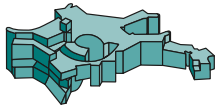
Disentangling the Fermi LAT sky

Multicomponent gamma-ray imaging in the spatio-spectral domain



HELMHOLTZ MUNICH

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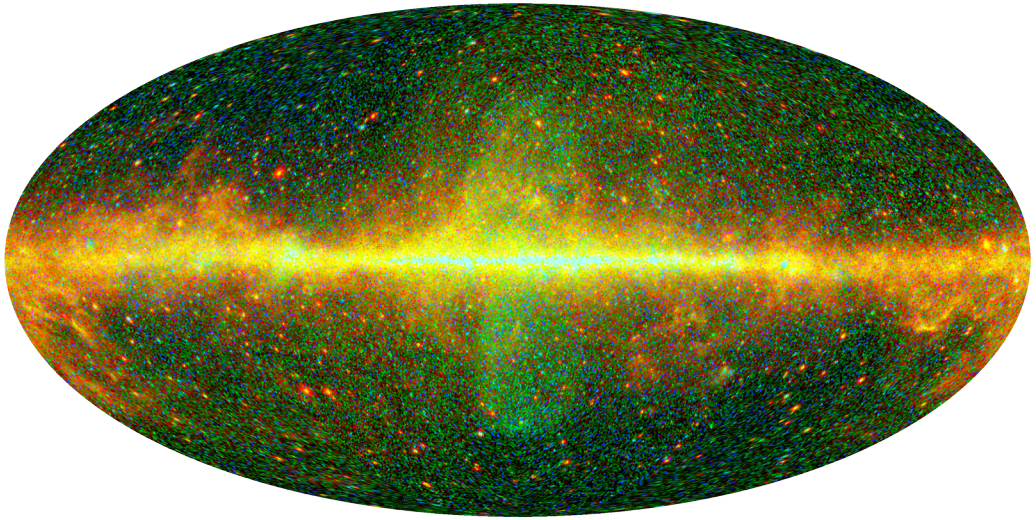

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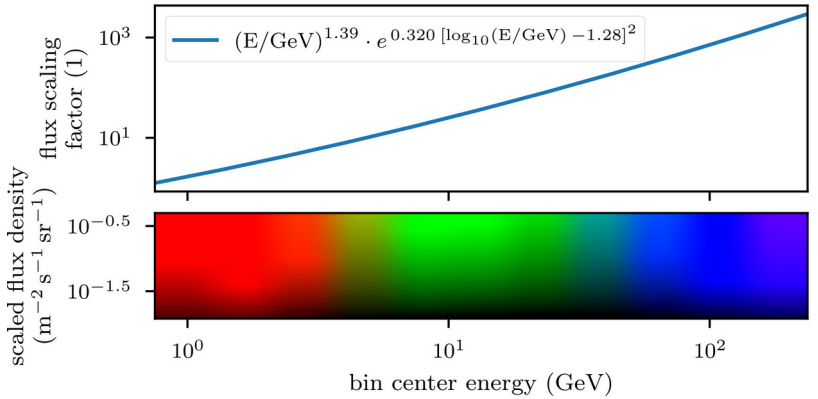

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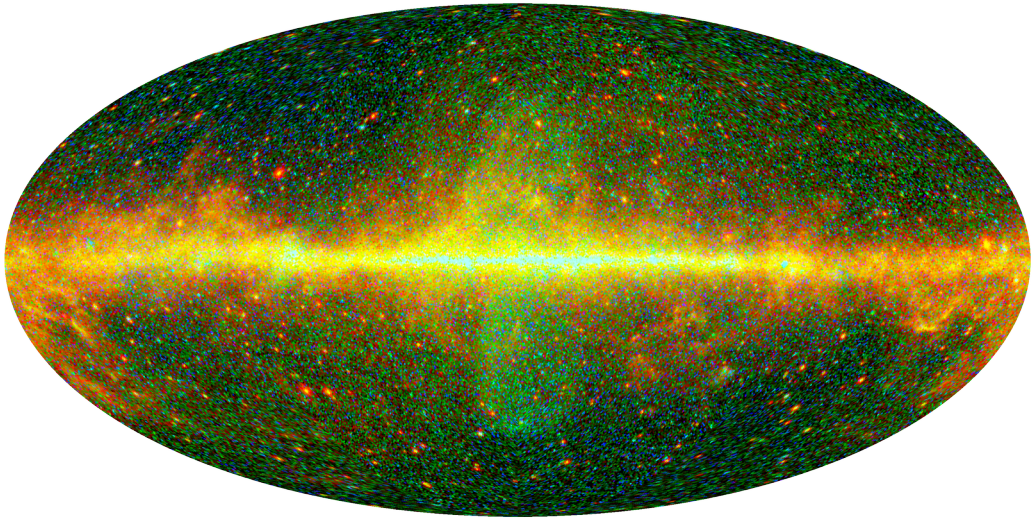

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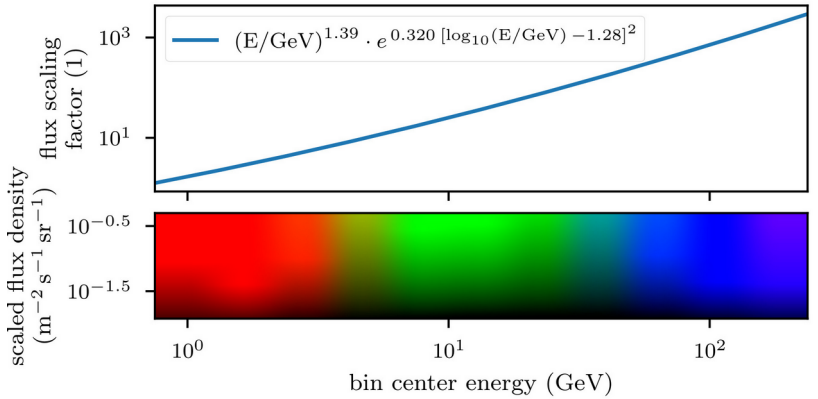

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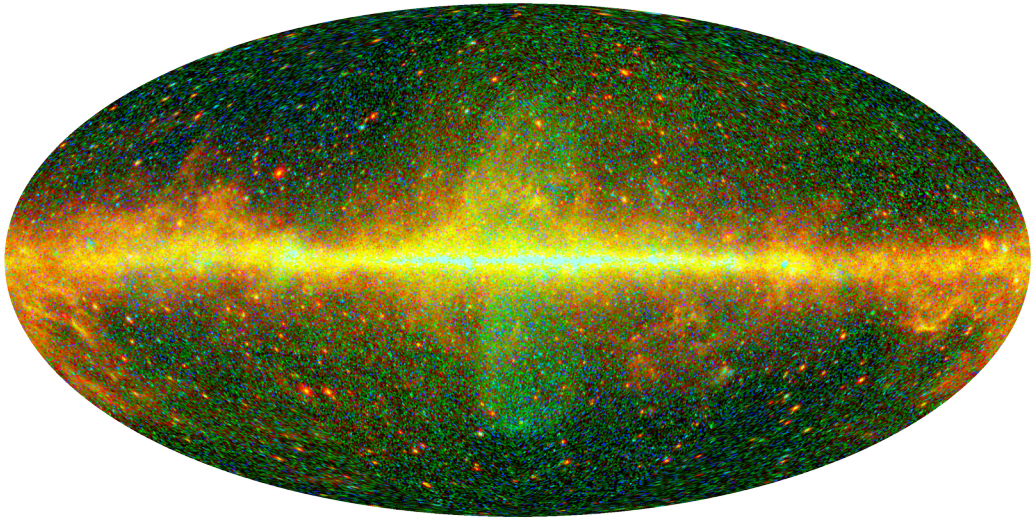

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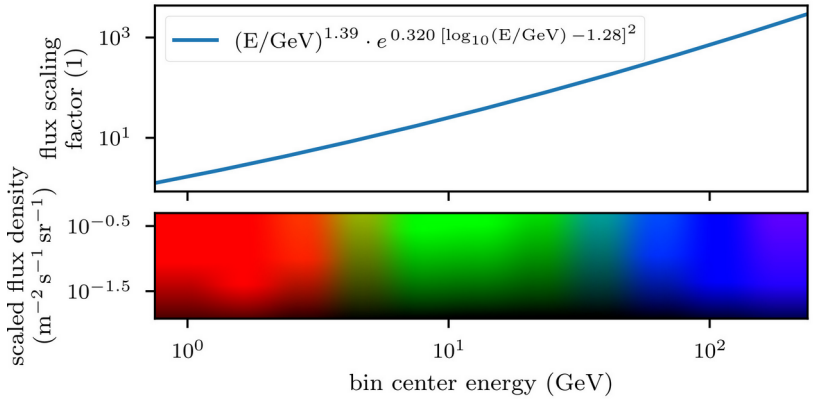

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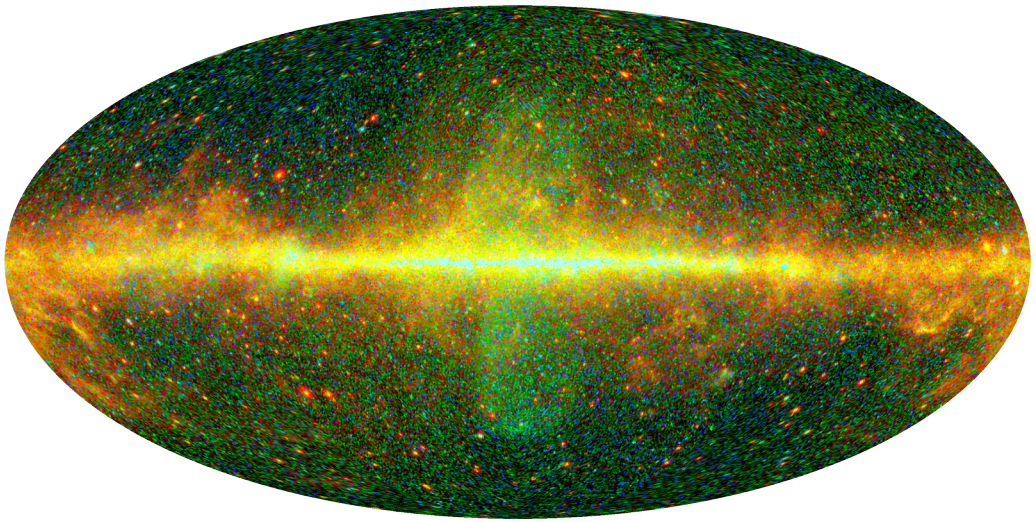

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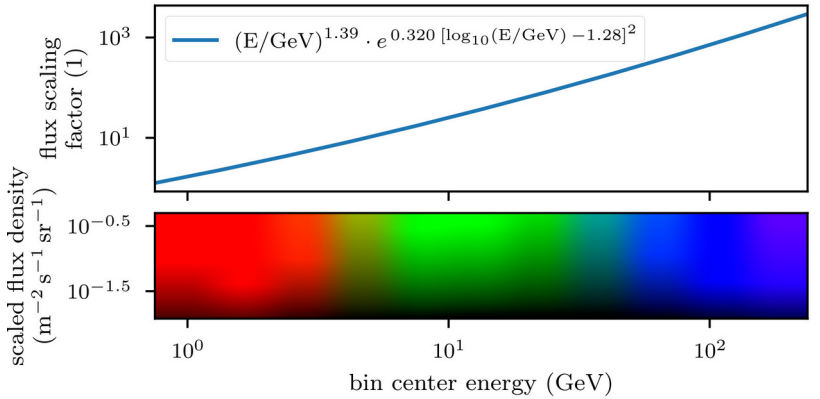

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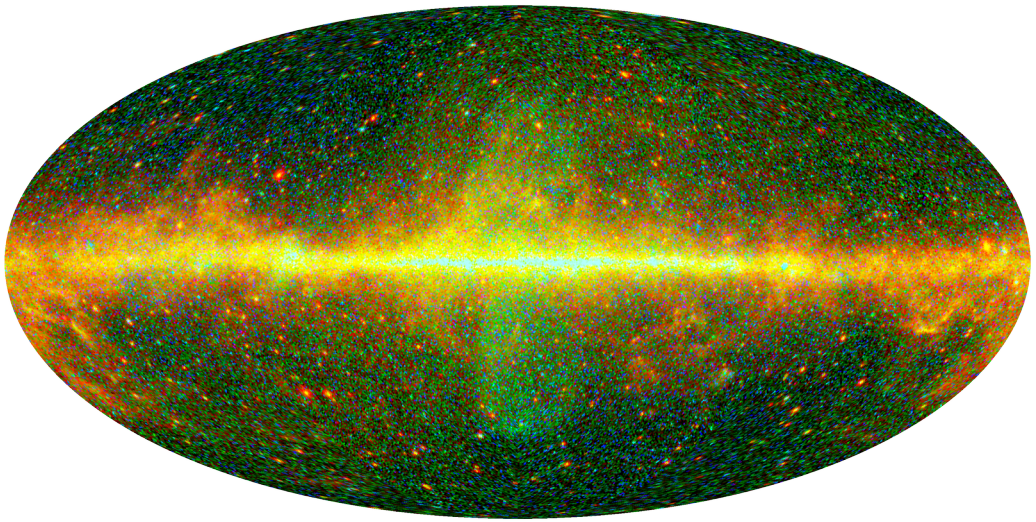

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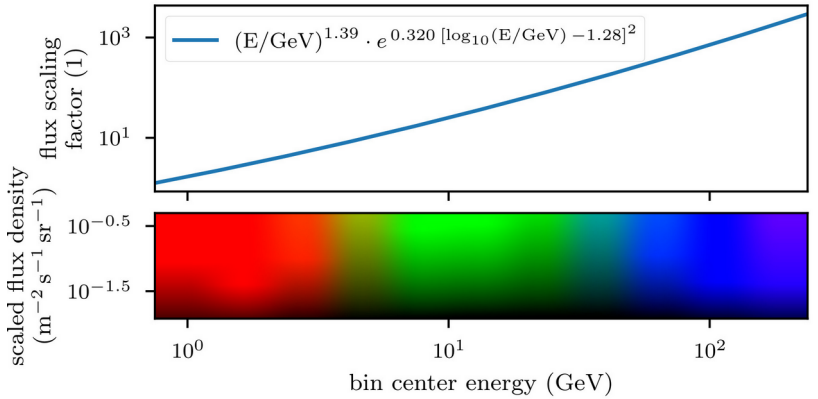

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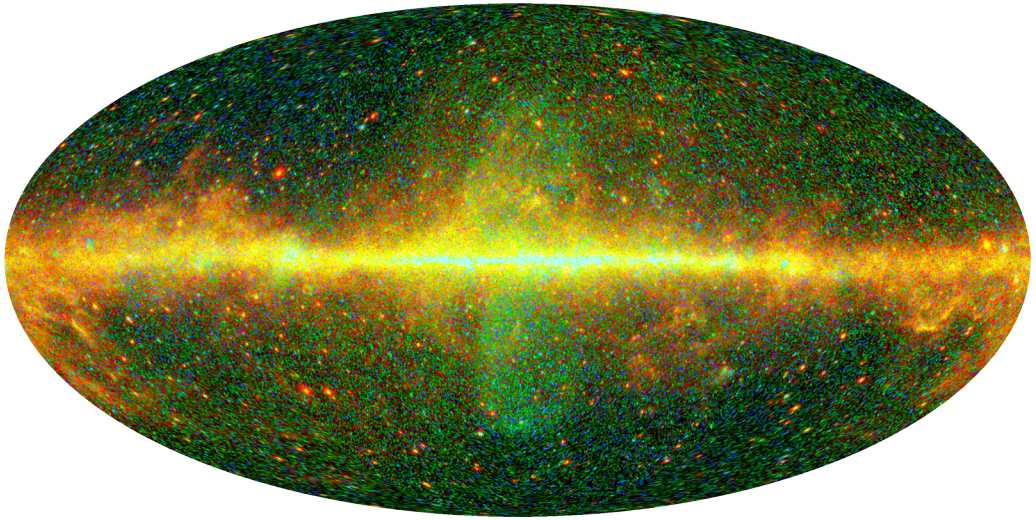

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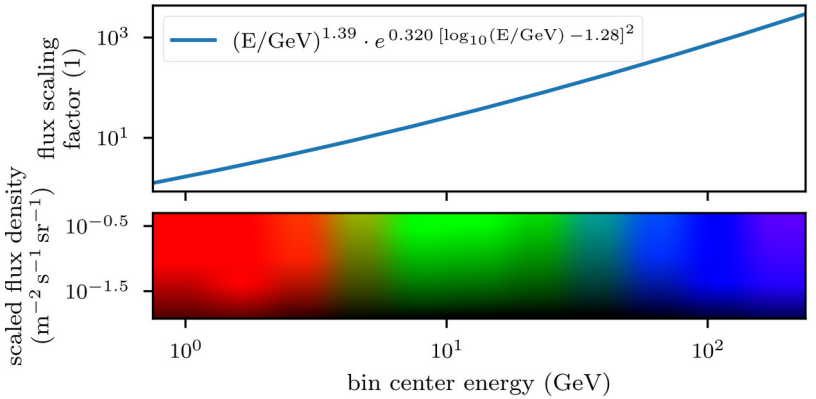

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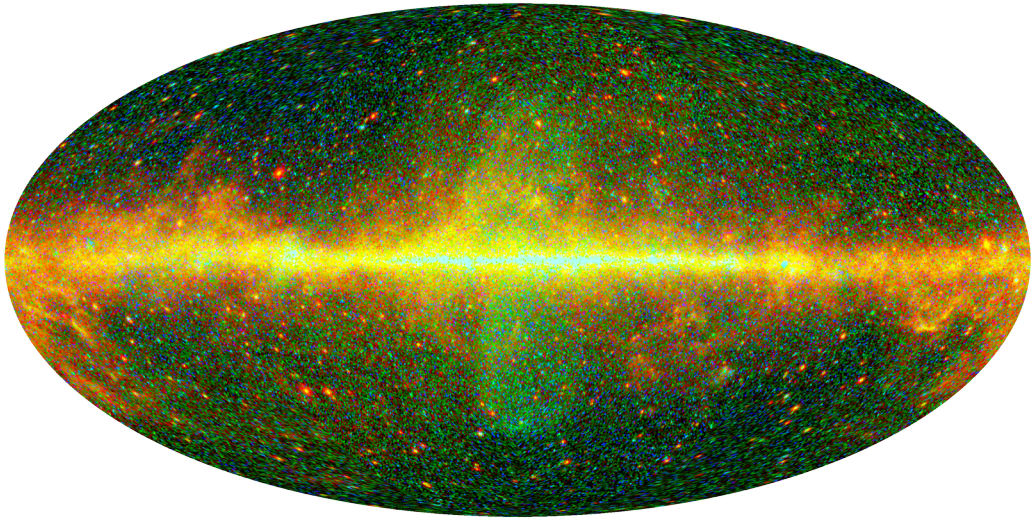

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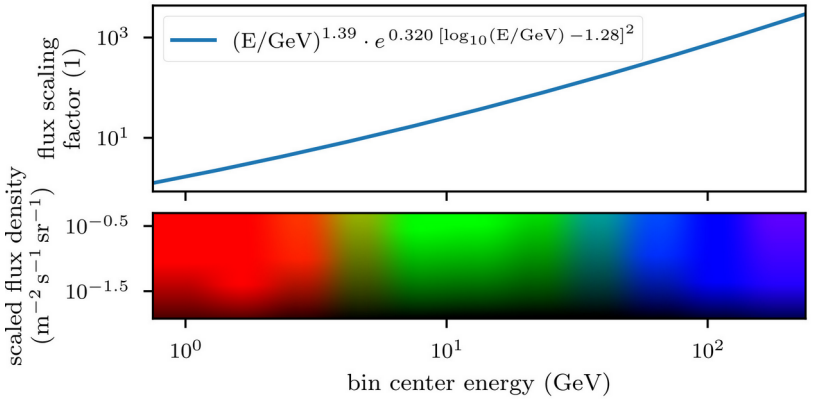

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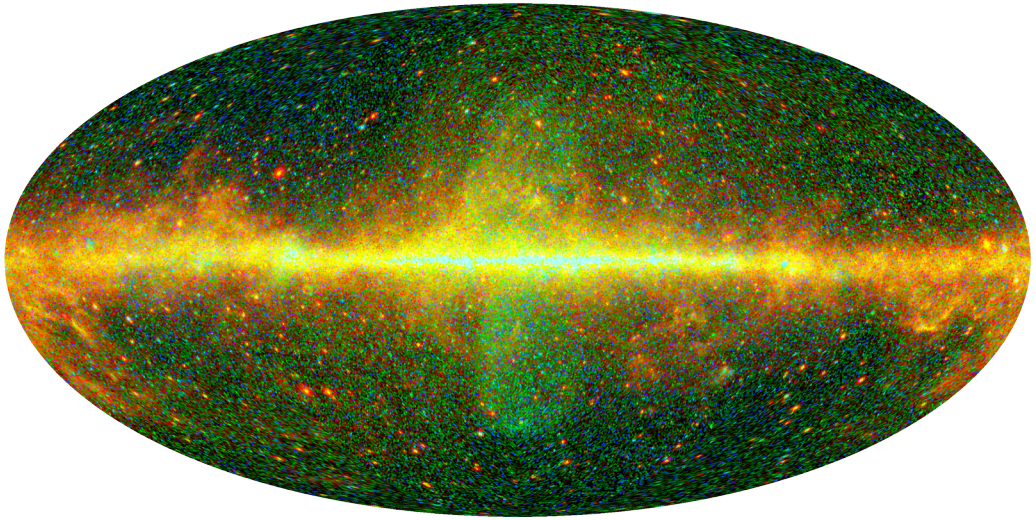

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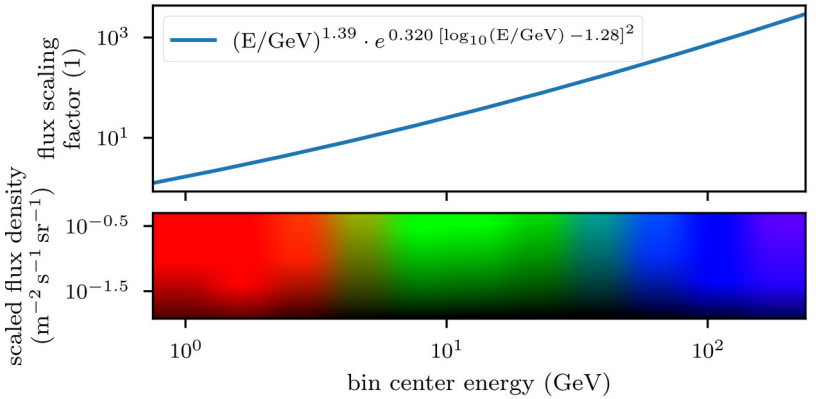
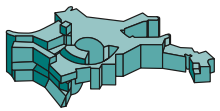


- Recently: machine learning (ML)-based approaches with promising capabilities
  - **Results not as explainable as one would like**

Promises: What do we claim to deliver?



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- Existing templates can be used to inform the reconstruction without sacrificing data-drivenness (within limits).
- Weak, otherwise „hidden“ emission structures can be unveiled.

Methods: How did we approach the task?

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High-level perspective: Bayesian inference

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High-level perspective: Bayesian inference

- **Poissonian data likelihood** with Instrument Response model
  - Point spread function (PSF), energy dispersion function (EDF), effective area (EA), and exposure (EXP)
  - Fine-grained data bins corresponding to PSF and EDF dynamics

- **Hierarchical models for the expected emission components**
  - Model 1: Point-like and diffuse emission
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- **Posterior Approximation via variational inference** (Metric Gaussian Variational Inference)

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$$\langle \tau_{ij}\, \tau_{i'j'} \rangle_{(\tau)} = C(|x_j - x_{j'}|)\, D(|y_i - y_{j'}|)$$

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Implementation:
Pixel-wise independent models for total brightness and spectrum shape of point-like emissions

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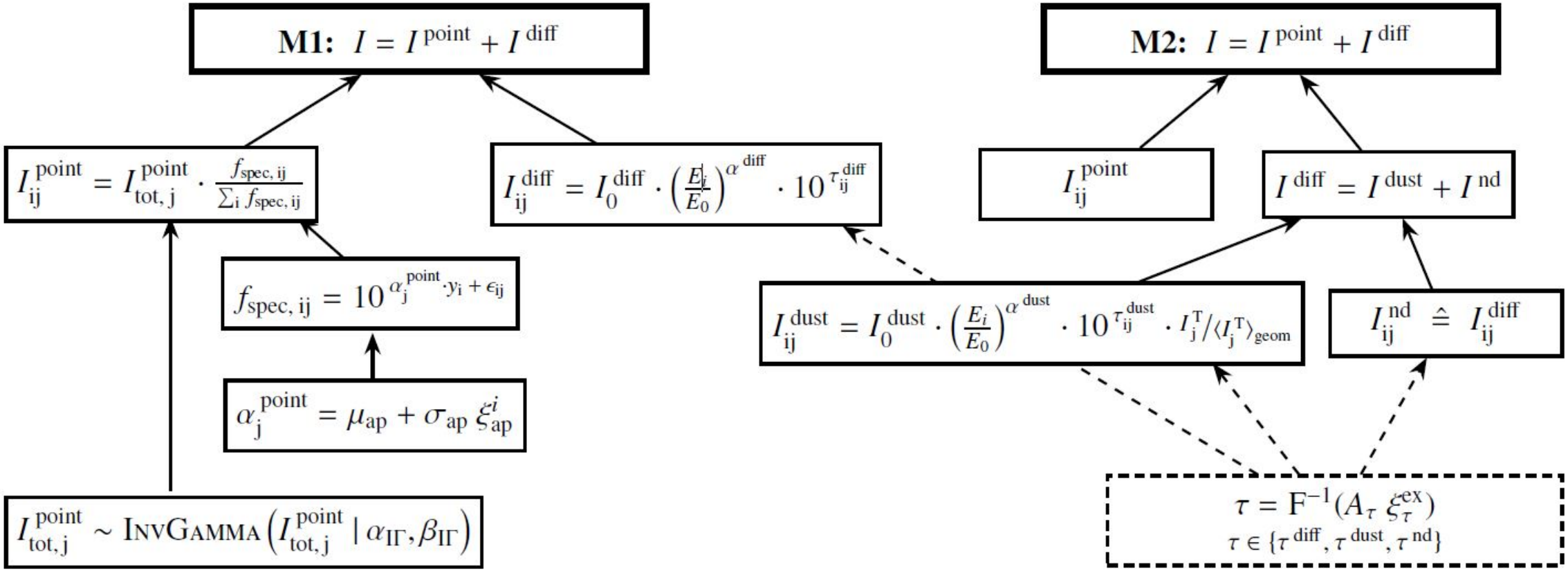

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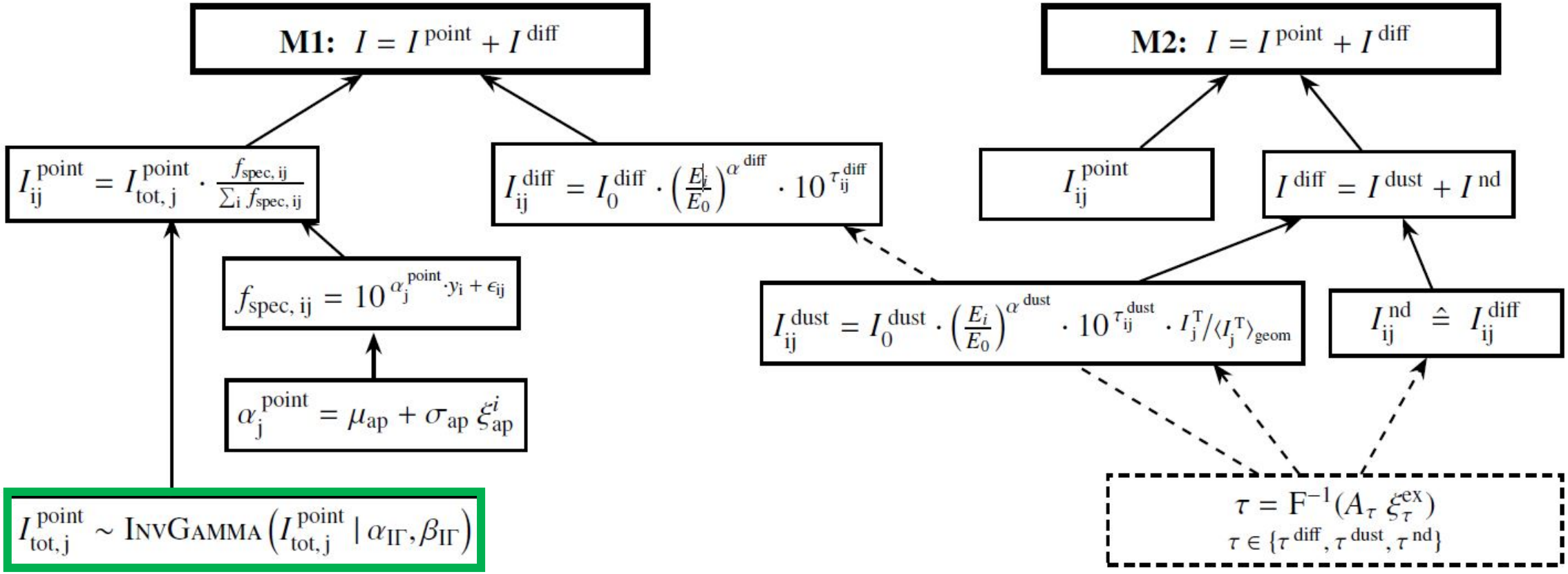

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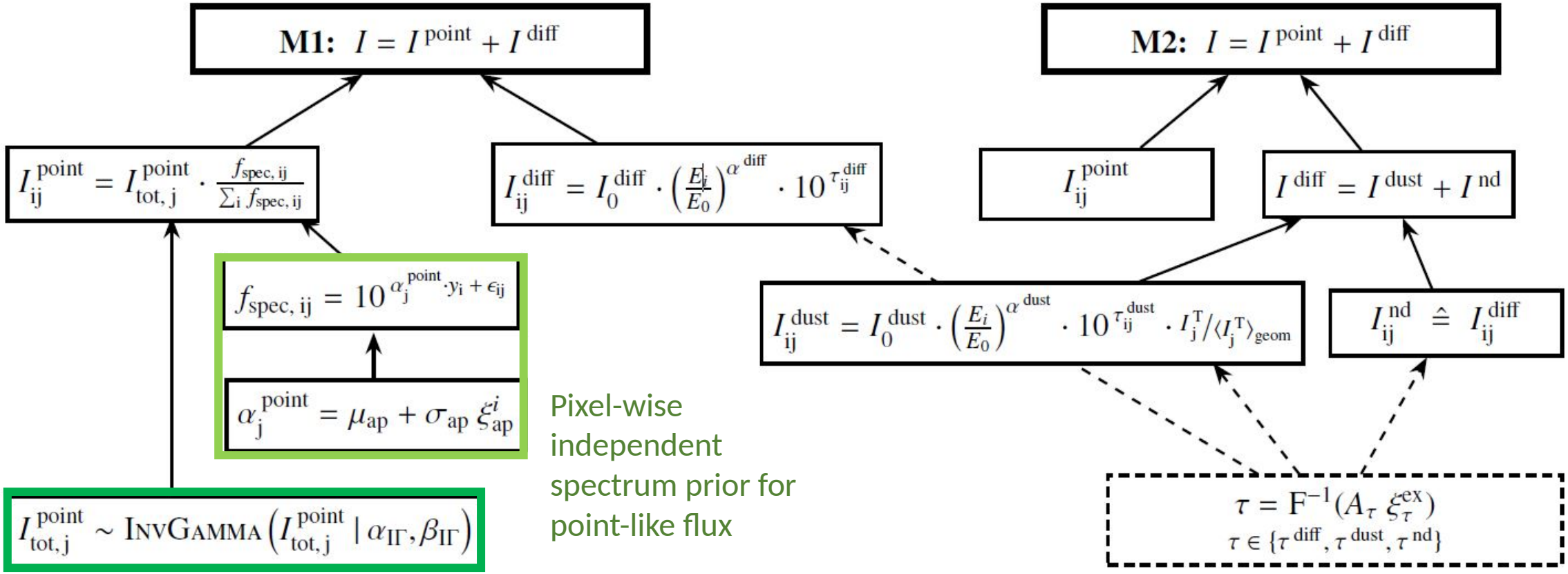

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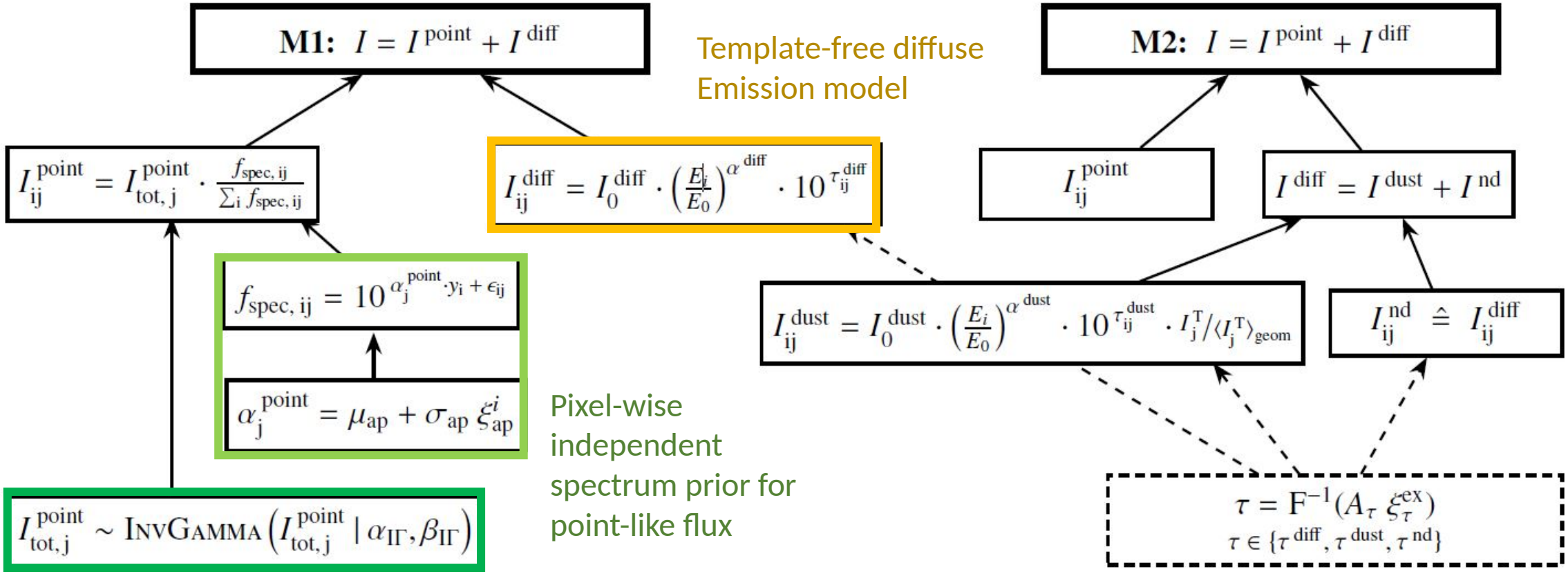

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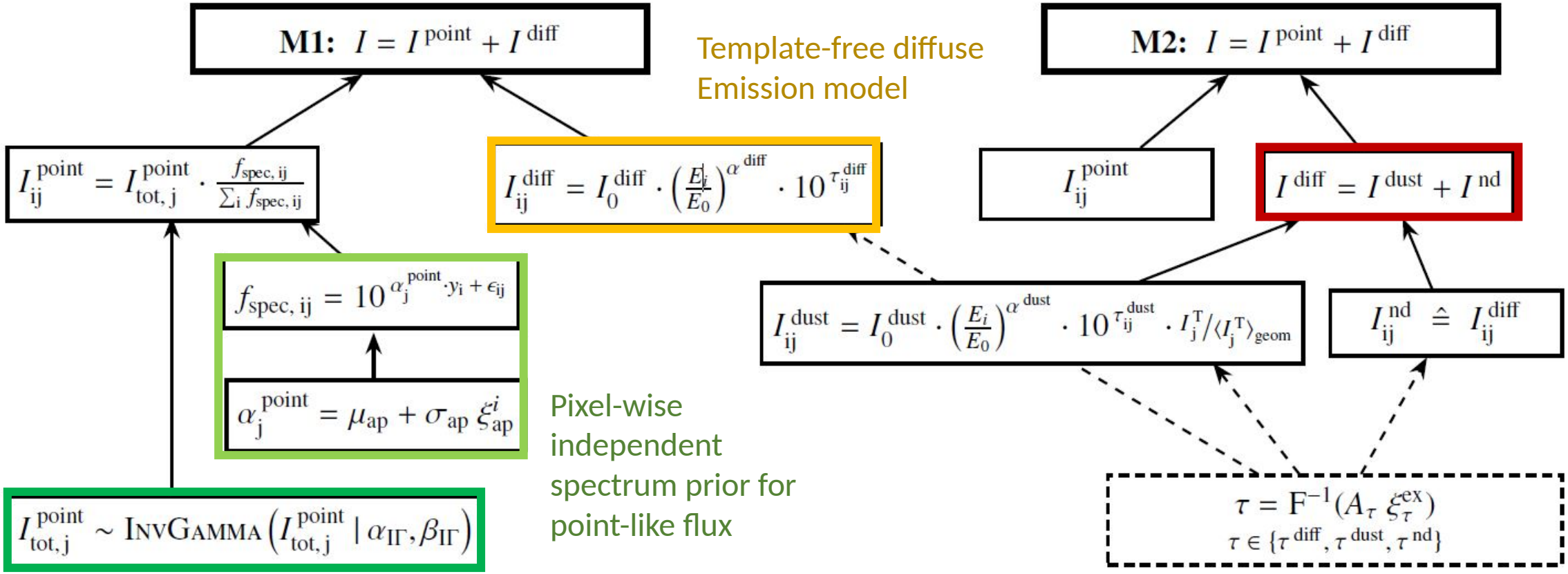

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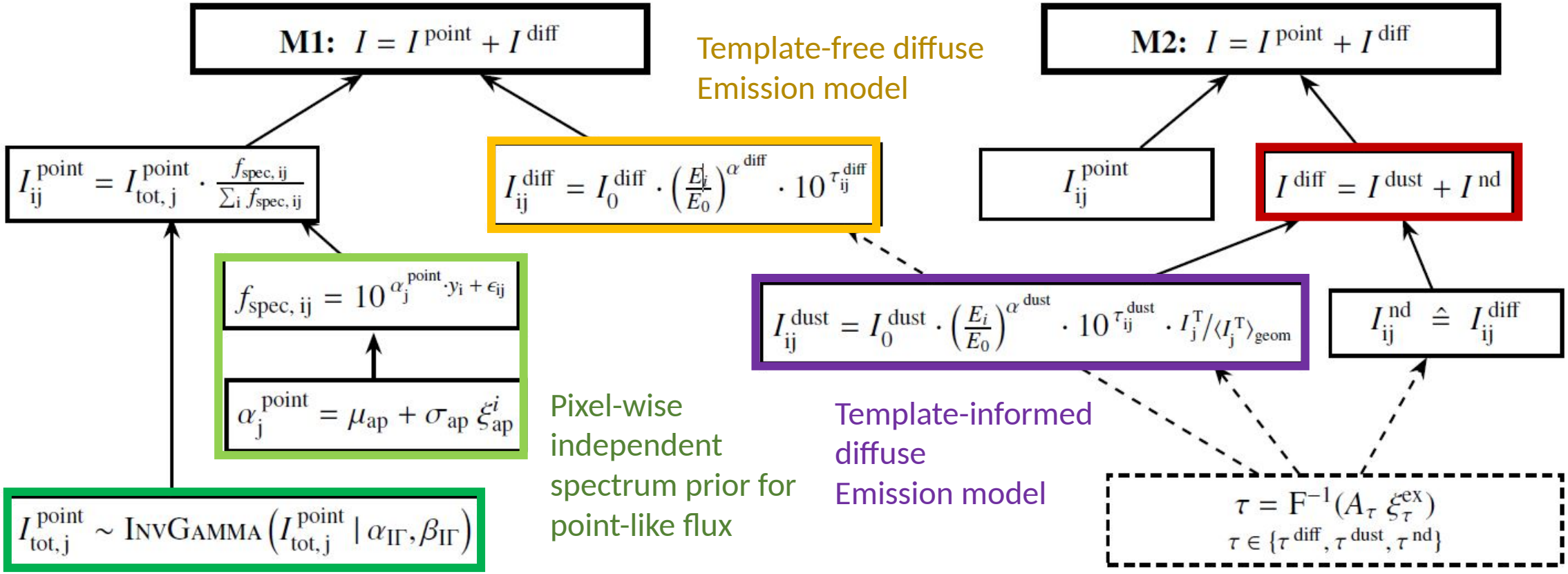

Template-free diffuse Emission model

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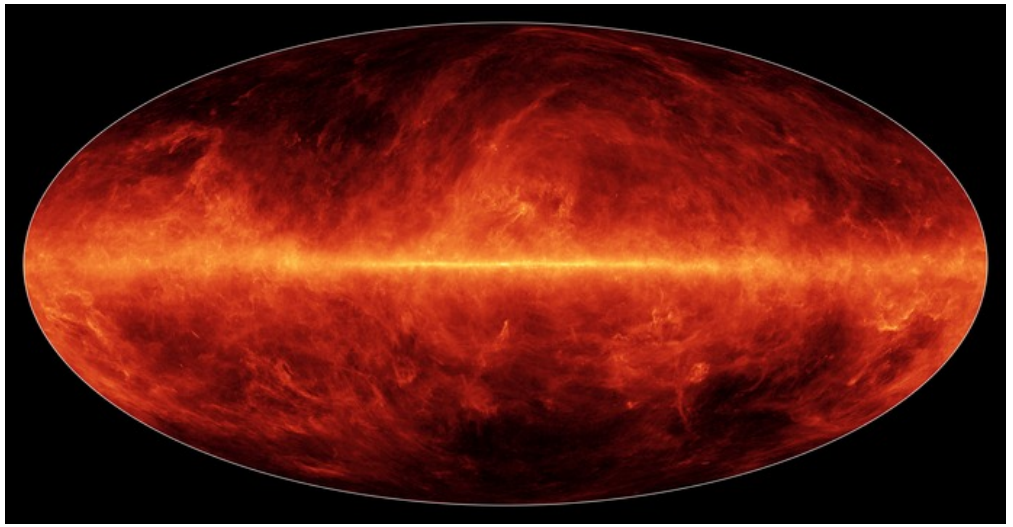
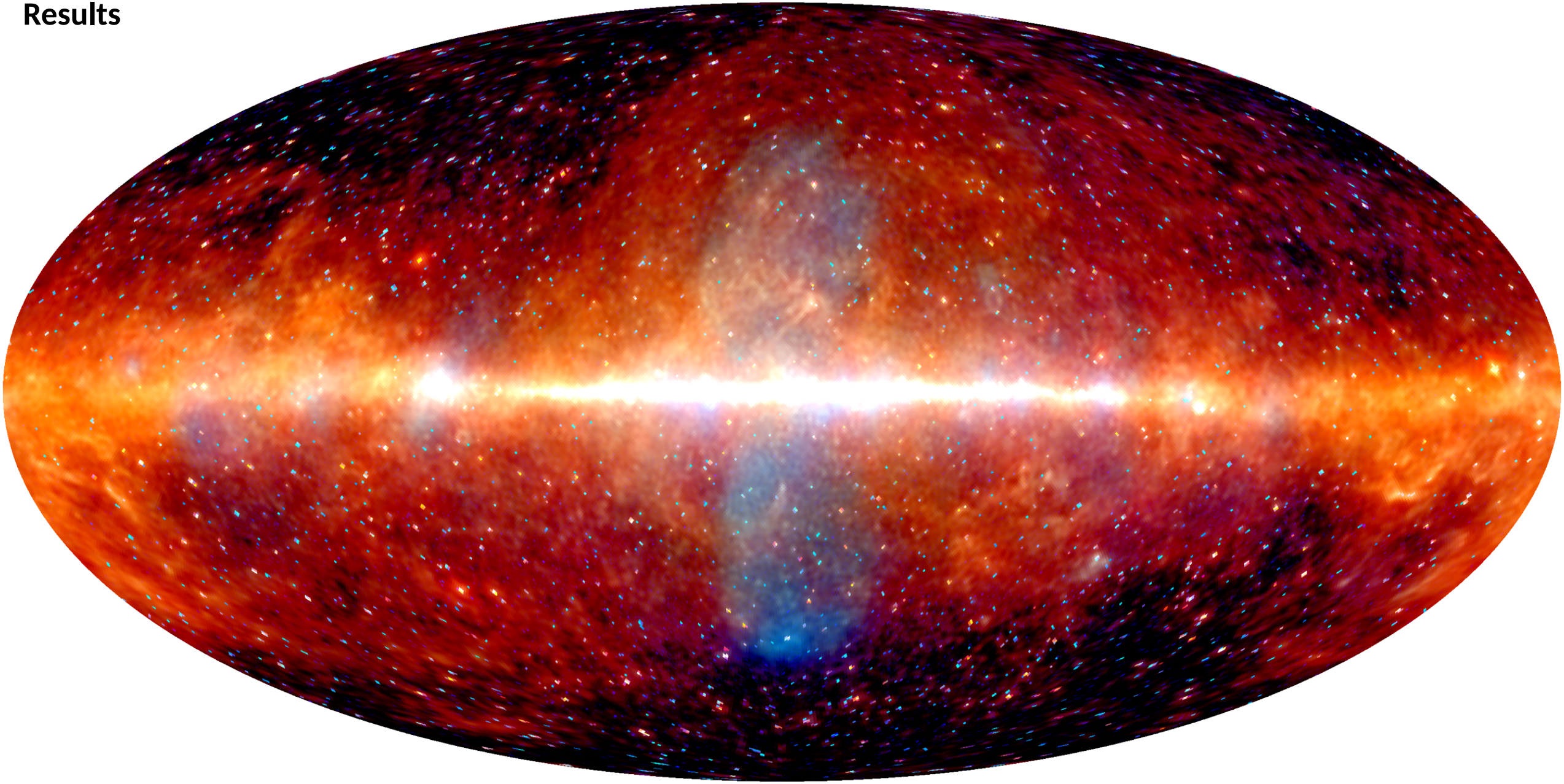


Image source: https://planck.ipac.caltech.edu/image/planck15-002b, 20.11.2023

Results



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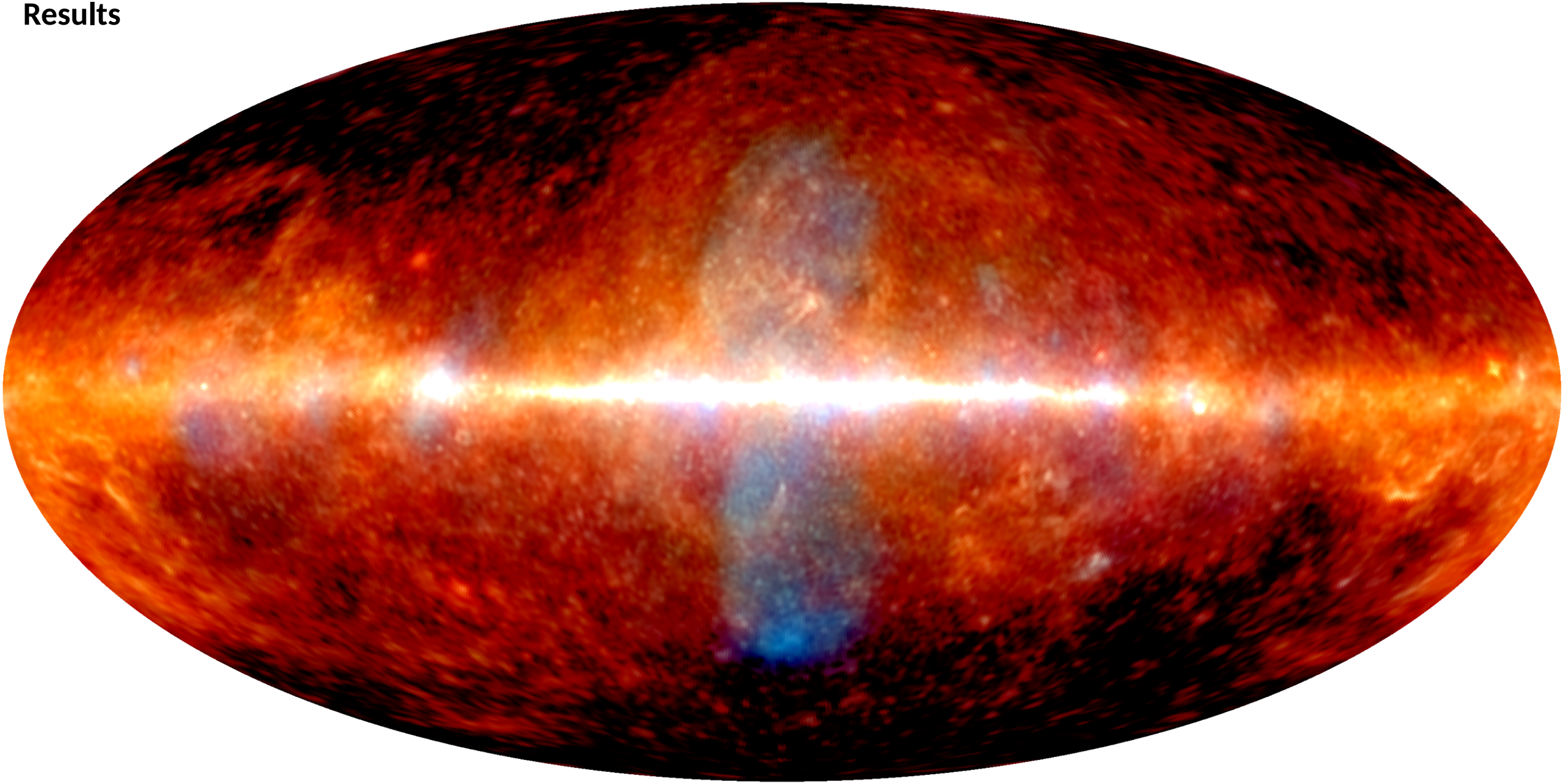

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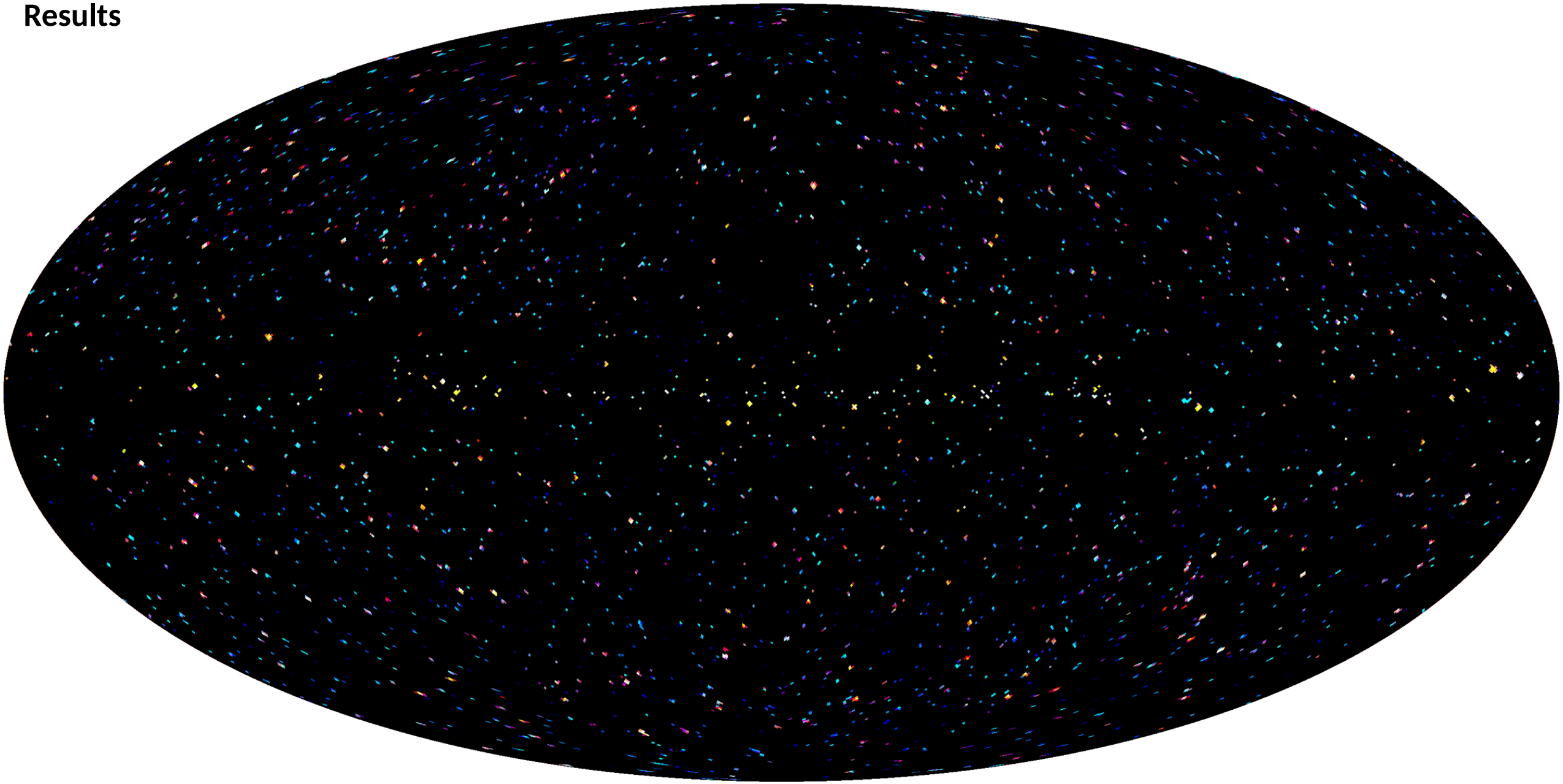

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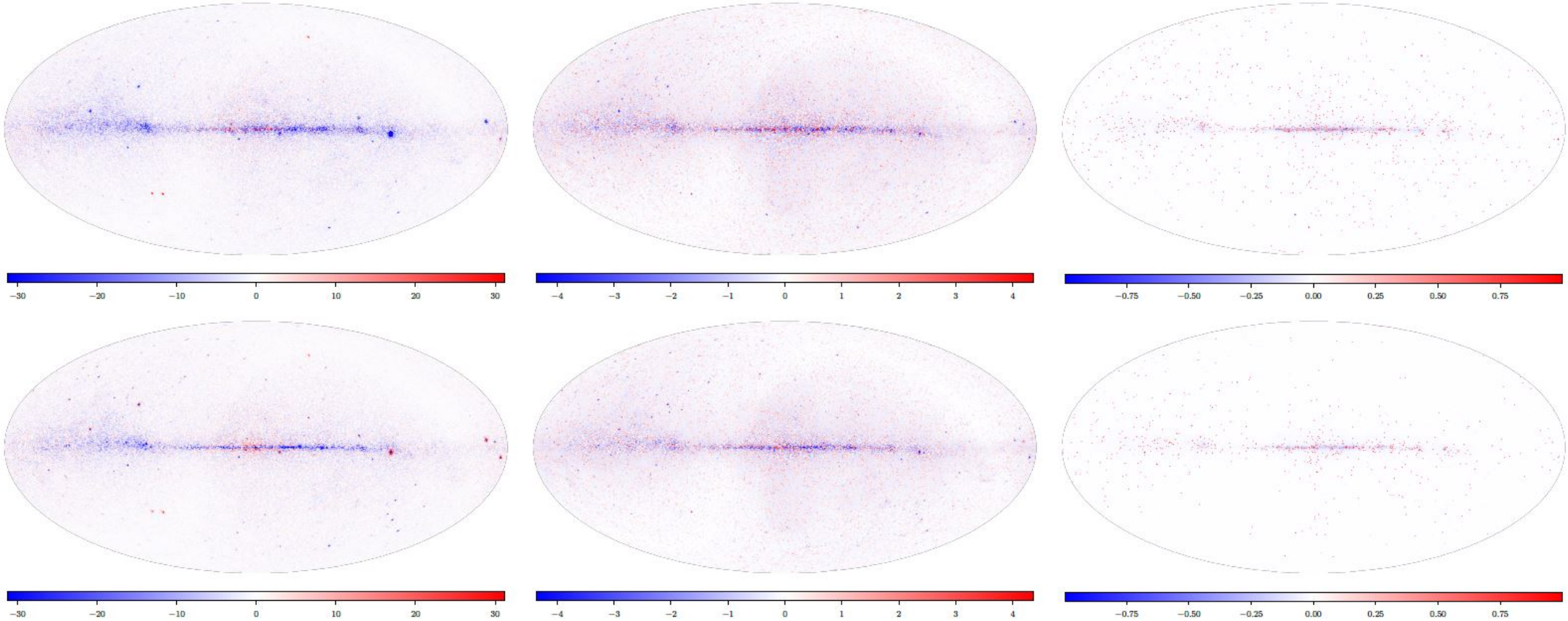
- Reduced values of 1.1 and 0.9 for FRONT and BACK events
- Few structures in the residuals (exceptions: galactic disk, bright extended sources, bright point sources)



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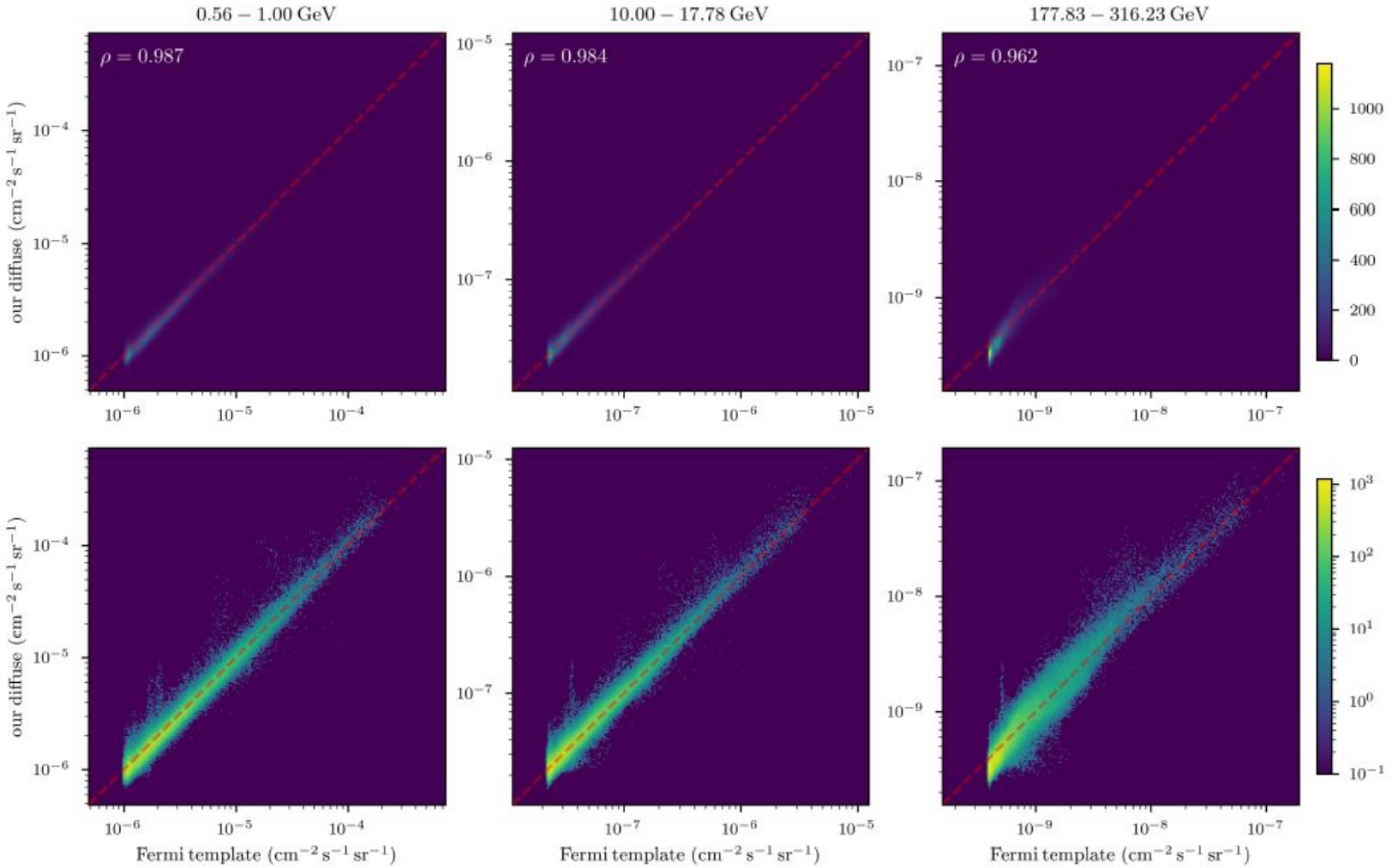
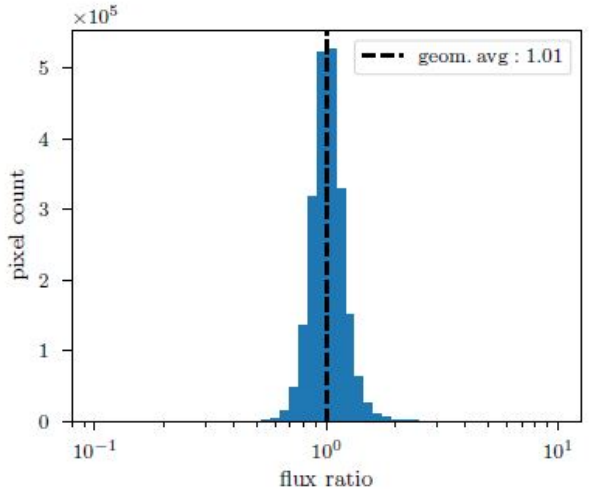
High quantitative agreement with the emission templates by the *Fermi Collaboration*:

- Used Templates: gll_iem_v07 (diffuse foregrounds), iso_P8R3_SOURCE_V3_v1 (isotropic backgrounds)





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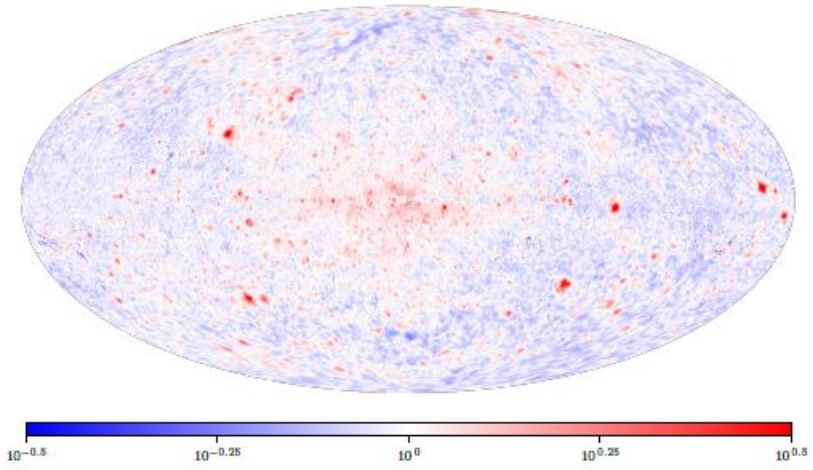
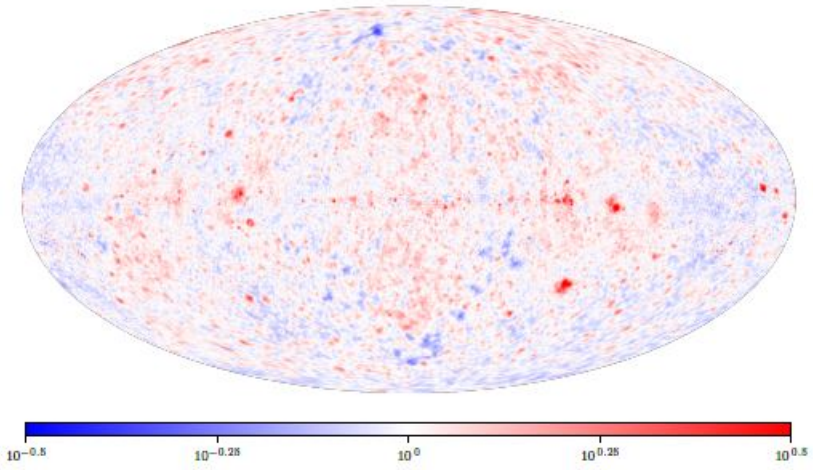
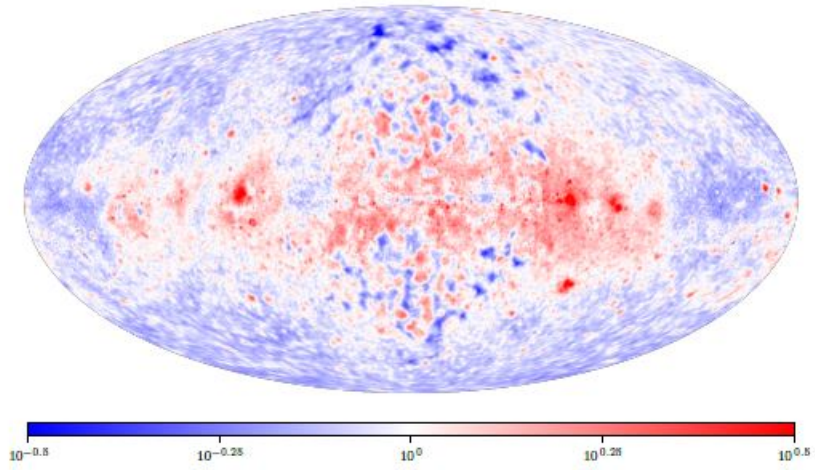
- Disagreements:
  - Extended emission sources (vela supernova remnant, crab nebula, …)
  - Isotropic background at high energies
  - 5° scale structures at high energies



$0.56 - 1.00$ GeV



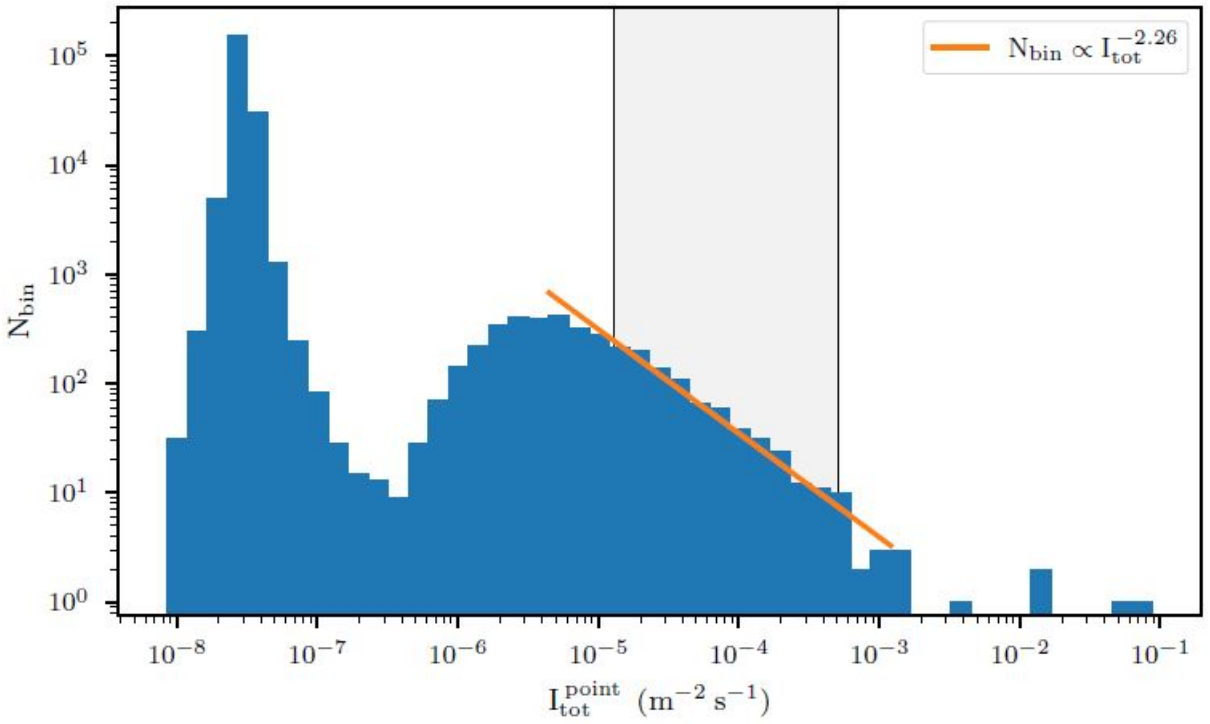
$10.00 - 17.78$ GeV



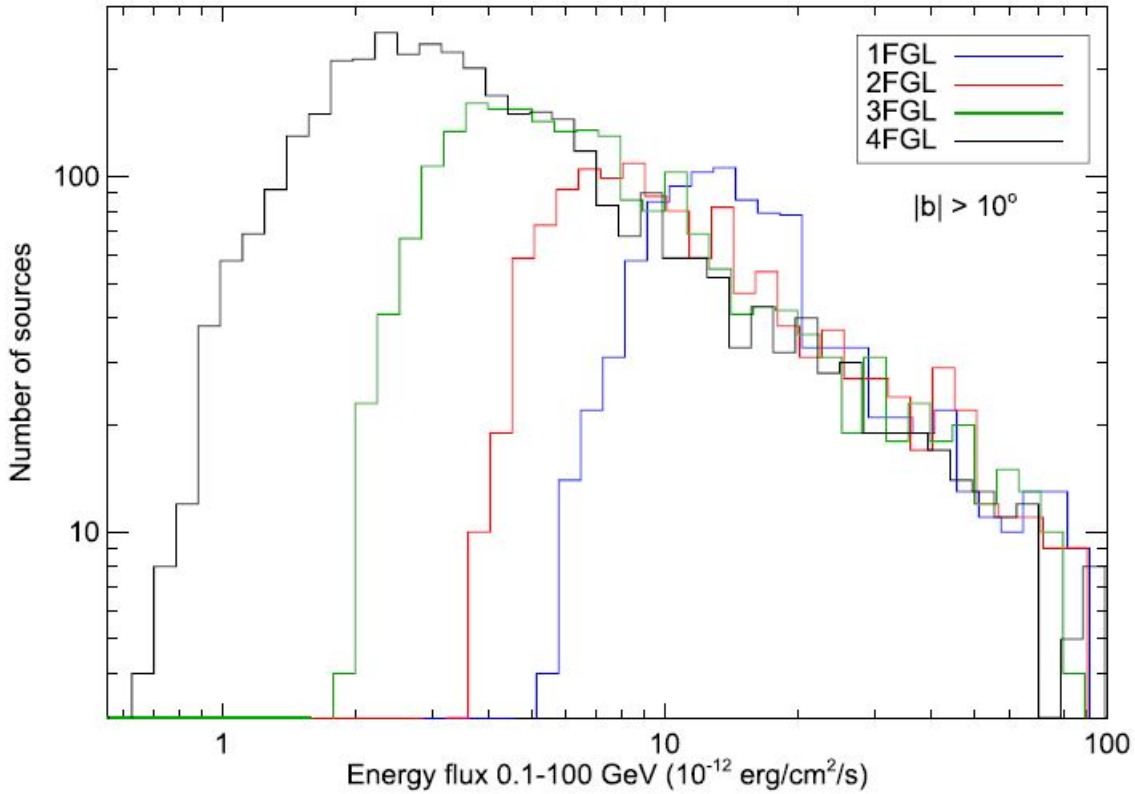
$177.83 - 316.23$ GeV

Results

Plausible point-like flux pixel brightness distribution:

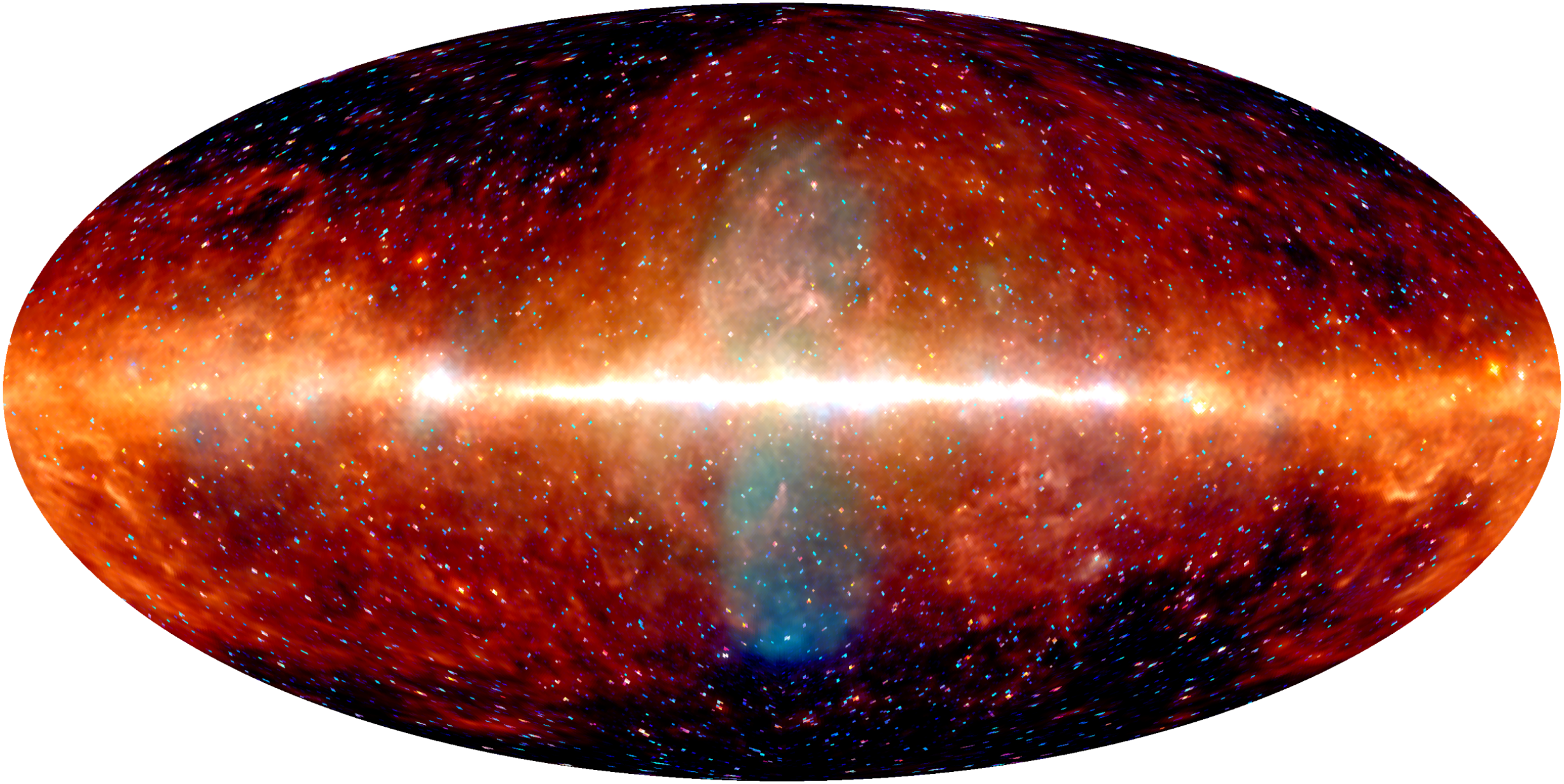


Point source brightness distribution in the *Fermi* point source catalogs



Abdollahi et al., 2022, The Astrophysical Journal Supplement Series, „Fermi Large Area Telescope Fourth Source Catalog“

Results



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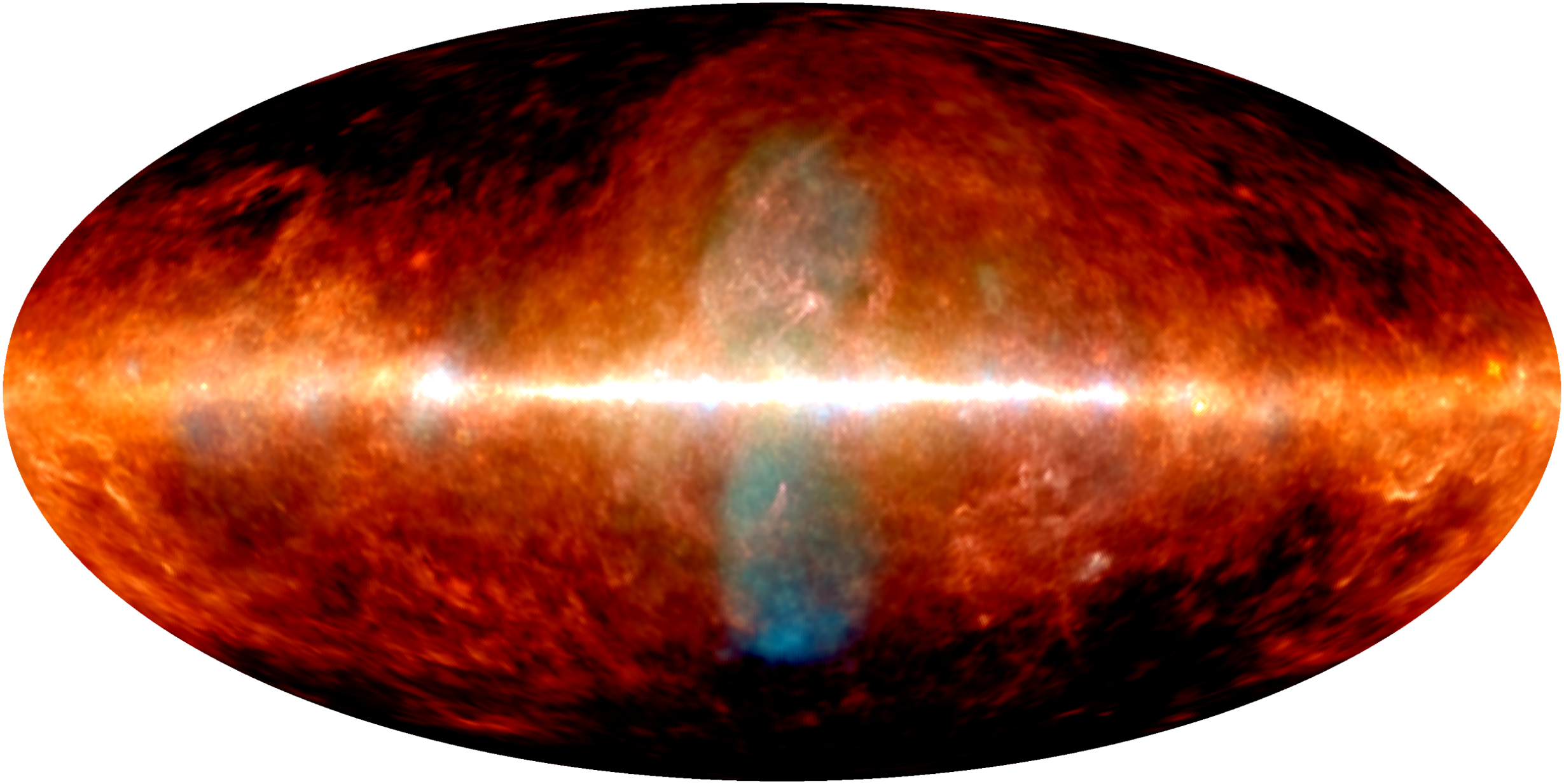

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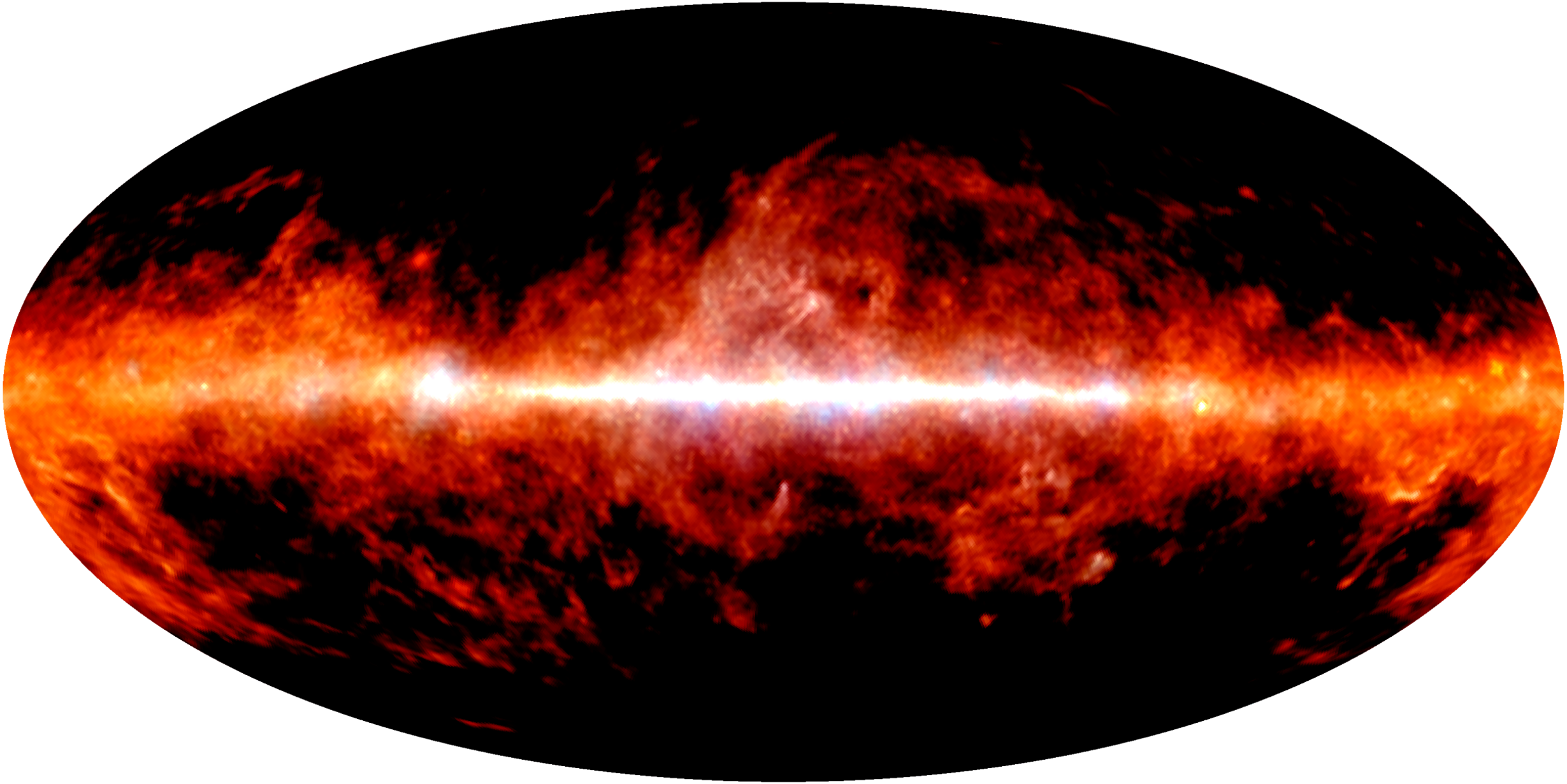

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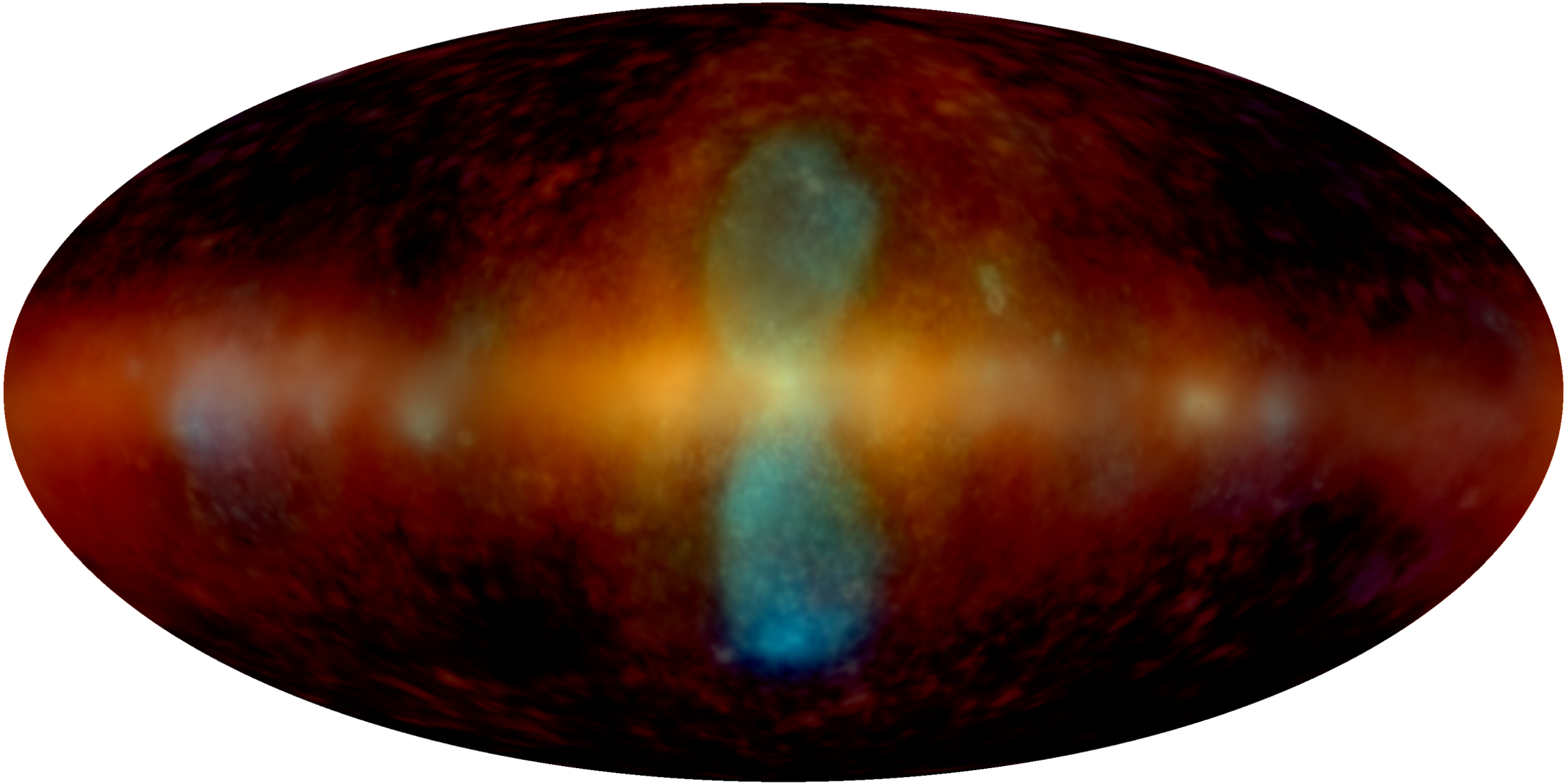

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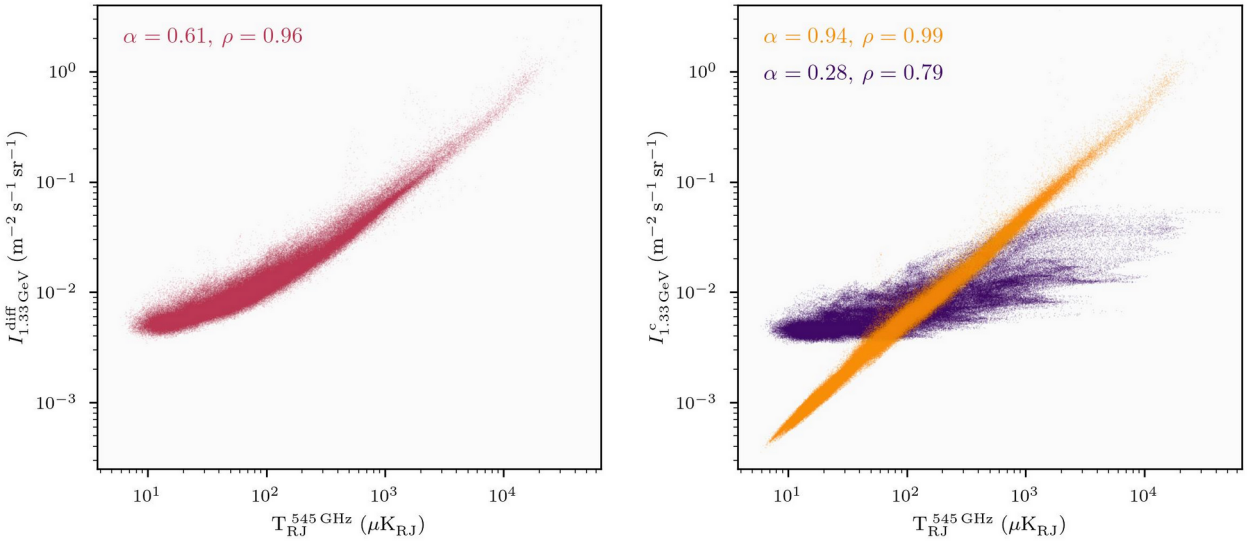

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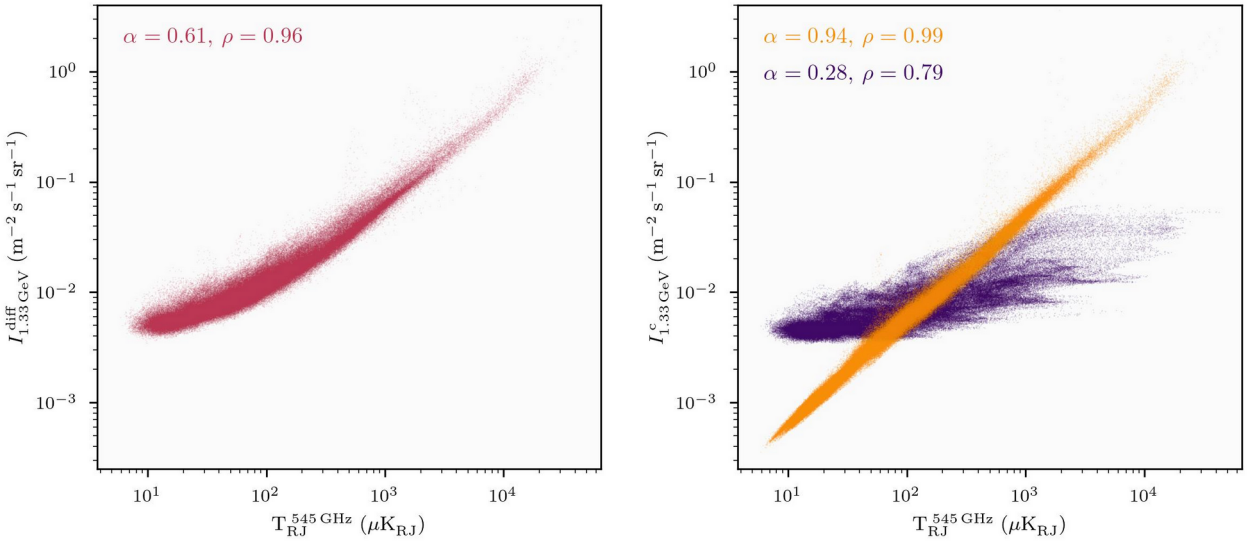

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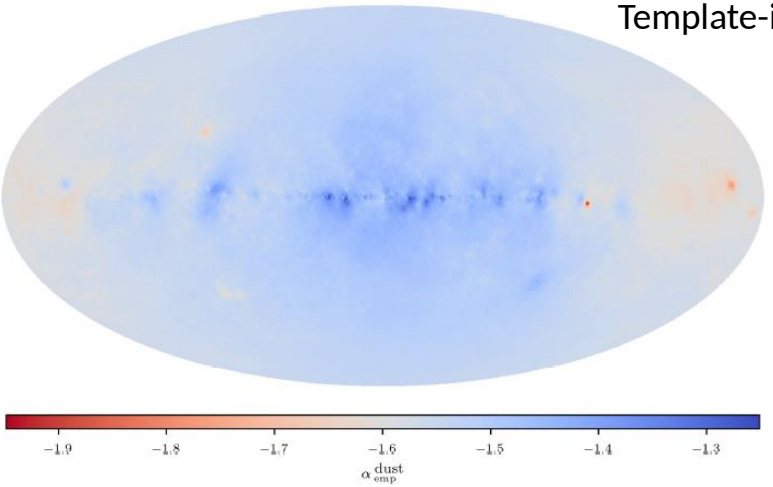
Model 2 diffuse emission spectral index maps

Template-informed



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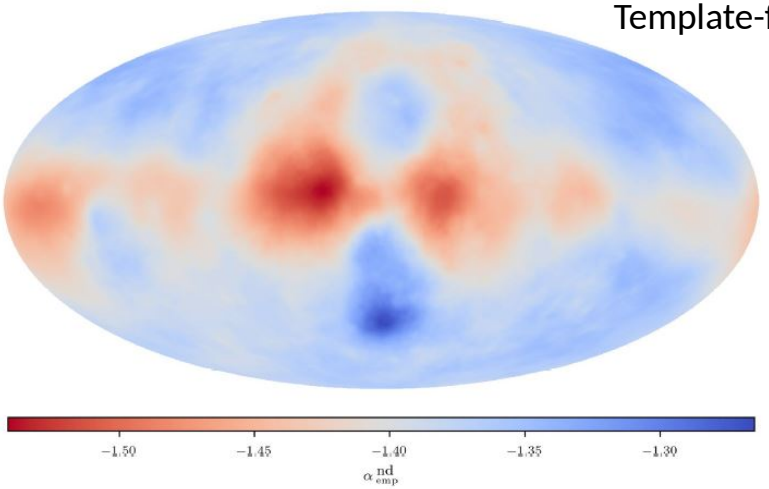

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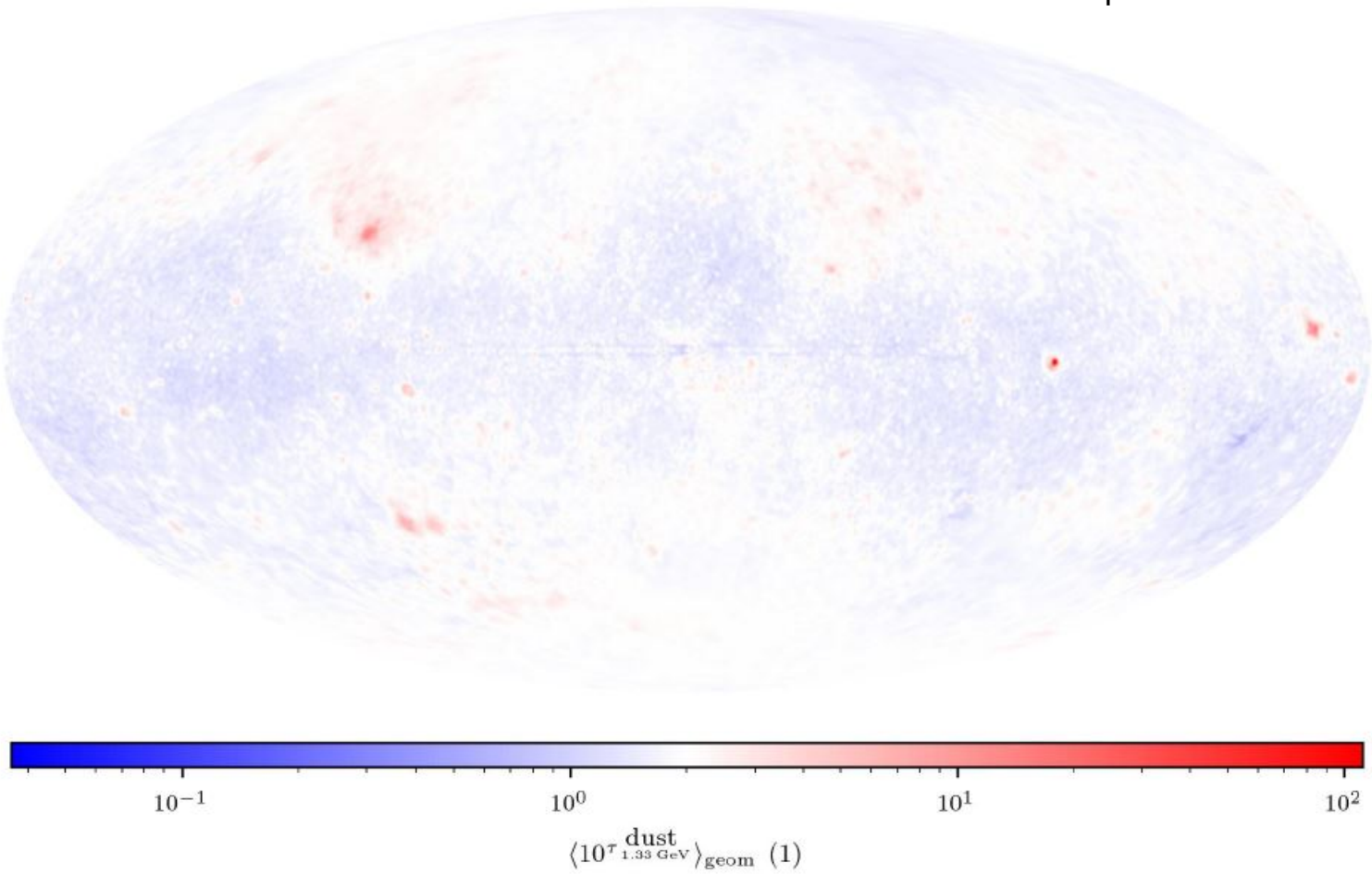
Flexible modification of template:

- Strong modifications where necessary (extended emission sources)

Template modification field



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- Weak, otherwise „hidden“ emission structures can be unveiled.

Summary

Find the full paper at **scheel-platz.de/pub/fermi.pdf**

We show a template-free, highly data-driven reconstruction of the gamma-ray sky based on an interpretable hirarchical model of the observed emissions.

- We build **hierarchical generative models** of the expected emission components
- These models have a **high degree of flexibility**, allowing them to **represent** a wide variety of **fluxes as requested by the data**
- We approximate the posterior distribution over the parameters of our model **using variational inference**
- We reach **a good quality of fit**, but also find traces of instrument response mismodelling
- Our purely **data-driven, template-free reconstuction largely agrees with** the traditional **diffuse emission templates** published by the *Fermi Collaboration*

We show a template-informed, yet still highly data-driven reconstruction of the gamma-ray sky

- We still reach a good quality of fit, but **additionally perform** a self-consistent **component separation between thermal-dust-associated emissions and other diffuse emission** in the reconstruction process
- **Analyses indicate a good separation** of the emission component
- „Overshadowed“ emission components get „de-masked“ in the process