Observation of the High Energy Gamma-ray Emission towards the Galactic Center

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On behalf of the Fermi LAT Collaboration

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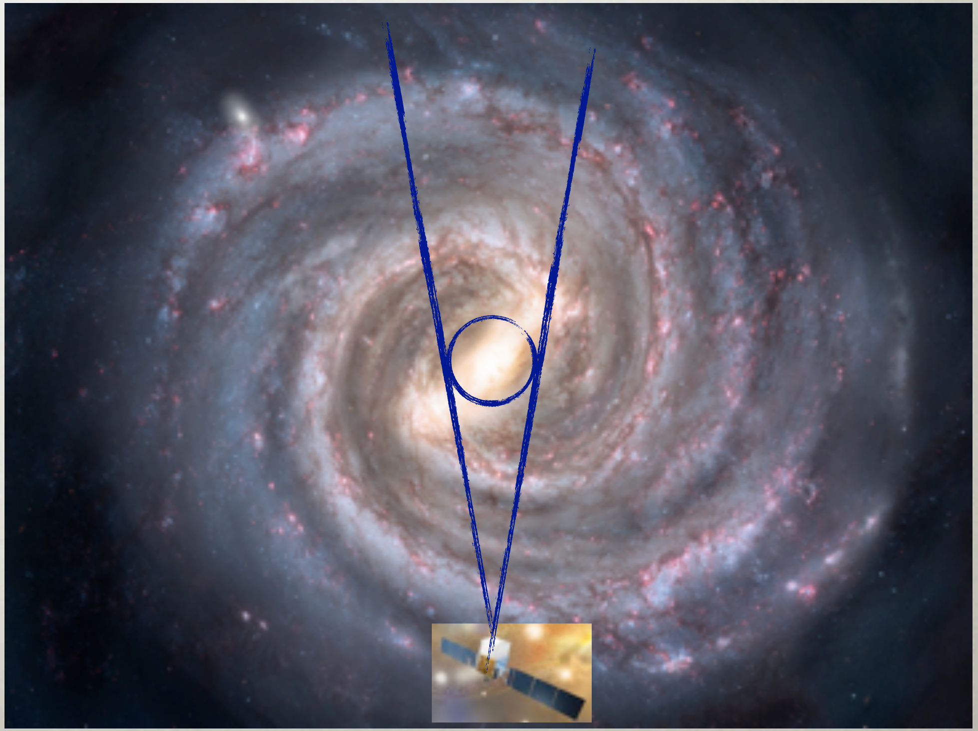
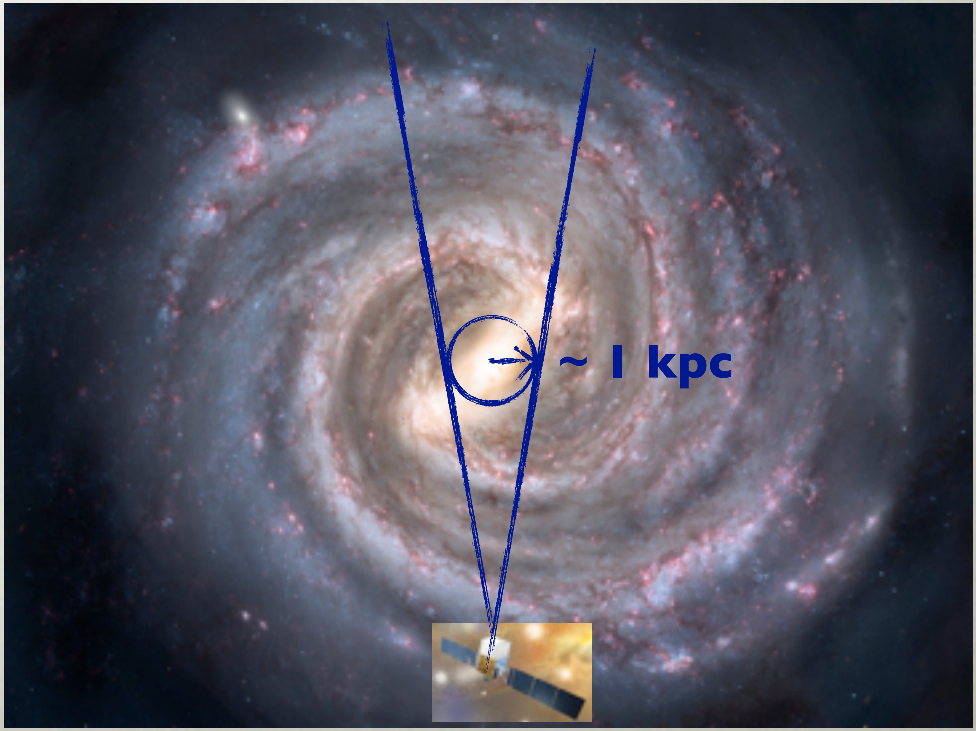
Galactic Center Region

- Complex region: CR intensities, density of radiation fields and gas are highest; large uncertainties modeling the gamma-ray interstellar emission, significant foreground/background contribution with long integration path over the entire Galactic disc
- Large density of gamma-ray sources: many energetic sources near to or in the line of sight of the GC, difficult to disentangle from interstellar emission
- A signal of new physics (dark matter annihilation/decay) is also predicted to be largest here
- Claims of a potential signal of dark matter annihilation from this region have been made by several groups in the past few years (see next talk and Thursday afternoon session on the Galactic center)



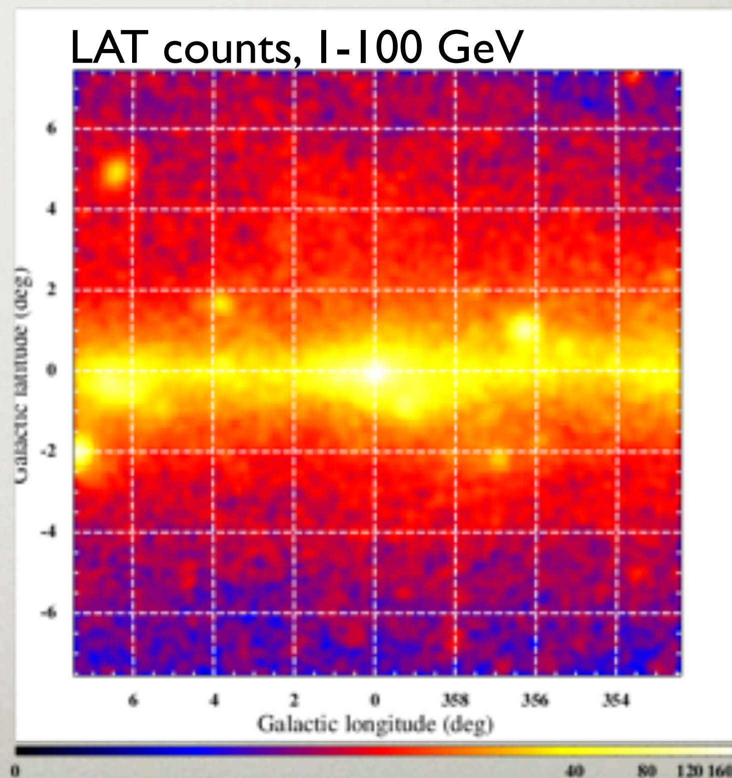
Galactic Center Region

- Focus on a 15°x15° region (~ 1 kpc) around Galactic center



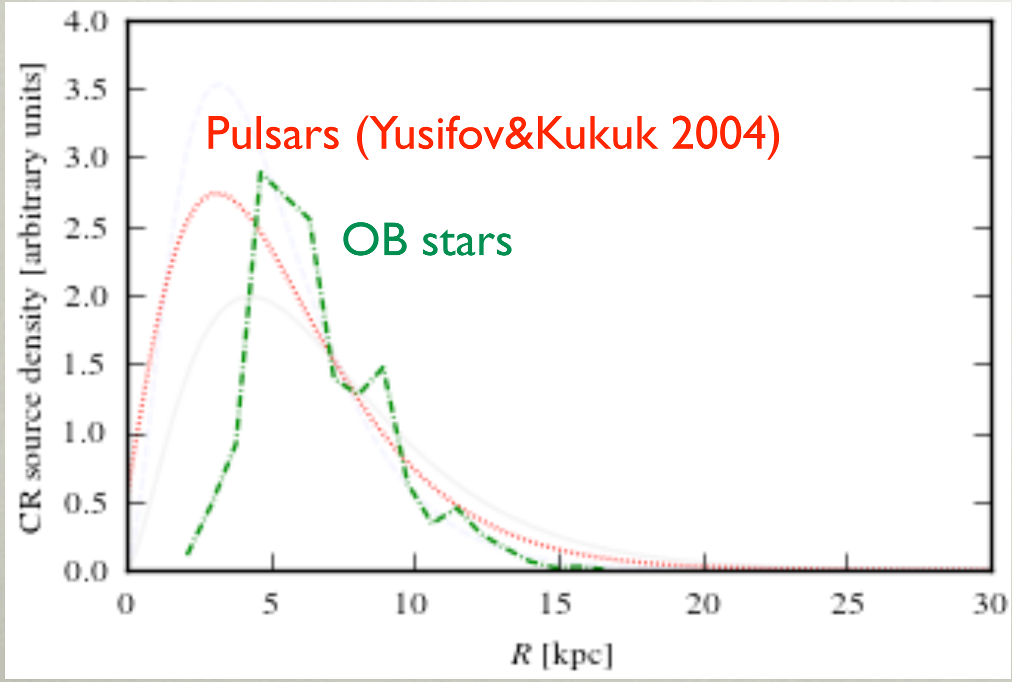
Galactic Center Region

- Focus on a 15°x15° region (~ 1 kpc) around Galactic center
- Data selection: 1-100 GeV, CLEAN class, FRONT converting events (large effective area and narrow PSF); PASS 7 reprocessed; 62 months.

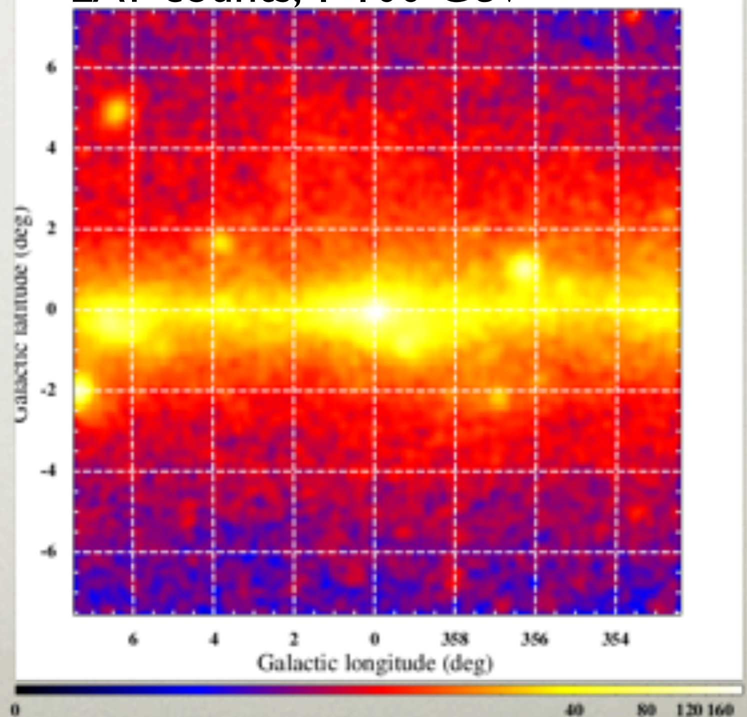


Modeling the Interstellar Emission

- Interstellar emission models: use GALPROP models with prop. parameters consistent with CR data and in good agreement with all-sky gamma-ray data, from *Ackermann et al, 2012, ApJ 750*. Select two models with broad range in the radial extent of the CR source distribution (Pulsars, OB stars) as baseline
- Tune the baseline models to gamma-ray data outside of the ROI for improved foreground/background determination



LAT counts, 1-100 GeV



Background Tuning Procedure

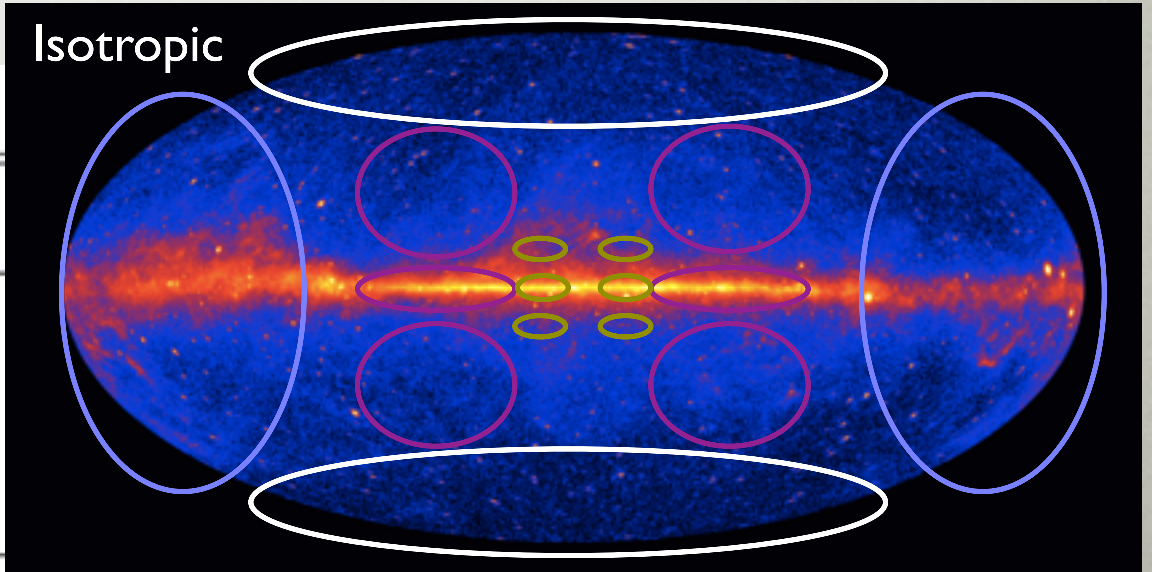
- Determine intensity for π^0 (from HI and H_2 gas) and IC contributions in galactocentric rings,
  - IC component divided in rings (dev. version of GALPROP), same boundaries as the gas: these additional degrees of freedom can compensate for uncertainties in the GALPROP model of the electron spectrum or ISRF used to calculate the IC templates
- Isotropic and Loop I (*Wolleben, 2007, ApJ 664*) emissions also fitted to the data
- Different sky regions are employed based on where the components that are fitted contribute most. Point source locations and spectra taken from the preliminary 3FGL.
- Regions containing structures not modeled or that might bias the fit results are not used to tune the IEM (Fermi bubbles, Cygnus region.)The 15°x15° region is also excluded

➡ Two tuning procedures: one adjusting intensity only, the other also allowing spectral adjustment (broken power law, break at ~2 GeV) for π^0 production within the solar circle. No freedom in IC spectrum

➡ Four variants for the foreground/background IEM: Pulsars/OB Stars, tuned intensity/index

Galactocentric ring boundaries.

Ring #	$R_{\rm min}$ [kpc]	$R_{\rm max}$ [kpc]	Longitude Range (Full)
1	0	1.5	$-10° \le l \le 10°$
2	1.5	2.5	$-17° \le l \le 17°$
3	2.5	3.5	$-24° \le l \le 24°$
4	3.5	8.0	$-70° \le l \le 70°$
5	8.0	10.0	$-180 \le l \le 180°$
6	10.0	50.0	$-180 \le l \le 180°$

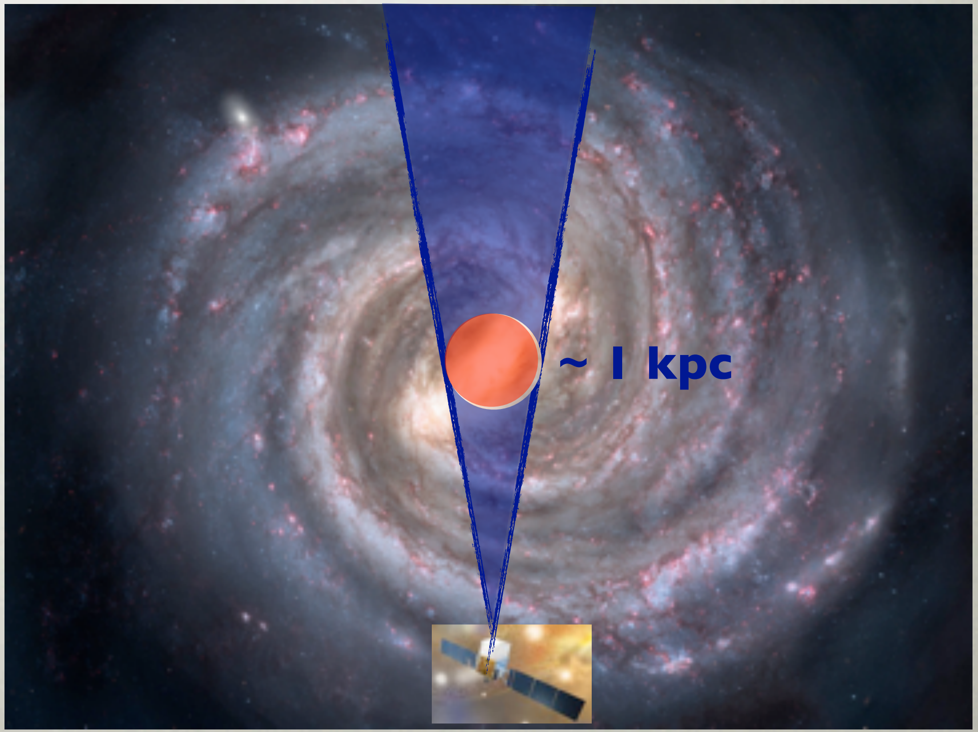


Modeling the 15°x15° ROI

- Model the emission from the 15°x15° ROI for each of the 4 foreground/background models
- Point sources in the region are determined consistently with these models - we do not use existing catalogs
    - identify preliminary locations of point source candidates by applying *PGWave* (*Damiani et al. 1997, ApJ, 483* wavelet algorithm, assumes flat background) to the data in 4 equally spaced LogE bins in the1-100 GeV range
    - for each of the (fixed) models, determine position and initial values of the spectra of the point source candidates (*Pointlike*)
    - obtain list of point source candidates with TS>9 for the analysis of the 15°x15° ROI

➡ Intensities for the innermost ring for HI/H_2 π^0, and IC are determined by fitting the data in this region concurrently with the point source candidates. Fore/background models held fixed

- Repeat procedure twice, until no significant point-like excesses are left in the residuals
- Bremsstrahlung and HII π^0 emissions are subdominant and are fixed to GALPROP prediction

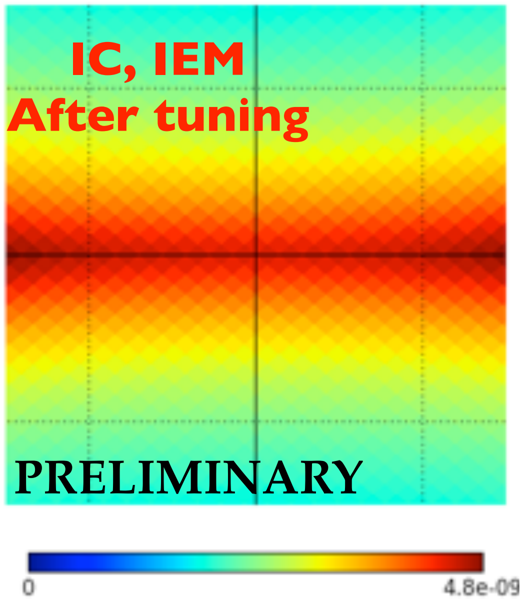


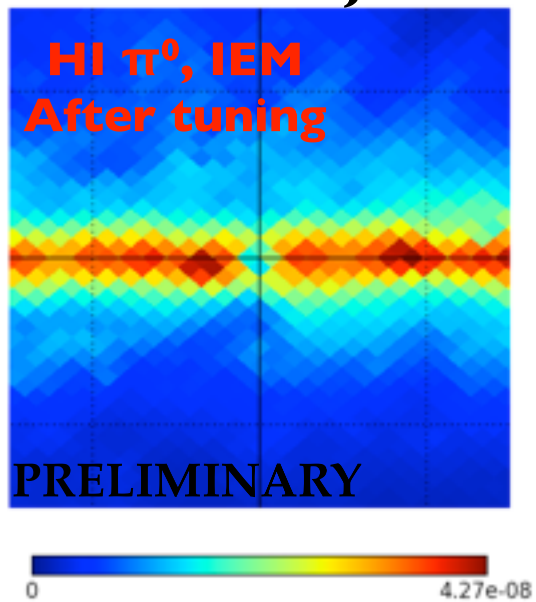
Model Intensities

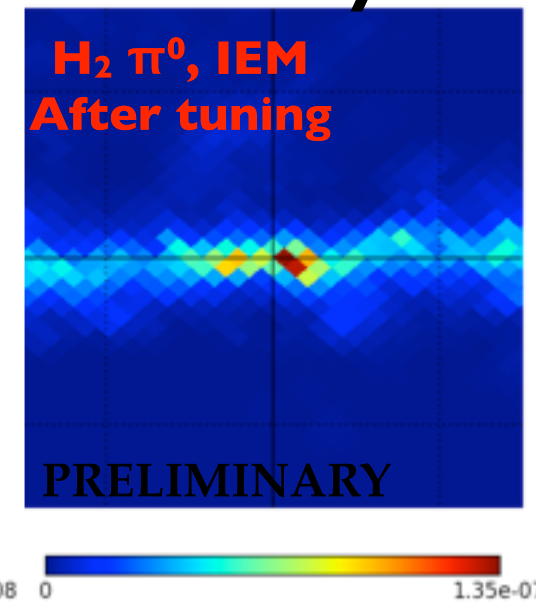
Fixed in 15°x15° fit:

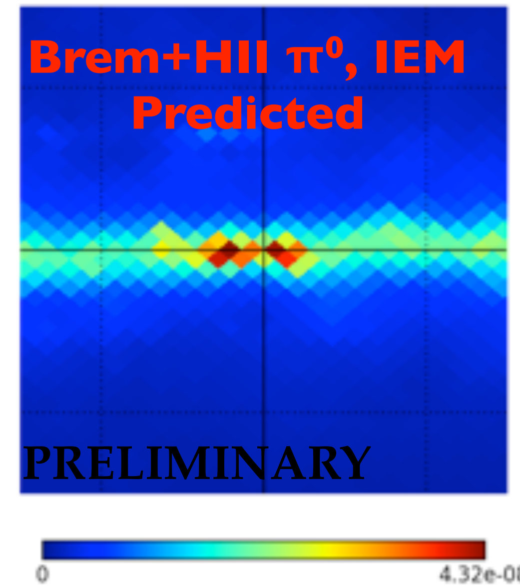
Pulsars, tuned intensity

Units: $MeV^{-1}\ cm^{-2}\ s^{-1}\ sr^{-1}$

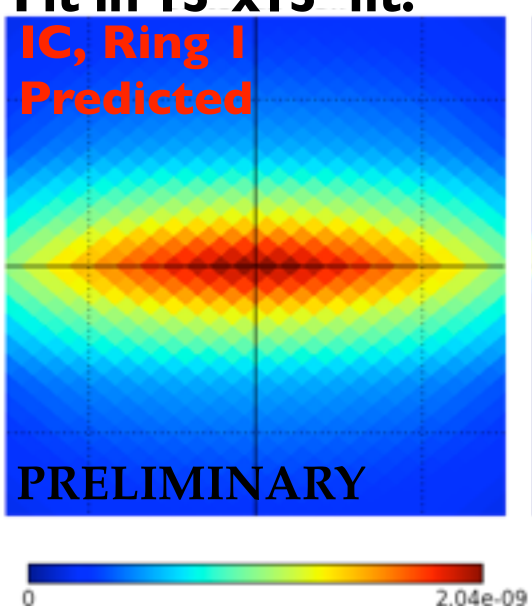


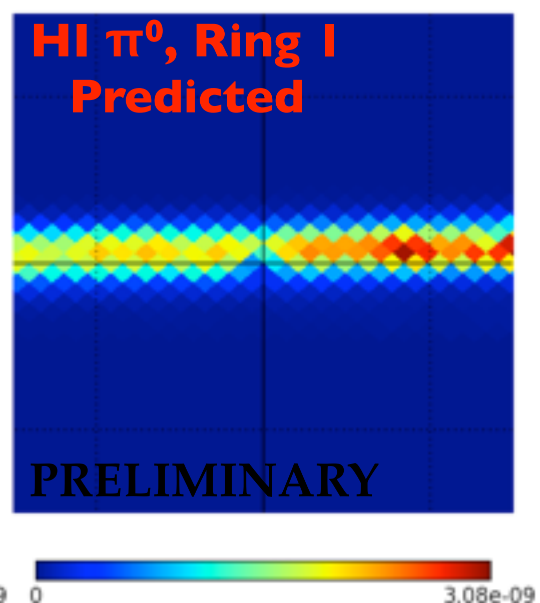


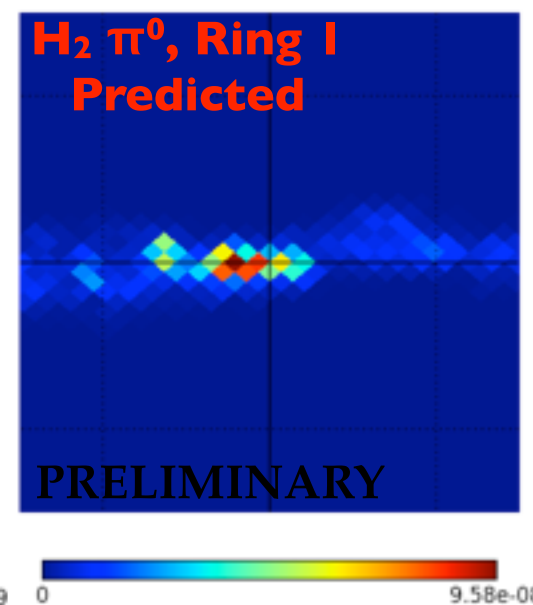




Fit in 15°x15° fit:







<u>IEM refers to foreground/ background model</u>

15°x15° ROI

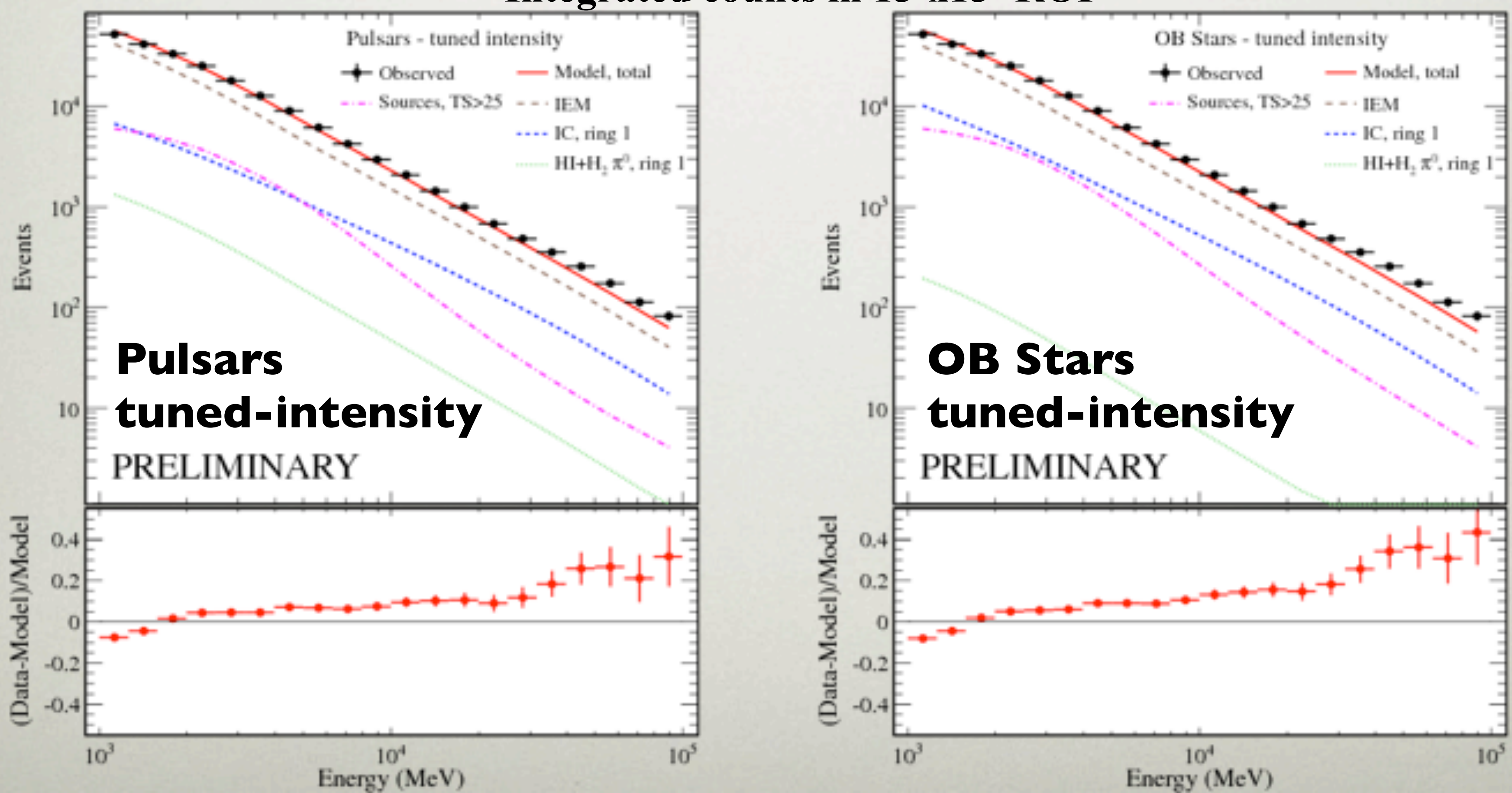
E>1 GeV

~0.23° pixels

RESULTS

- The foreground/background accounts for most of the emission in the region.
- The data-model agreement is within 5-10% averaged over the 15°x15° ROI up to ~ 10 GeV. The models are too bright below ~2 GeV, and too dim above

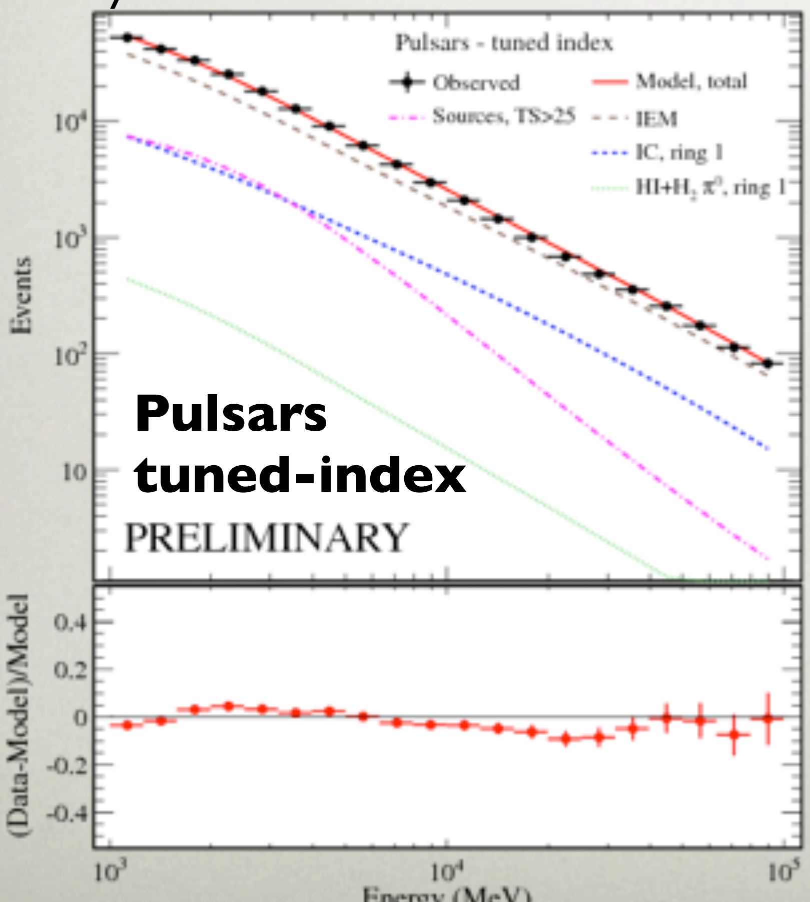
Integrated counts in 15°x15° ROI

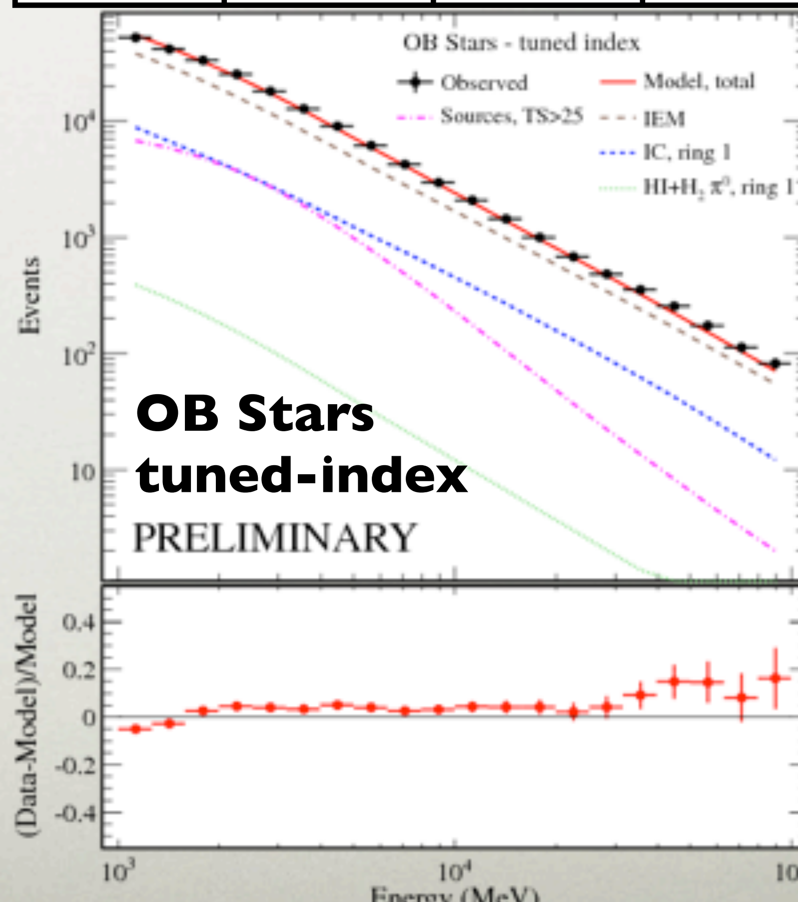


Results

- Agreement is better for tuned index models
- ➡ For all foreground/background models, the fitted IC emission for ring 1 is brighter than the gas emission and larger (7-30x) than predicted from GALPROP for the baseline models. This could be due to higher intensity of ISRF and/or higher CR lepton intensities than assumed
- Point source contribution comparable to IC
- HI/H_2 pi0 intensities are subdominant and less than predicted by GALPROP for the baseline models

Integrated flux in 15^ox15^o ROI, E>1GeV, 10^{-8} ph cm^{-2} s^{-1}			
IC, Ring 1	π^0, Ring 1	IC, IEM	π^0, IEM
41-59	1-8	**24-33**	151-164





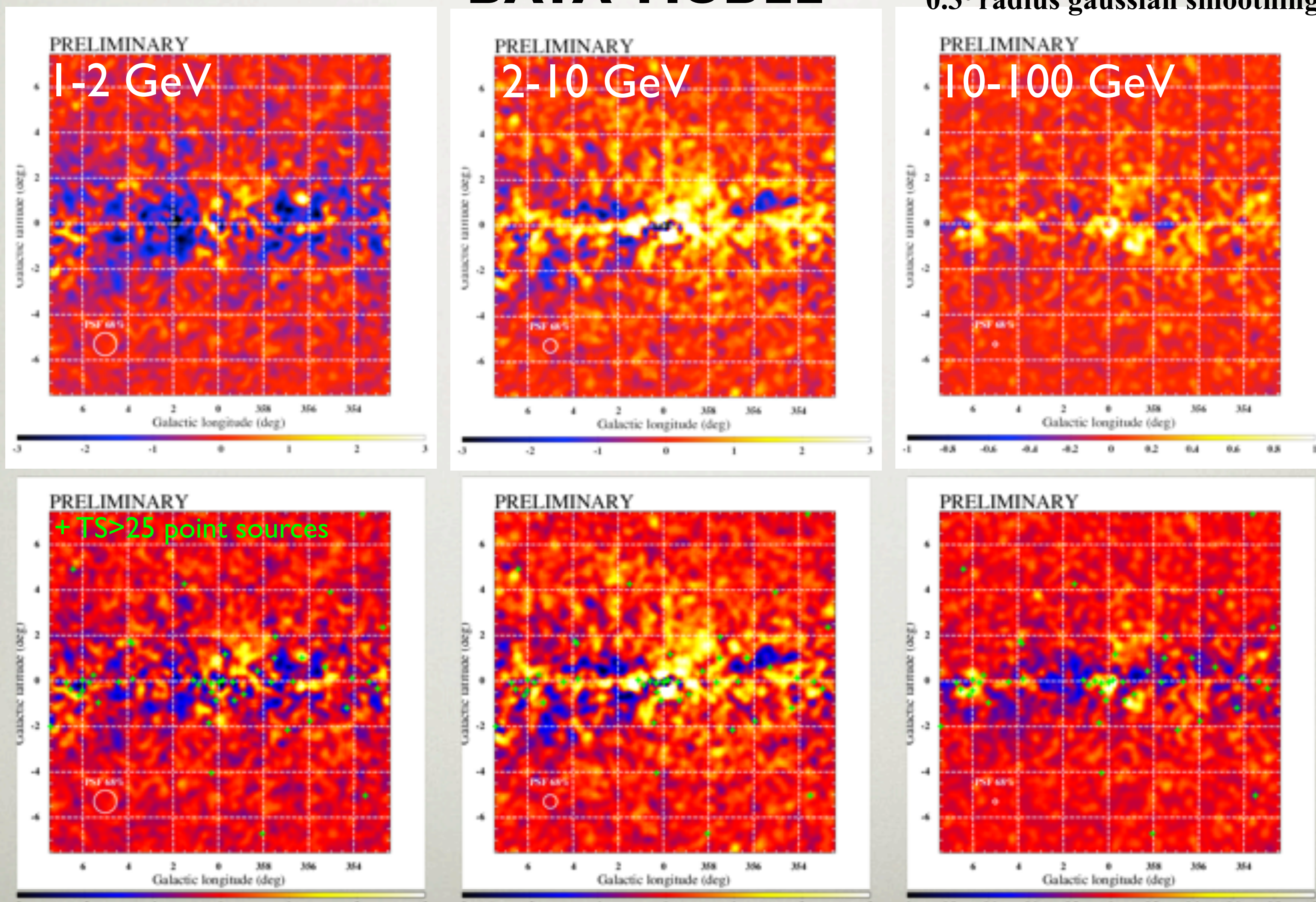
Results - Residual Maps

DATA-MODEL

Counts in 0.1°x0.1° pixels
0.3° radius gaussian smoothing

Pulsars, tuned-intensity

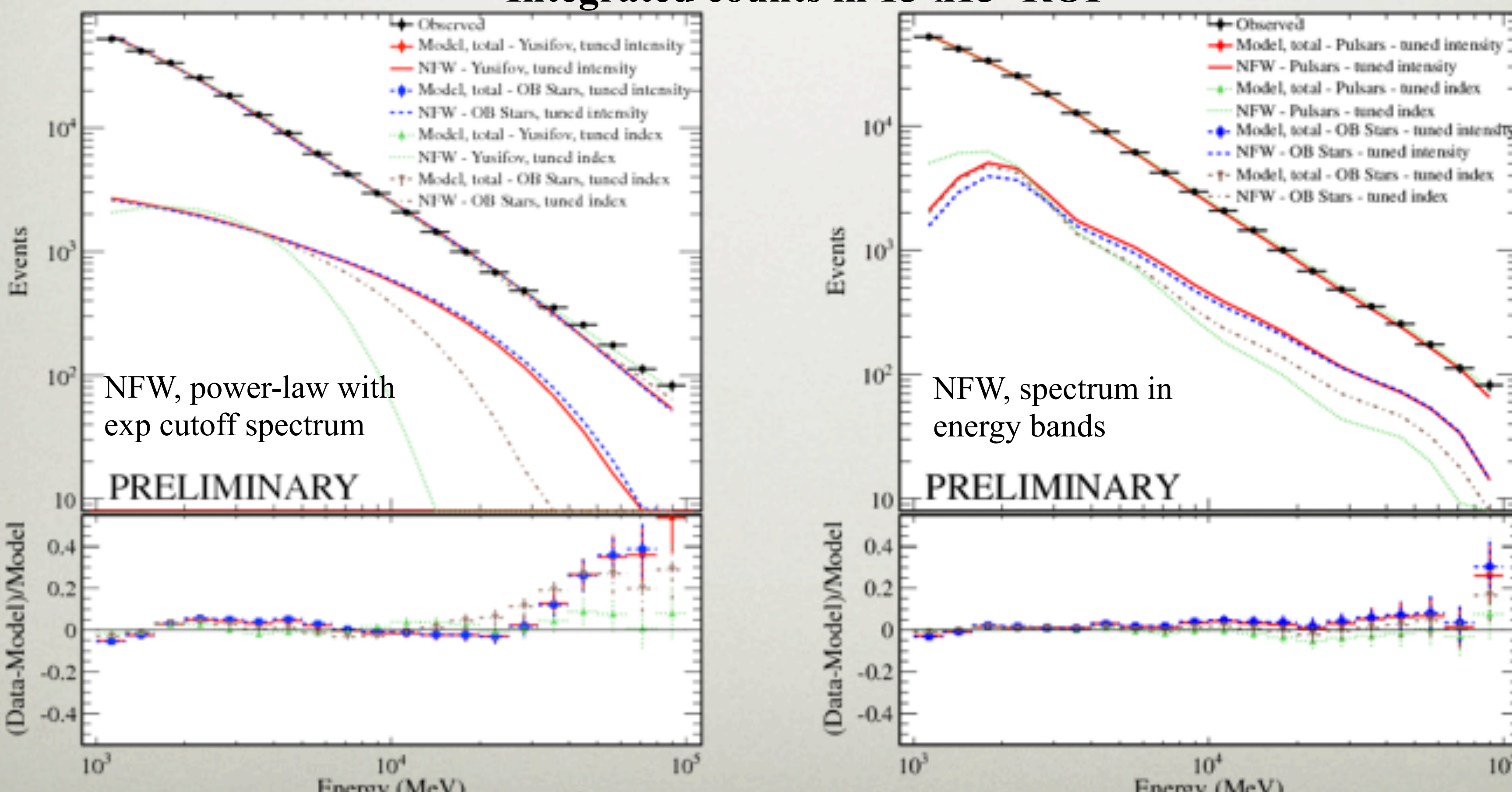
Pulsars, tuned-index



Additional Templates

- We test the possibility that an additional component centered at the GC contributes to the data (2D gaussians, Navarro-Frenk-White, or a gas-like distribution as proxy for unresolved sources)
- Peaked profiles with long tails (NFW, NFW contracted) yield the most significant improvements in the data-model agreement for the four variants of the foreground/background models. IC ring 1 contribution ~2-3x smaller than without additional component and HI ring 1 contribution is ~2-5x larger
- ➡ The predicted spectrum depends on the foreground/background models.

Integrated counts in 15^ox15^o ROI



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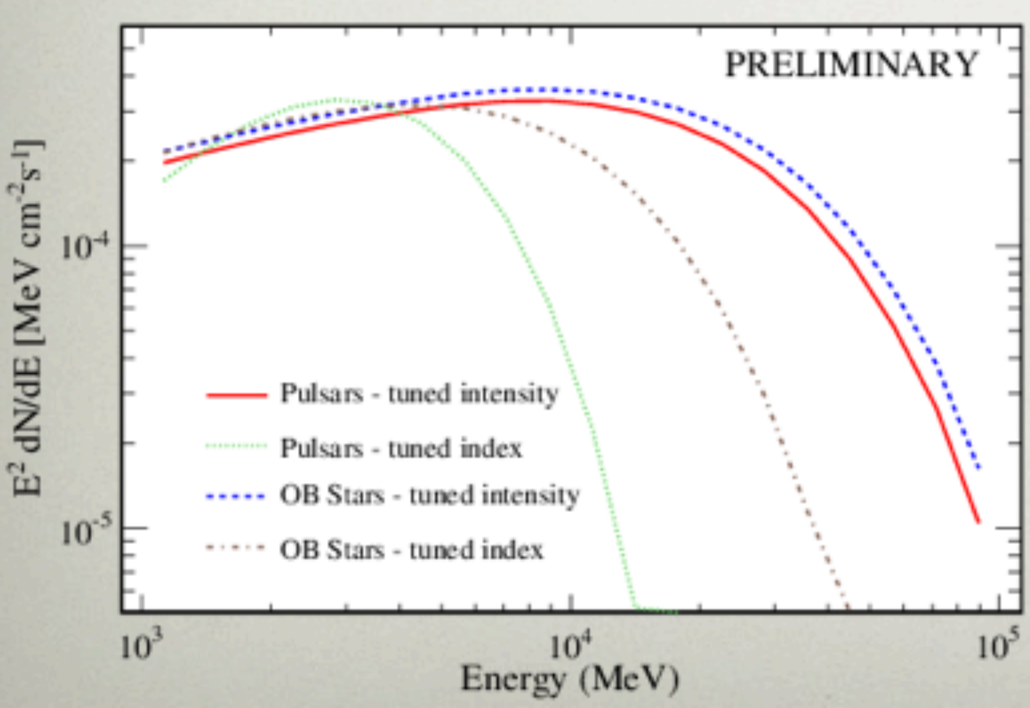
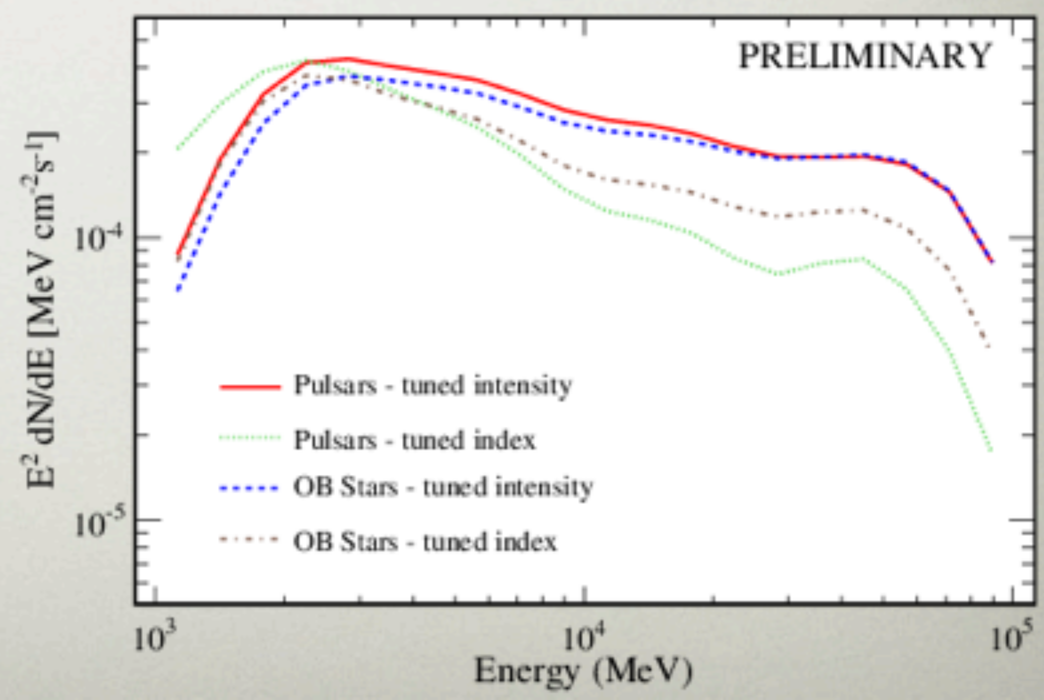
- ➡ The predicted spectrum depends on the foreground/background models.

Integrated flux in 15°x15° ROI, NFW component





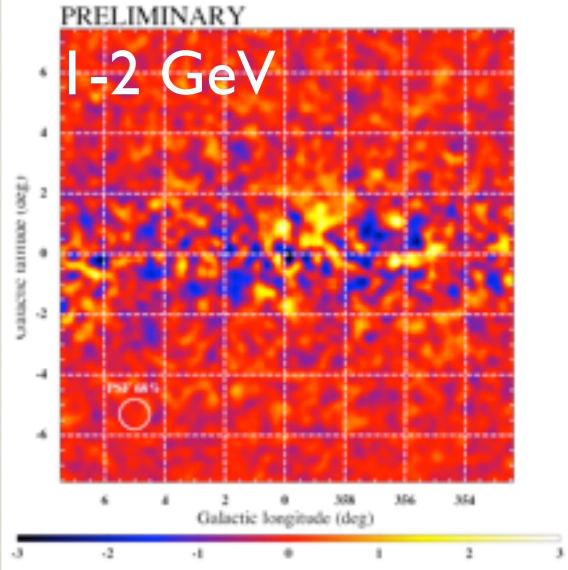
Additional Templates

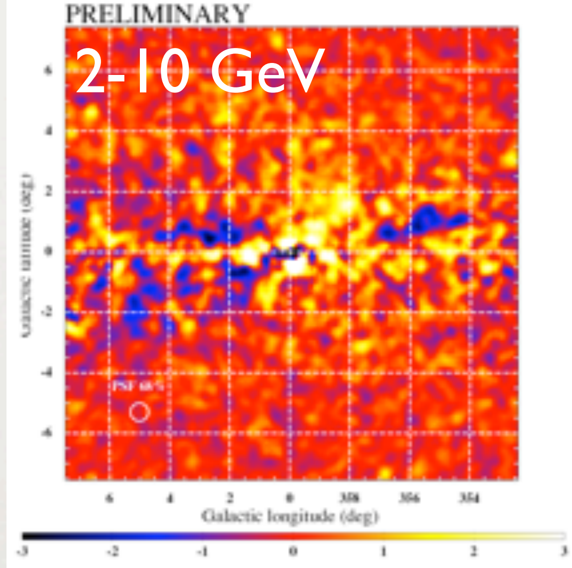
Counts in 0.1°x0.1° pixels
0.3° radius gaussian smoothing

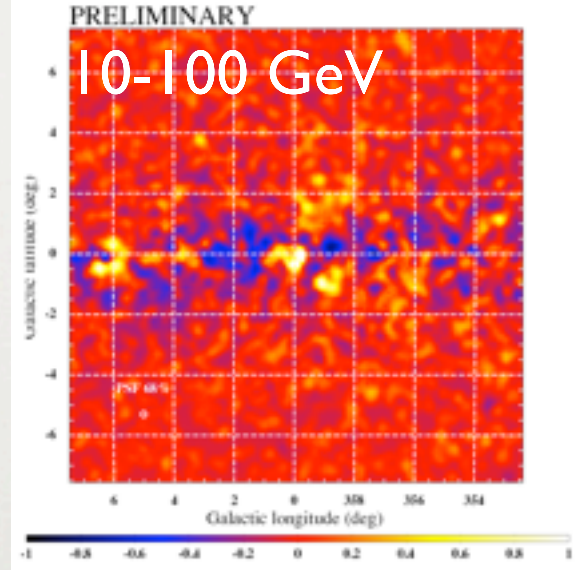
Without NFW:

DATA-MODEL

Pulsars, tuned-index

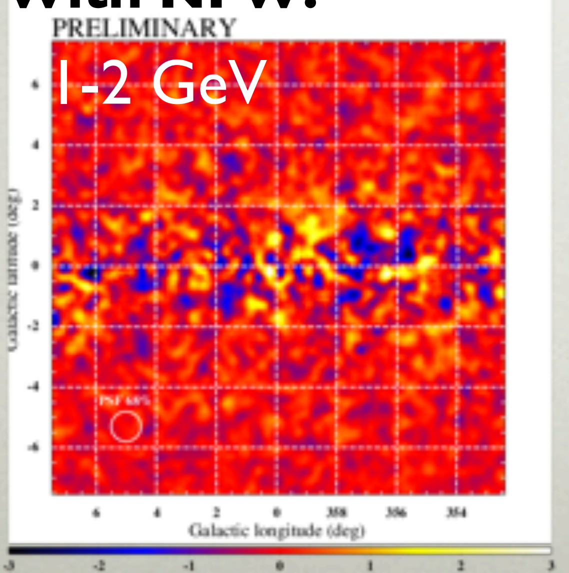


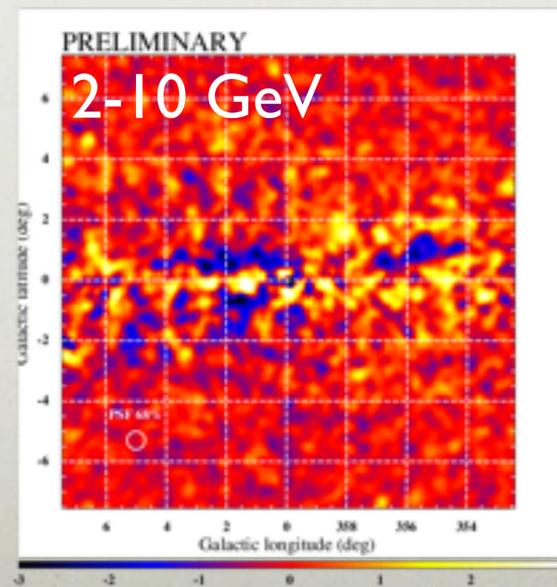


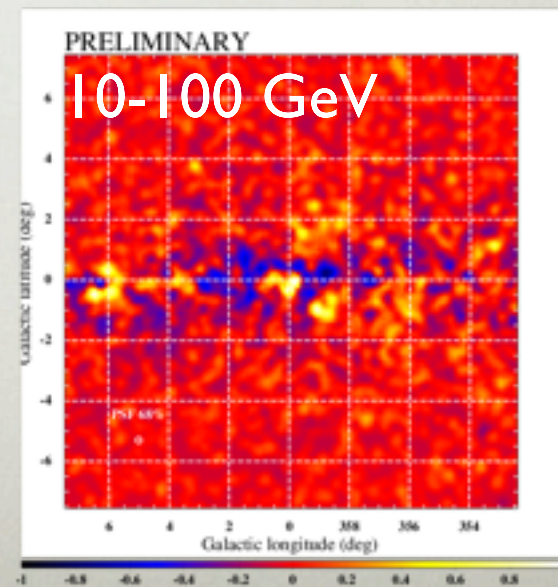


With NFW:

Pulsars, tuned-index







Summary/Conclusions

- We have systematically developed a set of models for the diffuse emission in the inner 15°x15° of the Milky Way, by fitting GALPROP-derived templates in a way not done before
- We determined the point sources as part of the development of this model
- We employ all sky data to constrain the foreground/background emission, excluding the 15°x15° region, <u>for different assumptions on the CR source distribution, gas intensity and spectral index, and IC intensity across galactocentric rings</u>
- We find:
  - IC emission from inner kpc is higher than predicted and is the dominant interstellar emission component in this region. We are exploring the origin of the enhanced IC in the IG to see what combination of ISRF and CR leptons best explains the data.
  - We find an enhancement approximately centered the Galactic center with a spectrum that peaks in the GeV range, that persist across the models we have employed. The spectral properties vary widely depending on the modeling of the interstellar emission
  - Foreground/background accounts for most of the emission. Its determination is crucial in extracting the contribution from the Galactic center region

➡ We are further exploring the systematic uncertainties in the IEM, e.g. <u>gas distribution, ISRF, cylindrical symmetry</u>. This is crucial in determining properties of the IEM in the innermost kpc and to confirm the presence and properties of an additional component

Thank you!