Dark Matter and the Galactic Center Radio Filaments

Tim Linden

with Dan Hooper[1] and Farhad Yusef-Zadeh[2]

Fermi National Accelerator Laboratory
and
University of California - Santa Cruz

1) FNAL/U Chicago
2) Northwestern

2011 Fermi Symposium

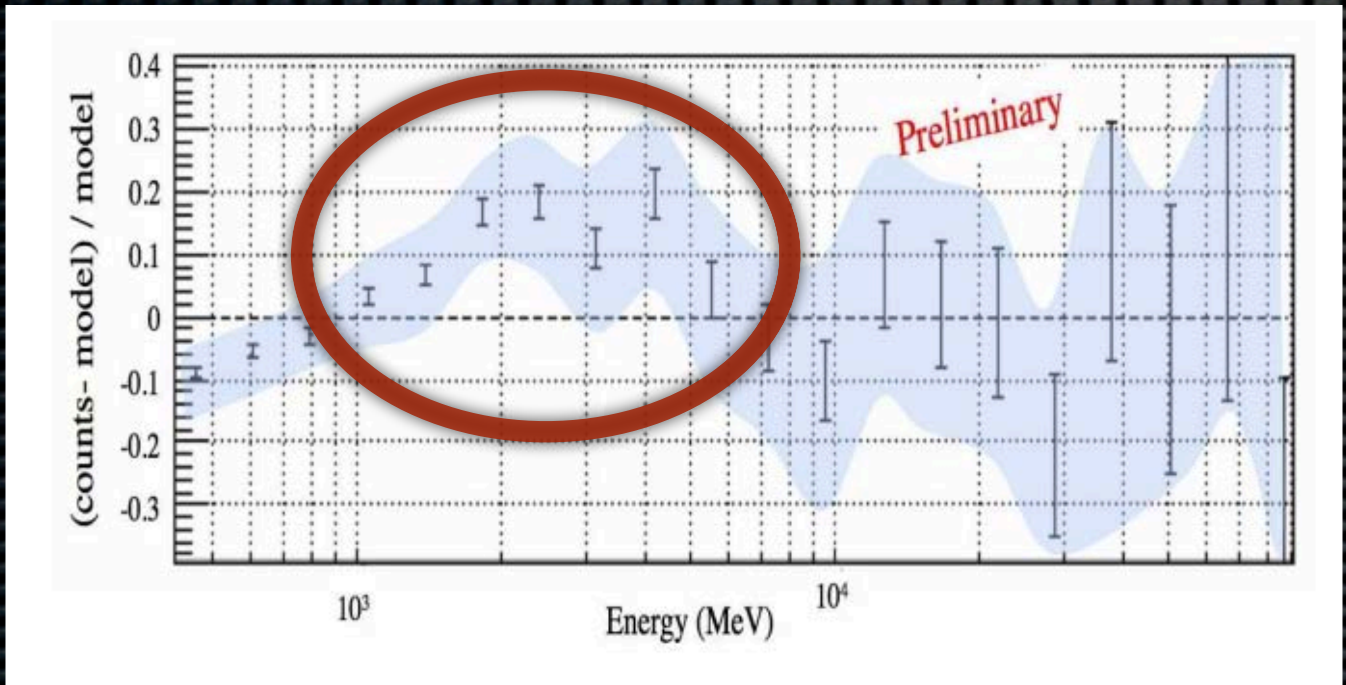
May 10, 2011

Introduction

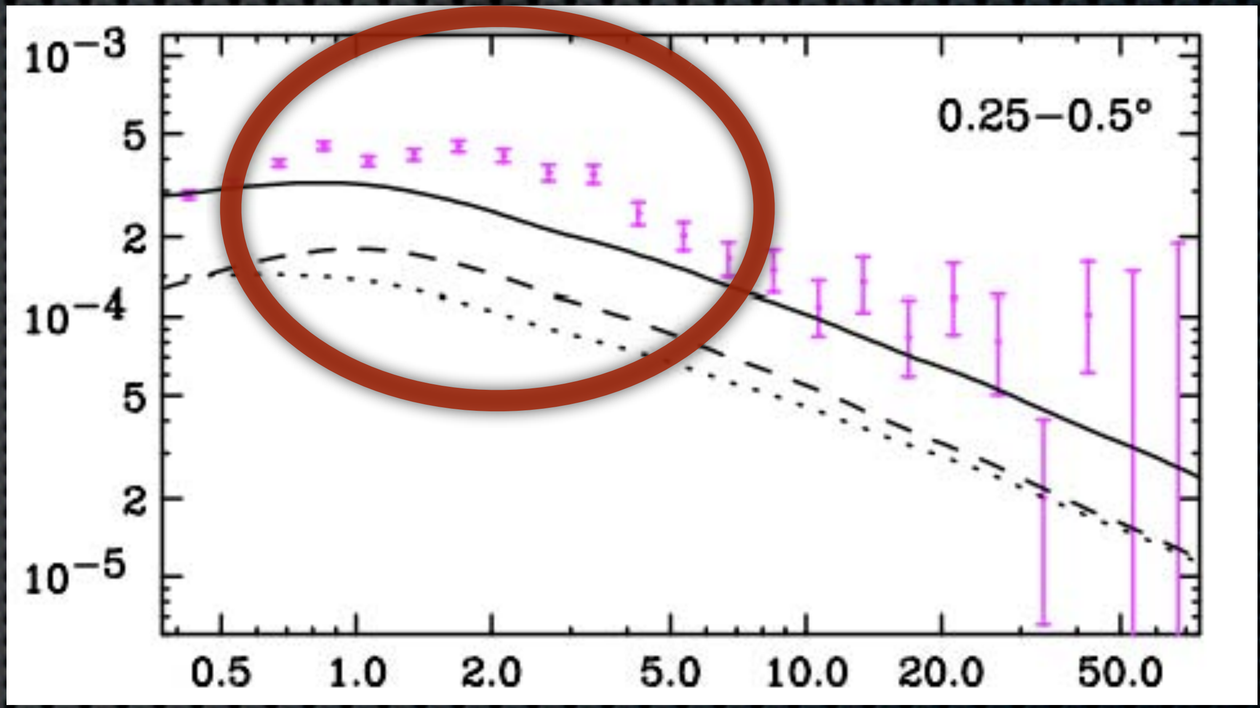
- γ-rays and synchrotron in the galactic center
- Non-thermal radio filaments in the Galactic Center
- Dark matter spectrum in the filamentary arcs
- Models of specific filaments
- Conclusions and Future Tests

Fermi Galactic Center Observations

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



Vitale, Morselli et al. (2009)



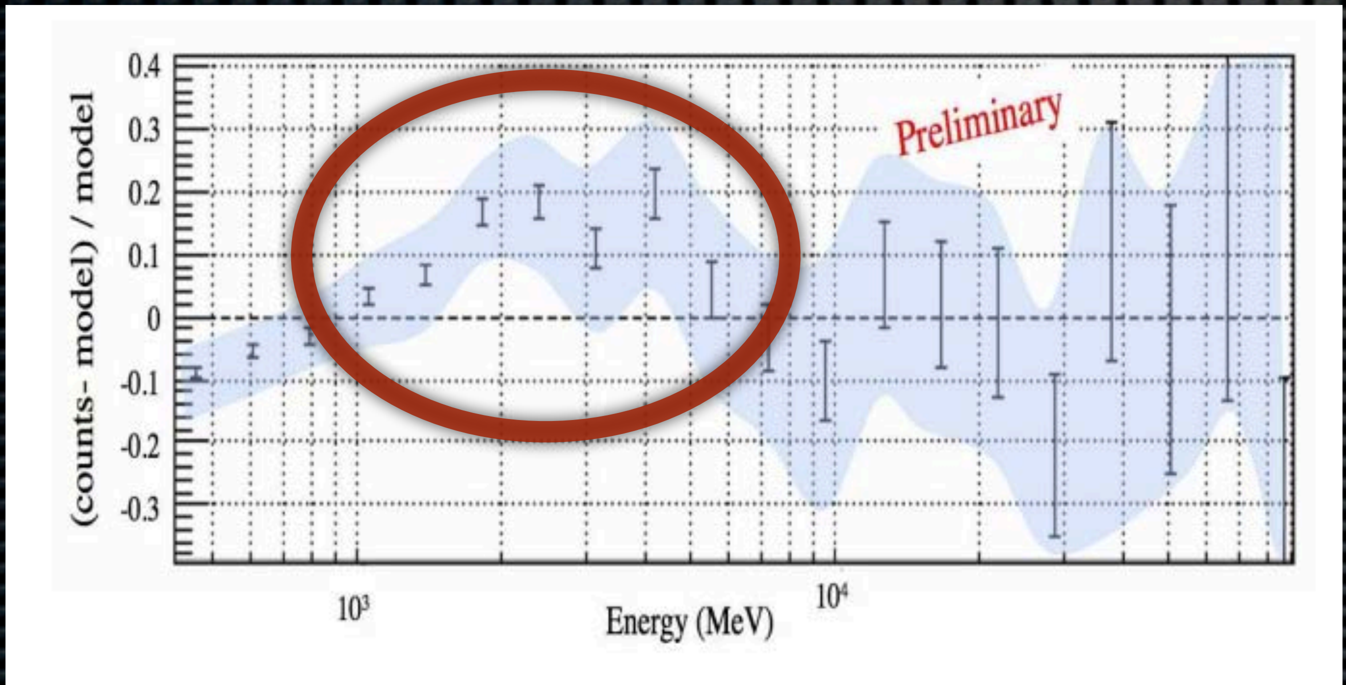
Hooper & Goodenough (2011)

For alternate view see poster by Canãdas et al

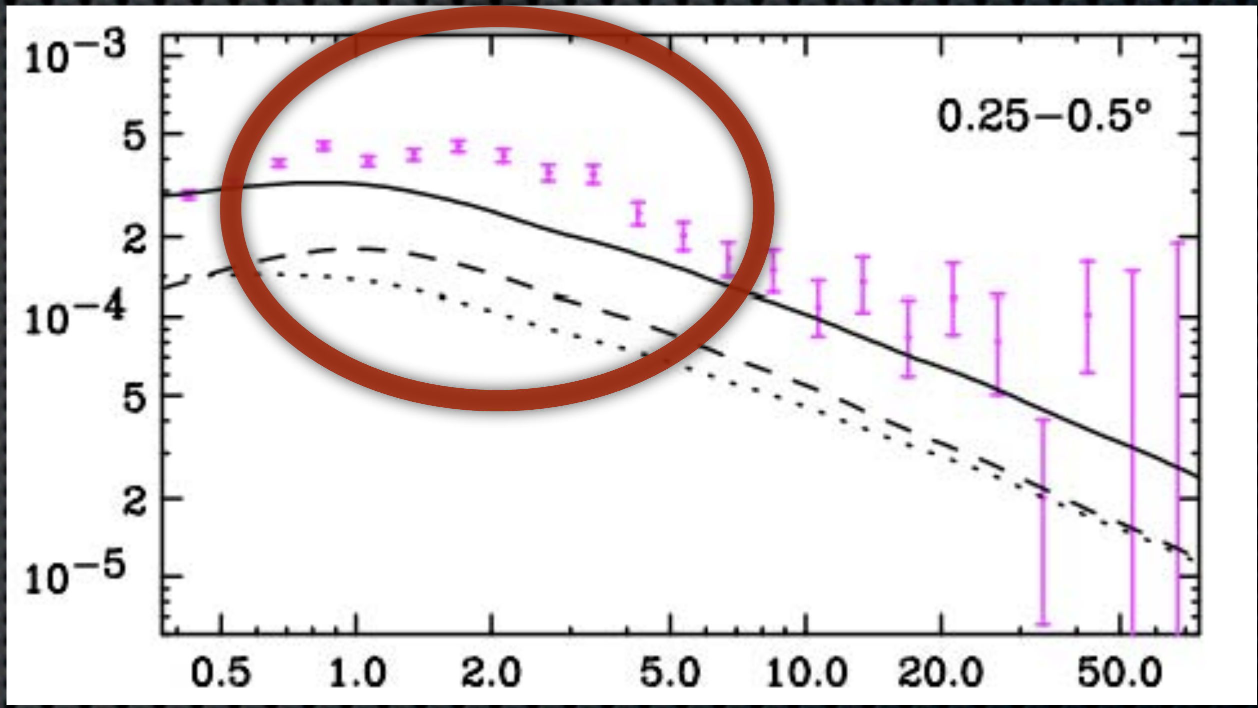
Tim Linden - 5/10/11

Fermi Galactic Center Observations

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



Vitale, Morselli et al. (2009)



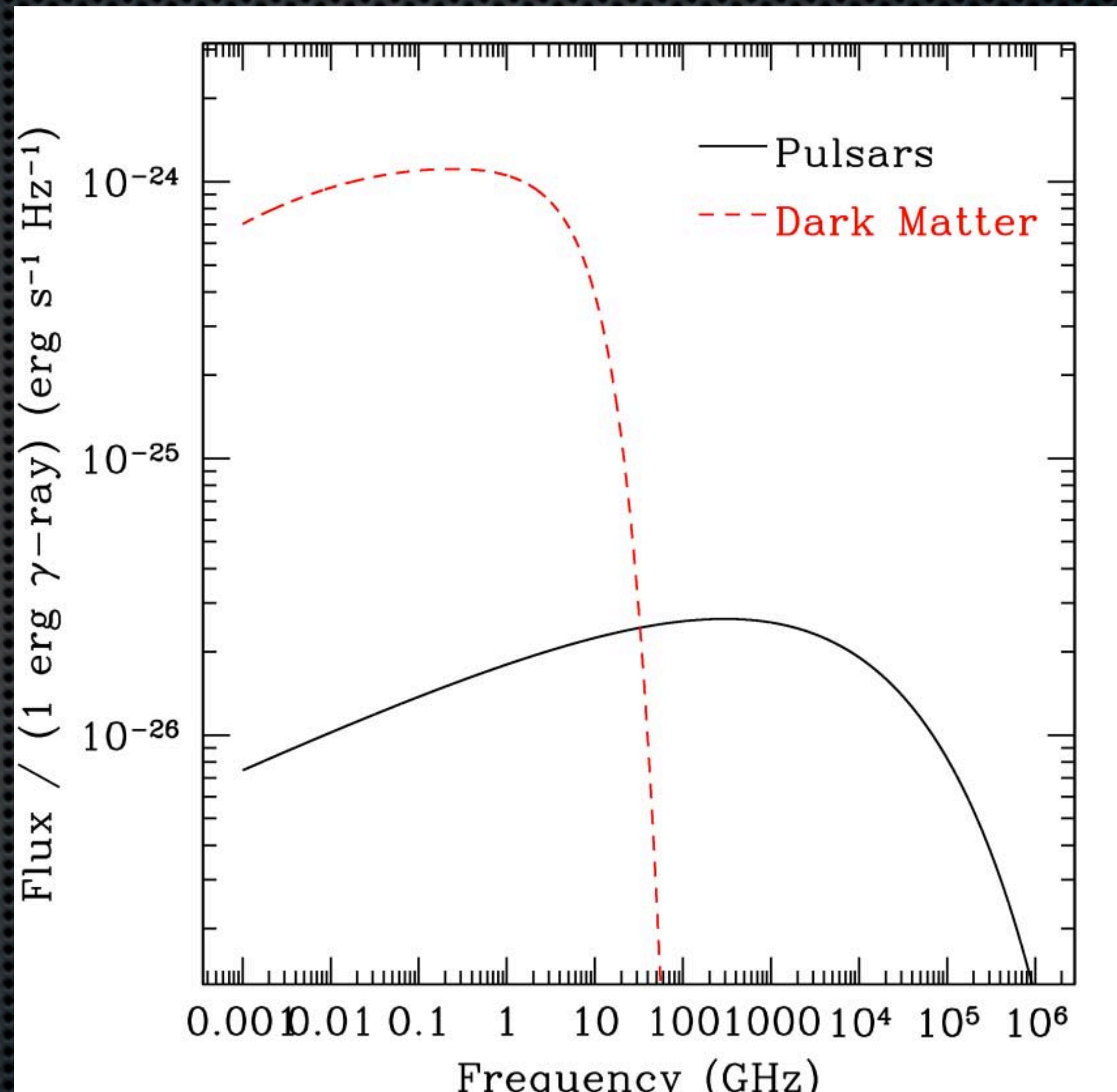
Hooper & Goodenough (2011)

Can we observe this at radio frequencies?

Tim Linden - 5/10/11

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

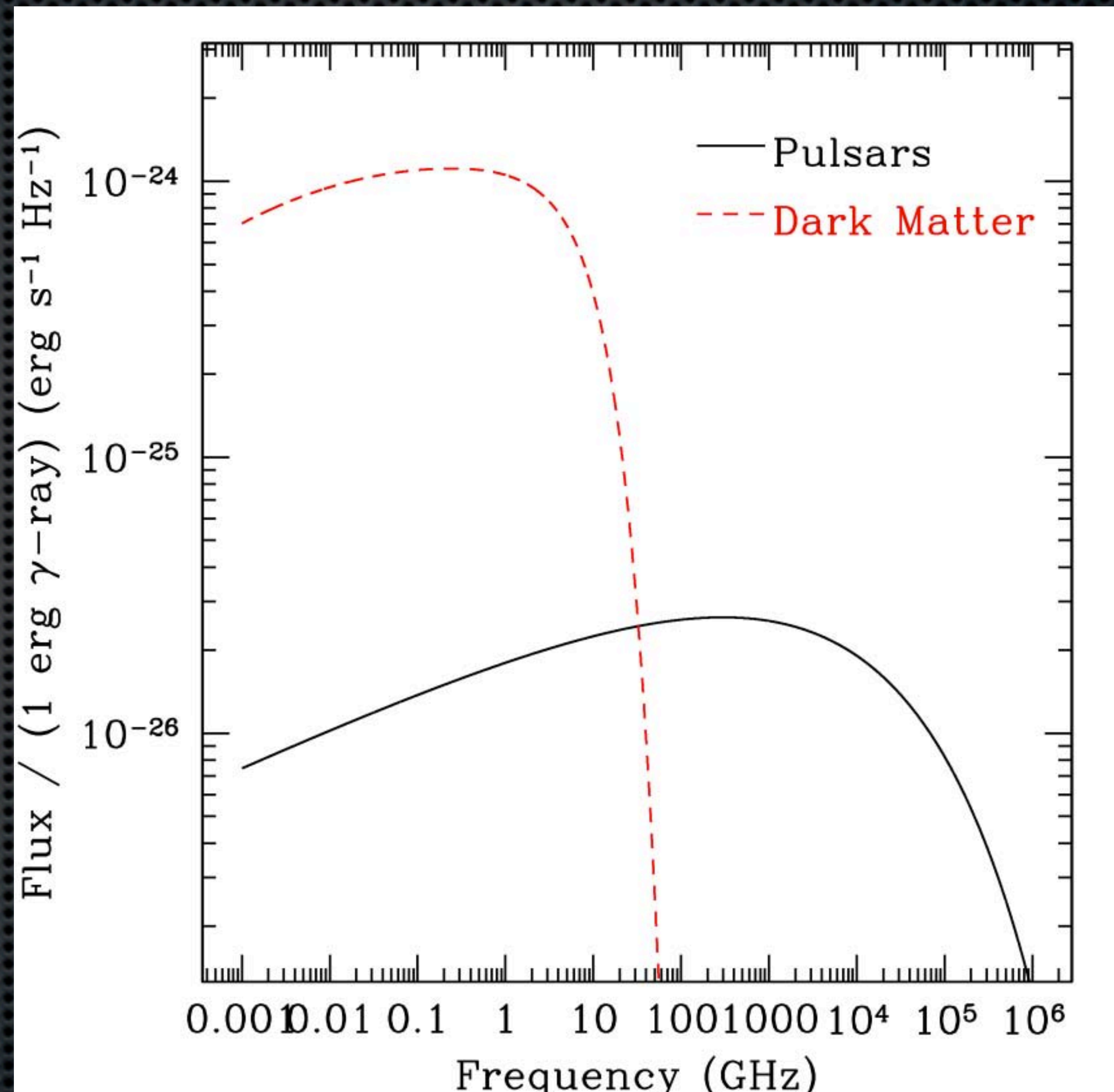
Pulsar $e^+e^- \propto E^{-1.5}$ exp(-E/1 TeV); Efficiency = 10%

Tim Linden - 5/10/11

Synchrotron Observations

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

Considerable problem



Tim Linden - 5/10/11

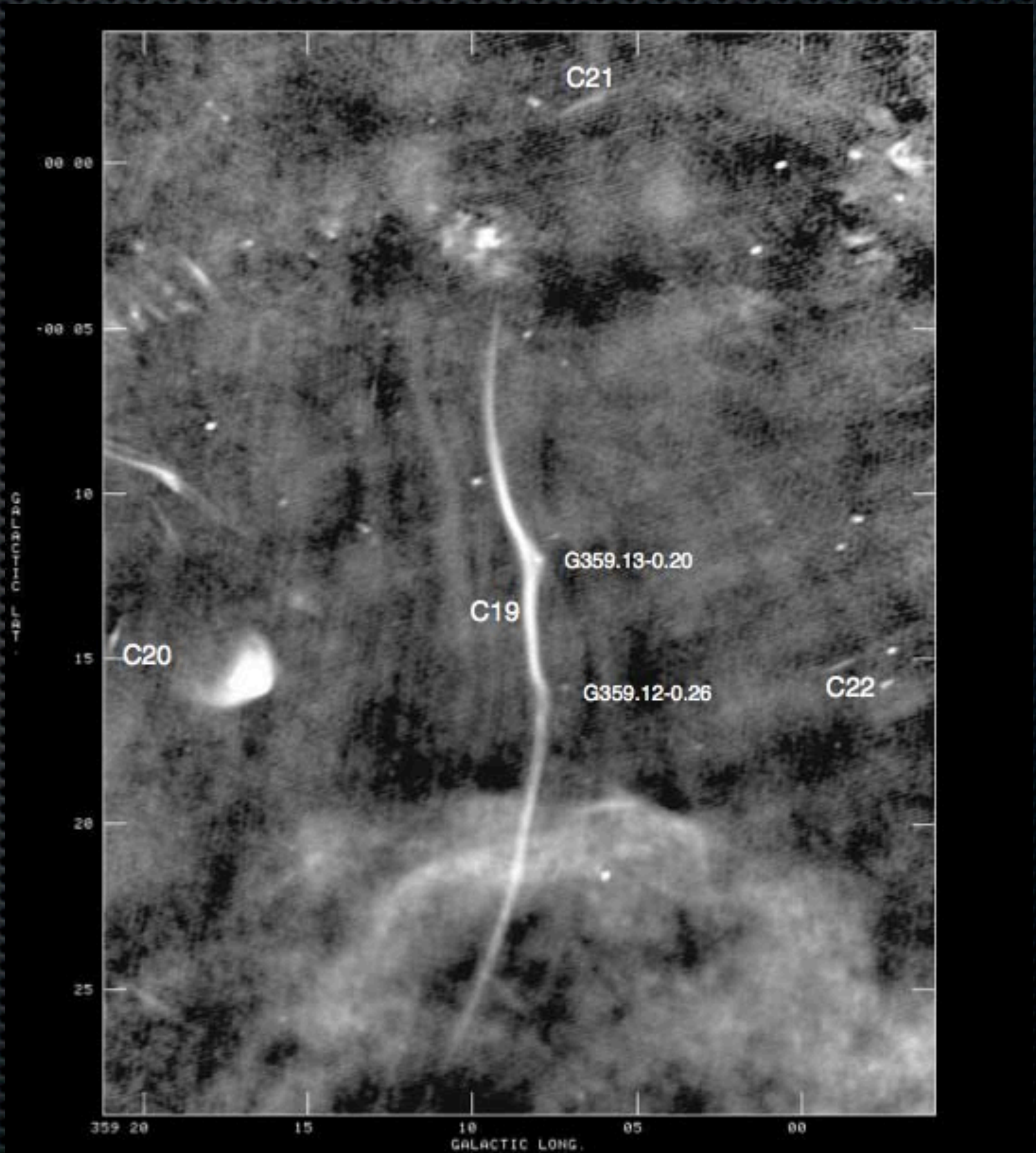
Non-Thermal Radio Filaments

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

B_{tot} ~ 50-1000 μG

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

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



Yusef-Zadeh et al. 2004

Tim Linden - 5/10/11

Non-Thermal Radio Filaments

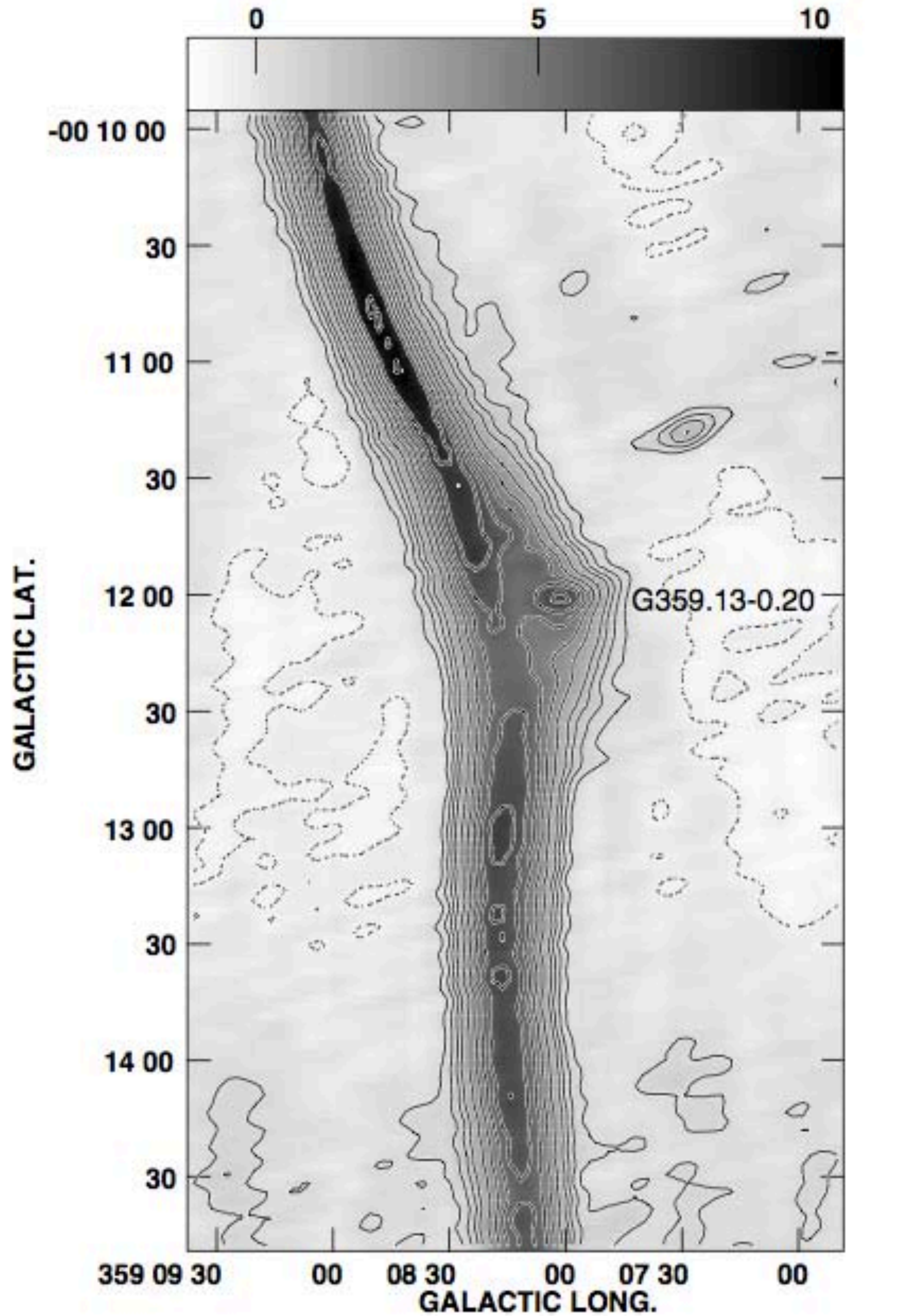
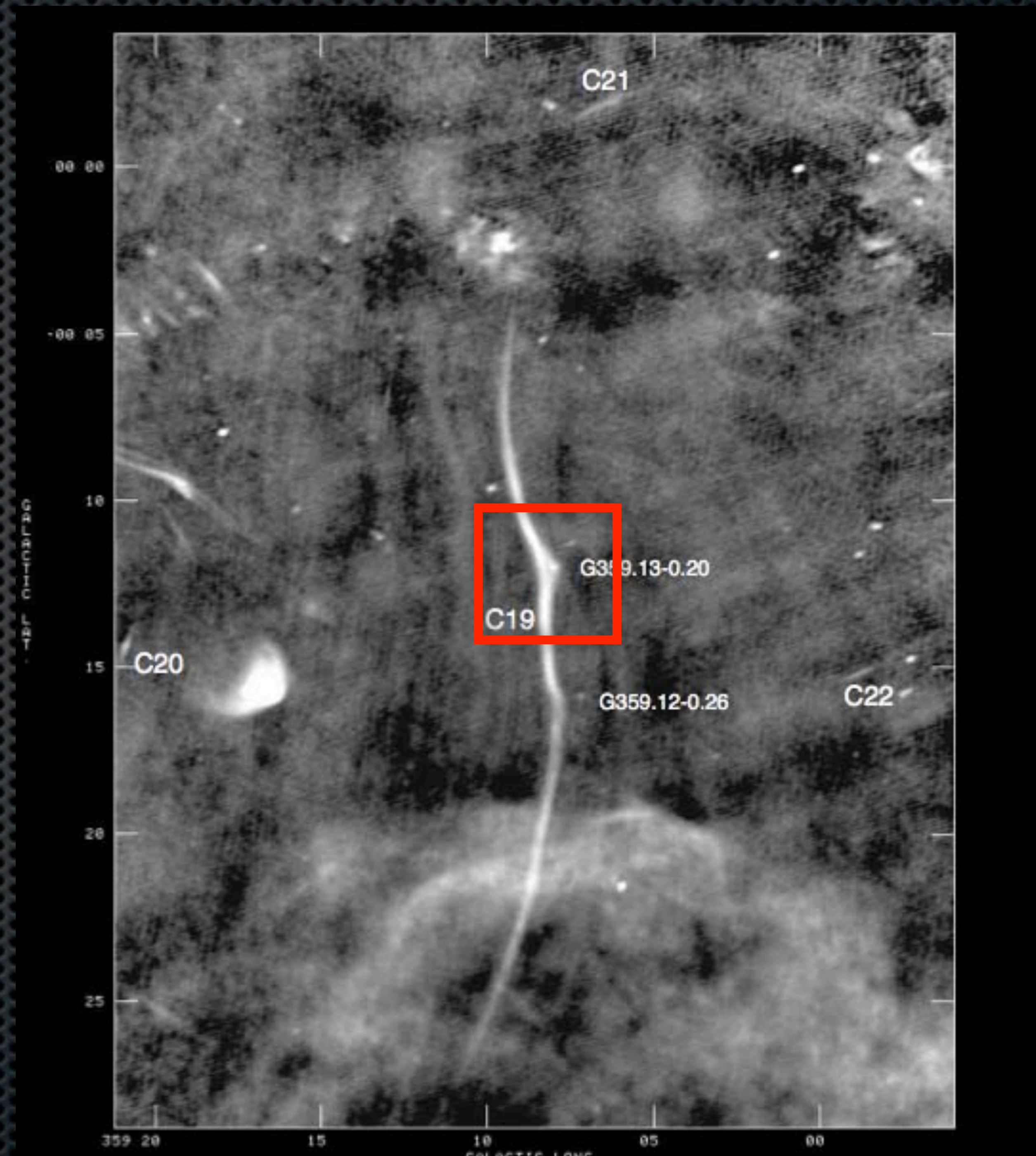


FIG. 12m



Yusef-Zadeh et al. 2004

Tim Linden - 5/10/11

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

Astrophysical shock has p > 2
α > 0.5

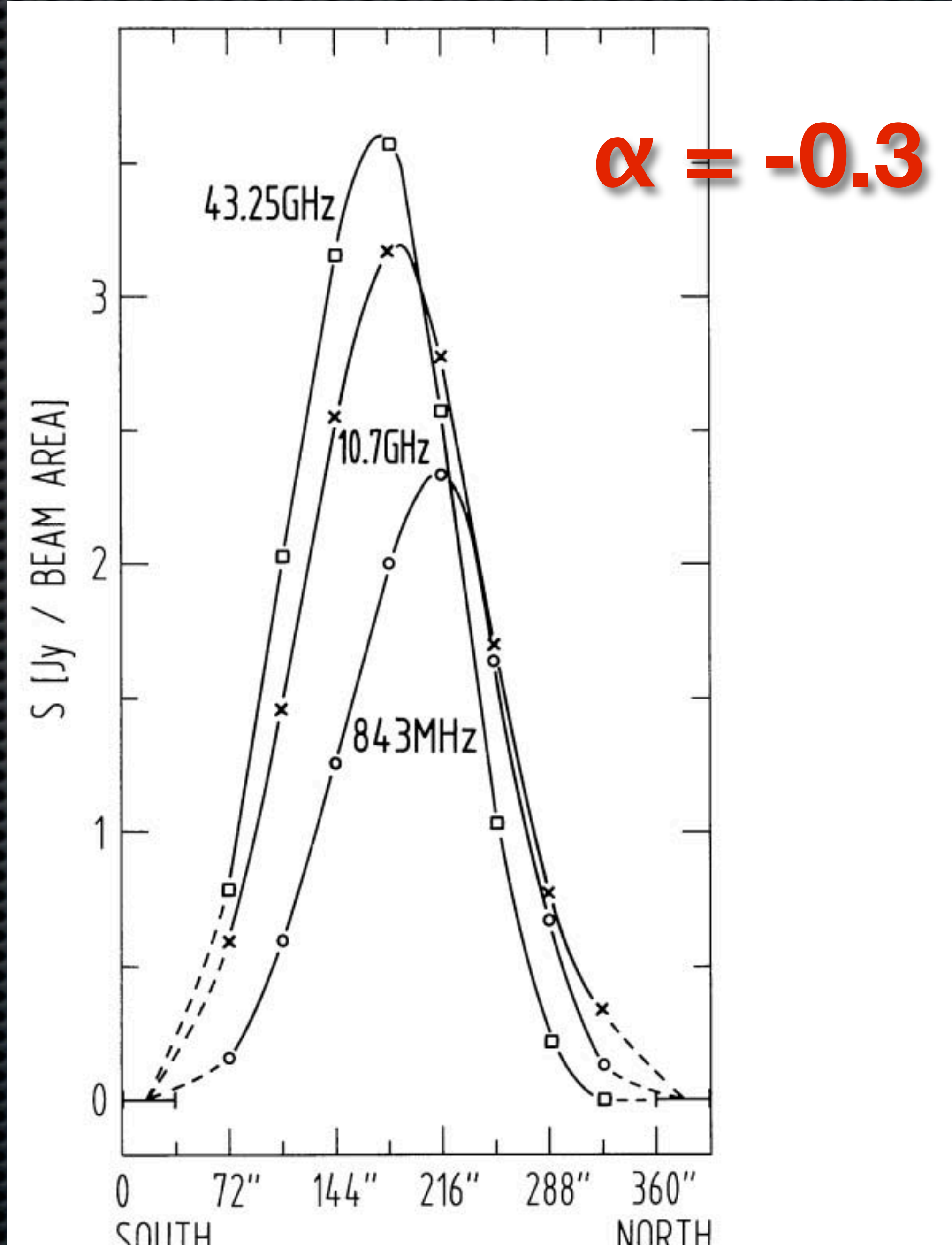


Fig. 10. Average cross cut of the Arc region as obtained by averaging the data at 843 MHz, 10.7 GHz and 43.25 GHz of the field indicated in Fig. 1

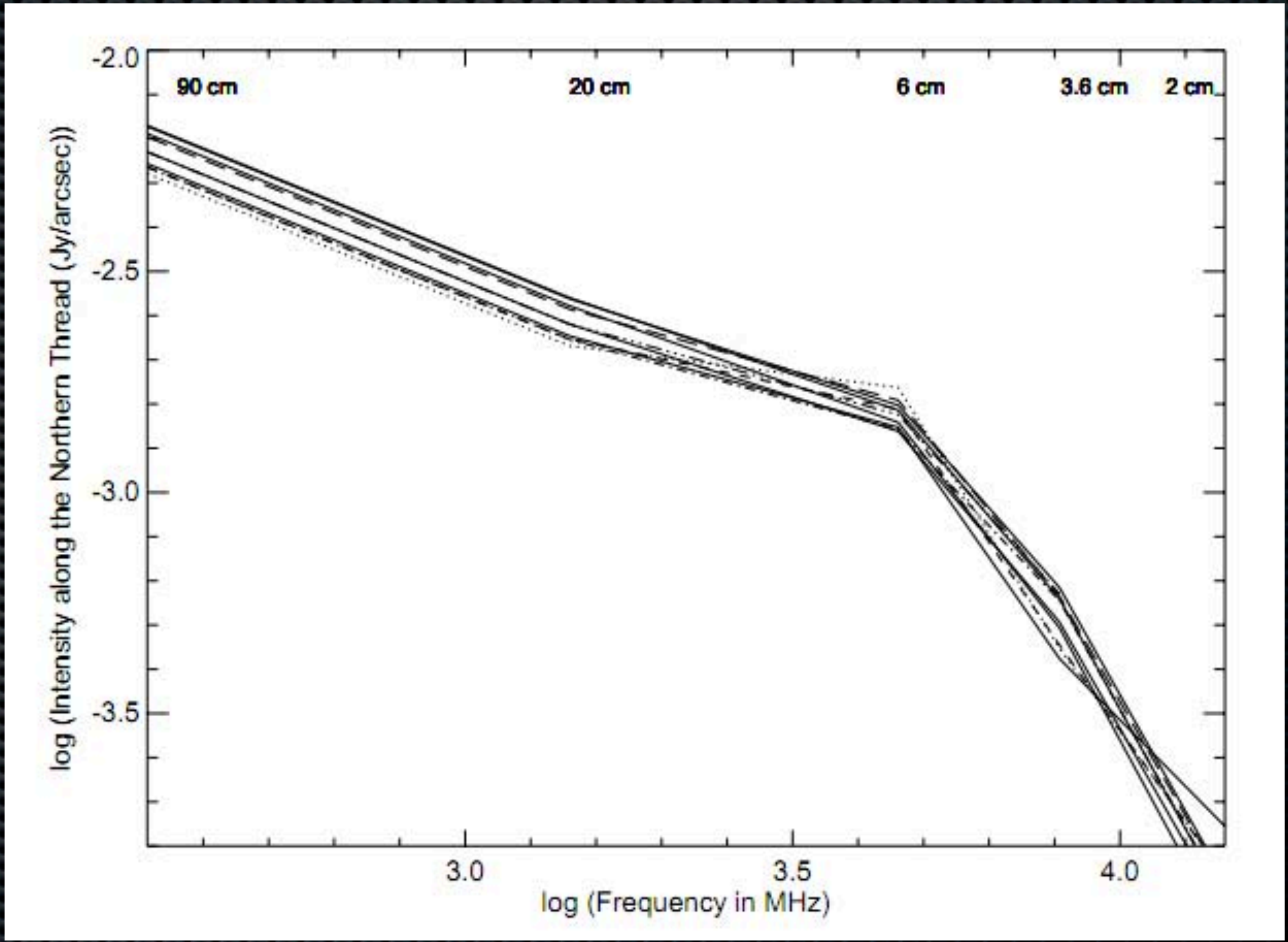
Radio Arc

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



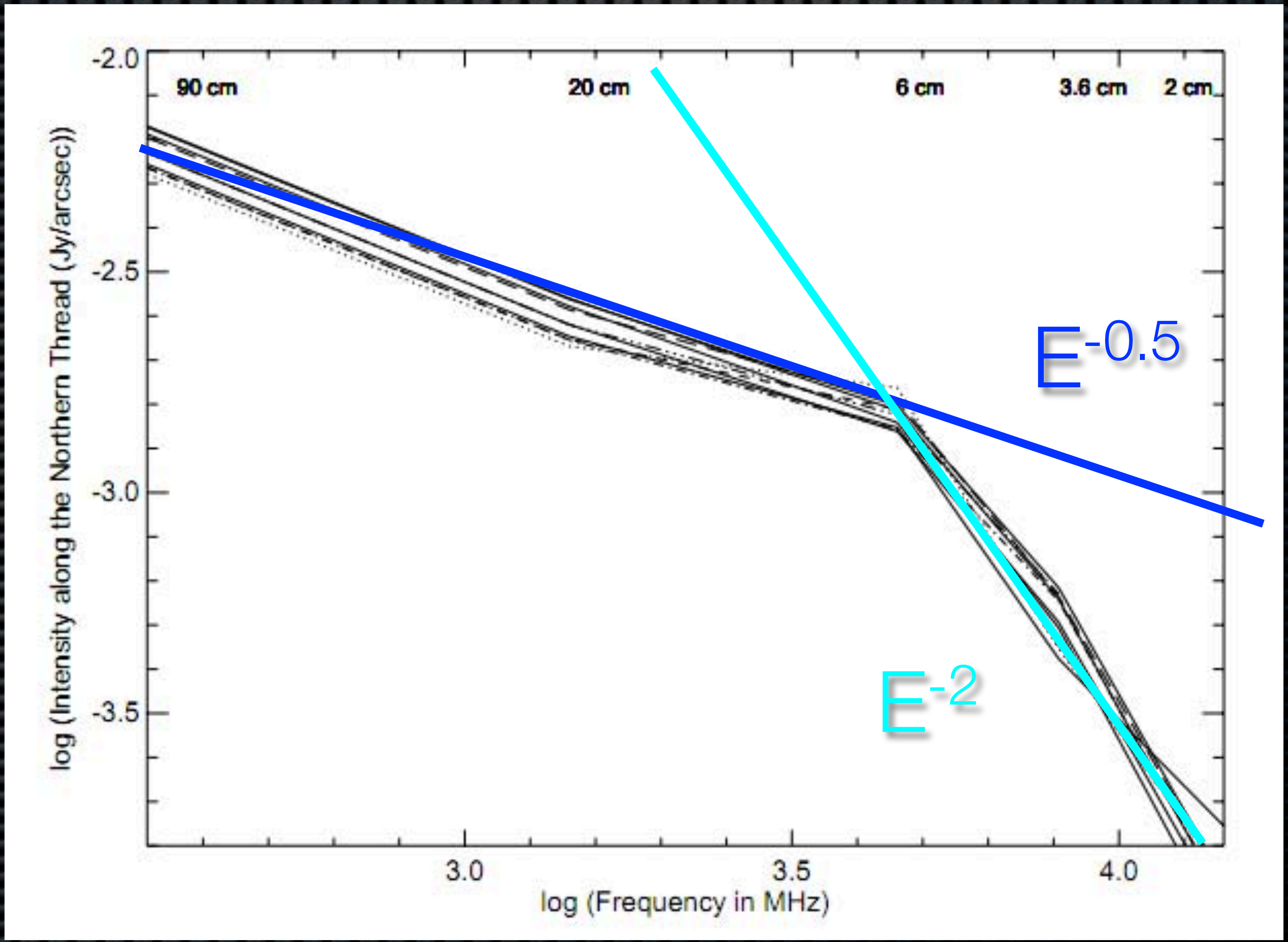
Lang et al. 1999

Tim Linden - 5/10/11

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

Tim Linden - 5/10/11

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 ± 0.64

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

Tim Linden - 5/10/11

Non-Thermal Radio Filaments

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

H. Lesch[1,2,3] and W. Reich[1]

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, W-5300 Bonn 1, Federal Republic of Germany
[2] Department of Astronomy, University of Toronto, 60 St. George Street, Toronto M5S 1A1, Canada
[3] Canadian Institute for Theoretical Astrophysics, University of Toronto, Toronto M5S 1A1, Canada

Received February 27, accepted June 11, 1992

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)

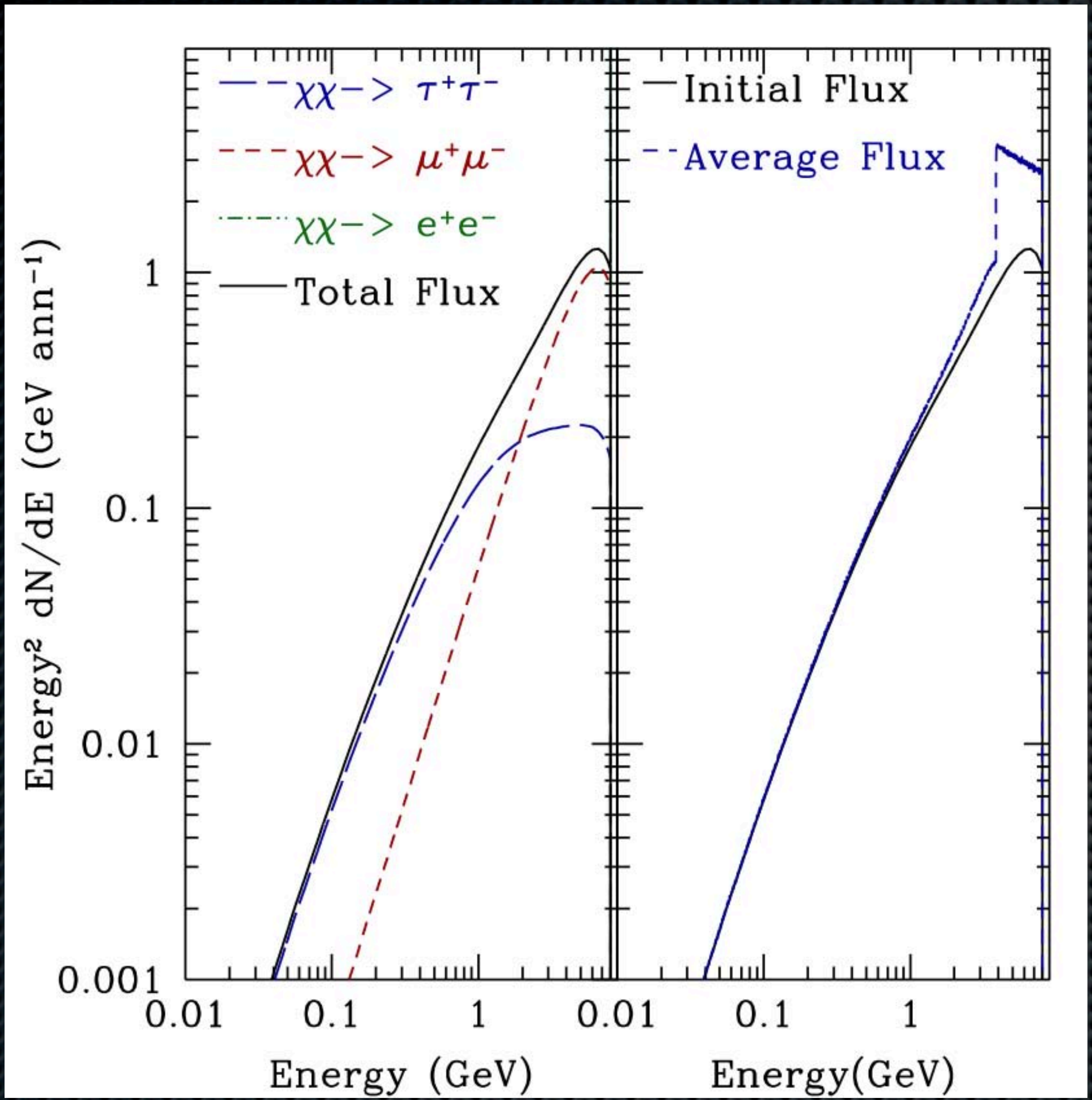
$$t_{syn} \simeq \frac{5 \cdot 10^8}{\gamma B^2} \simeq 7 \cdot 10^3 \text{ years} \left[\frac{\gamma}{2 \cdot 10^3}\right]^{-1} \left[\frac{B}{10^{-3}\,\text{Gauss}}\right]^{-2}, \quad (1)$$

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

Lesch et al. 1988

Tim Linden - 5/10/11

Dark Matter Lepton Spectrum

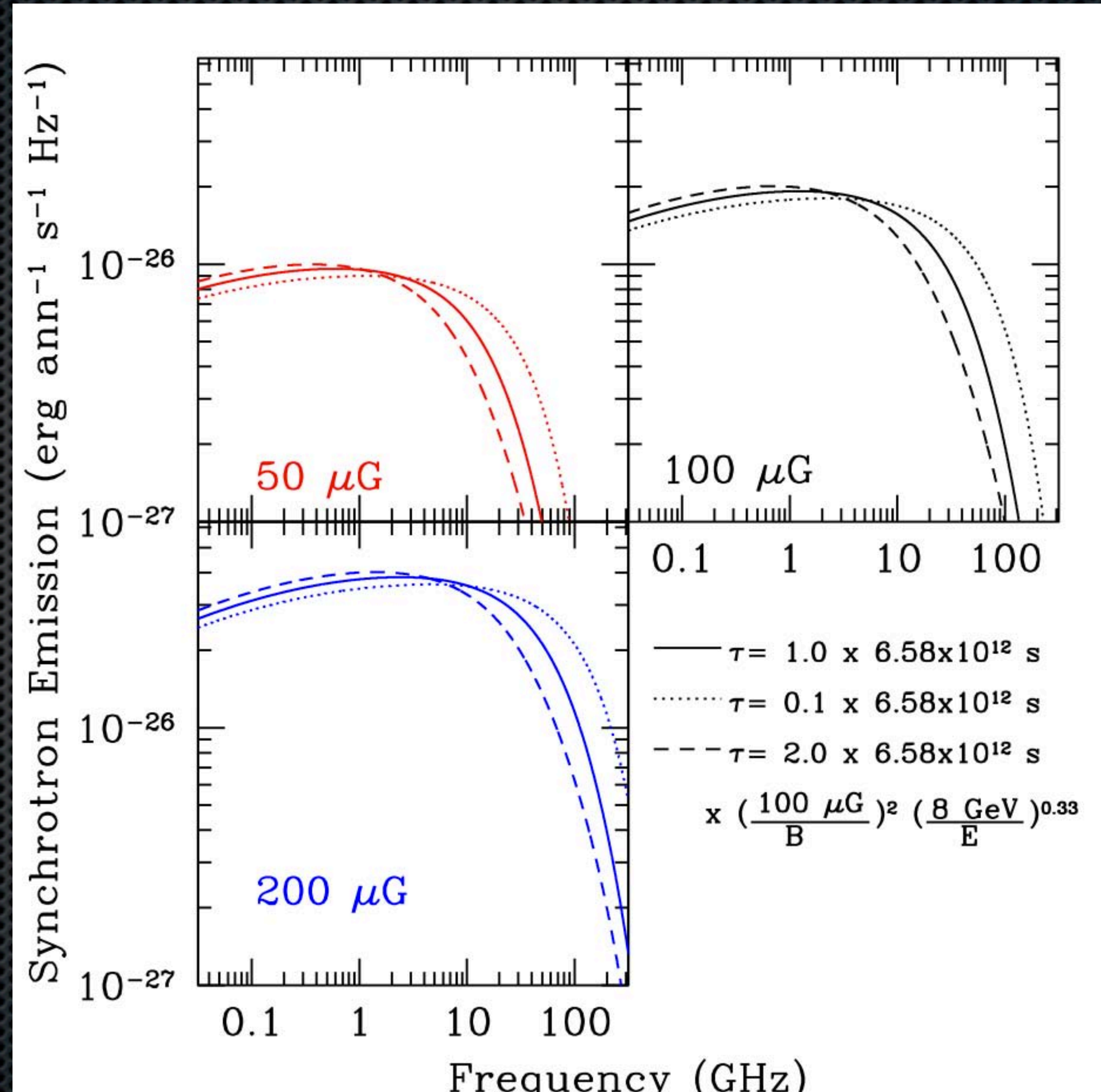


- Light dark matter model naturally produces ~ 8 GeV leptons
- Few adjustable parameters
- Ordered magnetic field may contain leptons for a significant time

Tim Linden - 5/10/11

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

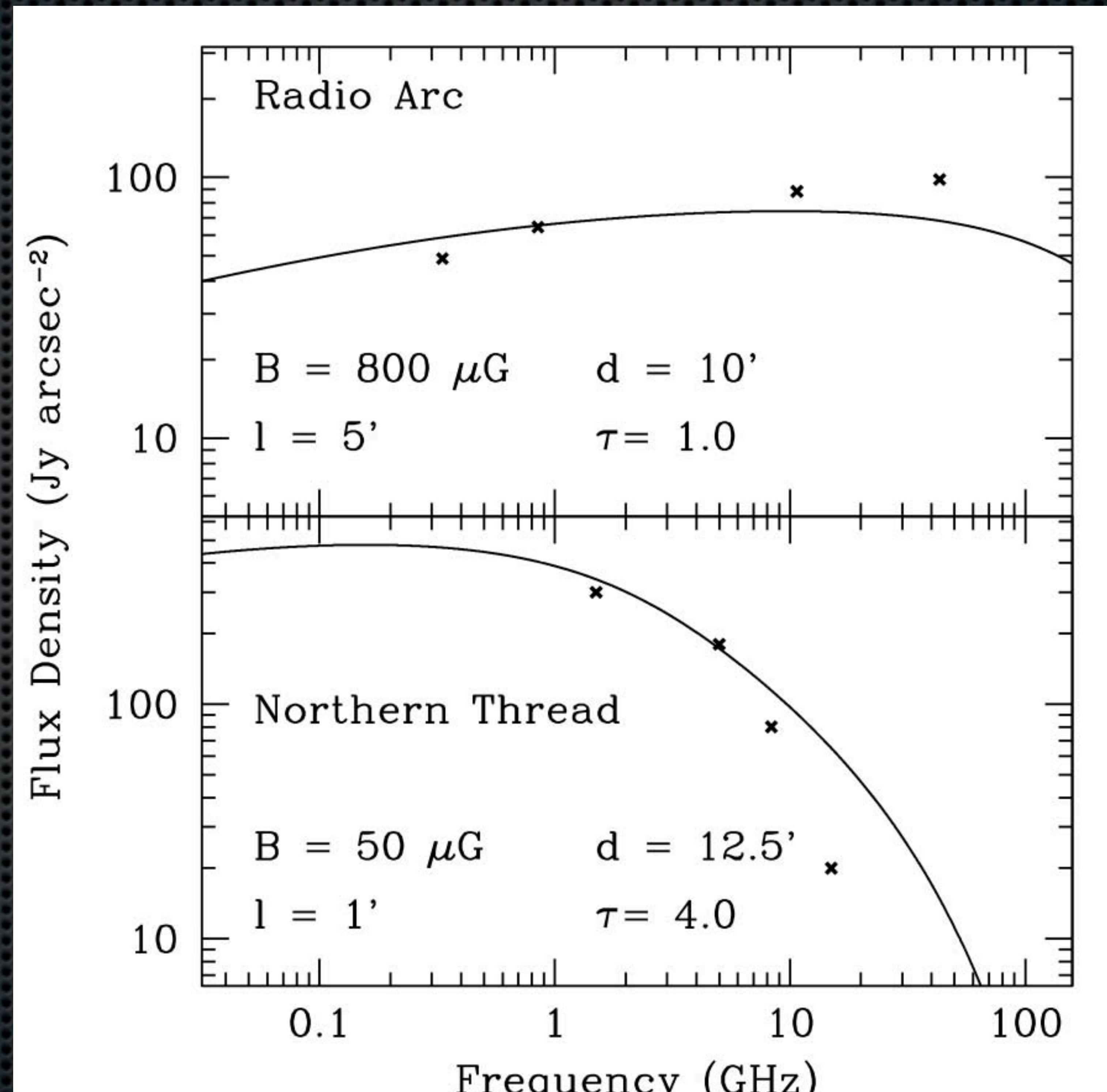


Tim Linden - 5/10/11

Comparison to Specific NRFs

Very Preliminary

- The same electron spectrum can explain the extremely and moderately hard spectra of the Radio Arc and Northern Thread



Tim Linden - 5/10/11

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

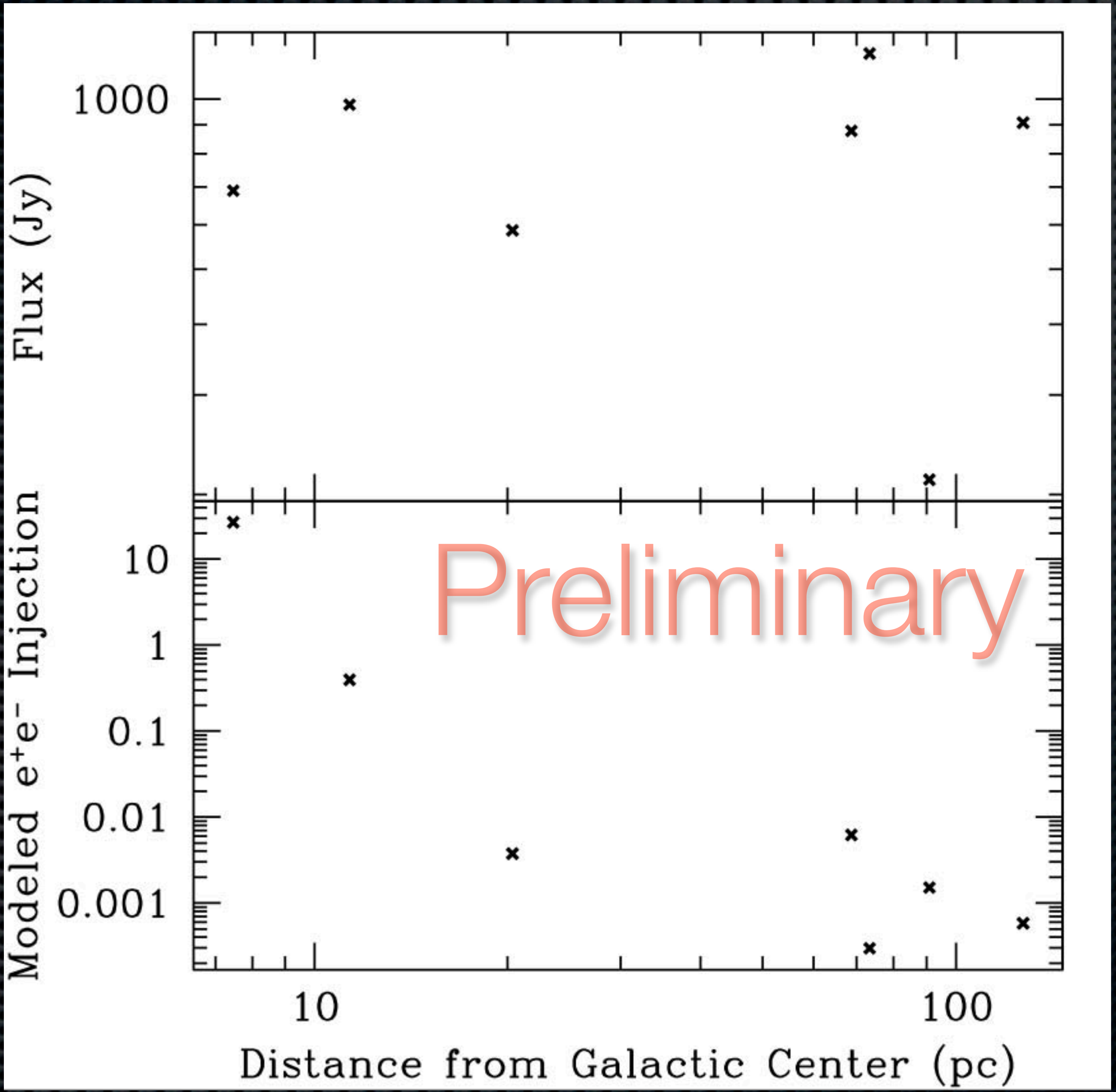
- There is currently no accepted astrophysical explanation for the hard lepton spectrum necessary to explain the filamentary arcs

- 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

Luminosity vs. GC Distance



Tim Linden - 5/10/11