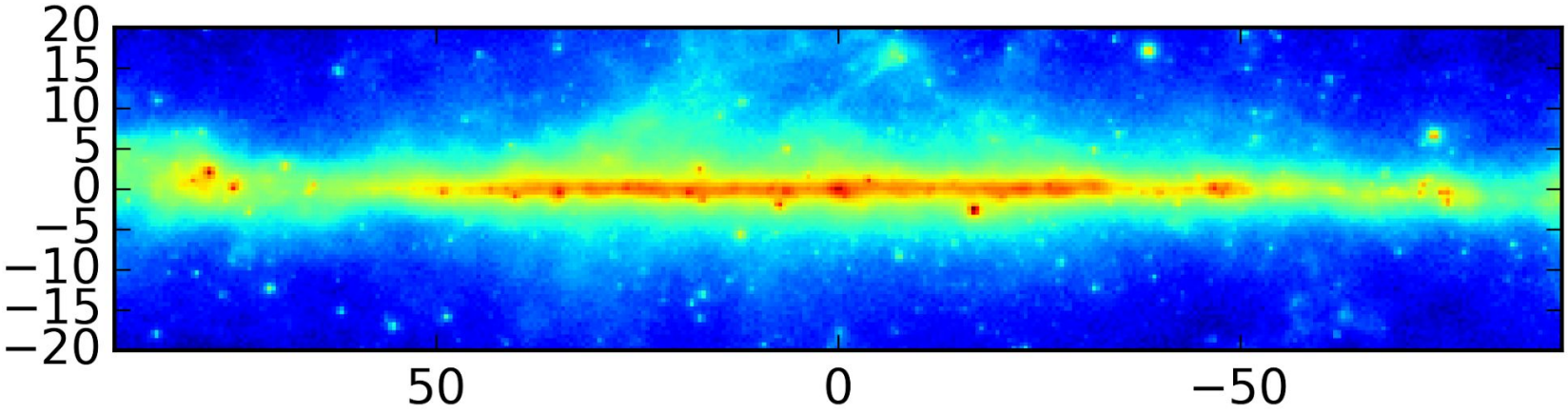
Understanding Uncertainties in the Galactic Diffuse Gamma-ray Emission

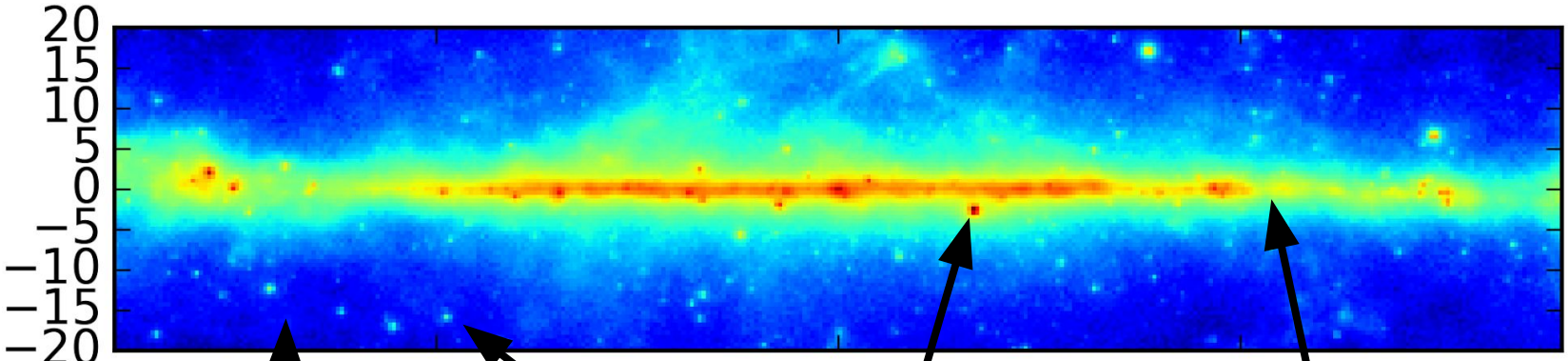
Emma Storm
with Francesca Calore, Christoph Weniger

APS
August 30th, 2016

The Gamma-ray Sky



The Gamma-ray Sky



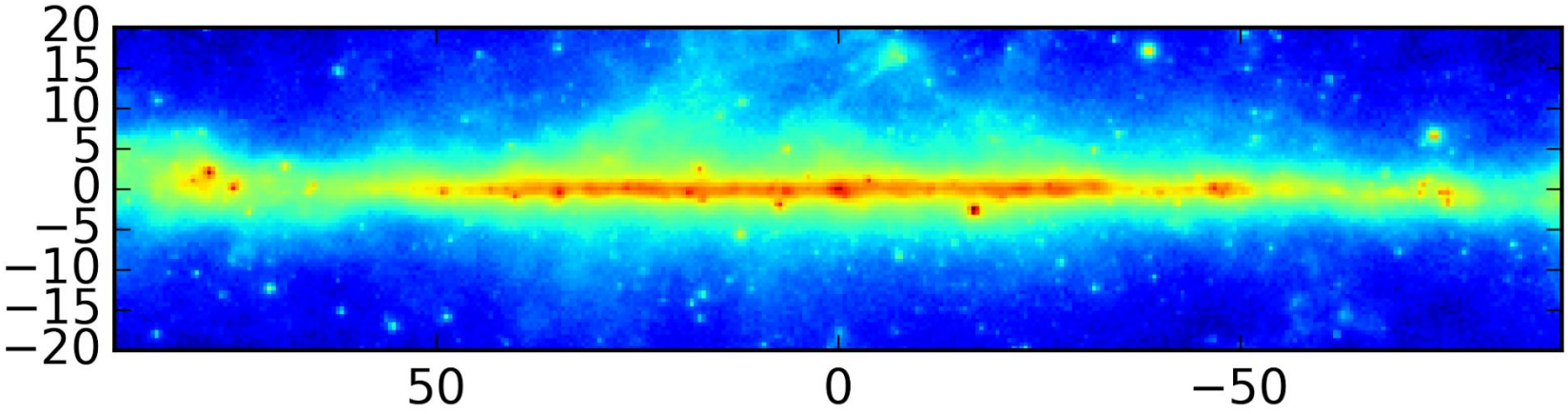
extragalactic

point sources

galactic

+ others…

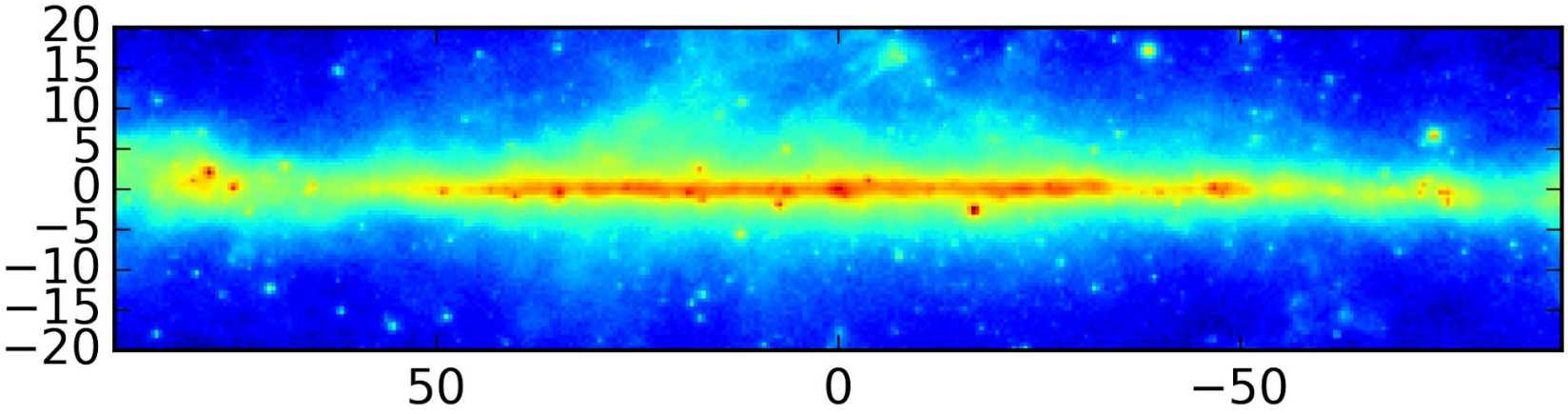
Template Fitting: The Standard Approach



=

sum of modeled components

Template Fitting: The Standard Approach



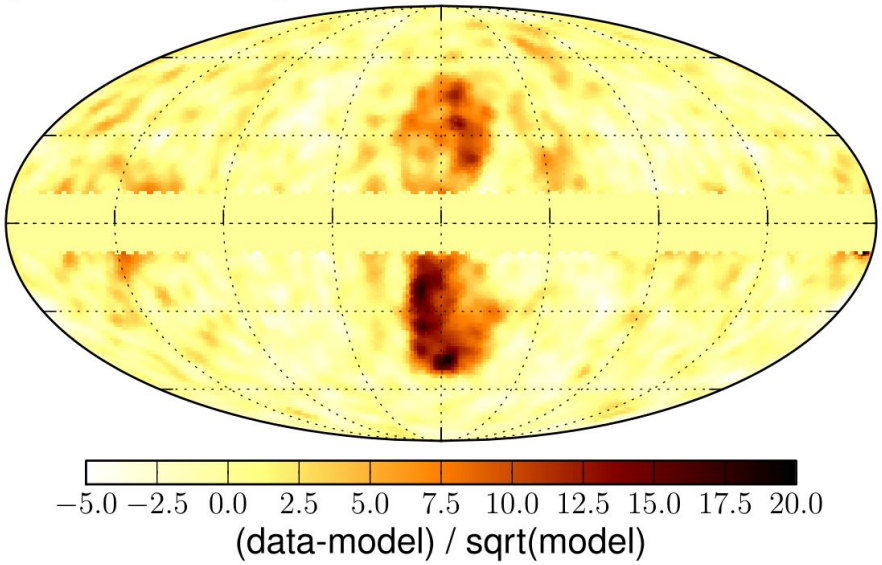
=

sum of modeled components

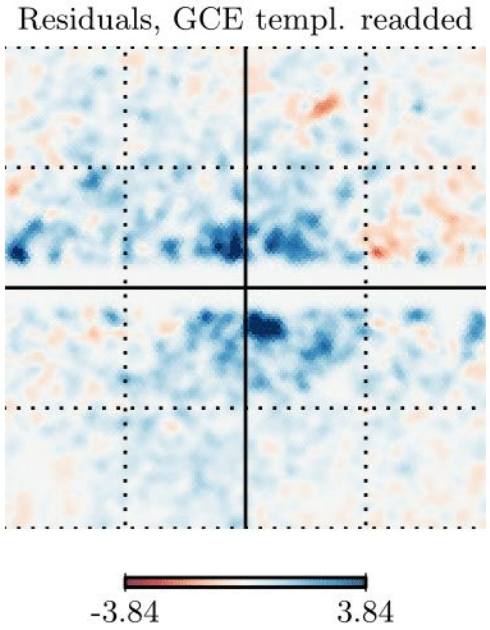
→ examine residuals

Template Fitting: The Standard Approach

Fermi Bubbles
LAT Collaboration, 2014



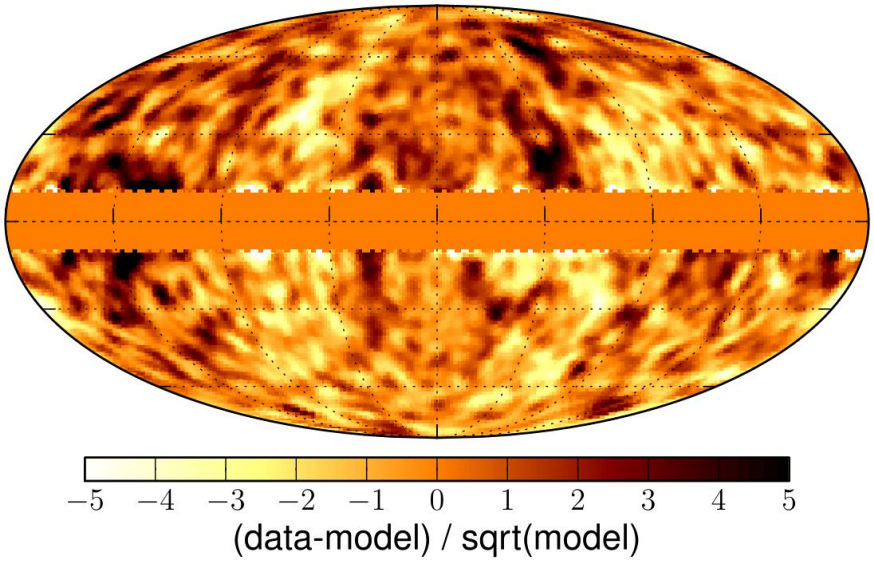
GeV Excess
Calore+2015



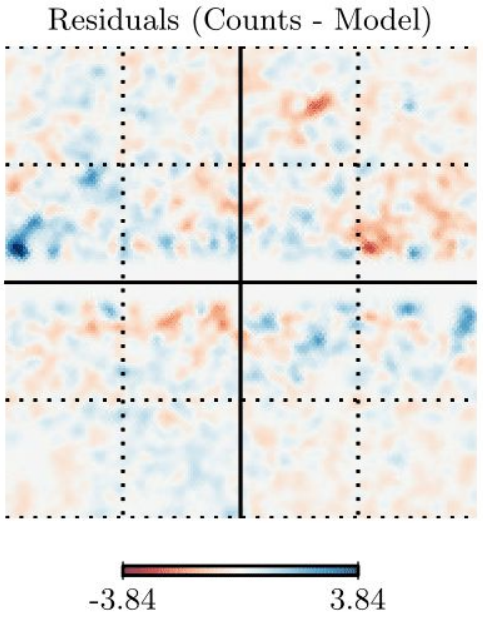
Fruitful approach, so far

Template Fitting: The Standard Approach

LAT Collaboration, 2014



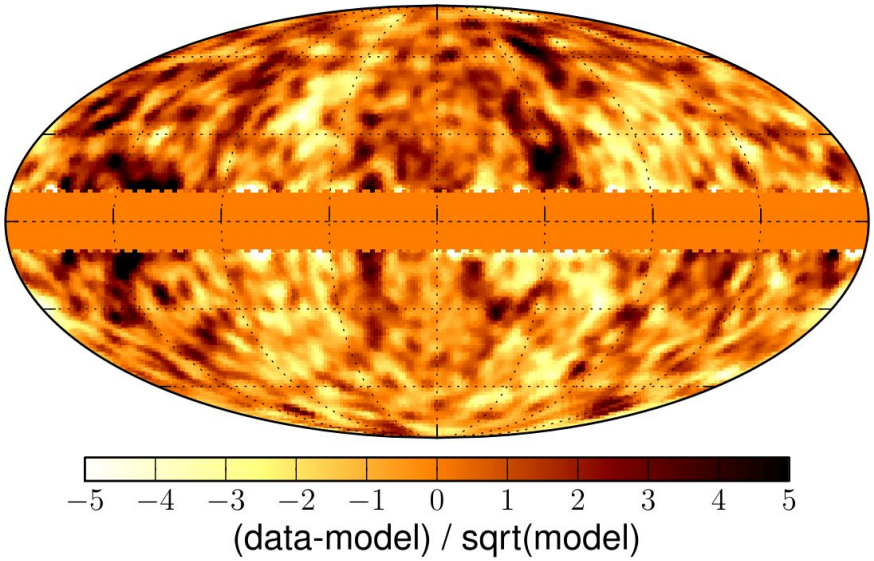
Calore+2015



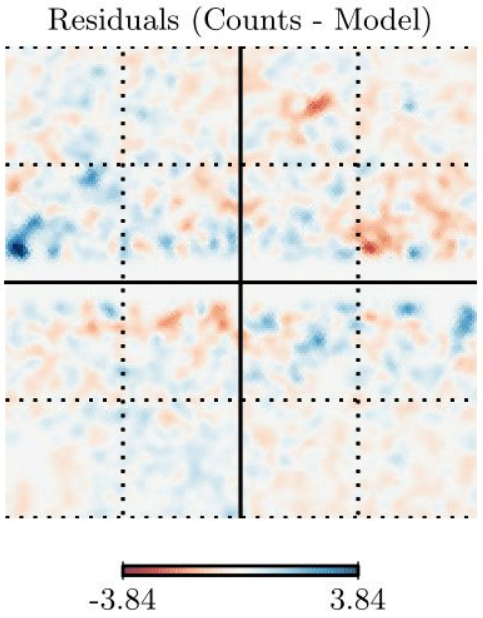
Always present: other residuals

Template Fitting: The Standard Approach

LAT Collaboration, 2014

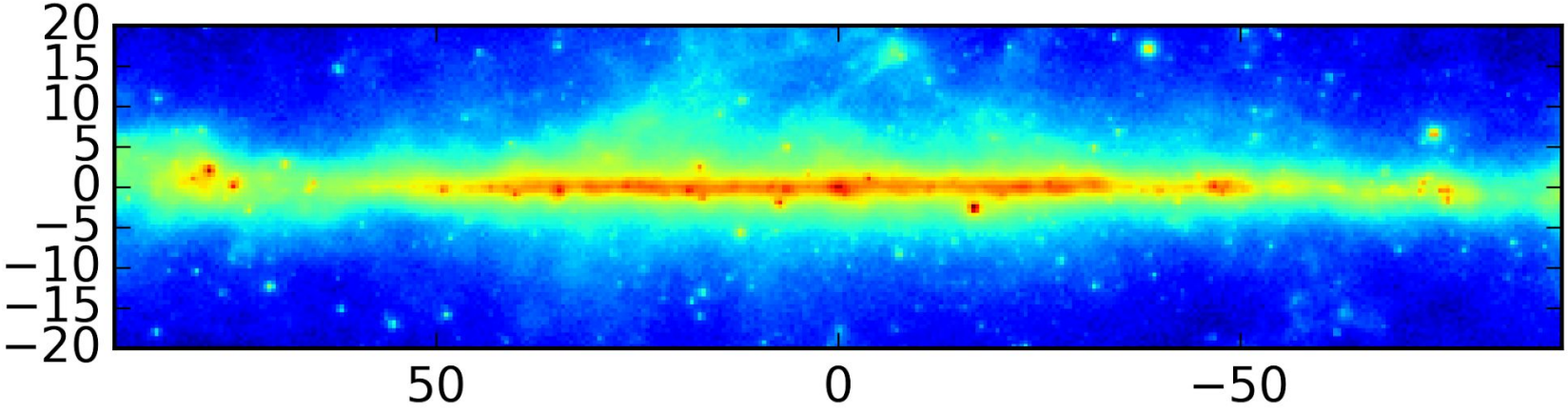


Calore+2015



Residuals: missing components? Mis-modeling?
Consistent with uncertainties in data/model?

Template Fitting: The Standard Approach



What can we do?

- Develop better data analysis techniques
- Develop better theoretical predictions
- Parameterize uncertainties in models

Template Fitting: A Primer

$$\text{Model} = \sum_{k} \text{Spectrum} \times \text{Morphology}$$

The Traditional Approach

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Spectra free to vary in energy bin by bin

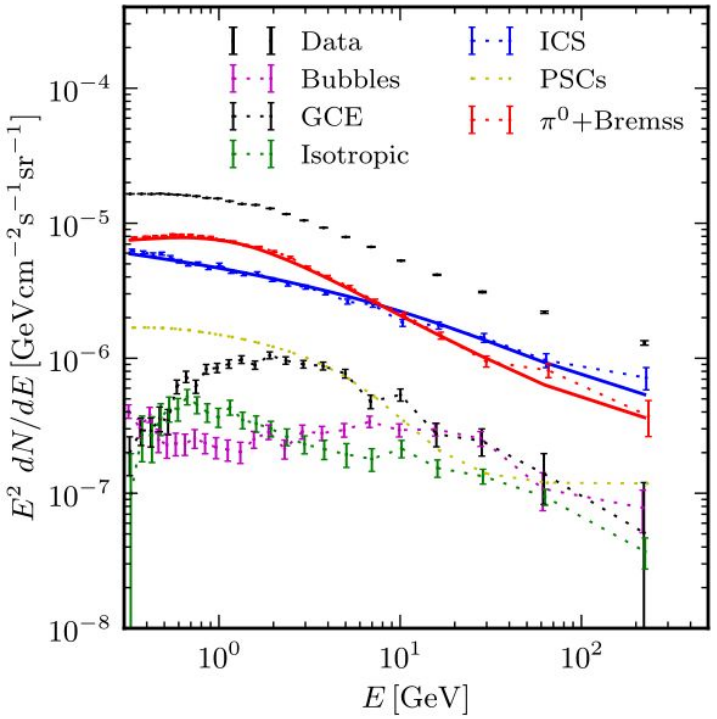
Templates fixed to (data-driven) model predictions

The Traditional Approach

$$\text{Model} = \sum_k \text{Spectrum} \times \text{Morphology}$$

$$\mu_{ij} = \sum_k \mathsf{T}_i^{(k)} \theta_j^{(k)}$$

i: spatial pixel
j: energy bin
k: model component

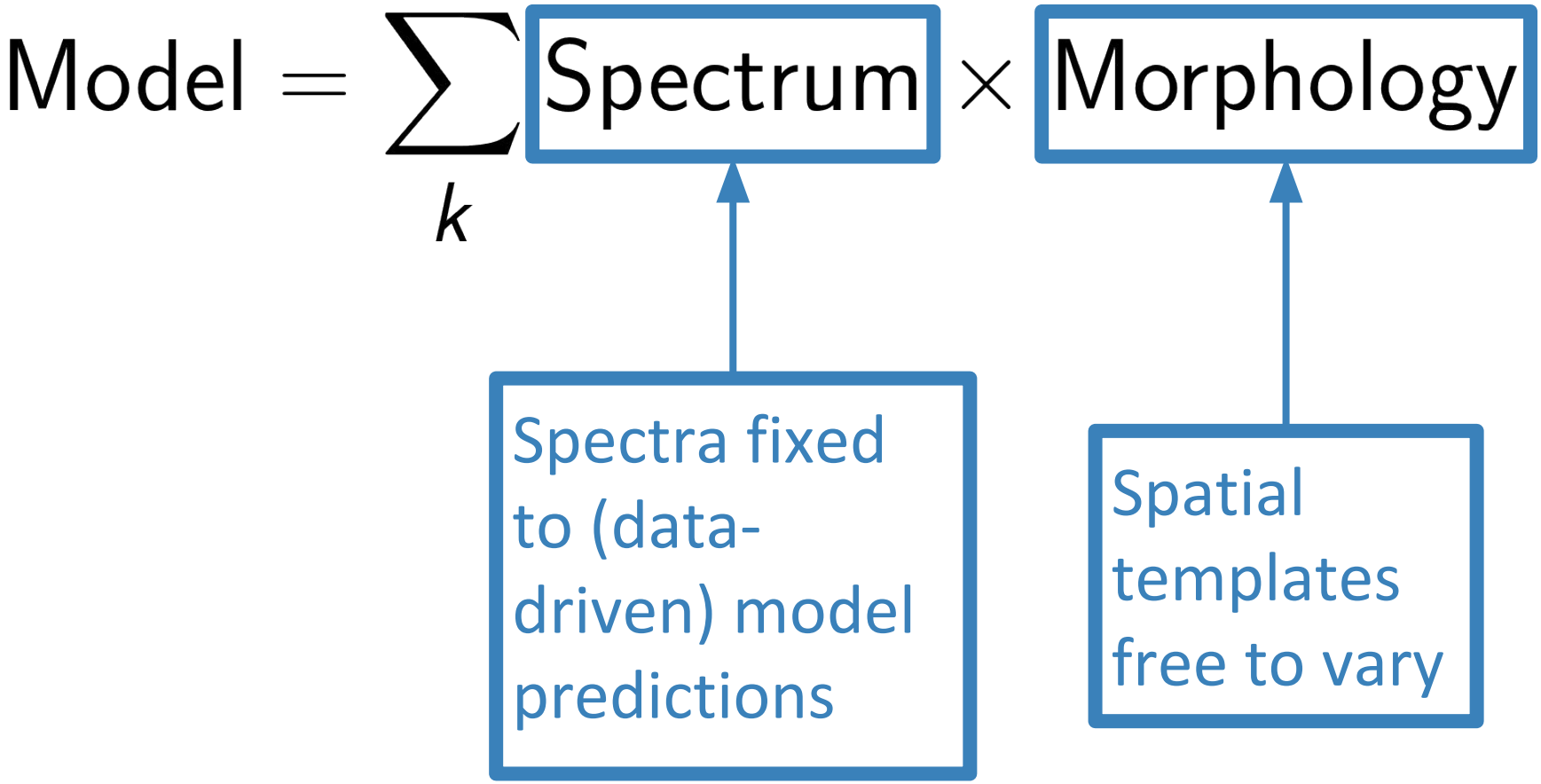


Calore+2015

Spectral Decomposition

$$\text{Model} = \sum_{k} \text{Spectrum} \times \text{Morphology}$$

Spectral Decomposition



Spectral Decomposition

$$\text{Model} = \sum_k \text{Spectrum} \times \text{Morphology}$$

$$\mu_{ij} = \sum_k S_j^{(k)} \theta_i^{(k)}$$

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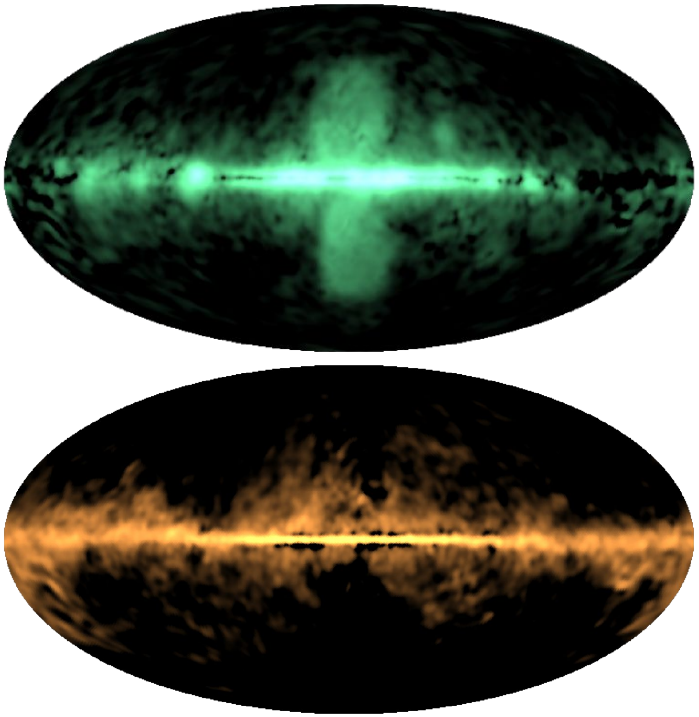

Selig+2015, Huang+2016

A New Approach

$$\text{Model} = \sum_{k} \text{Spectrum} \times \text{Morphology}$$

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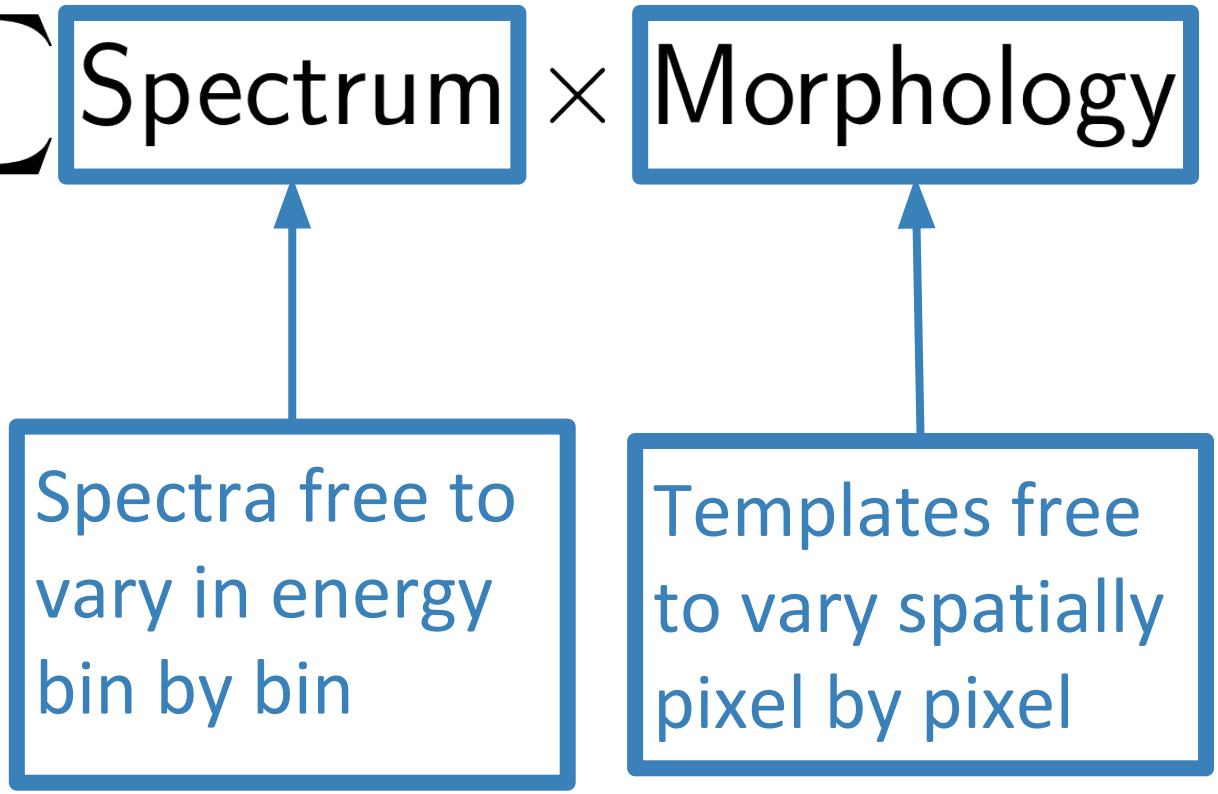
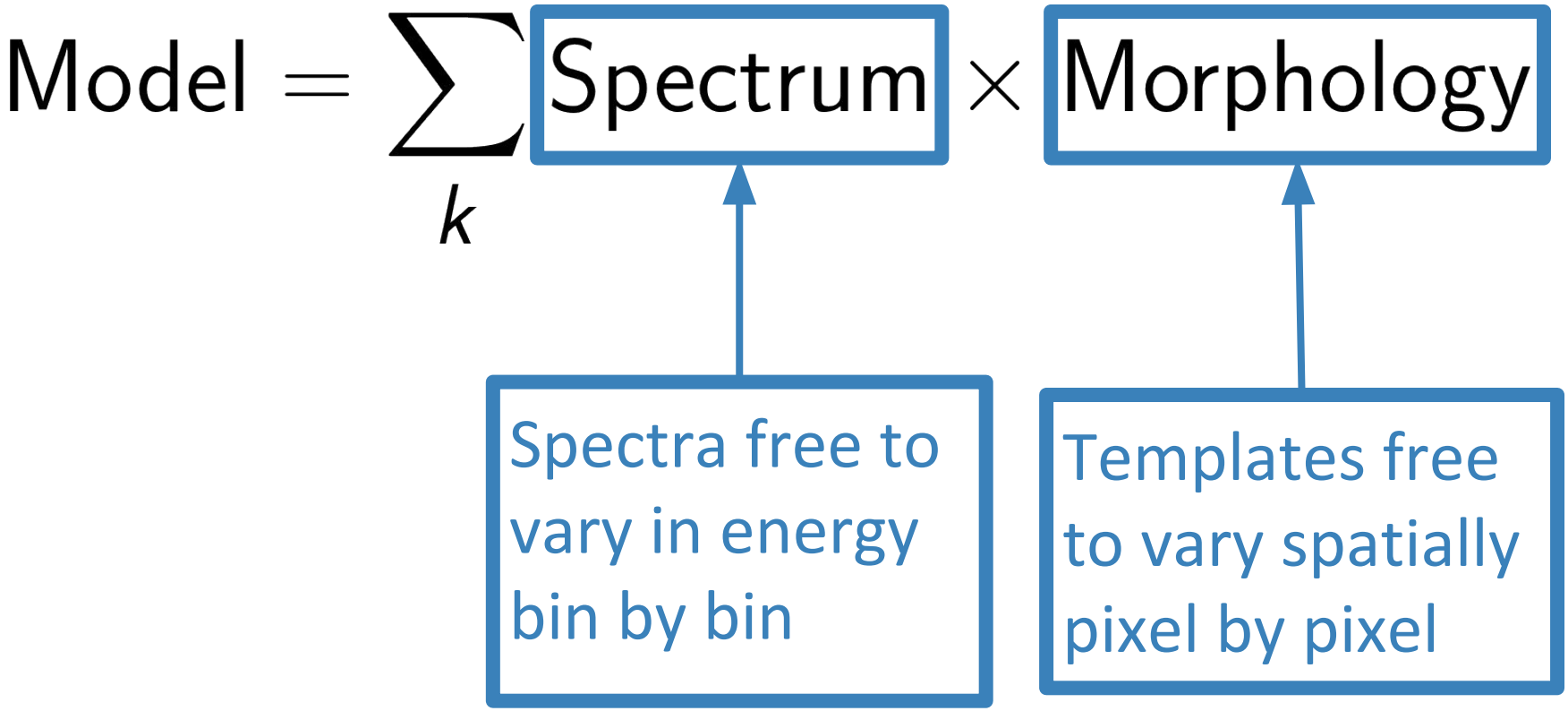


A New Approach



SkyFACT

SkyFACT

Sky Factorization with Adaptive Constrained Templates

SkyFACT

Sky Factorization with Adaptive Constrained Templates

$$\mu_{ij} = \sum_k \mathsf{T}_i^{(k)} \mathsf{S}_j^{(k)} \theta_i^{(k)} \theta_j^{(k)} \theta^{(k)}$$

SkyFACT

Sky Factorization with Adaptive Constrained Templates

$$\mu_{ij} = \sum_k \underbrace{\mathrm{T}_i^{(k)} \mathrm{S}_j^{(k)}}_{\text{Spatial + spectral templates}} \underbrace{\theta_i^{(k)} \theta_j^{(k)} \theta^{(k)}}_{\text{Scaling parameters:}}$$

- Spatial
- Spectral
- overall

SkyFACT

Sky Factorization with Adaptive Constrained Templates

$$\mu_{ij} = \sum_k \underbrace{\mathrm{T}_i^{(k)} \mathrm{S}_j^{(k)}}_{\text{Spatial + spectral templates}} \underbrace{\theta_i^{(k)} \theta_j^{(k)} \theta^{(k)}}_{\text{Will be around 1 for reasonable templates!}}$$

SkyFACT

Sky Factorization with Adaptive Constrained Templates

Traditional Approach:

- 10s of free parameters
- Slow fitting (e.g. Minuit)
- Rigid spatial templates not accurate enough for data
- Large residuals that are difficult to interpret

SkyFACT:

- ~100,000 free parameters
- Super fast fitting algorithm
- Realistic model uncertainties built in
- Flexible physically motivated templates

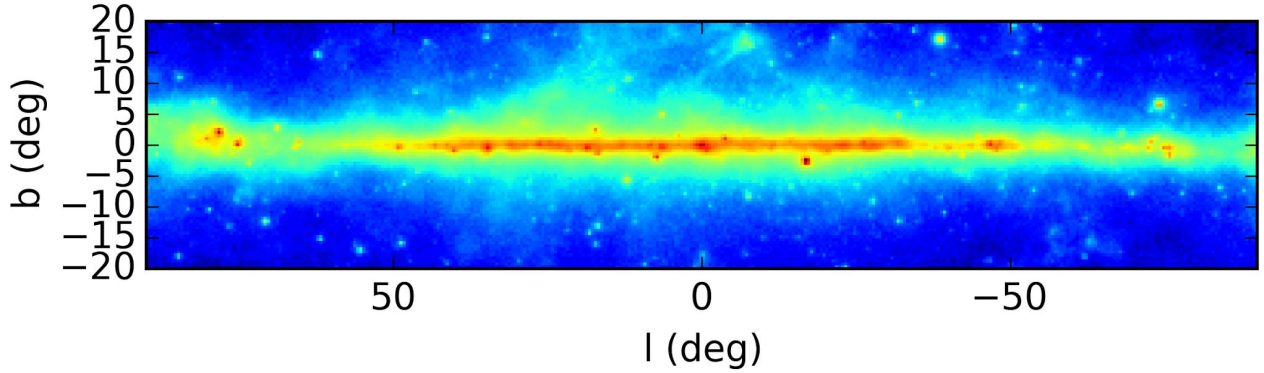
SkyFACT

Sky Factorization with Adaptive Constrained Templates

Preliminary Science

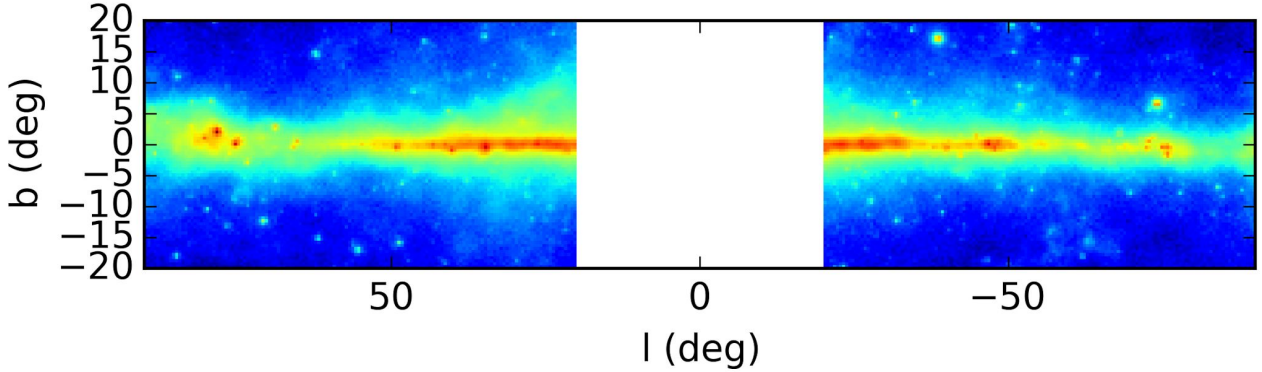
SkyFACT vs the Traditional Approach

Data:



SkyFACT vs the Traditional Approach

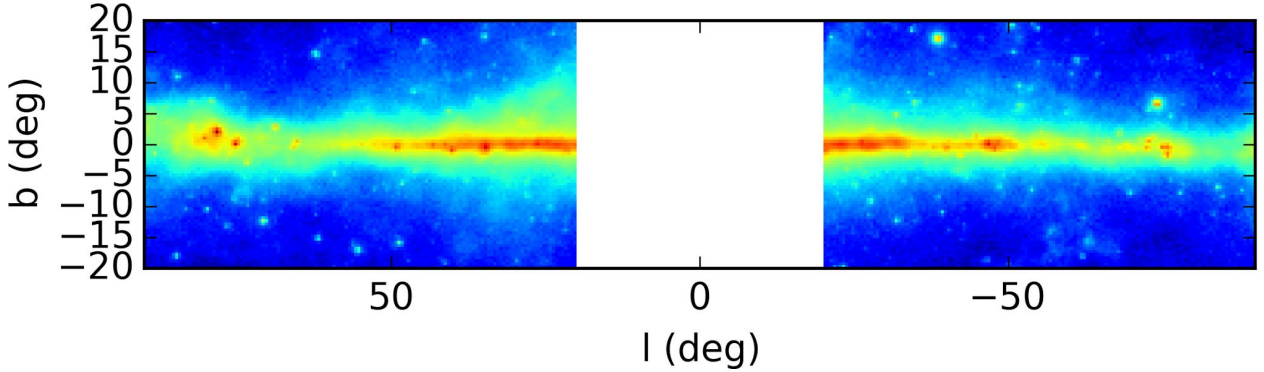
Data:



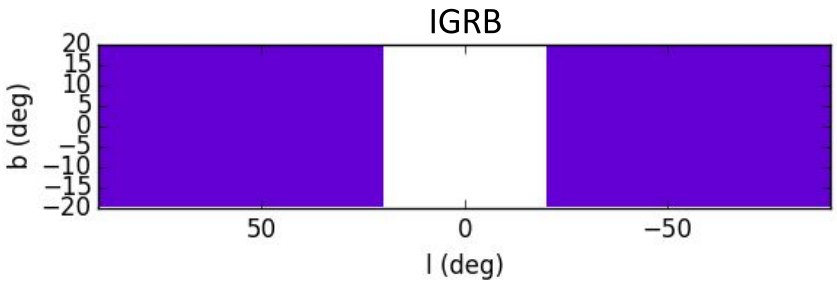
Mask inner galaxy (for now)

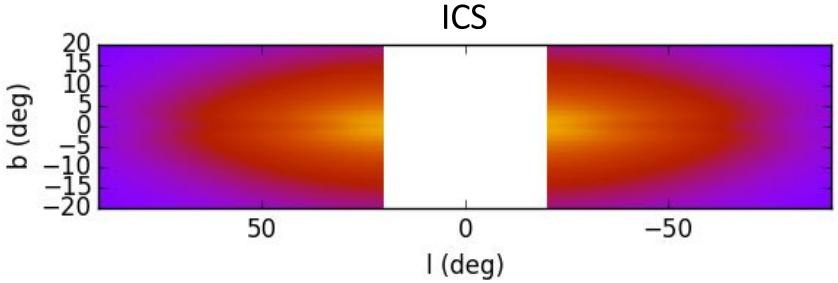
SkyFACT vs the Traditional Approach

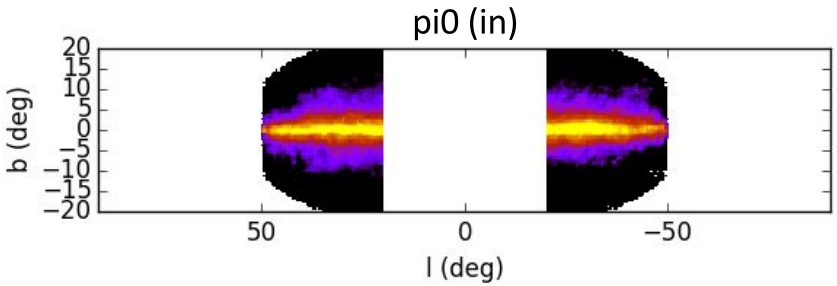
Data:

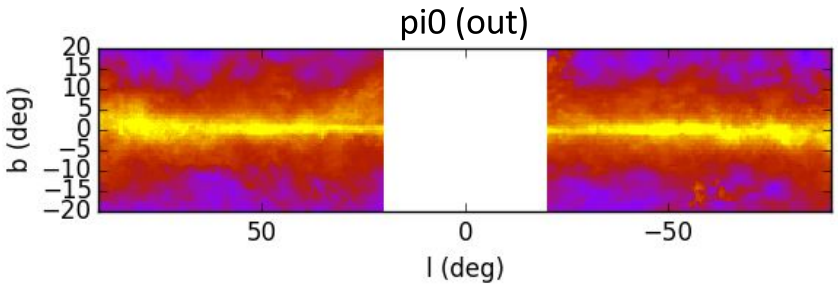


Model:





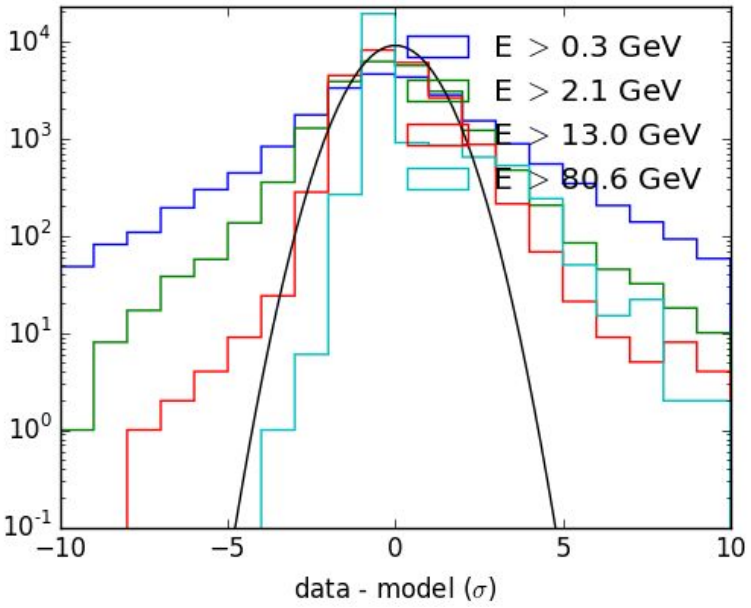


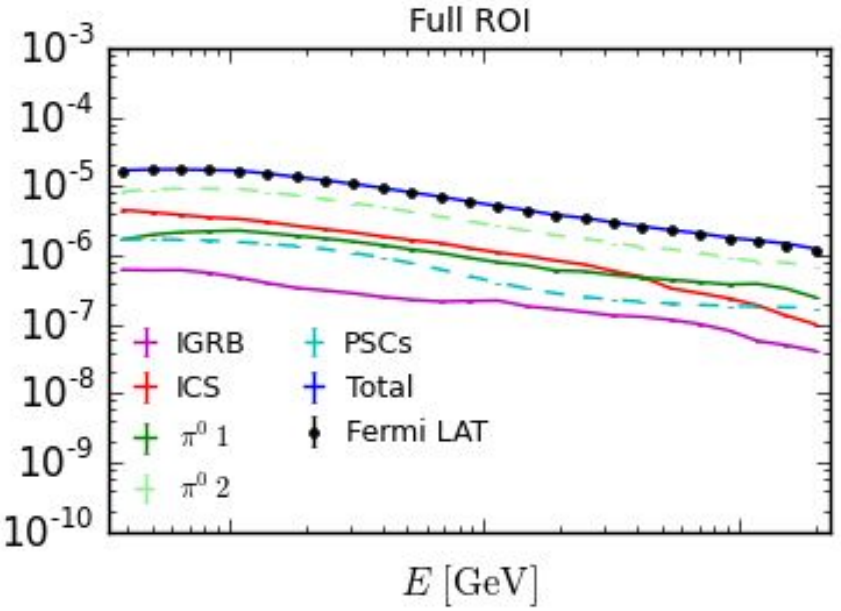


\+ 3FGL point sources

SkyFACT vs the Traditional Approach

Fixed templates, free spectra

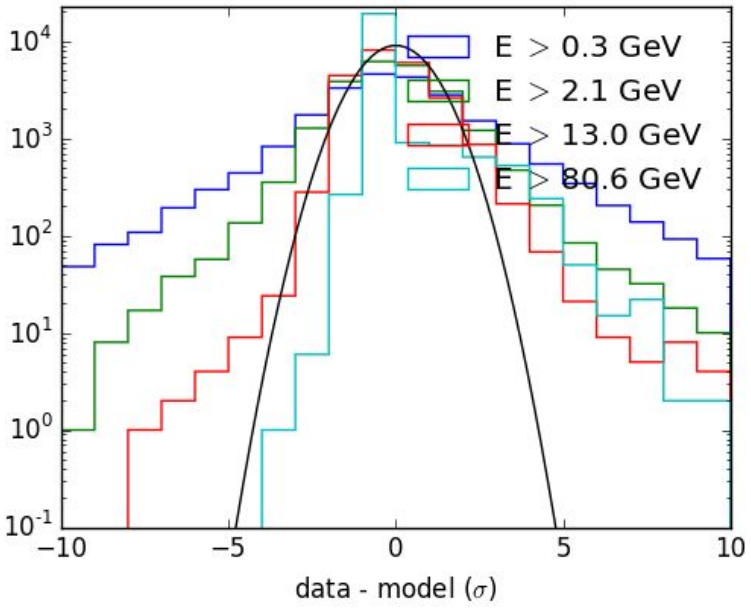


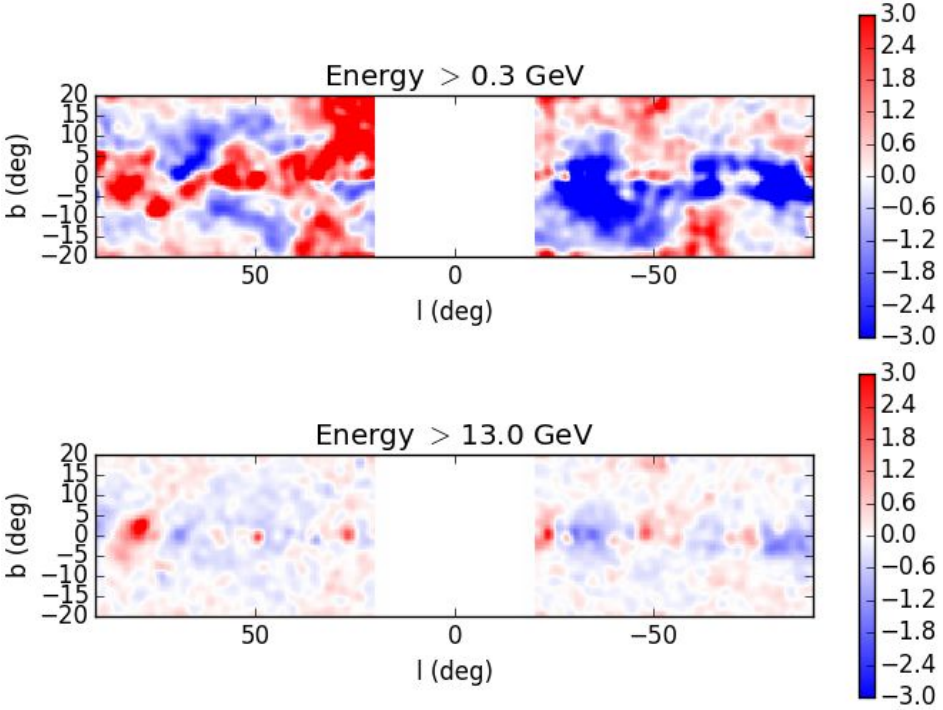


The traditional approach

SkyFACT vs the Traditional Approach

Fixed templates, free spectra

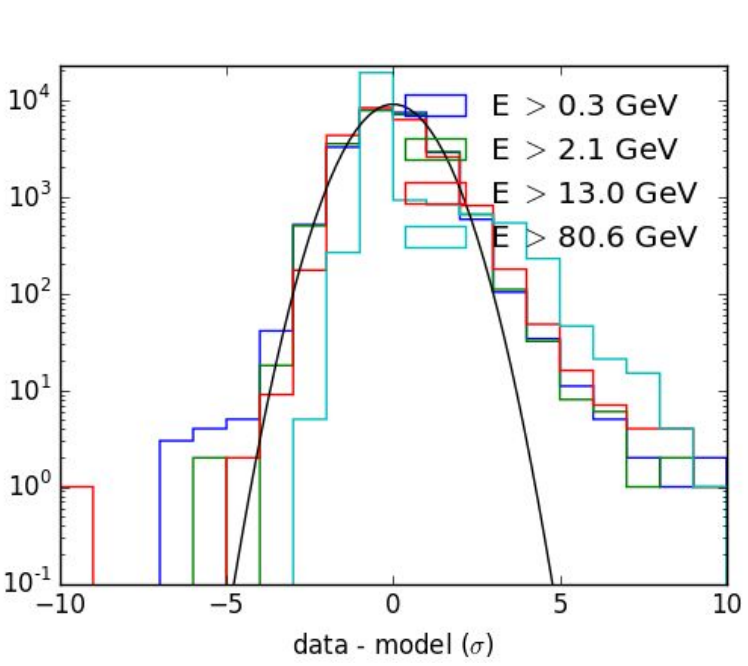


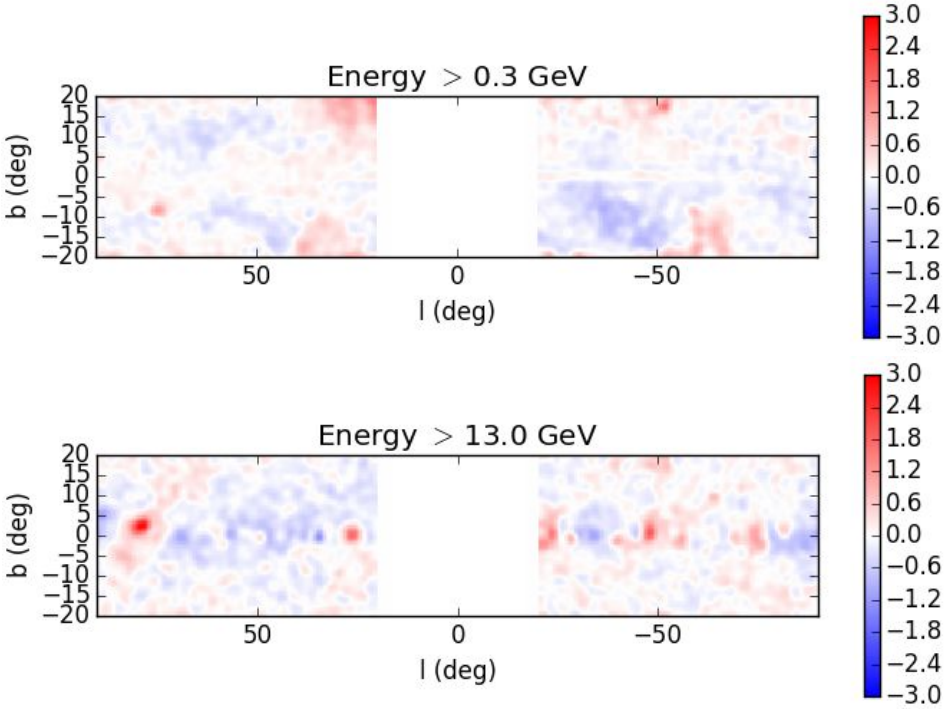


The traditional approach

SkyFACT vs the Traditional Approach

Free templates, free spectra

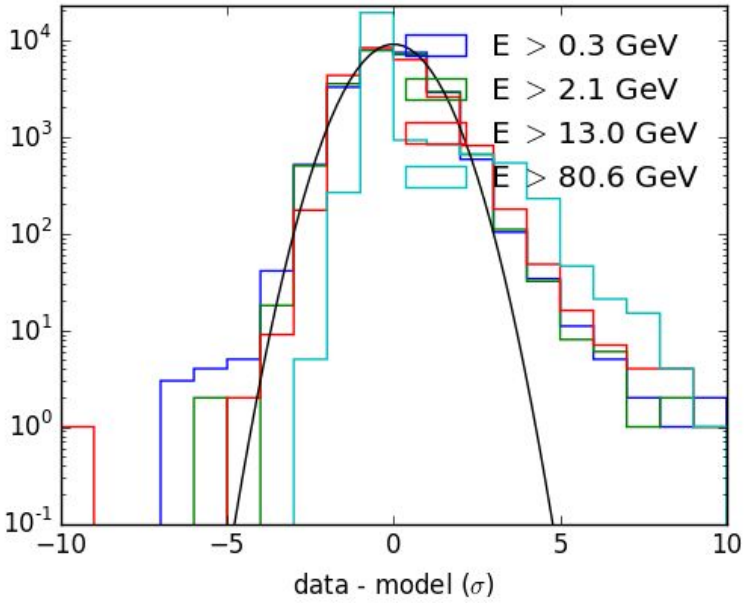


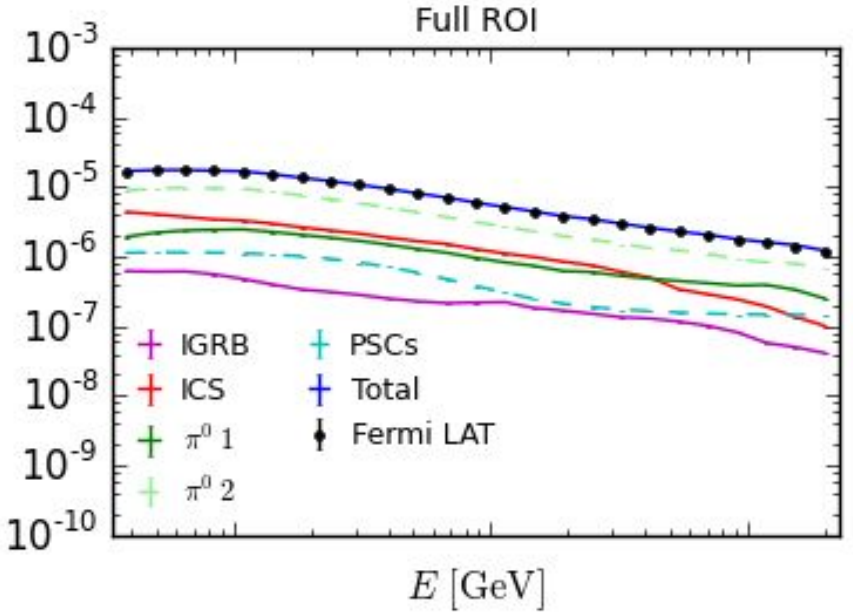


With adaptive template fitting

SkyFACT

Free templates, free spectra

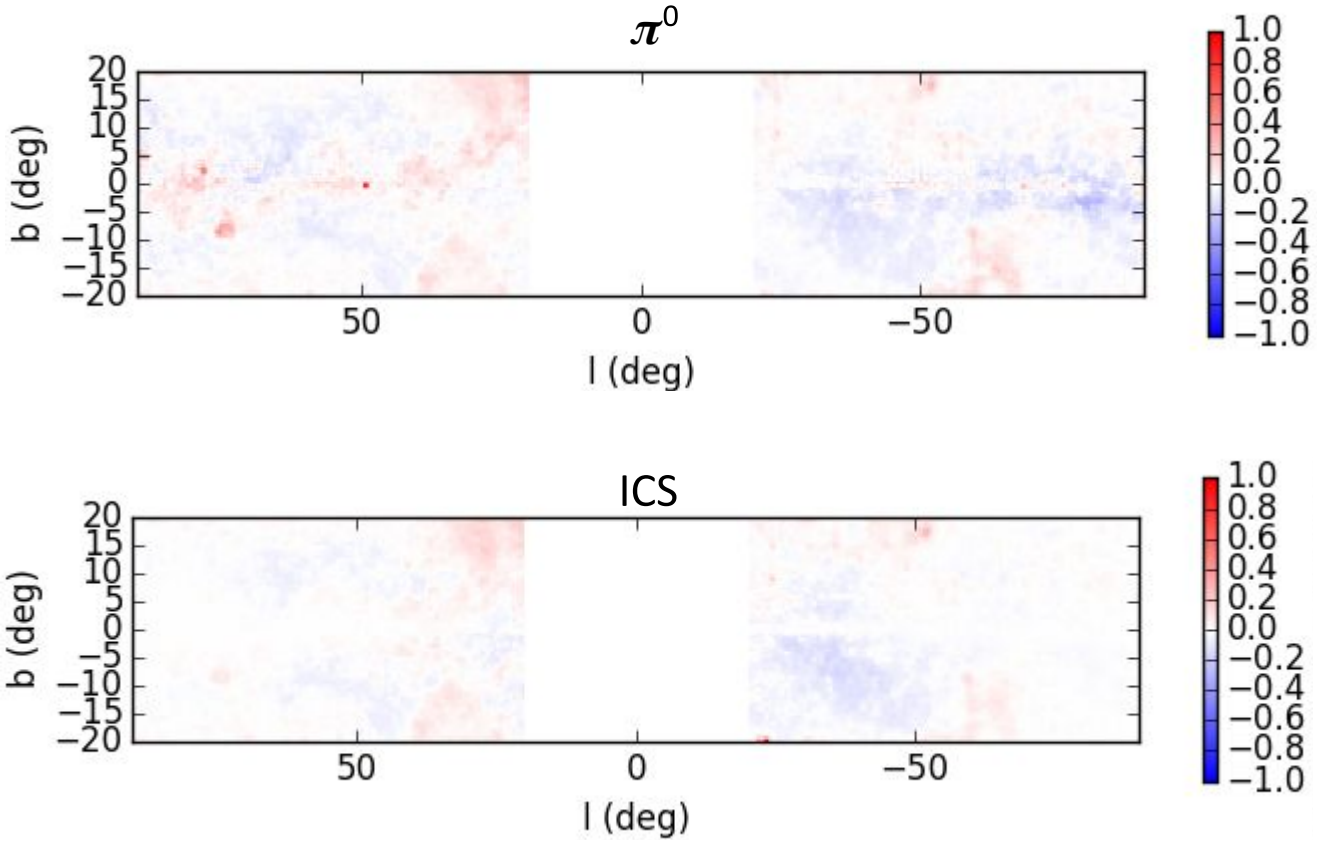




With adaptive template fitting

SkyFACT

Template rescaling factors



SkyFACT

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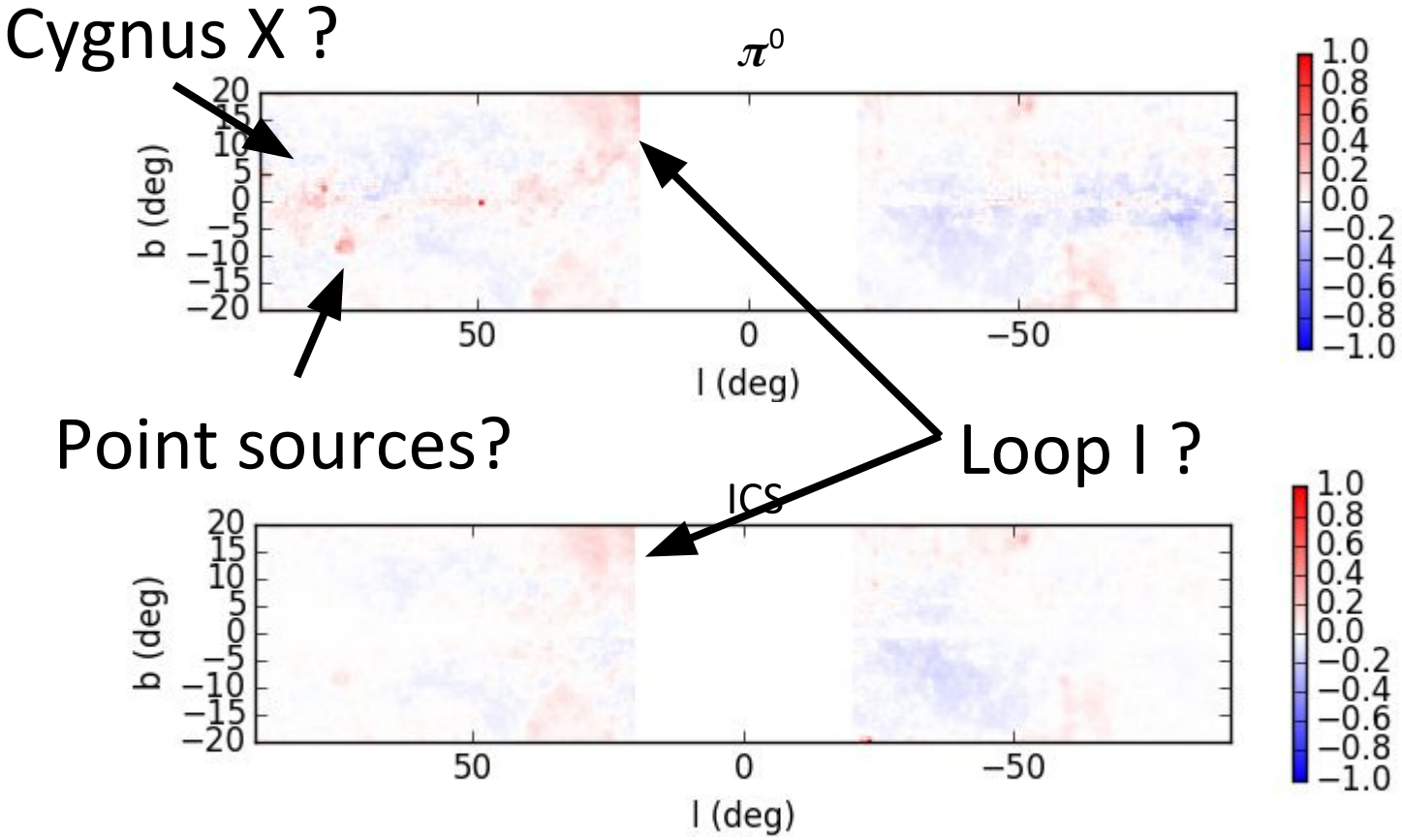
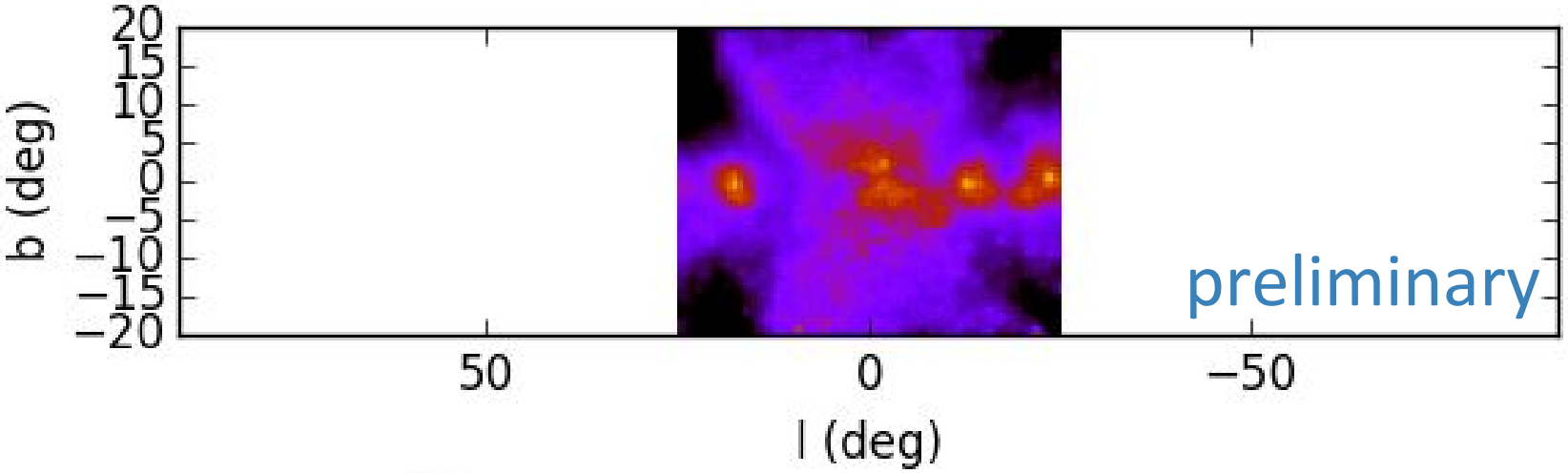
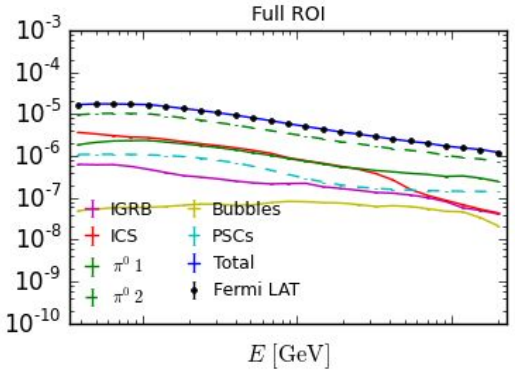
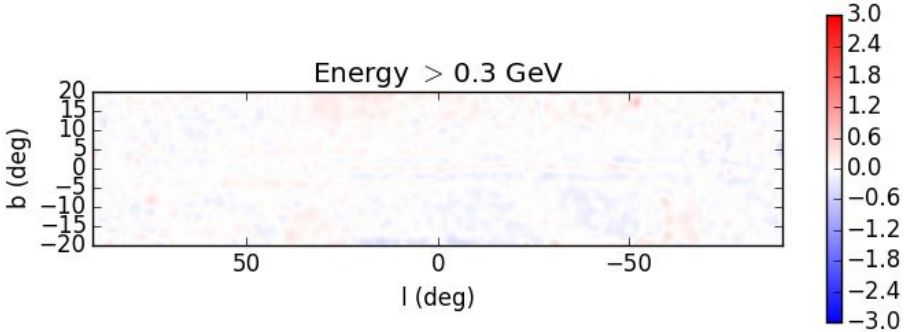


SkyFACT

Inner Galaxy Unmasked
Add bubble spectrum







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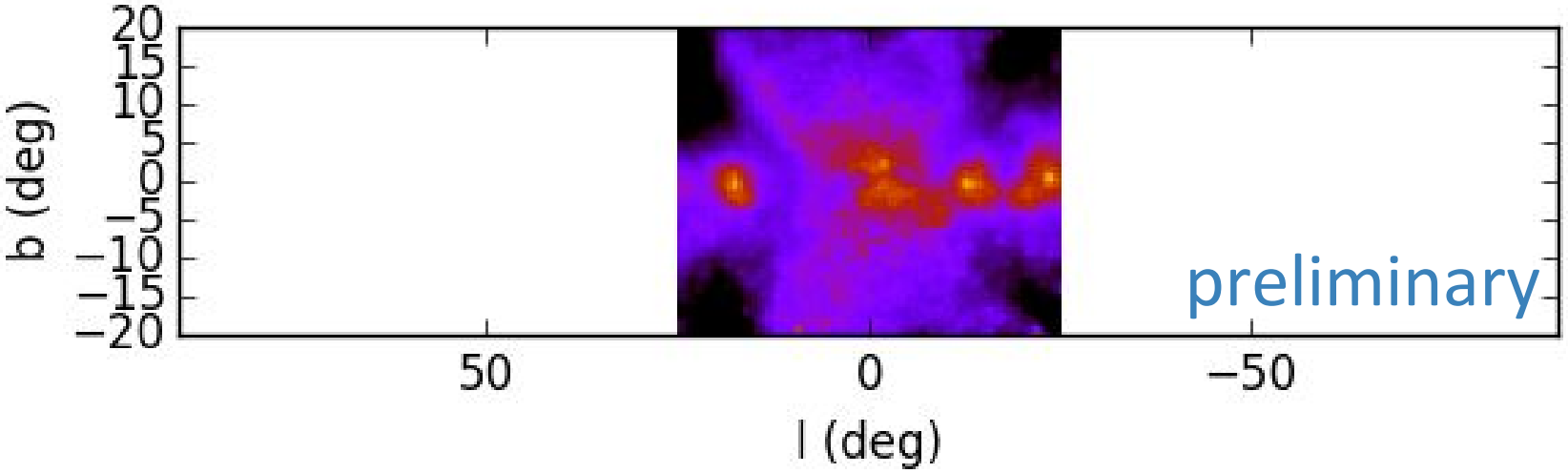

Bubble morphology recovered!

SkyFACT

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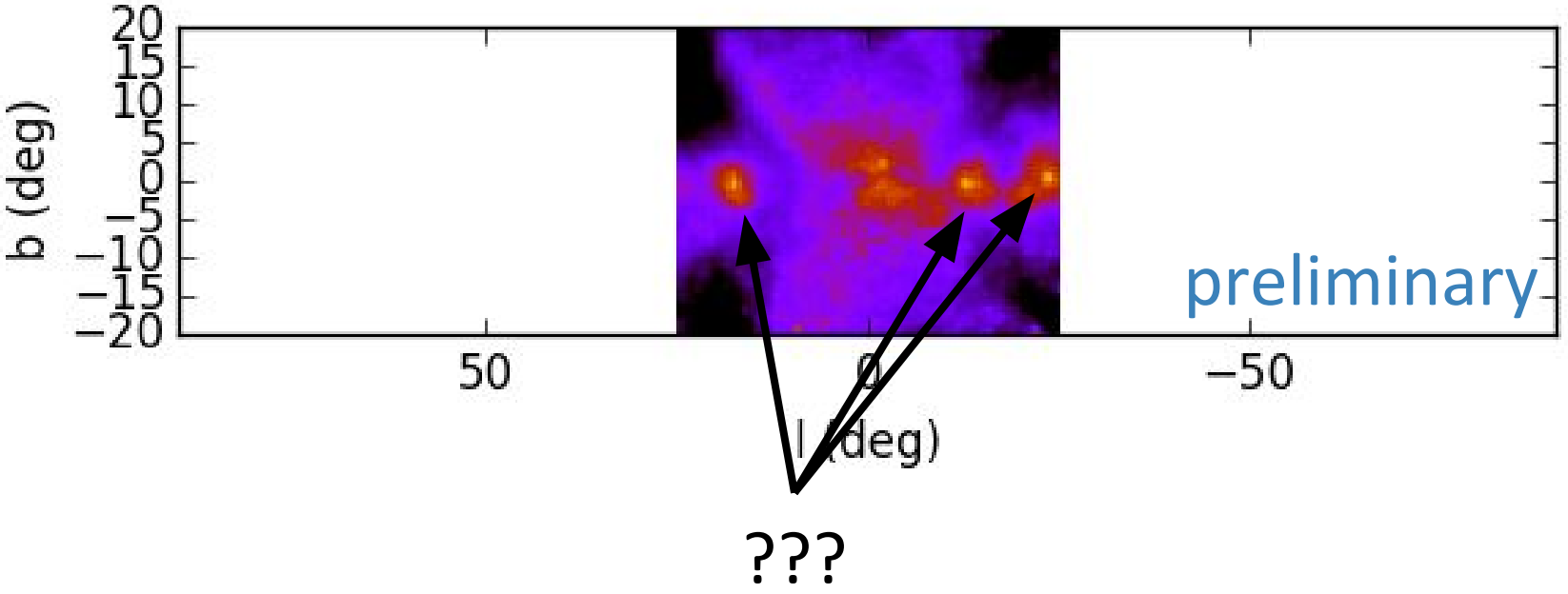
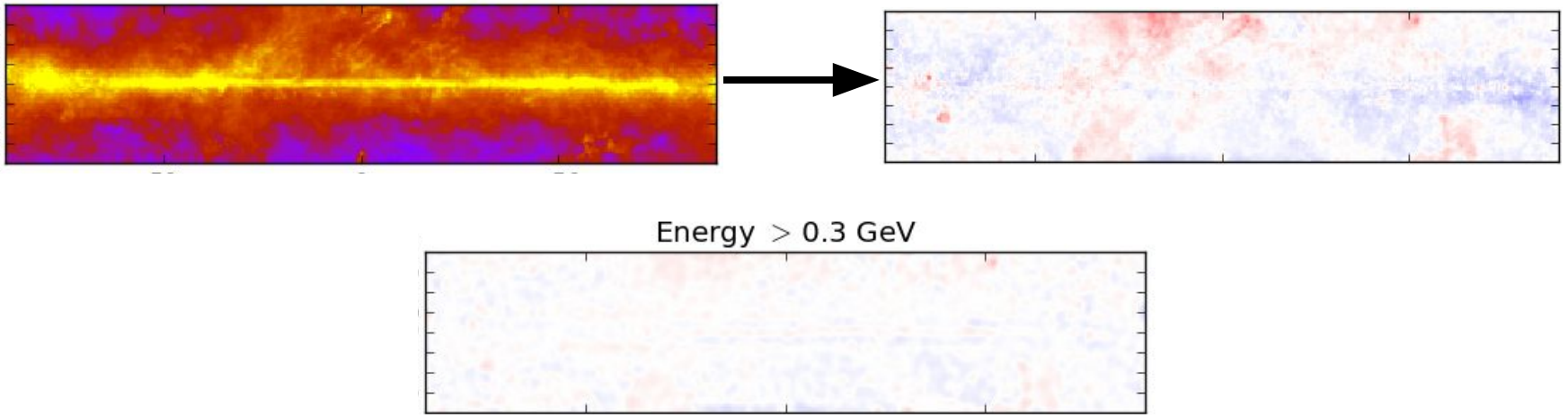
Add bubble spectrum



Summary and future plans

SkyFACT: towards zero residuals



Future plans:

- Robustly determine the best fit to the galactic center, within uncertainties
- Understand degeneracies between model/data components