Kavli Institute
for Cosmological Physics
at The University of Chicago

The GeV Gamma-Ray Excess:
Overview and Astrophysical Models

Tim Linden

along with:

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Ilias Cholis, Dan Hooper (1406.????)

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Overview of this Section

- **This Talk** (Overview, and non-DM models)
- **Stephan Portillo** (CTBCORE)
- **Nick Rodd** (The Inner Galaxy Analysis)
- **Tansu Daylan** (Template Modeling and Ring Fits)

Goals of the Project

- The region around the Galactic Center is expected to produce the brightest signal from dark matter indirect detection

- Study the Fermi-LAT gamma-ray signal from the galactic center, and set limits (or possibly discover) a residual component

Hooper & Goodenough (2011)
Hooper & Linden (2011)
Abazajian & Kaplinghat (2012)
Hooper & Slatyer (2013)

Gordon & Macias (2013)
Macias & Gordon (2013)
Abazajian et al. (2014)
Daylan et al. (2014)

Two Separate Analyses

- <u>Inner Galaxy</u>
  - $|b| > 1^{o}, 2^{o}$.
  - Bright Point Sources Masked
- See talk by Nick Rodd

- <u>Galactic Center</u>
  - $|b| < 5^{o}, |l| < 5^{o}$
  - Use likelihood analysis to calculate the normalizations and spectra of each source
  - Calculate the log-likelihood fit for models where an excess component is, or is not, included

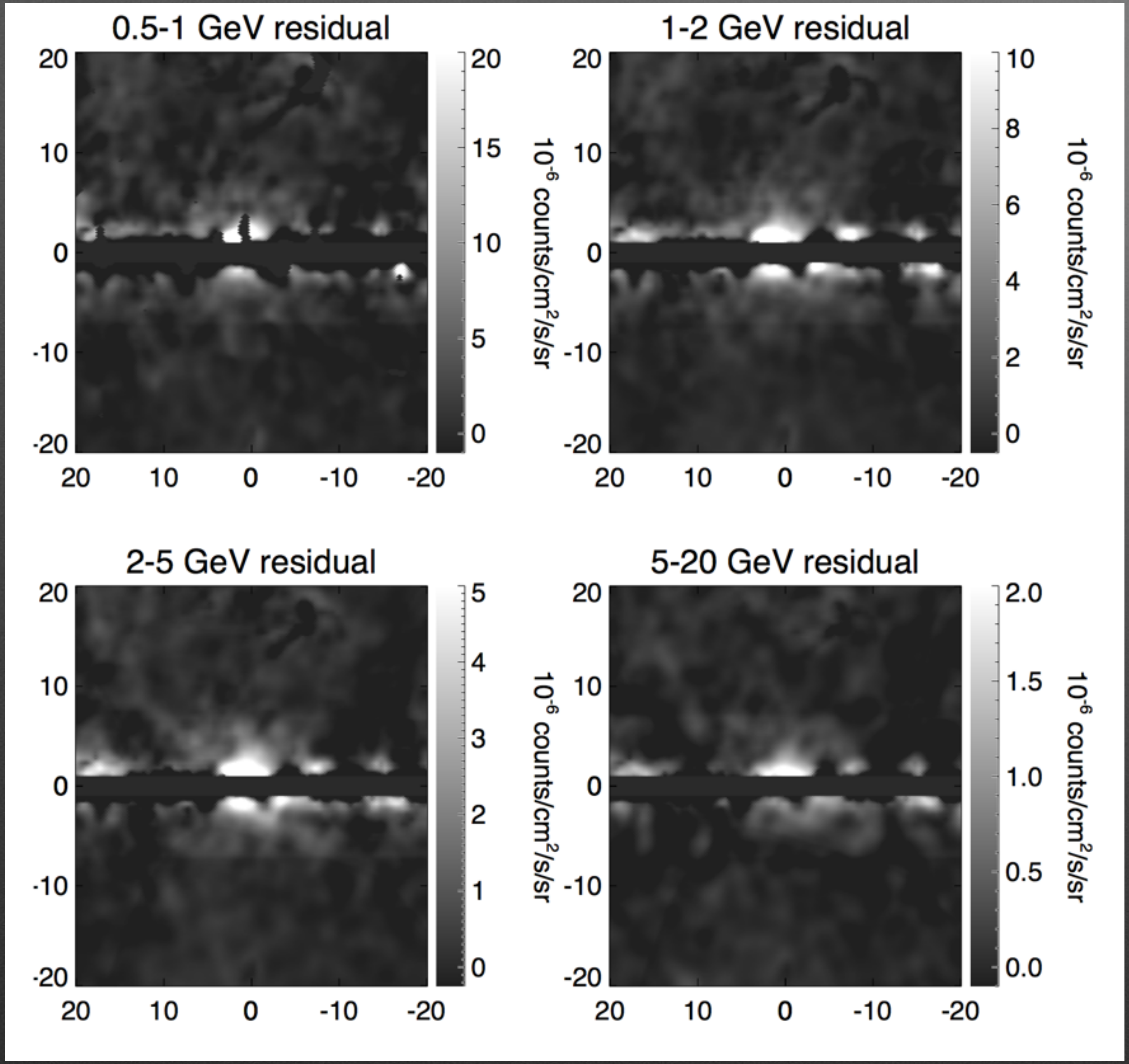
Galactic Center Details

- Use Front-Converting photons with the 50% best CTBCORE Values (Stephan Portillo's Talk)
- Allow the value of 41 different parameters to float independently. Normalization of diffuse and isotropic models, normalization of dark matter models, 38 parameters corresponding to point sources
- In order to obtain a model independent spectrum of the dark matter component, a secondary fit is attempted where the dark matter component is allowed to vary arbitrarily in each energy bin, the resulting best fit spectrum is then inserted back into the overall model fit, and the process is repeated iteratively

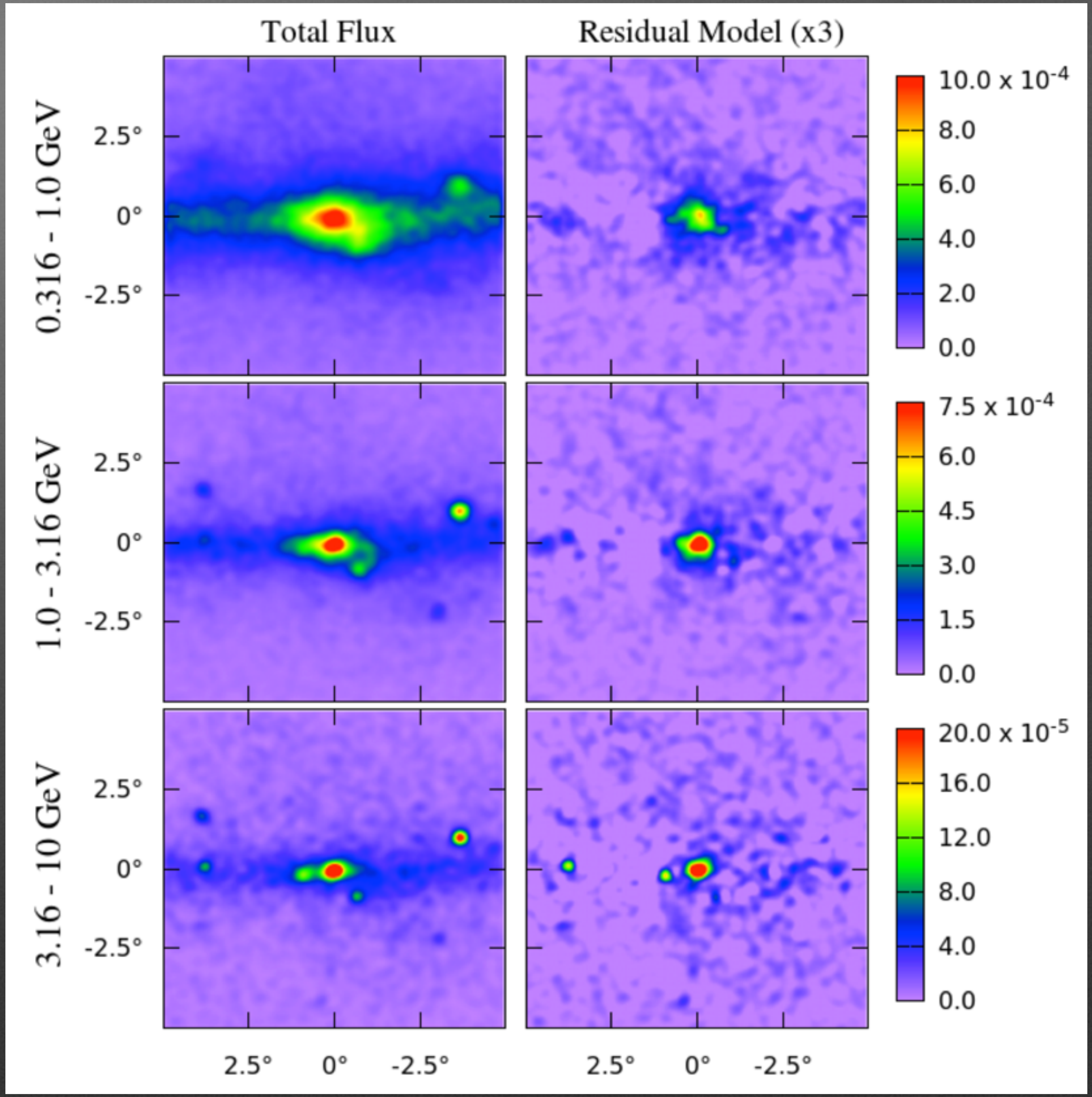
Galactic Center Details

- Multiple additional tests of this excess:
  - Different diffuse emission models (P7V6 Reprocessed, P6)
  - Different isotropic background models (Source/Clean for P7V6, Abdo. et al. (2010) extragalactic background, Ackermann et al. diffuse emission models)
  - Addition of multiple additional point sources into the GC Region (PS1, PS2 from Yusef-Zadeh et al. (2013) PS3, PS4, PS5, PS6 from Abazajian et al. (2014)
  - Arbitrarily normalized diffuse and isotropic emission spectra
  - Multiple Sgr A* point sources (to allow for arbitrary point source spectrum)

Consistent Results!

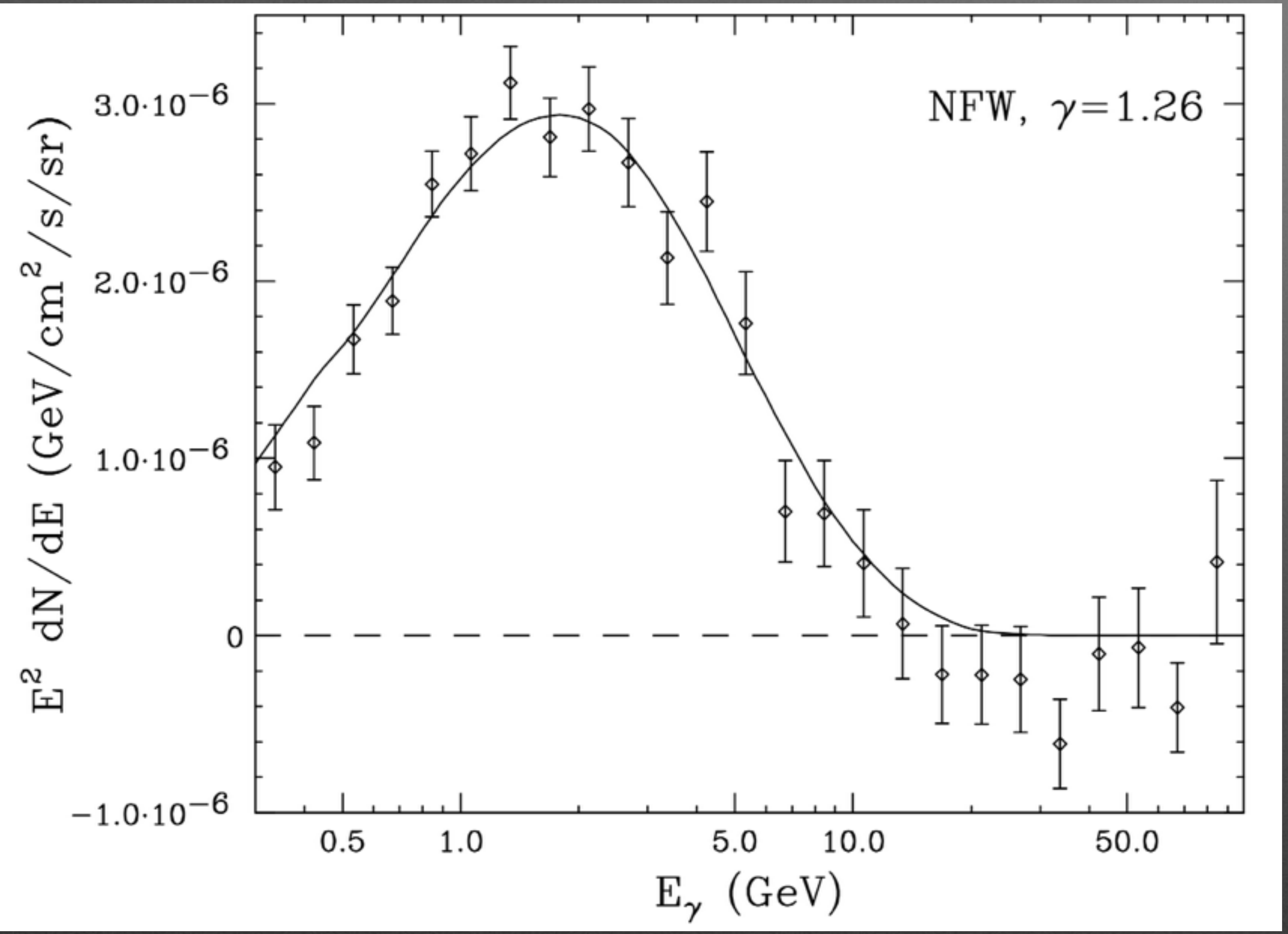


Inner Galaxy

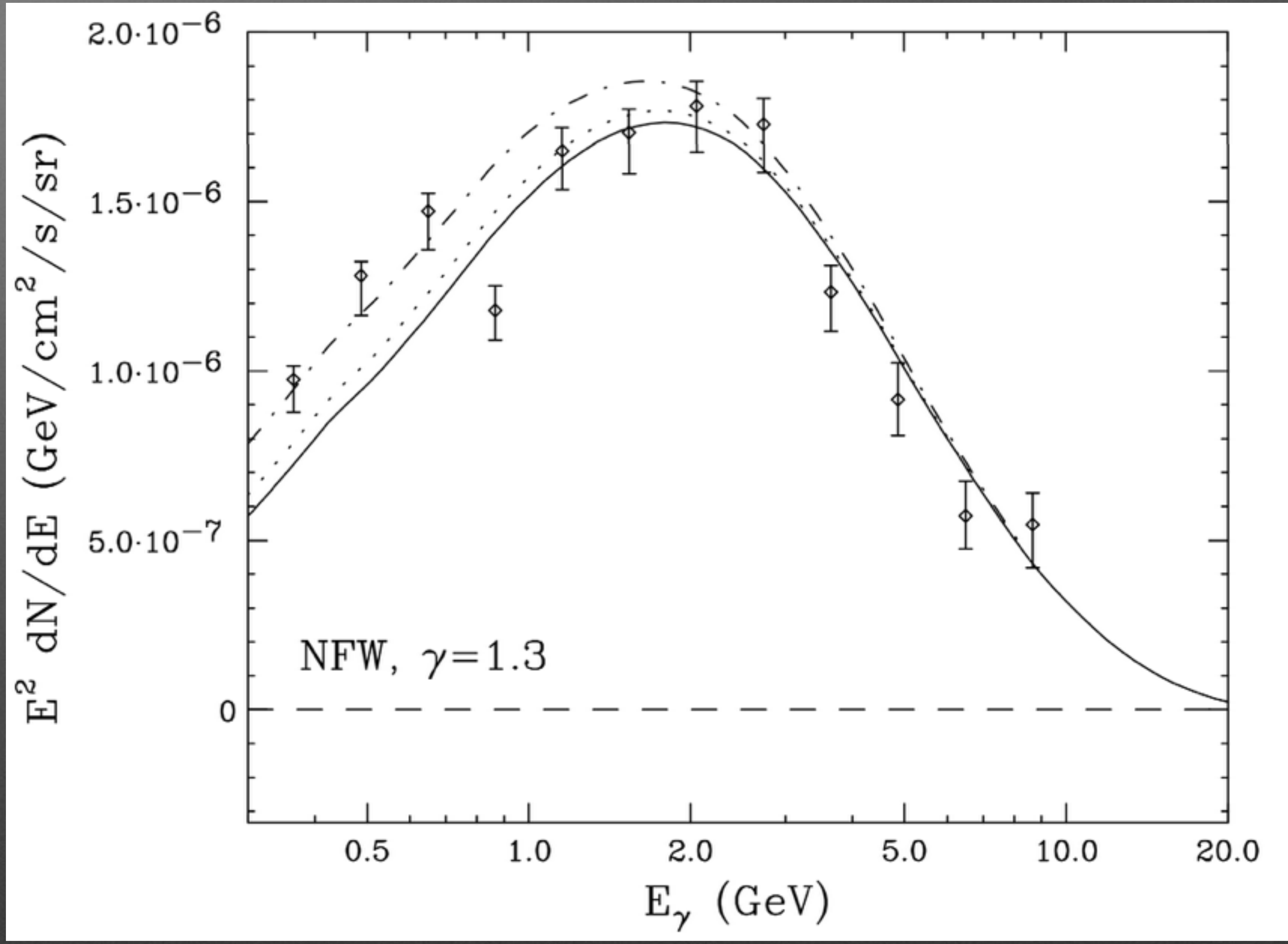


Galactic Center

Consistent Results!



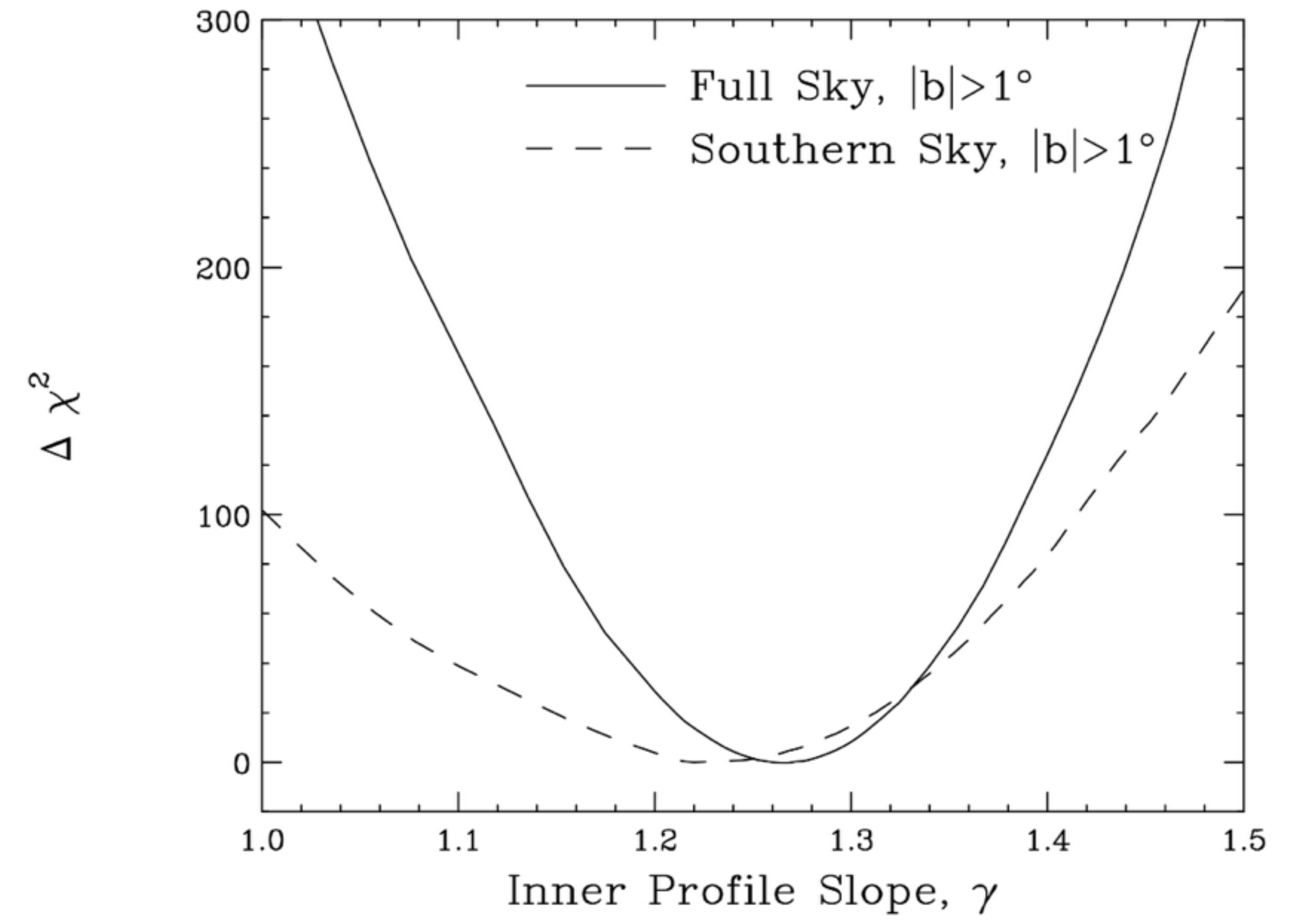
Inner Galaxy



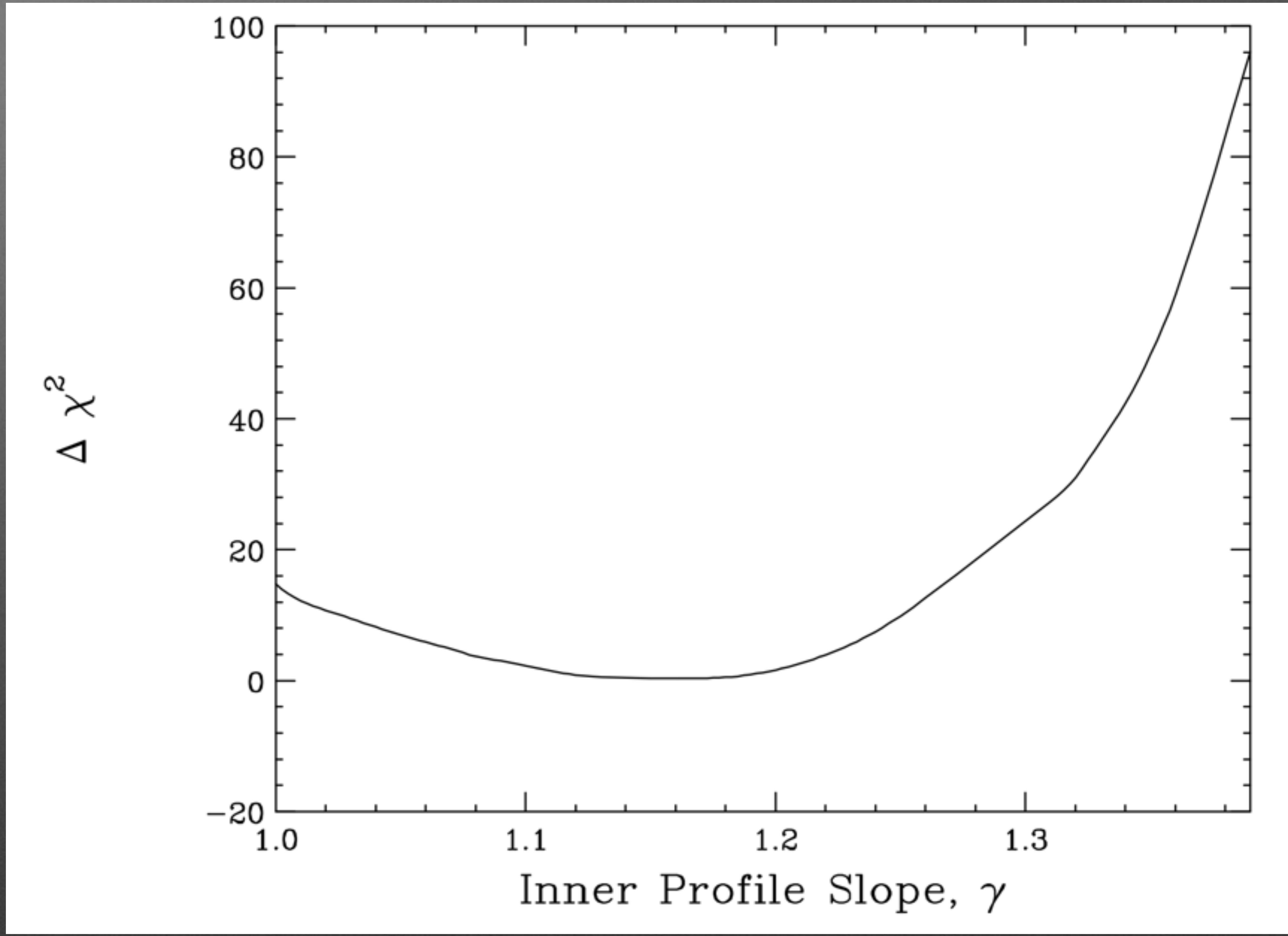
Galactic Center

* Reanalysis of Inner Galaxy excess changes intensity of peak by ~20%, see talk by Nick Rodd

Consistent Results!

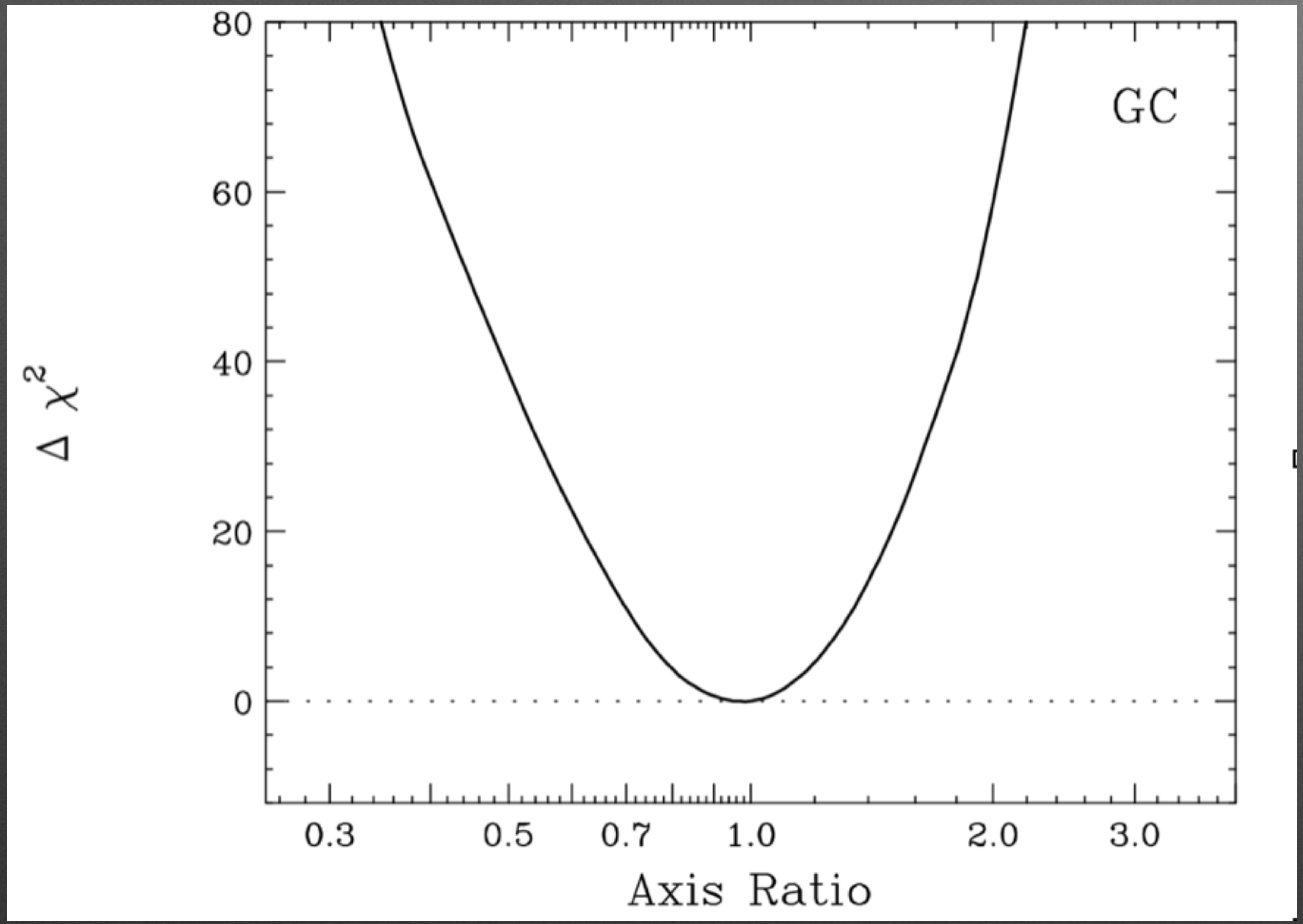


Inner Galaxy

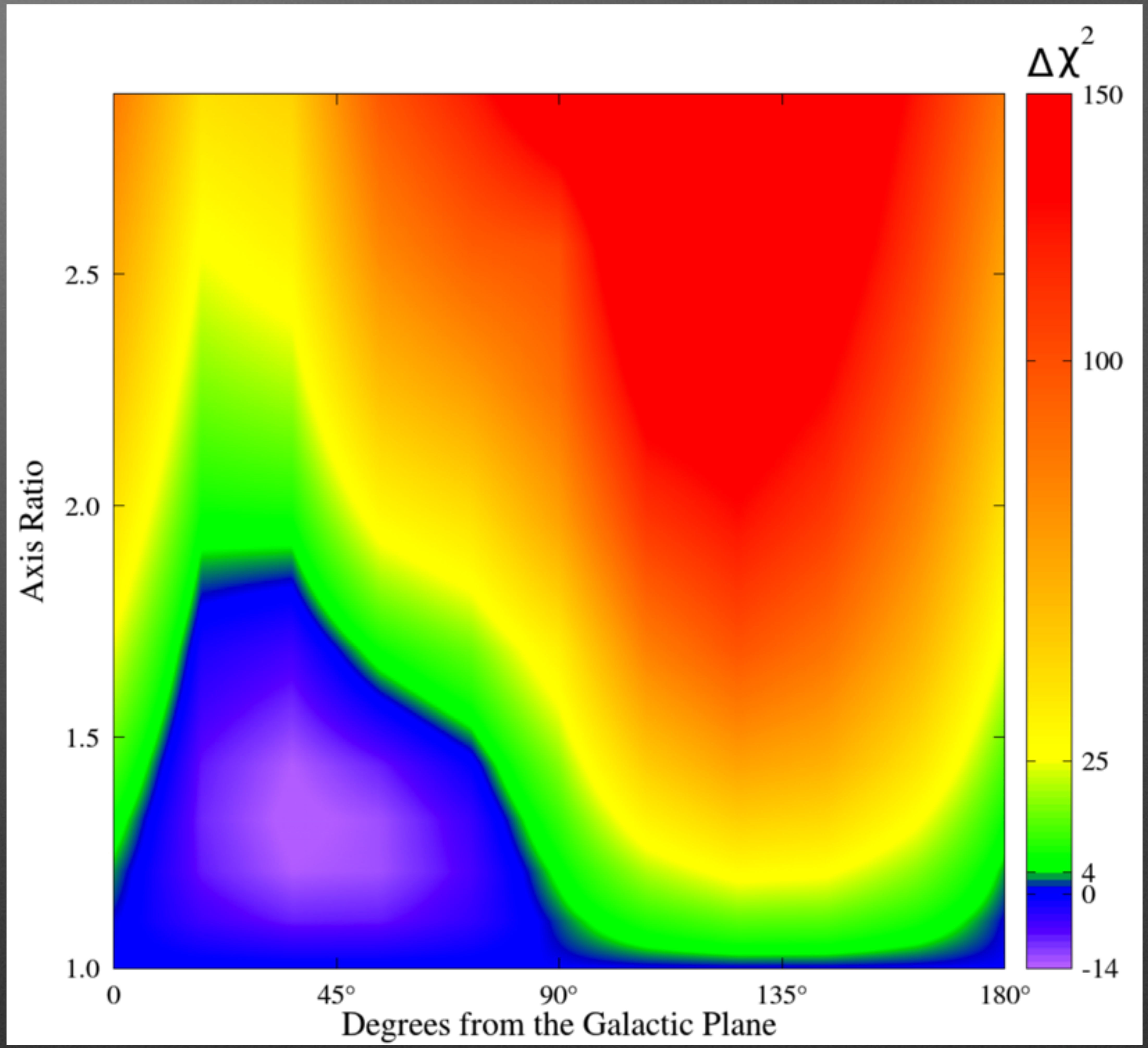


Galactic Center

Constraining Results!

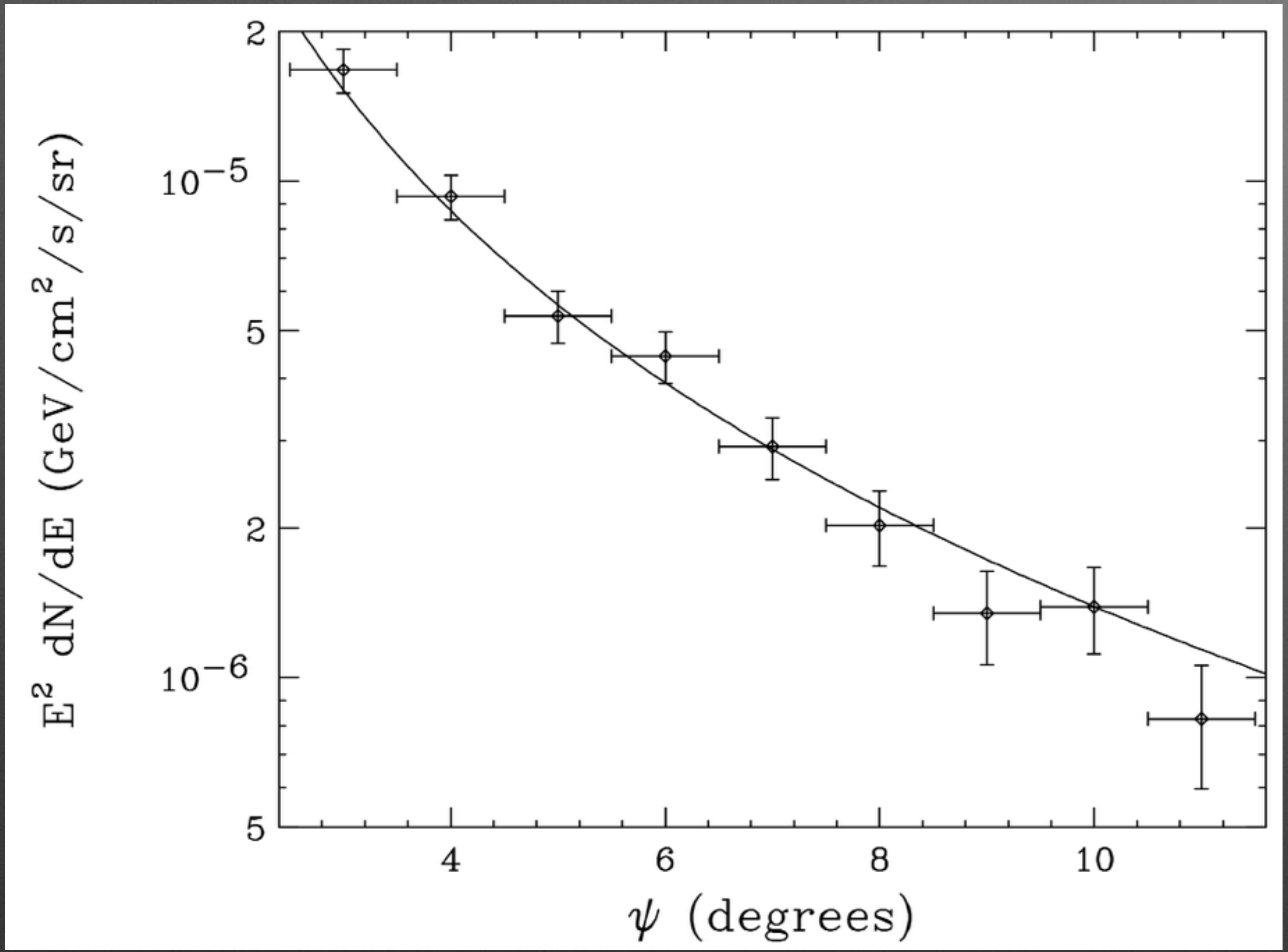


Galactic Center

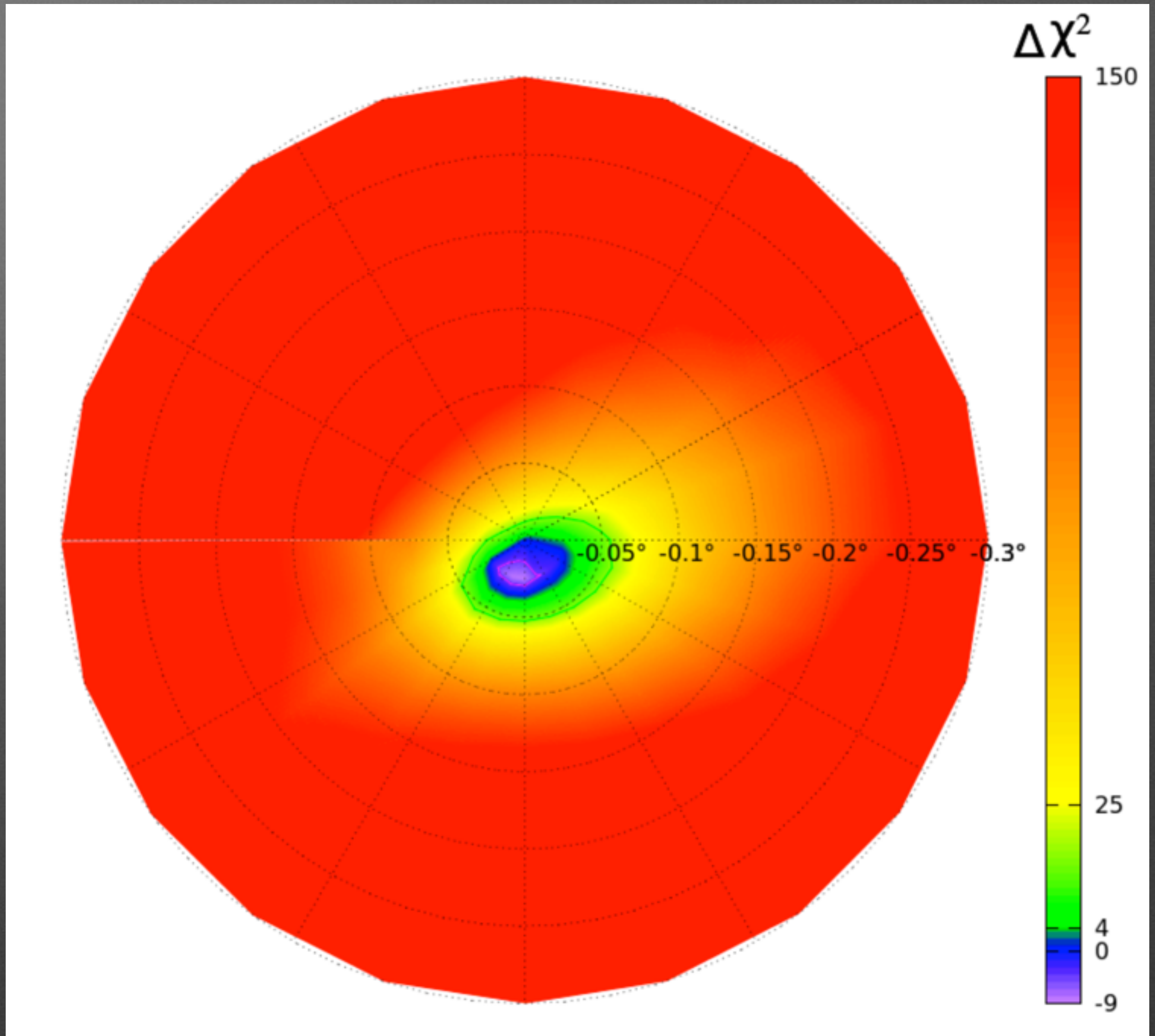


Inner Galaxy - Renalysis in progress, see talk by Nick Rodd

Constraining Results!



Inner Galaxy



Galactic Center

Alternative Emission Models

- Two Relatively Non-Controversial Assertions:
  - The residual emission is real, compared to the Fermi-LAT diffuse models
  - The residual emission is not an obvious, previously known, extension of the Fermi-LAT diffuse model (e.g. it doesn't trace known missing gas)

Alternative Emission Models

- Some novel astrophysical models have been proposed:
  - An undetected population of MSPs (Abazajian et al. 2011)
  - A recent outburst from the galactic center
    - Hadrons (Carlson & Profumo 2014)
    - Leptons (Petrovic et al. 2014)

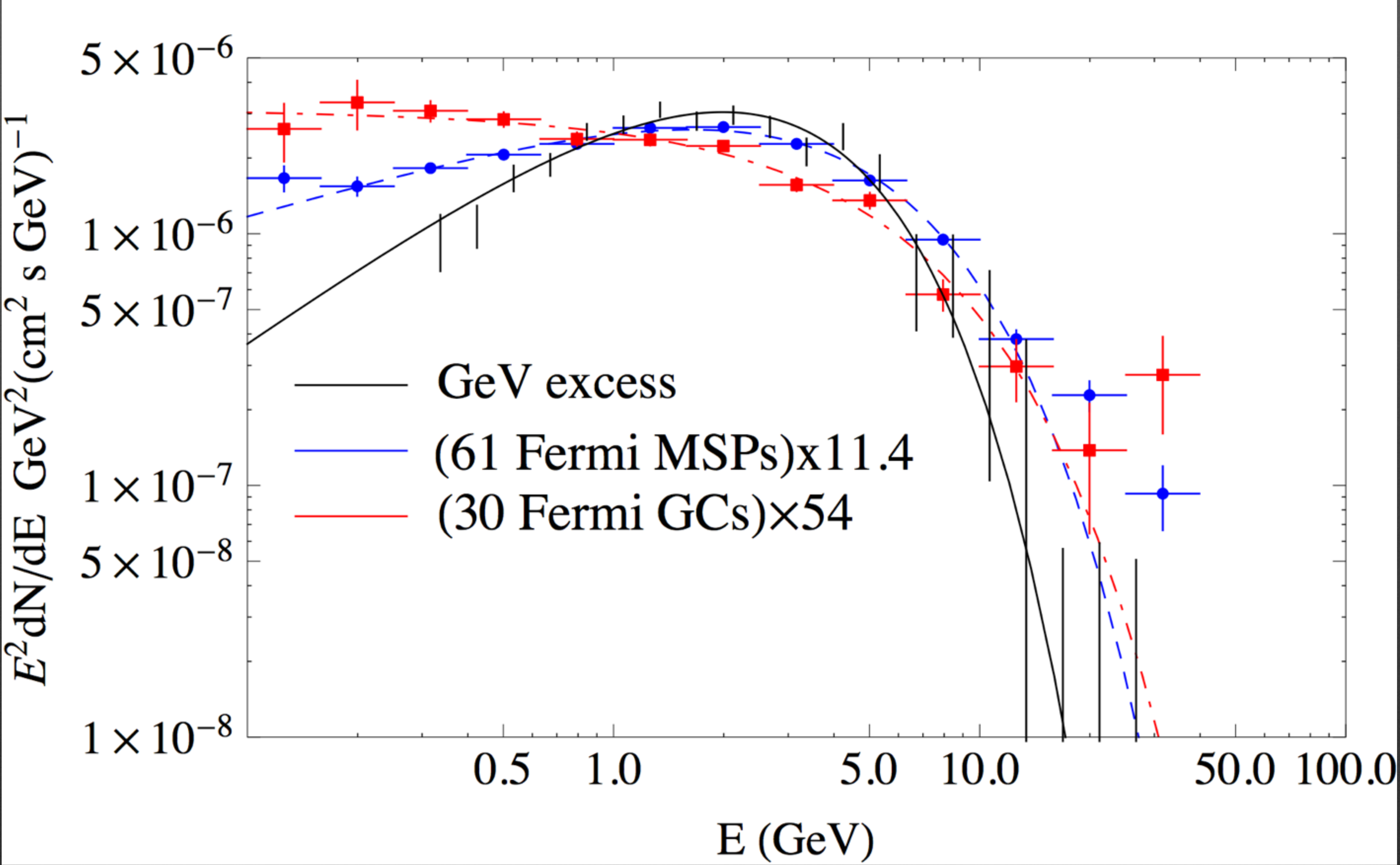
Pulsar Emission Models

Cholis, Hooper, TL (2014, TBS)

- We can additionally study the average spectrum of MSPs and globular clusters

Cholis, Hooper, TL (2014, TBS)

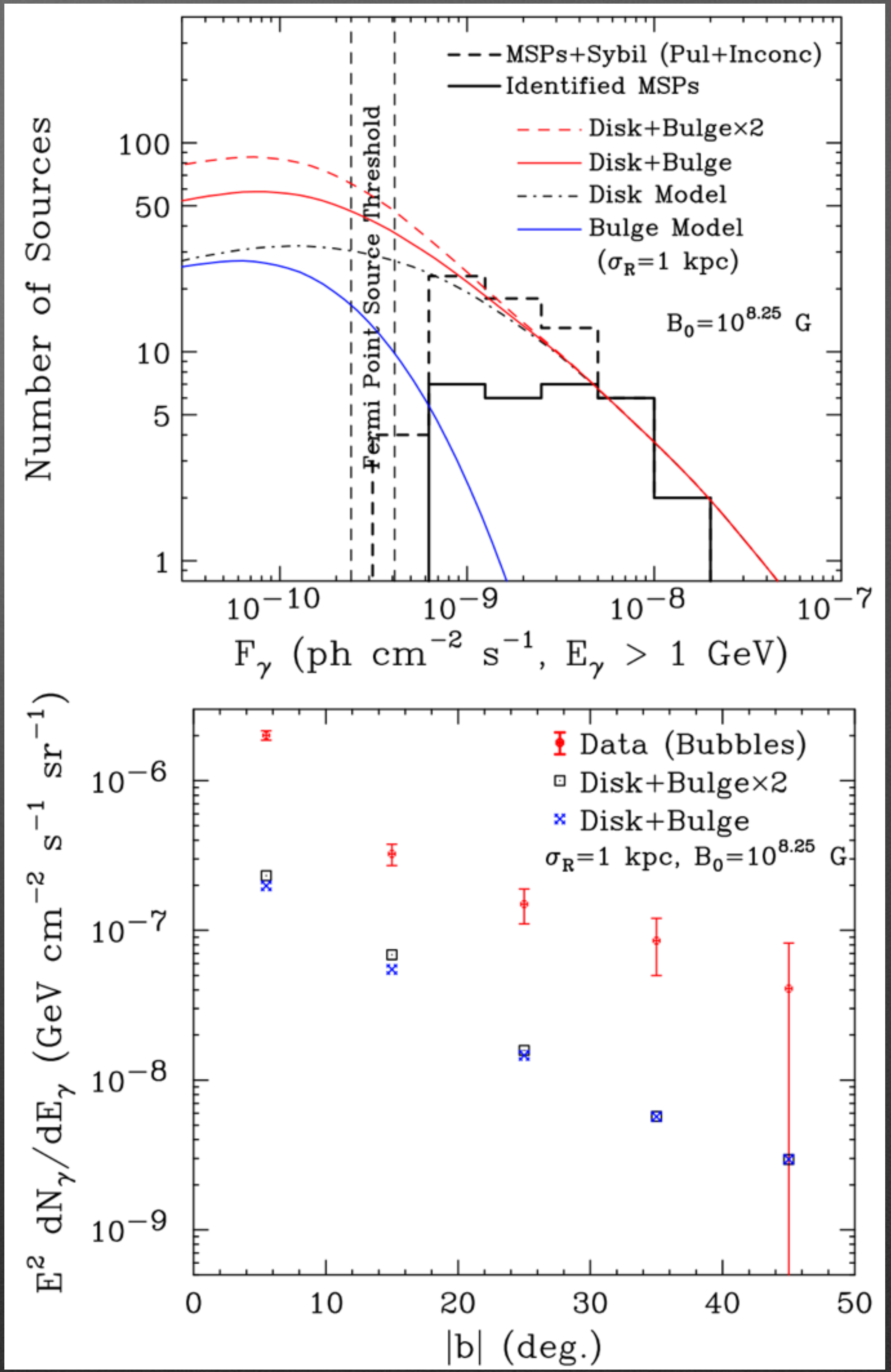
Pulsar Emission Models



Pulsar Emission Models

- Hooper et al. (2013) showed that MSPs could not produce the total diffuse intensity of the excess, without overproducing the number of bright point sources that should be detected by Fermi-LAT

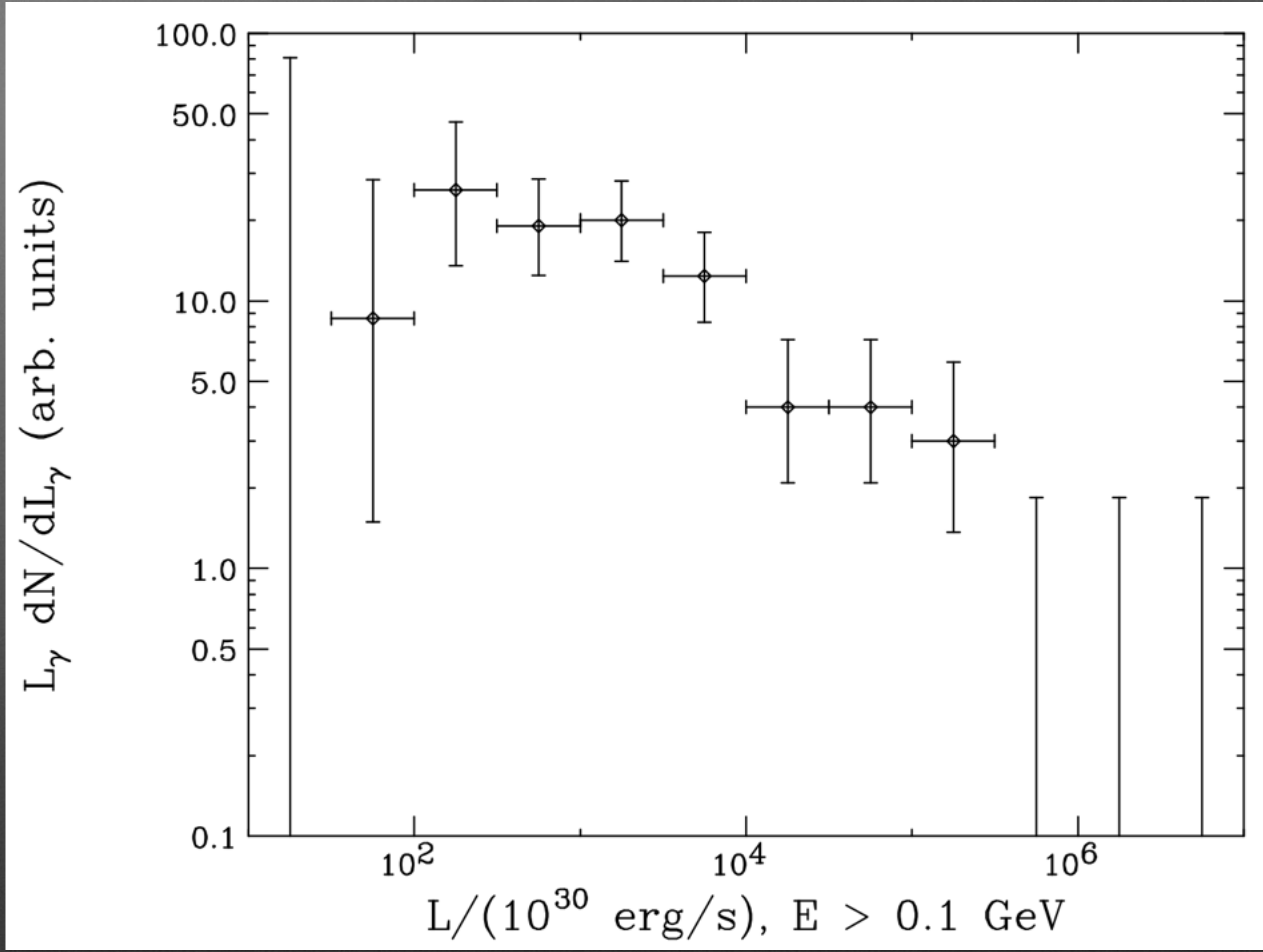
- This relied on theoretical models of the MSP luminosity function



Hooper et al. (2013)

Pulsar Emission Models

- Using 5.5 years of data and the observation of 62 MSPs, we can now *measure* the luminosity function of the MSP population

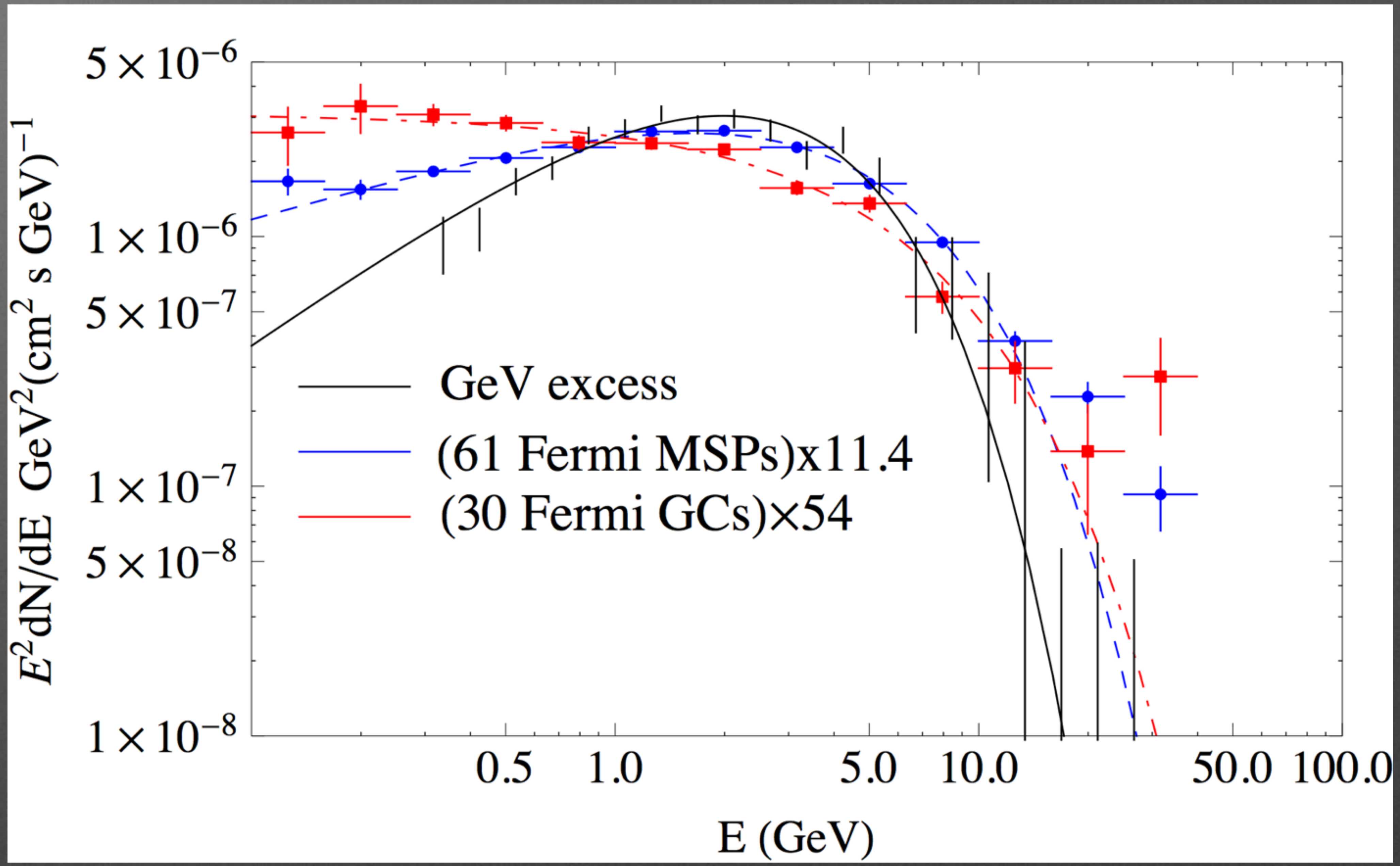


Cholis, Hooper, TL (2014, TBS)

Pulsar Emission Models

Cholis, Hooper, TL (2014, TBS)

- The intensity of the excess requires 2002 pulsars, 270 of which are likely to be detectable given the 2FGL constraints



- Only 7 unidentified sources in this region are detected

- Conclusion: Pulsars can account for approximately 5-10% of the total excess, but are strongly prohibited from accounting for 100%.

Hadronic Emission Models

Carlson & Profumo (2014)

- Recent work indicated that an outburst from Sgr A* could produce the spectrum and morphology of the excess

Hadronic Emission Models

Spectral fits are based on “delta-function” proton injection spectra, which are not astrophysical motivated

Hadronic Emission Models

Carlson & Profumo (2014)

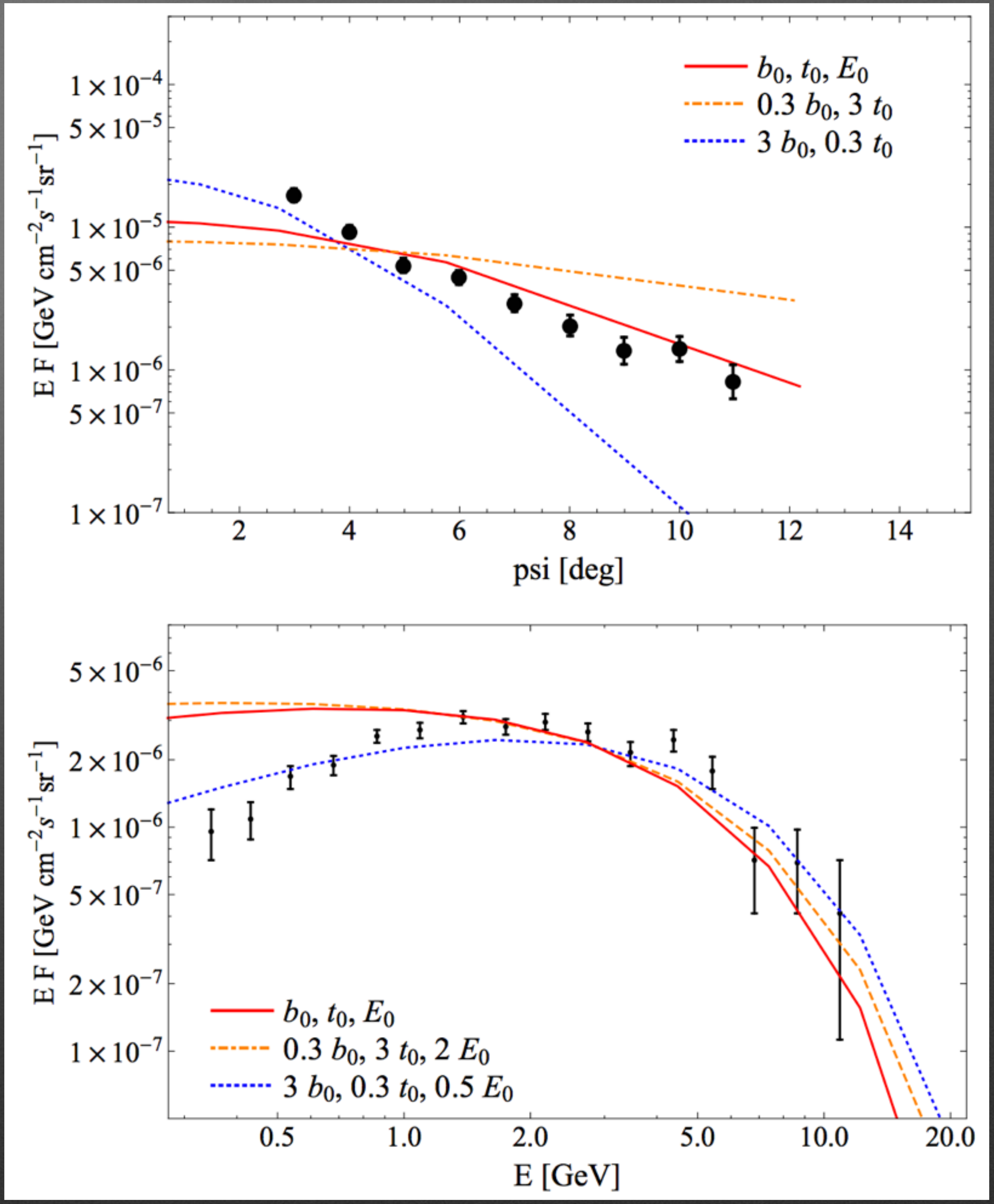
- Thanks to Eric Carlson and Stefano Profumo for providing us with the galprop output files.

- We have run these models through our code (similar to what we do with the dark matter fits). The models pick up the following TS values:
    - 19 kyr: **TS = 14.5** (with arbitrary spectrum: **TS = 26.6**)
    - 100 kyr: **TS = 0.0** (with arbitrary spectrum: **TS = 0.28**)
    - 2 Myr: **TS = 0.0**, (with arbitrary spectrum: **TS = 0.0**)
    - 7.5 Myr Continuous: **TS = 0.0** (with arbitrary spectrum: **TS = 0.0**)
    - Dark Matter Template (Daylan et al. 2014): **TS = 288**

Leptonic Emission

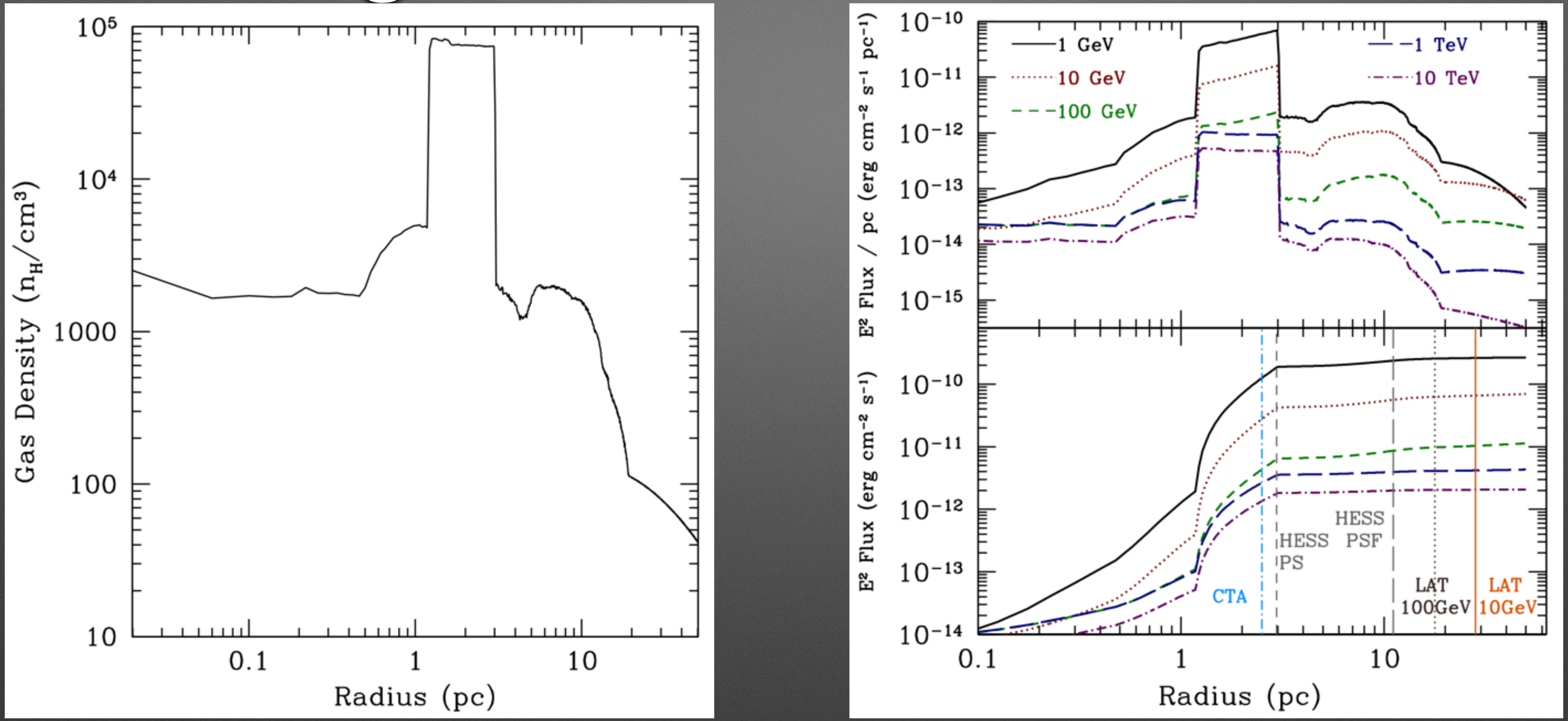
- A peaked spectrum of cosmic-ray leptons can also produce hard emission from bremsstrahlung or inverse Compton scattering

- However, electrons cool rapidly, it is difficult to produce the same hard spectrum over several degrees in the sky



Petrovic et al. (2014)

Sgr A* Emission Models



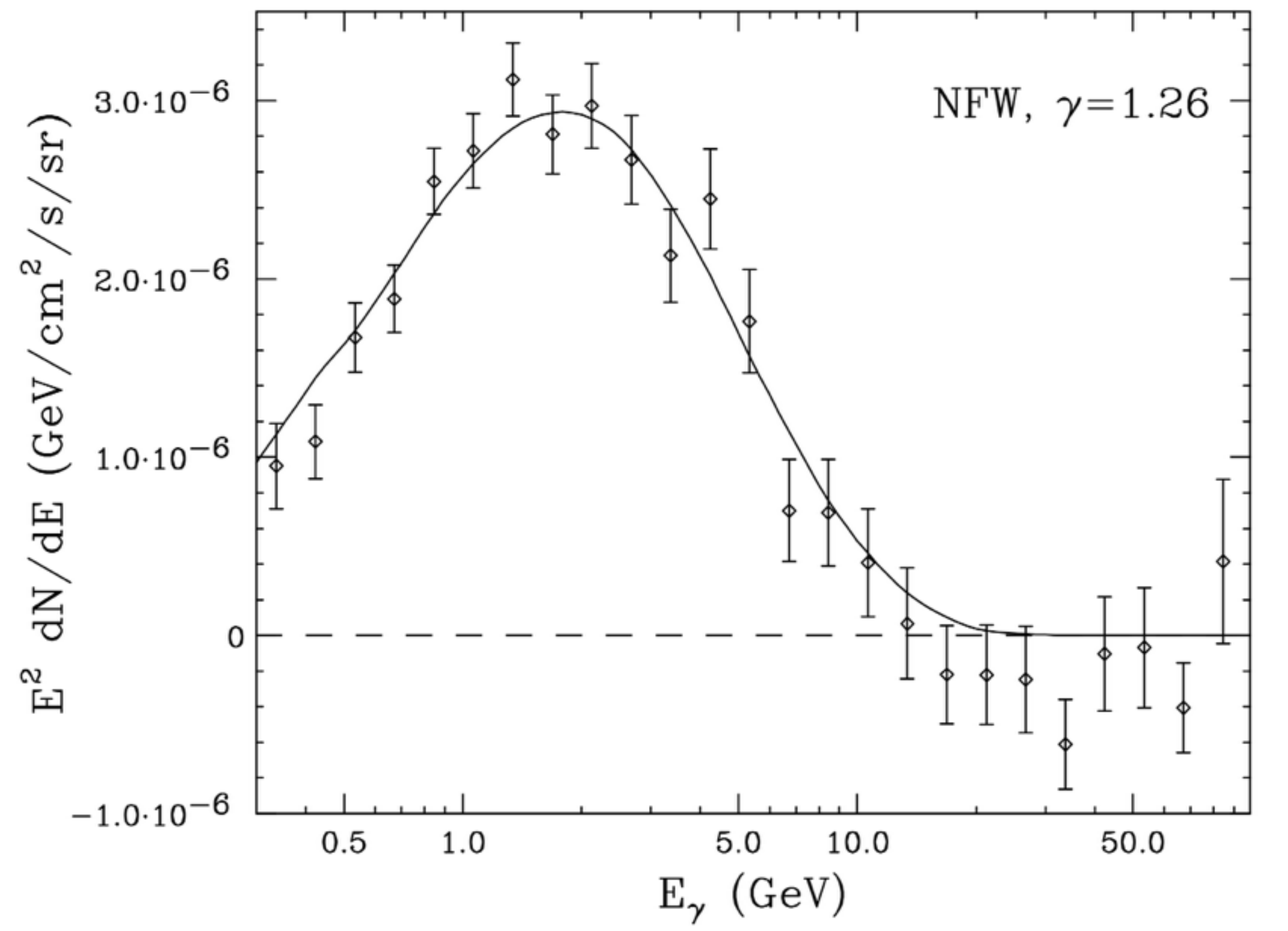
- Emission from Sgr A* produces point-like emission due to interactions with the circumnuclear ring. Constraints from this process must be accounted for.

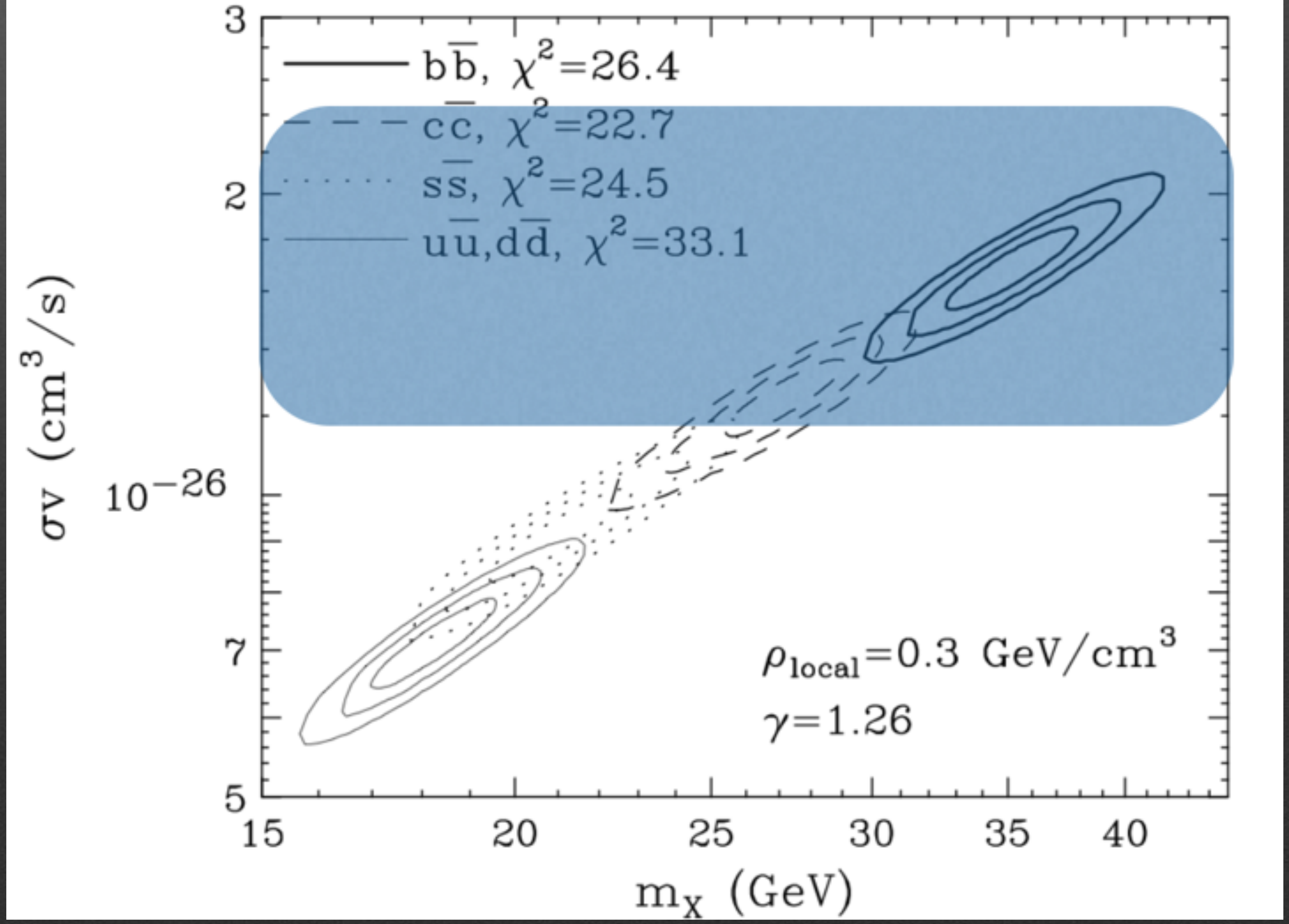
Linden et al. (2012)

Dark Matter

- Dark Matter Models provide a great fit to the spectrum and morphology

- These dark matter models are ‘natural’. The cross-section is compatible with a thermal relic, no theoretical tricks are necessary





See slides from Dan Hooper and Sam McDermott in Monday’s session

Conclusions

- The excess in emission at the galactic center (compared to diffuse models) is well established, and extremely bright

- There is no clear astrophysical interpretation of the data. In particular the hard spectrum and spherical morphology of the excess are hard to model with astrophysical templates

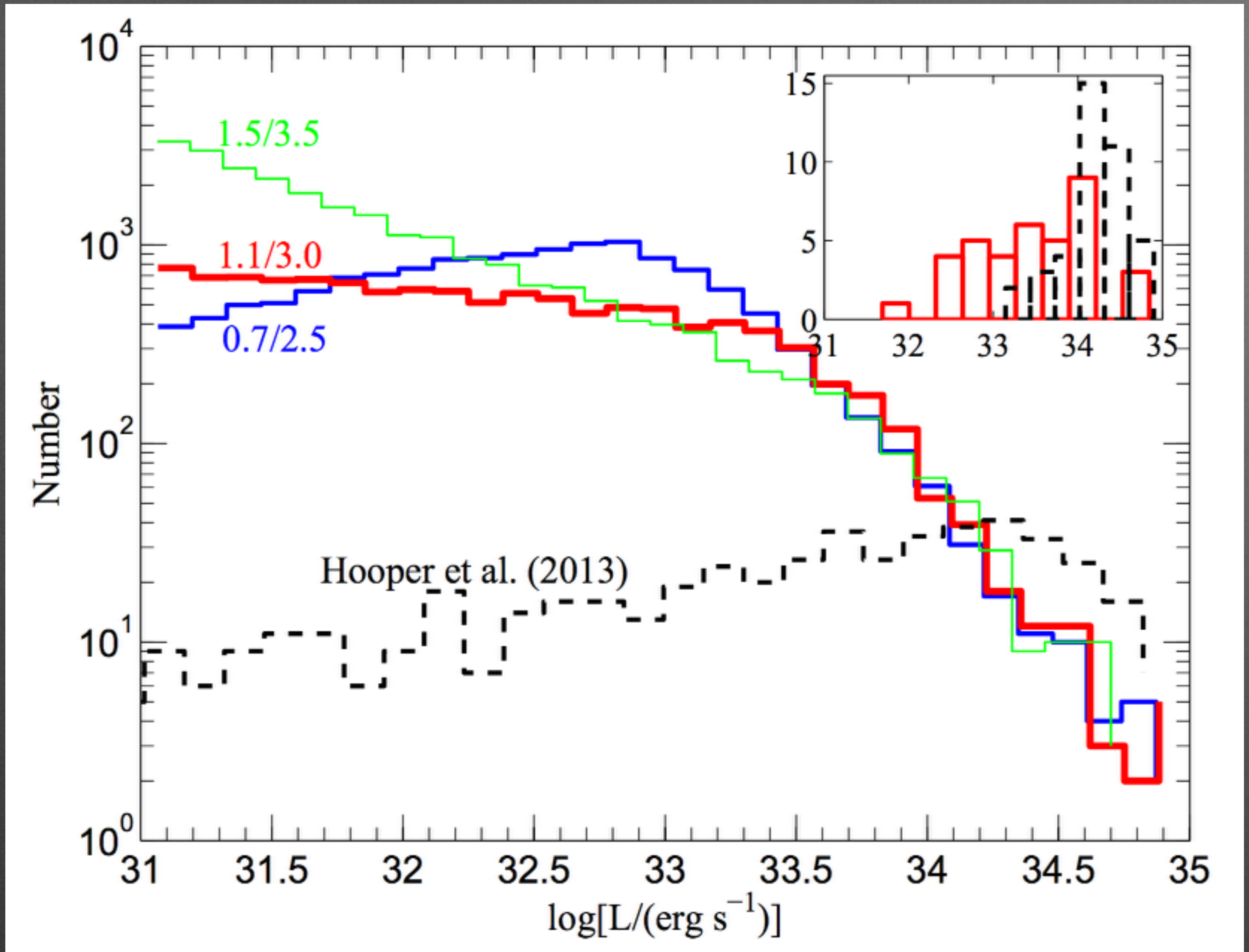
- Dark Matter provides a natural fit to all aspects of the data. The dark matter templates are “natural” and consistent with all astrophysical constraints

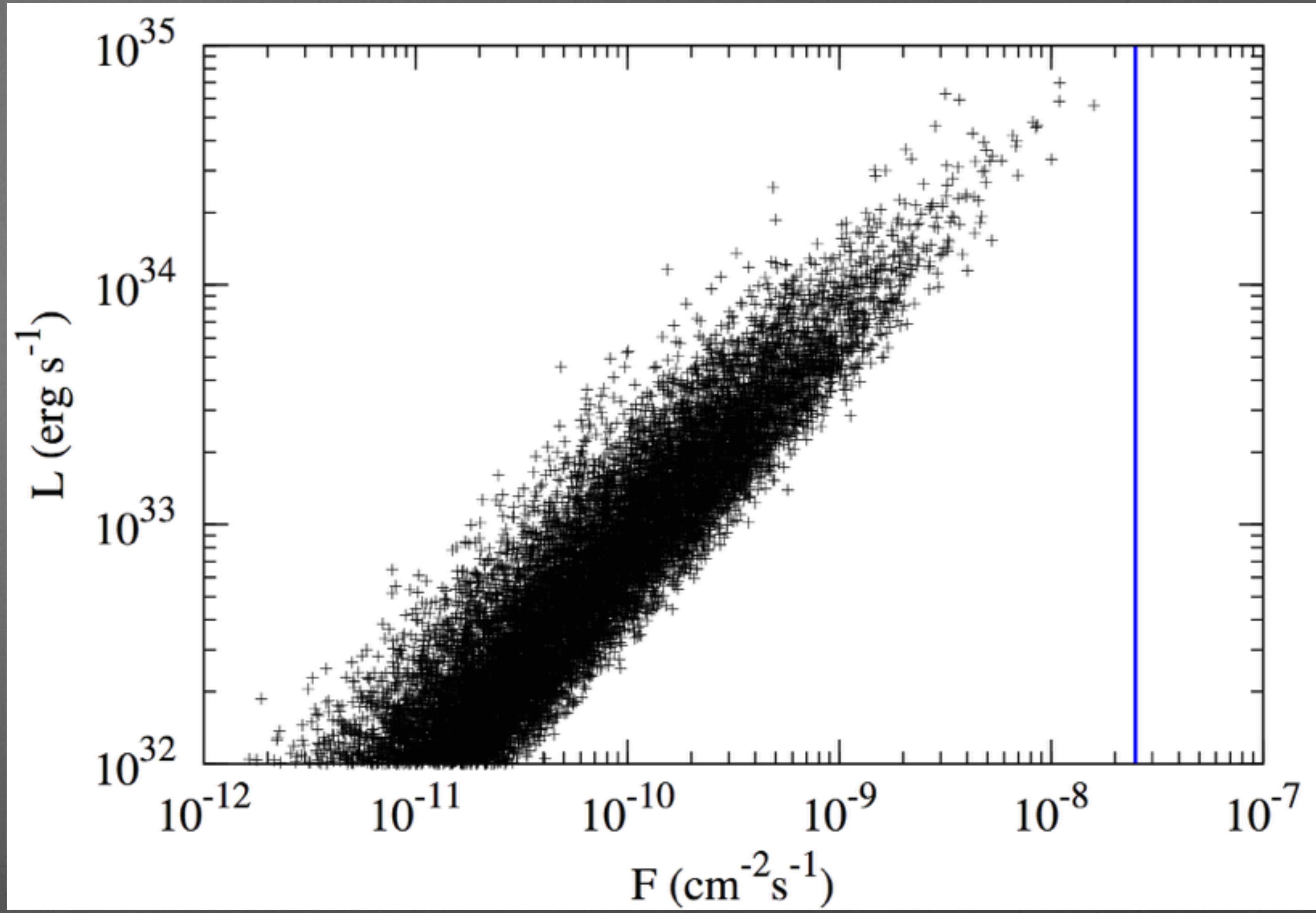
- These three above points do not establish a “bulletproof detection” of dark matter - and multiple astrophysical models should (and are) being attempted.

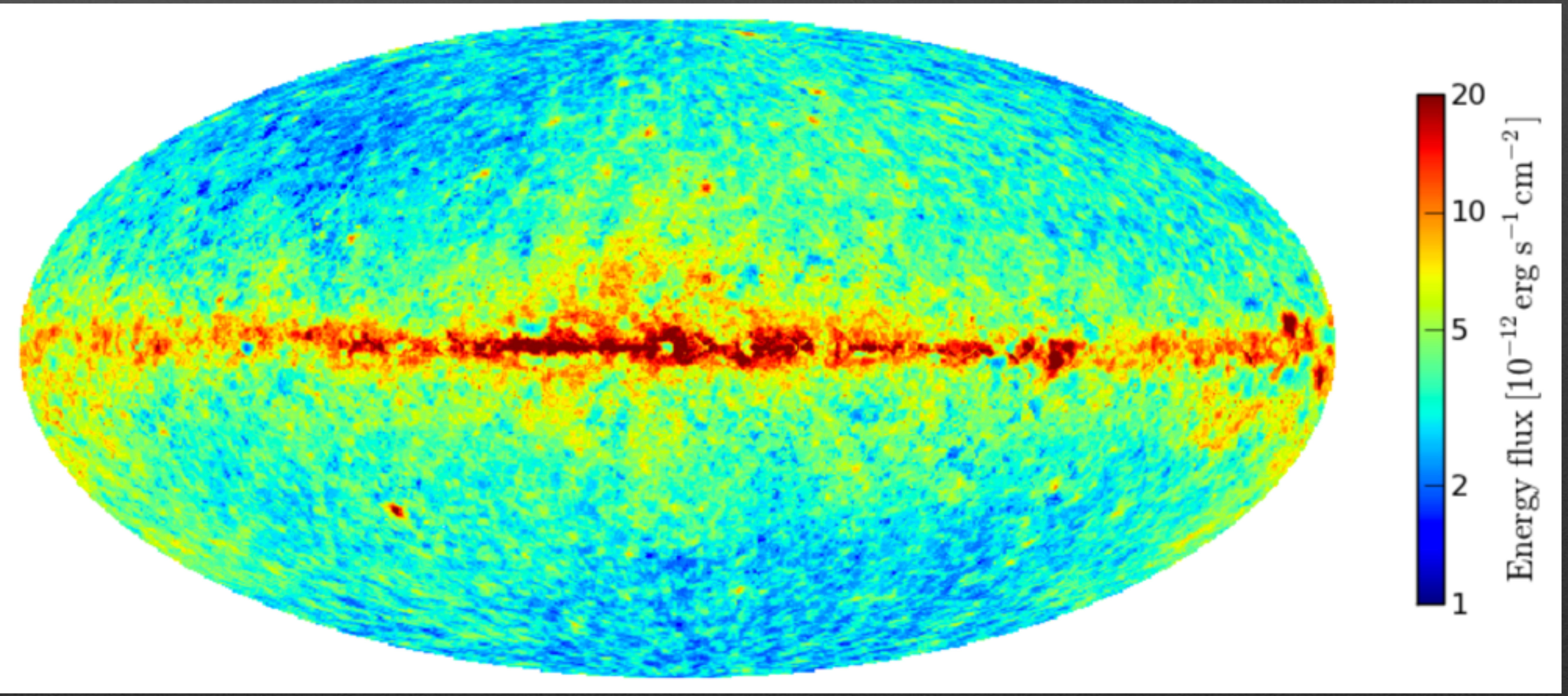
- Stay Tuned!

Extra Slides

Yuan & Zhang (2014)

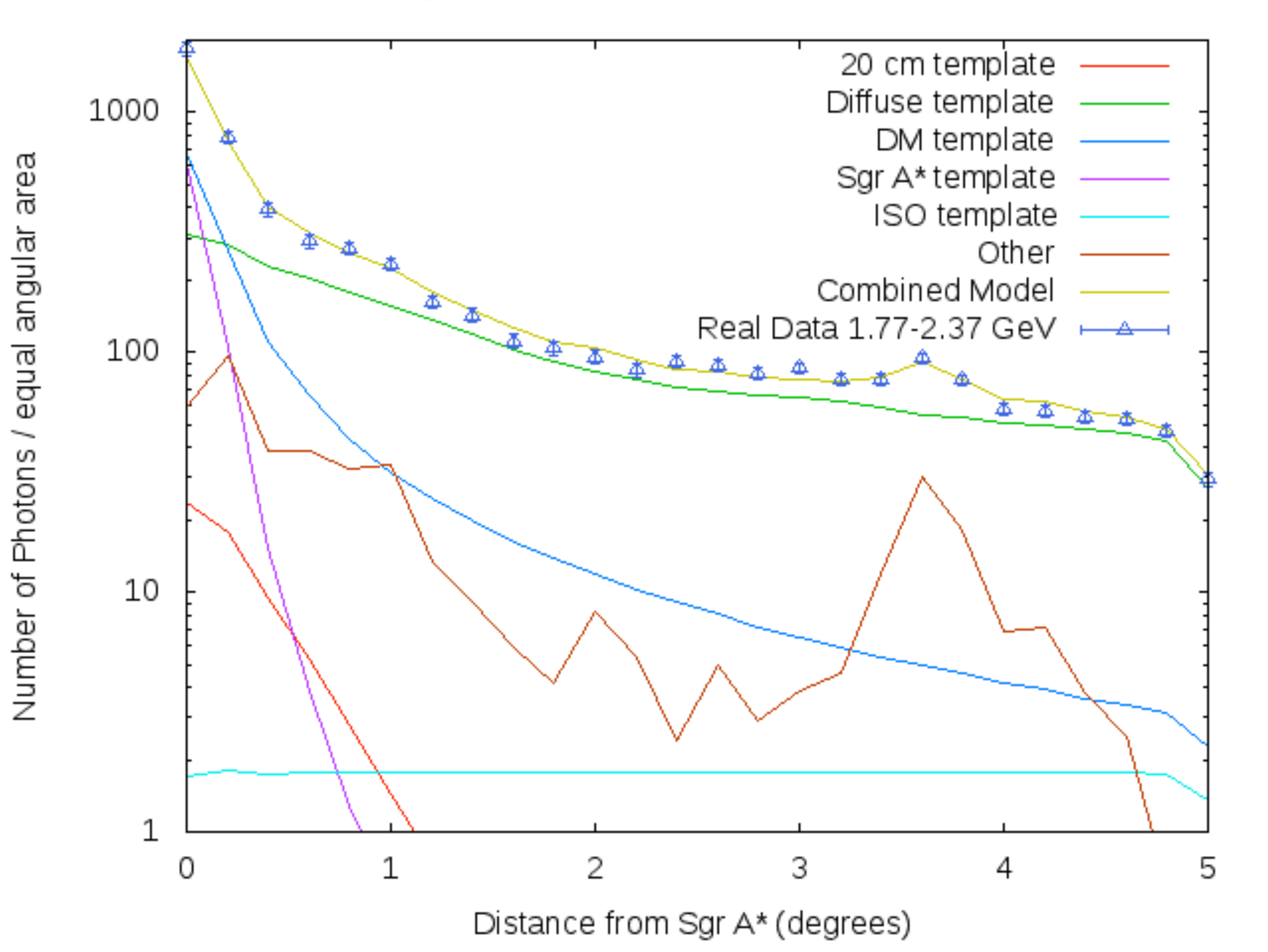




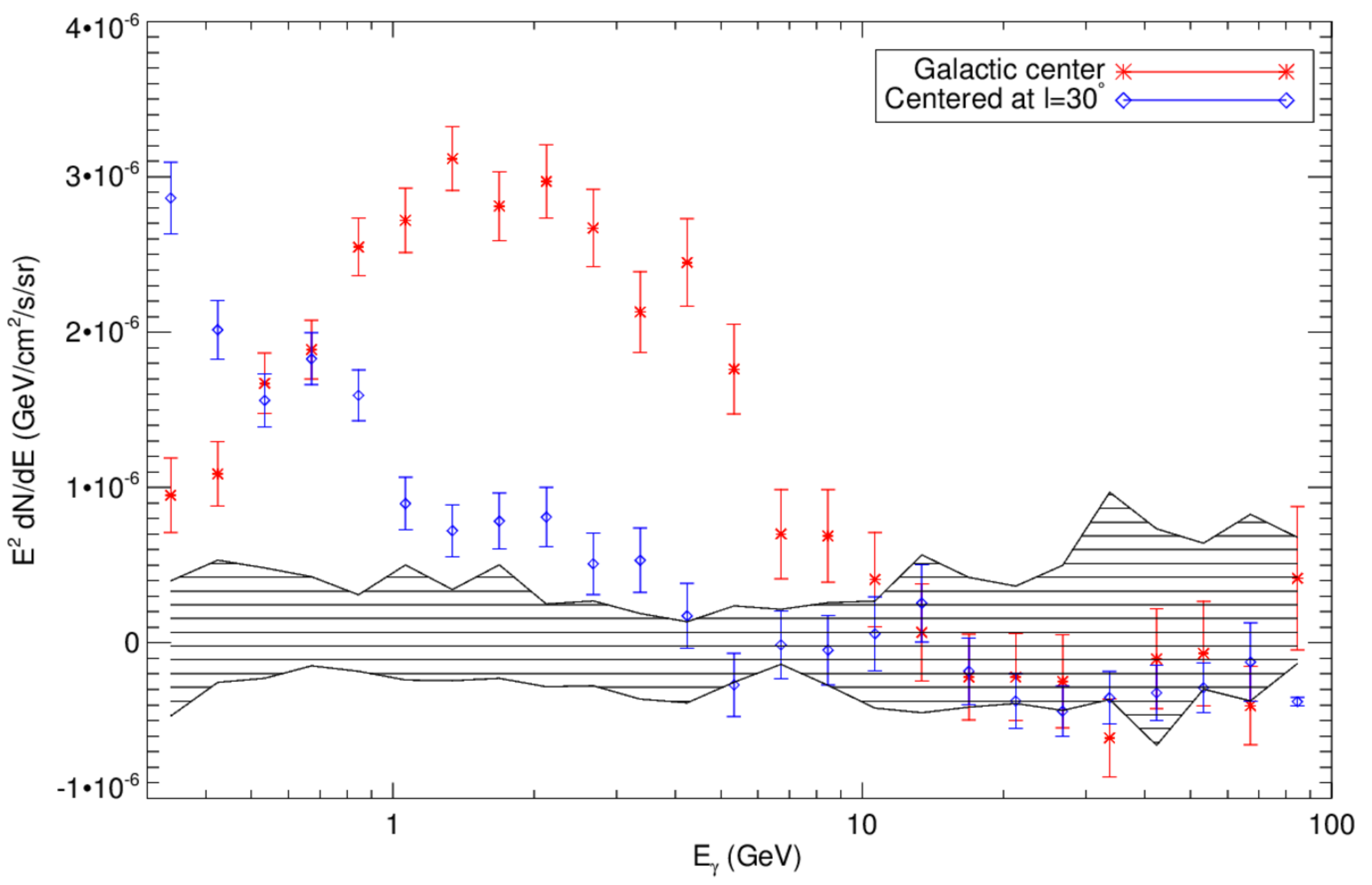


Assumes an incorrect sensitivity limit for the Fermi-LAT, actual constraints from the 2PC paper are nearly an order of magnitude stronger

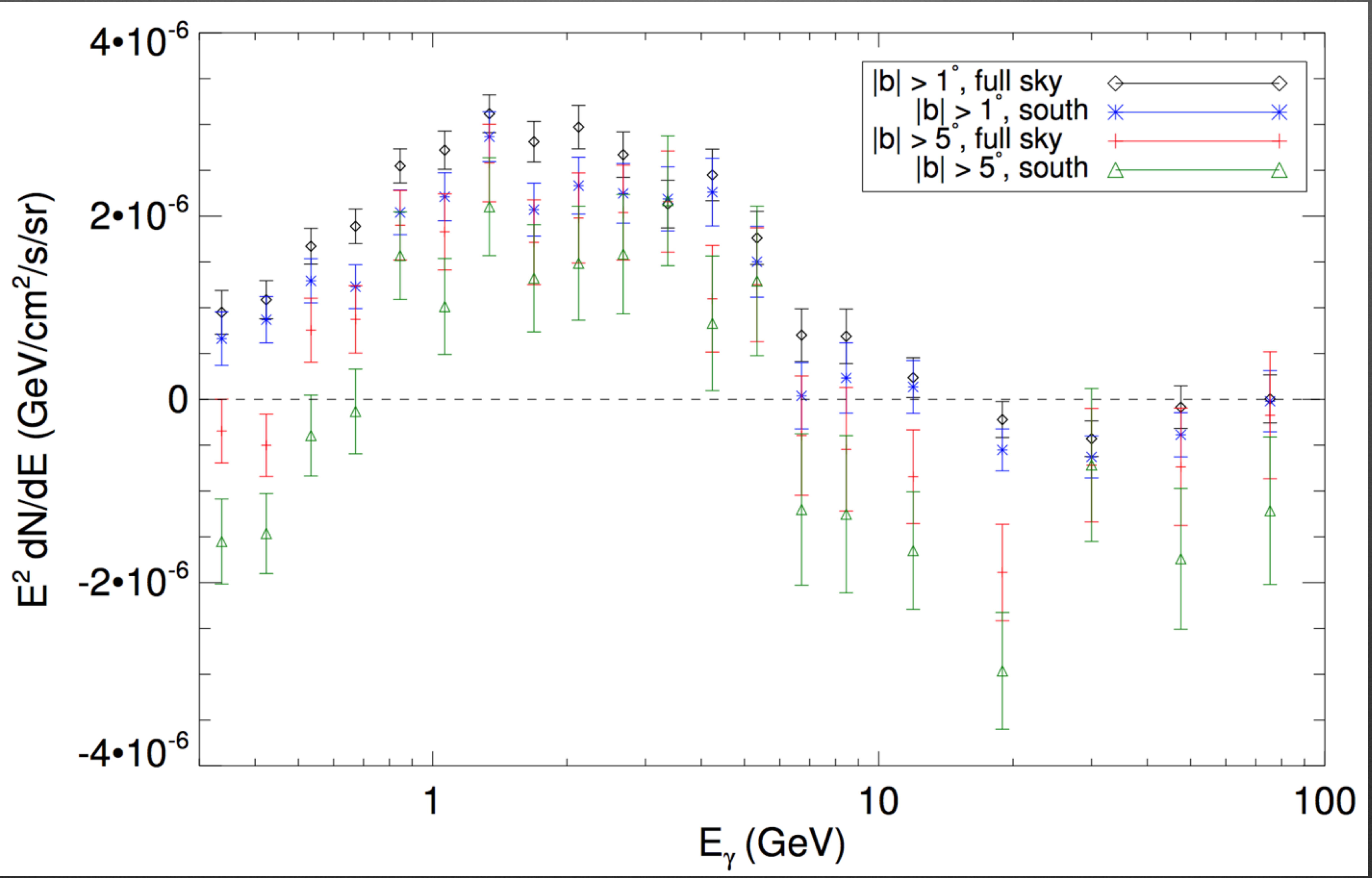
How Big is the Excess?



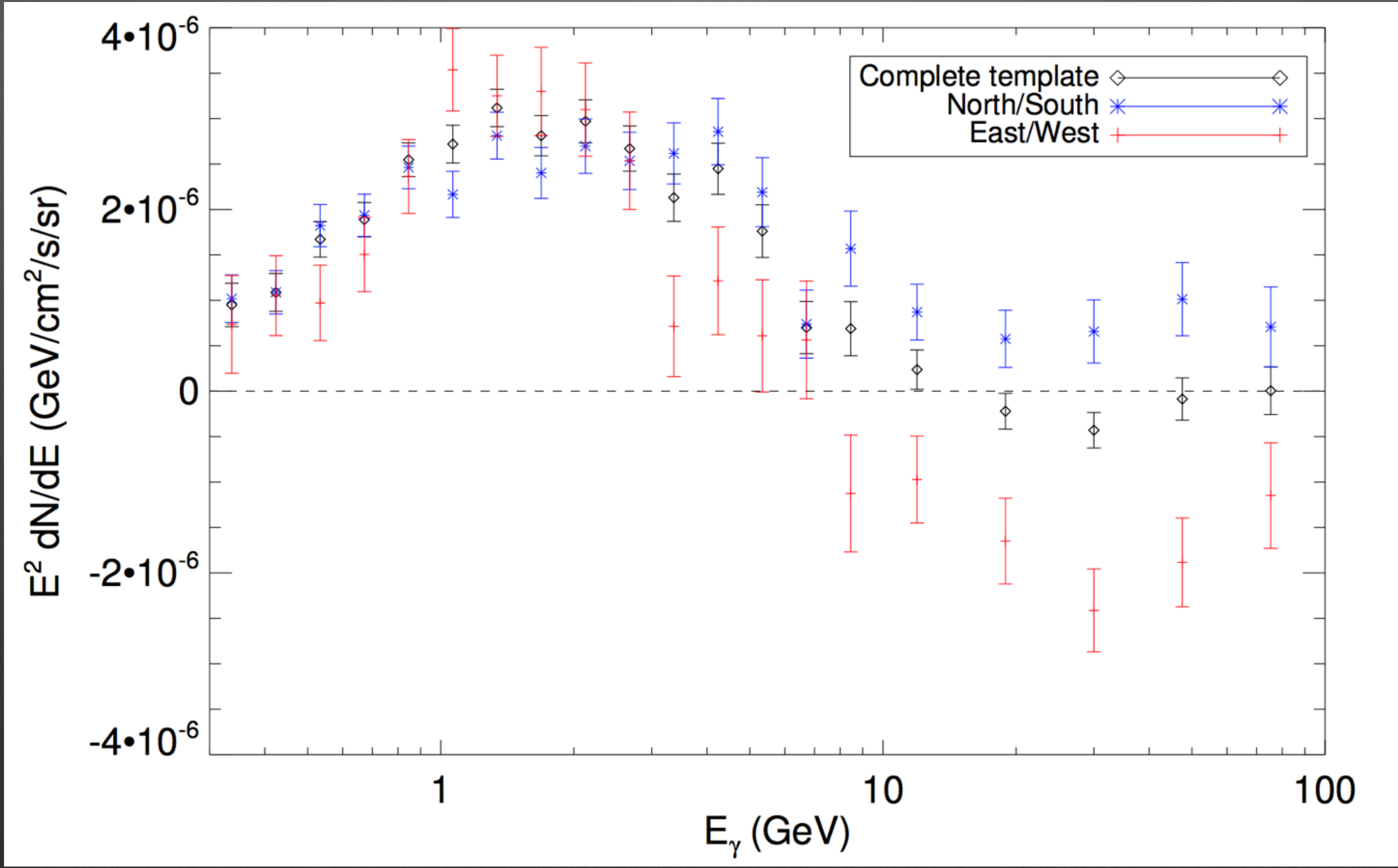
Do Other Residuals Have the Same Spectrum?



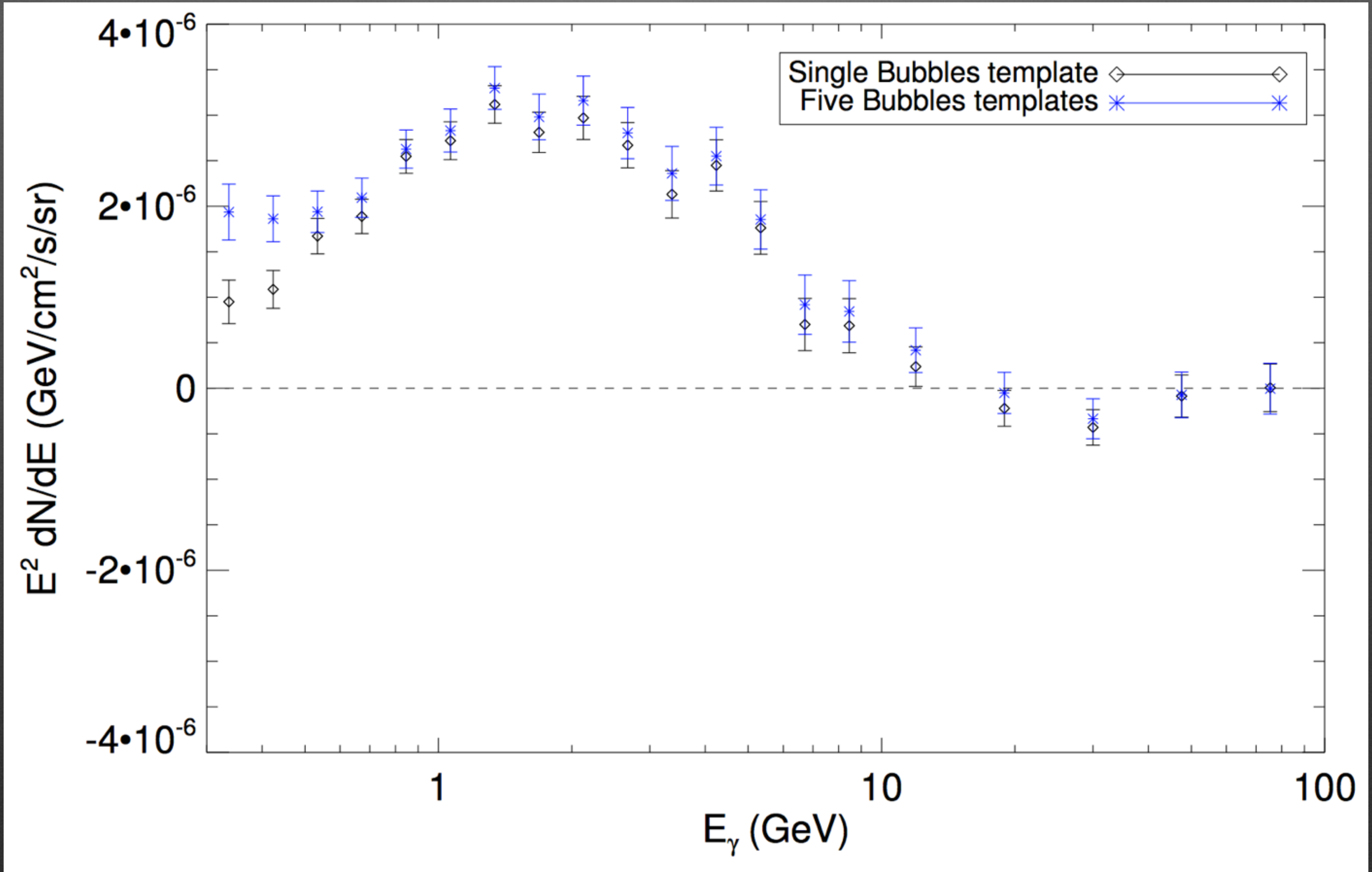
Wait, Some Photons are in both IG and GC?



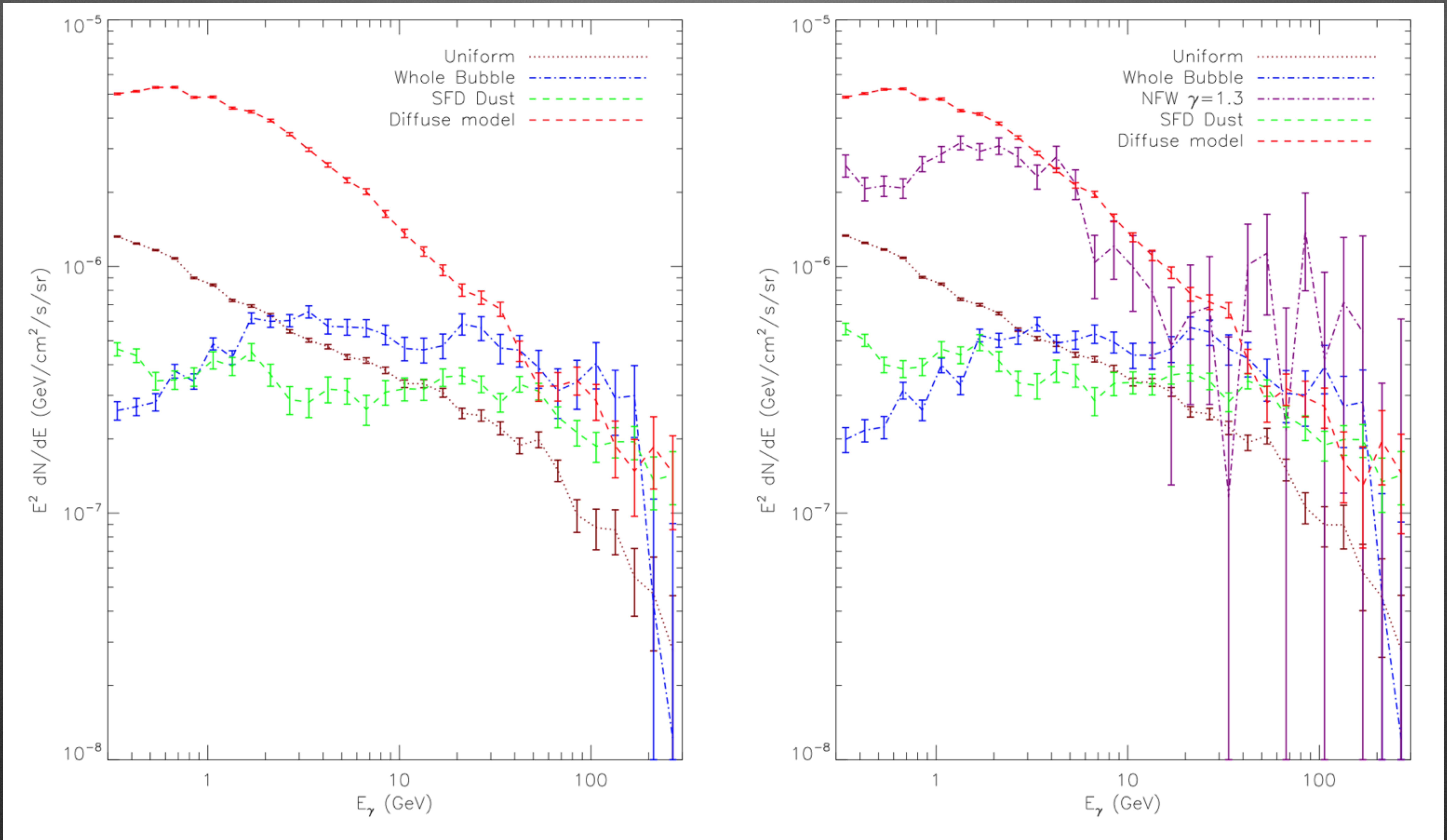
Is this just part of the Bubbles?



What if the bubbles have a spectral variation?



Does it Correlate with Gas?



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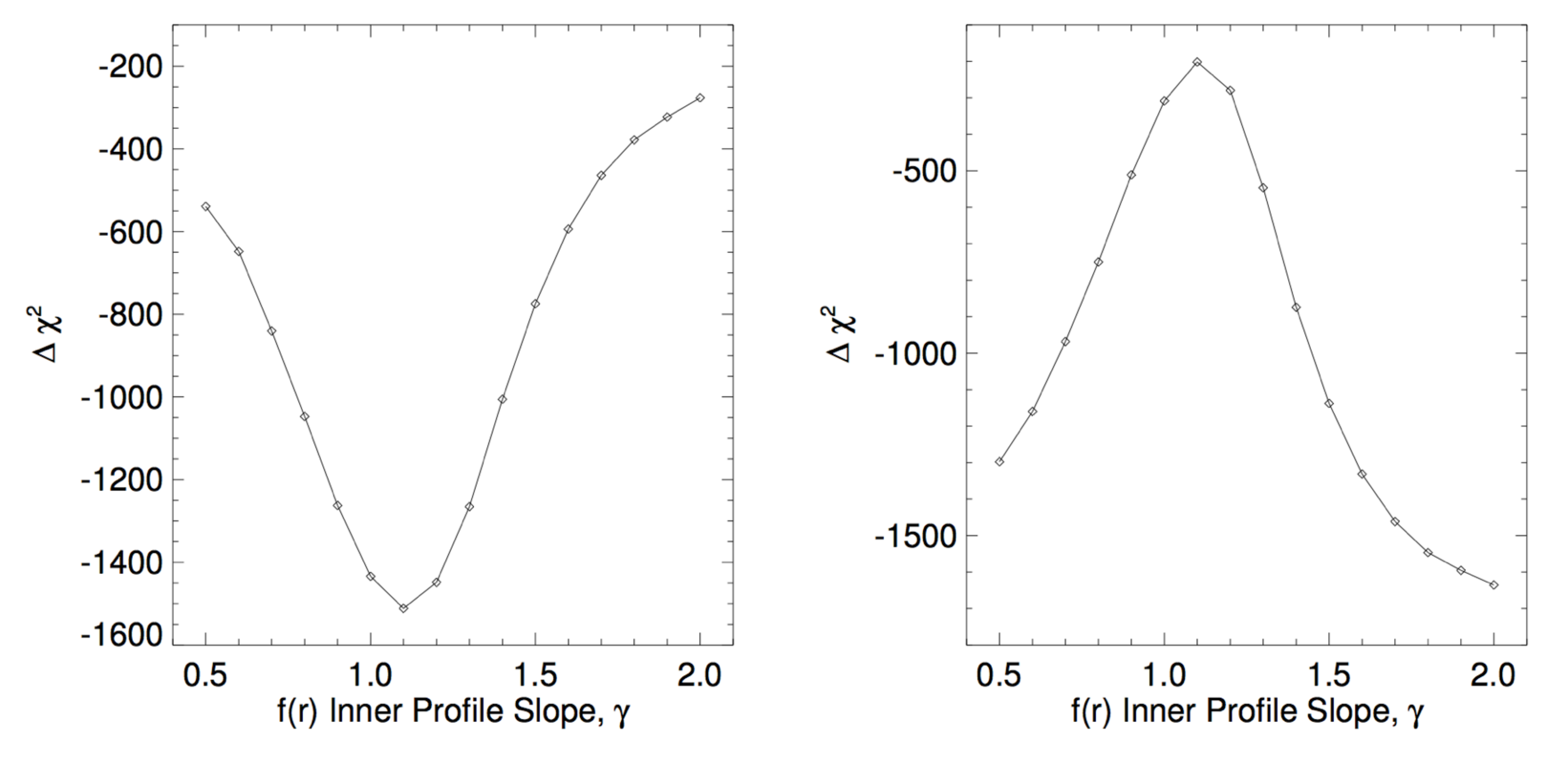

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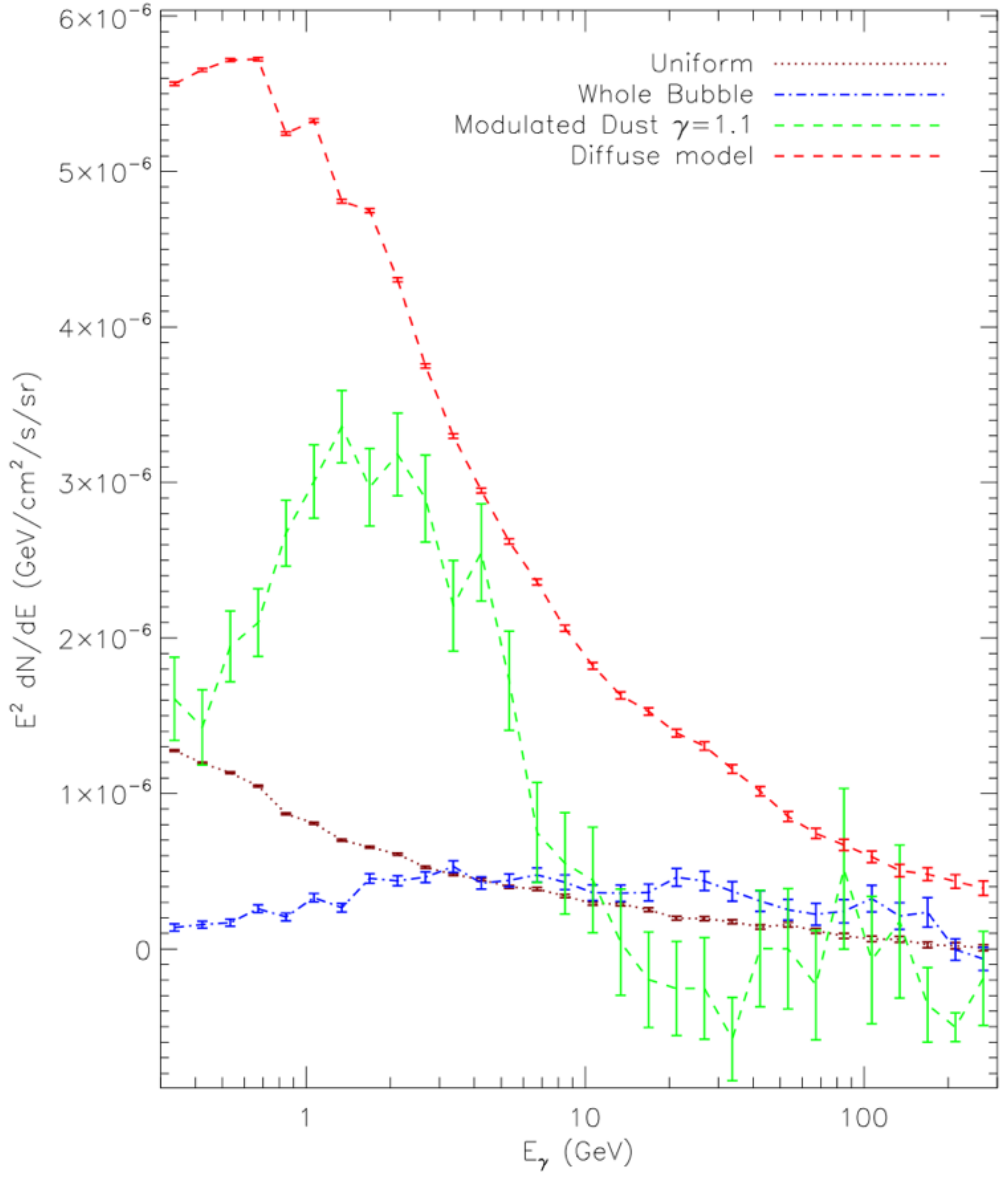

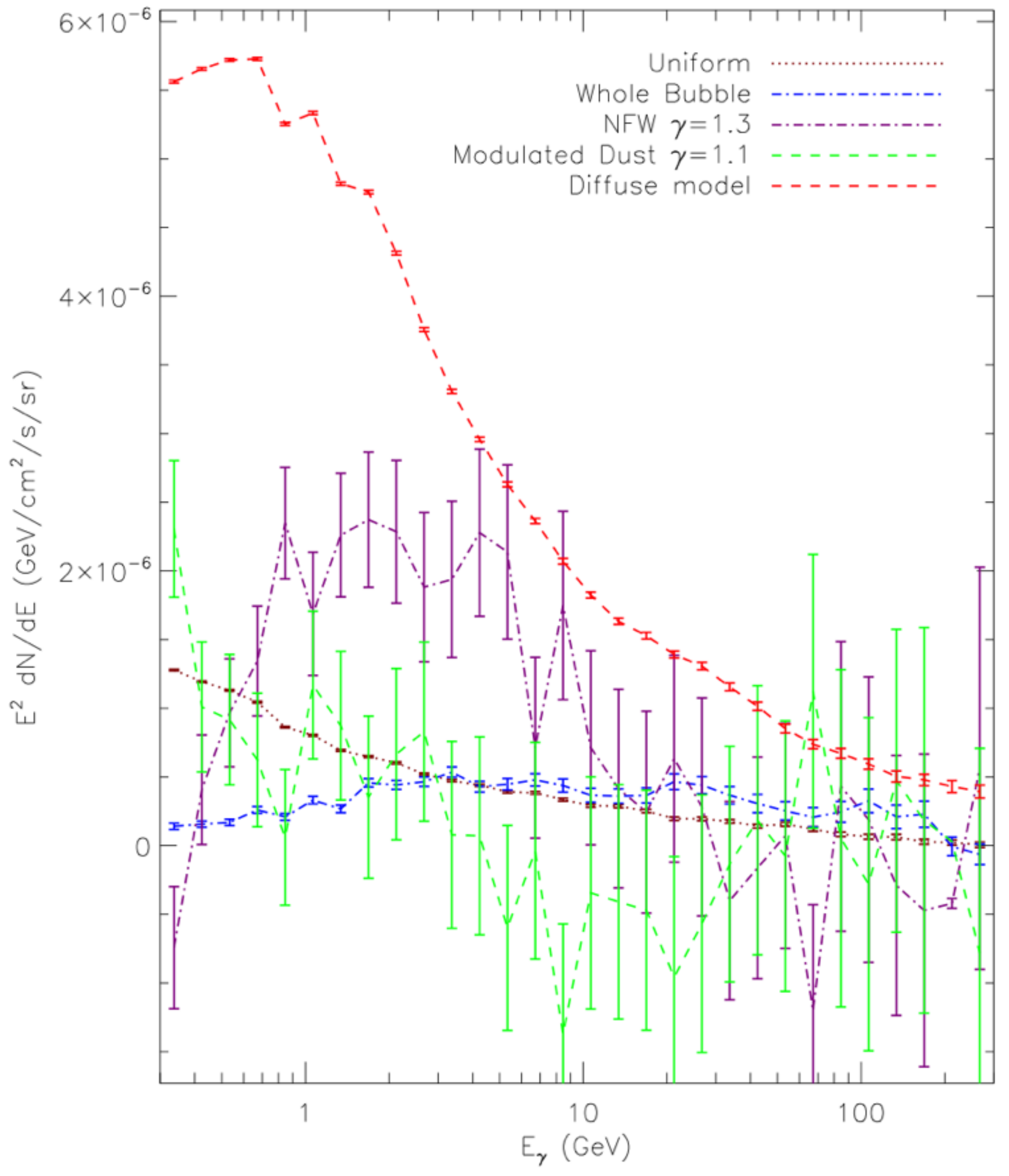

What about changes in the diffuse spectra?