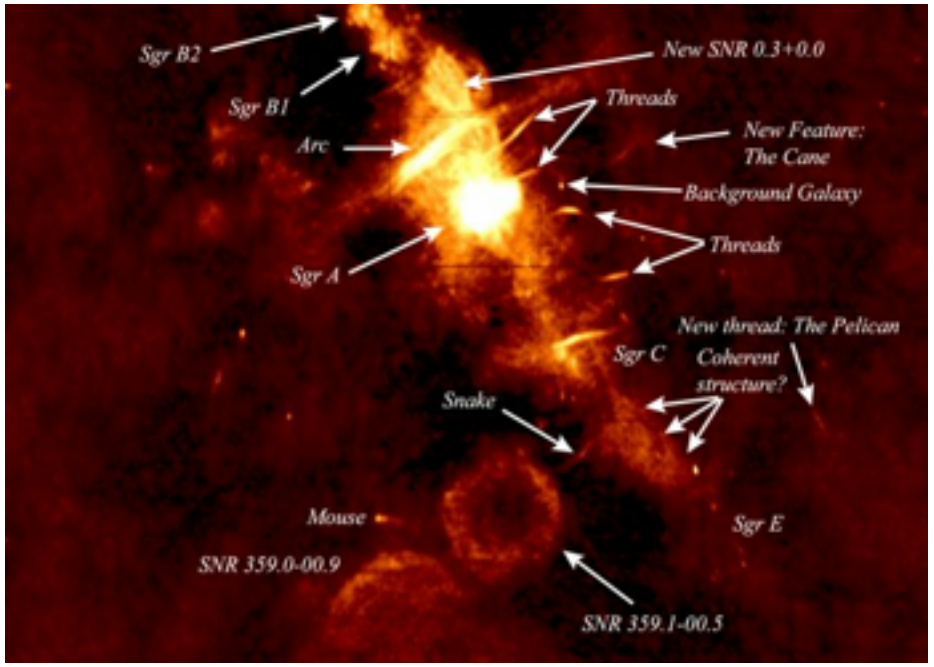
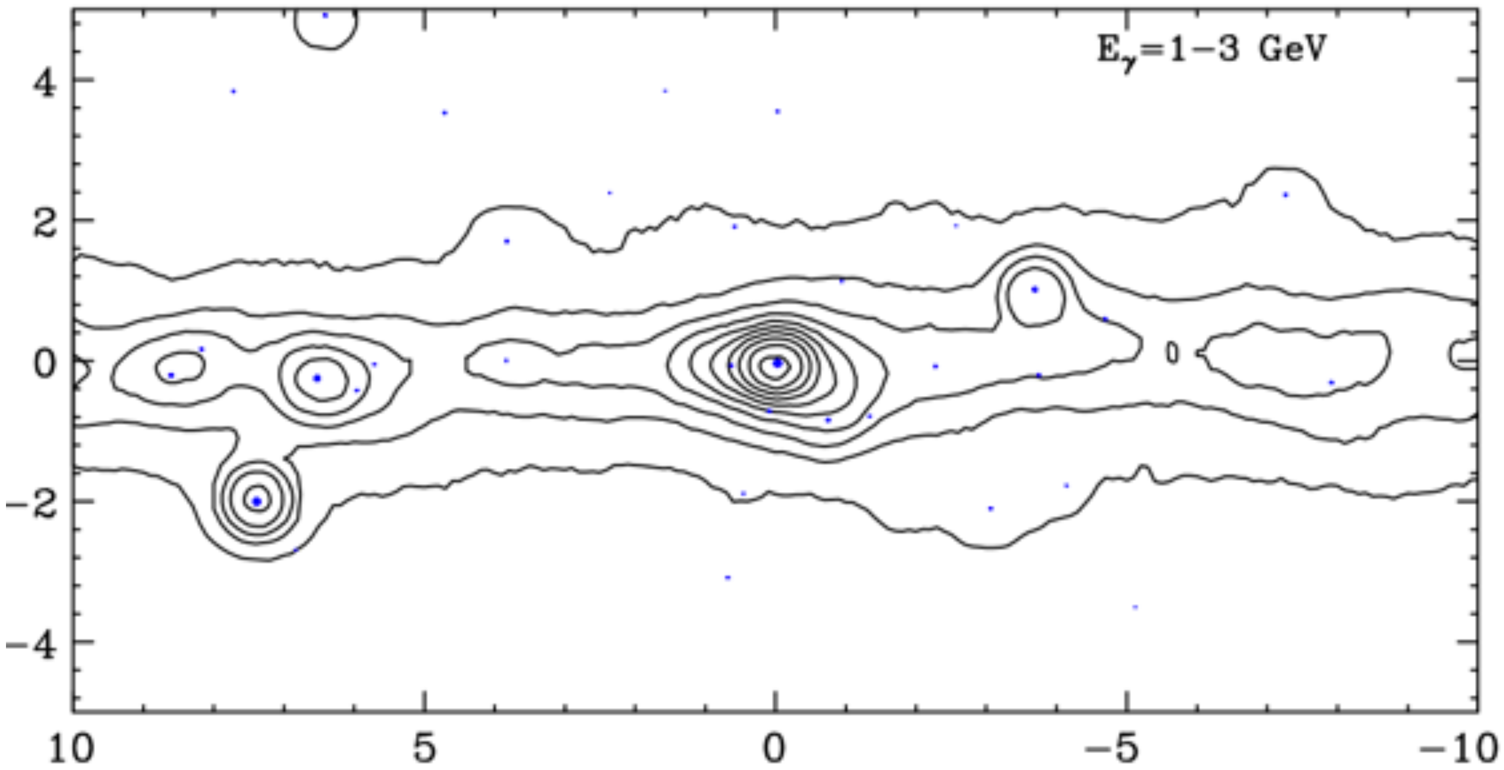
Gamma-Rays from the Galactic Center: Dark Matter or Hadronic Interactions?

Or any of the other models the speaker will fail to discuss?

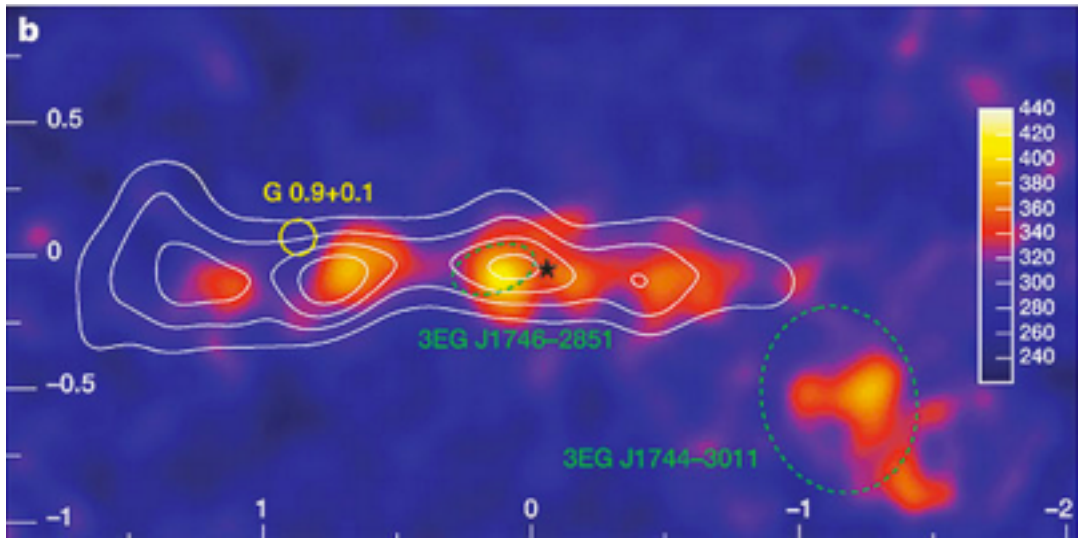




Tim Linden

UC - Santa Cruz

with Dan Hooper, Elizabeth Lovegrove, Stefano Profumo and Farhad Yusef-Zadeh



Identification of Dark Matter - Chicago Illinois - July 24, 2012

The J-Factor of the Galactic Center

Ackermann et al. 2012

Dwarfs

Name	l	b	d	$\log_{10}(J)$	σ	ref.
	deg.	deg.	kpc	$\log_{10}[\mathrm{GeV}^2\mathrm{cm}^{-5}]$		
Bootes I	358.08	69.62	60	17.7	0.34	[15]
Carina	260.11	−22.22	101	18.0	0.13	[16]
Coma Berenices	241.9	83.6	44	19.0	0.37	[17]
Draco	86.37	34.72	80	18.8	0.13	[16]
Fornax	237.1	−65.7	138	17.7	0.23	[16]
Sculptor	287.15	−83.16	80	18.4	0.13	[16]
Segue 1	220.48	50.42	23	19.6	0.53	[18]
Sextans	243.4	42.2	86	17.8	0.23	[16]
Ursa Major II	152.46	37.44	32	19.6	0.40	[17]
Ursa Minor	104.95	44.80	66	18.5	0.18	[16]

Ackermann et al. 2010

Clusters

Cluster	RA	Dec.	z	J (10^{17} GeV^2 cm^{-5})
AWM 7	43.6229	41.5781	0.0172	$1.4^{+0.1}_{-0.1}$
Fornax	54.6686	-35.3103	0.0046	$6.8^{+1.0}_{-0.9}$
M49	187.4437	7.9956	0.0033	$4.4^{+0.2}_{-0.1}$
NGC 4636	190.7084	2.6880	0.0031	$4.1^{+0.3}_{-0.3}$
Centaurus (A3526)	192.1995	-41.3087	0.0114	$2.7^{+0.1}_{-0.1}$
Coma	194.9468	27.9388	0.0231	$1.7^{+0.1}_{-0.1}$

- Corresponds to the relative annihilation rate of the region compared to other astrophysical sources

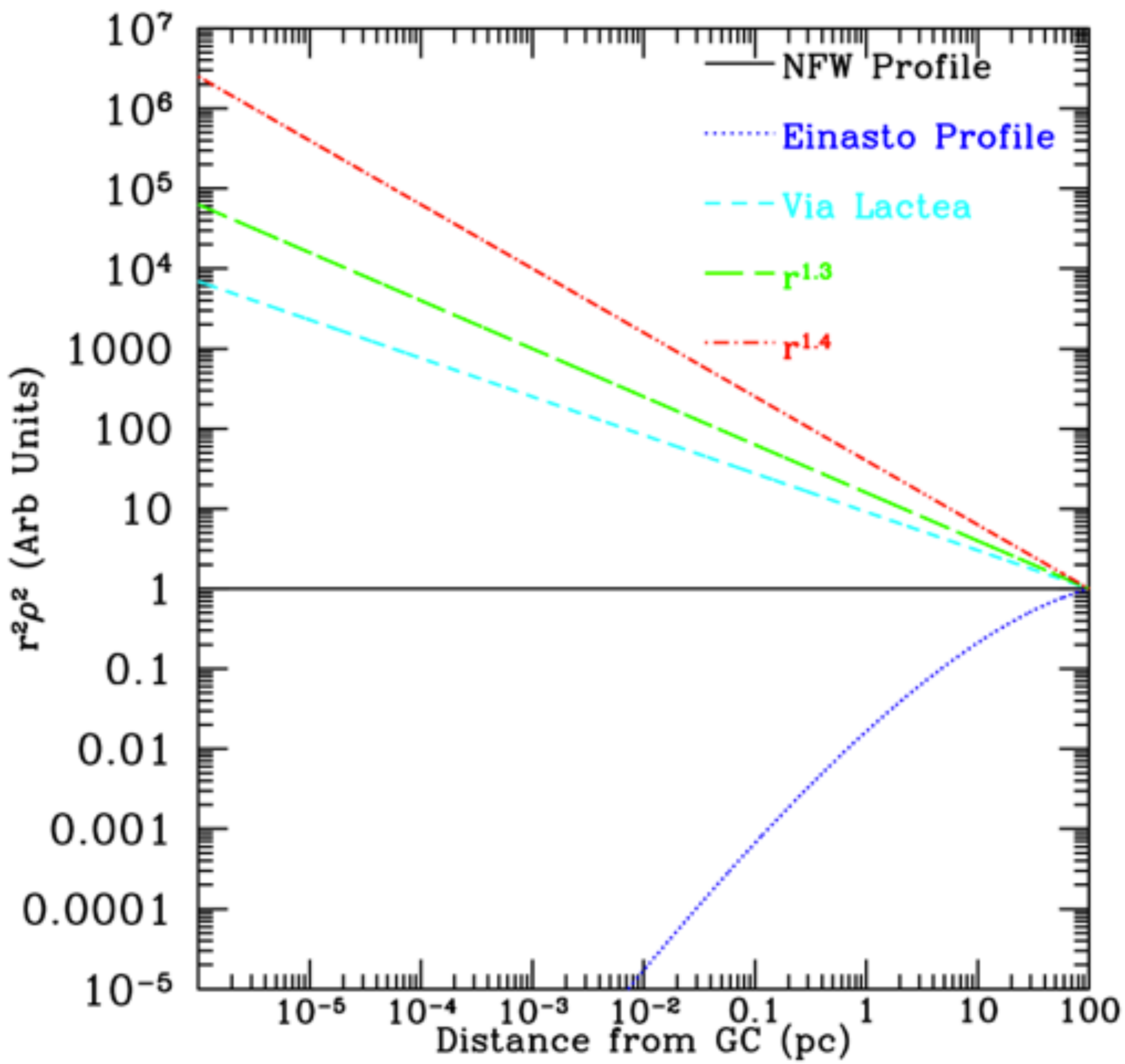
$$\Phi_\gamma \propto J = \frac{1}{\Delta\Omega}\int \mathrm{d}\Omega \int_{\mathrm{l.o.s.}} \rho^2(l)\mathrm{d}l(\psi)$$

- The J-factor of the galactic center is approximately:

$$\boxed{\log_{10}(J) = 23.91}$$

for a region within 100 pc of the Galactic center and an NFW profile

Negative: The Profile Dependence



Cored dark matter profiles too depressing to show on this plot

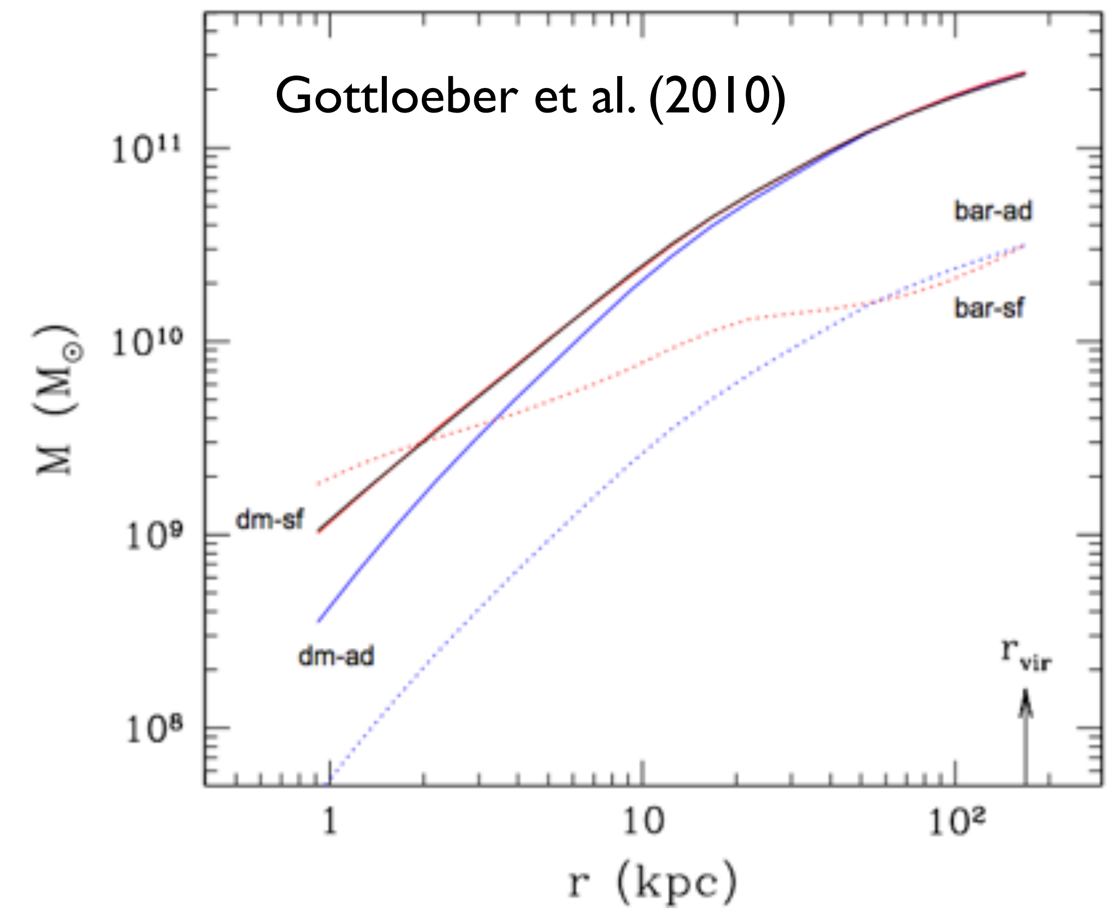
- Assumptions for the slope of the inner dark matter profile can make **orders of magnitude** differences in the expected dark matter annihilation rate
- Dark Matter is not a dominant gravitational source near the galactic center, so there are few observational handles on the dark matter density in the GC region

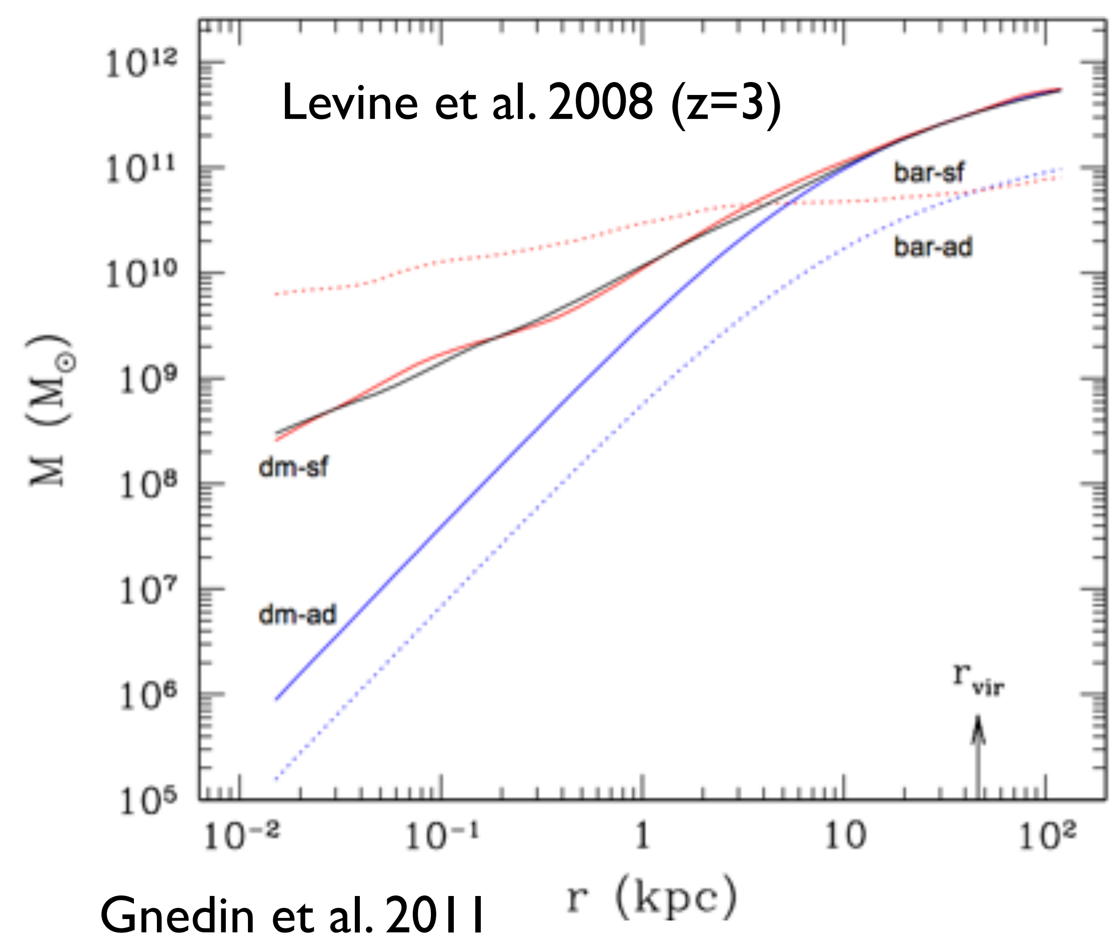
Positive! Progress in Simulations

- Simulations including the effects of baryonic contraction show a steepening of the spectral slope from γ≈1.0 to γ≈1.2-1.5

- Much more work is required to understand the dark matter content of the GC region

- **However,** see work showing a core in the inner region of the galaxy (e.g. Governato et al. 2012) -- need to understand the region in which a core might form.

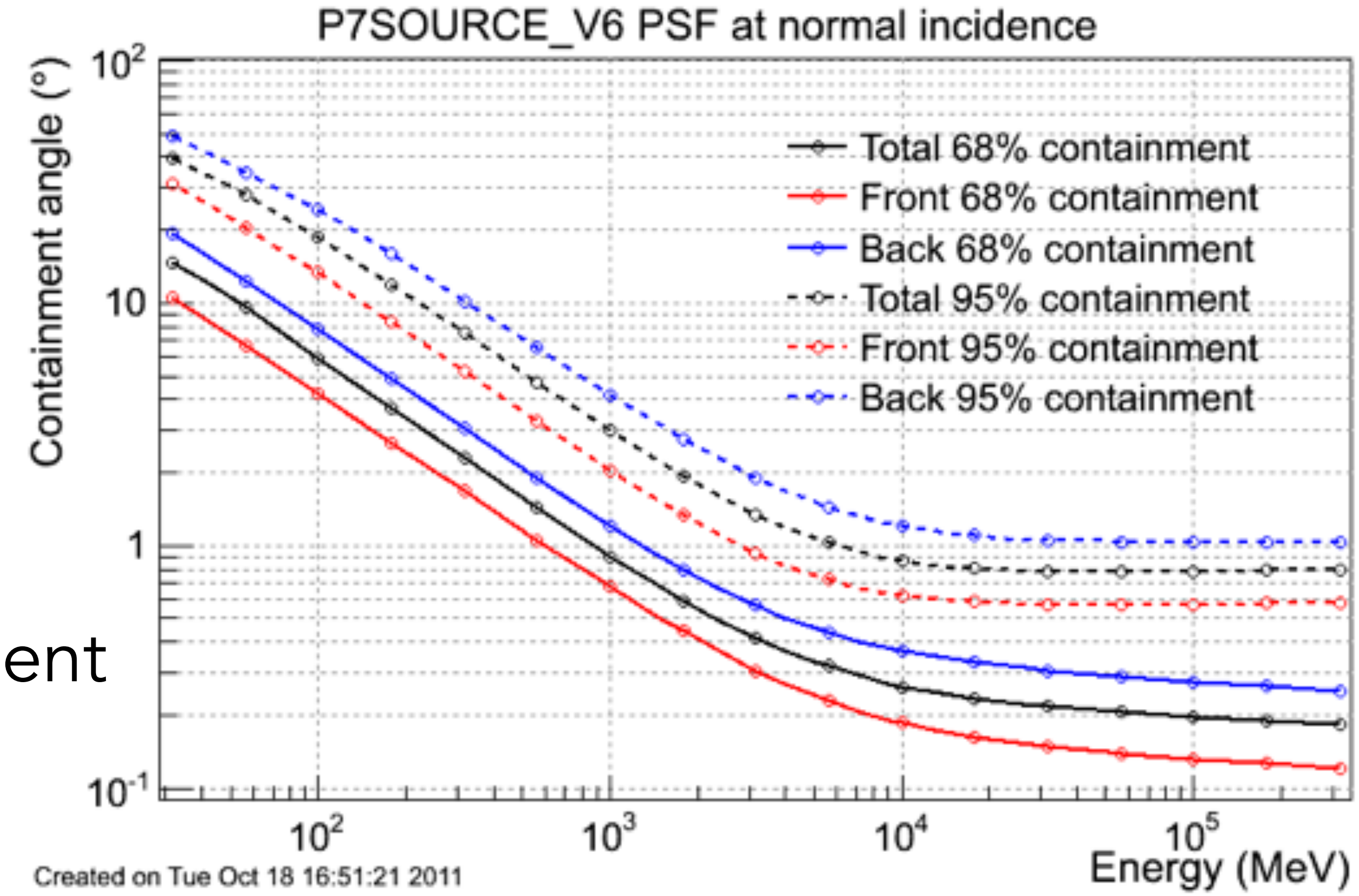




Gnedin et al. 2011

Fermi Telescope (2008-Present)

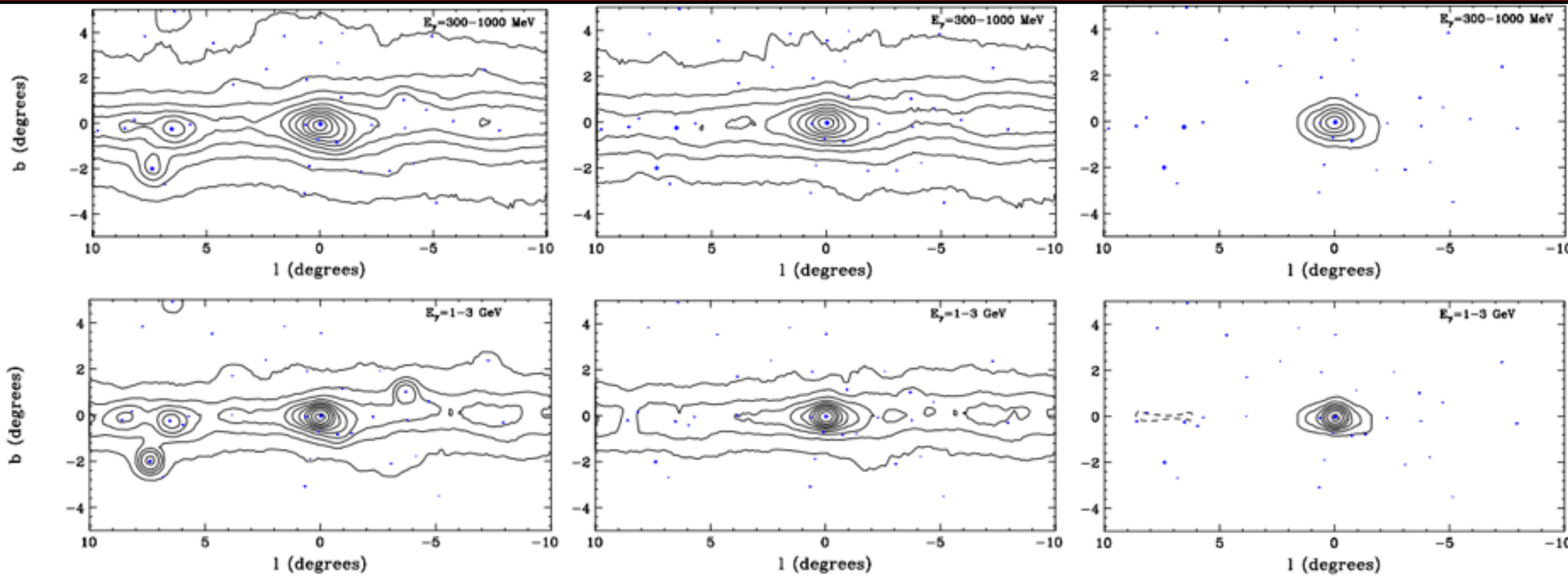
- Fermi-LAT is a space based gamma-ray detector with an effective energy range of 20 MeV-300 GeV

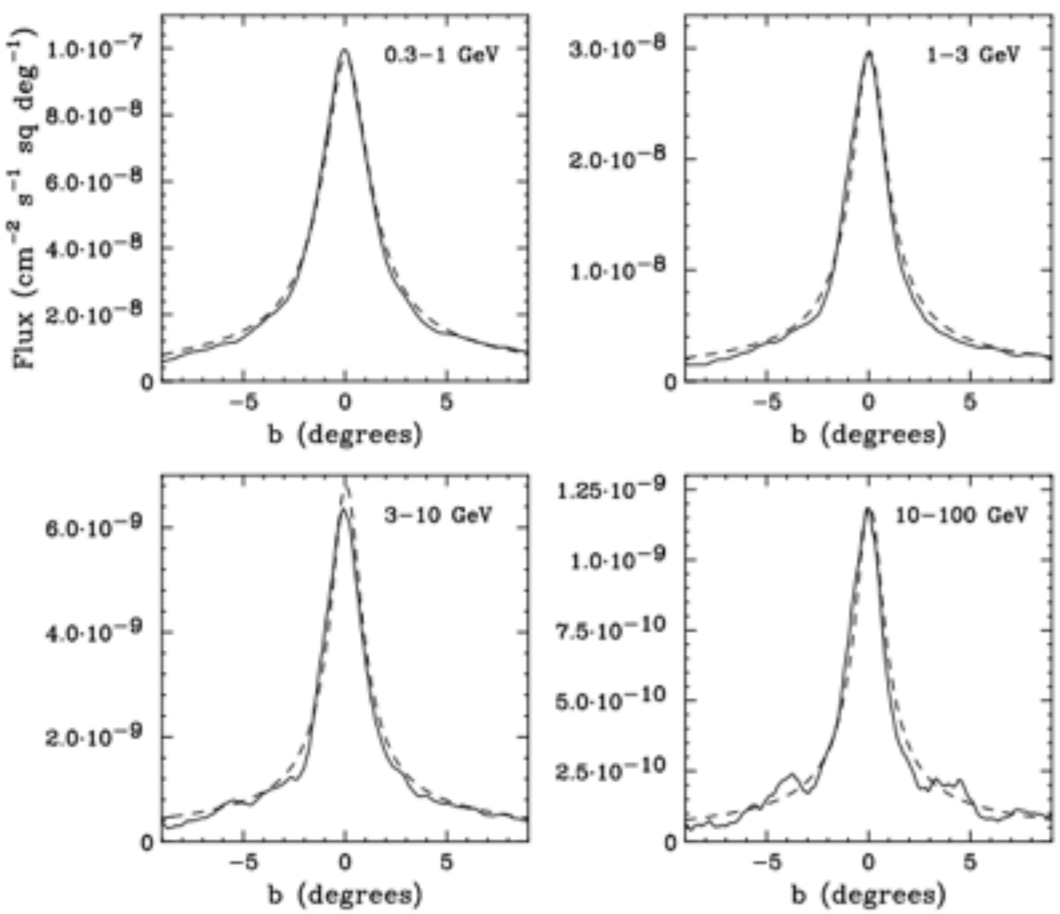


- Effective Area ~ 0.8 m^2
- Field of View ~ 2.4 sr
- Energy Resolution ~ 10%
- Angular Resolution: Energy Dependent

- In analyses of the Galactic Center, we will constrict ourselves to Front converting events

Subtracting the Astrophysical Background: Fermi

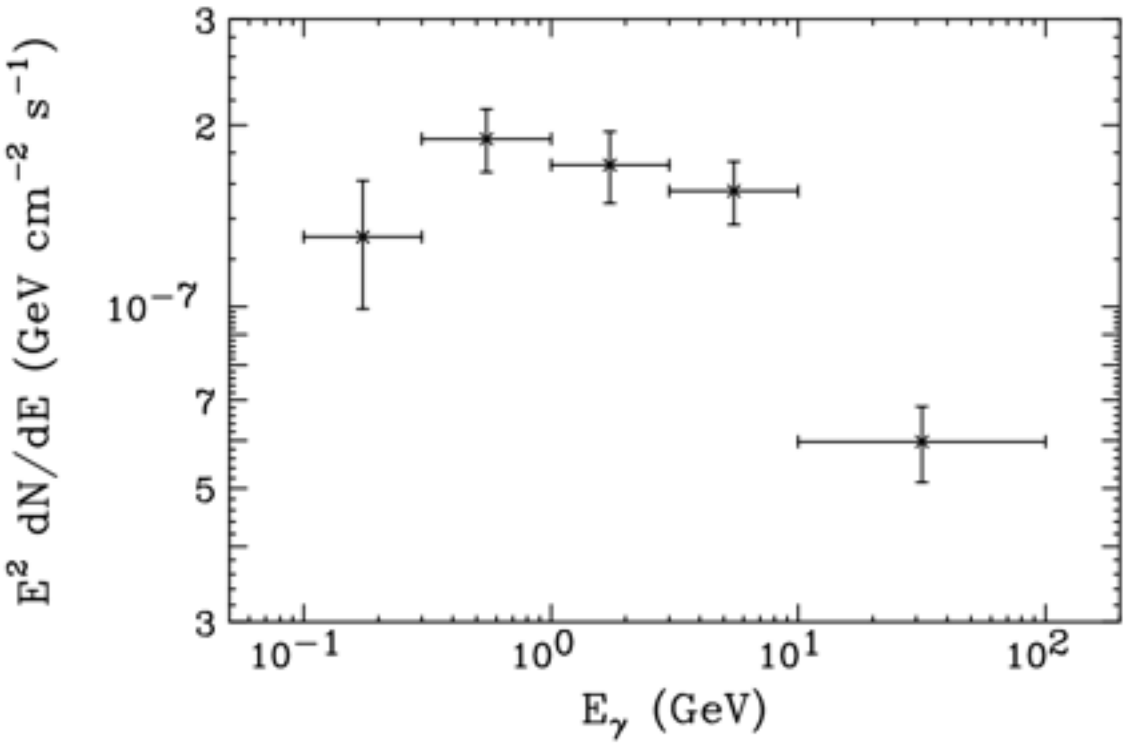




Hooper & Linden (2011)

- We employ a model of the galactic gas density (Kalberla & Kerp 2009) to subtract the contributions from the galactic plane.
- This emission template provides a superb match to the total emission spectrum outside of the central region
- This subtraction subtracts the vast majority of emission, leaving a single spherically symmetric emission around the GC

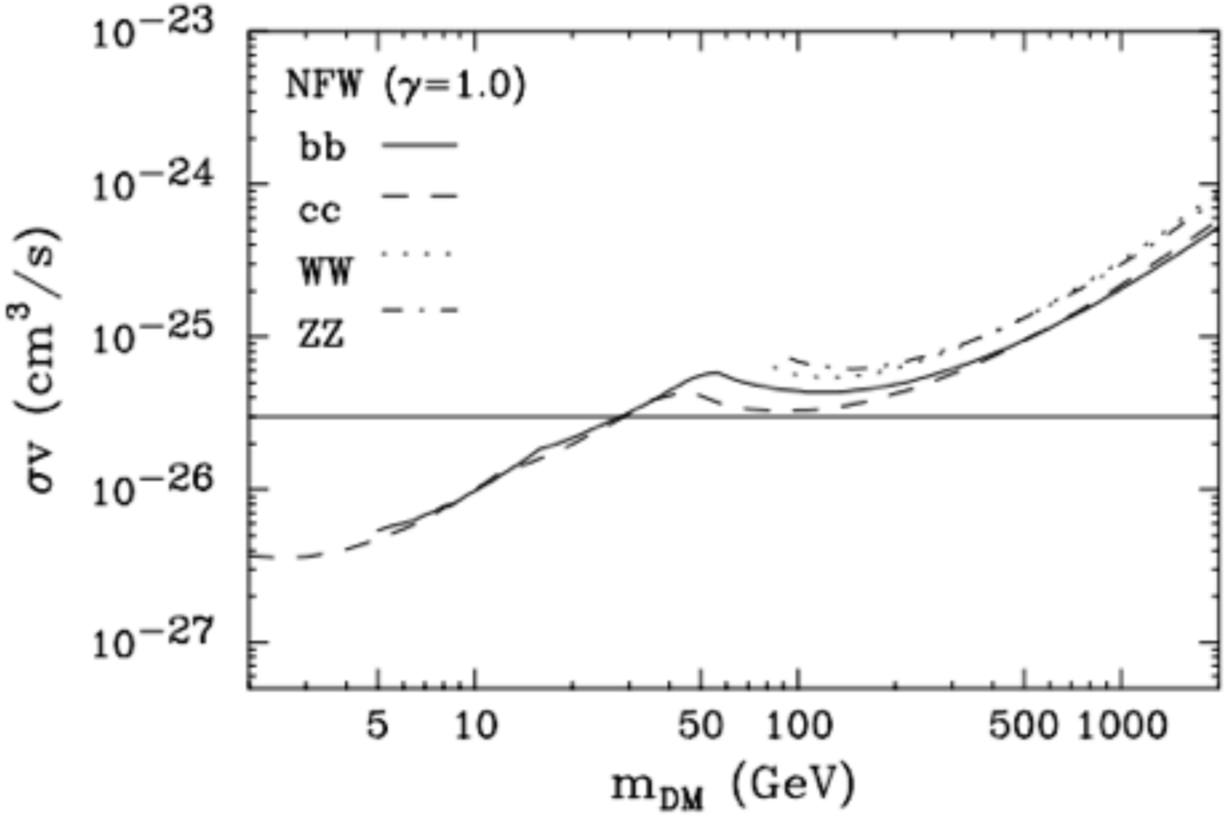
Dark Matter Limits in the Simplest Way Possible

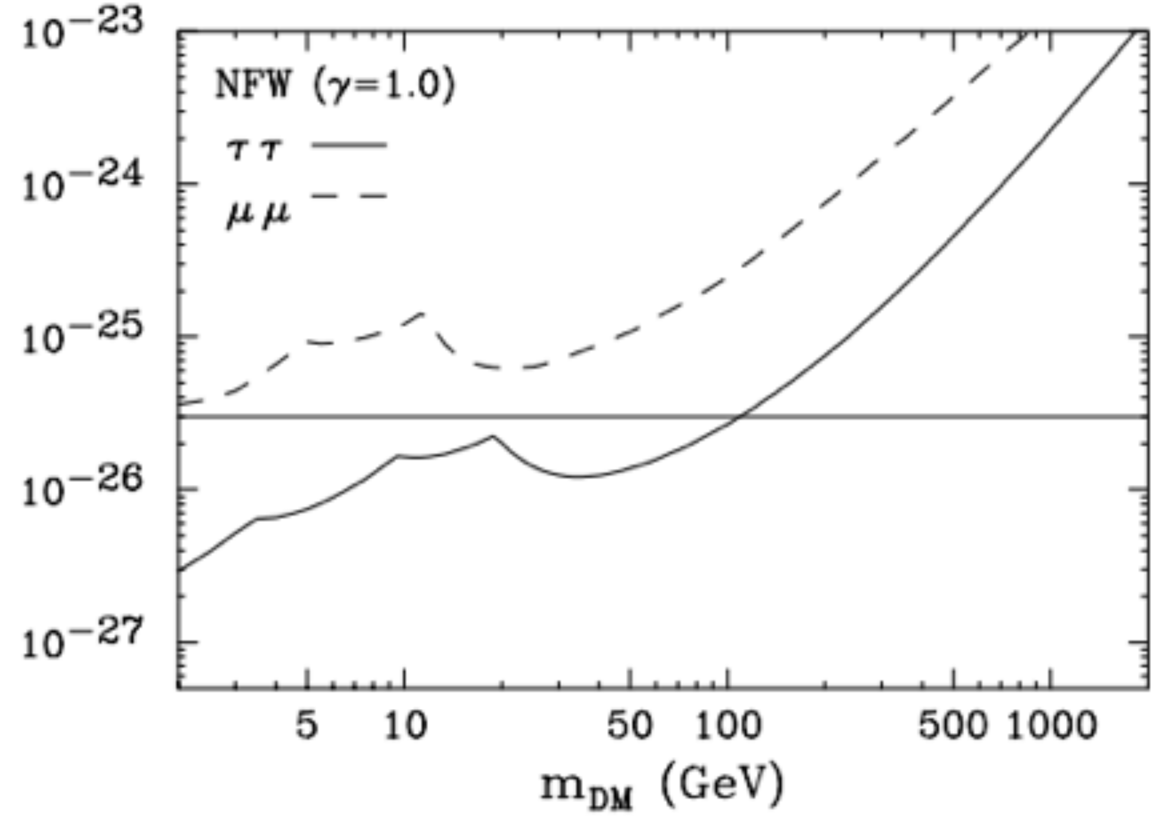


Hooper & Linden (2011)

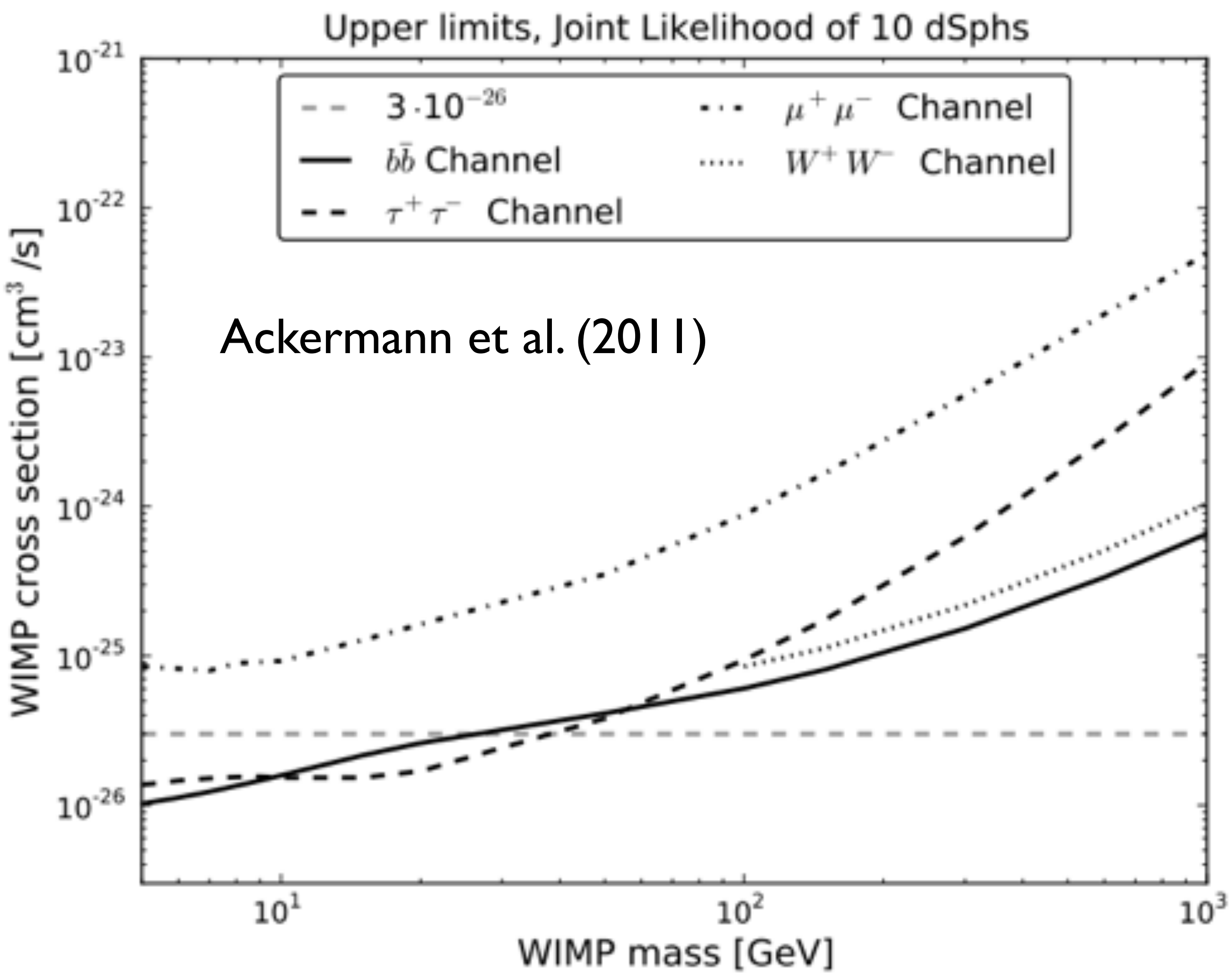
- After subtracting emission from known point sources, and an extrapolation of the line-of-sight gas density, the following "galactic center" emission is calculated

- This directly corresponds to a limit on the dark matter interaction cross-section which depends only on assumed dark matter density profile



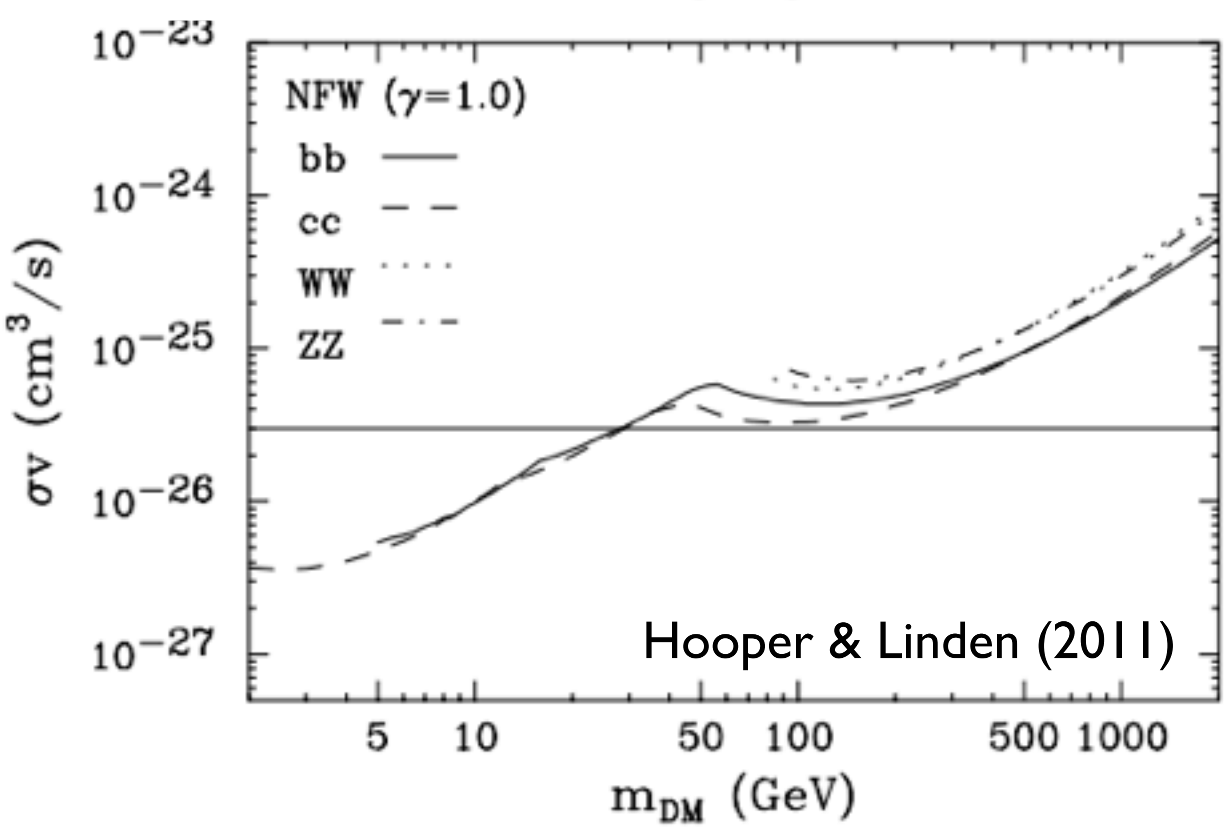


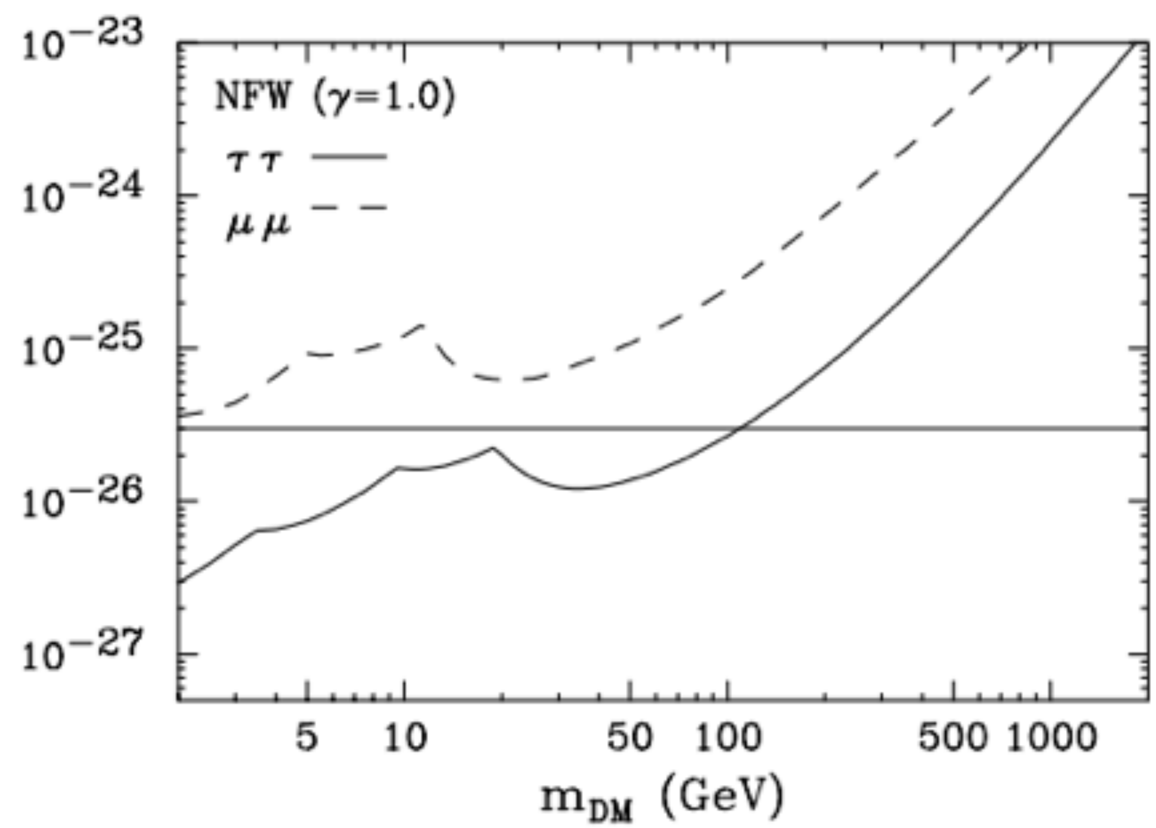
Comparison to Other Indirect Detection Regimes



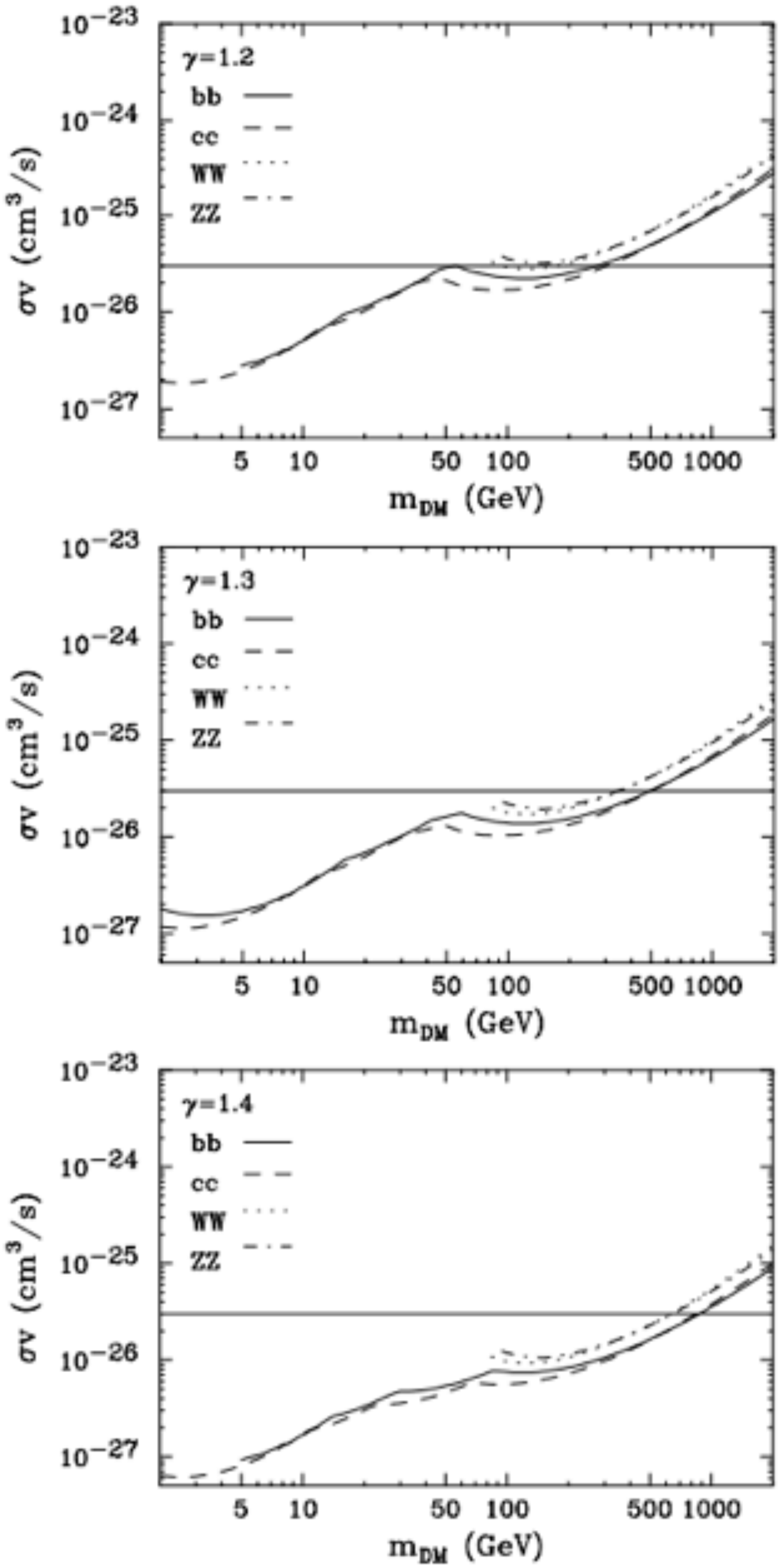
- Under the assumption of an NFW profile, the 95% confidence limits are as good or better than those from dwarf-spheroidals

- They are especially stronger for leptophilic annihilation paths



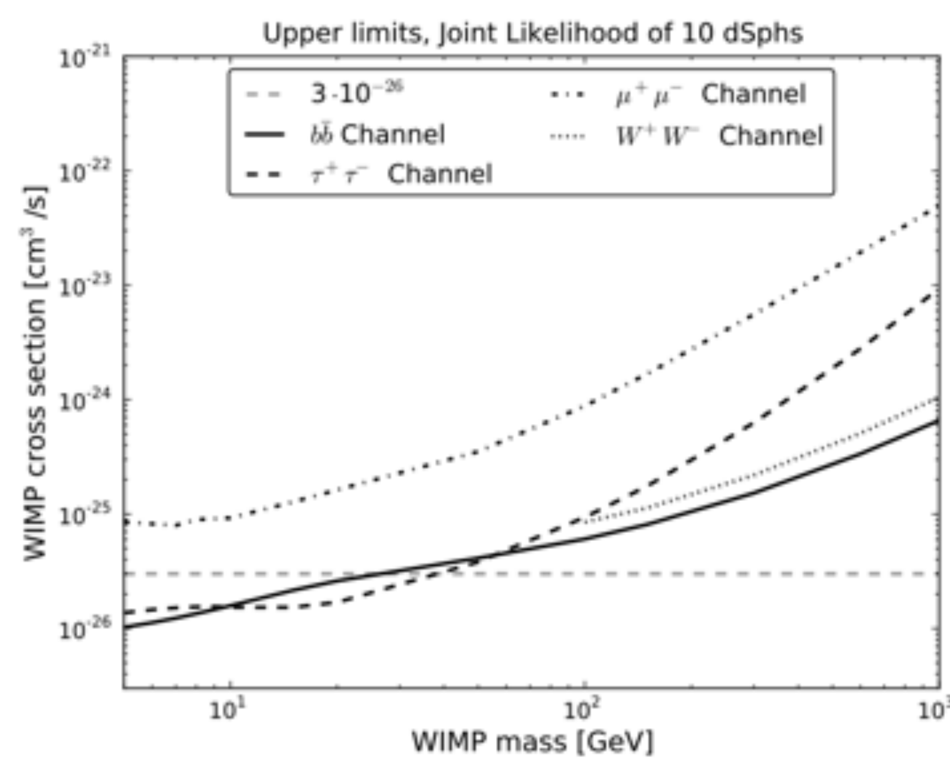


Comparison to Other Indirect Detection Regimes



Hooper & Linden (2011)

- With some adiabatic contraction of the inner dark matter profile, these limits can become substantially stronger than any other indirect detection limit



Ackermann et al. (2011)

Comparison to Other Indirect Detection Regimes

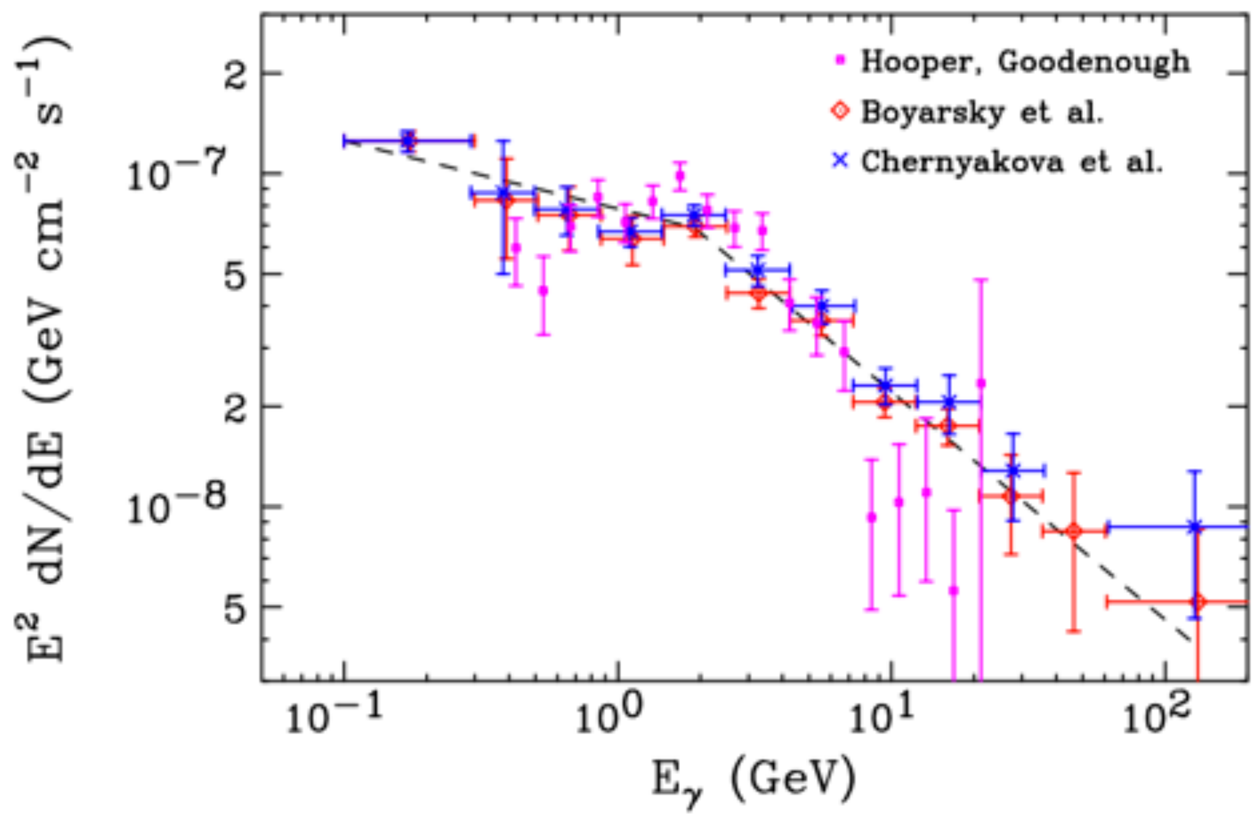
- Note: Knowledge of the dark matter density distribution may be sufficient in order to move below the thermal cross-section

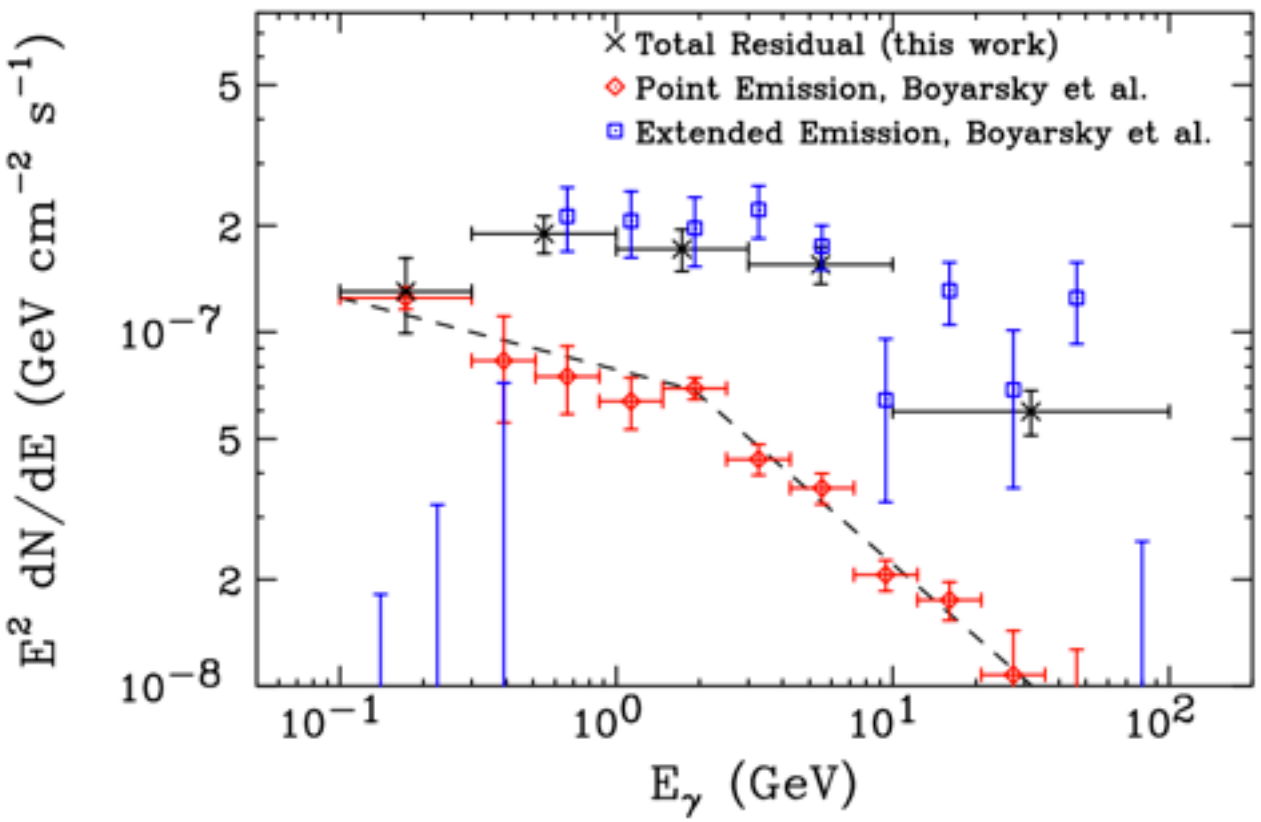
- Can set **strong** limits with negligible astrophysical knowledge.

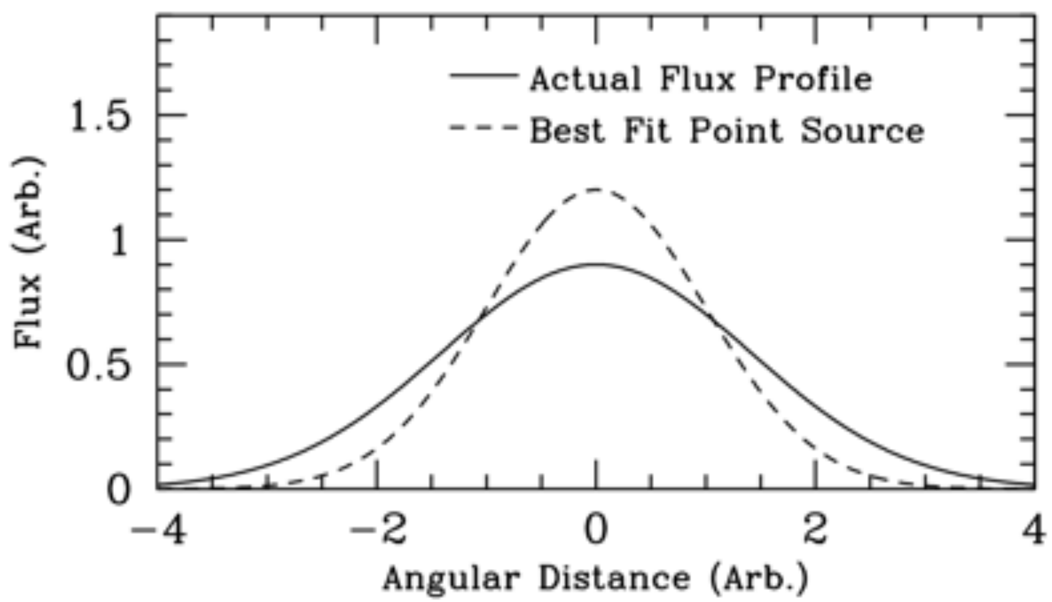
Understanding the GC Point Source: Fermi

- Several efforts have been made to fit the GC point source, using both best-fitting point-source tools from the Fermi collaboration (Boyarsky et al. Chernyakova et. al), as well as independent software packages (Hooper & Goodenough)

- In all cases, the morphology of the observed emission cannot be fully accounted for by a single point source smeared out by the angular resolution of the Fermi-LAT



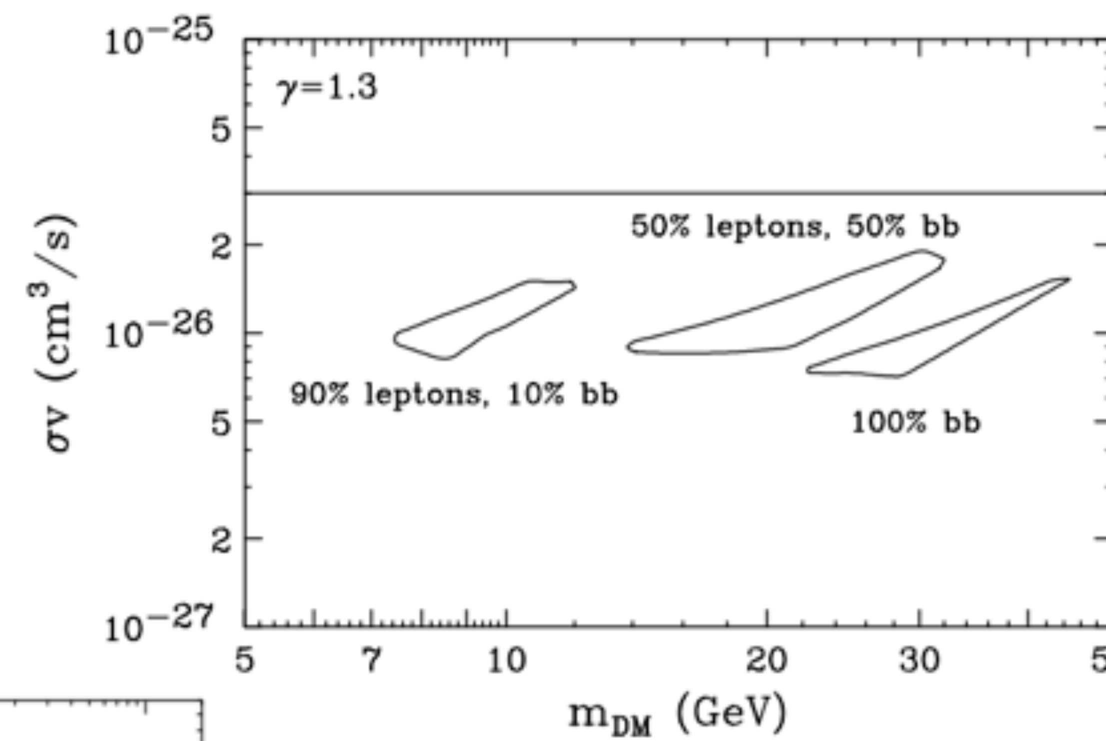




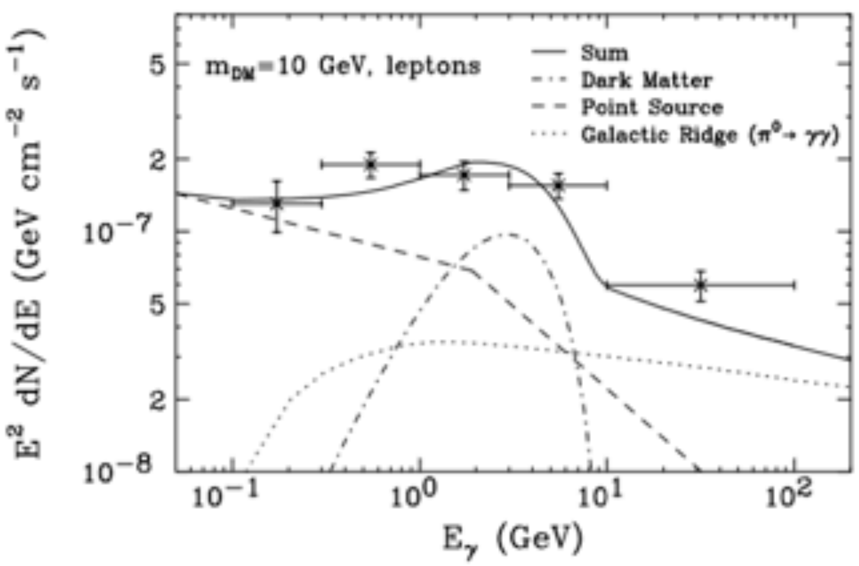
Hooper & Linden (2011)

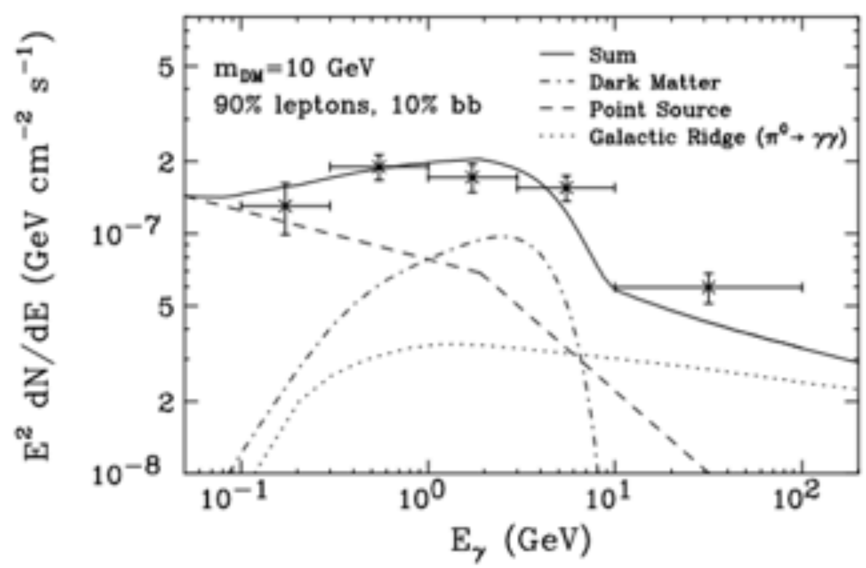
Best fitting Models for Low-Mass Dark Matter

- For a best fitting profile γ = 1.3, we find an available parameter space for dark matter models which match the observed GC excess

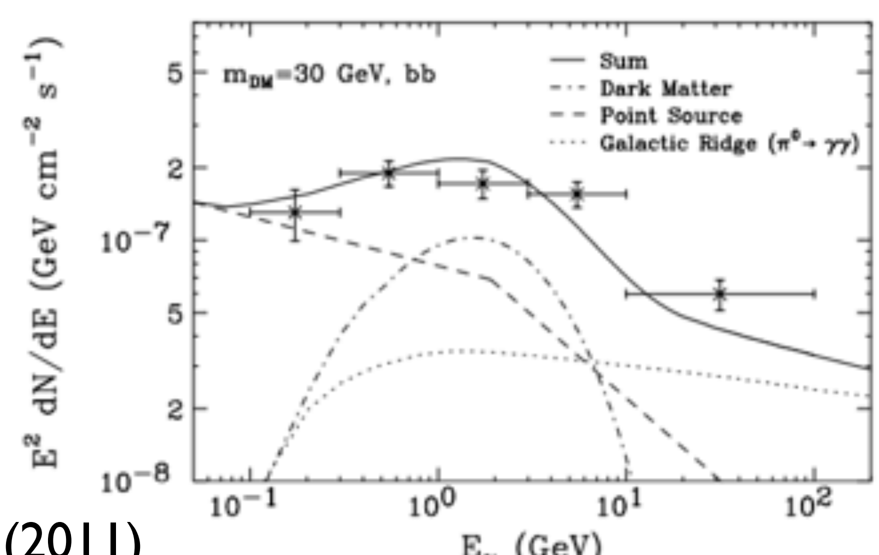


- These models are compatible with estimates for the relic density of dark matter



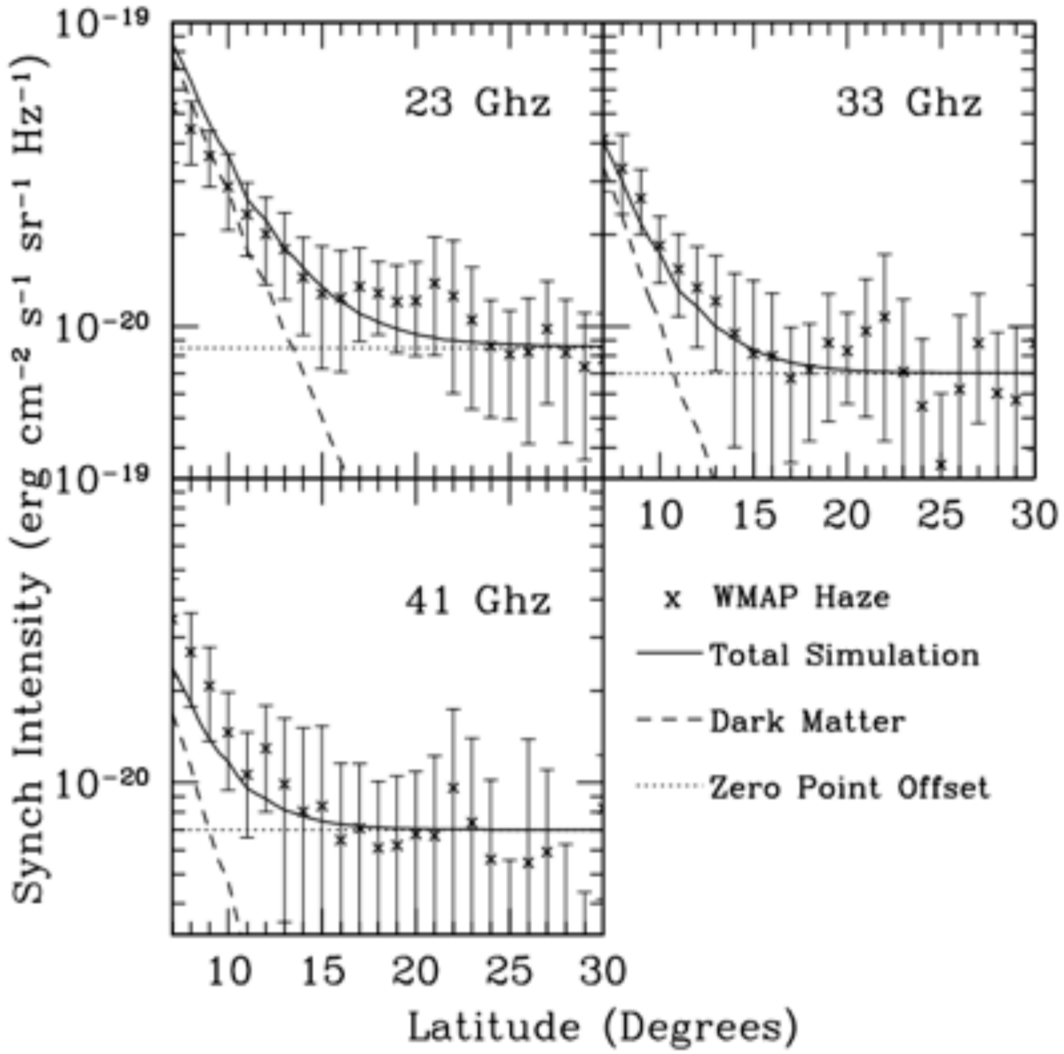


- The models combine with best fitting astrophysical backgrounds such as the GC point source and the galactic ridge, to fit the total GC excess



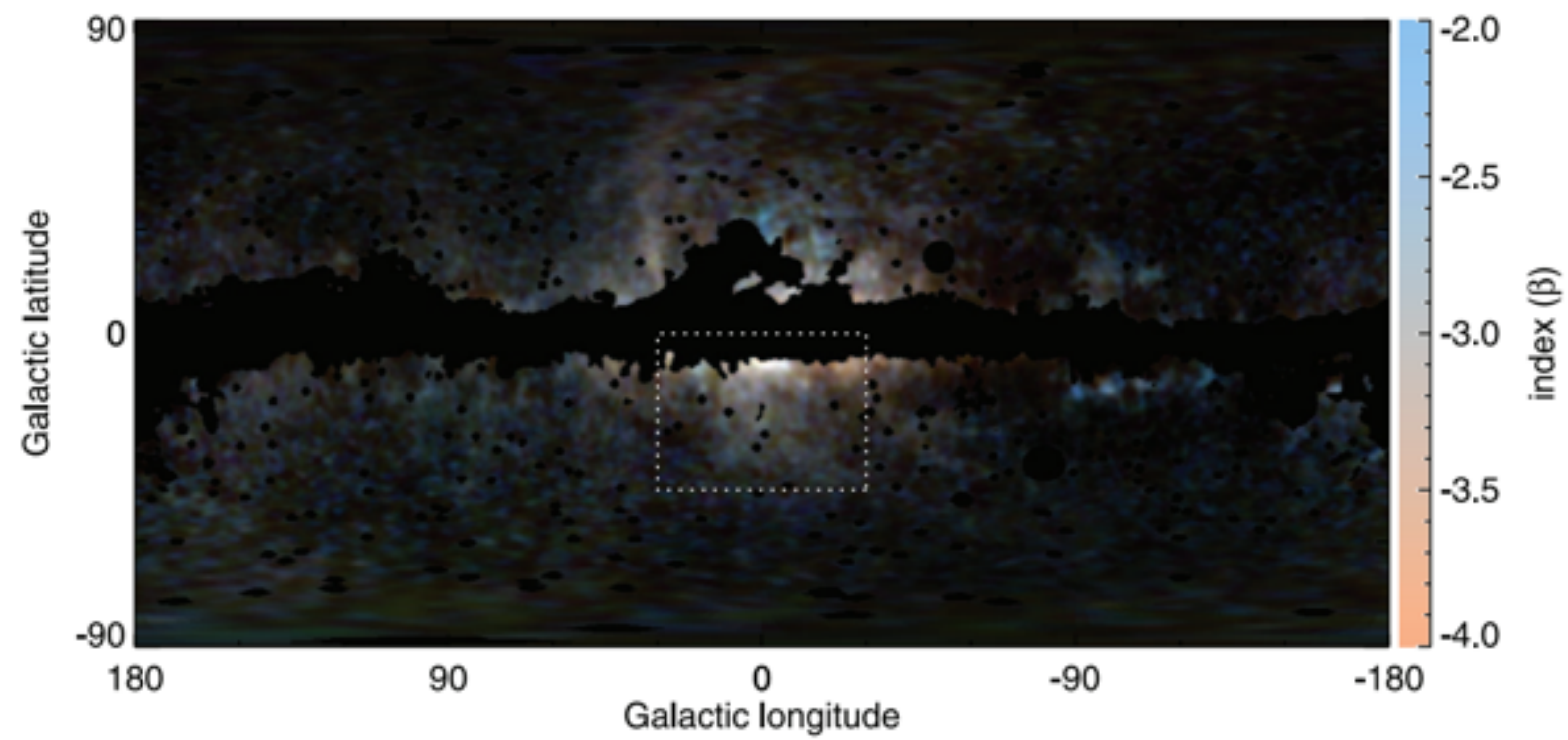
Hooper & Linden (2011)

Other Observations Fitting Light DM: Indirect

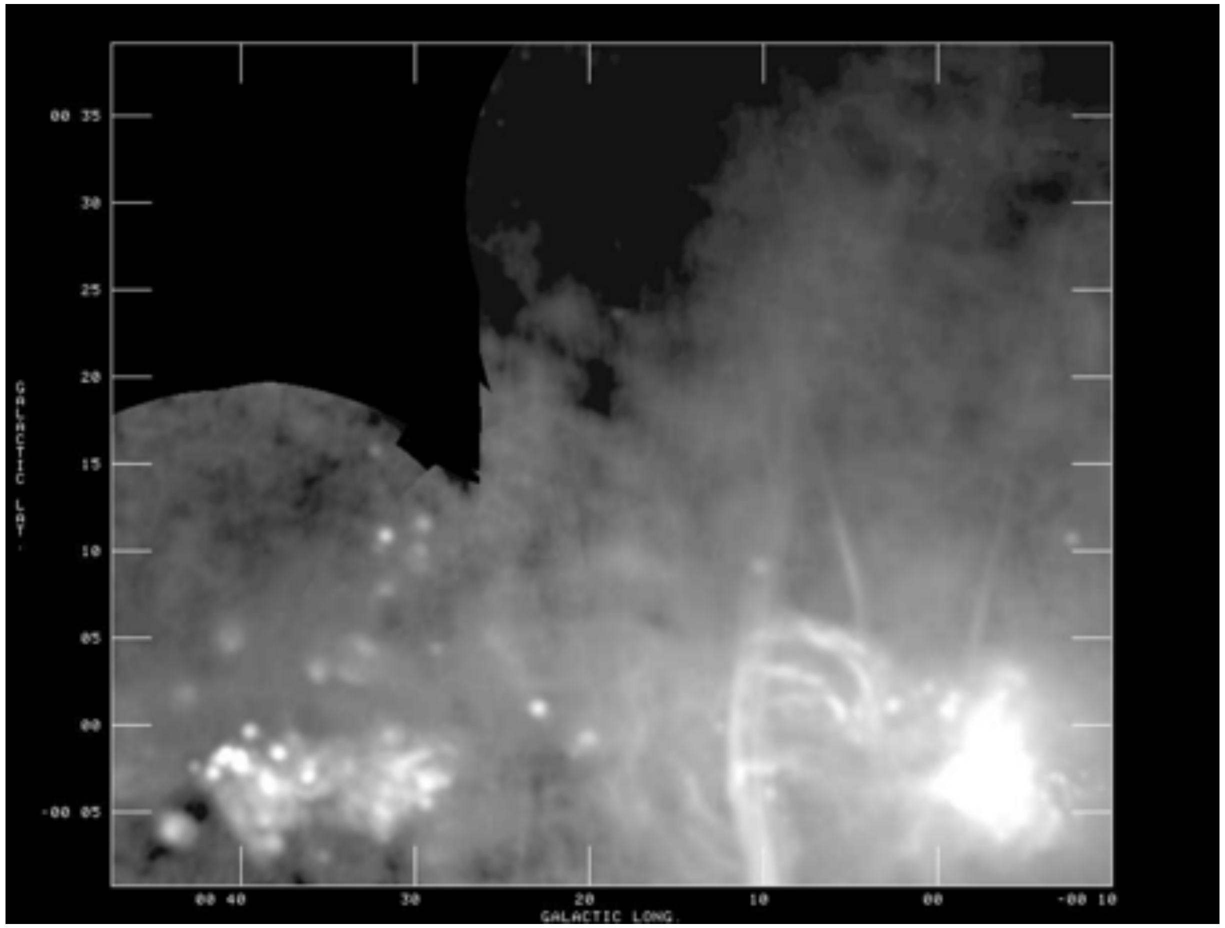


Hooper & Linden (2011)

- The same dark matter model provides a reasonable explanation to the intensity and morphology of the WMAP haze
- The magnetic field must be slightly stronger above the galactic plane than usually assumed



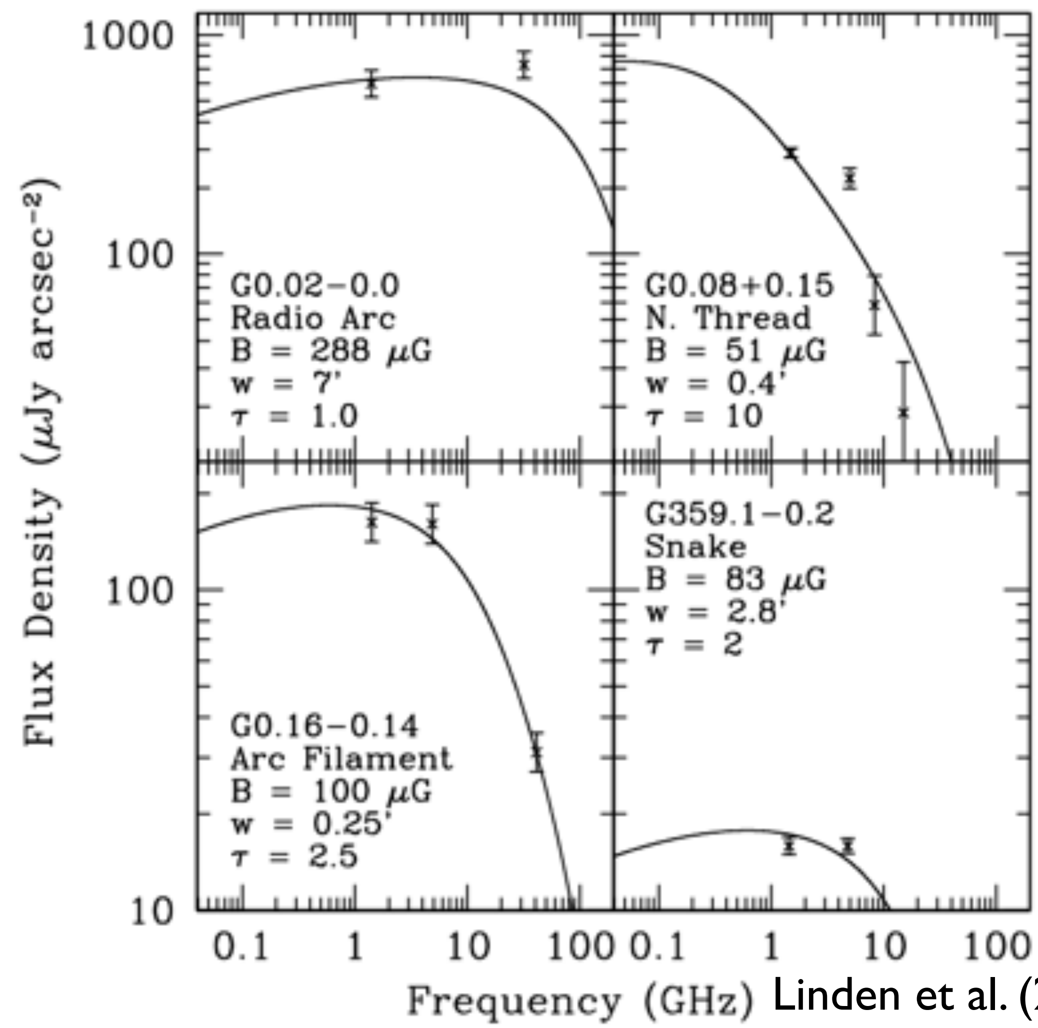
Focus on the Filamentary Arcs



- Numerous long, thin and polarized radio filaments observed in radio data (since the 1980s)
- High polarization fraction implies a strong, structured magnetic field

- Dark Matter annihilation implies a strong constraint on the input electron density

- The model is still able to explain the synchrotron flux (intensity and spectrum) observed in multiple radio filaments



Linden et al. (2011)

Other Observations Fitting Light DM: Indirect

Astron. Astrophys. 200, L9–L12 (1988)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

Monoenergetic relativistic electrons in the galactic center

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Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-5300 Bonn 1, Federal Republic of Germany

Received March 29, accepted May 27, 1988

Summary

It is shown that the nonthermal radio spectra of the galactic center, including Sgr A* and the extended components (Bridge and Arc) is neither due to self-absorbed synchrotron radiation, nor due to thermal absorption. A physical model is discussed in which Sgr A* represents the source of energetic electrons which propagate with an almost monoenergetic distribution function into the extended components.

Key words: particle acceleration – galactic nuclei – plasma – synchrotron radiation

1. Introduction

Interferometric measurements of the compact radio

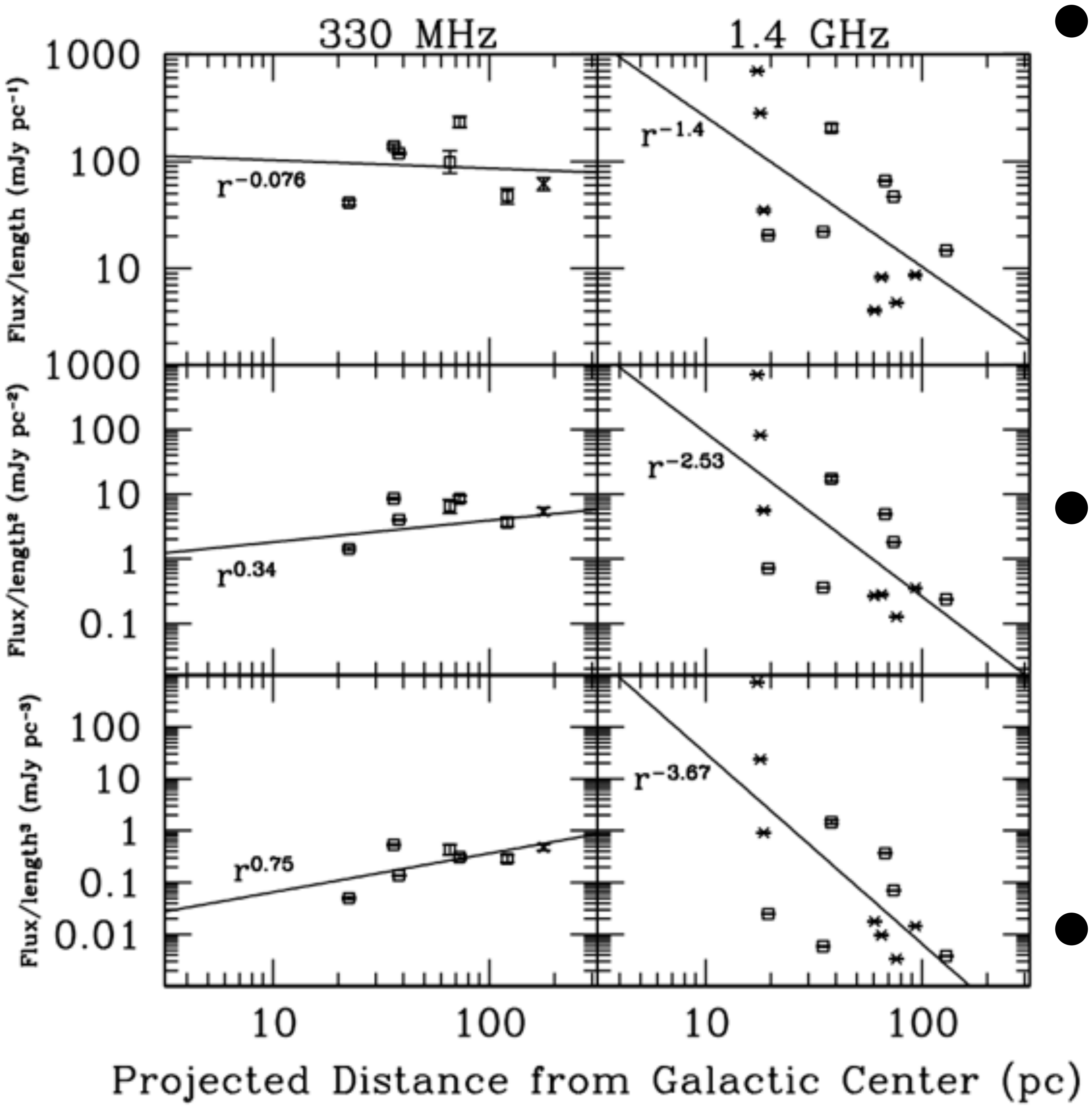
$$\delta\theta_{crit} = 2.6\cdot 10^{9}\, S_M^{1/2}\, \nu_M^{-5/4}\, B^{1/4} \text{ arcseconds} \qquad (1),$$

where S_M is the observed flux density for an unresolved self-absorbed source at a frequency ν_M and B denotes the magnetic field. With the flux density of 2.5 Jy at 10 GHz (Reich et al., 1988) and a magnetic field of

in (Lesch and Schlickeiser, 1987). According to Schlickeiser (1984, eq. 13) the maximum energy of the pile-up electrons is

$$E_M = 7\text{ GeV}\left(\frac{V_A}{2000\text{ km s}^{-1}}\right)^{2}\left(\frac{B^2/8\pi}{8\cdot 10^{-6}\text{ erg cm}^{-3}}\right)^{-1}\left(\frac{K_\parallel}{10^{24}\text{ cm}^2\text{ sec}^{-1}}\right)^{-1} \qquad (7a).$$

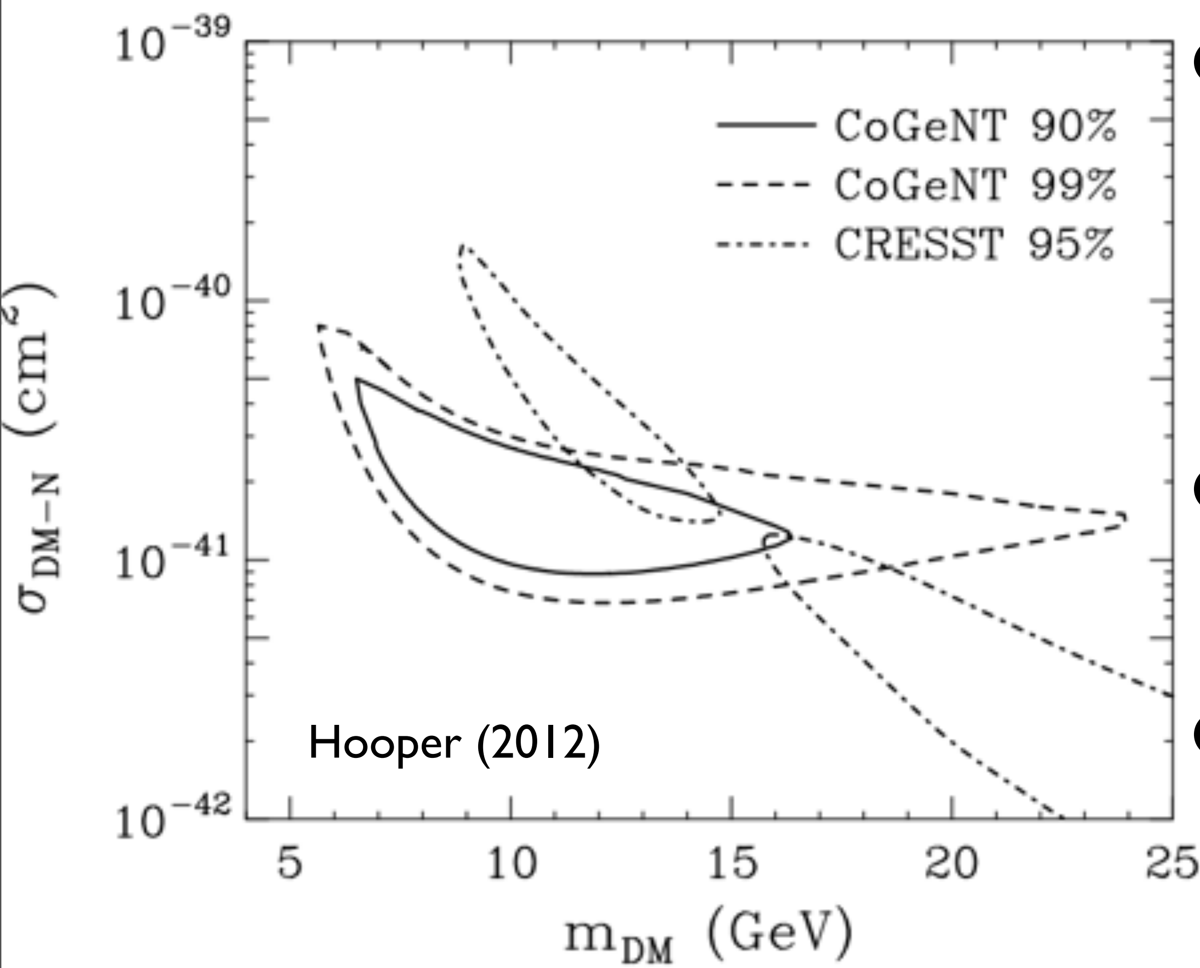
Other Observations Fitting Light DM: Indirect



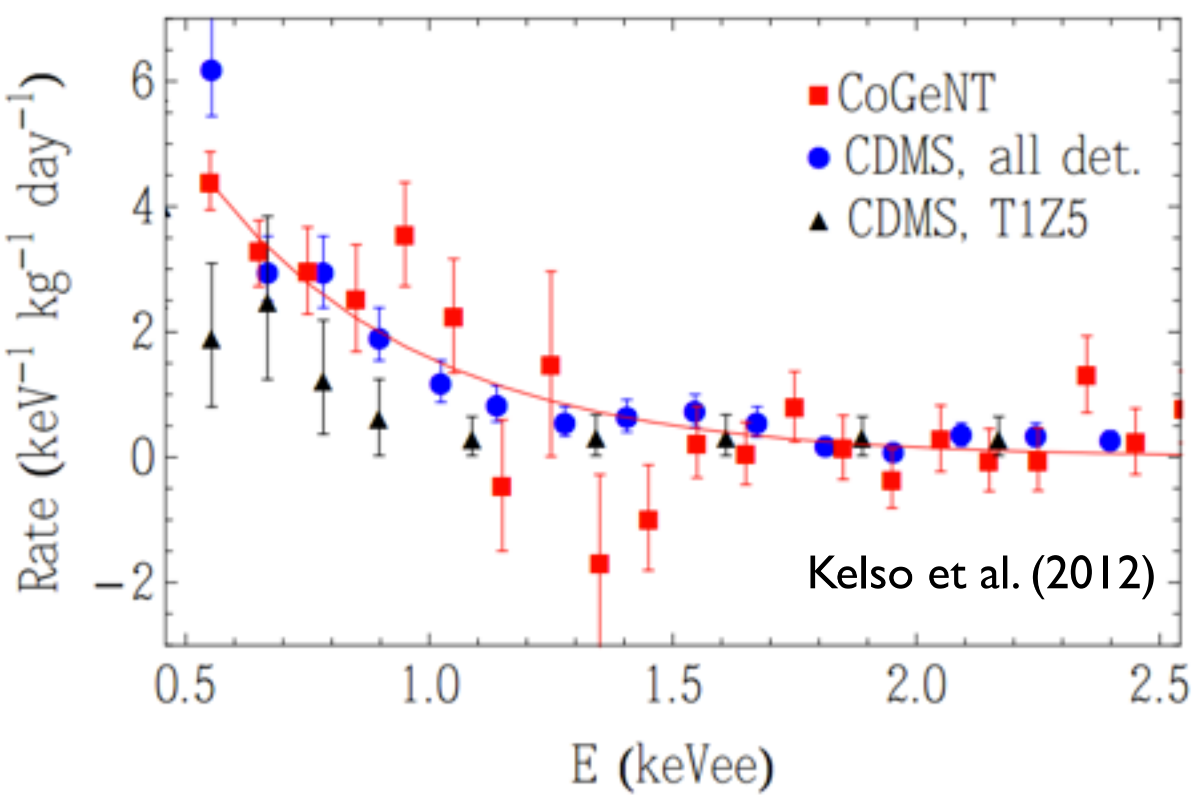
- Moreover, the population of observed radio filaments shows a strong trend towards higher luminosities nearby the galactic center
- This is **not** generically expected in situations where the electron flux is generated by local astrophysical conditions
- The large uncertainties in this trend may be offset by the very steep slope expected from dark matter annihilation

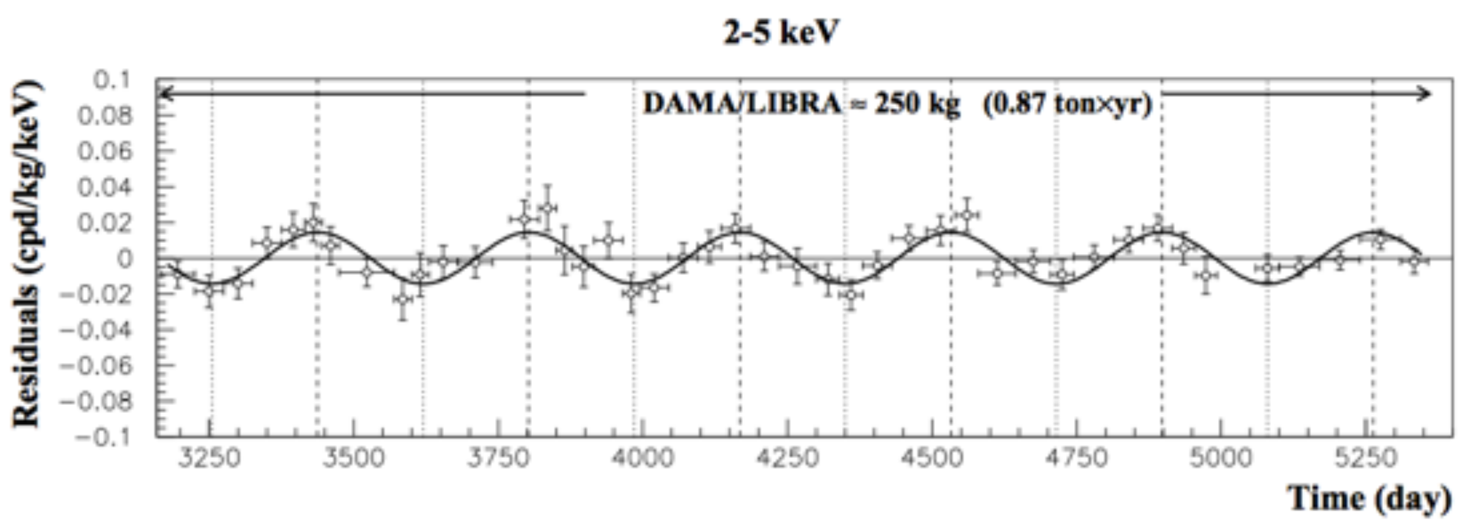
Linden et al. (2011)

Other Observations Fitting Light DM: Direct



- Light Dark Matter (~10 GeV) provides a compelling fit to the excesses currently observed by DAMA, CoGeNT and CRESST
- Light Dark Matter may also be compatible with observed signal/limits at CDMS
- However, a recent error found in CoGeNT analysis may affect some early dark matter interpretations





Conclusions on Dark Matter Model

- Subtraction of both a model for the galactic diffuse emission as well as all known Fermi-LAT point sources yields a bright residual emission
  - This emission is spatially extended, and not well modeled by a point source convolved with the Fermi PSF
  - The emission is well fit by light dark matter particles annihilating to b b-bar (~30 GeV), or $\tau^+\tau^-$ (~10 GeV)
  - In the case of annihilations to $\tau^+\tau^-$, a 10 GeV dark matter candidate also provides a compelling fit to both radio observations and signals in direct dark matter experiments