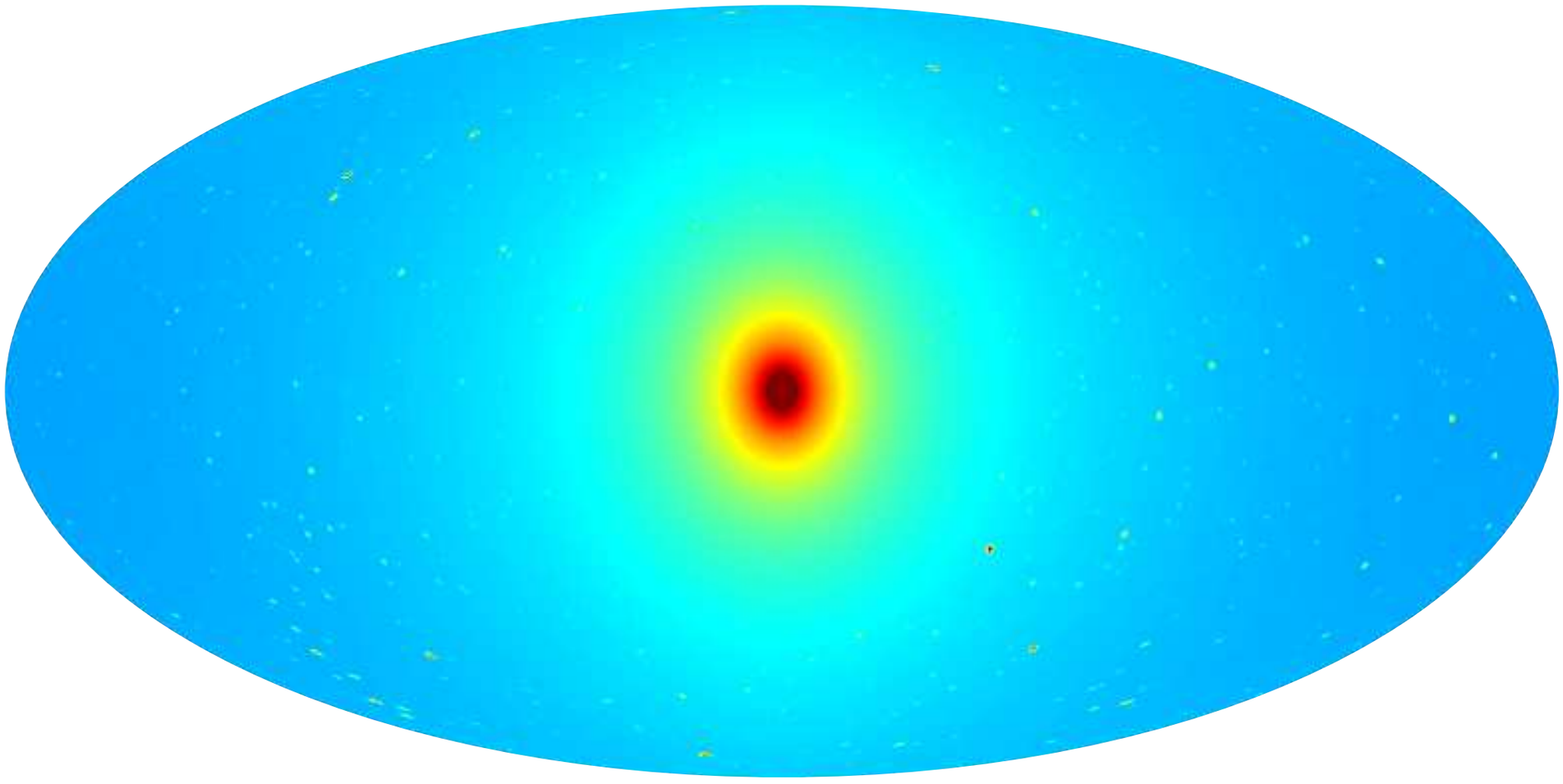
Image Credit: Springel et al. 2008

Dark matter signals from the Inner Galaxy?



Jennifer Siegal-Gaskins

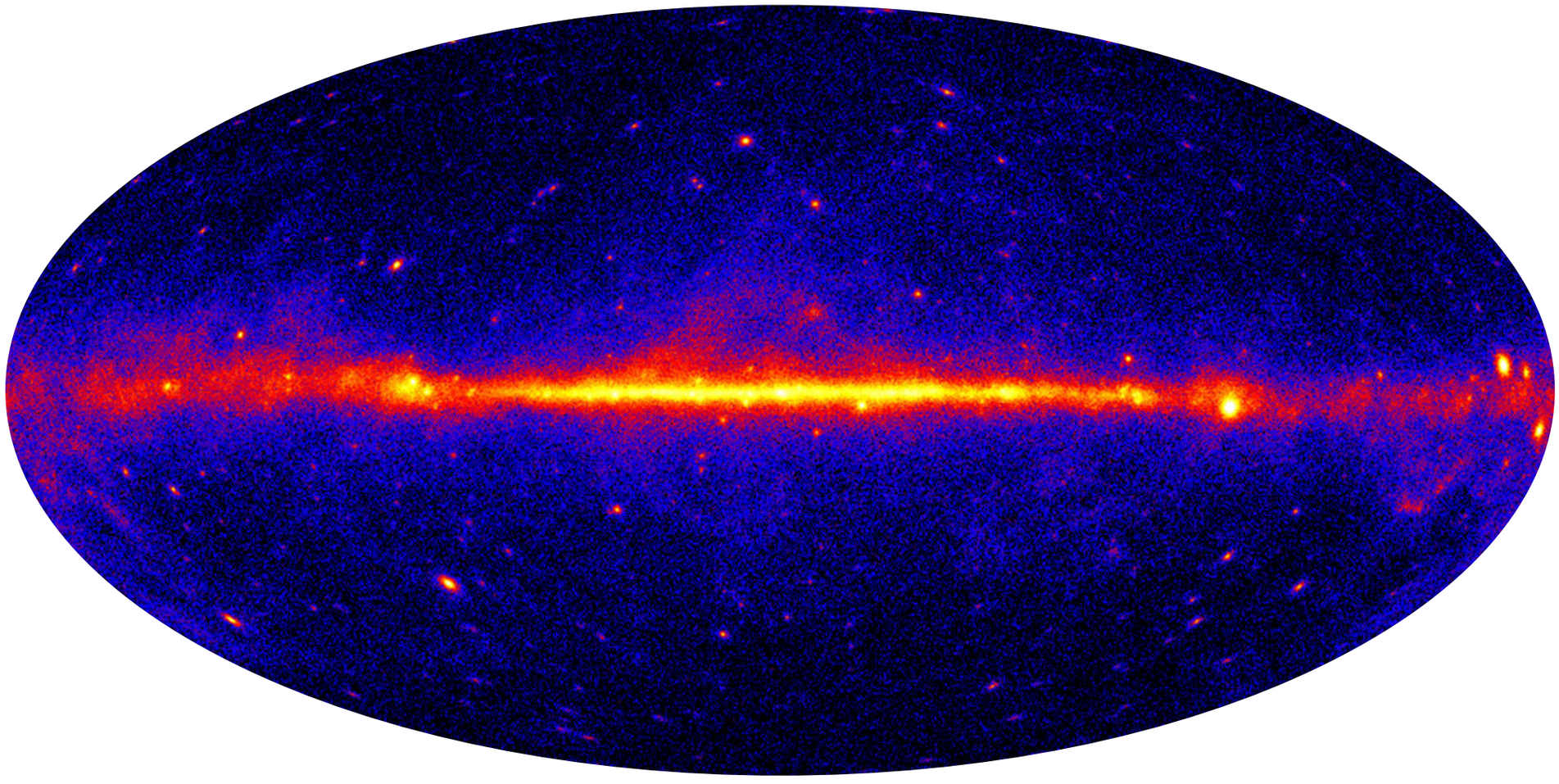
Caltech

Dan Hooper, Ilias Cholis, Tim Linden, JSG, Tracy Slatyer:
Phys. Rev. D, 88, 083009 (2013), arXiv:1305.0830

Andrey Egorov, JSG, Elena Pierpaoli, in prep

Image Credit: NASA/DOE/International LAT Team

Dark matter signals from the Inner Galaxy?



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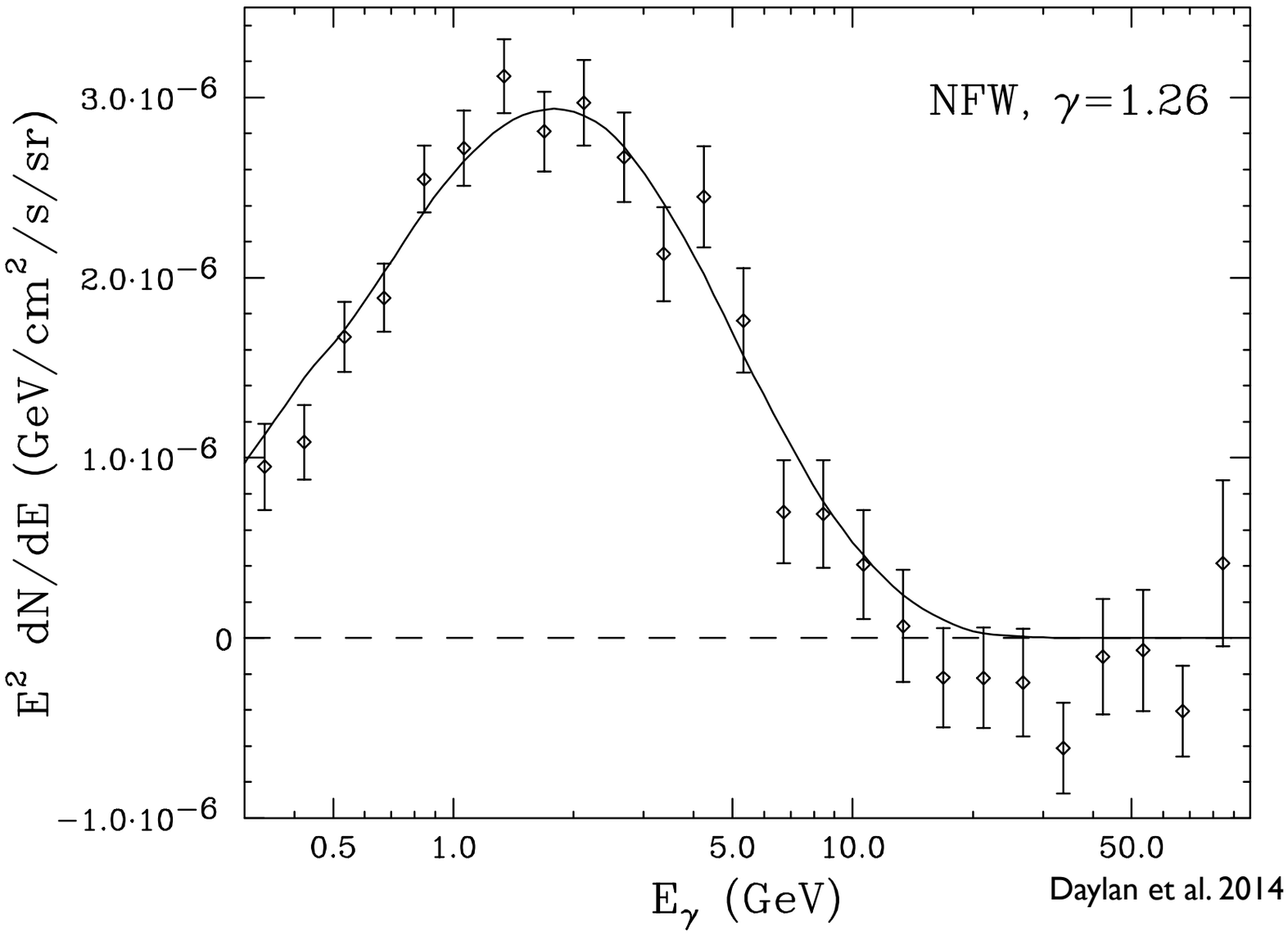
A dark matter signal in the Inner Galaxy?

A dark matter signal in the Inner Galaxy?

- Using Fermi LAT data, multiple groups have claimed an excess at a few GeV from the Galactic Center and higher Galactic latitudes. The excess has been interpreted as emission from dark matter (DM) annihilation and/or unresolved millisecond pulsars (MSPs).



Daylan et al. 2014

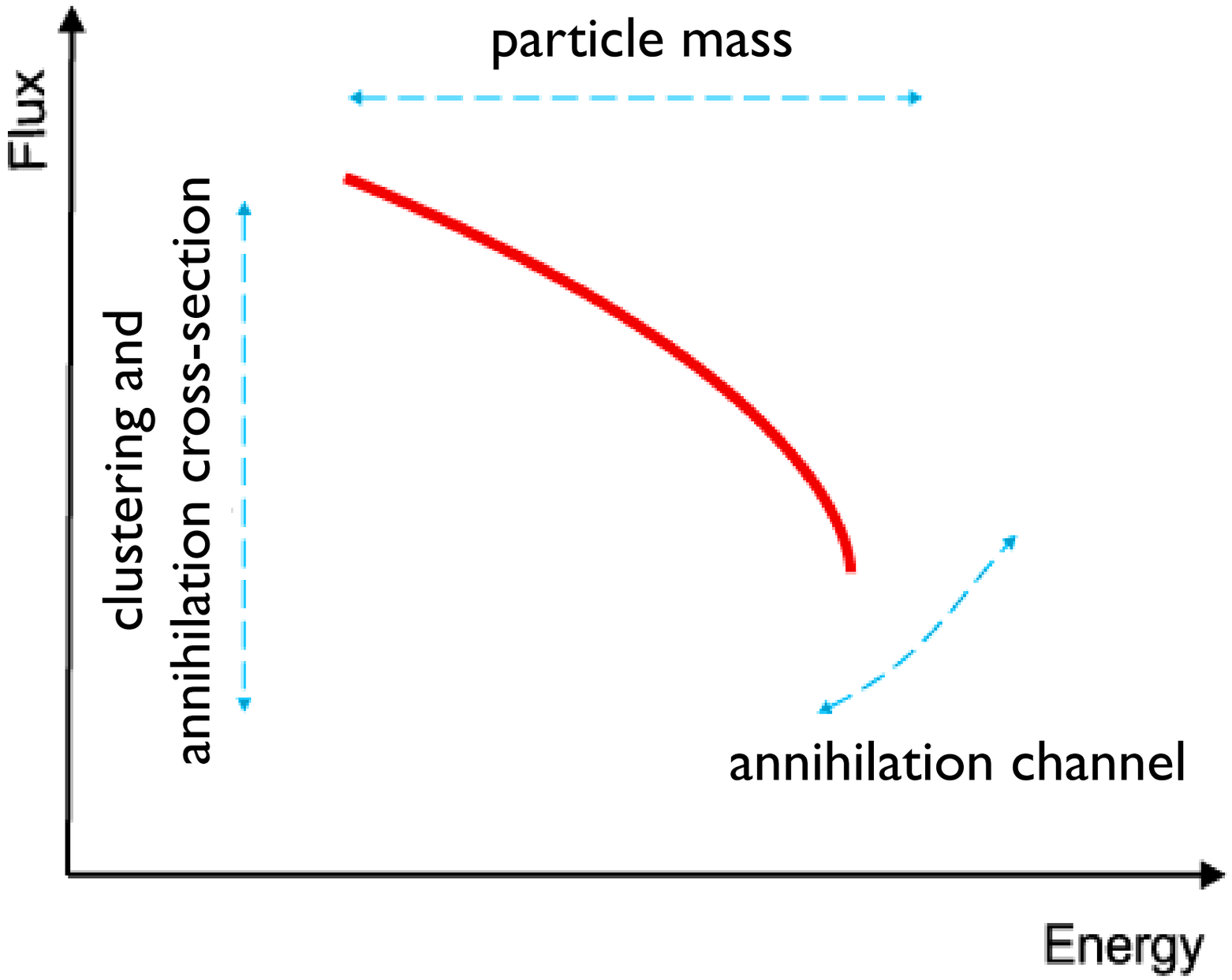
see: Hooper & Goodenough 2011, Morselli, Cañadas, Vitale (Fermi LAT) 2011, Abazajian & Kaplinghat 2012, Hooper & Slatyer 2013, Gordon & Macías 2013, Abazajian et al. 2014, Daylan et al. 2014, and others

A dark matter signal in the Inner Galaxy?

- Using Fermi LAT data, multiple groups have claimed an excess at a few GeV from the Galactic Center and higher Galactic latitudes. The excess has been interpreted as emission from dark matter (DM) annihilation and/or unresolved millisecond pulsars (MSPs).
- Energy spectrum of the excess:
  - can be fit by DM with mass of ~10-40 GeV, depending on annihilation channel
  - uncomfortably similar to MSPs
- Excess is spatially extended:
  - if from annihilation, need steep DM density profile $r^{-\gamma}$ with γ = 1.2-1.4
  - uncertain if MSPs could explain large extension and steep profile
- To generate amplitude of the excess:
  - requires roughly thermal relic DM annihilation cross section
  - for the Galactic Center would require a few thousand MSPs, which seems plausible
  - for higher Galactic latitudes (|b|>10 deg), hard to explain with MSP models

see: Hooper & Goodenough 2011, Morselli, Cañadas, Vitale (Fermi LAT) 2011, Abazajian & Kaplinghat 2012, Hooper & Slatyer 2013, Gordon & Macías 2013, Abazajian et al. 2014, Daylan et al. 2014, and others

Indirect dark matter signals



Bertone 2007

The dark matter annihilation signal

intensity = particle physics term "K" • astrophysics term "J"

$$K_{\rm ann} = \frac{{\rm d}N}{{\rm d}E}\frac{\langle\sigma v\rangle}{2m_\chi^2} \qquad J_{\rm ann}(\psi) = \frac{1}{4\pi}\int_{los} {\rm d}s\ \rho^2(s,\psi)$$

The dark matter annihilation signal

intensity = particle physics term "K" • astrophysics term "J"

$$K_{\rm ann} = \frac{{\rm d}N}{{\rm d}E}\frac{\langle\sigma v\rangle}{2m_\chi^2}$$

spectrum of particles produced

$$J_{\rm ann}(\psi) = \frac{1}{4\pi}\int_{los} {\rm d}s\ \rho^2(s,\psi)$$

The dark matter annihilation signal

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dark matter particle mass

The dark matter annihilation signal

intensity = particle physics term "K" • astrophysics term "J"

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average of pair annihilation cross section times relative velocity

The dark matter annihilation signal

intensity = particle physics term "K" • astrophysics term "J"

$$K_{\rm ann} = \frac{{\rm d}N}{{\rm d}E}\frac{\langle\sigma v\rangle}{2m_\chi^2}$$

$$J_{\rm ann}(\psi) = \frac{1}{4\pi}\int_{los} {\rm d}s\,\rho^2(s,\psi)$$

dark matter density

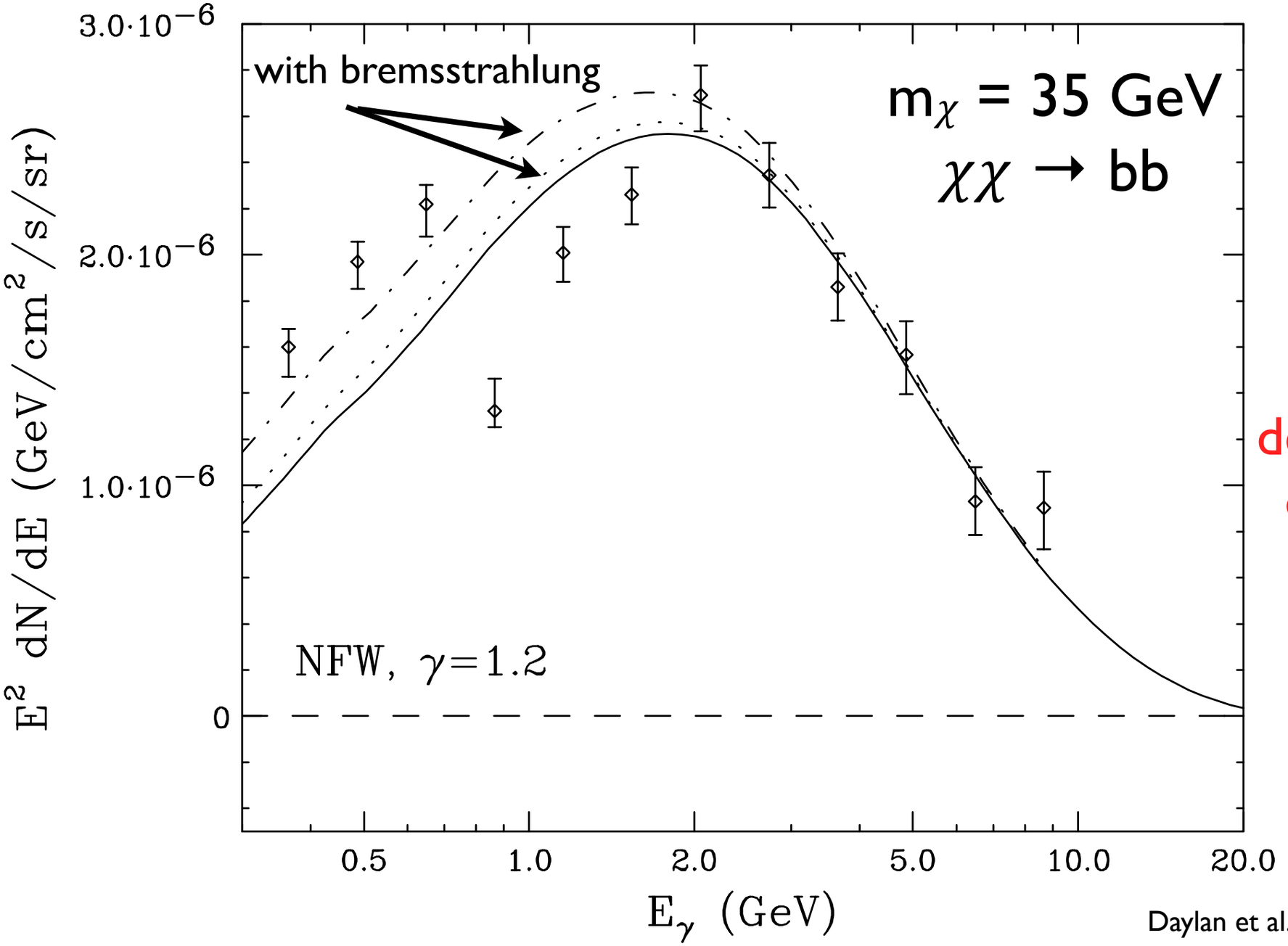
The dark matter annihilation signal

intensity = particle physics term "K" • astrophysics term "J"

$$K_{\rm ann} = \frac{{\rm d}N}{{\rm d}E}\frac{\langle\sigma v\rangle}{2m_\chi^2} \qquad J_{\rm ann}(\psi) = \frac{1}{4\pi}\int_{los} {\rm d}s\ \rho^2(s,\psi)$$

A dark matter signal in the Inner Galaxy?

Energy spectrum of excess in Galactic Center

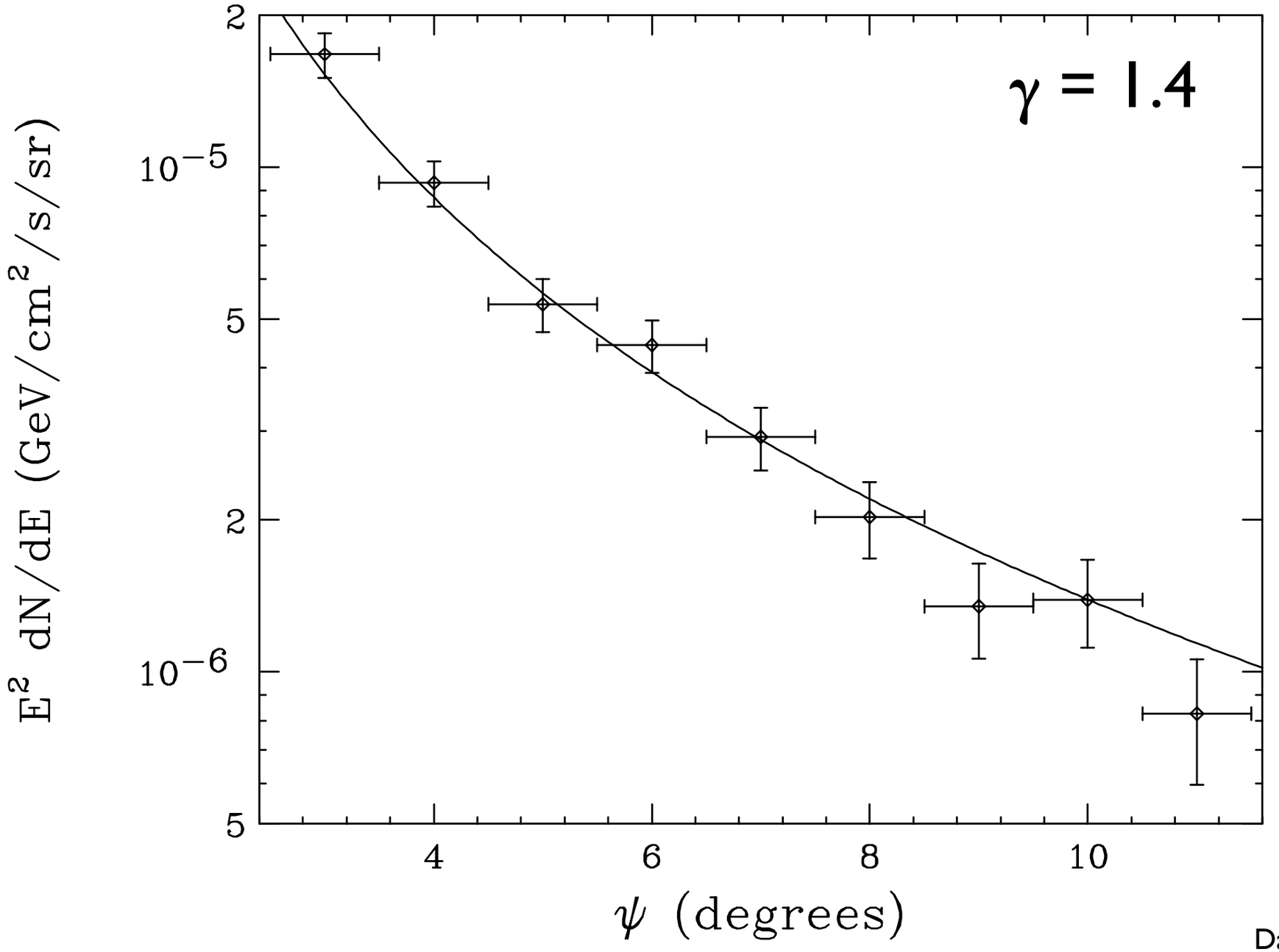


Daylan et al. 2014

NB: Abazajian et al (2014) find strong dependence of spectrum of excess on details of background model

A dark matter signal in the Inner Galaxy?

Excess is spatially extended



also detected out to at least |b| ~ 20 deg (Hooper & Slatyer 2013)

Daylan et al. 2014

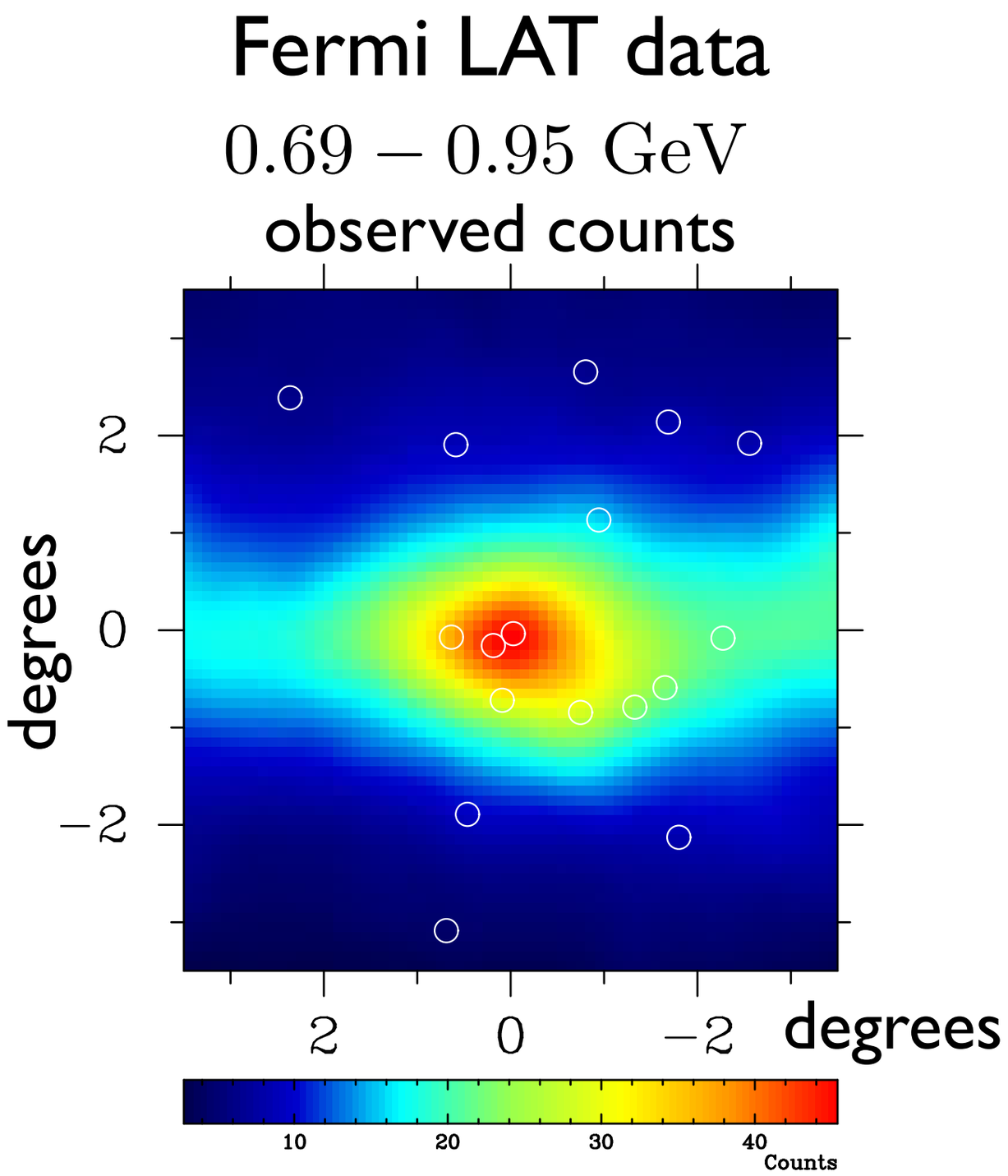
Excess over what?

What's in the model:

- Galactic diffuse emission associated with cosmic-ray interactions (sum of many processes)
- isotropic gamma-ray background (measured)
- detected gamma-ray sources (e.g., pulsars, supernova remnants)

What's not in the model:

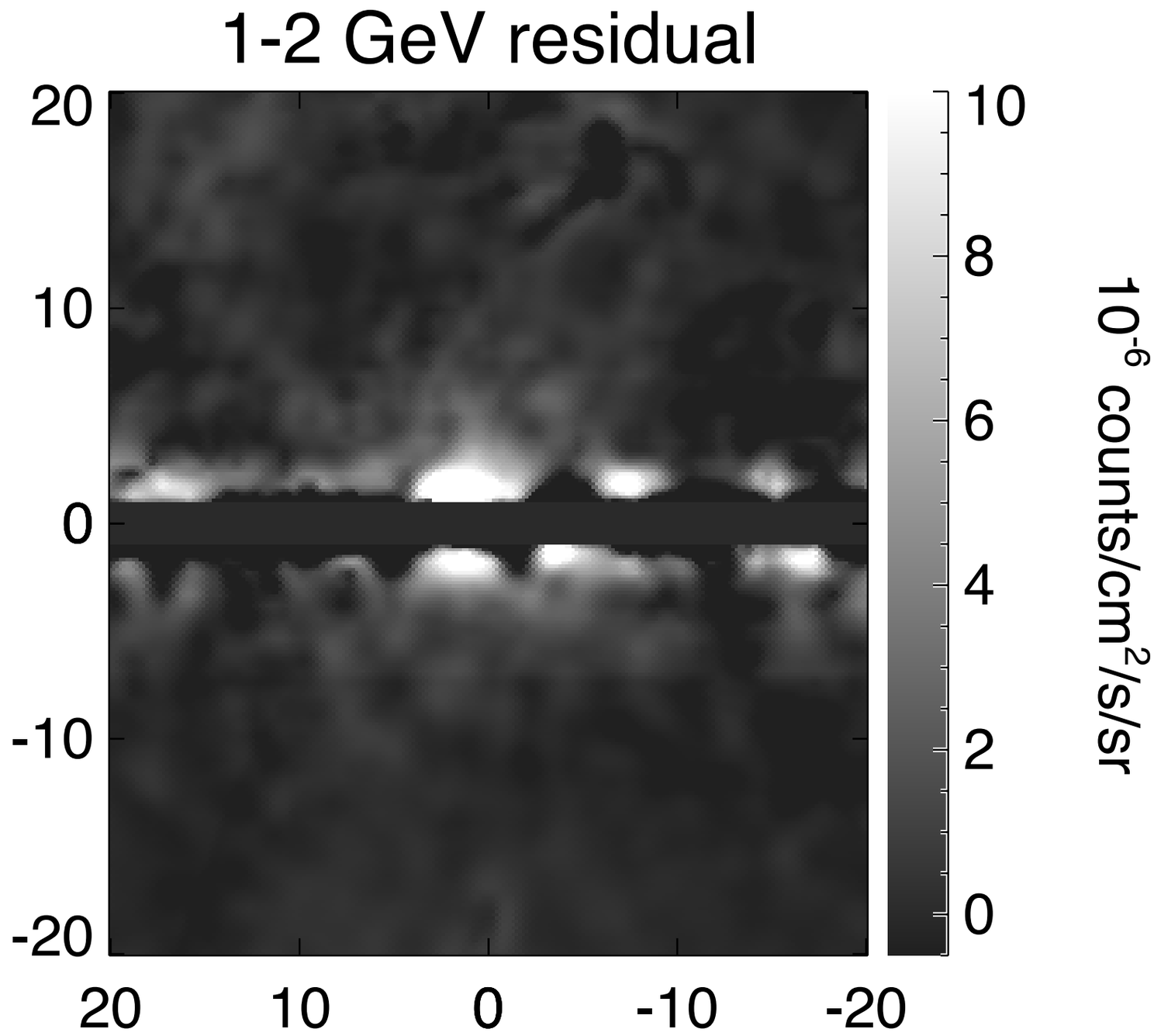
- unresolved gamma-ray sources
- dark matter



Abazajian & Kaplinghat 2012

Residuals

(for best-fit model w/o dark matter component)



Daylan et al. 2014

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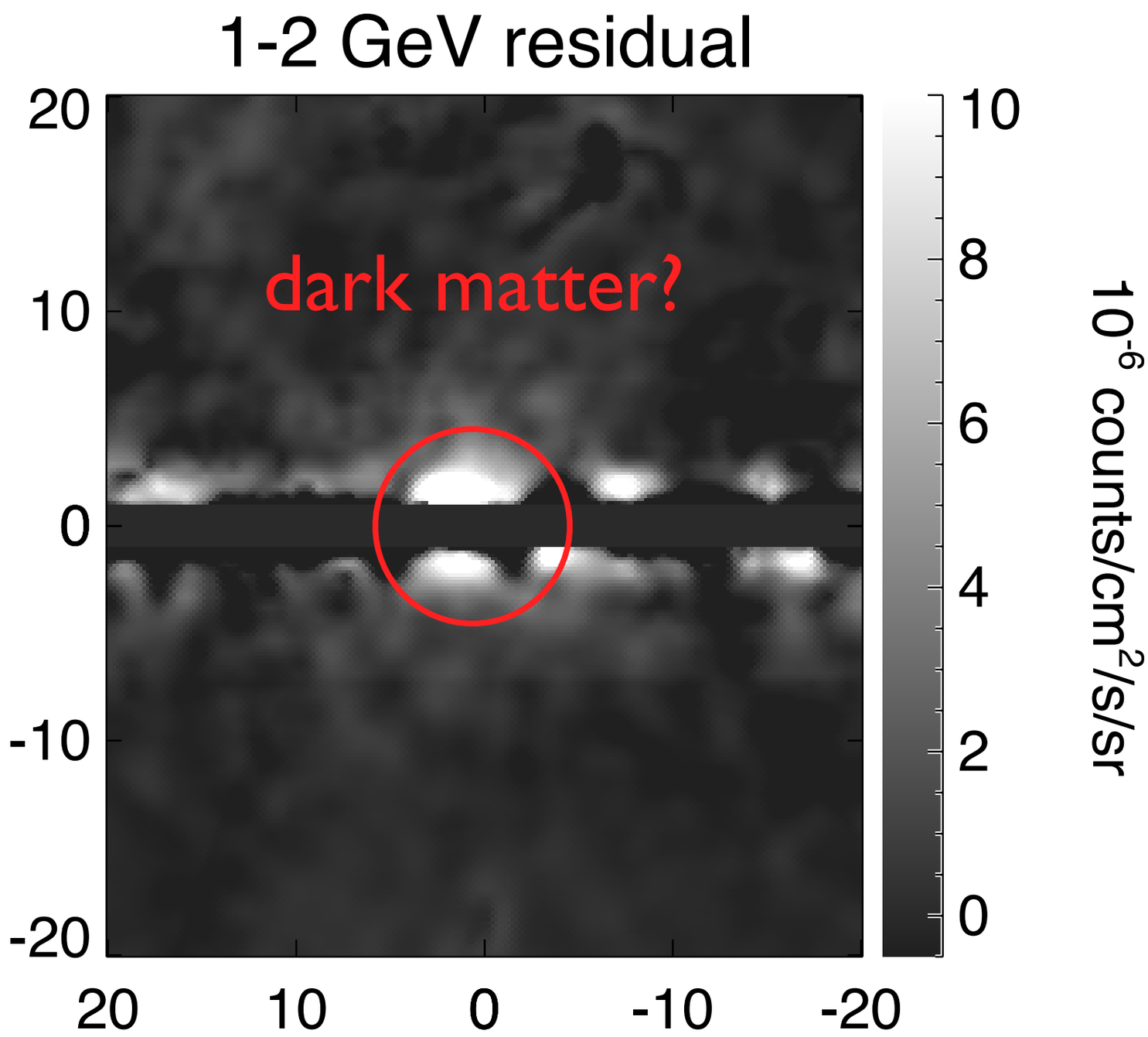

Daylan et al. 2014

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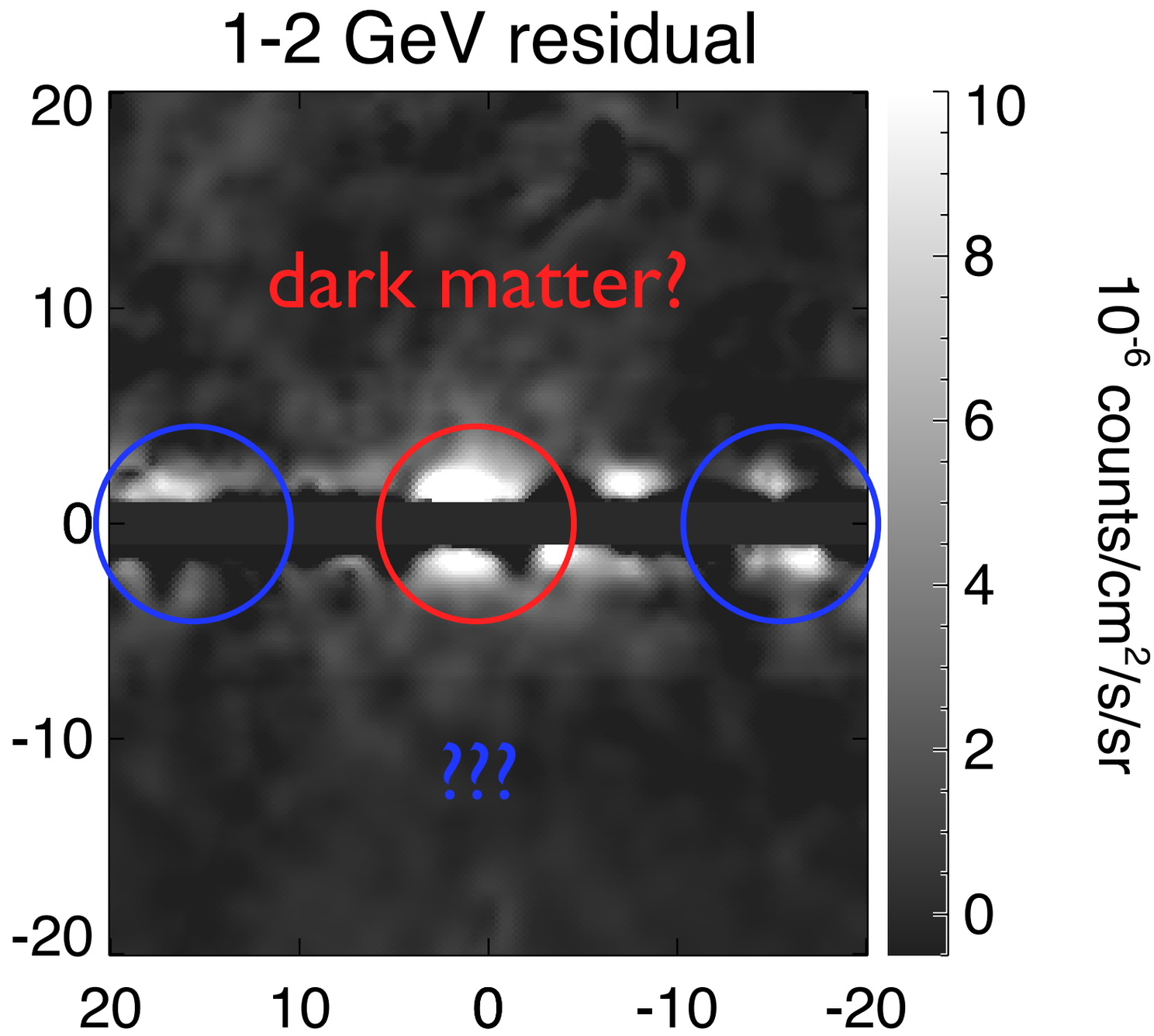

Daylan et al. 2014

Does DM uniquely improve the fit?

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No.

Does DM uniquely improve the fit?

models adding an additional component with an extended spatial distribution

TABLE I. The best-fit $TS_{\approx}$, negative log-likelihoods, and $\Delta \ln \mathcal{L}$ from the baseline for general models in the 200 MeV–100 GeV analysis.

Spatial model	Spectrum	$TS_{\approx}$	$-\ln \mathcal{L}$	$\triangle \ln \mathcal{L}$
Baseline	···	···	140 070.2	···
Density $\Gamma = 0.7$	LogPar	1725.5	139 755.5	314.7
Density$^2 \gamma = 0.9$	LogPar	1212.8	139 740.0	330.2
Density$^2 \gamma = 1.0$	LogPar	1441.8	139 673.3	396.9
Density$^2 \gamma = 1.1$	LogPar	2060.5	139 651.8	418.3
Density$^2 \gamma = 1.2$	LogPar	4044.9	139 650.9	419.2
Density$^2 \gamma = 1.3$	LogPar	7614.2	139 686.8	383.4
Density^2 Einasto	LogPar	1301.3	139 695.7	374.4
Density$^2 \gamma = 1.2$	PLCut	3452.5	139 663.2	407.0

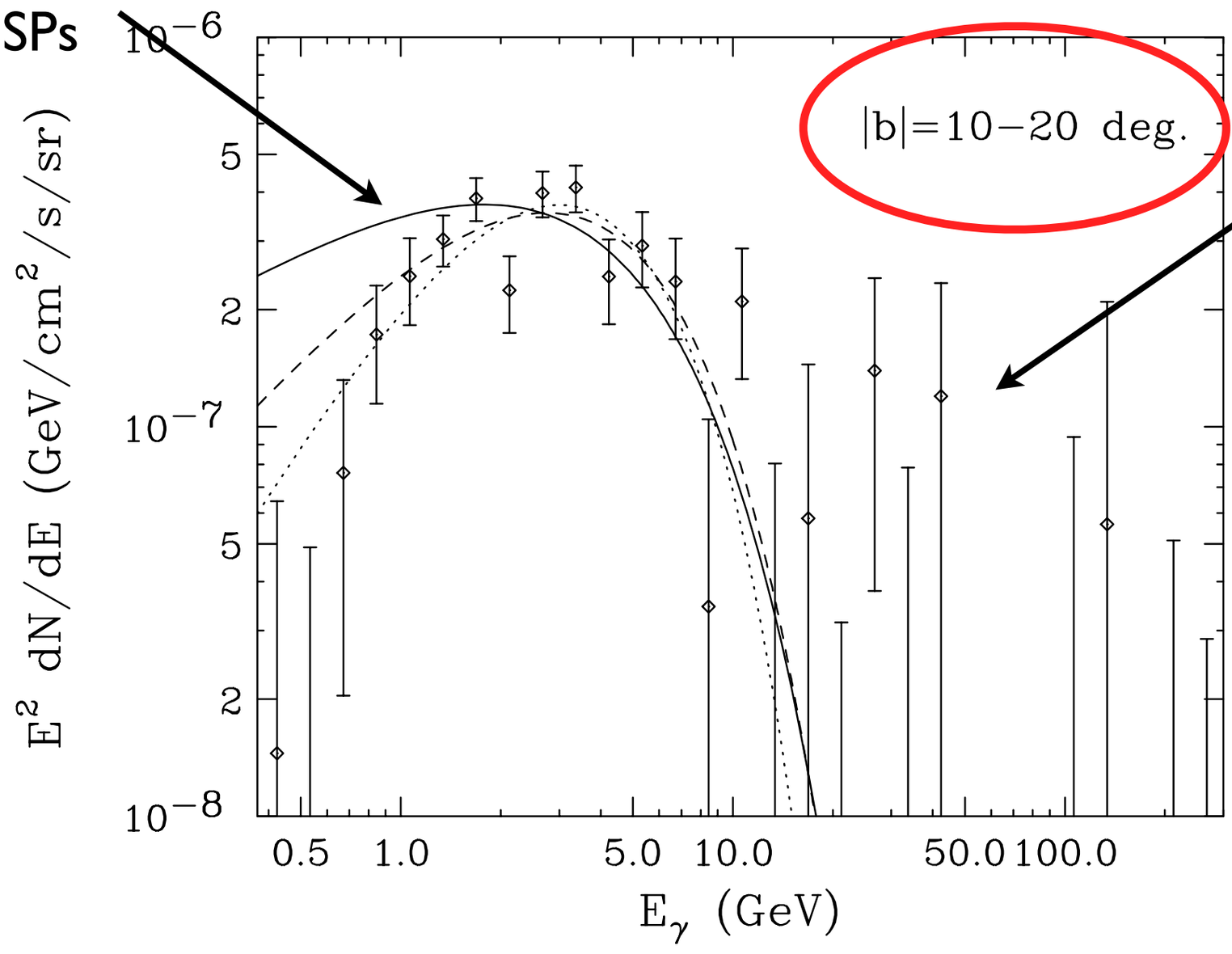
improvement in fit ($2\Delta \ln \mathcal{L} > 25$ is highly significant)

Abazajian & Kaplinghat 2012

Can the GeV excess be millisecond pulsars?

best-fit to Fermi-detected MSPs

spectral comparison



GeV excess at high latitudes (data points)

Hooper, Cholis, Linden, JSG, Slatyer 2013

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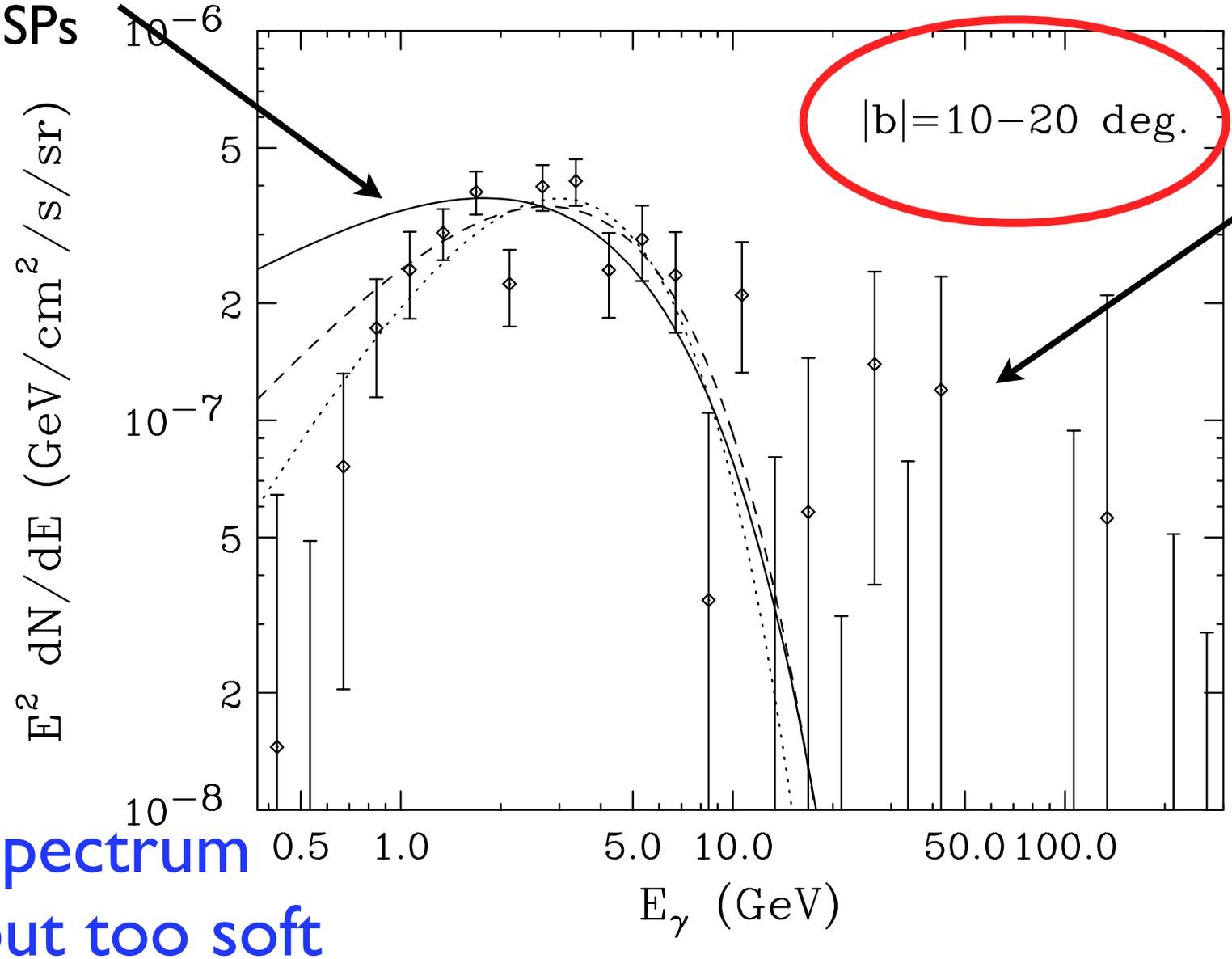


GeV excess at high latitudes (data points)

MSP spectrum similar but too soft at low energies

Hooper, Cholis, Linden, JSG, Slatyer 2013

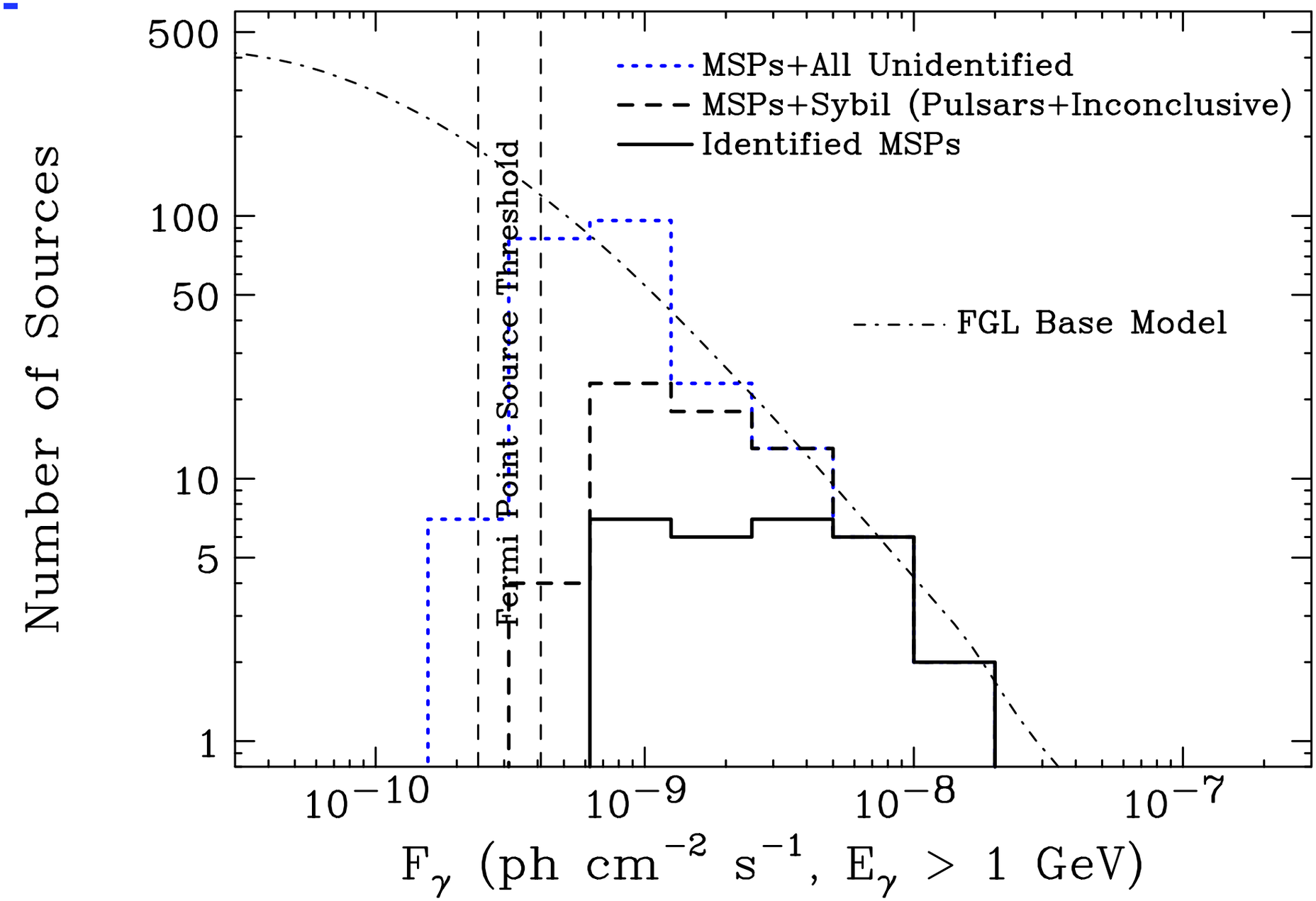
Can the GeV excess be millisecond pulsars?

Unresolved sources (contribute to diffuse) | Resolved sources

Can unresolved MSPs produce the high-latitude excess?

- adopt a spatial model and luminosity function for the MSPs, calibrated to detections in radio
- base model can roughly account for the amplitude of Inner Galaxy excess, but strongly overpredicts number of Fermi-detected MSPs

source count distribution (|b|>10 deg)



Hooper, Cholis, Linden, JSG, Slatyer 2013

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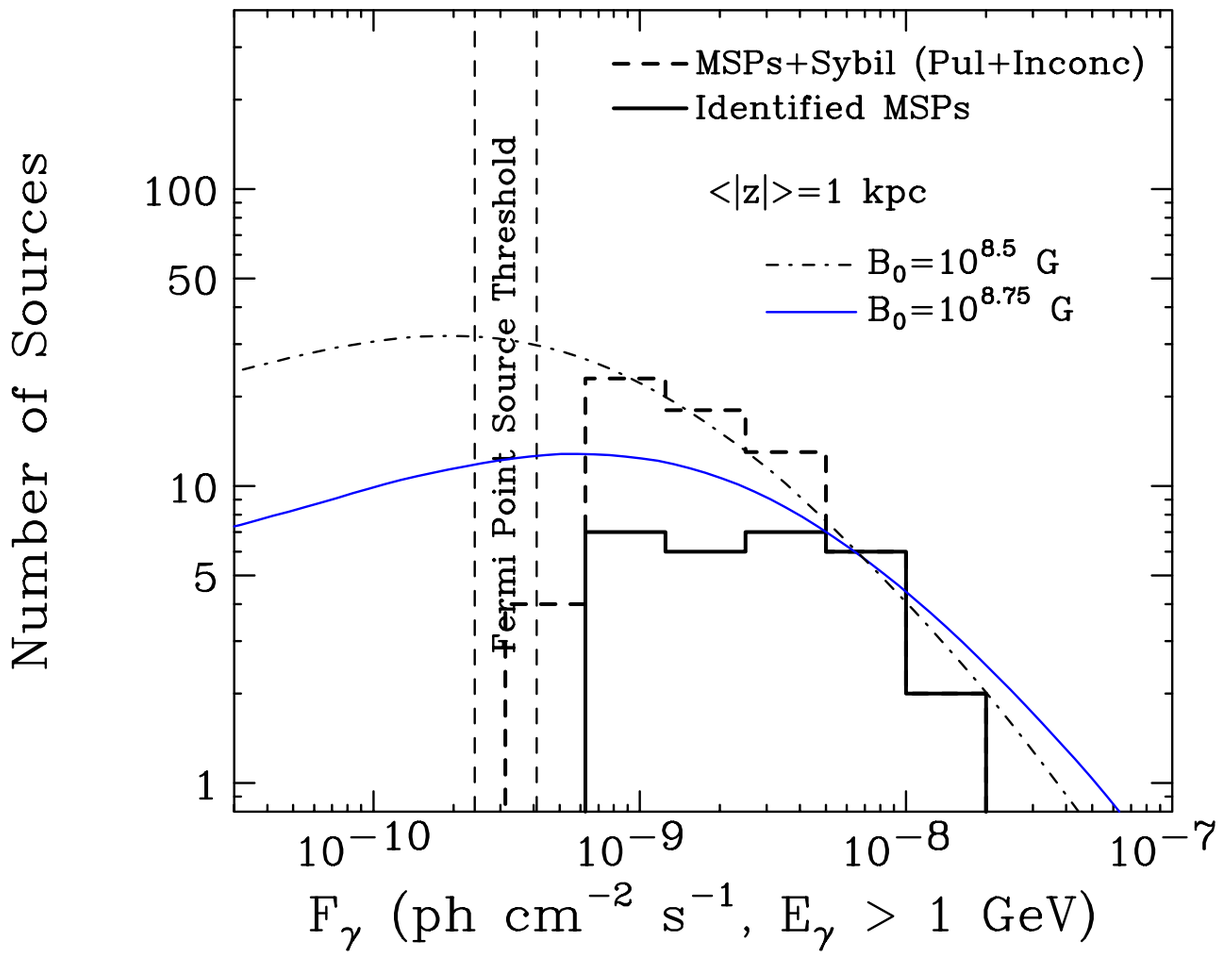
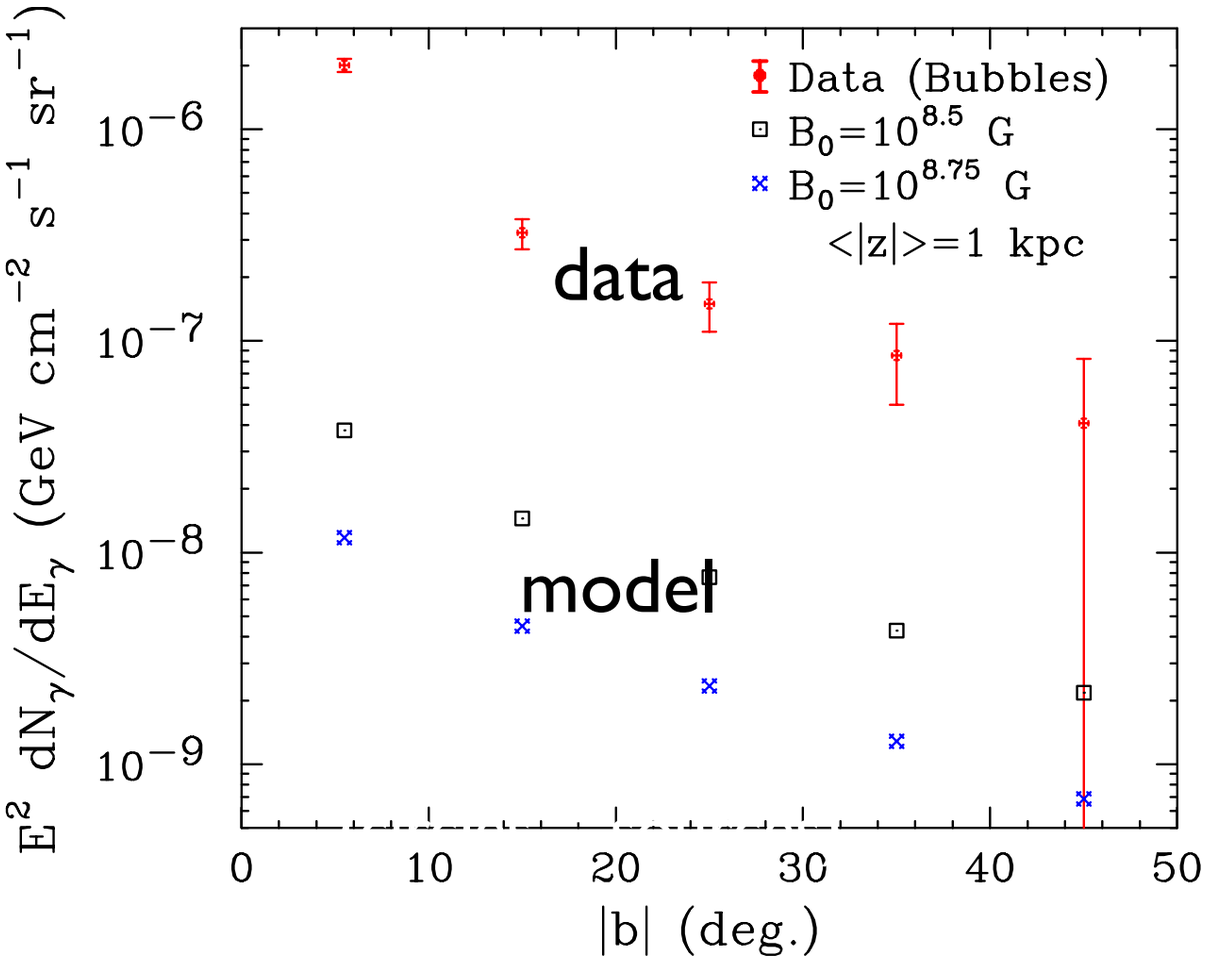
Source count distribution



Latitude dependence of excess



adjusting MSP model parameters to better reproduce the observed source counts leads to models that cannot explain the *amplitude* of the observed excess

Hooper, Cholis, Linden, JSG, Slatyer 2013

Is the GeV excess dark matter?

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  - Sum of several processes with not-strongly-constrained inputs:

    - cosmic-ray spectra and distribution
    - gas distribution
    - interstellar radiation field
    - magnetic fields

See talk by Germán Gomez-Vargas!

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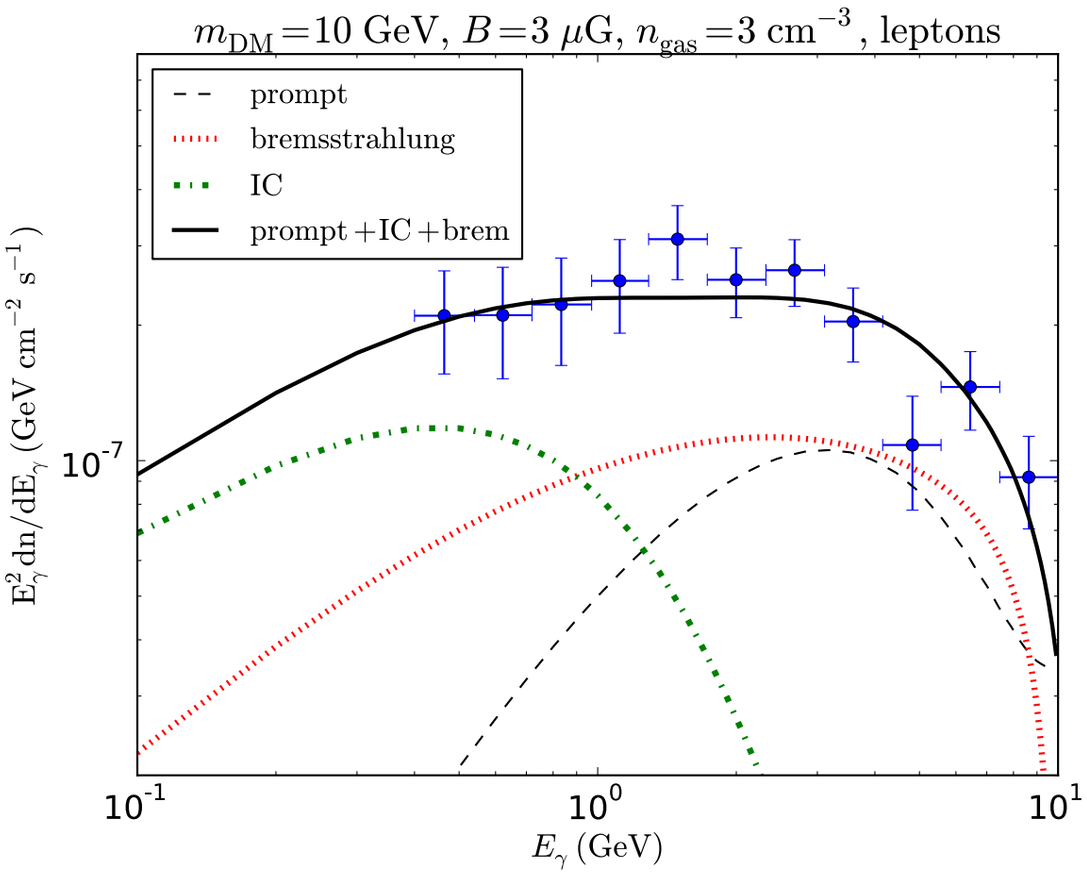
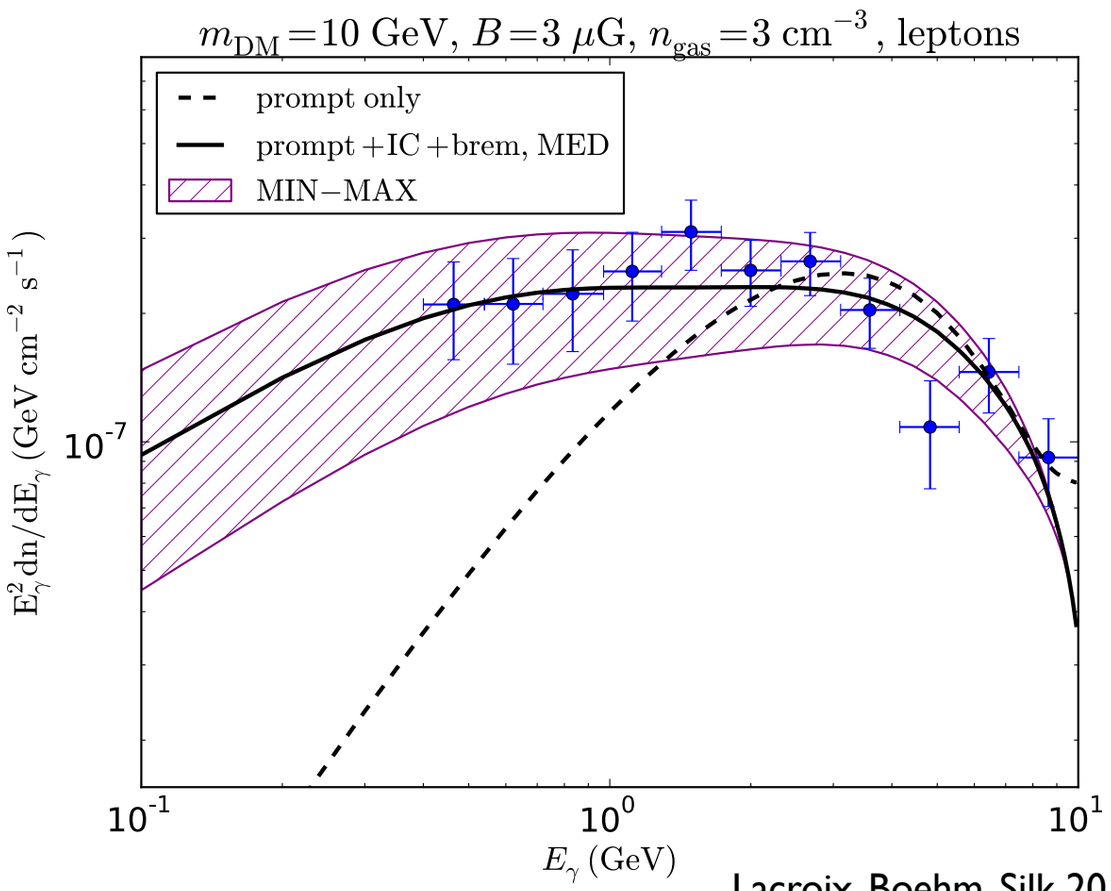
- Systematics? (Not statistics-limited!)

See talk by Germán Gomez-Vargas!

Bed of Procrustes

Bed of Procrustes





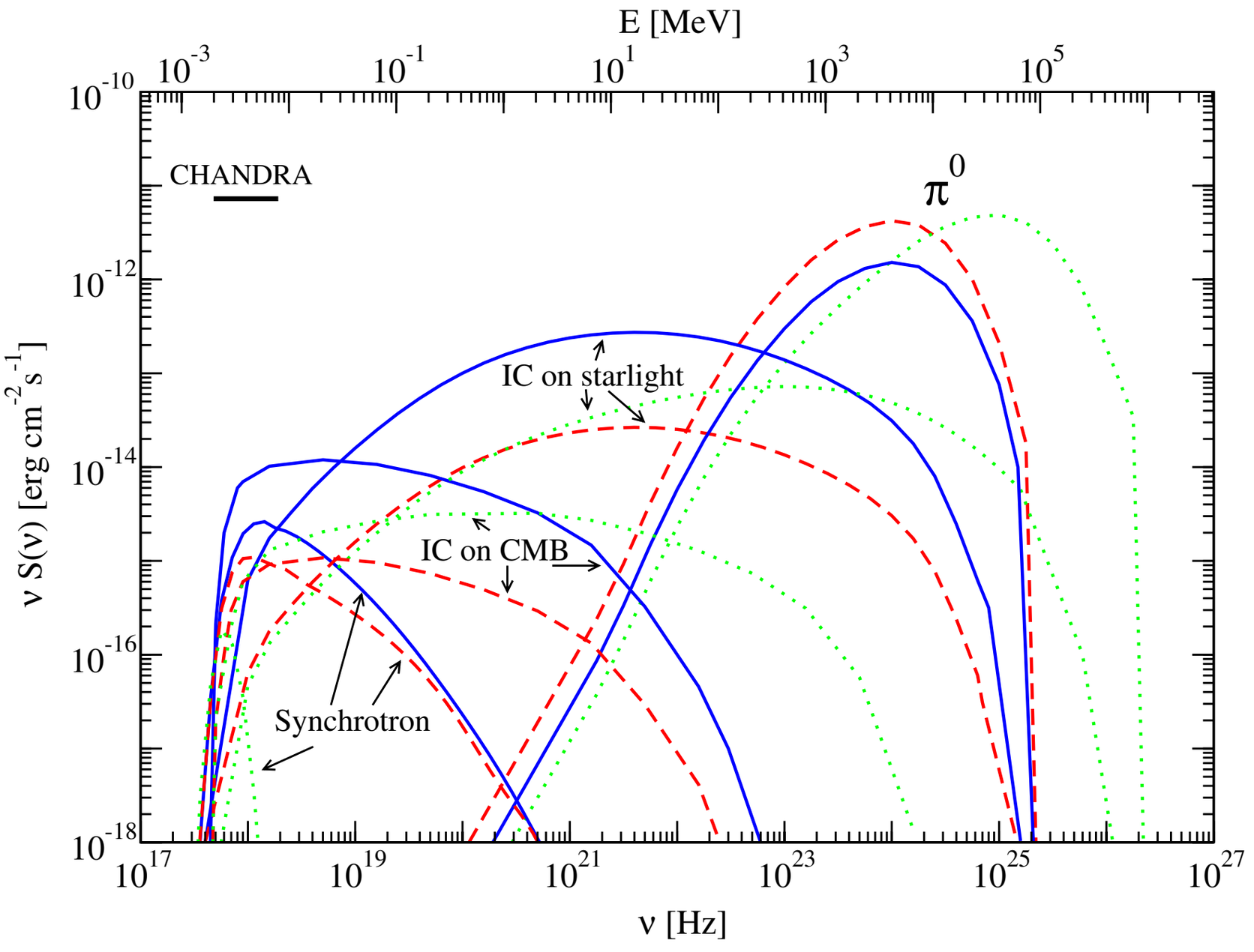
Lacroix, Boehm, Silk 2014

- Lacroix et al. point out importance of:
  - inverse Compton
  - propagation model
  - diffusion (and latitude dependence of secondary emission)

Multi-wavelength dark matter photon spectra

- secondary photon emission associated with charged particle final states:
  - bremsstrahlung
  - inverse Compton scattering of starlight, CMB
  - synchrotron due to magnetic fields

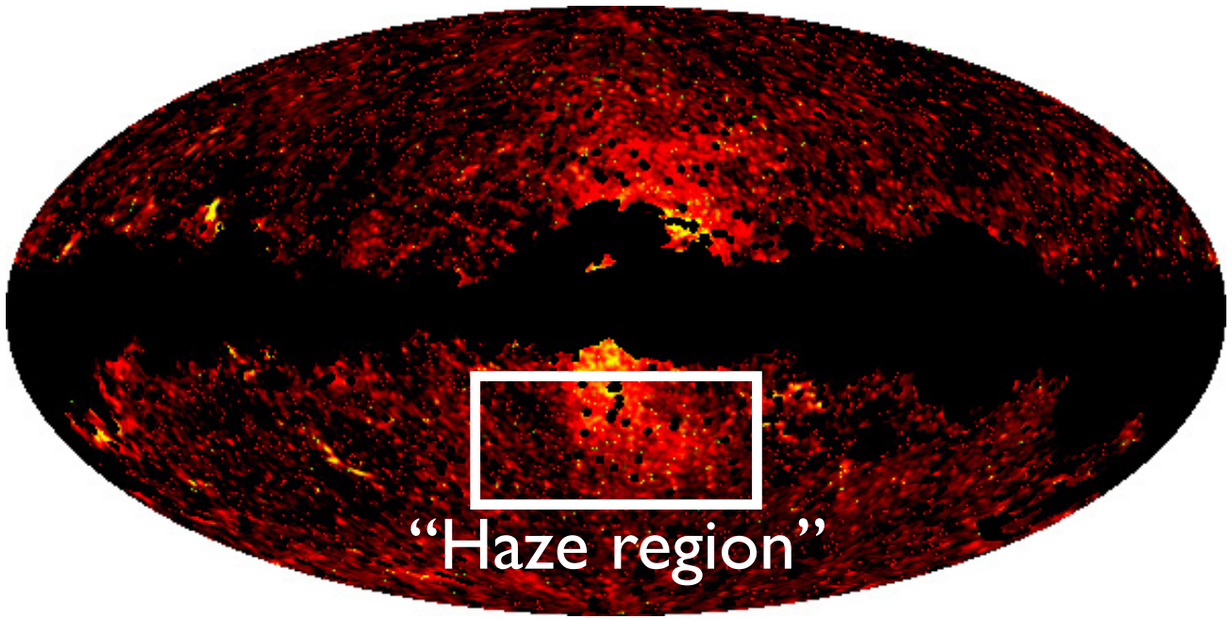
DM spectrum from the Galactic Center



Regis & Ullio 2008

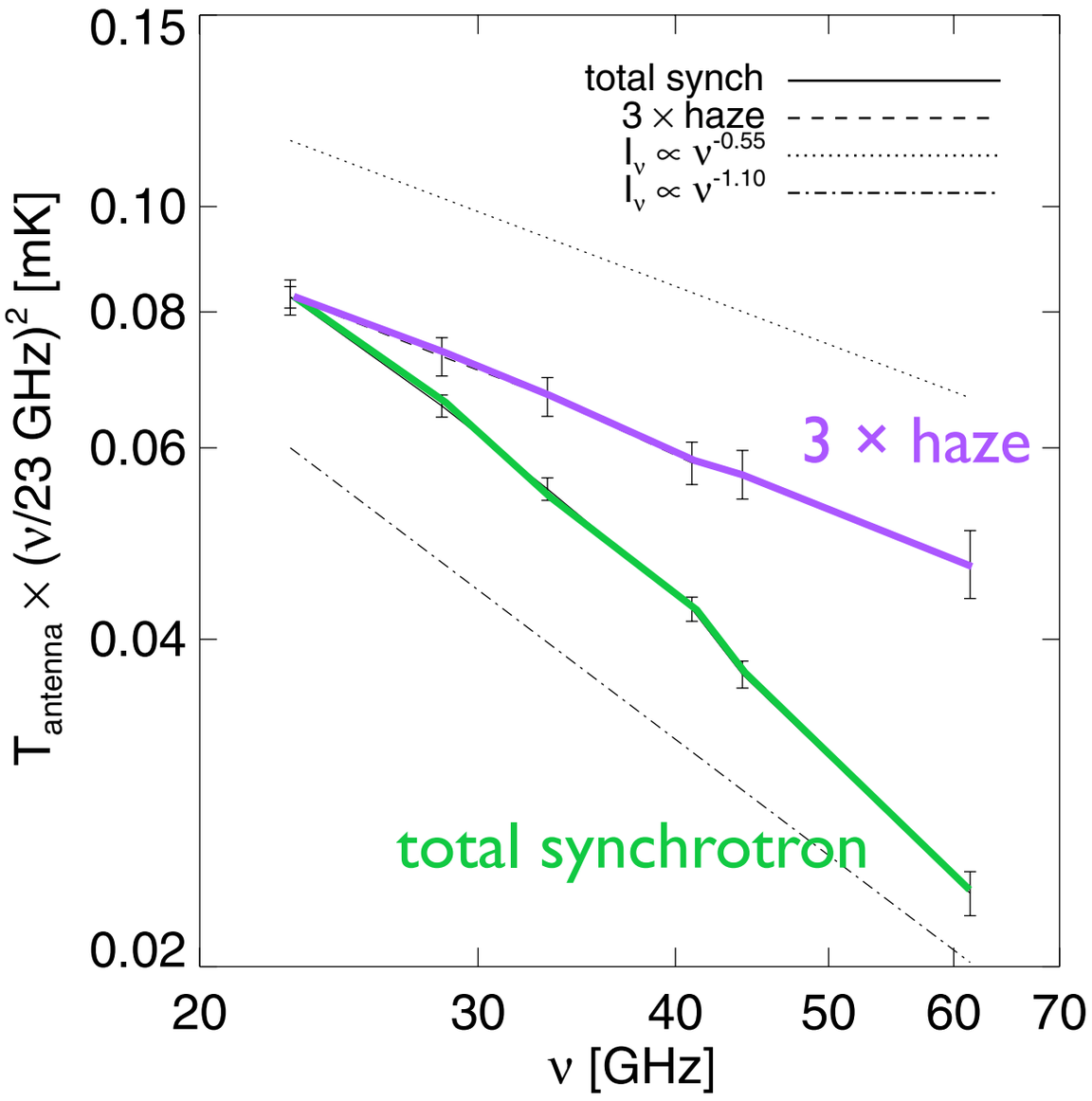
Dark Matter and the WMAP/Planck Haze

Planck haze (30 GHz)



- Planck collaboration confirms WMAP "Haze" (Hooper, Finkbeiner, and Dobler, 2007)
- spectrum of Haze harder than total synchrotron spectrum

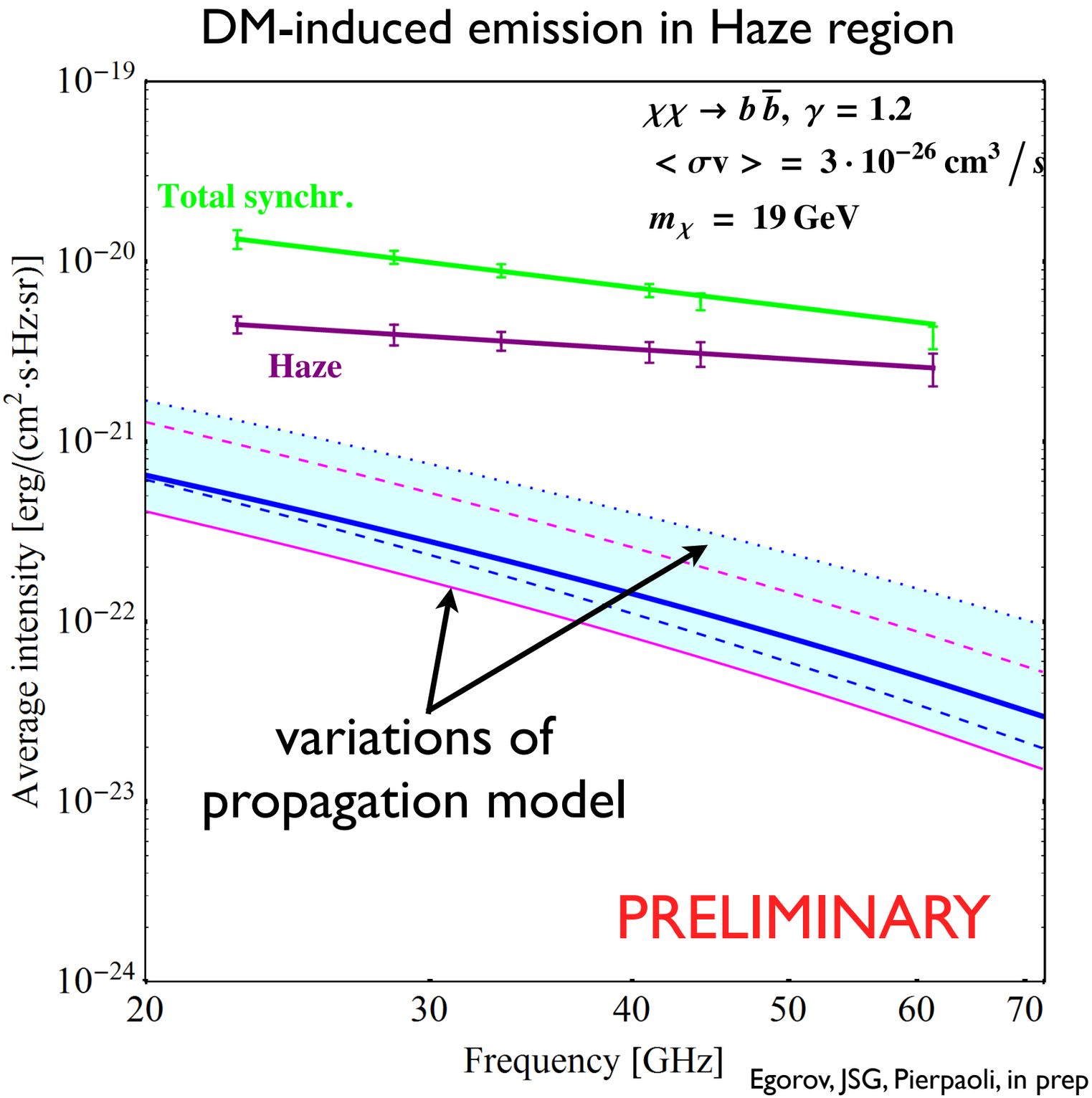
Haze spectrum
($|\ell|$<35°, -35°<b<-10°)



Planck Collaboration 2013

Dark Matter and the WMAP/Planck Haze

- models that explain GeV excess with annihilation to b quarks generally cannot account for most of the Haze
- spectrum of DM-induced emission for annihilation to b quarks generally softer than Haze spectrum

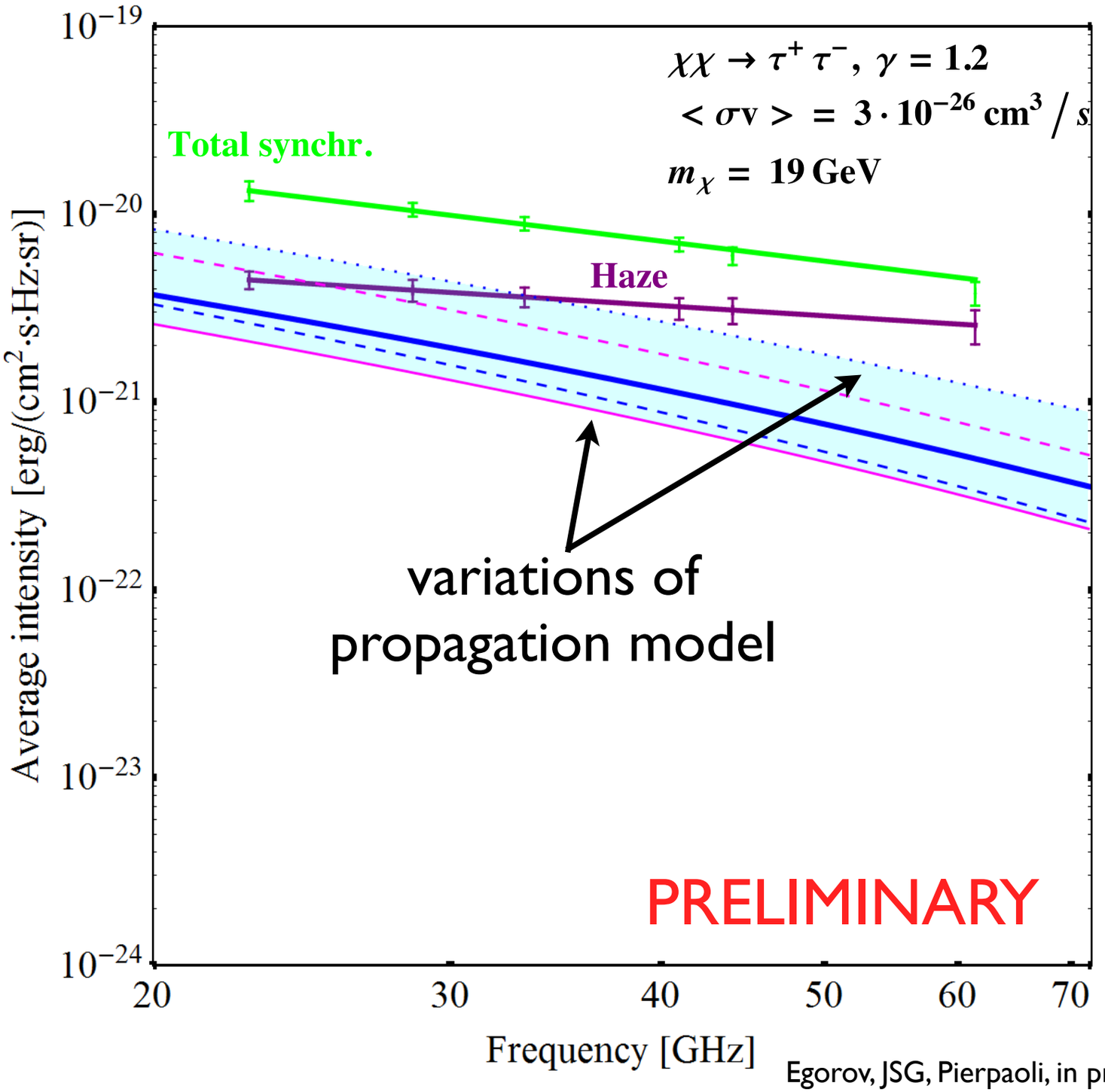


Egorov, JSG, Pierpaoli, in prep

Dark Matter and the WMAP/Planck Haze

- models that explain GeV excess with annihilation to tau leptons in tension with Haze amplitude and spectrum

DM-induced emission in Haze region

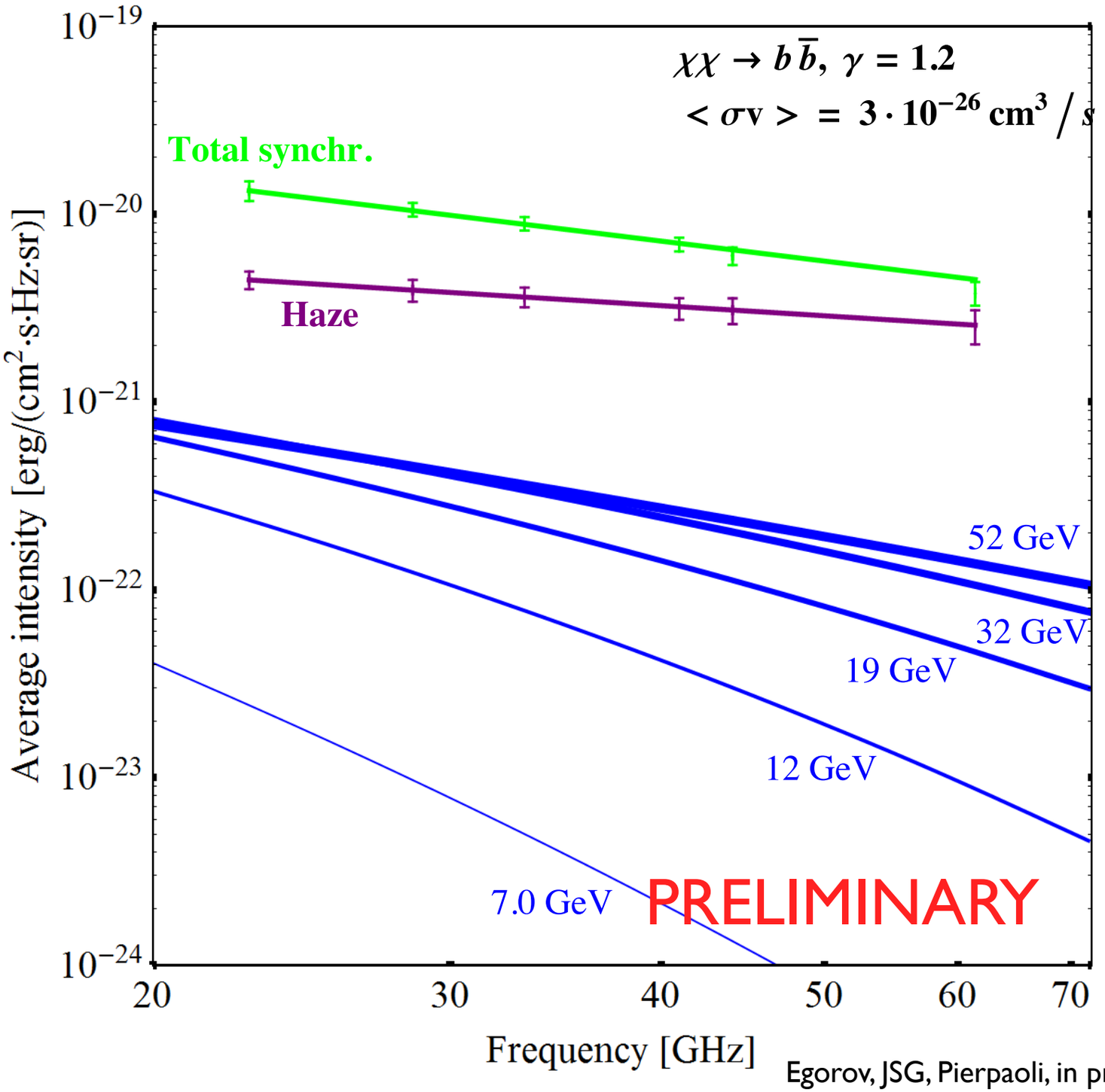


Egorov, JSG, Pierpaoli, in prep

Dark Matter and the WMAP/Planck Haze

- DM spectrum in Haze region tends to be harder with increasing DM mass → need a more massive particle than has been invoked to explain the GeV excess

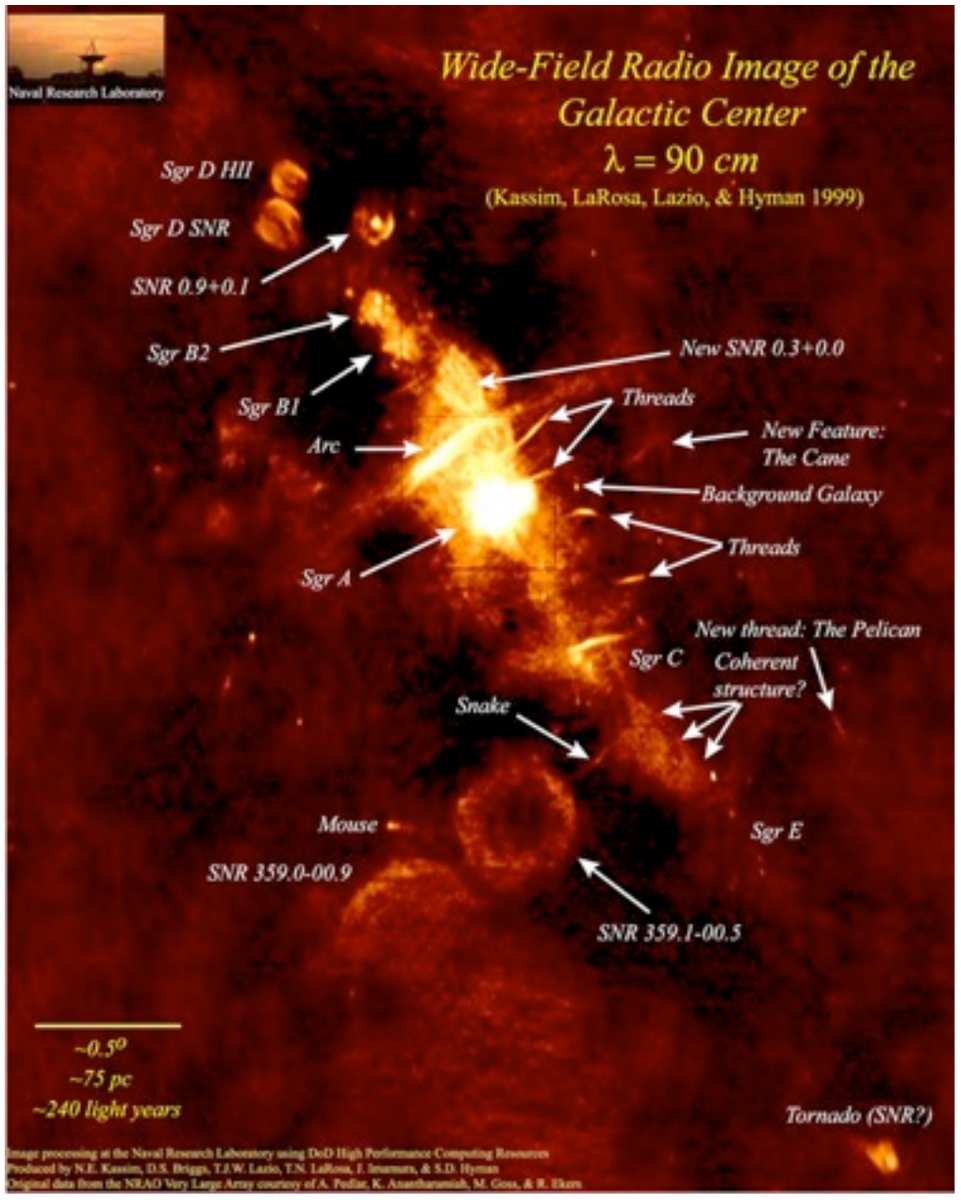
DM-induced emission in Haze region



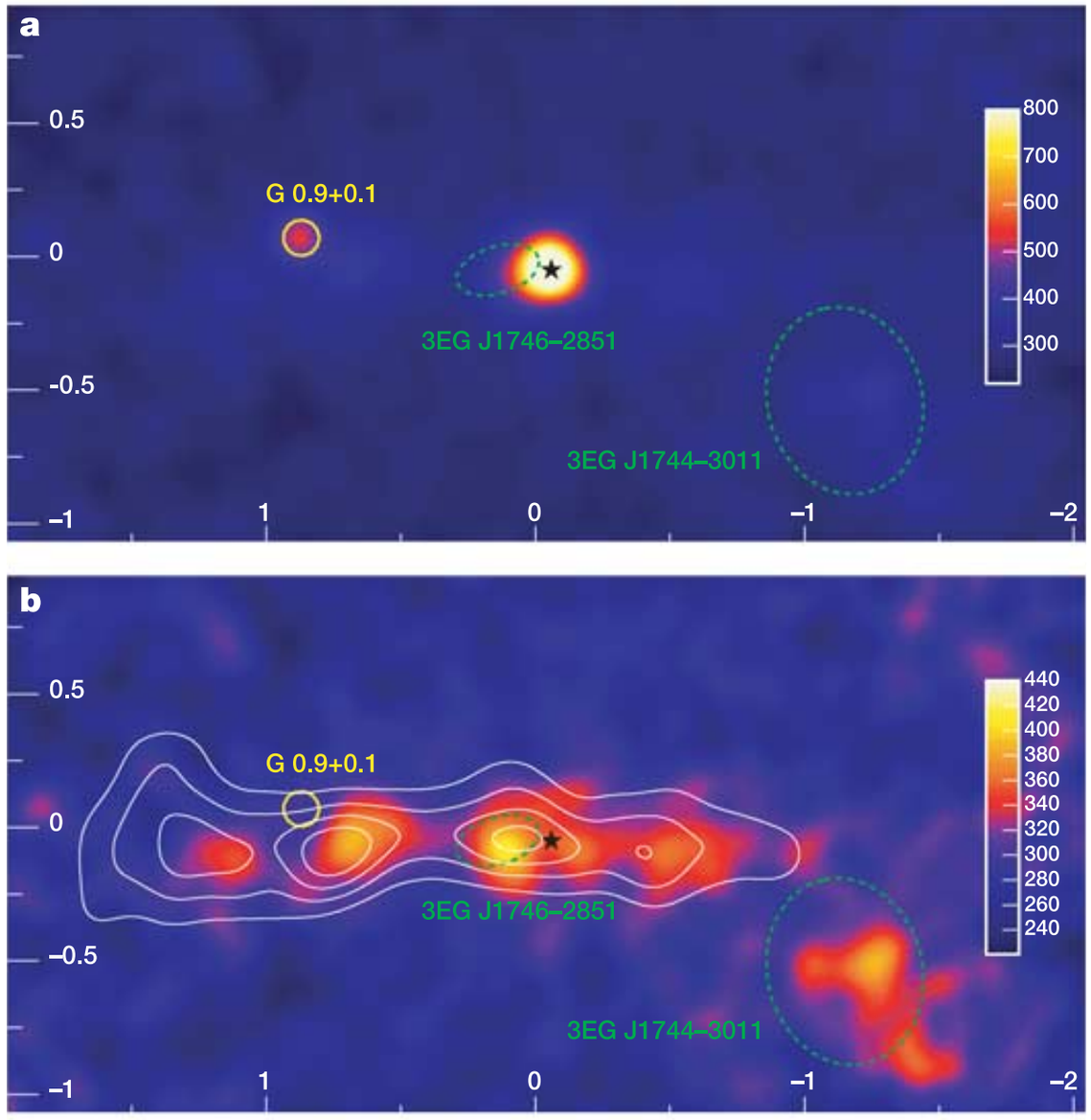
Egorov, JSG, Pierpaoli, in prep

The multi-wavelength Inner Galaxy

VLA @ 330 MHz



HESS > 380 GeV



Aharonian et al. 2006

Summary

- Hints of a possible dark matter signal have been uncovered in the form of a GeV gamma-ray excess from the Galactic Center!
- Spectrum of excess reasonably consistent with MSPs, but difficult to explain high-latitude emission with MSPs
- DM models are very flexible... beware of overinterpretation of signals
- Multi-wavelength studies can help test a DM interpretation