Dark Matter and the Galactic Center Radio Filaments

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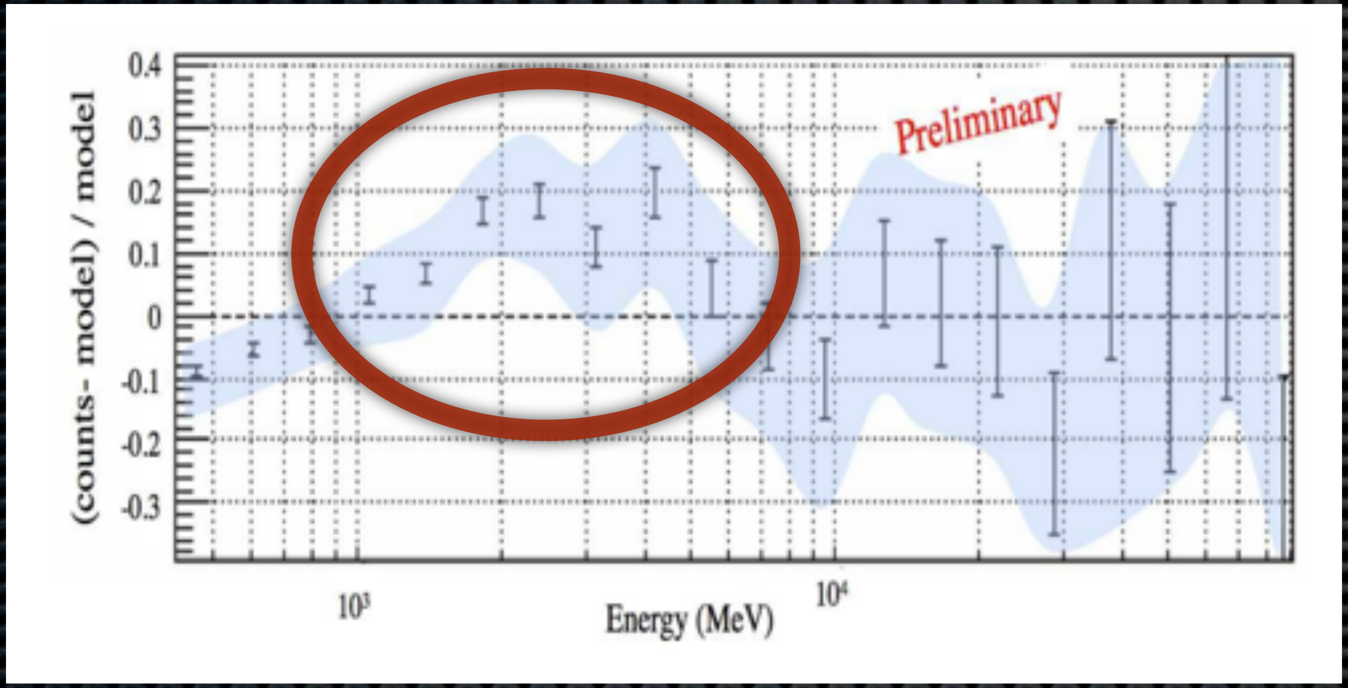
Introduction

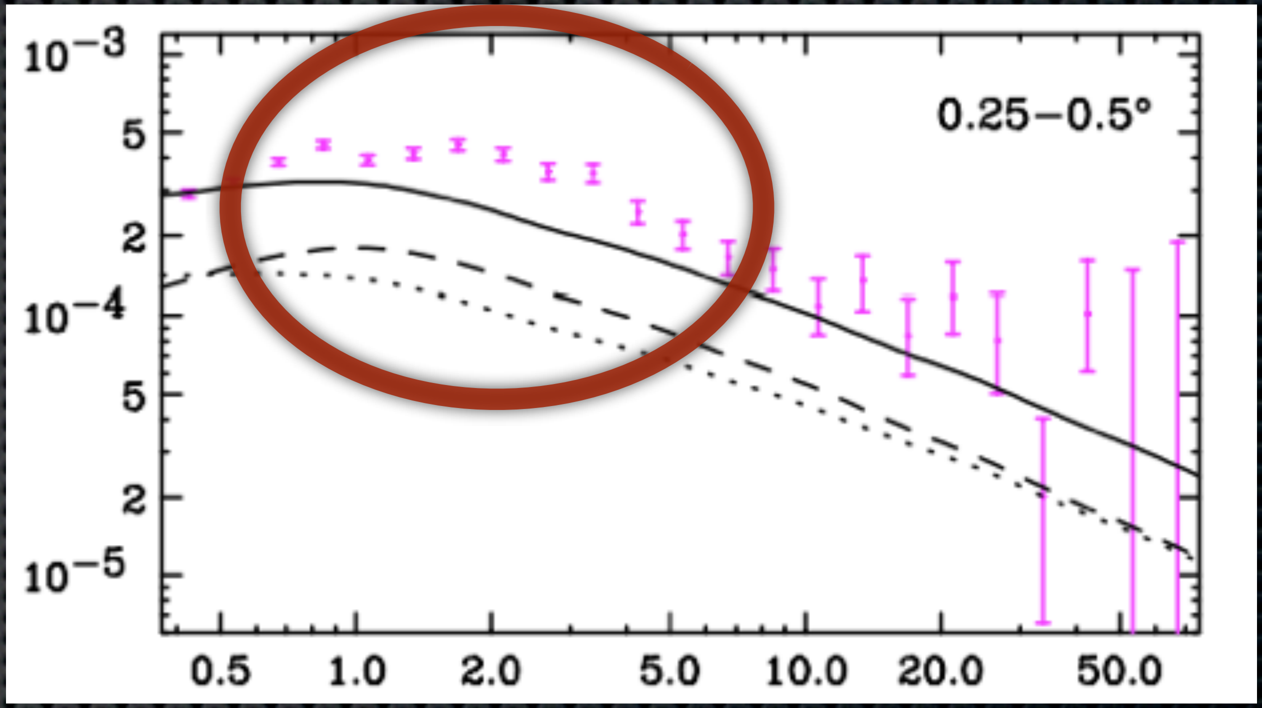
- γ-rays in the galactic center
- Non-thermal radio filaments in the Galactic Center
- Dark matter spectrum in the filamentary arcs
- Models of specific filaments
- Conclusions and Future Tests

Fermi Galactic Center Observations

- Possible (controversial) excess in the galactic center
    - At energies of 1-5 GeV



Vitale, Morselli et al. (2009)



Hooper & Goodenough (2011)

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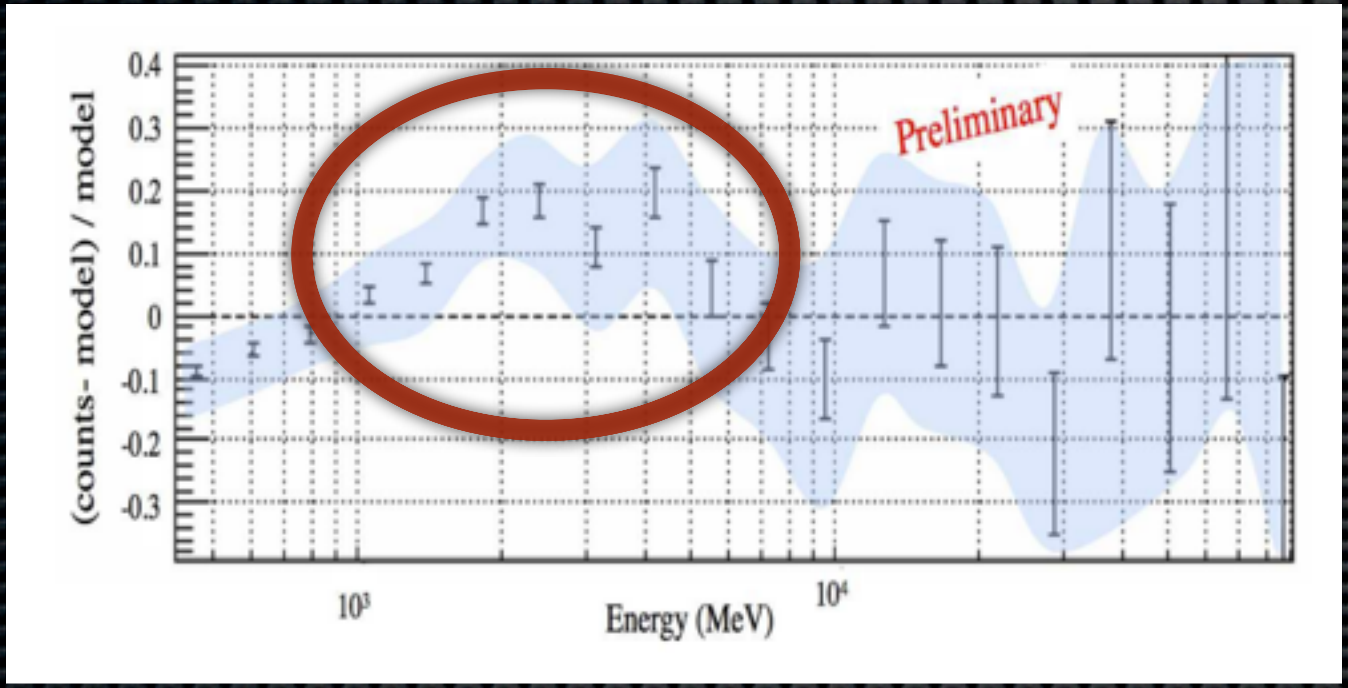

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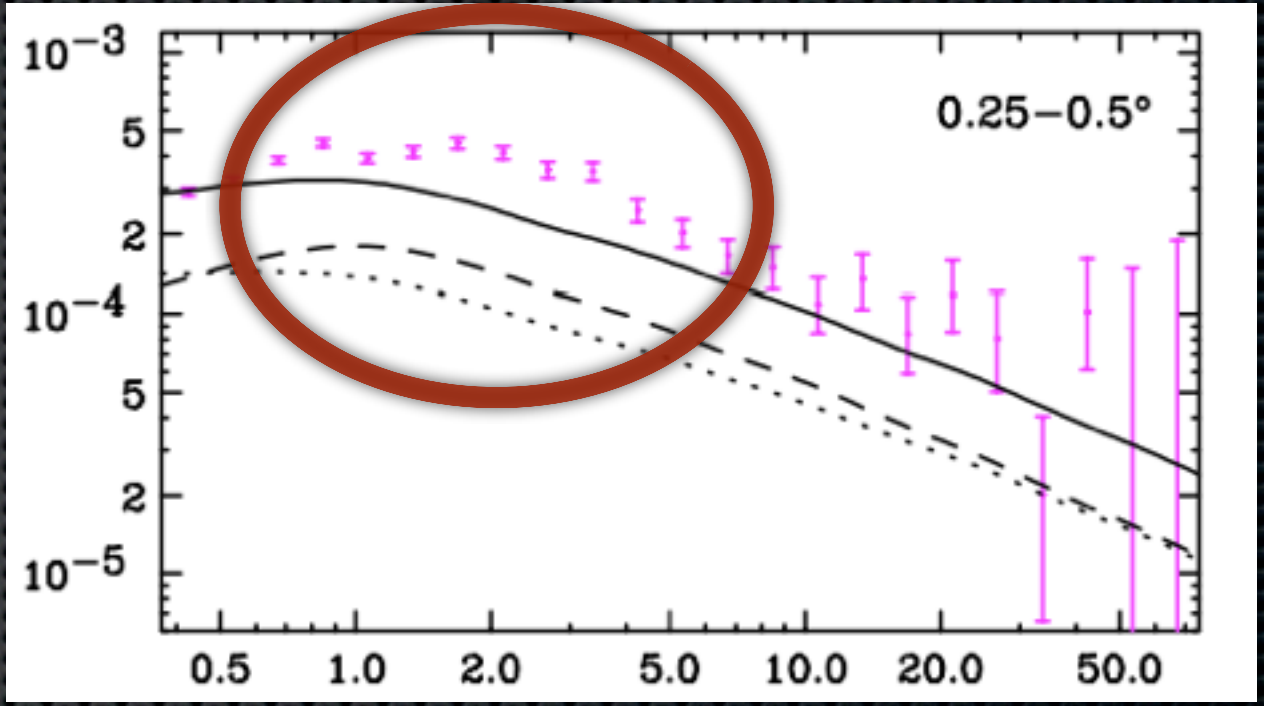
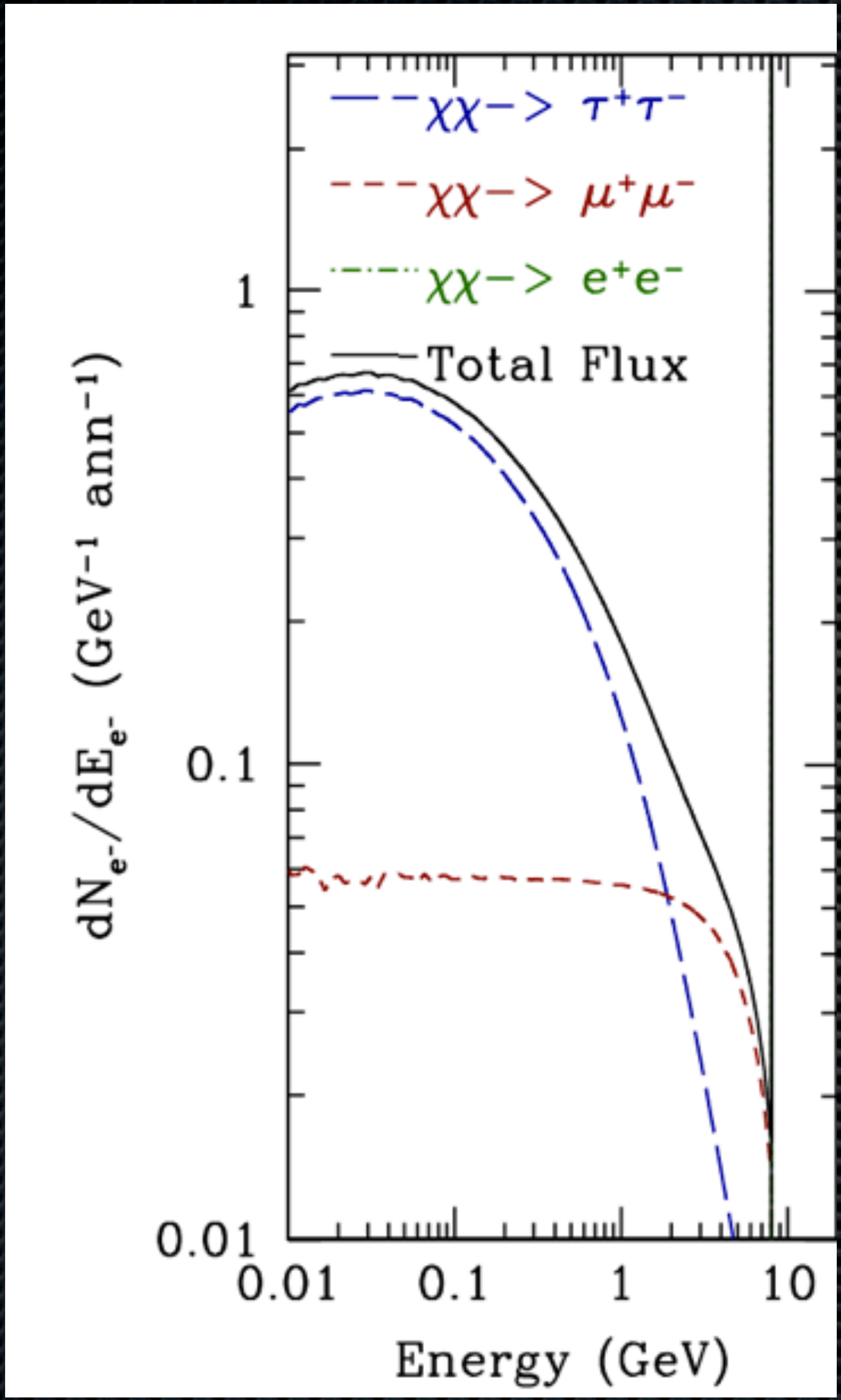


Hooper & Goodenough (2011)

Can we observe this at radio frequencies?

Dark Matter Lepton Spectrum



- Generic WIMP produces both γ-rays and electron flux
- Relative spectra are set by mass and annihilation pathway
- Here we assume an 8 GeV WIMP annihilating democratically to leptonic final states

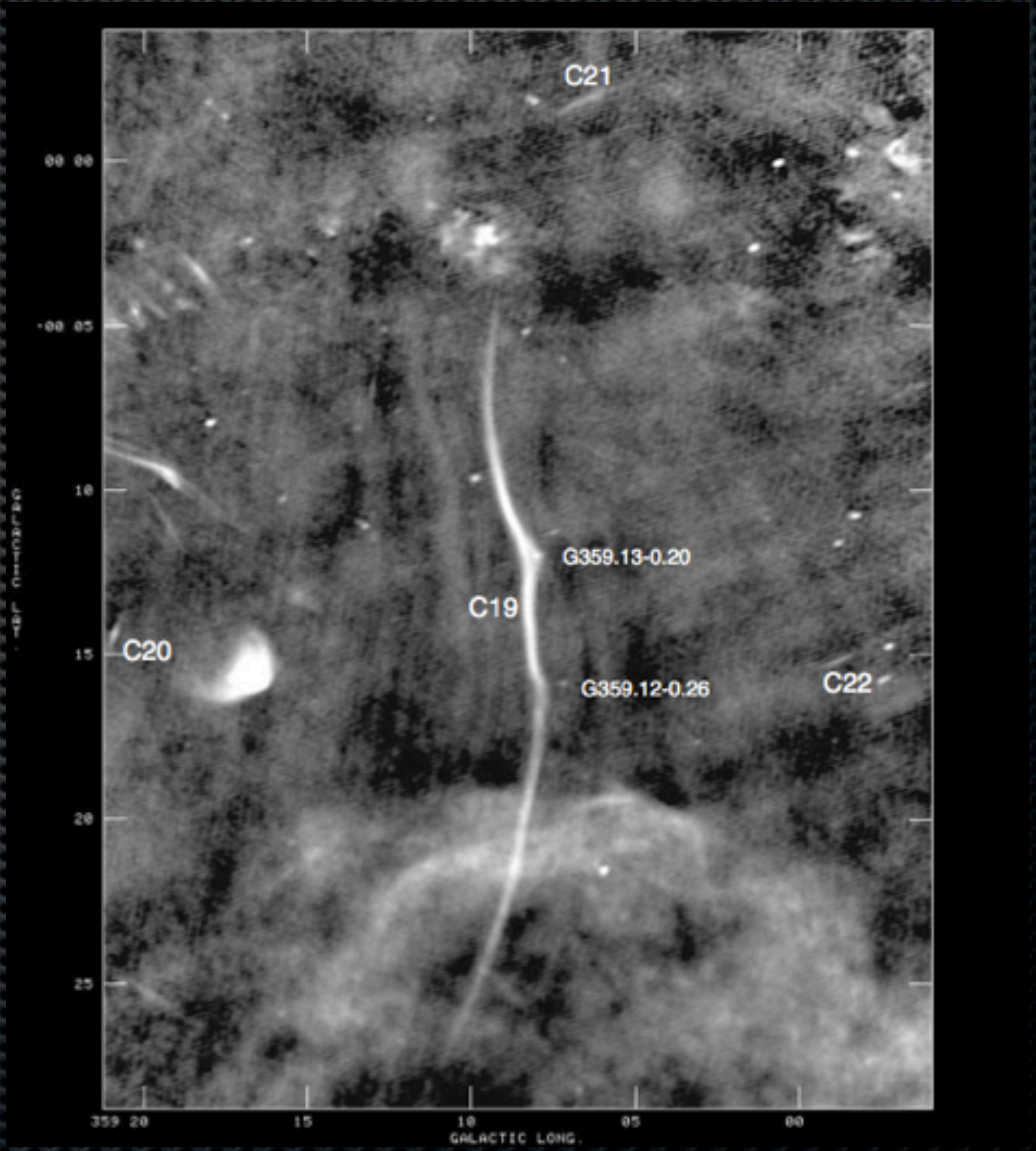
Non-Thermal Radio Filaments

- Long (~30 pc) thin (<1 pc) "tubes" with enhanced, and ordered, magnetic field

$$B_{tot} \sim 50\text{-}1000\ \mu G$$

$$\frac{B_{ord}^2}{B_{tot}^2} > 0.6$$

- ~30 known sources within 100 pc of galactic center
- Mechanism for filament creation is unknown



Yusef-Zadeh et al. 2004

Non-Thermal Radio Filaments

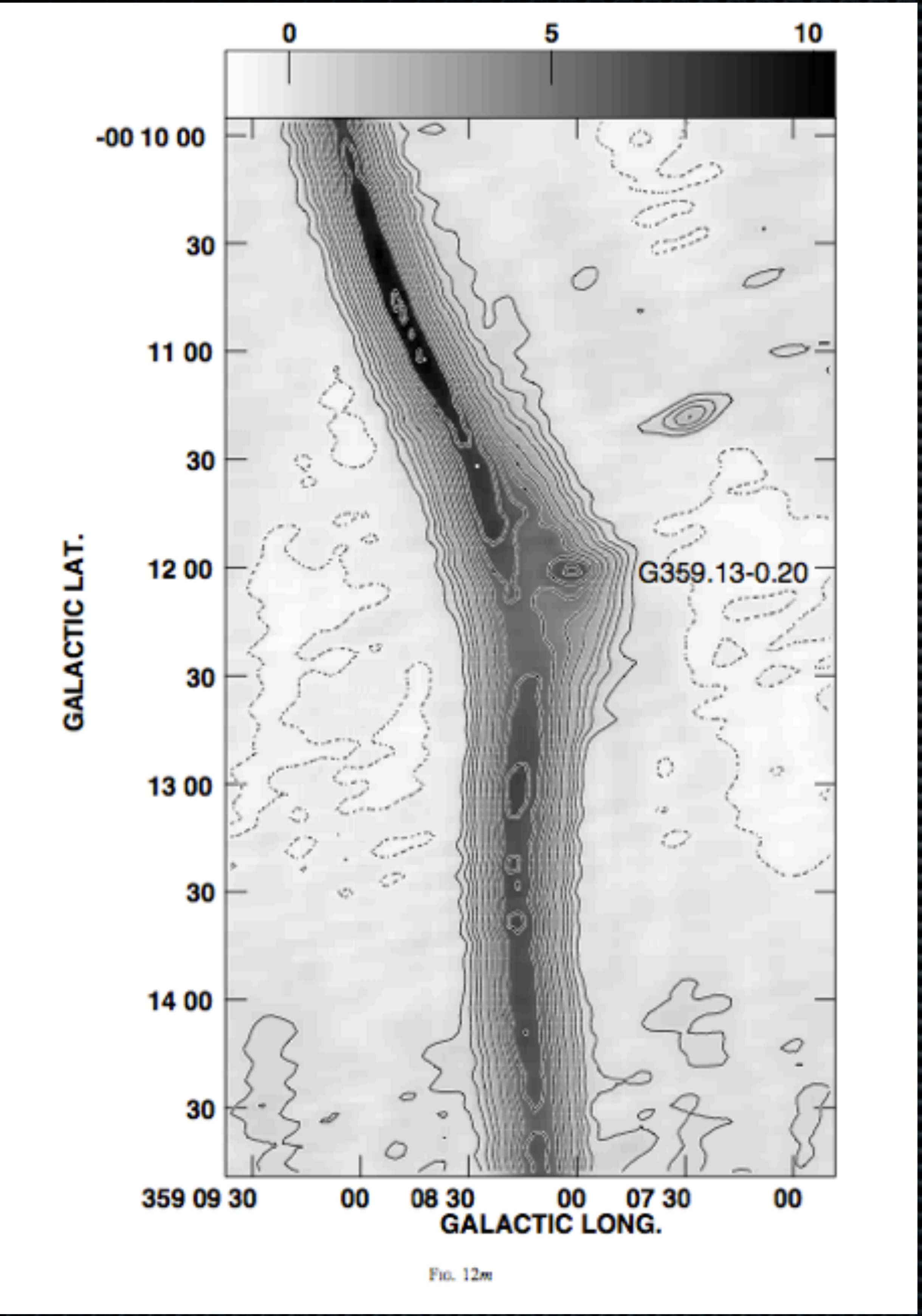
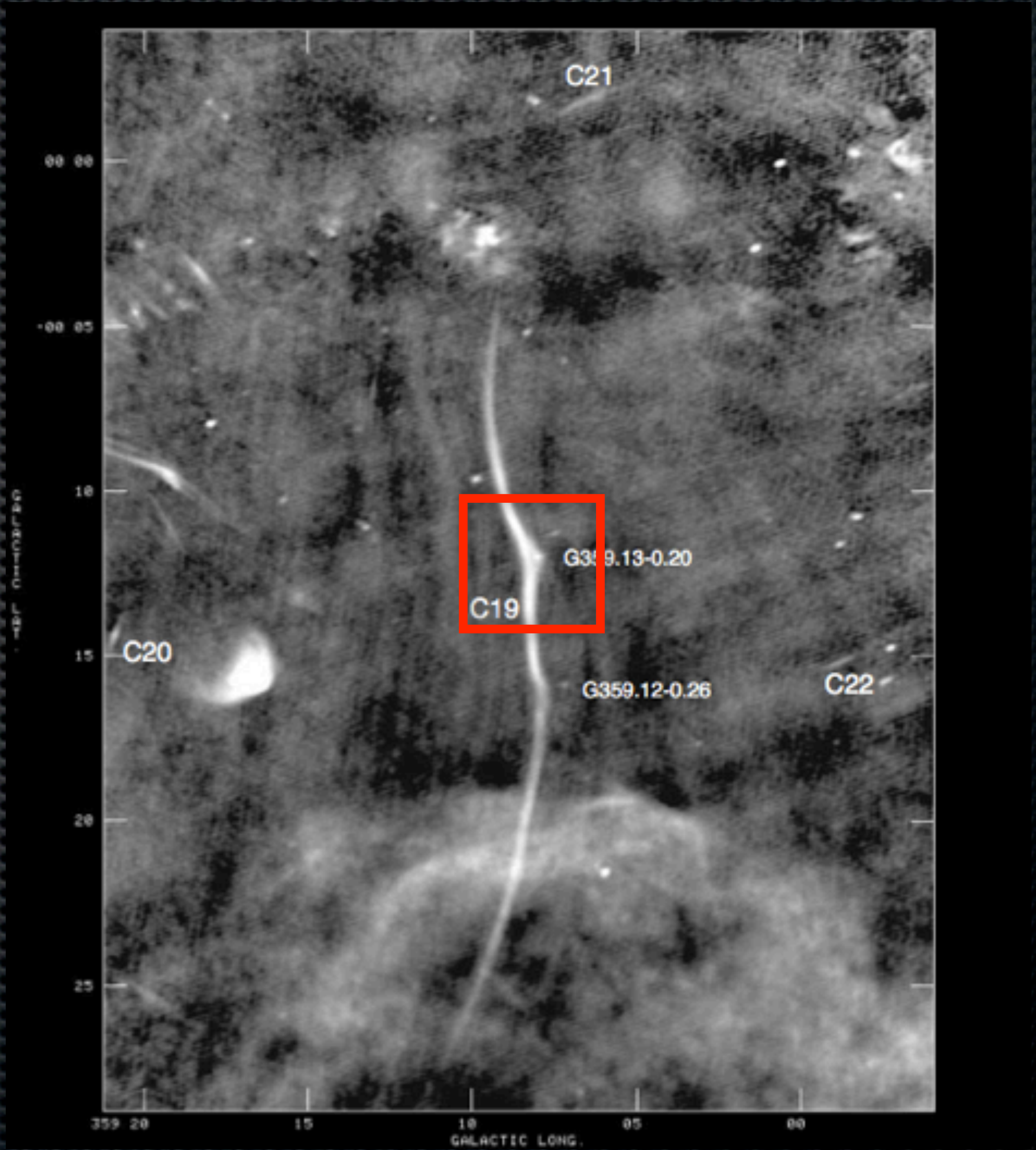


FIG. 12m



Yusef-Zadeh et al. 2004

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Non-Thermal Radio Filaments

- Synchrotron Spectrum cannot be explained by power-law lepton injection spectra

$$p = 2\alpha + 1$$

-p is the power-law index of the electron injection spectrum

-α is the power-law index of the synchrotron radiation spectrum

Shock Acceleration => p ~ 2.4
α ~ 0.7

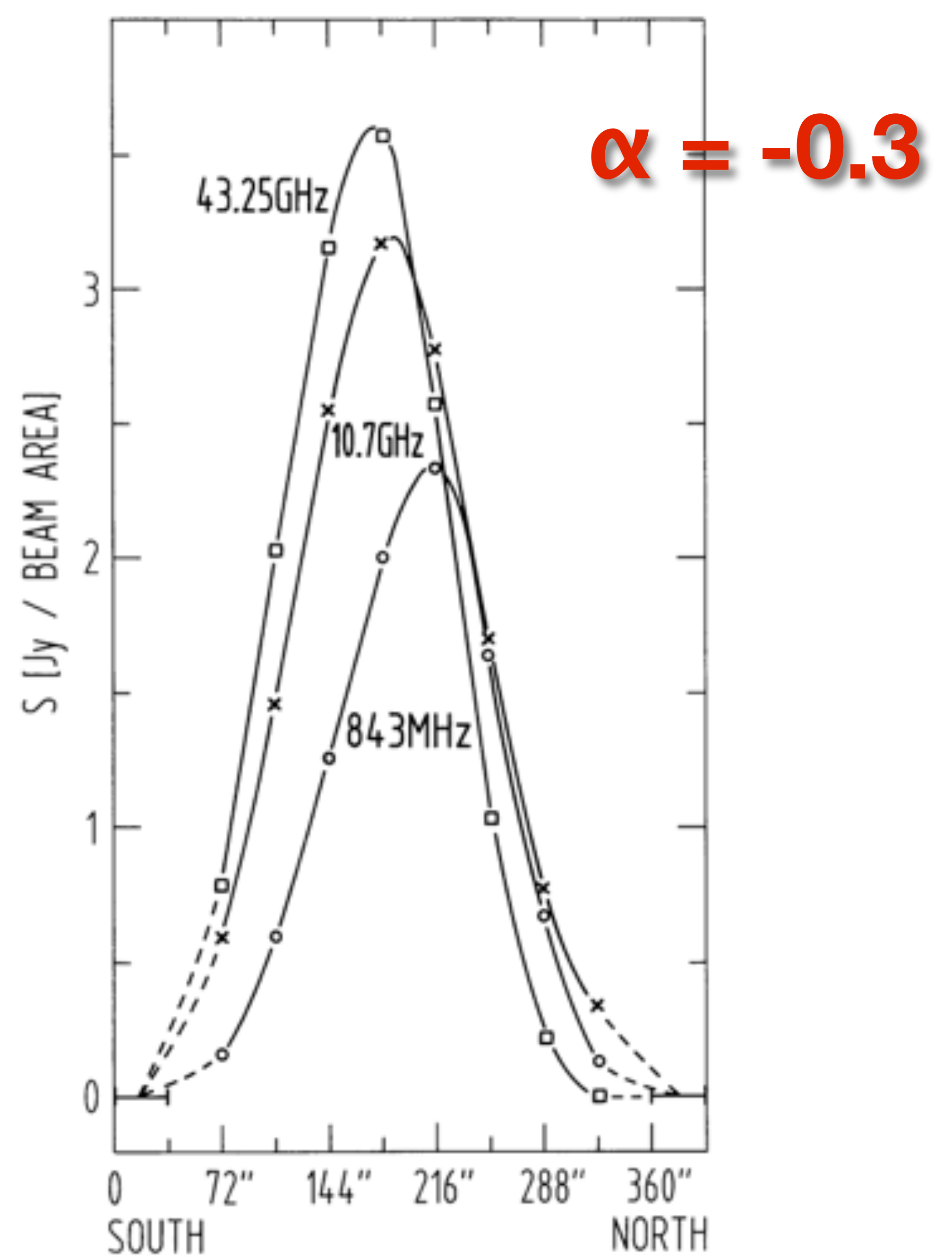


Fig. 10. Average cross cut of the Arc region as obtained by averaging the data at 843 MHz, 10.7 GHz and 43.25 GHz of the field indicated in Fig. 1

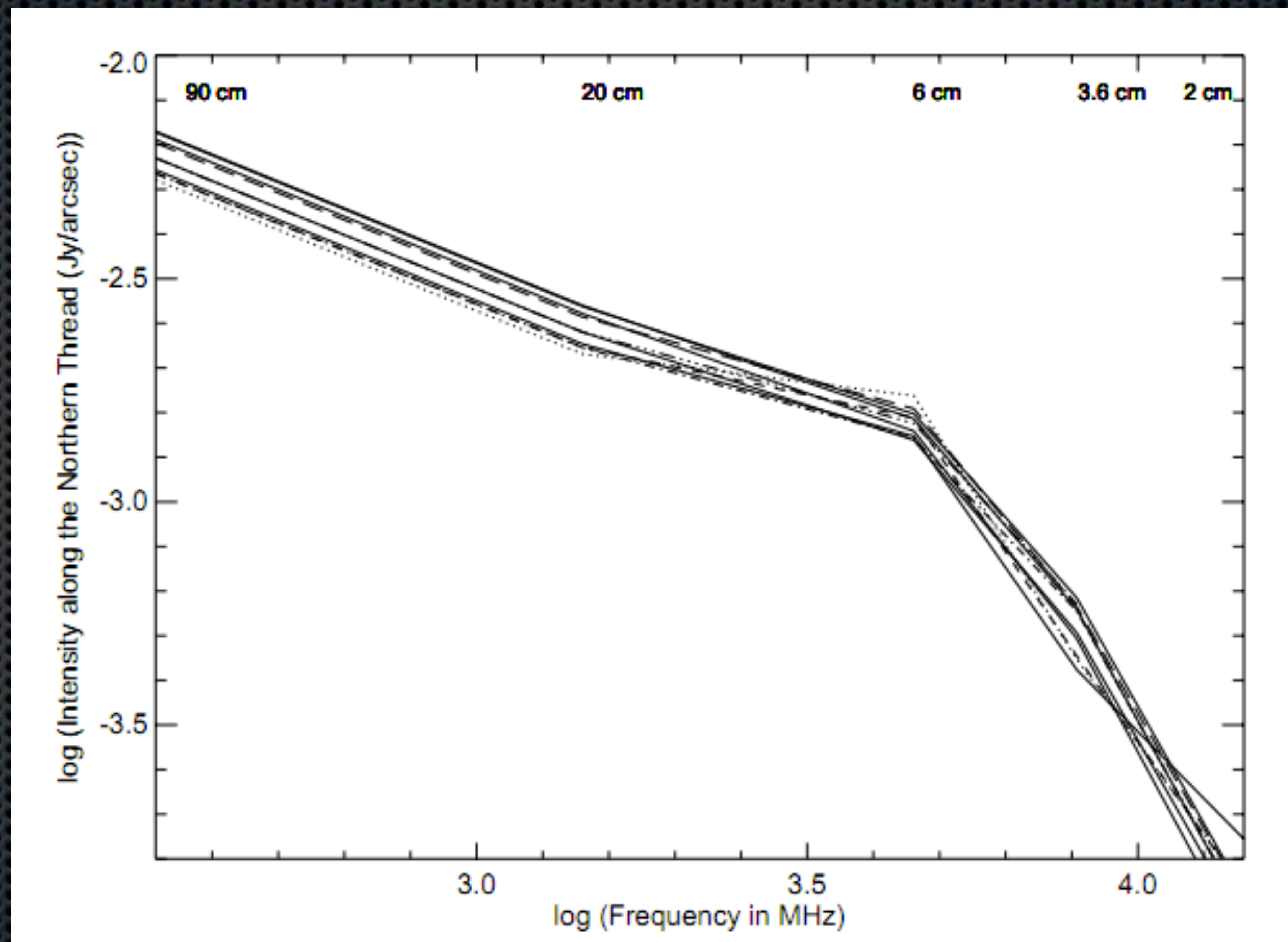
Radio Arc

Reich et al. 1988

Non-Thermal Radio Filaments

- Synchrotron Spectrum cannot be explained by power-law lepton injection spectra

Northern Thread G0.08+0.15



Lang et al. 1999

Non-Thermal Radio Filaments

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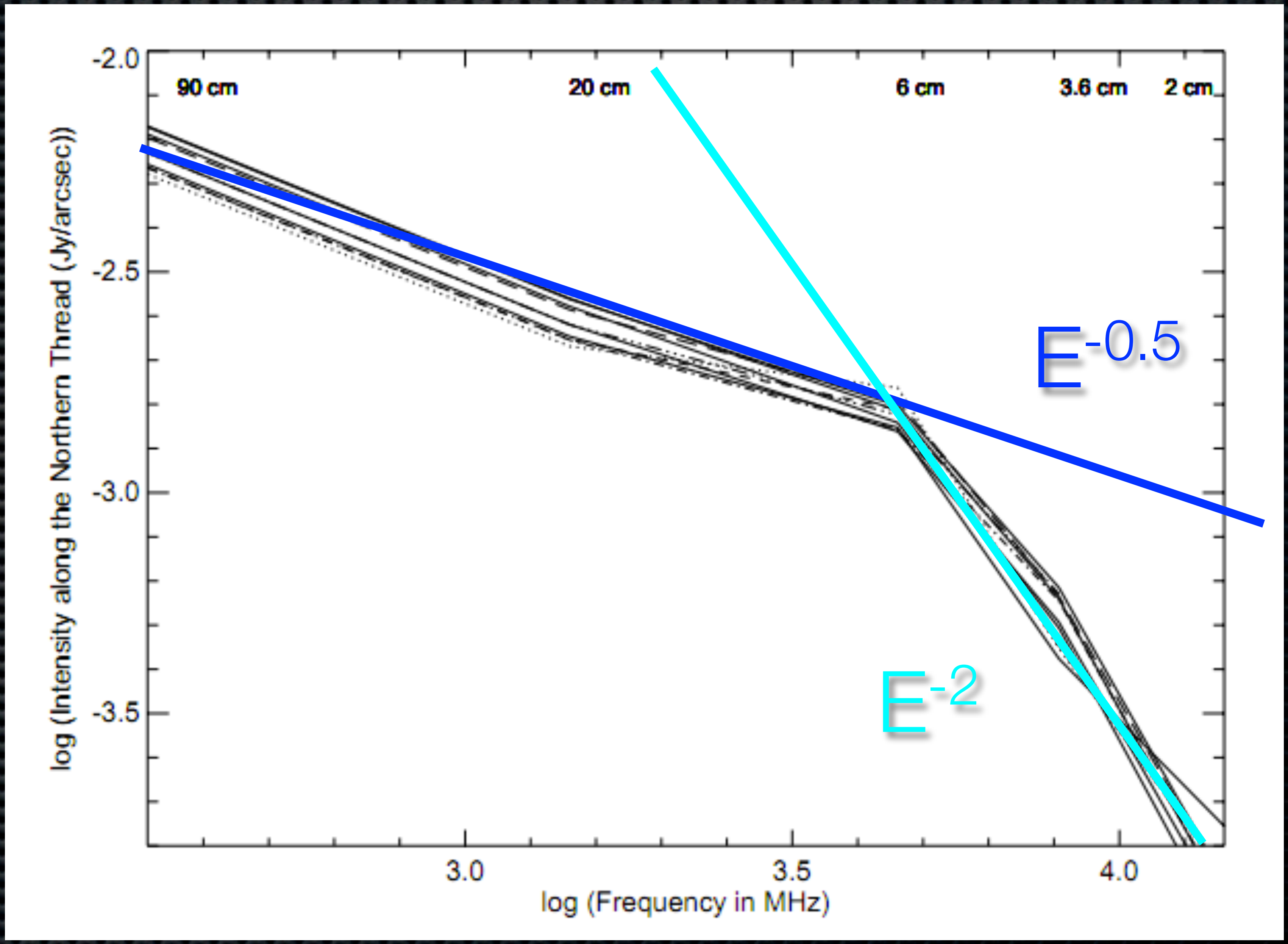

Lang et al. 1999

Non-Thermal Radio Filaments

- Synchrotron spectrum is similar in many NRFs

Name	Alternative Name	$\alpha_{0.33GHz}^{1.4GHz}$	$\alpha_{1.4GHz}^{4.8GHz}$	$\alpha_{4.8GHz}^{>}$	References
G0.08+0.15	Northern Thread	-0.5	-0.5	-2.0	Lang et al. (1999b); LaRosa et al. (2000)
G358.85+0.47	The Pelican	-0.6	-0.8 ± 0.2	-1.5 ± 0.3	Kassim et al. (1999); Lang et al. (1999a)
G359.1-0.02	The Snake	-1.1	~0.0	*	Nicholls & Gray (1993); Gray et al. (1995)
G359.32-0.16	———	-0.1	-1.0	———	LaRosa et al. (2004)
G359.79+0.17	RF-N8	-0.6 ± 0.1	-0.9 to -1.3	———	Law et al. (2008a)
G359.85+0.39	RF-N10	0.15 to -1.1**	-0.6 to -1.5**	———	LaRosa et al. (2001); Law et al. (2008a)
G359.96+0.09	Southern Thread	-0.5	———	———	LaRosa et al. (2000)
G359.45-0.040	Sgr C Filament	-0.5	———	-0.46 ± 0.32	Liszt & Spiker (1995); Law et al. (2008a)
G359.54+0.18	Ripple	———	-0.5 to -0.8	———	Law et al. (2008a)
G359.36+0.10	RF-C12	———	-0.5 to -1.8	———	Law et al. (2008a)
G0.15+0.23	RF-N1 (in Radio Arc)	———	+0.2 to -0.5	———	Law et al. (2008a)
G0.09-0.09	———	———	———	0.15	Reich (2003)

*Two very different values exist in the literature for the high frequency spectrum of the Snake. Gray et al. (1995) cites a value of -0.2 ± 0.2, while a more recent analysis by Law et al. (2008b) yields $\alpha_{4.8GHz}^{8.33} = -1.86 \pm 0.64$

*Spectrum is highly position dependent, but shows a clear trend towards steeper spectral slopes at high frequencies for any given position

Non-Thermal Radio Filaments

The origin of monoenergetic electrons in the arc of the galactic center. Particle acceleration by magnetic reconnection

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Abstract. The Arc filaments in the Galactic Center exhibit an *inverted* radio spectrum with a spectral index $\alpha \sim 0.3$ ($S_\nu \propto \nu^\alpha$). Such a spectrum can be interpreted as optically thin synchrotron radiation from monoenergetic electrons. We propose magnetic reconnection as the acceleration process for these particles. Quantitative estimates are in agreement with the observed properties of the Arc. The motion of molecular clouds in a strong poloidal magnetic field serves as trigger mechanism for the magnetic reconnection process, which in general is likely an important acceleration process in galactic nuclei.

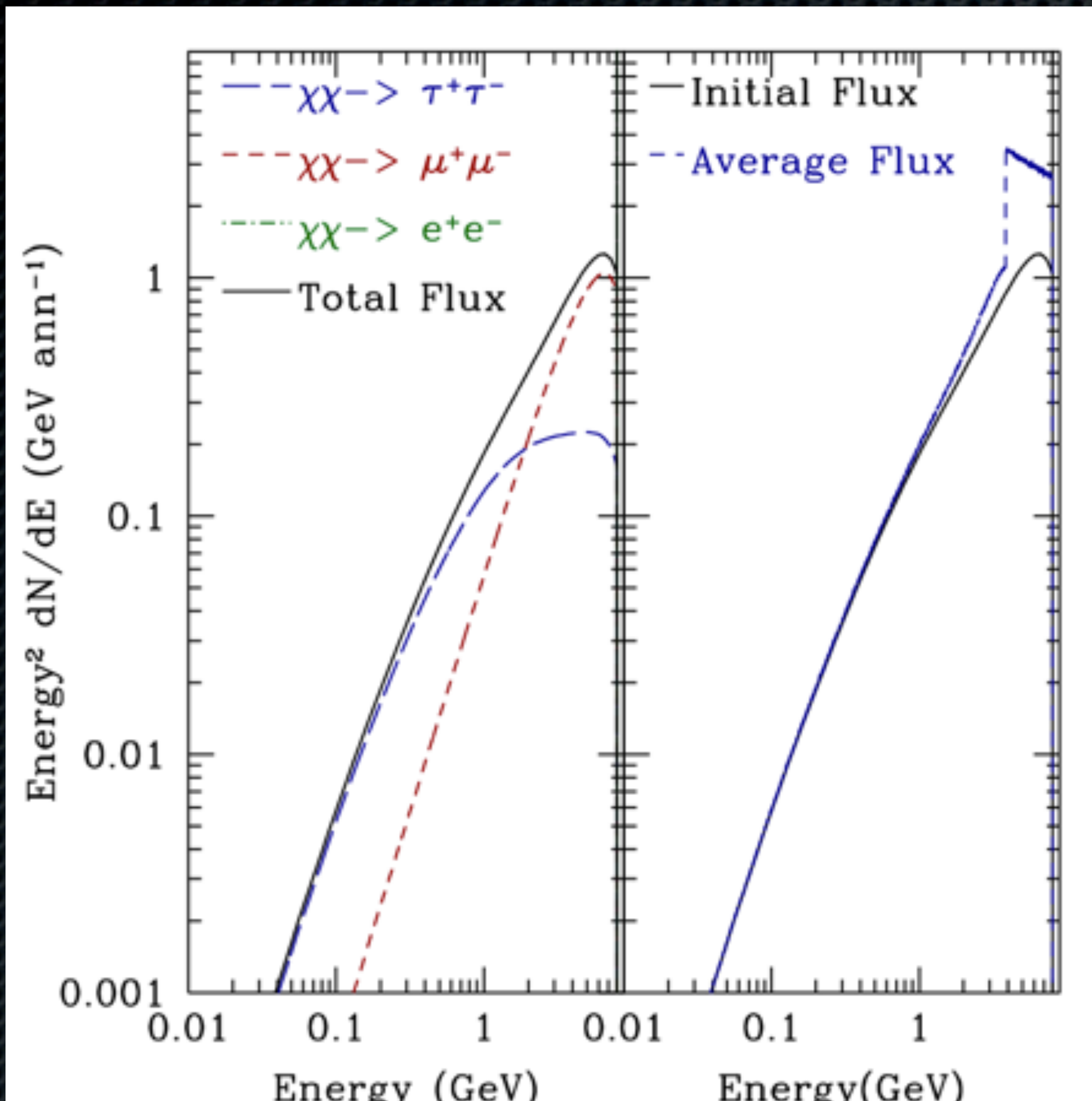
synchrotron lifetime t_{syn} at an observing frequency of 15 GHz, which is the highest frequency where the filaments have been clearly detected (Inoue et al. 1989)

$$t_{syn} \simeq \frac{5 \cdot 10^8}{\gamma B^2} \simeq 7 \cdot 10^3 \text{ years} \left[\frac{\gamma}{2 \cdot 10^3}\right]^{-1} \left[\frac{B}{10^{-3}\,\text{Gauss}}\right]^{-2}, \qquad (1)$$

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

Lesch et al. 1988

Dark Matter Lepton Spectrum



- **Light dark matter model naturally produces ~ 8 GeV leptons**
- **Synchrotron energy loss smooths the spectrum**
- **We define a parameter τ**

$$T_{confinement} \propto \tau \times B^{-2} \times E^{-1} \times E^{-0.33}$$

↖ Kolmogorov Spectrum

Softened electron spectrum depends only on **τ!**

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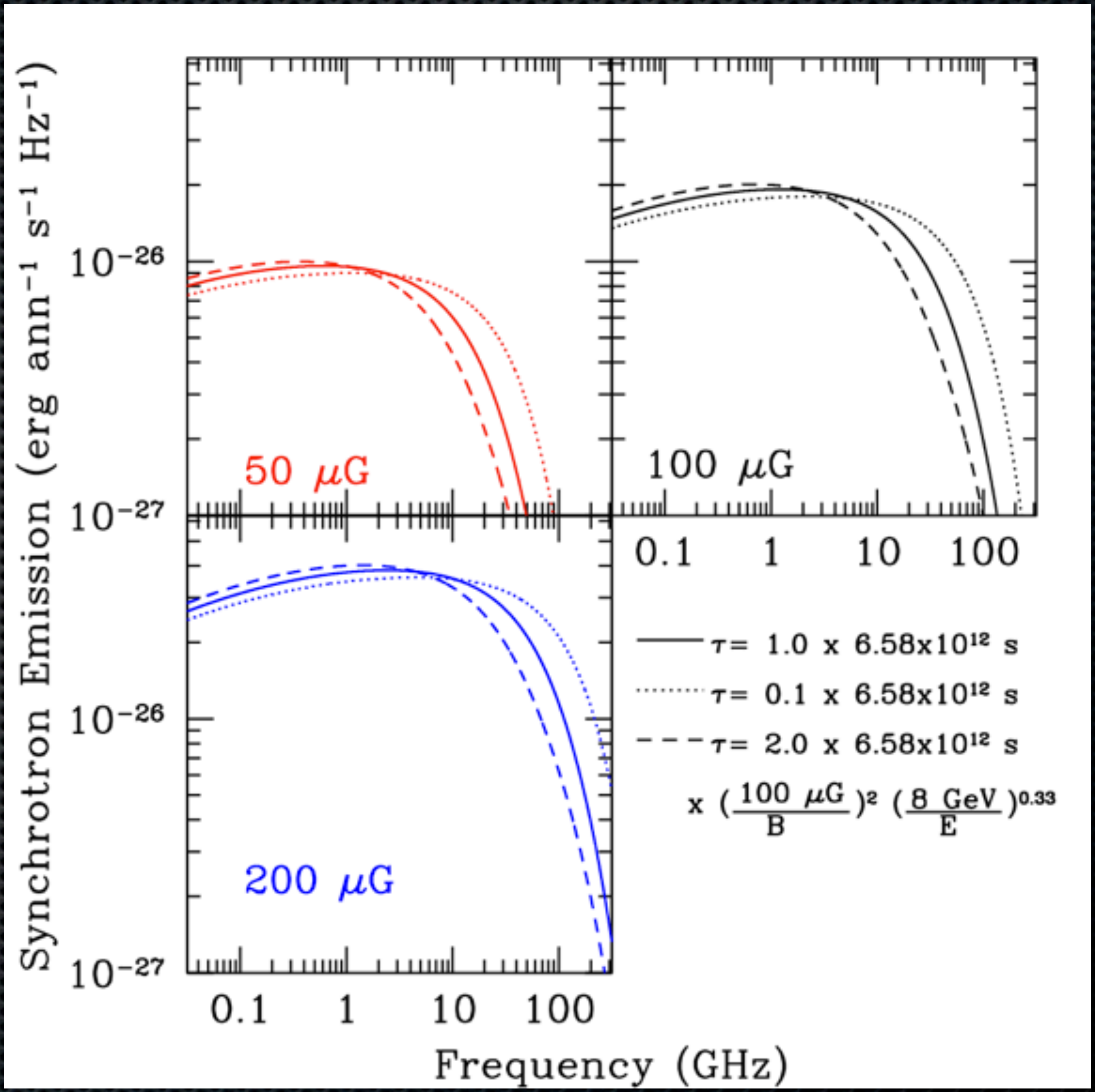
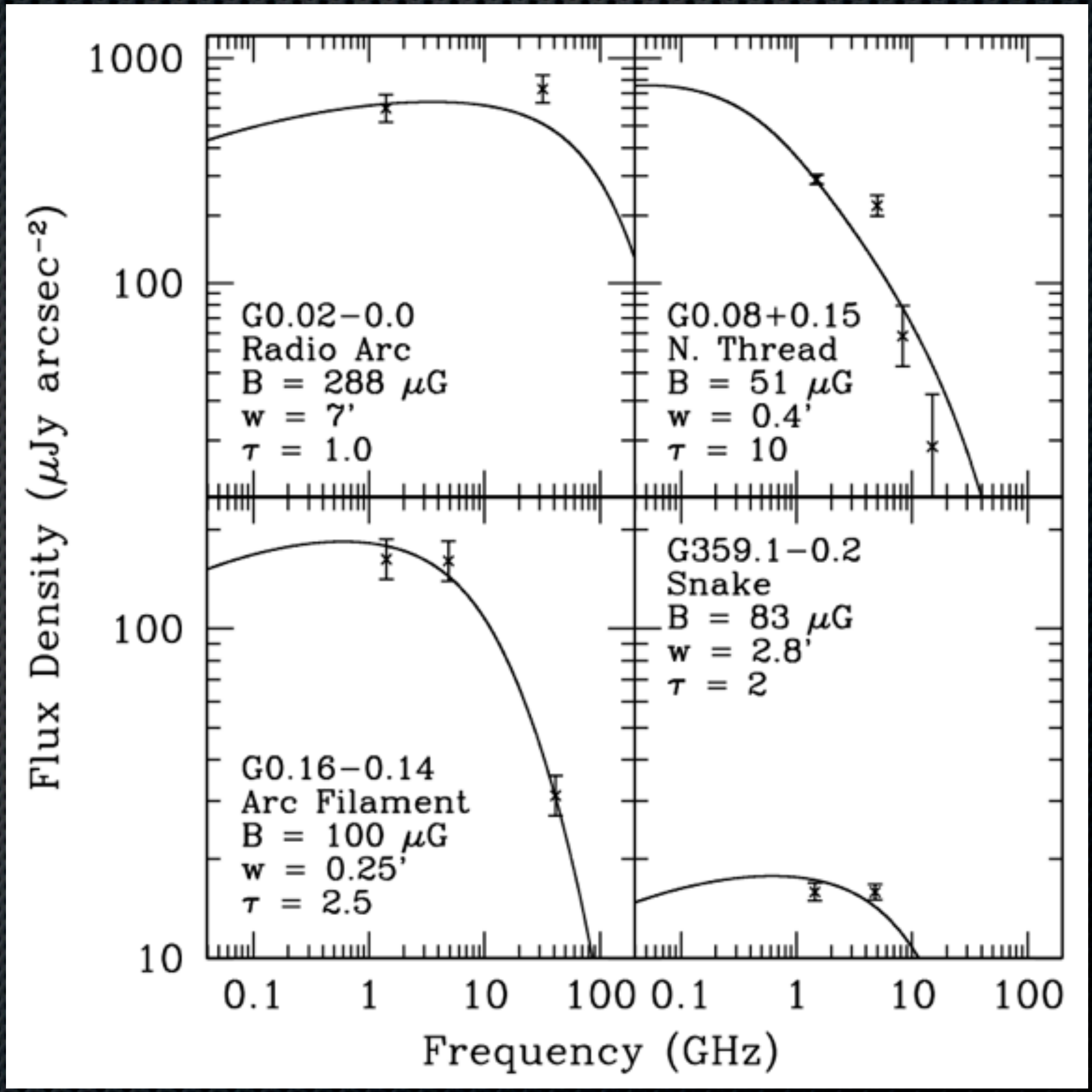
Dark Matter Synchrotron Spectrum

- Produces the flat spectral slope from 1-10 GHz
- Cuts off above 10 GHz - in agreement with observations
- Explains similar spectrum observed in all filamentary arcs



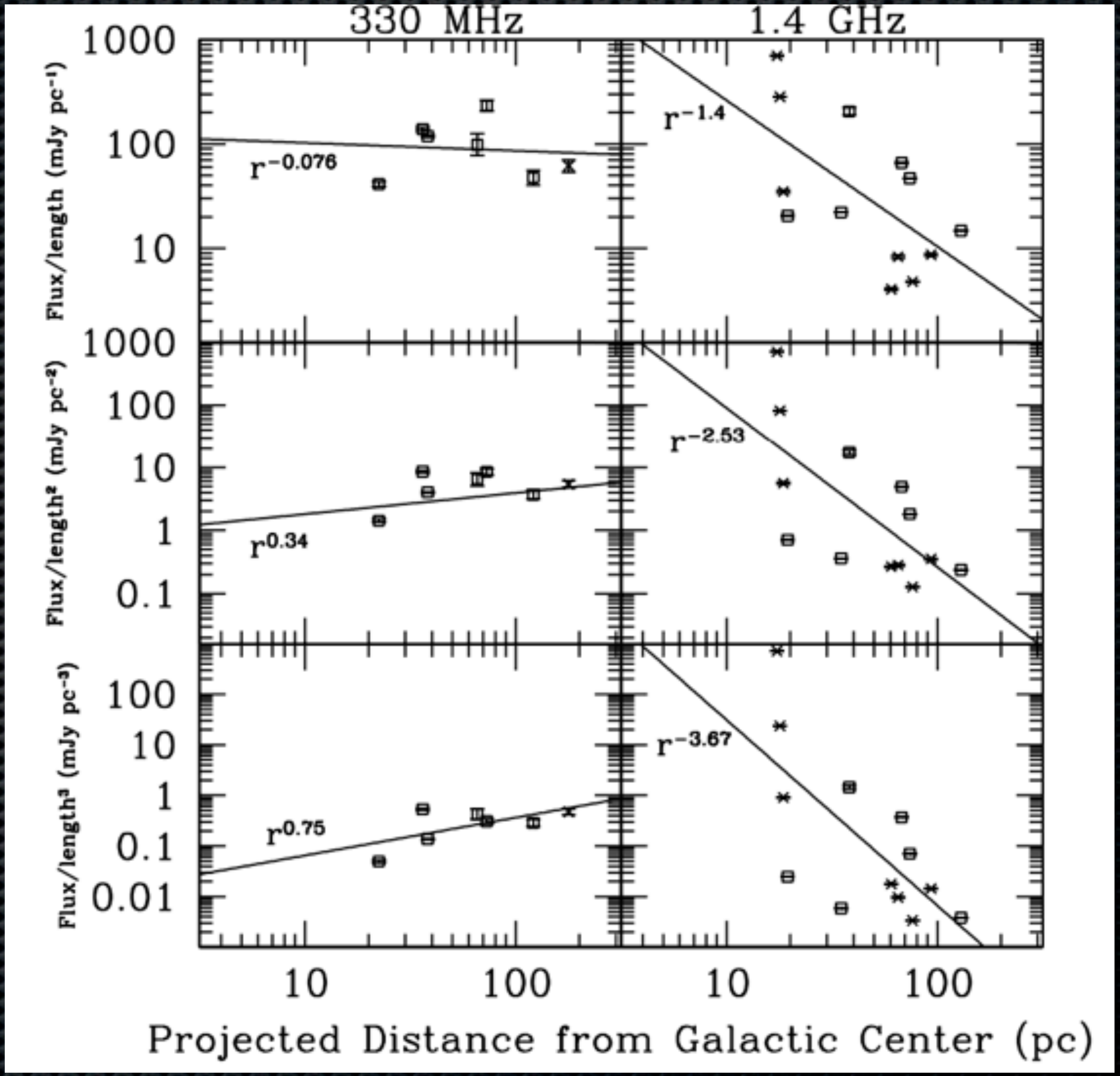
Comparison to Specific NRFs

- The same electron spectrum can explain multiple NRFs
- Magnetic fields lie near equipartition values



Luminosity vs. GC Distance

- **Dark Matter interpretation predicts decrease in luminosity for NRFs farther from the galactic center**
- **Slope at 1.4 GHz expected based on ~1 GHz peak of 7 GeV electrons in 100 μG B-field**



Discussion

- The dark matter pathway employed to explain the γ-ray signal observed by Fermi-LAT requires the lepton spectrum necessary to explain the filamentary arcs

- Excess of ~10 GeV monoenergetic leptons in galactic center suggests correlation between Fermi gamma-ray analysis and radio surveys

Testable Predictions

- NRFs will have equivalent electron injection spectra
- Regions of high luminosity are astrophysical
  - Will have softer spectra
  - May have lower polarization
- Existence of any under-luminous filament could undermine dark matter explanation

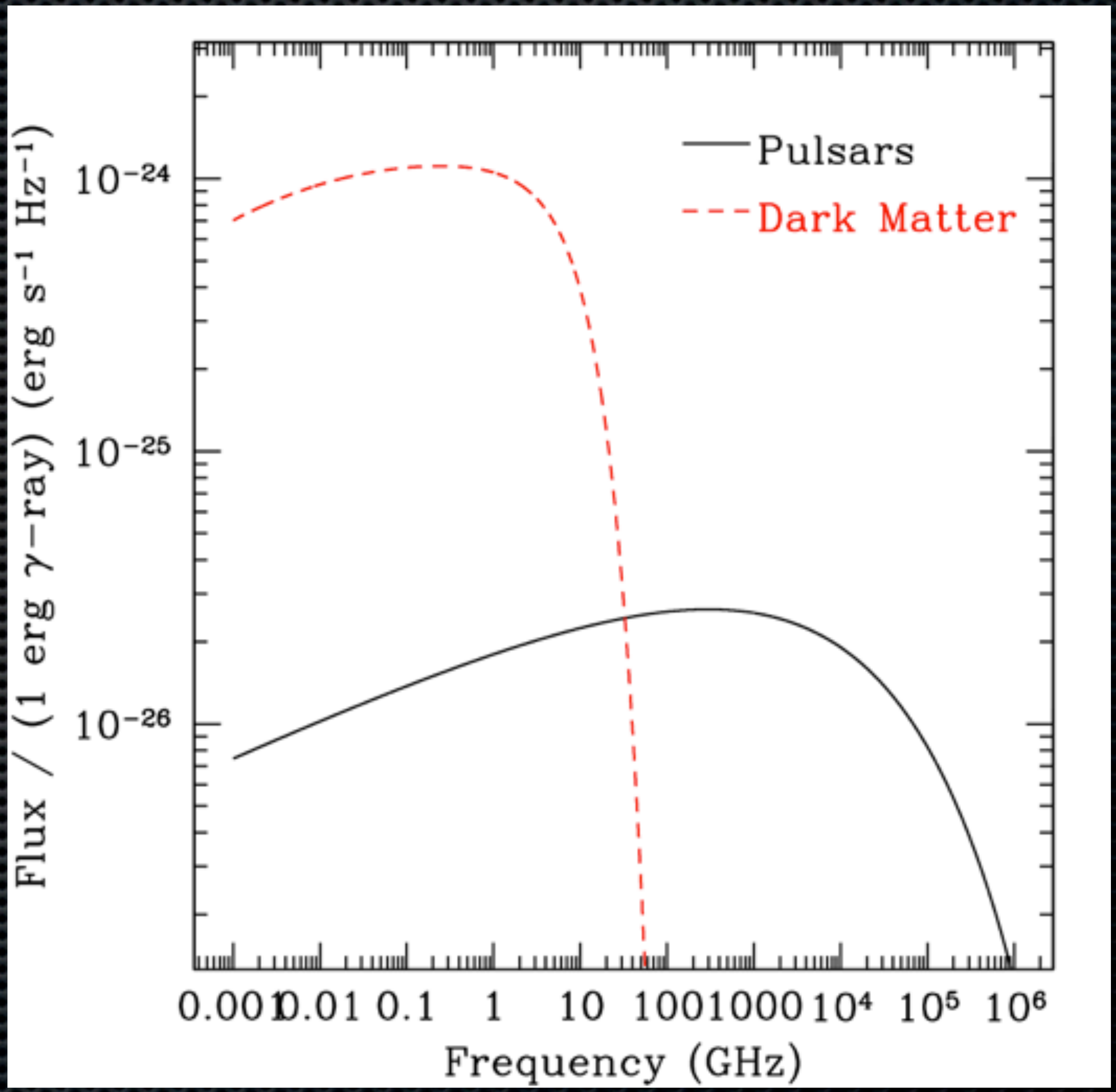
Conclusions

- There is currently no accepted astrophysical explanation for the hard lepton spectrum necessary to explain the filamentary arcs
- Light dark matter provides a natural explanation for this lepton population, and additionally explains the spectral similarities and radial symmetry of NRF emission
- The prediction is easily falsifiable and warrants observational tests

Extra Slides

Synchrotron Observations

- Sources that appear identical in γ-rays may have different synchrotron signatures
- One example is MSPs vs. Dark Matter (Abazajian 2011)

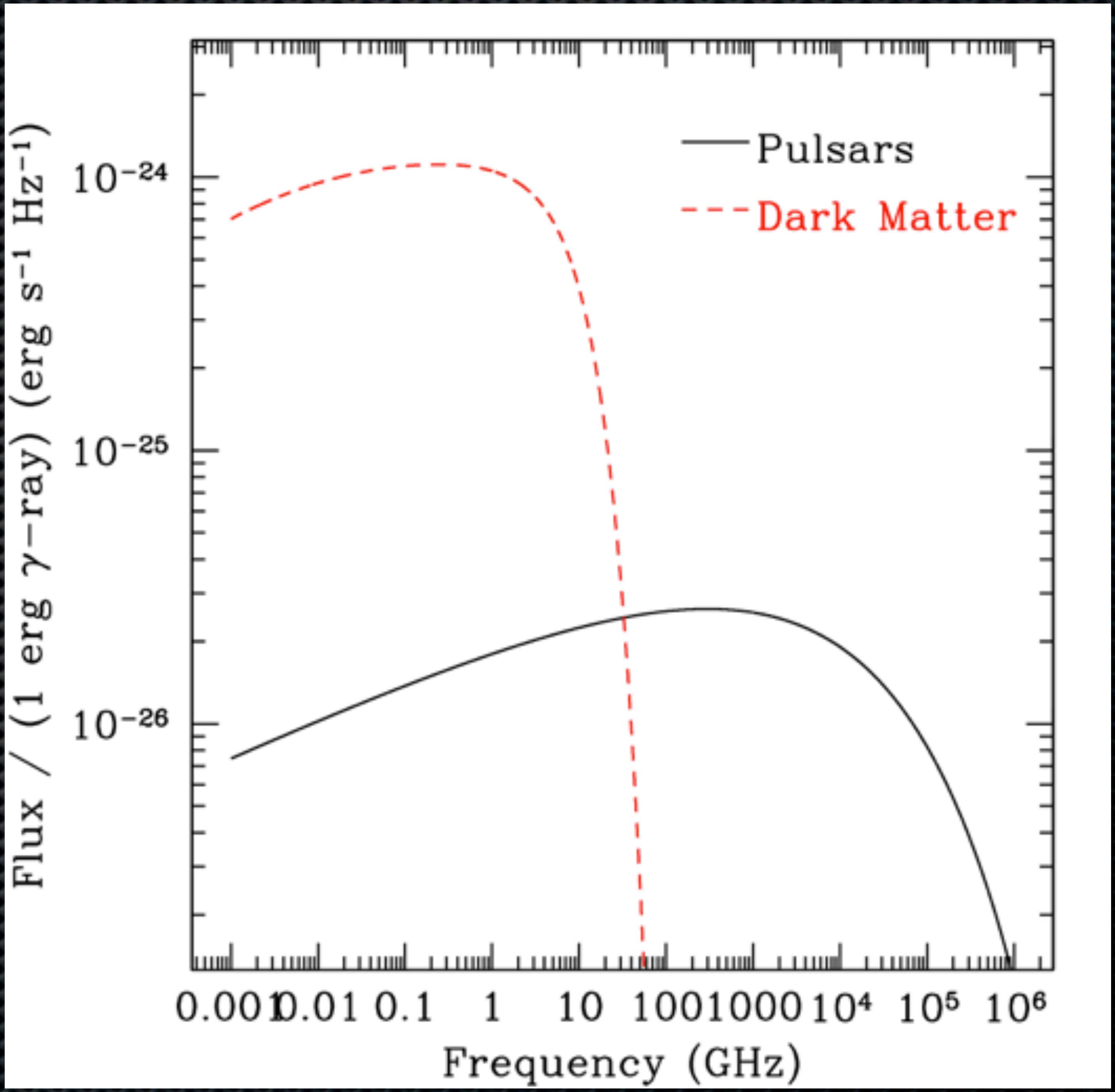


8 GeV democratic Dark Matter

Pulsar e^+e^- α $E^{-1.5}$ exp(-E/1 TeV); Efficiency = 10%

Synchrotron Observations

- Tradeoff:
  - Synchrotron observations have higher angular resolution
  - Must worry about cosmic ray propagation



Considerable problem