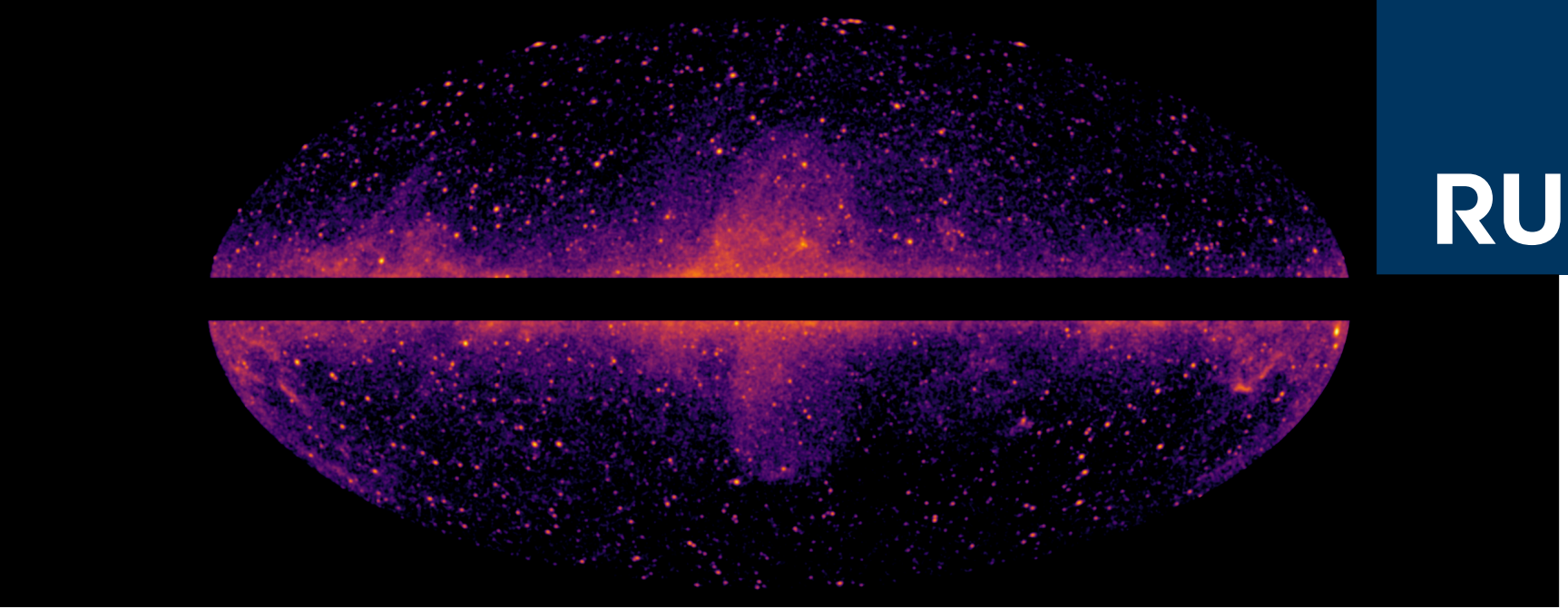

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RUHR-UNIVERSITÄT BOCHUM

ANALYSING THE FERMI BUBBLES

USING IMPROVED MODELS AND DATASETS

Paul-Simon Blomenkamp
Anna Franckowiak

Fermi Gamma-ray Space Telescope

SFB1491

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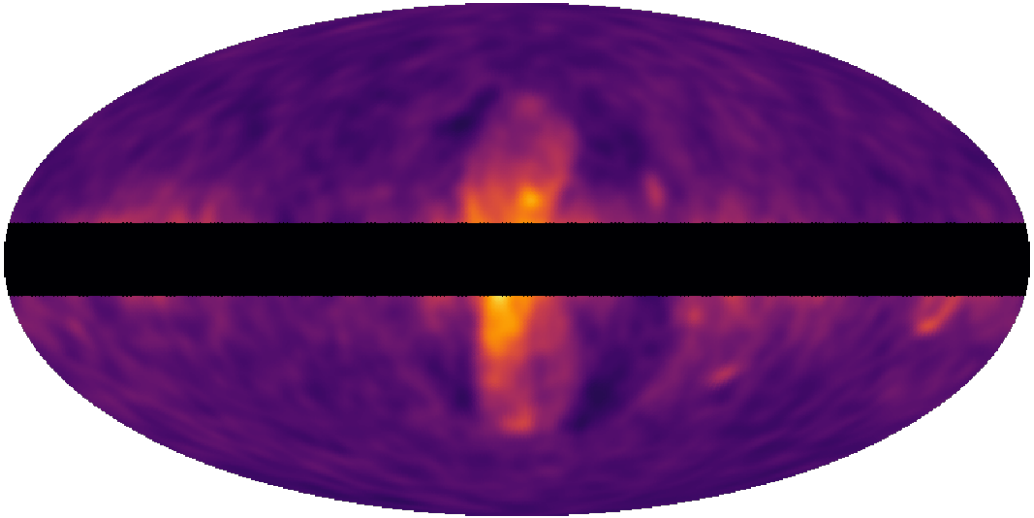
Fermi Bubbles

- One of the largest unexplained objects in the gamma ray sky
- Characteristic features:
  - Sharp edges
  - Spatially uniform hard spectrum
- Three popular models for origin[1]:
  - Wind Models
  - Jet Models
  - In situ acceleration



[1] Yang, H.-Y., Ruszkowski, M., & Zweibel, E. 2018, doi.org/10.3390/galaxies6010029

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Credit: NASA, ESA and the Hubble Heritage Team (STScI/AURA).

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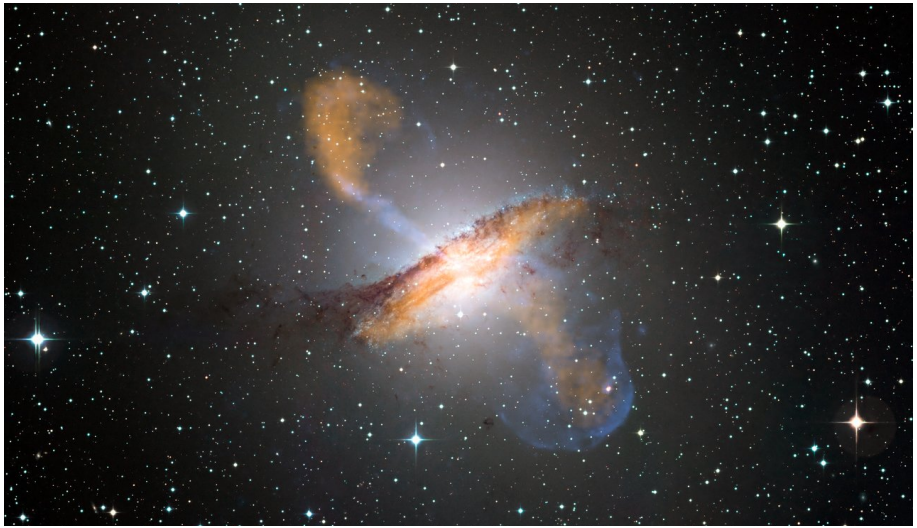

Credit: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)

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Uncovering the cause of the Fermi Bubbles

- **No model can be conclusively ruled out:**
  - **Improved constraints necessary**
- **Spectrum and morphology are deciding features**

Analysis | Template Fitting

- Follow method laid out in M. Ackermann et al 2014
- Goal: Isolating and fitting a template for the Fermi Bubbles
- Approach:
  - Create model containing all known Sources
  - Fit to Fermi LAT data
  - Difference between data and model reveals bubbles

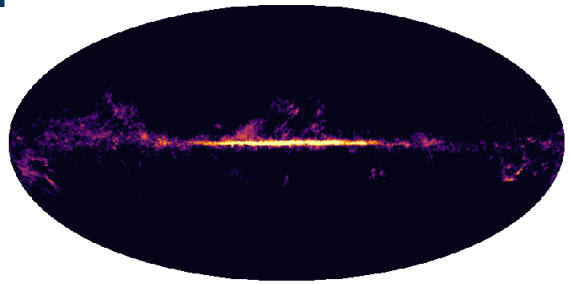
Analysis | Template Fitting

- **Approach:**
  - **Create model containing known Sources**
  - **Fit to Fermi LAT data**
  - **Difference between data and model reveals bubbles**
- **Diffuse emission models from upcoming IGRB analysis by Markus Ackermann**

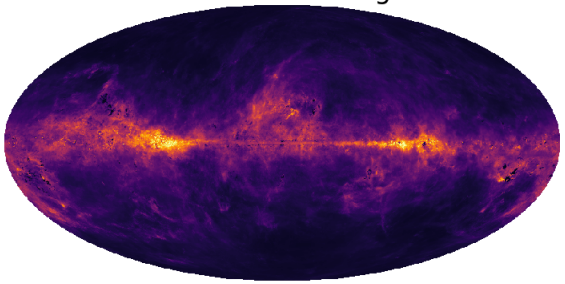
Analysis | Diffuse Sources

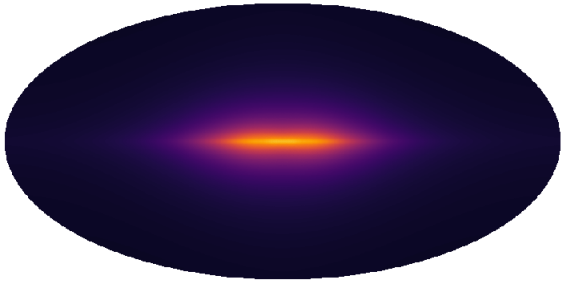
- **Diffuse emission Templates based on GALPROP**
- **Combine diffuse components to single diffuse emission model:**
  - **Atomic ionised Gas + Dark Gas**
  - **Molecular Gas**
  - **Loop I + Local Loop**
  - **Inverse Compton**
  - **Isotropic Background (not from template)**

Molecular Gas

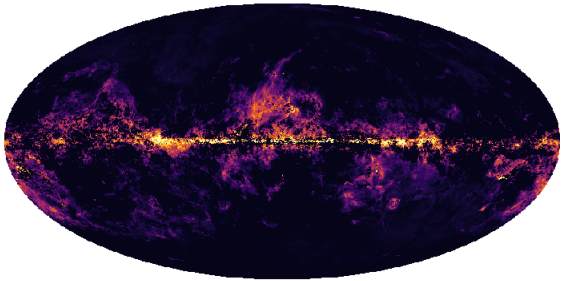


Non local atomic gas





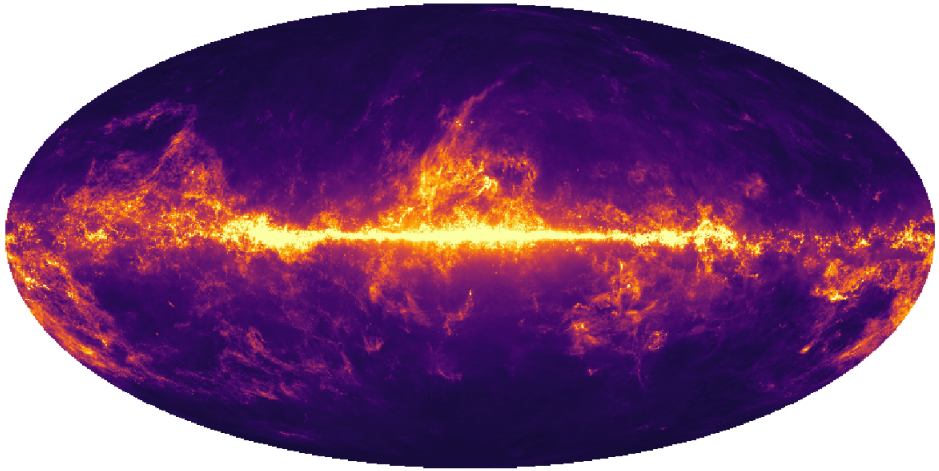
Inverse Compton



Dark Gas

Analysis | Diffuse Sources

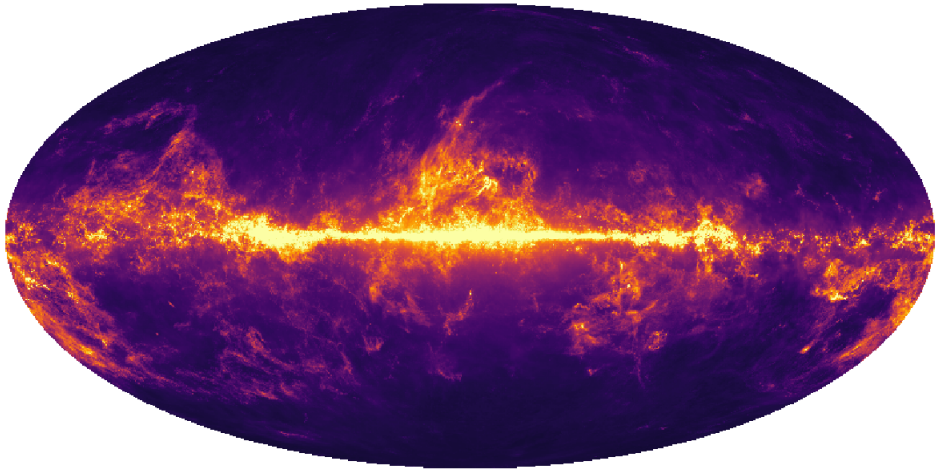
- Diffuse emission Templates base on GALPROP
- Combine diffuse components to single diffuse emission model:
  - Atomic ionised Gas + Dark Gas
  - Molecular Gas
  - Loop I + Local Loop
  - Inverse Compton
  - Isotropic Background (not from template)



Combined

Analysis | Diffuse Sources

- **Fit normalization:**
  - **Over entire energy range for GALPROP based templates**
  - **In 16 energy bins of variable size for Local Loop/ Loop I**
  - **In 25 energy bins of variable size for Isotropic background**

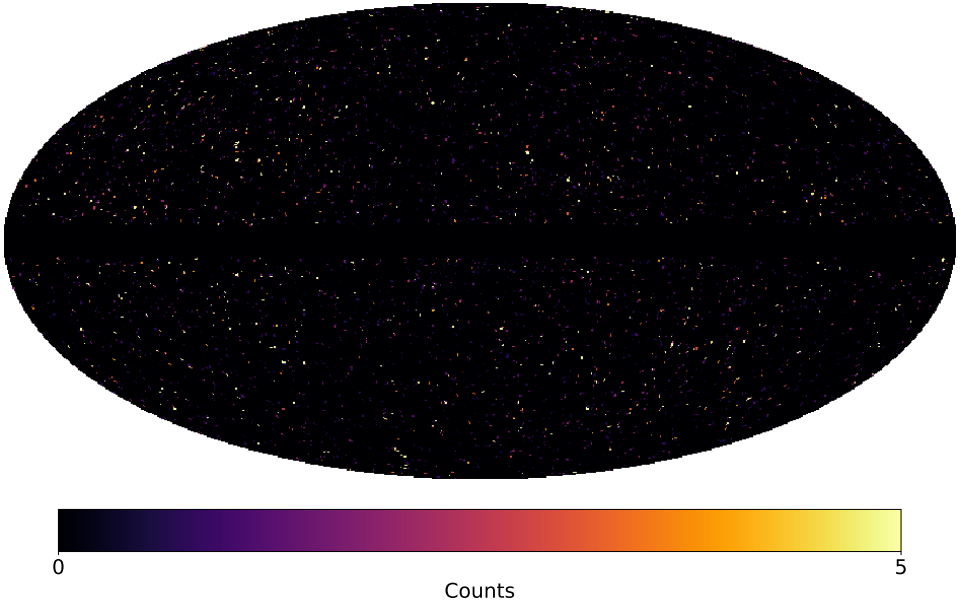


Combined

Analysis | Point Sources

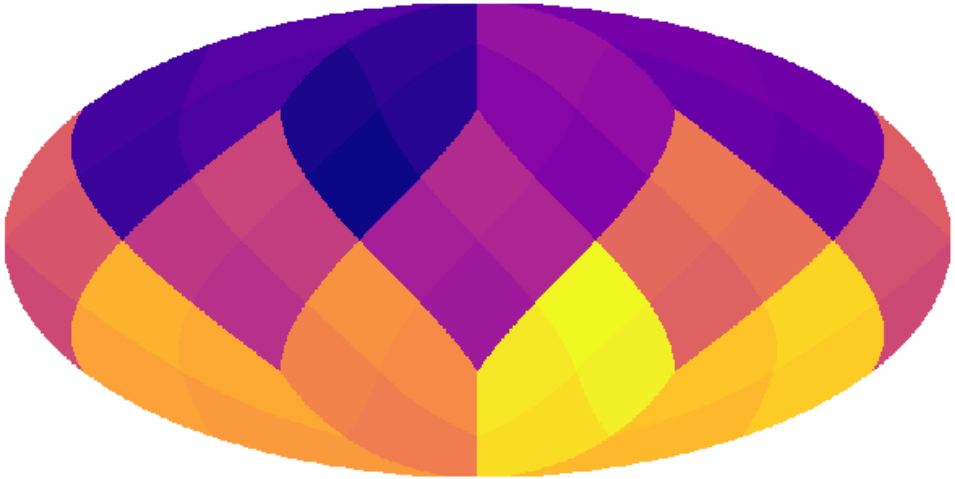
- **Use 4FGL-DR3 catalog**
- **Based on 12 years of data**
- **Fit normalisation**
- **Create three fit populations:**

Population	Criterion	Fit method
1	TS > 150	Individual fit in 16 energy bins
2	TS > 15 & |lat| > 10°	Individual fit with single normalisation
3	Not in population 1 or 2	Group sources and fit as one.



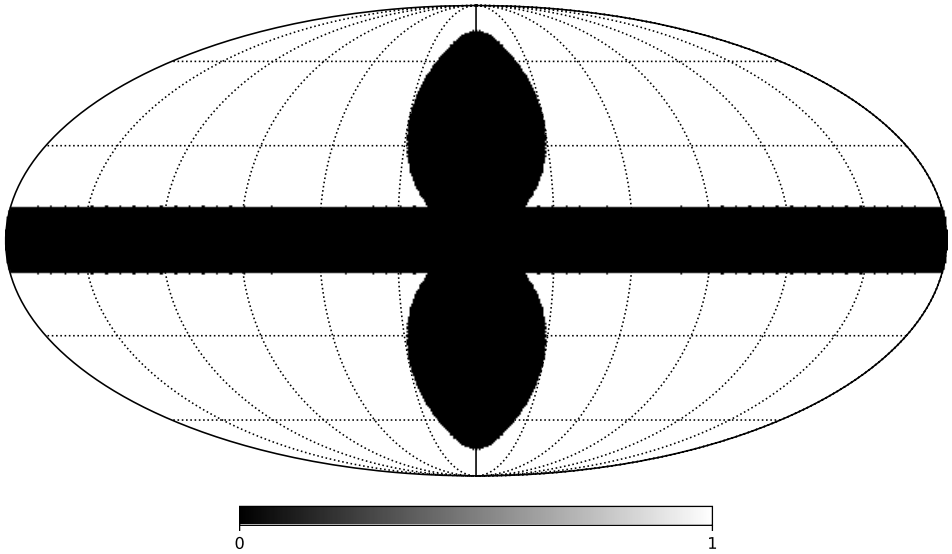
Analysis | Fit

- Perform all sky fit
- Using skylike created by Markus Ackermann
- Use HEALPix pixelisation to fit 48 ROIS
- 1st pass: diffuse + point sources
- 2nd pass: only diffuse sources



Analysis | Fit

- **Masking:**
  - **Galactic Plane |b| < 10 deg**
  - **Rough Fermi Bubble area**
- **Masked Point Sources:**
  - **Fixed for |b| > 5 deg**
  - **Otherwise removed**



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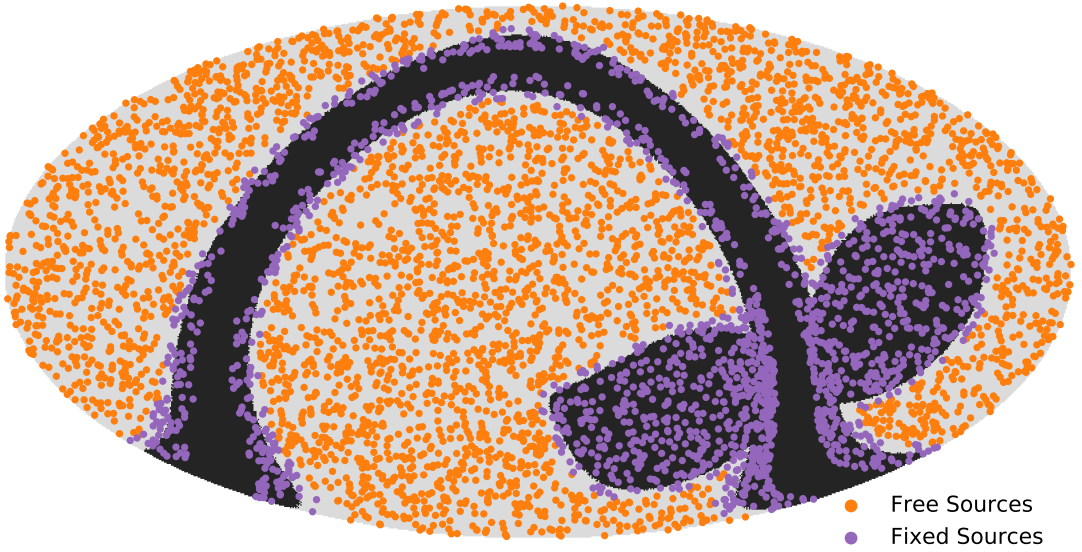
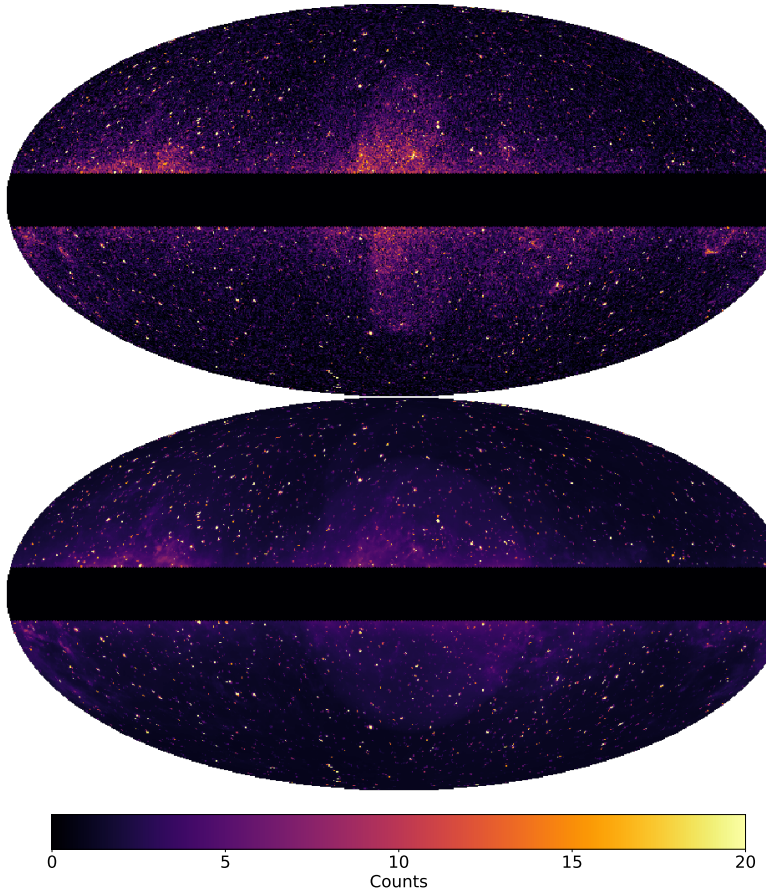


Analysis | Residuals

- **Subtract model from data to reveal residuals:**

$$\text{residual} = \frac{\text{data} - \text{model}}{\sqrt{\text{model}}}$$

- **Isolate Fermi Bubbles from residuals**
  - **Perform significance cut in region around bubbles**



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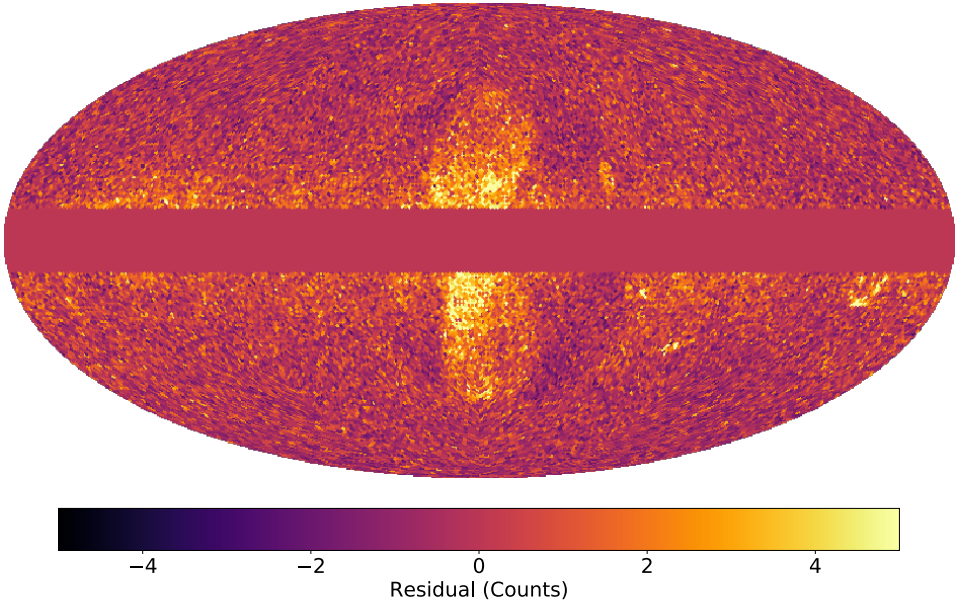

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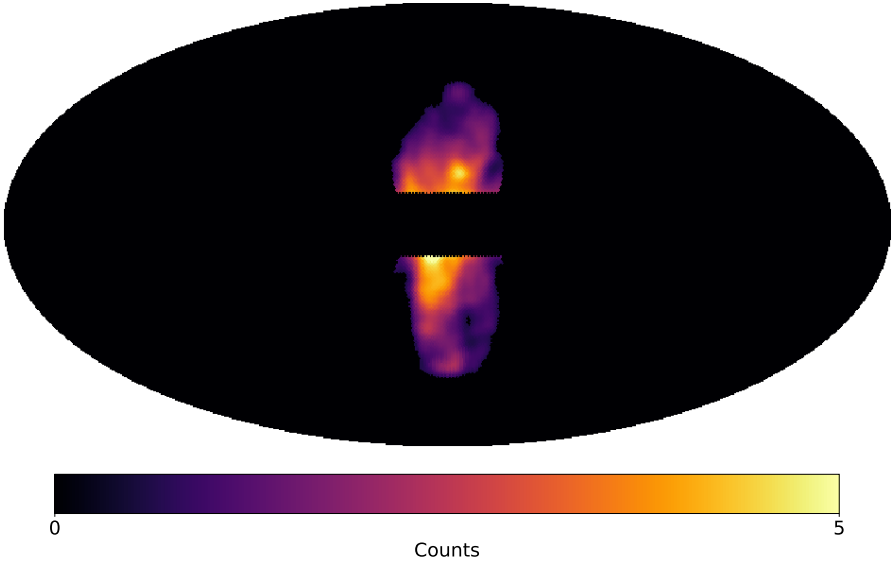
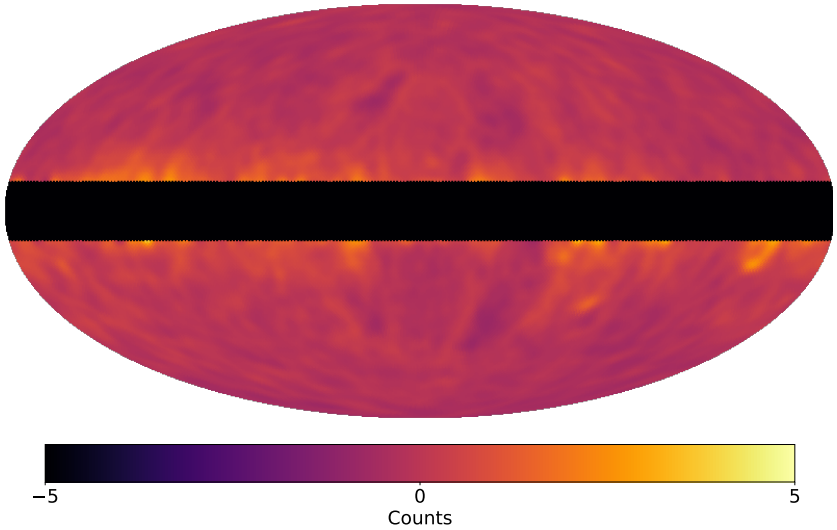
Analysis | Determining the Fermi Bubble spectrum

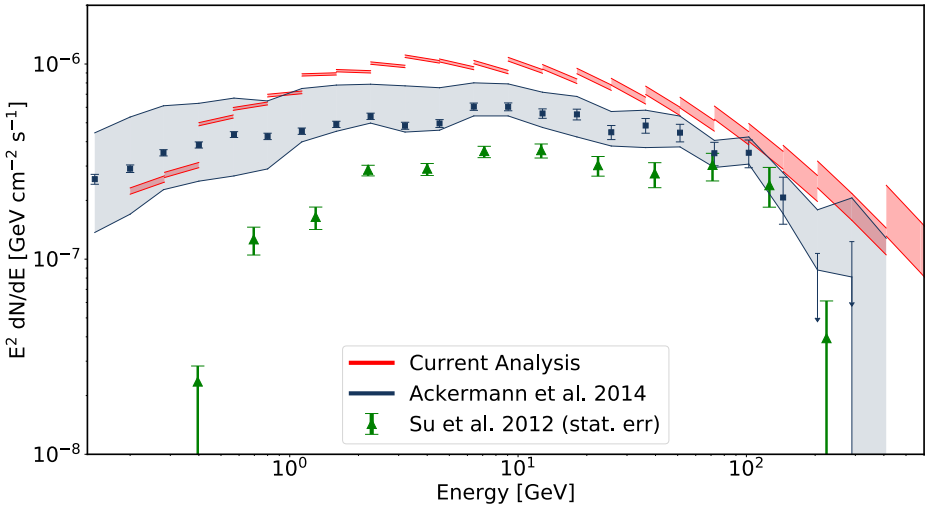
- **Use residuals to create Fermi Bubble template**
- **Include template in diffuse source model**
- **Fit new model to data**



Results



Residuals after fit with Fermi Bubble template



Spectrum of the Fermi Bubbles including results from previous analysis

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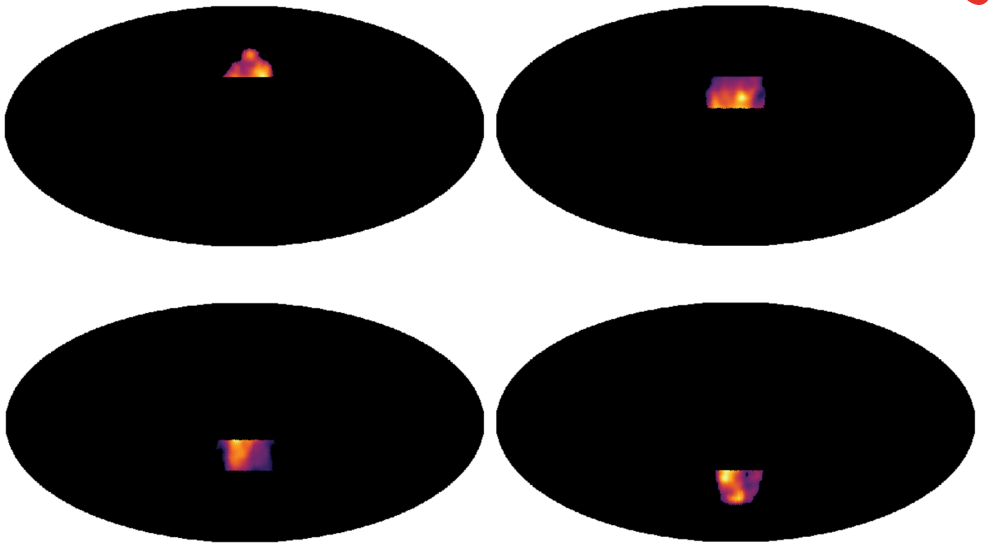
Further Analysis

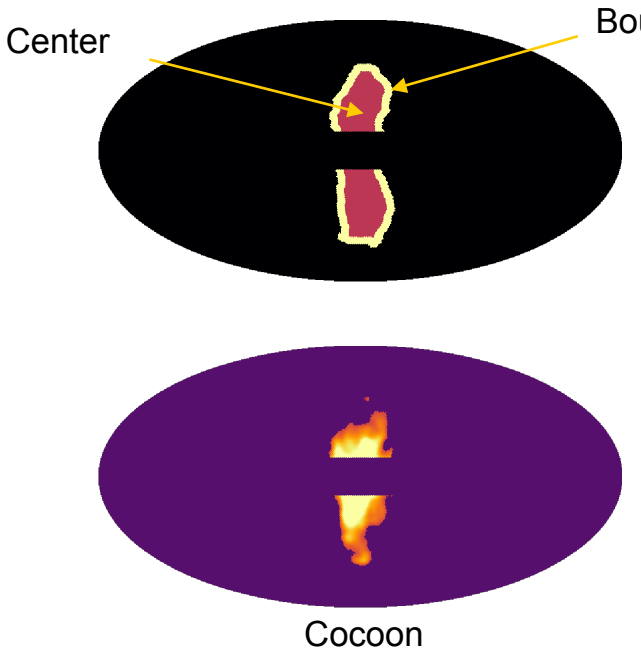
Work in Progress



- Split template into latitude strips
- Check for latitude dependency of spectrum
- Compare northern and southern bubble

Further Analysis

Work in Progress



- Looking for spatial variation of spectrum
  - Fit separate template for bubble boundary and center regions
  - Individual template for the “Cocoon”

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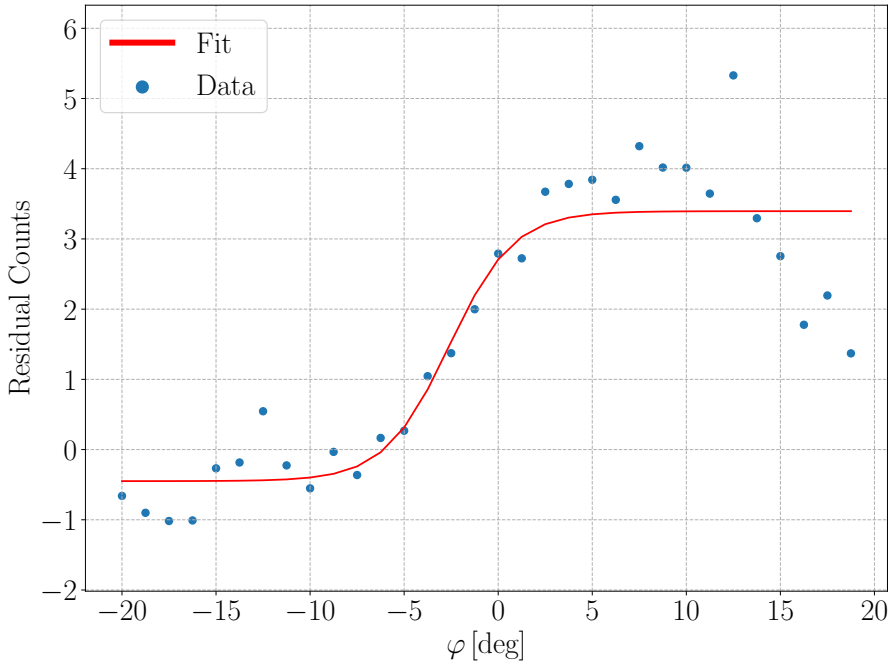
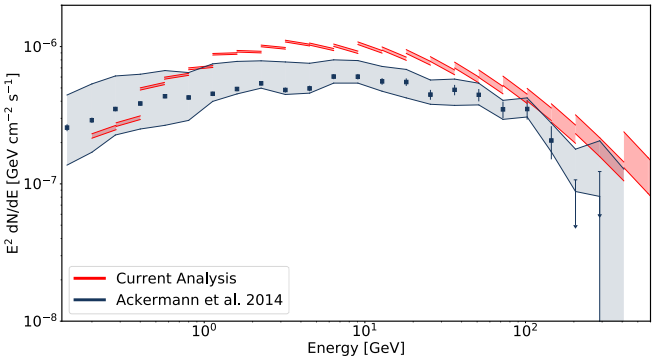
Analyse the bubble edges



- Check for energy dependency
- Only looking at southern bubble
- Split into western, southern and eastern region
- Use method laid out by Dmitry Malyshev
  - Fit smoothed step function to strips perpendicular to edge
- Still working on evaluation

Conclusion and Outlook



CRPropa

- Analysis still ongoing ⟶ initial results seem to confirm results from previous analysis
- Updated diffuse emission models
  - Current result show only baseline model
- Much larger dataset ⟶ Improved statistics for analysis of smaller structures
- Analysis of Fermi Bubbles close to GC planned
- Use of CRPropa simulations in future analysis planned

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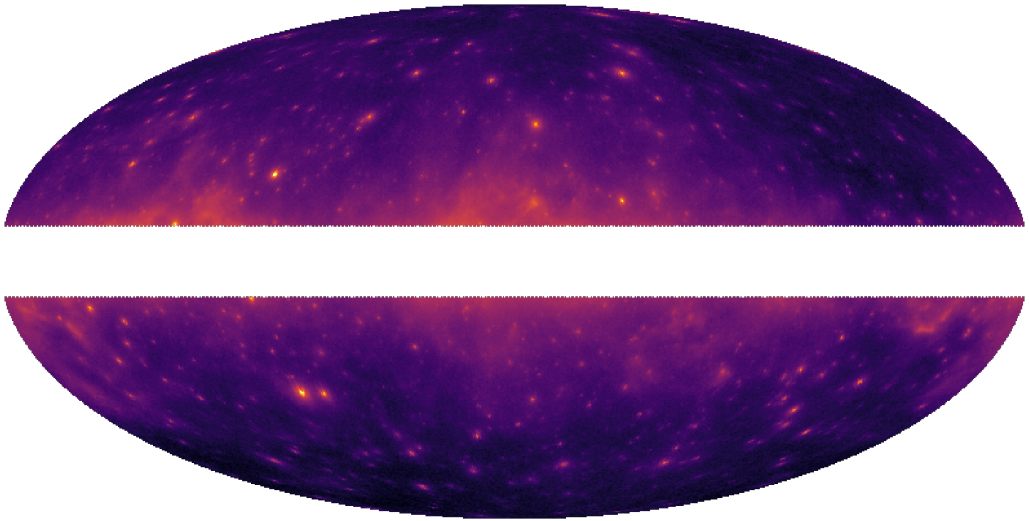
Analysis | Data



- Using 4FGL-DR3 (12 years of data)
- ULTRACLEANVETO class
  - SOURCEVETO considered
- 50 MeV - 1.6 TeV