

Cosmic Rays Interacting with Molecular Clouds in the Galactic Center

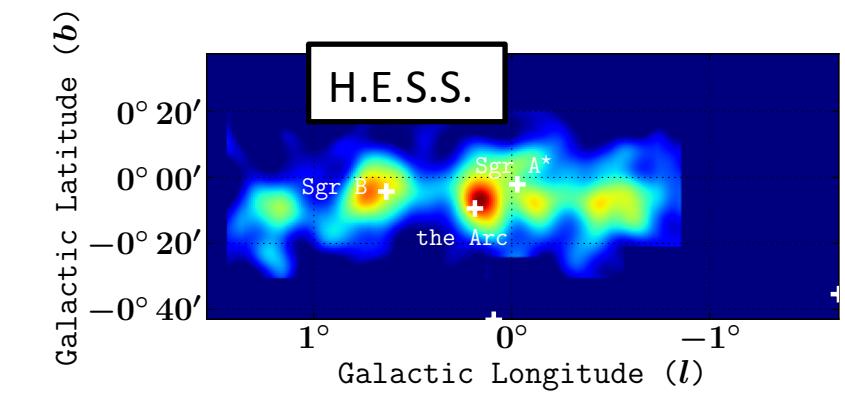
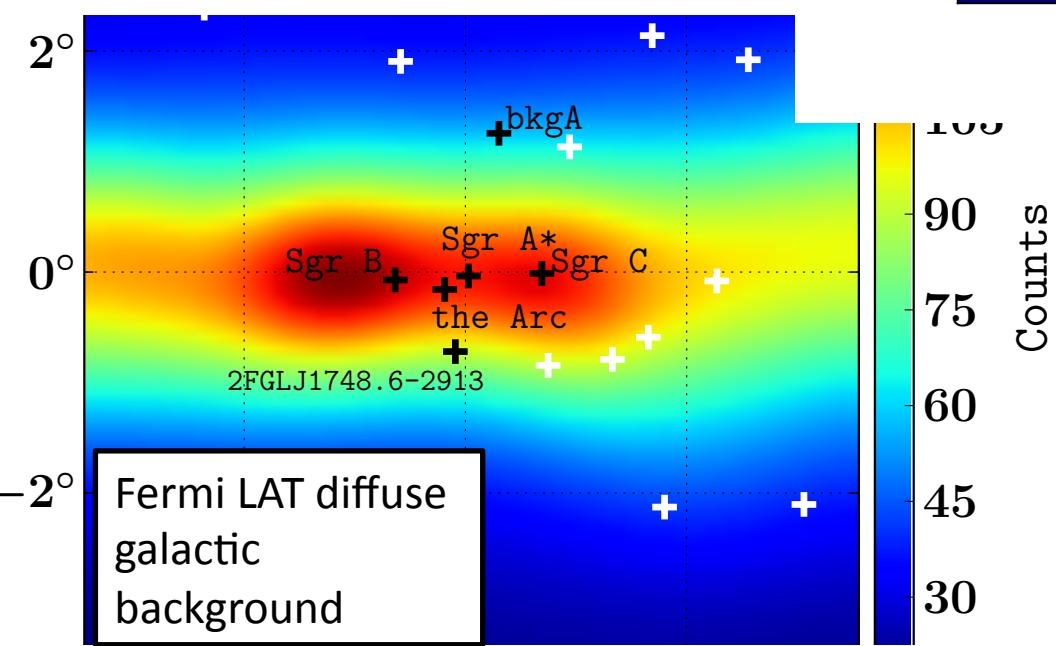
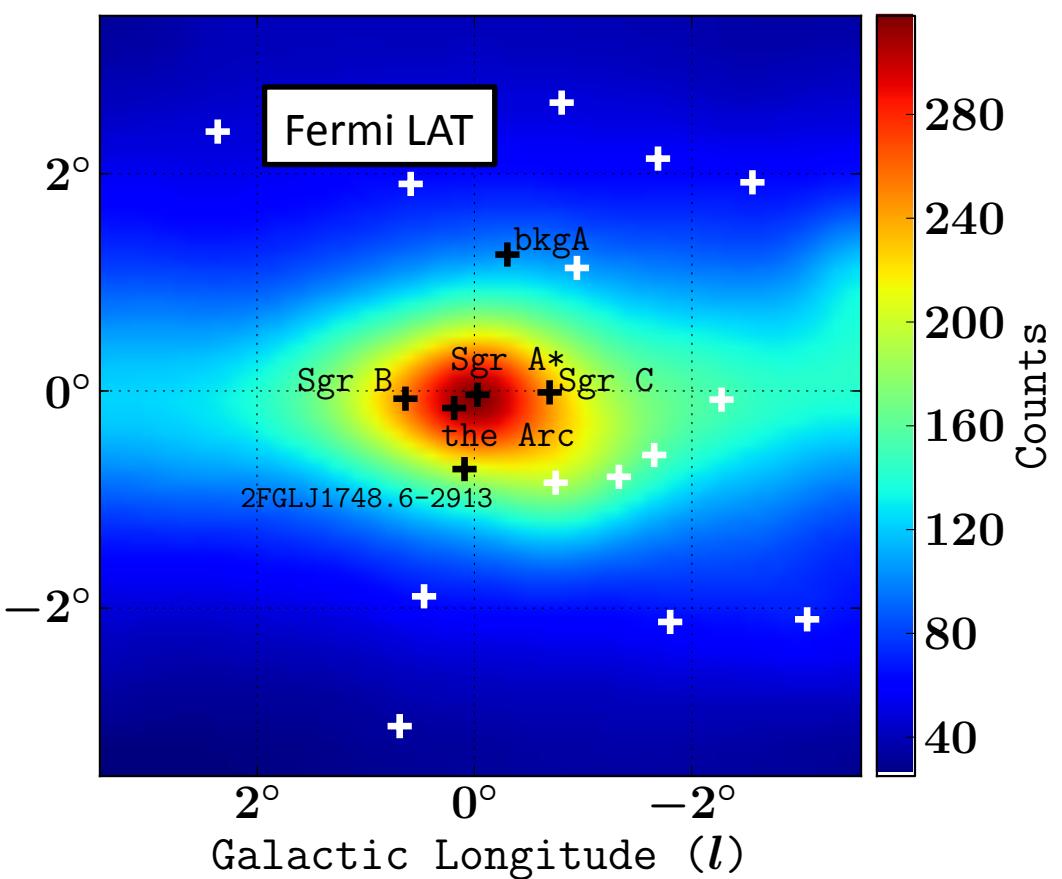
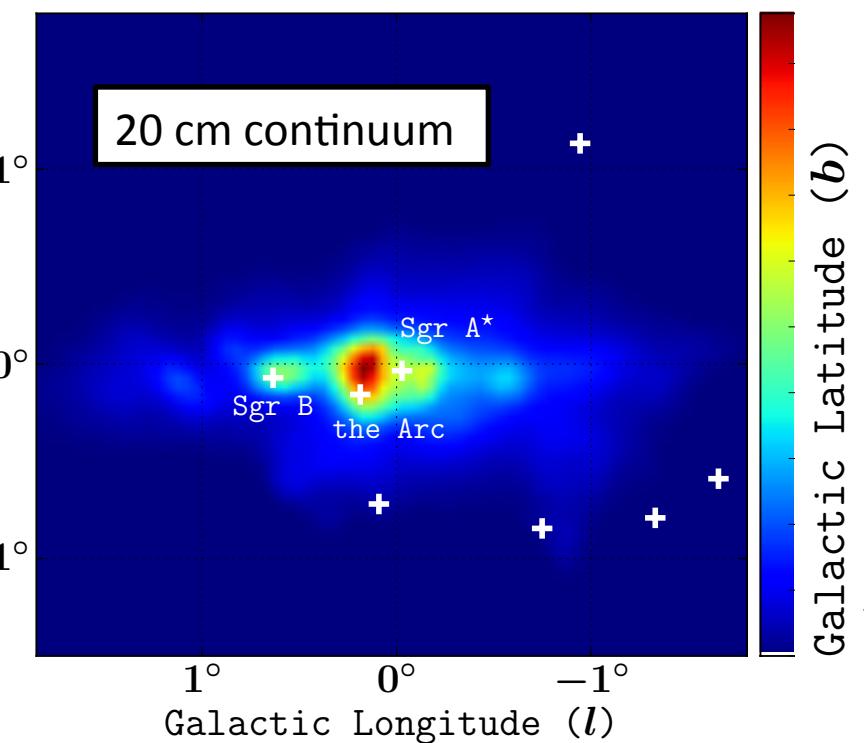
Chris Gordon

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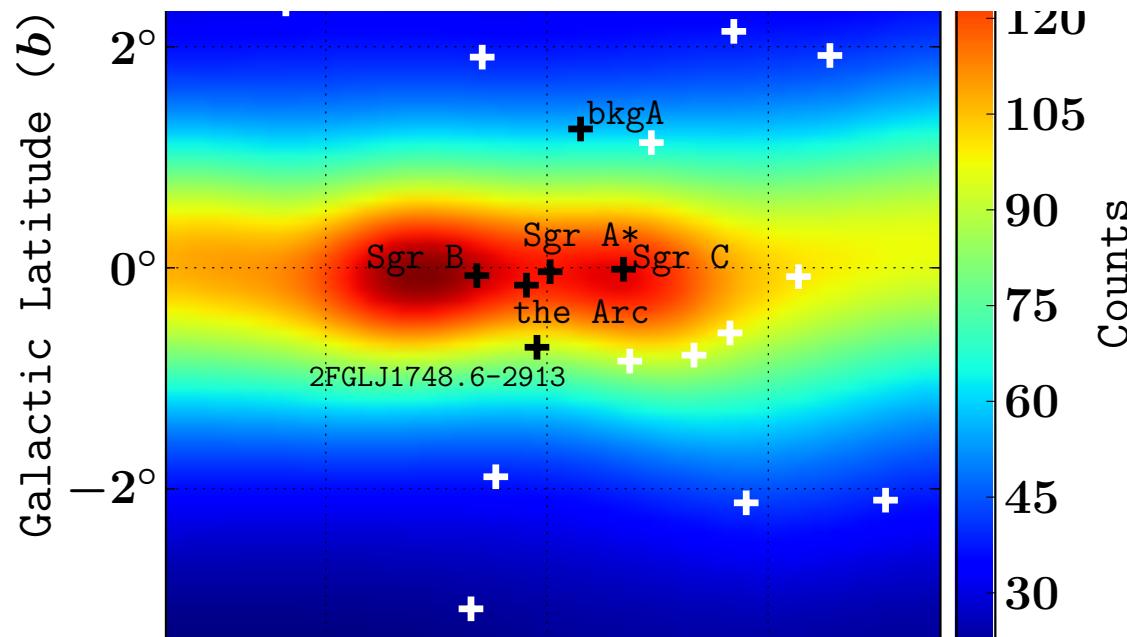
CG and O. Macias, Phys. Rev. D (2013)

O. Macias and CG, Phys. Rev. D (2014)

O. Macias, CG, R. Crocker, S. Profumo, MNRAS (2015)



Diffuse Galactic Background (DFGB)



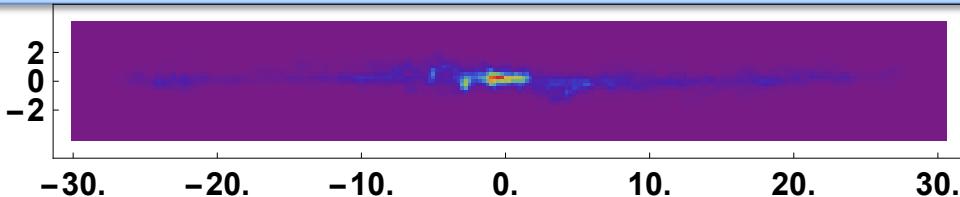
- Generated using gas column densities, and a GALPROP (Strong+2007) generated Inverse Compton (IC) intensity map.
- Effectively, assumes cosmic-ray population only varies on kpc scales.

Diffuse Galactic Background

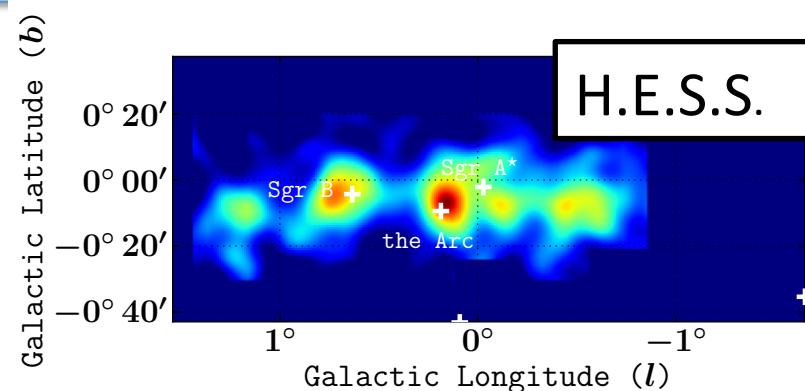
- Provided with Fermi Tools, pass 7:

$$N_{pred}(l, b) = \iint d\Omega_k \left(\sum_{i=rings} [q_{HI,i} N_{HI}(r_i, l_k, b_k) + q_{CO,i} W_{CO}(r_i, l_k, b_k)] \right. \\ \left. + q_{EBV} E(B - V)_{res}(l_k, b_k) + q_{IC} I_{IC}(l_k, b_k) + I_{iso}(l_k, b_k) \right) \epsilon(l_k, b_k) PSF(l, b, l_k, b_k) \\ + \sum_{j=sources} F_j \epsilon(l_j, b_j) PSF(l_j, b_j, l, b)$$

- First ring was from 0 to 4kpc.

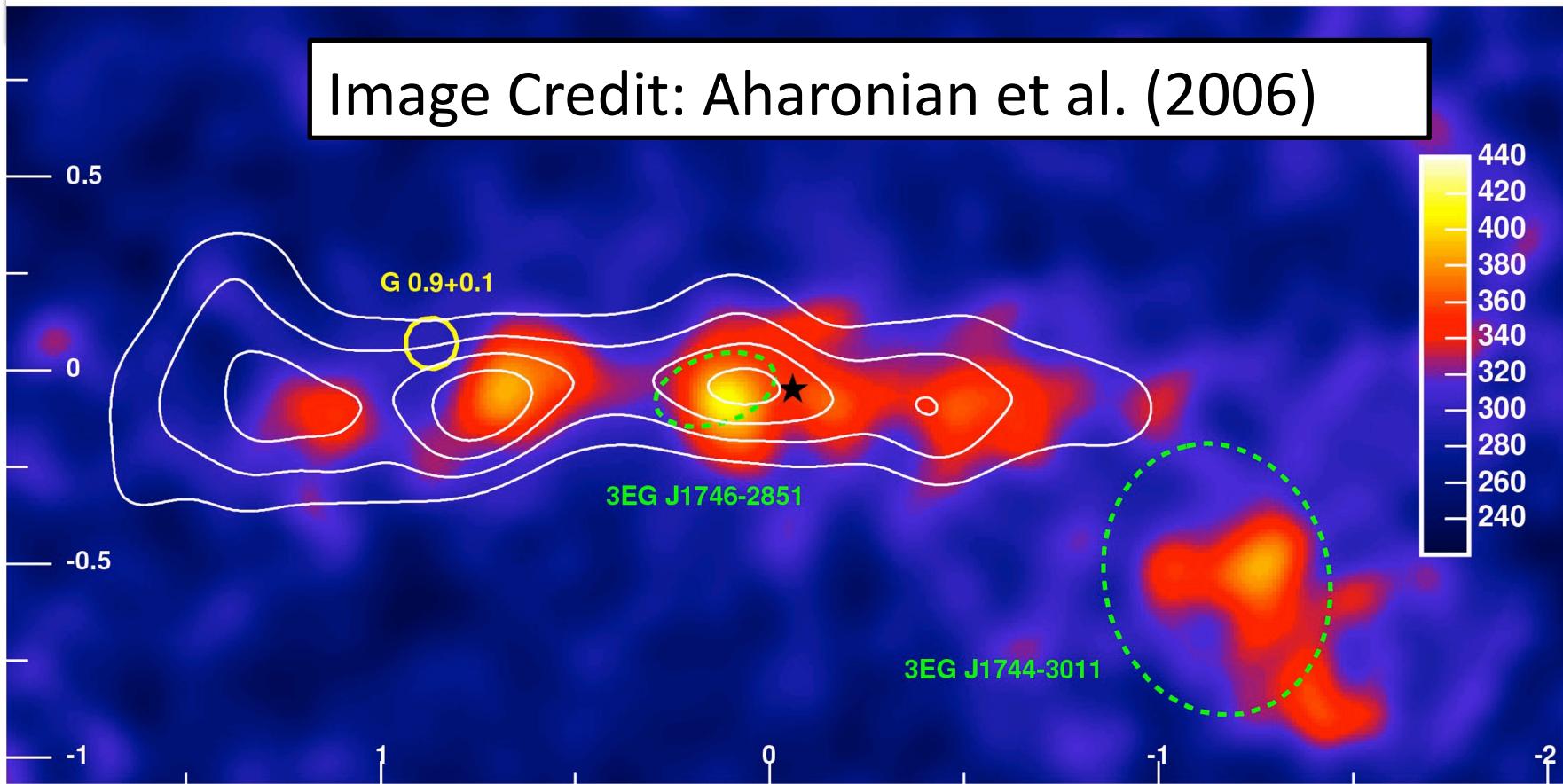


Fermi molecular gas column density



Galactic Center Ridge

Image Credit: Aharonian et al. (2006)

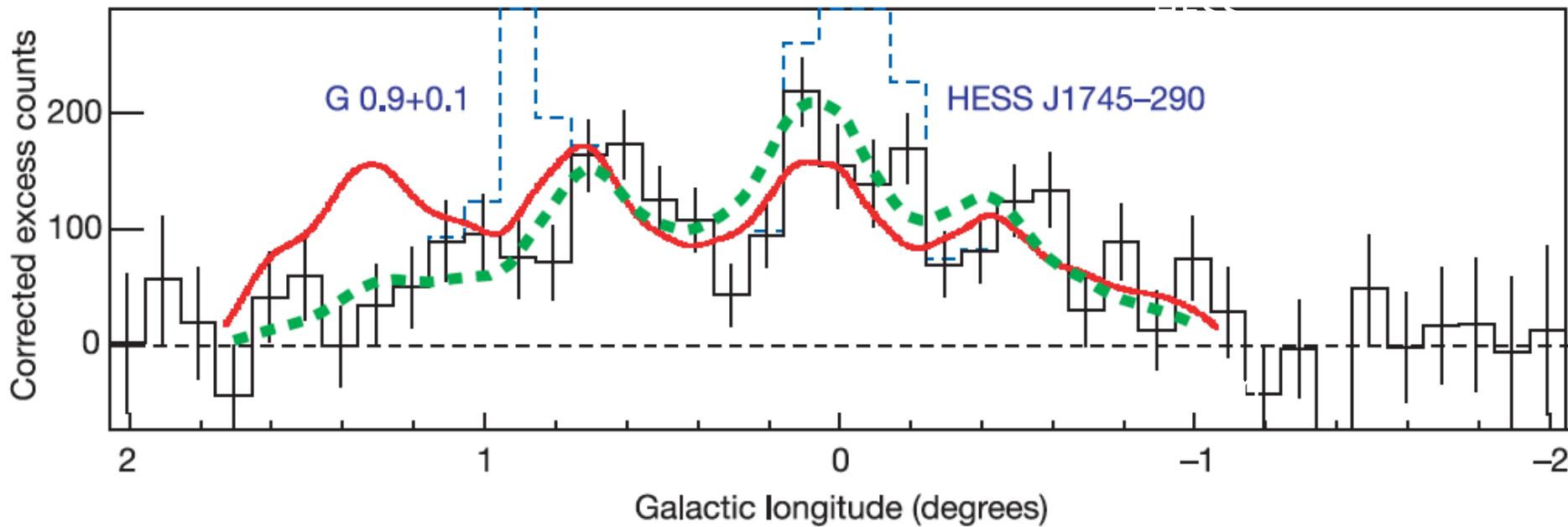


- Ridge seen in HESS TeV gamma-ray data.
- White contour lines indicate the density of molecular gas, traced by its CS emission.

Galactic Center Ridge

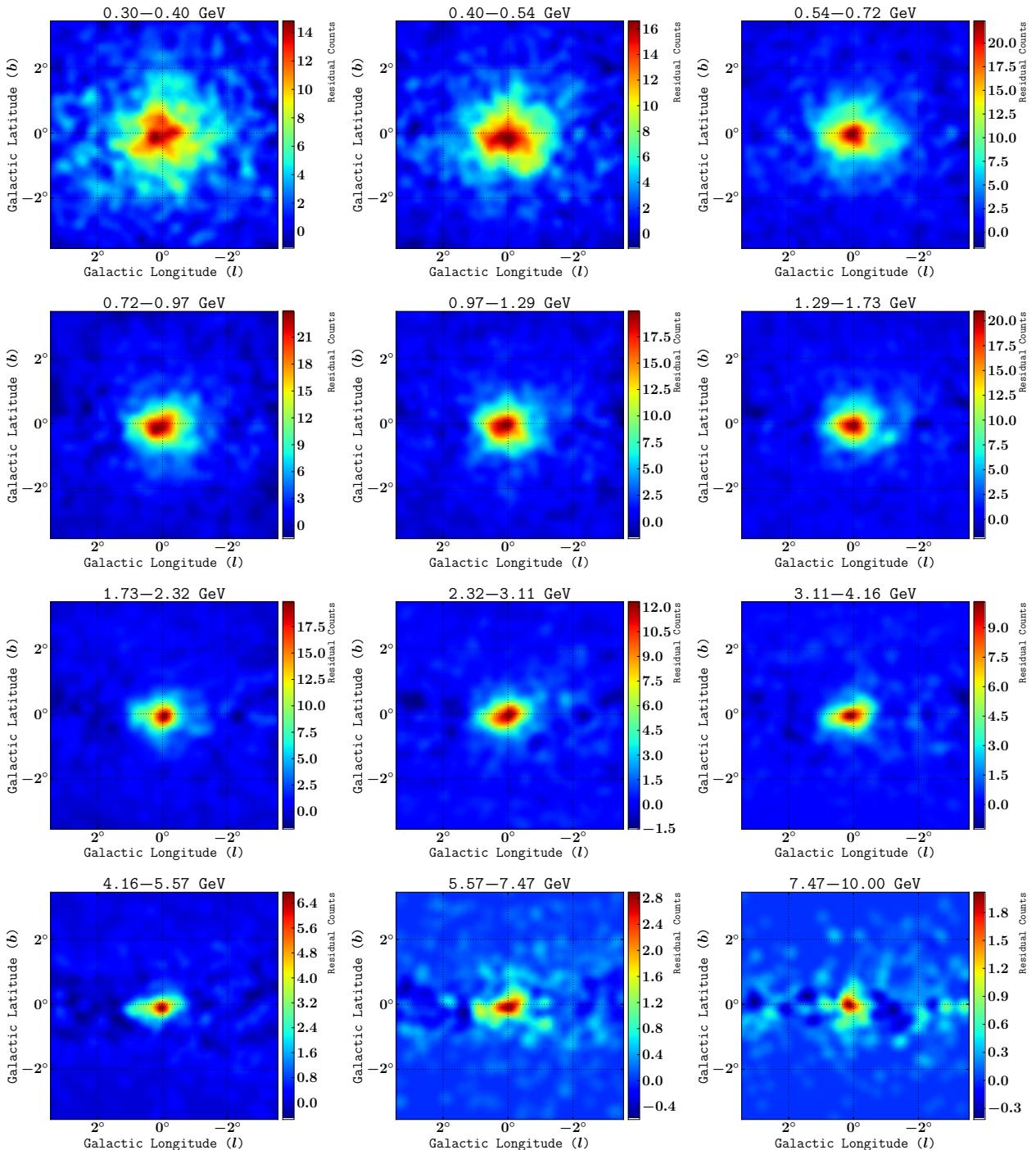
Image Credit: Aharonian et al. (2006)

b

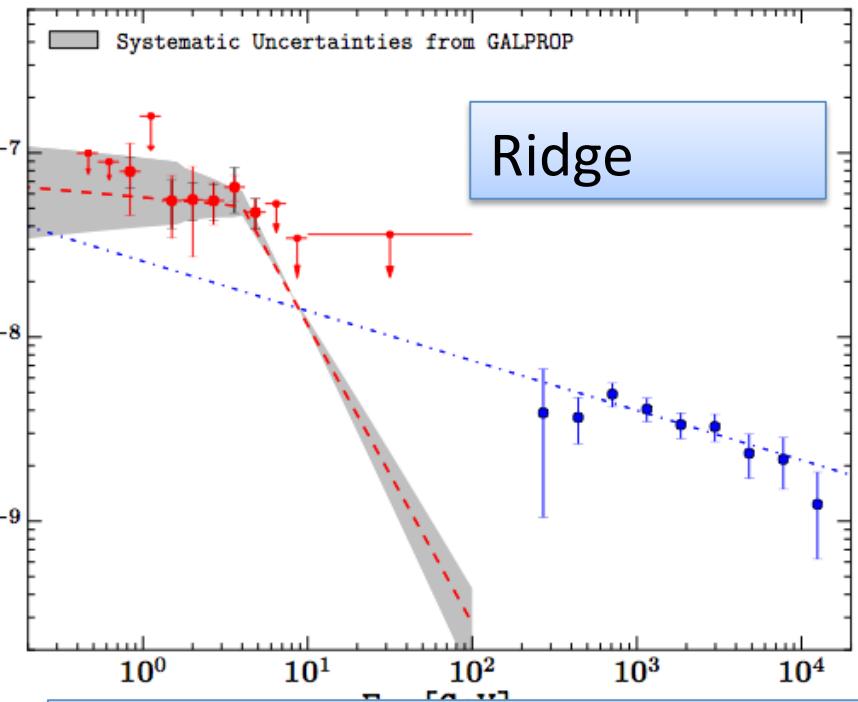


- Molecular gas (red) more extended than gamma-ray model (green) due to non-steady state injection from Galactic Center?
- Alternatively, some molecular gas may be erroneously assigned to central region.

Both a ridge
and spherical
component
are needed
to fit the
excess.

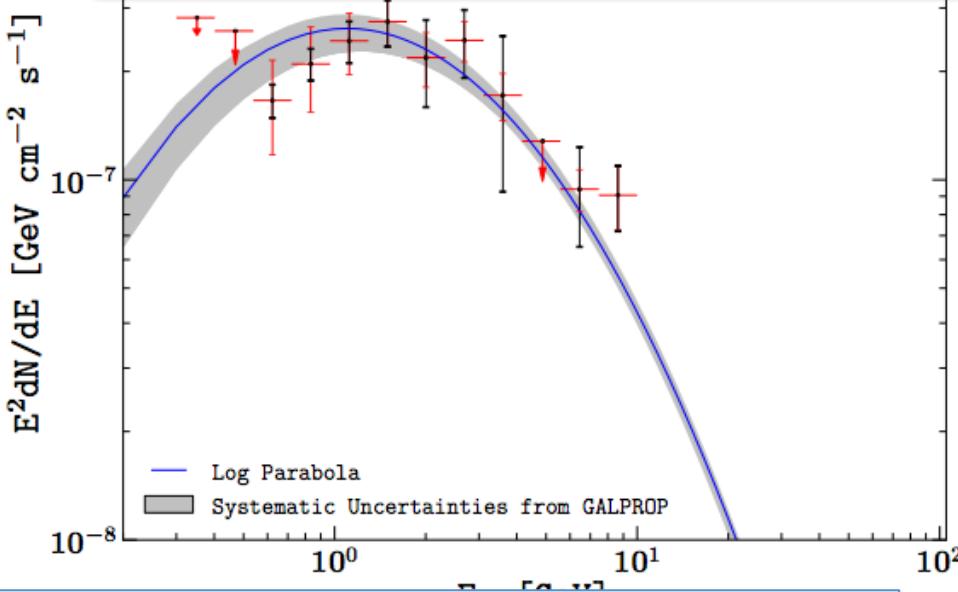


Spectra

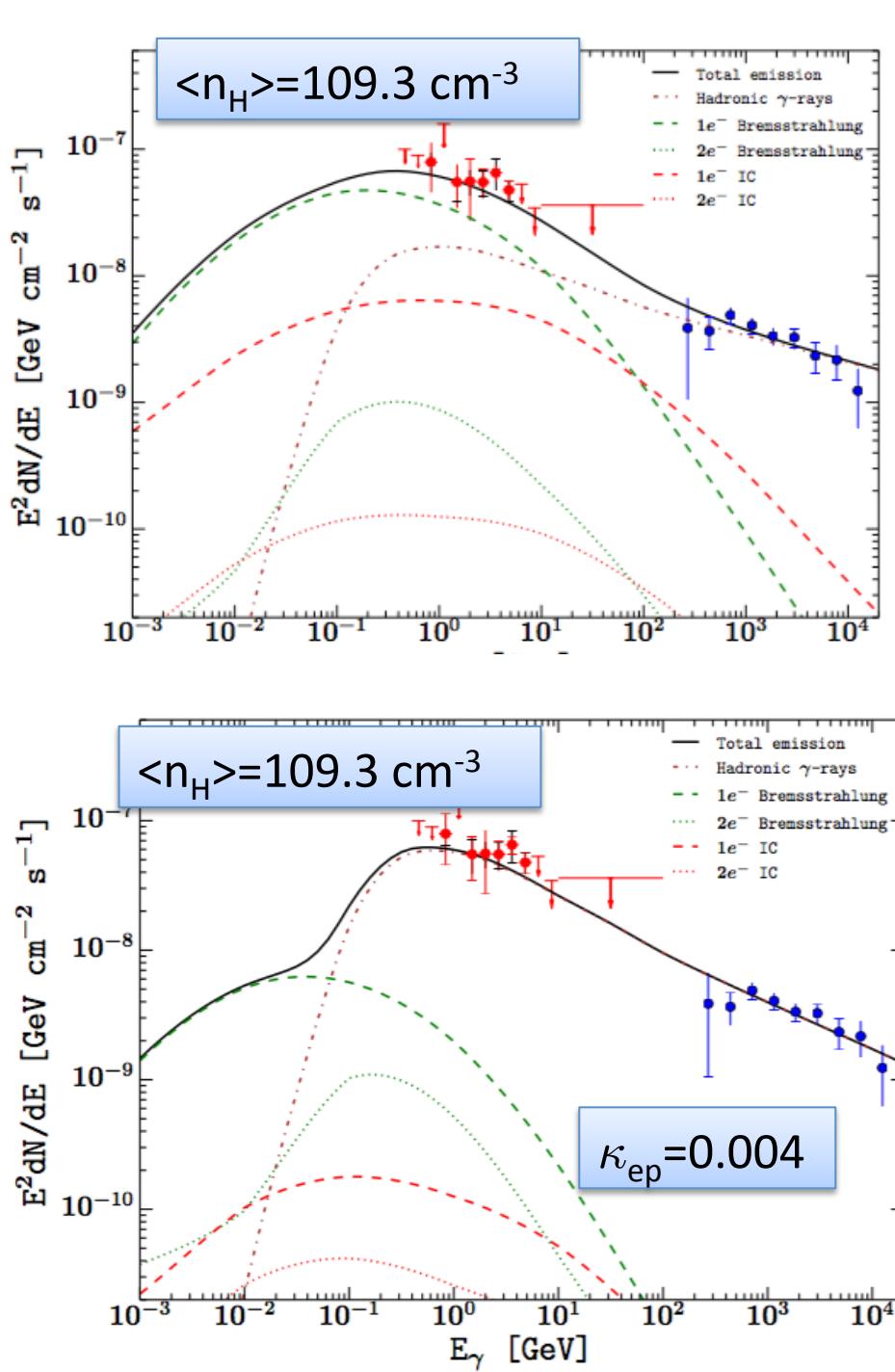
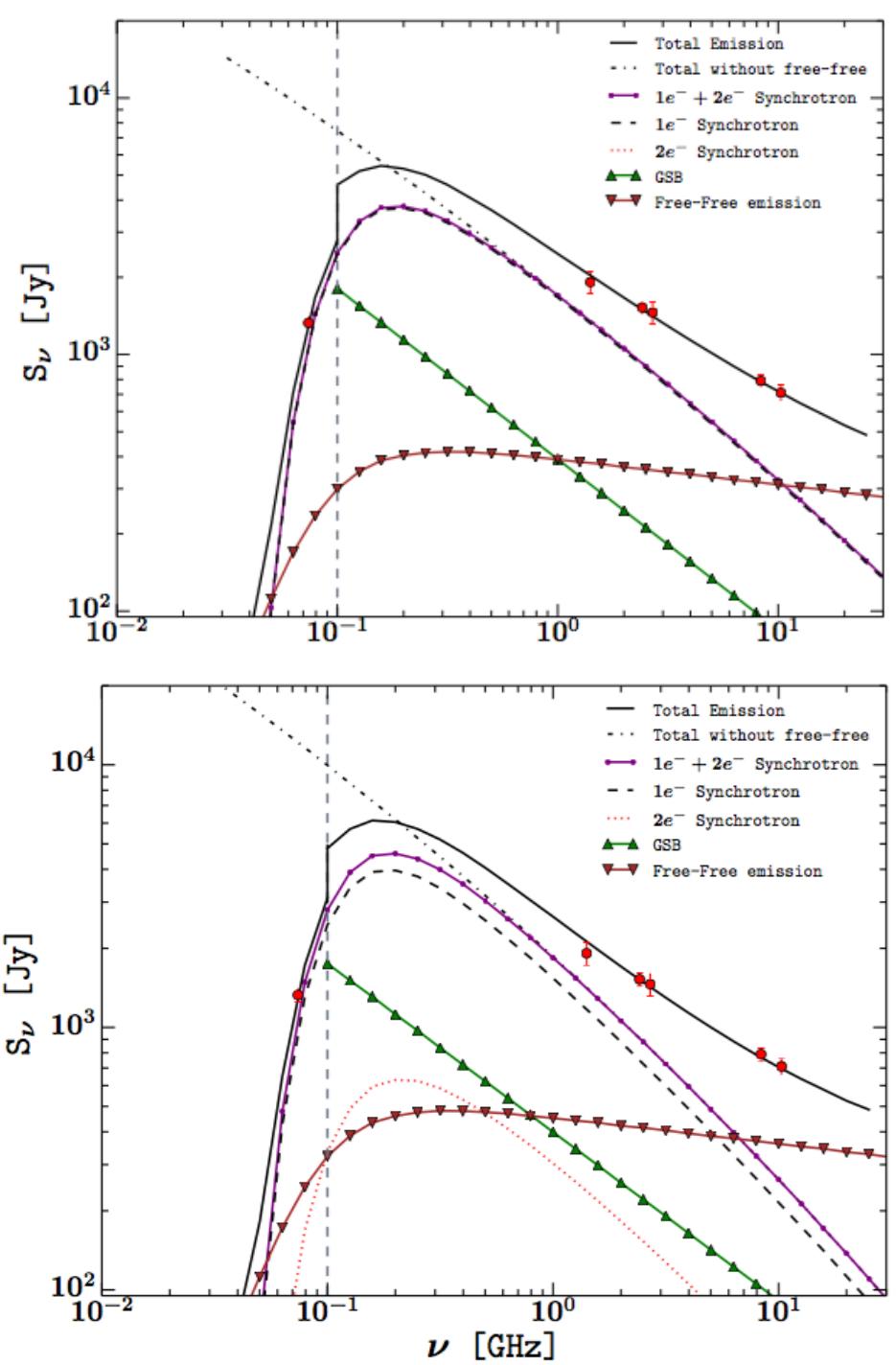


Ridge

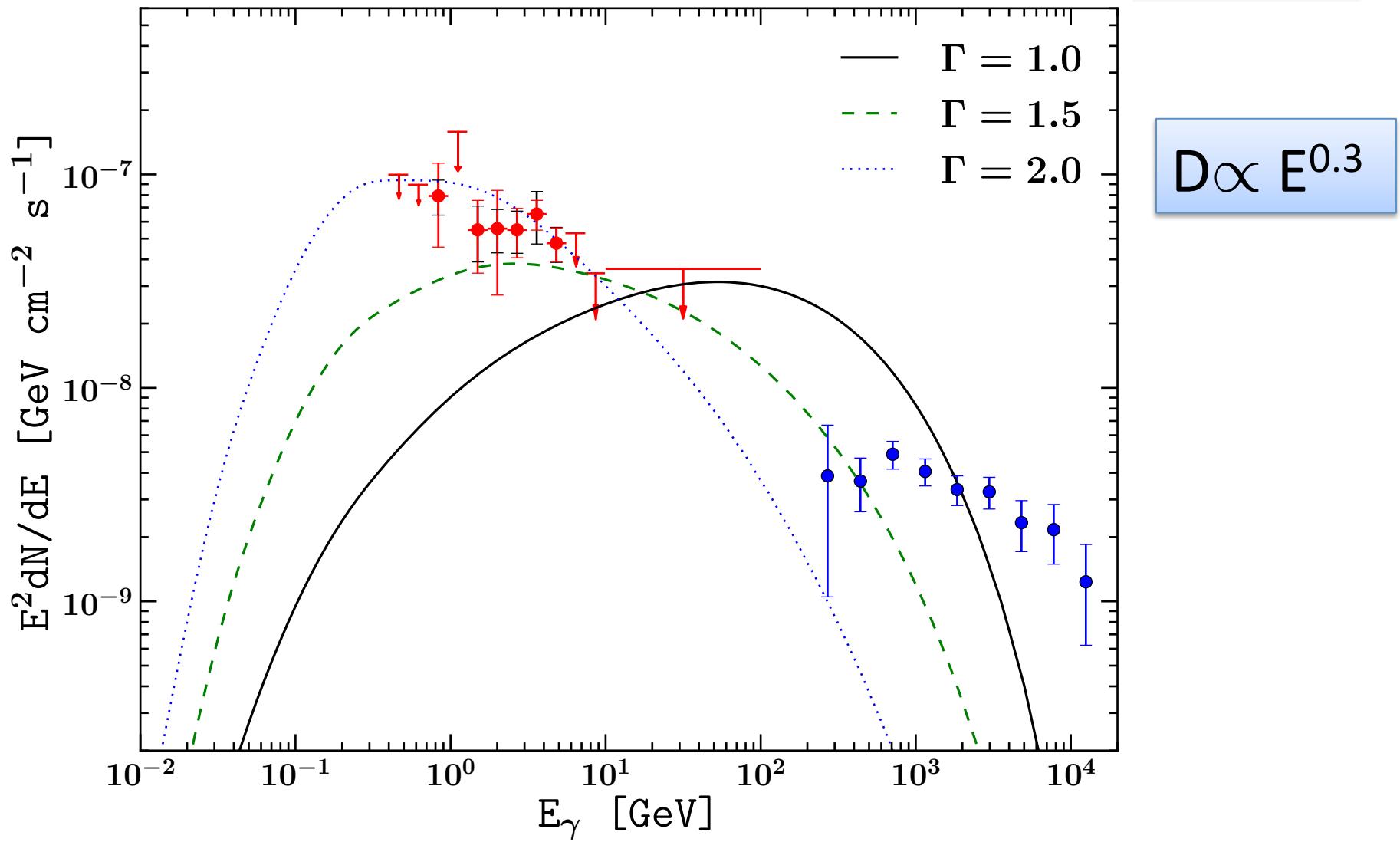
Spherically symmetric: radius $^{-2.4}$

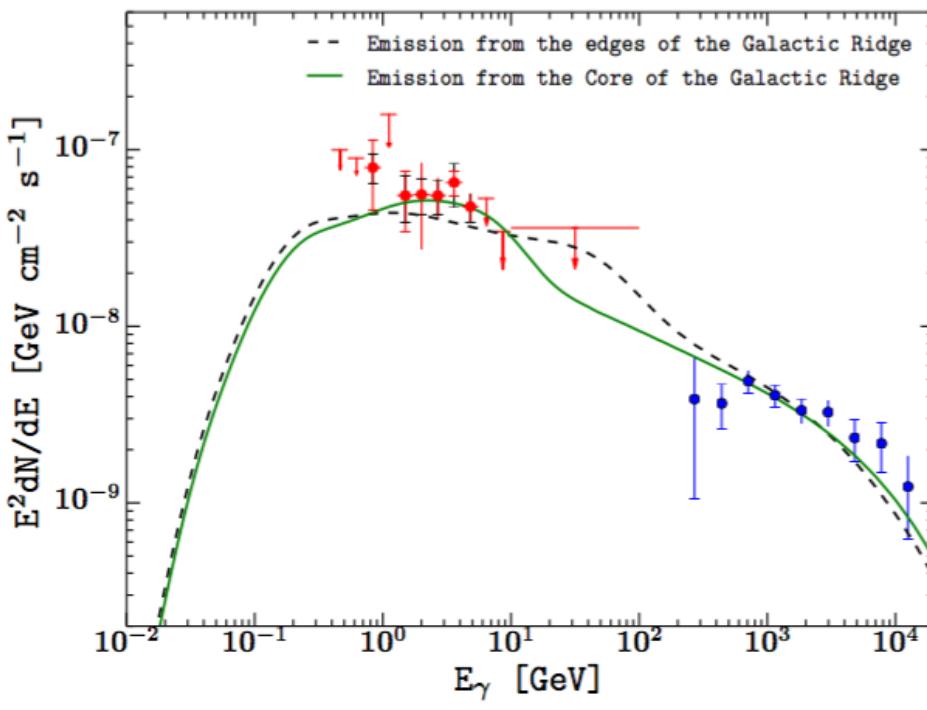
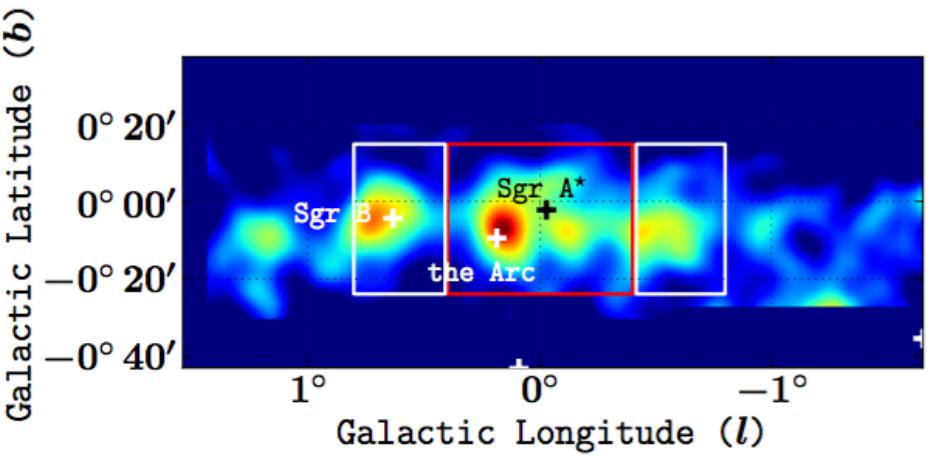
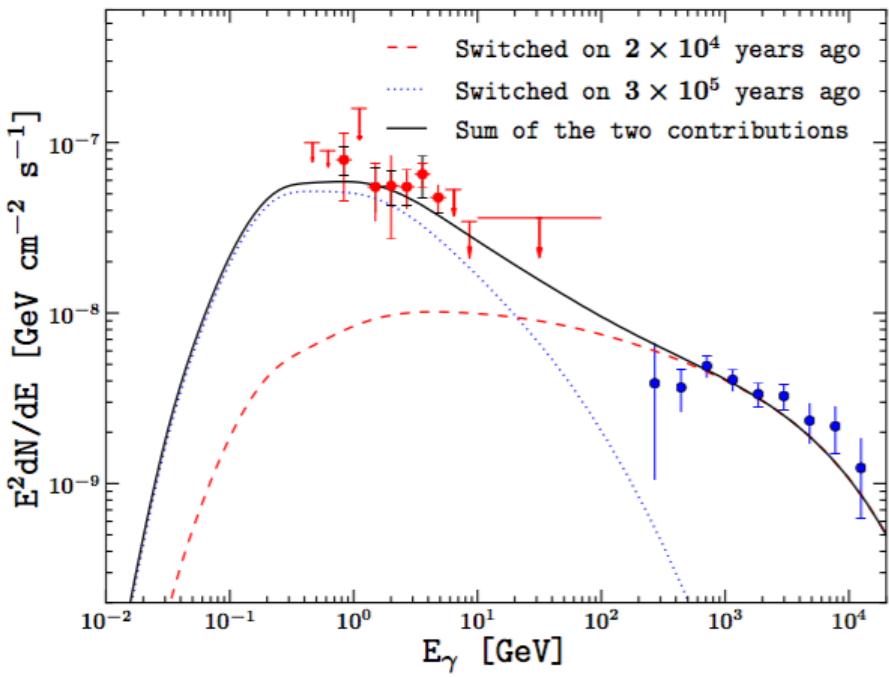
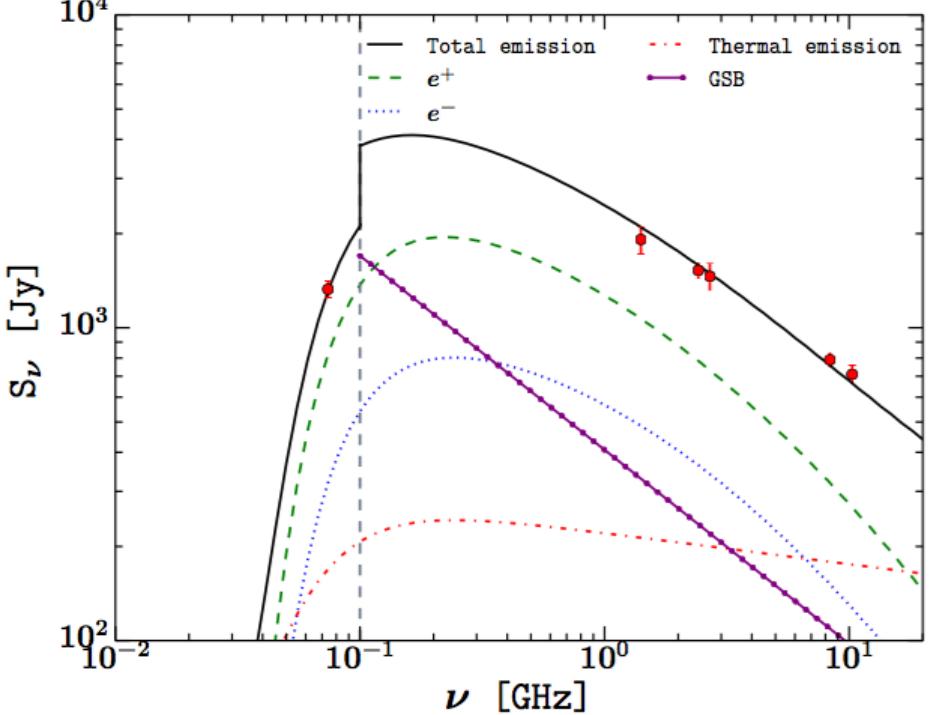


- Cosmic-ray models for the ridge: mainly pion decay (Crocker +2011) or mainly bremsstrahlung (Yusef-Zadeh+2012). See also Youst-Hull+2014.
- Proposals for spherical component: dark matter annihilation (Hooper&Goodenough, 2009), unresolved millisecond pulsars (MSPs) (Abazajian 2010), or DFGB error (Boyarsky+2011). See following talks.



Kolmogorov Diffusion





Conclusions

- Fermi-LAT data has excess extended emission in emission in Galactic Center.
- Both a spherical and ridge component present.
- The spherical component may be due to MSPs, an incorrect DFGB model or possibly dark matter self-annihilation.
- The ridge component may be explained by cosmic rays interacting with molecular gas.
- If Kolmogorov diffusion, then the ridge component needs a two flare model.

| Steady-State Model | B [μG] | Γ_e, Γ_p | Γ_{GSB} | Normalization of protons at 1 TeV [$\text{cm}^{-3} \text{s}^{-1} \text{eV}^{-1}$] | κ_{ep} | t_{esc} [years] | free-free flux density at 10 GHz [Jy] |
|---|-----------------------|------------------------|-----------------------|--|----------------------|--------------------------|---------------------------------------|
| Bremsstrahlung solution with $\langle n_H \rangle$ fixed | 130 ± 20 | $2.34^{+0.06}_{-0.07}$ | 0.7 ± 0.1 | $(2 \pm 1) \times 10^{-38}$ | 0.2 ± 0.1 | $(9 \pm 6) \times 10^4$ | 320 ± 20 |
| π^0 -solution with $\langle n_H \rangle$ and $\kappa_{\text{ep}}^{\text{Bell}}$ fixed | 490 ± 80 | 2.47 ± 0.02 | 0.6 ± 0.1 | $(11 \pm 7) \times 10^{-38}$ | 0.004 | $(3 \pm 2) \times 10^4$ | 360 ± 20 |

| Parameter | Γ_{GeV} | Γ_{TeV} | $E_{\text{total,GeV}} [10^{50} \text{ erg}]$ | $E_{\text{total,TeV}} [10^{50} \text{ erg}]$ | $B [\mu\text{G}]$ | Free-free flux density at 10 GHz [Jy] | Γ_{GSB} | $\chi^2_{\text{min}}/\text{dof}$ |
|------------------|-----------------------|-----------------------|--|--|-------------------|---------------------------------------|-----------------------|----------------------------------|
| Mean \pm error | 1.9 ± 0.1 | 1.8 ± 0.3 | 120^{+50}_{-60} | 1.5 ± 1.0 | 400 ± 300 | 150 ± 50 | 0.6 ± 0.1 | |
| Best fit | 2.0 | 1.8 | 150 | 1.5 | 200 | 180 | 0.6 | 16.0/ 21 |

Spherical excess

