Young Pulsars and the Galactic Center GeV Gamma-ray Excess

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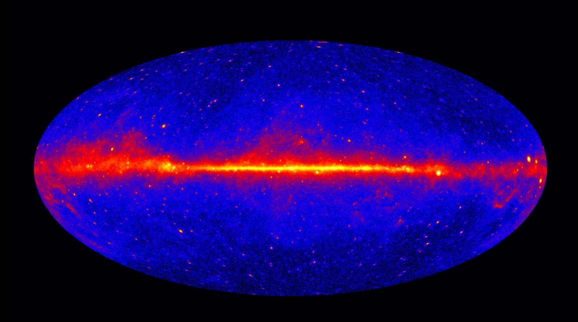
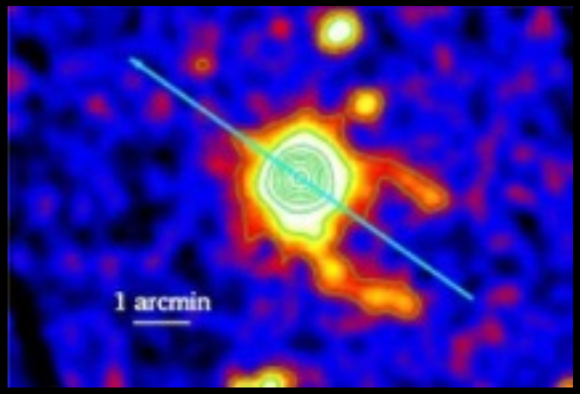
(JILA/CU Boulder)
with M. Kistler, M. Kerr, & J. Dexter

arXiv:1504.02477 + another soon

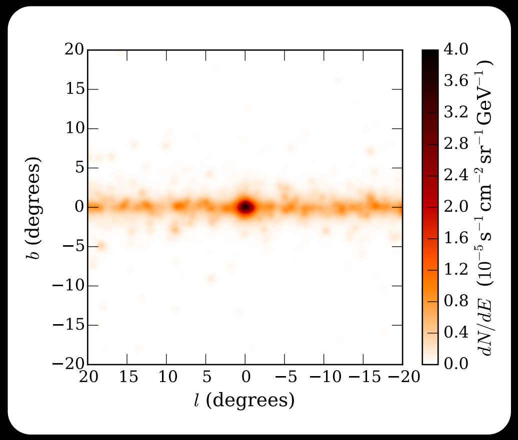
Outline



1) Motivate Pulsars

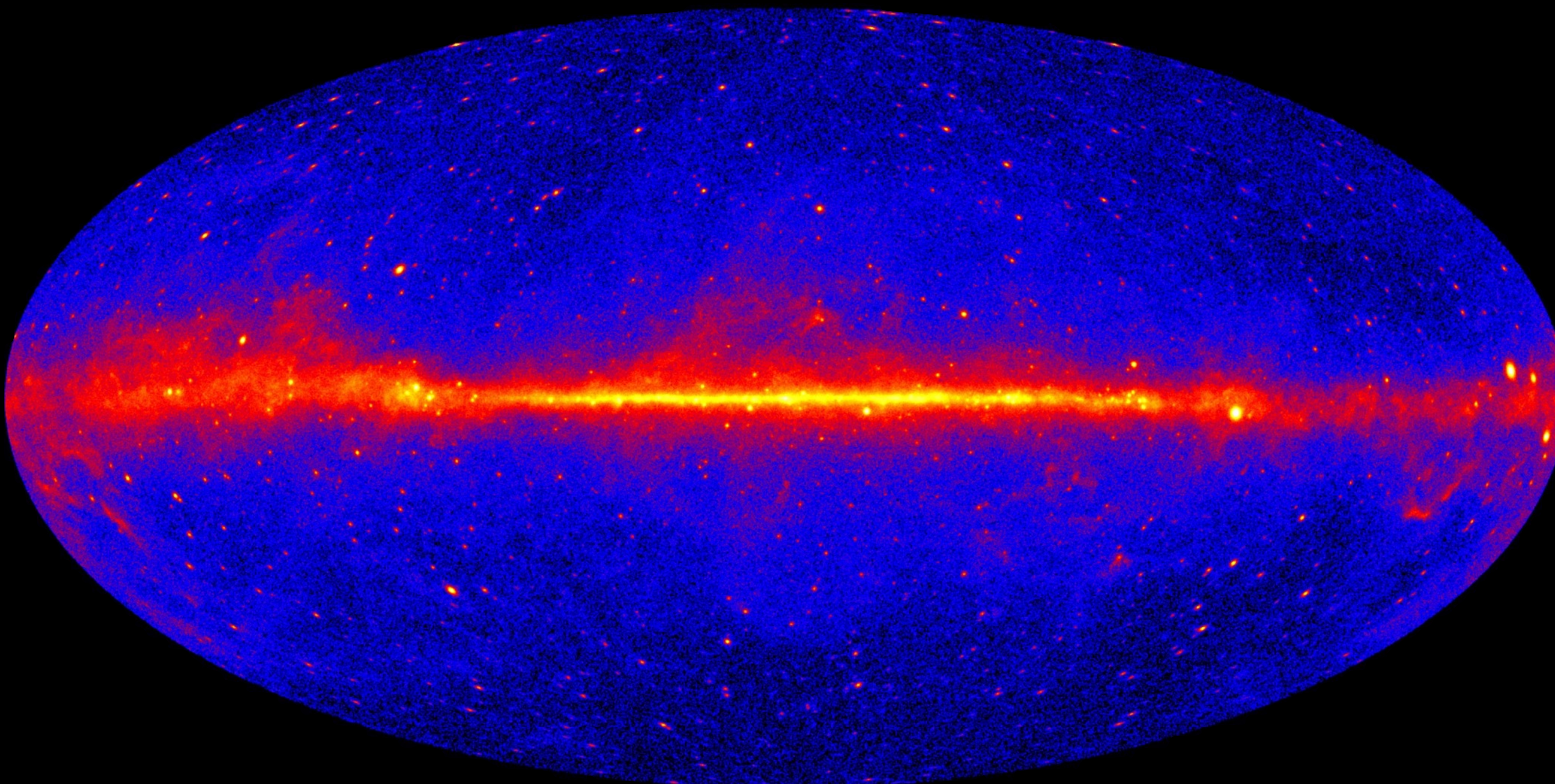


2) Gamma ray pulsar primer



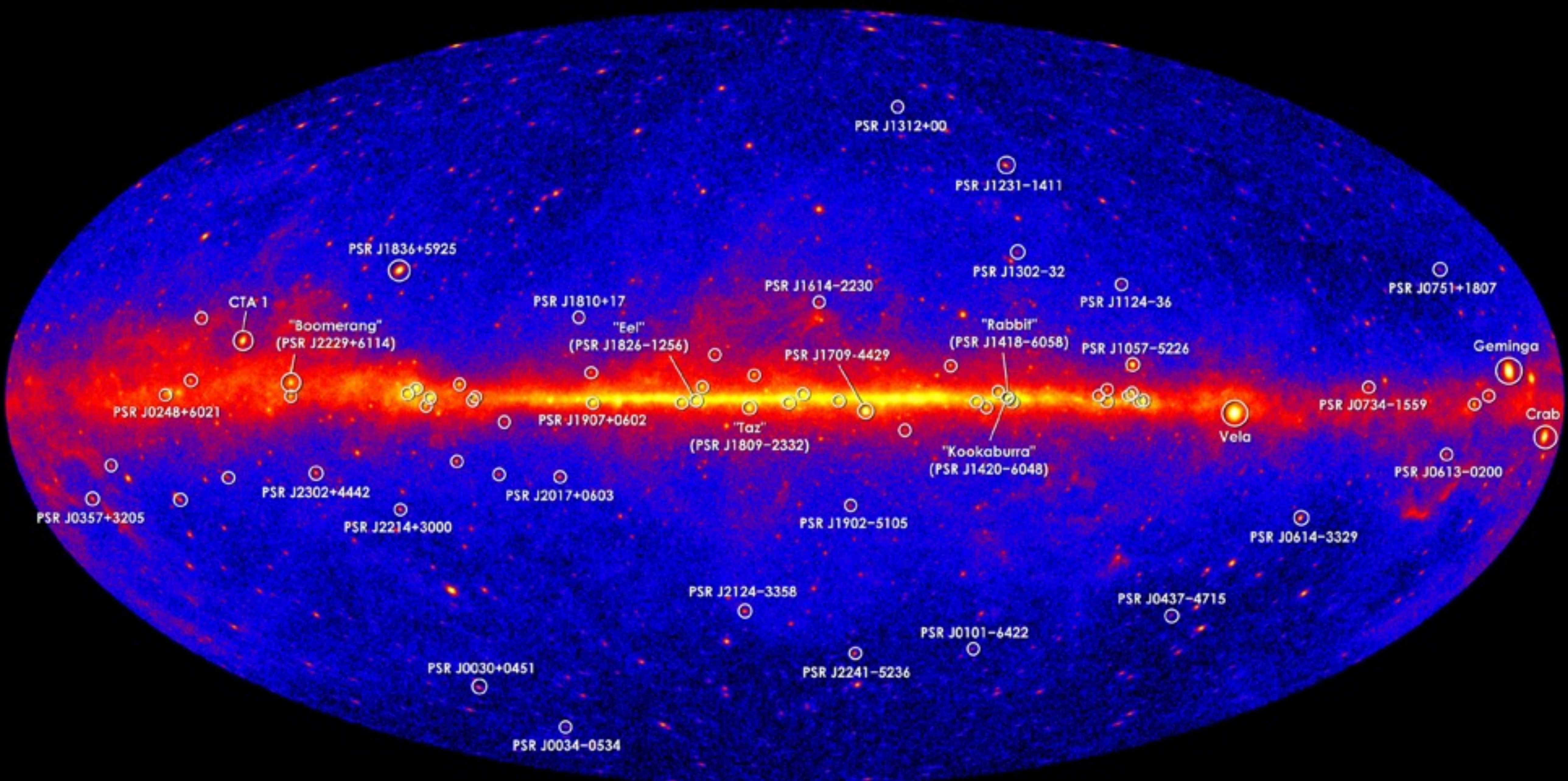
3) Population Synthesis Model & Results

Fermi's Gamma Ray Sky

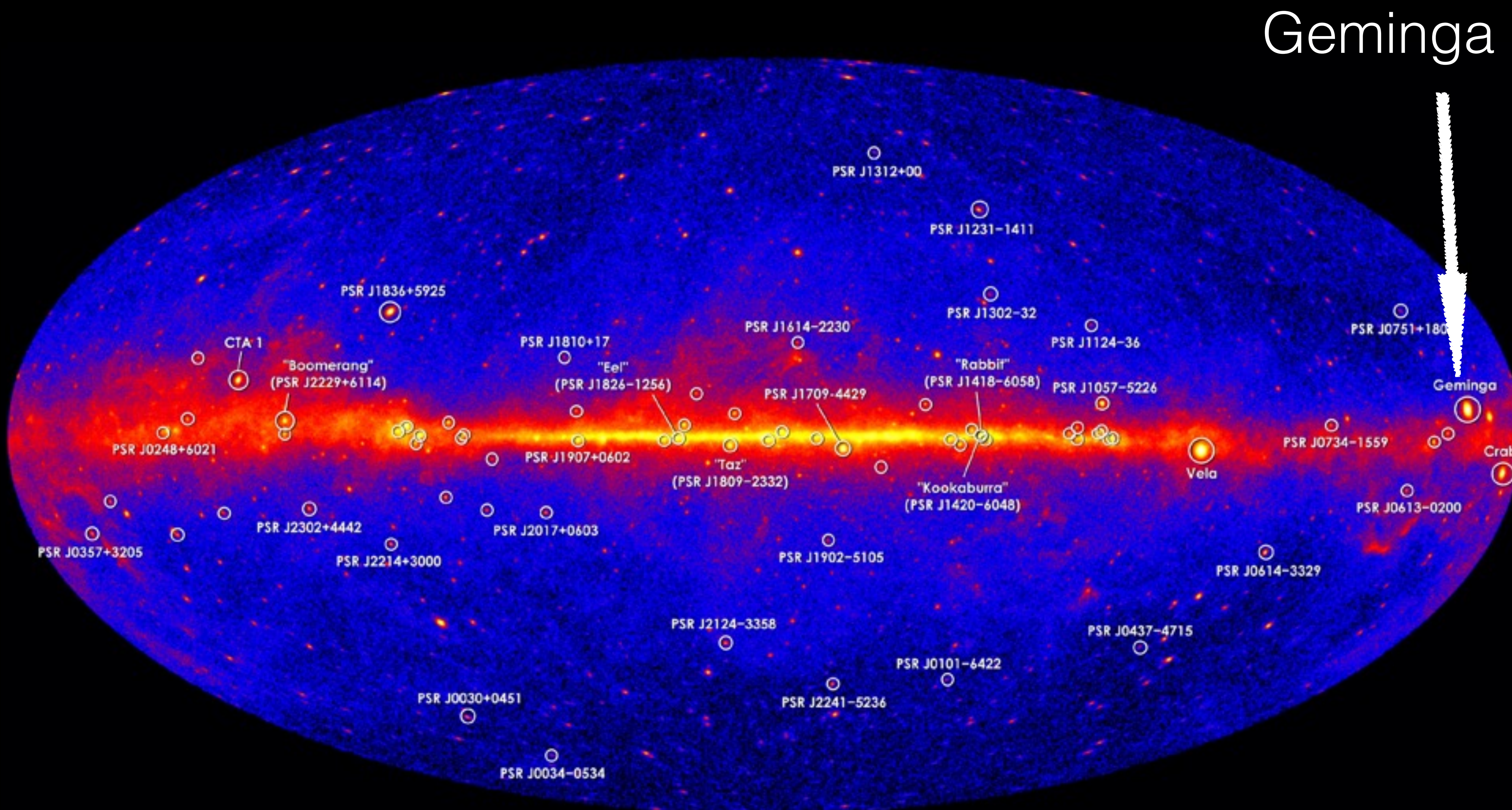


5 yr Fermi

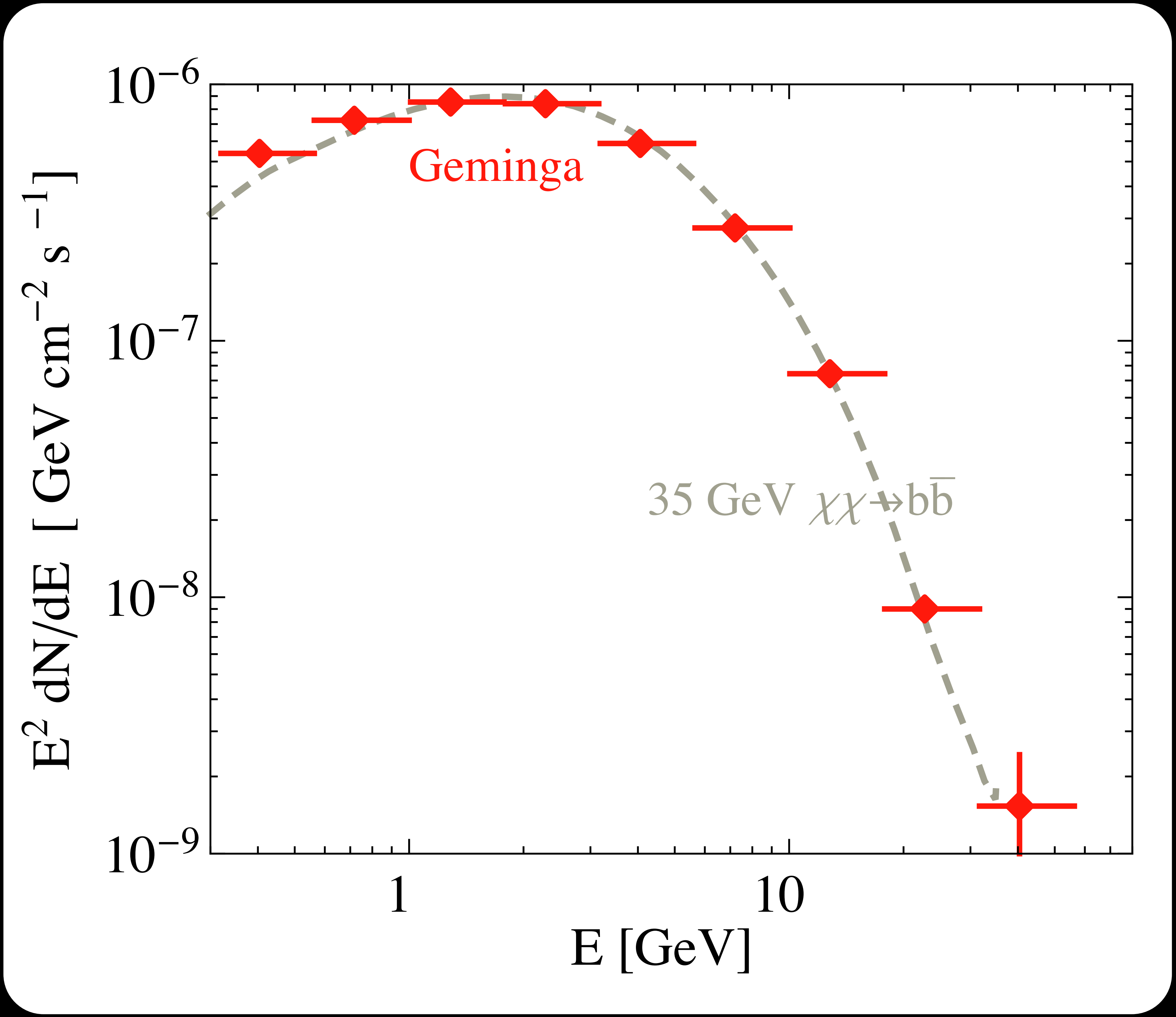
Fermi's Gamma Ray Sky



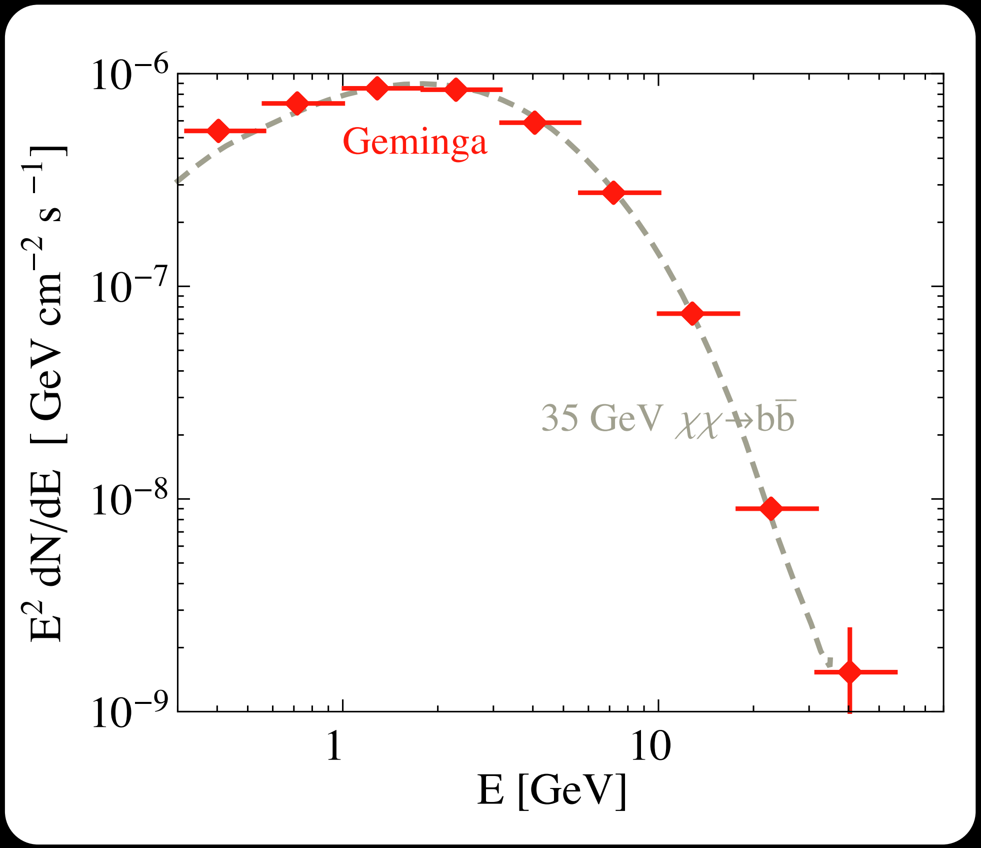
Geminga


Geminga
PSR J1312+00
PSR J1231-1411
PSR J1836+5925
PSR J1302-32
PSR J1614-2230
PSR J1124-36
PSR J0751+180
CTA 1
PSR J1810+17
"Rabbit"
(PSR J1418-6058)
"Boomerang"
(PSR J2229+6114)
"Eel"
(PSR J1826-1256)
PSR J1709-4429
PSR J1057-5226
Geminga
PSR J0248+6021
PSR J1907+0602
PSR J0734-1559
Crab
"Taz"
(PSR J1809-2332)
Vela
"Kookaburra"
(PSR J1420-6048)
PSR J0613-0200
PSR J2302+4442
PSR J2017+0603
PSR J0357+3205
PSR J2214+3000
PSR J1902-5105
PSR J0614-3329
PSR J2124-3358
PSR J0437-4715
PSR J0101-6422
PSR J0030+0451
PSR J2241-5236
PSR J0034-0534

Geminga v. Dark Matter



Geminga v. Dark Matter



Geminga:

$$L_\gamma \sim 3 \times 10^{34}\,\mathrm{erg\,s^{-1}}$$

GC Excess:

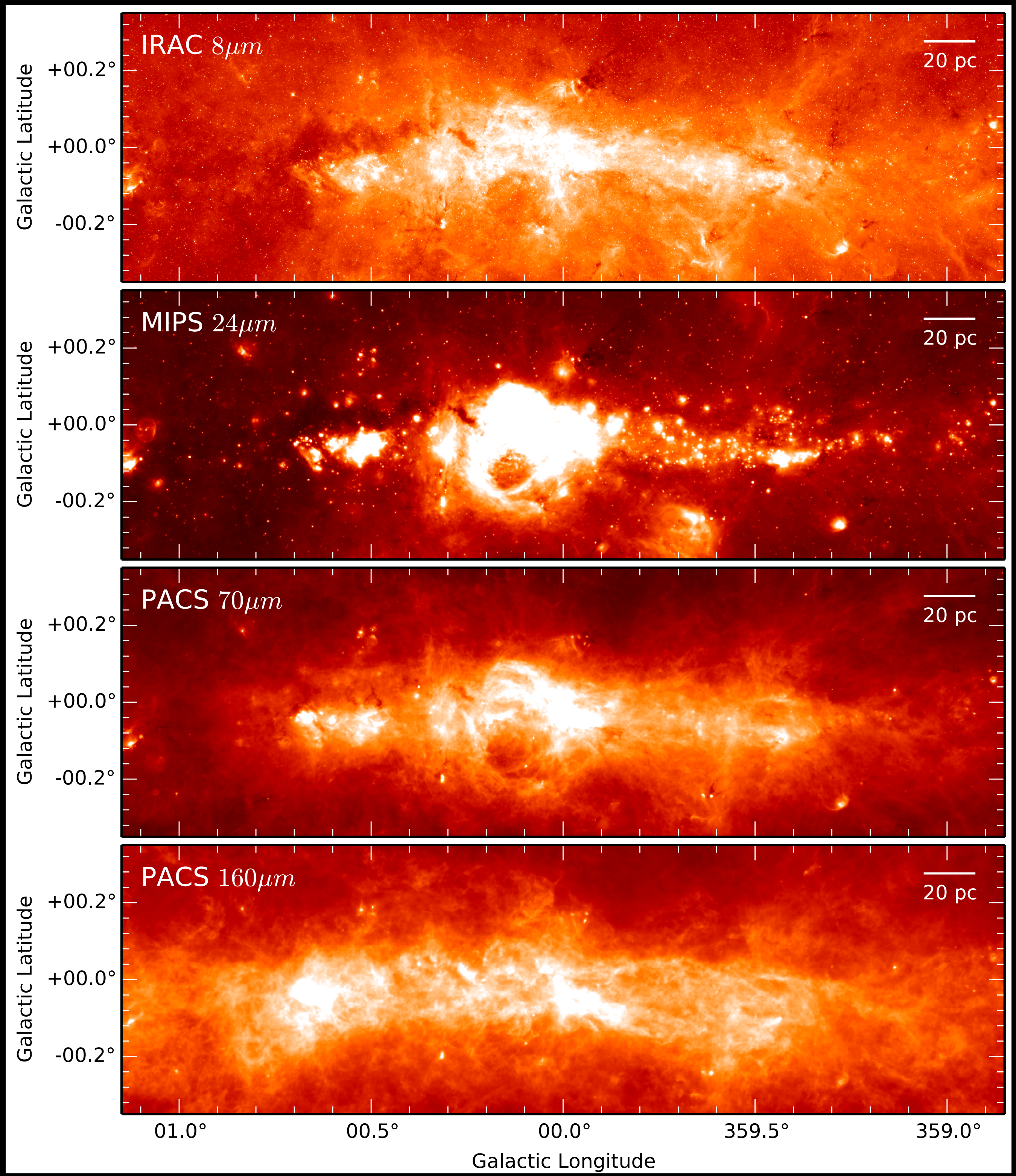
$$\sim 1 \times 10^{37}\,\mathrm{erg\,s^{-1}}$$

Need ~300 'Geminga's to explain entirety of the Excess

$$\rightarrow \frac{300}{5 \times 10^5\,\mathrm{yr}} \sim 6 \times 10^{-4}\,\mathrm{yr}^{-1}$$

~3 % of the MW SNR

Intense Star Formation in GC



Koepferl+2014

Central Molecular Zone

Star Formation & Supernovae Rates Uncertain.

~3% Free-Free Emission

Longmore+2013

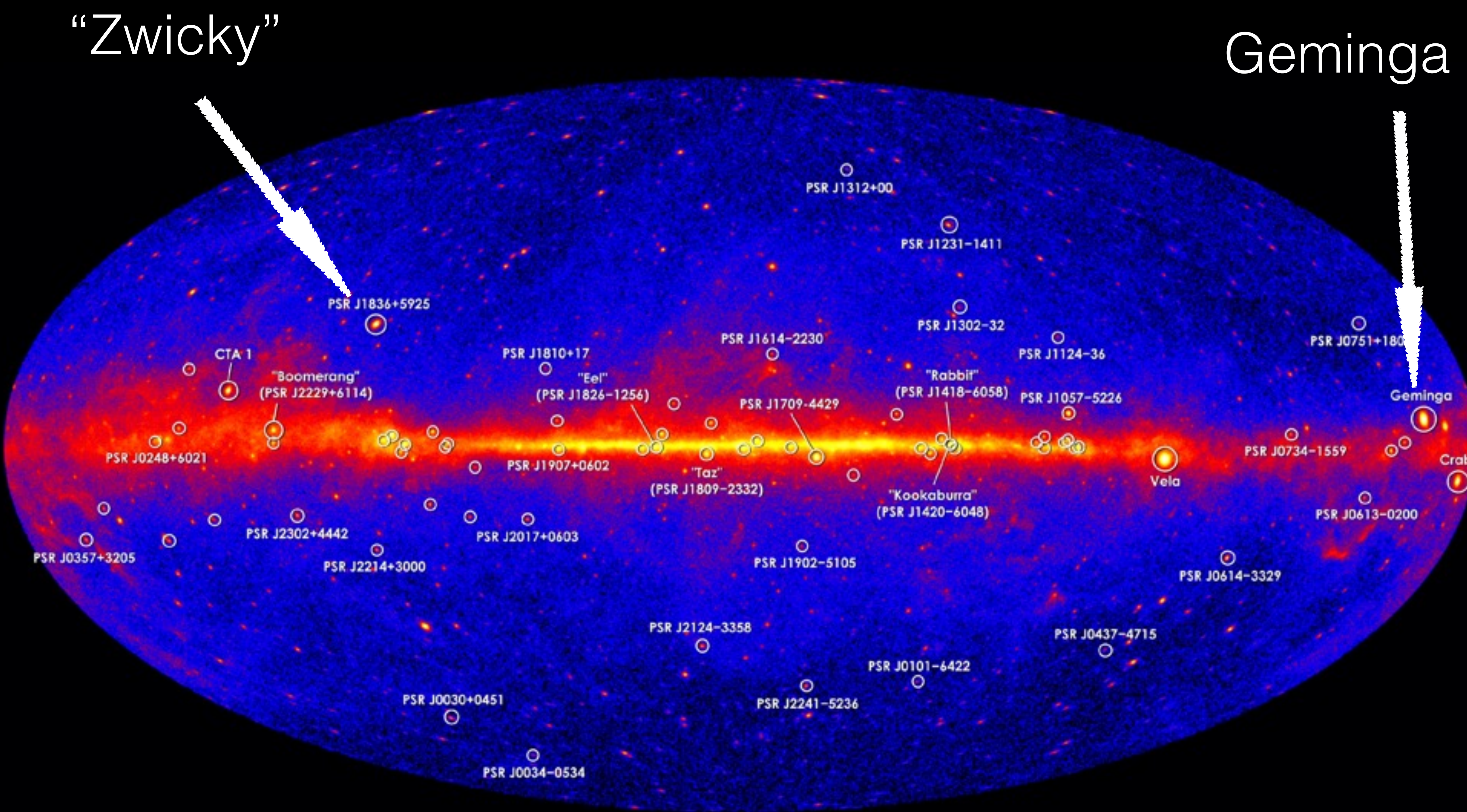
~10% YSOs

Yusef-Zudah+ 2009

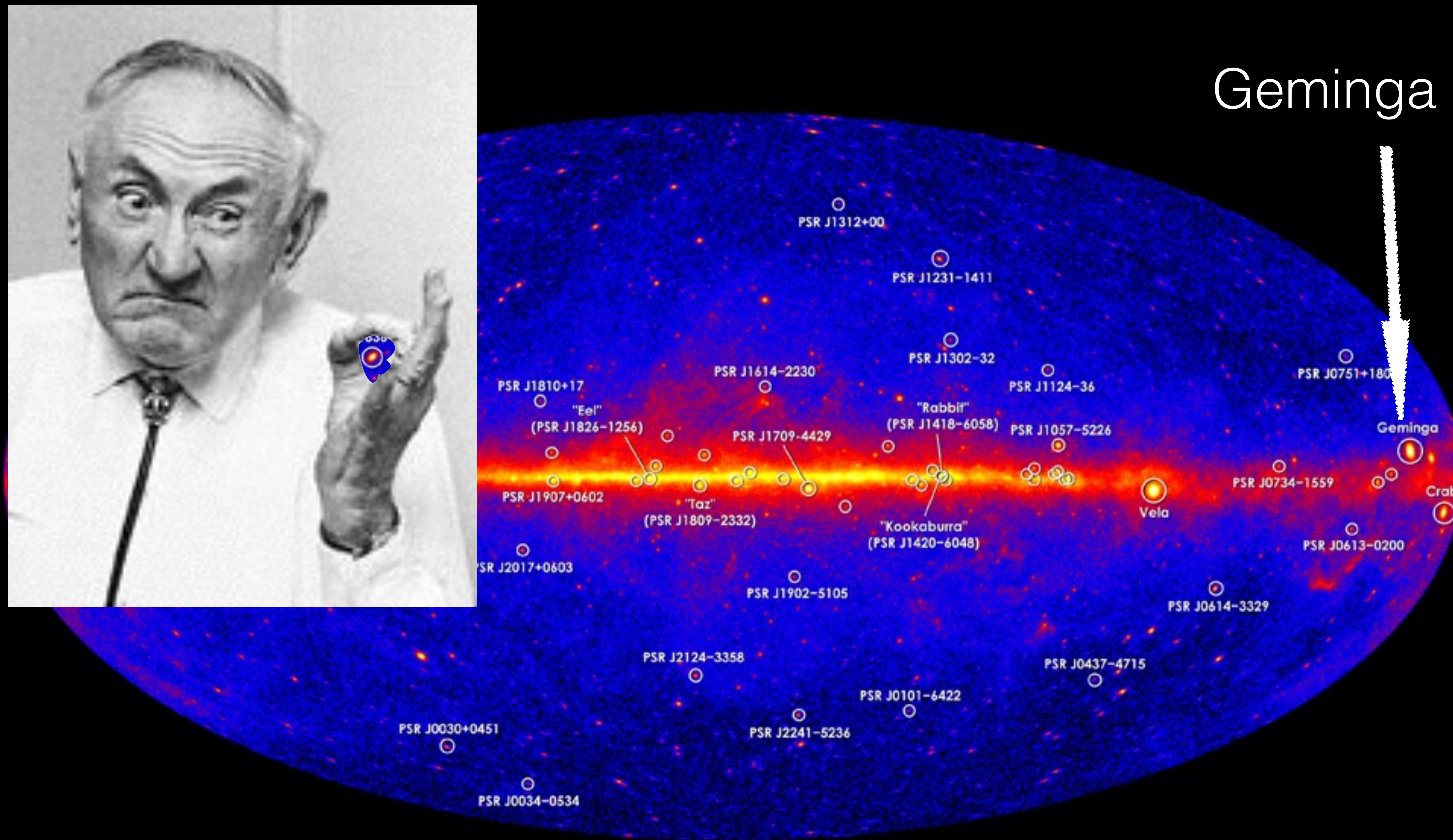
~20% Wolf-Rayet Stars

Rosslowe & Crowther 2015

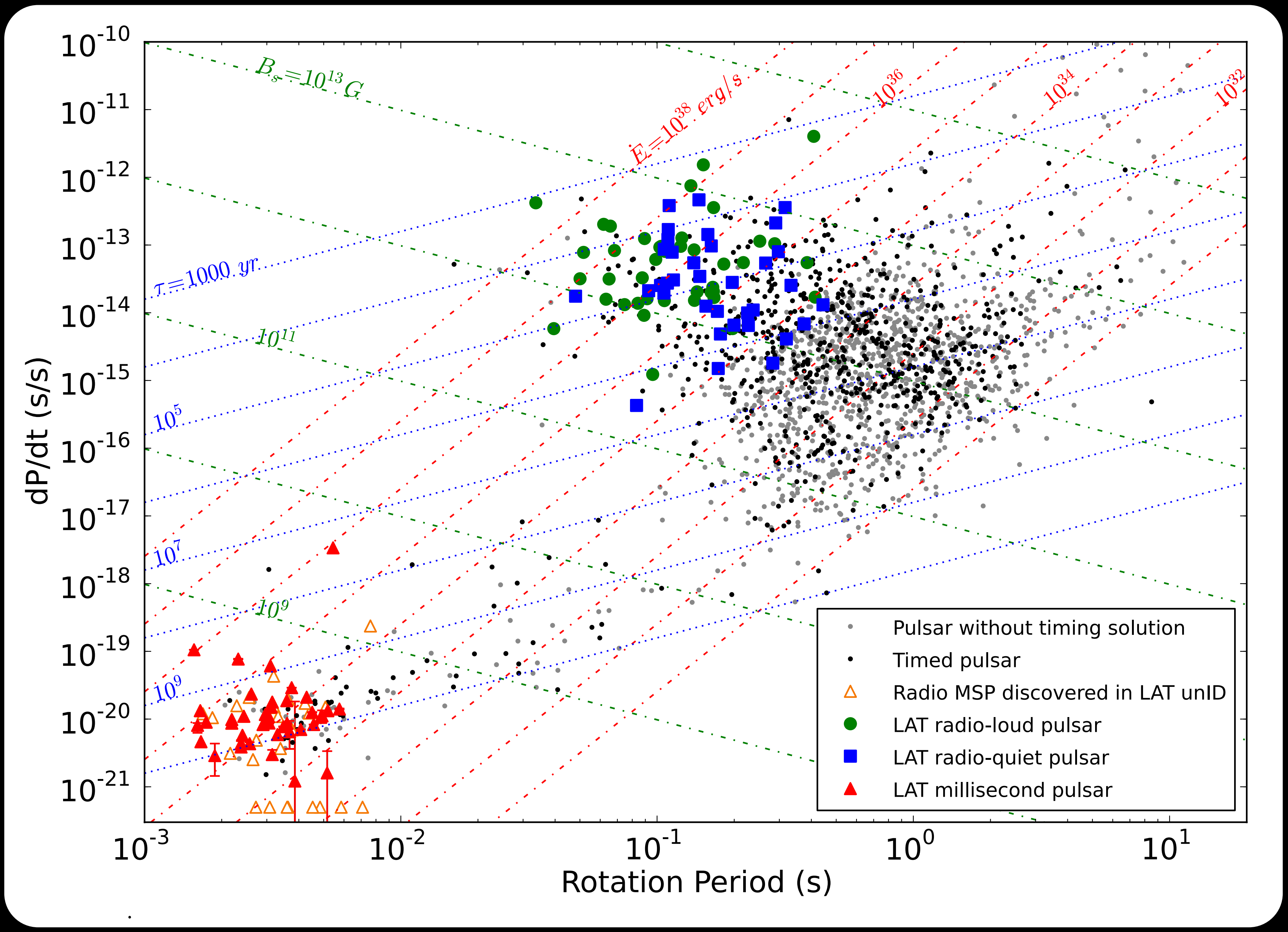
Not just Geminga



Not just Geminga

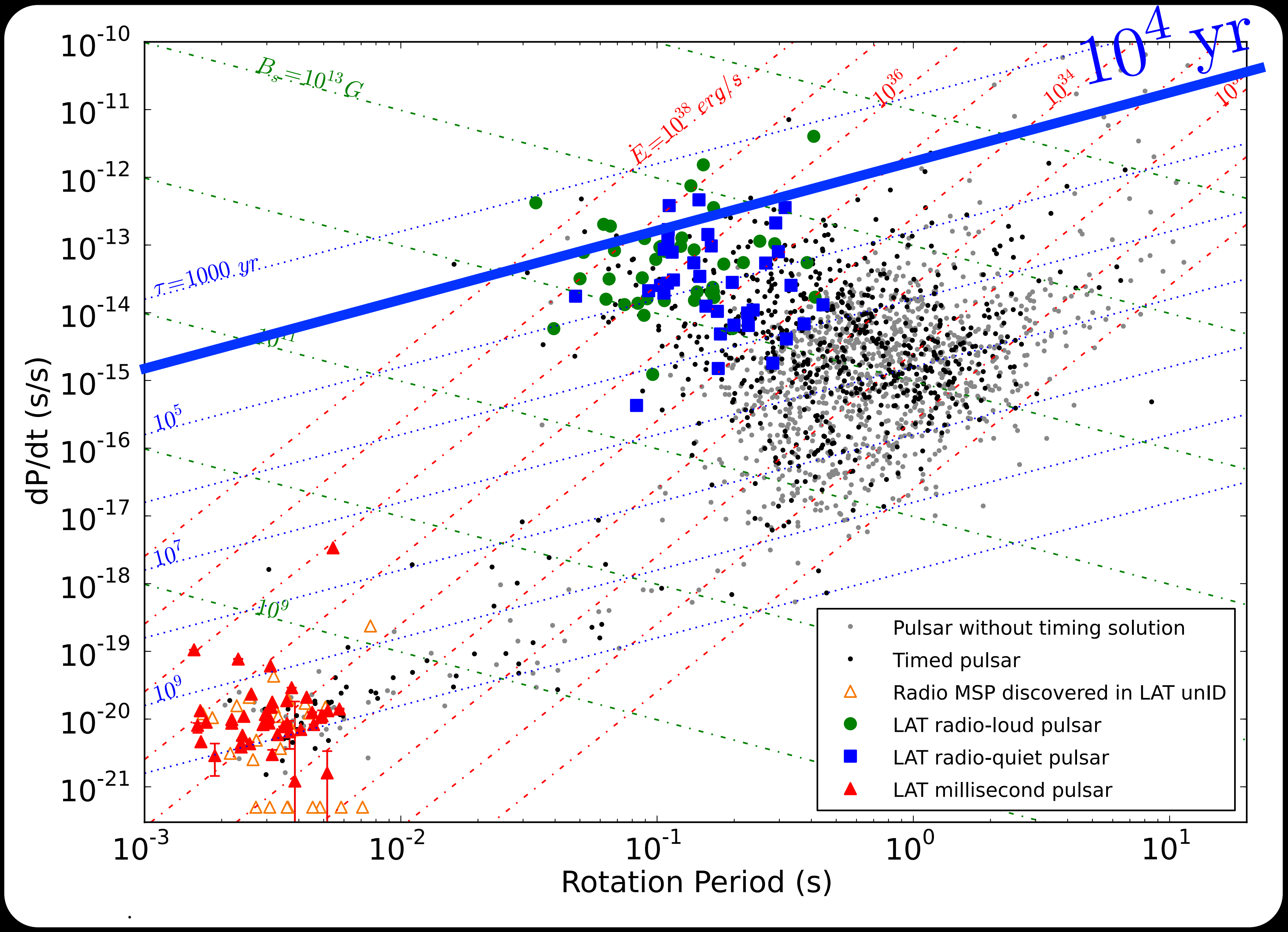


2) Types of Pulsars



2PC; Abdo et al. 2013

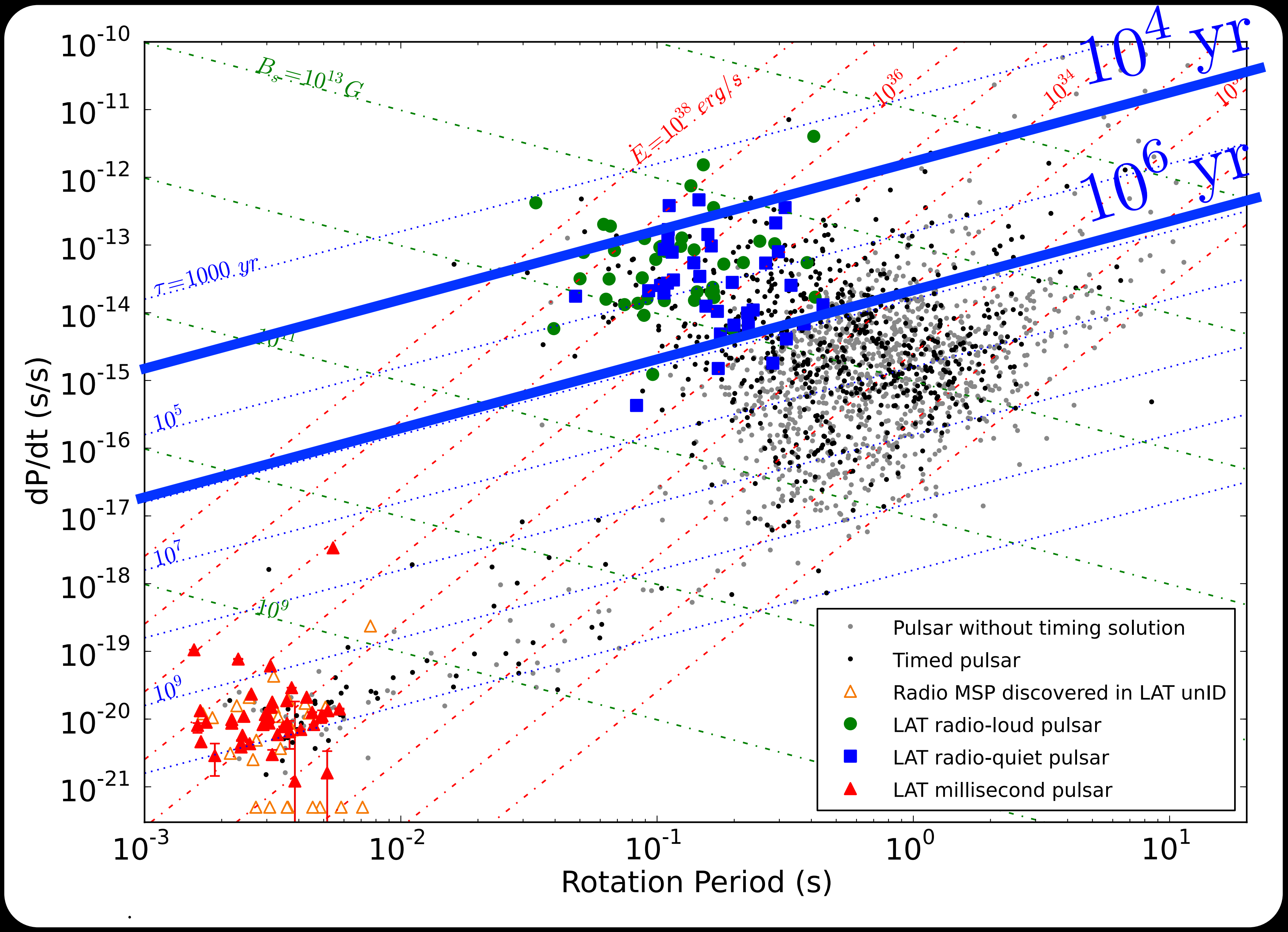
Types of Pulsars



Magnetars

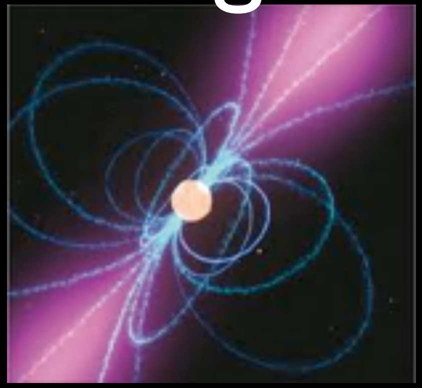
2PC; Abdo et al. 2013

Types of Pulsars



Magnetars

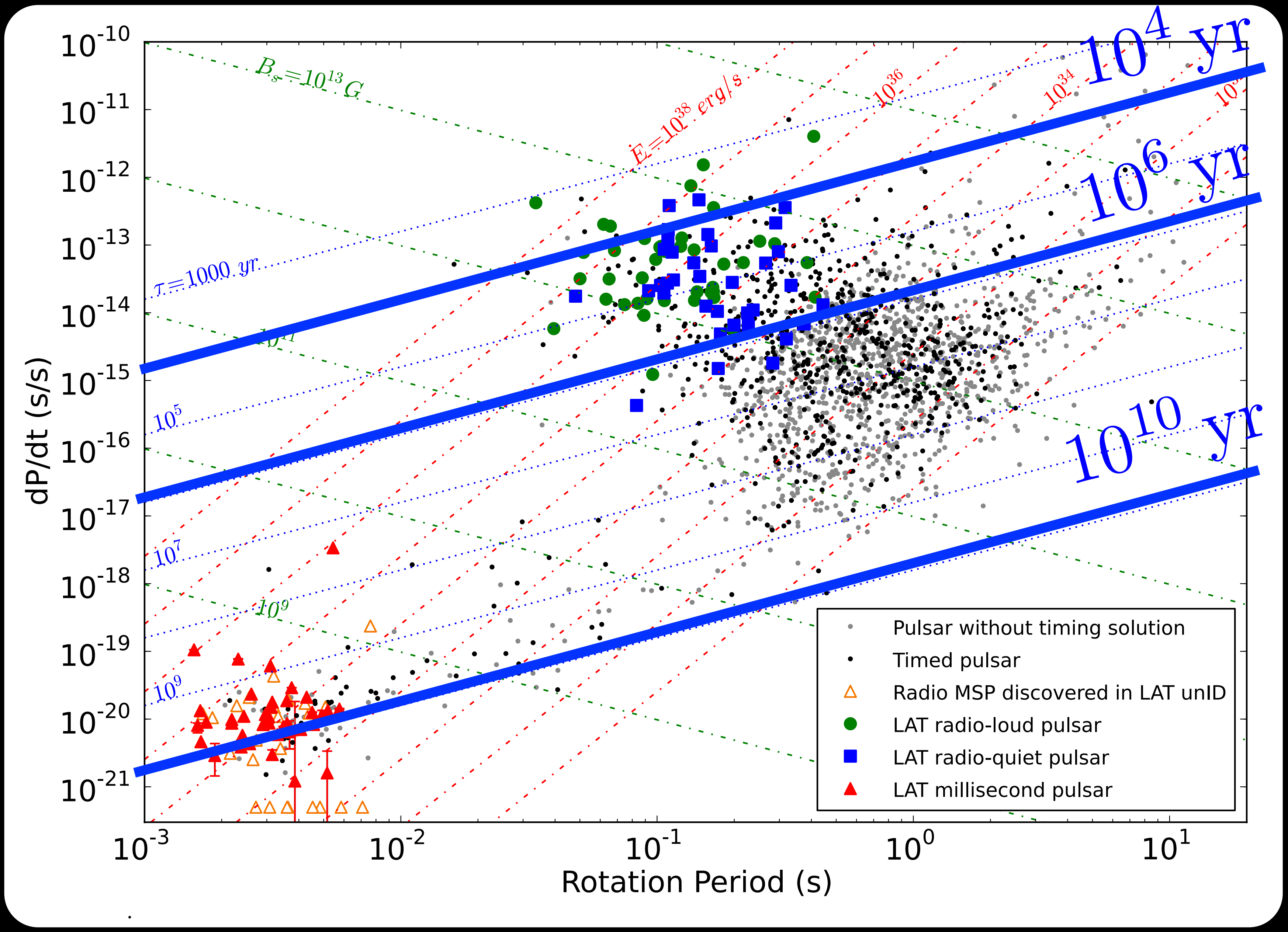
Young Pulsars



Radio Quiet
&
Radio Loud

2PC; Abdo et al. 2013

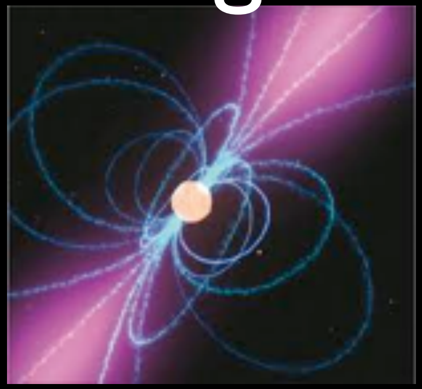
Types of Pulsars



2PC; Abdo et al. 2013

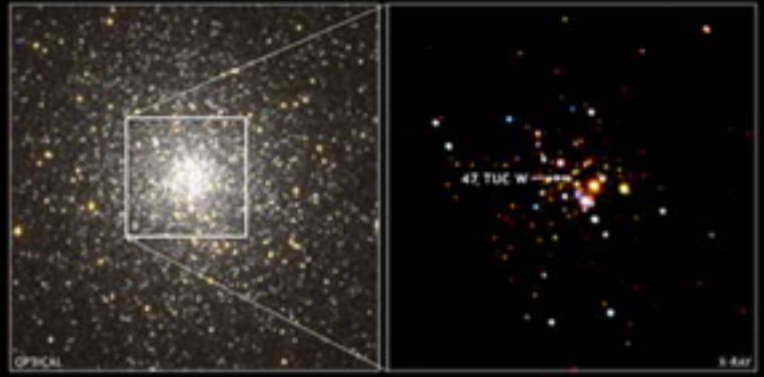
Magnetars

Young Pulsars

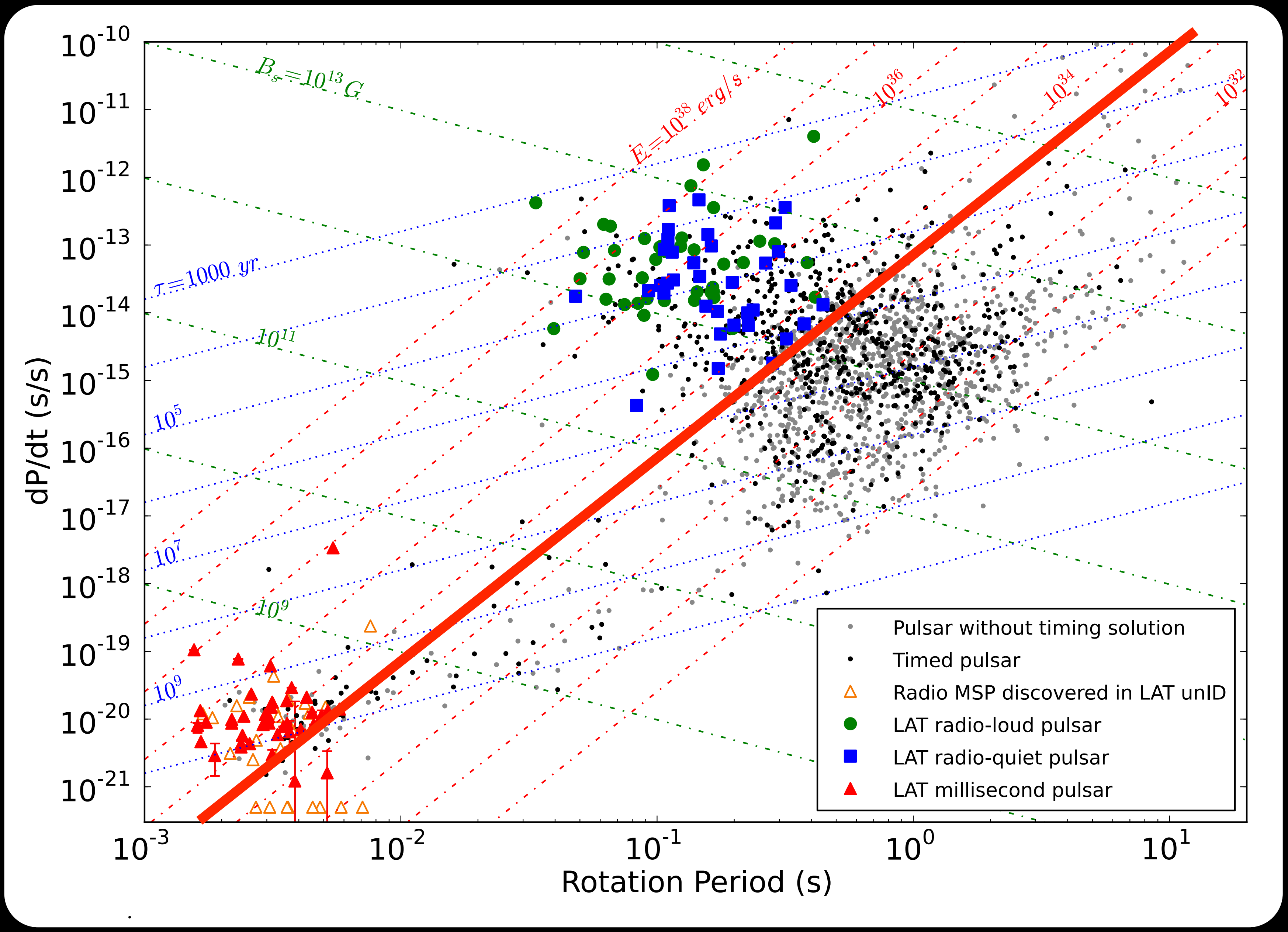


Radio Quiet & Radio Loud

Millisecond Pulsars



Gamma Ray Pulsar Death Line

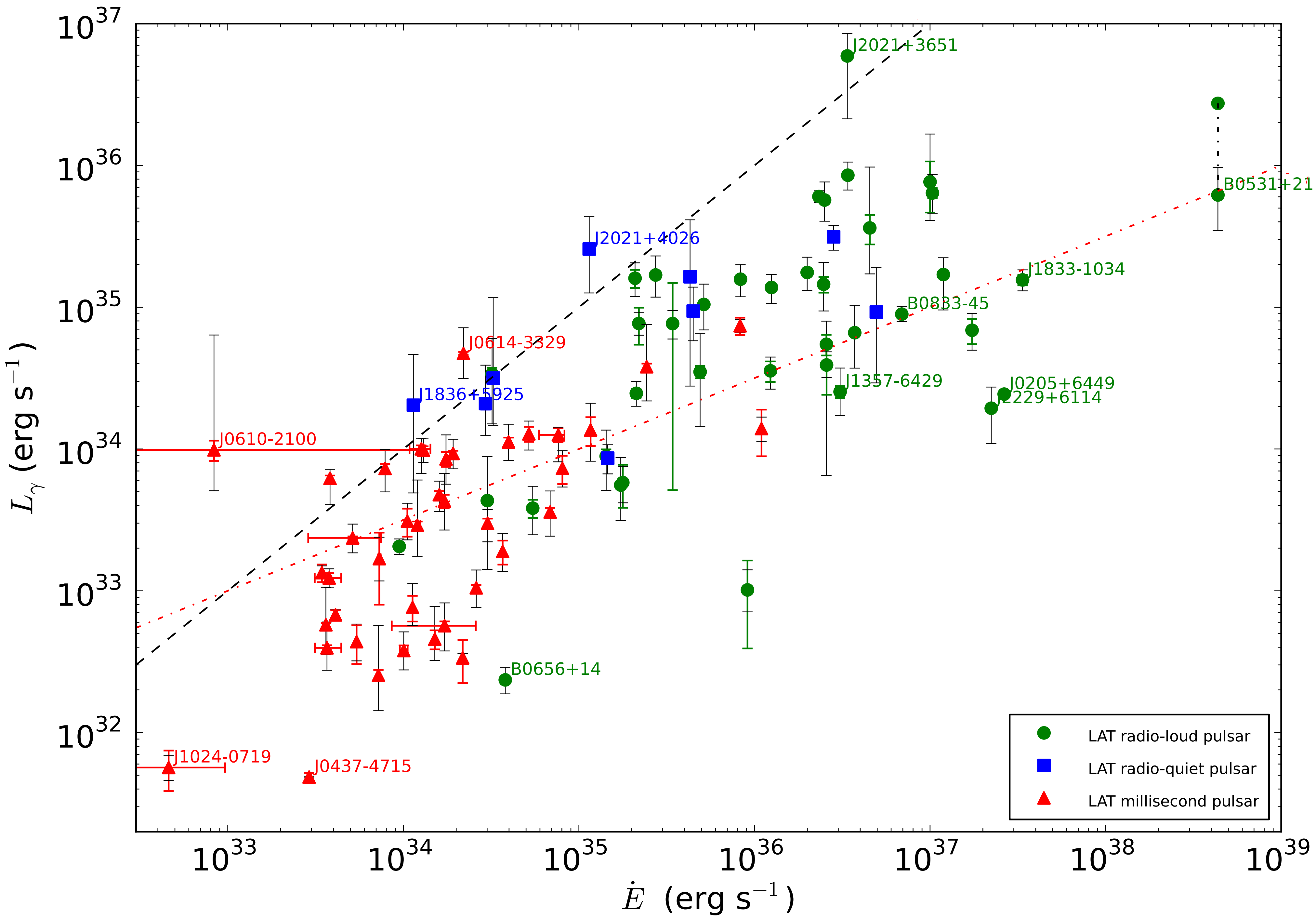


$$\dot{E} \gtrsim 10^{33.5}\,\mathrm{erg\,s^{-1}}$$

2PC; Abdo et al. 2013

Luminosity scales with $\dot{E}$

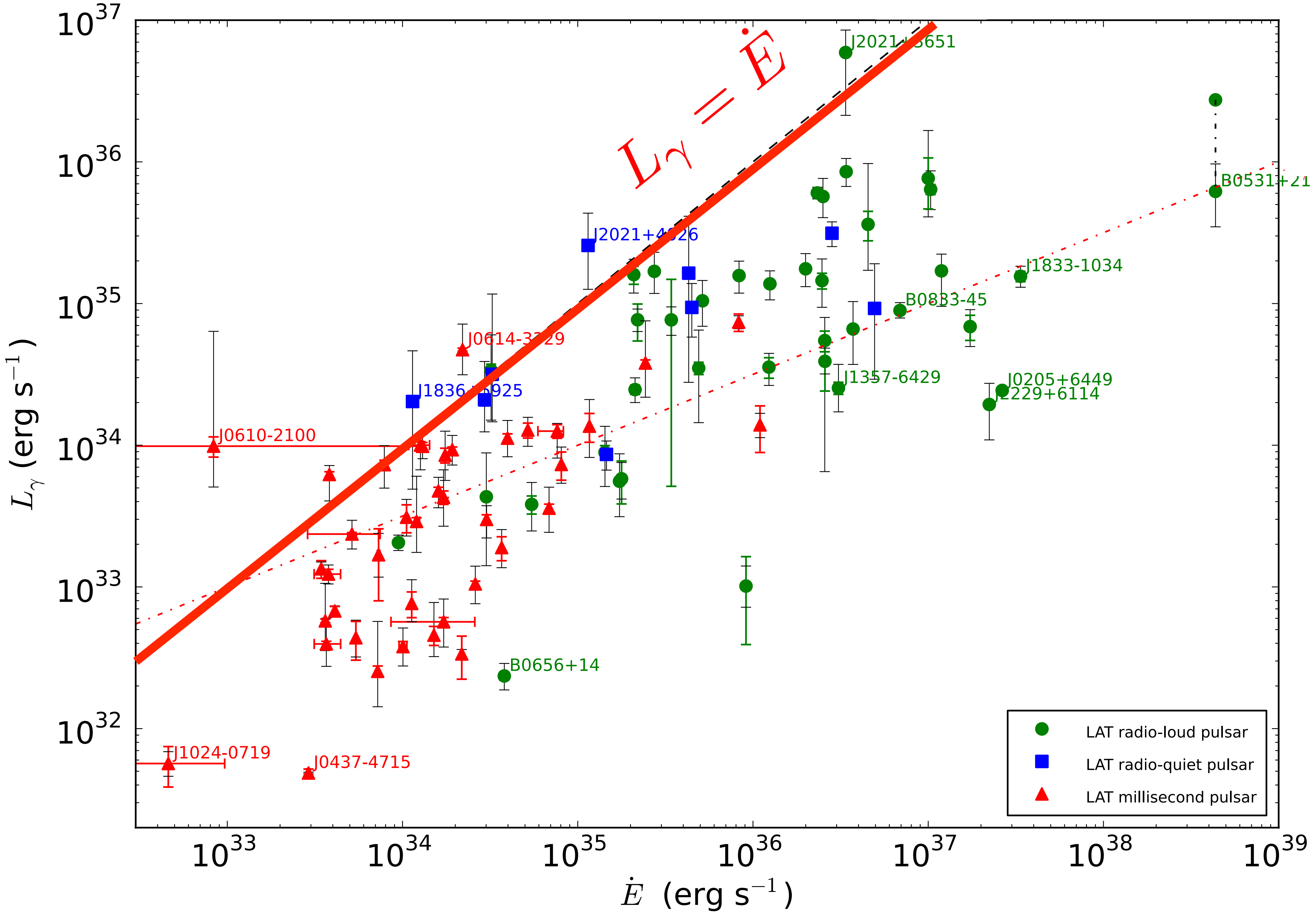
Luminosity



Spin Down Rate

2PC; Abdo et al. 2013

Luminosity scales with $\dot{E}$

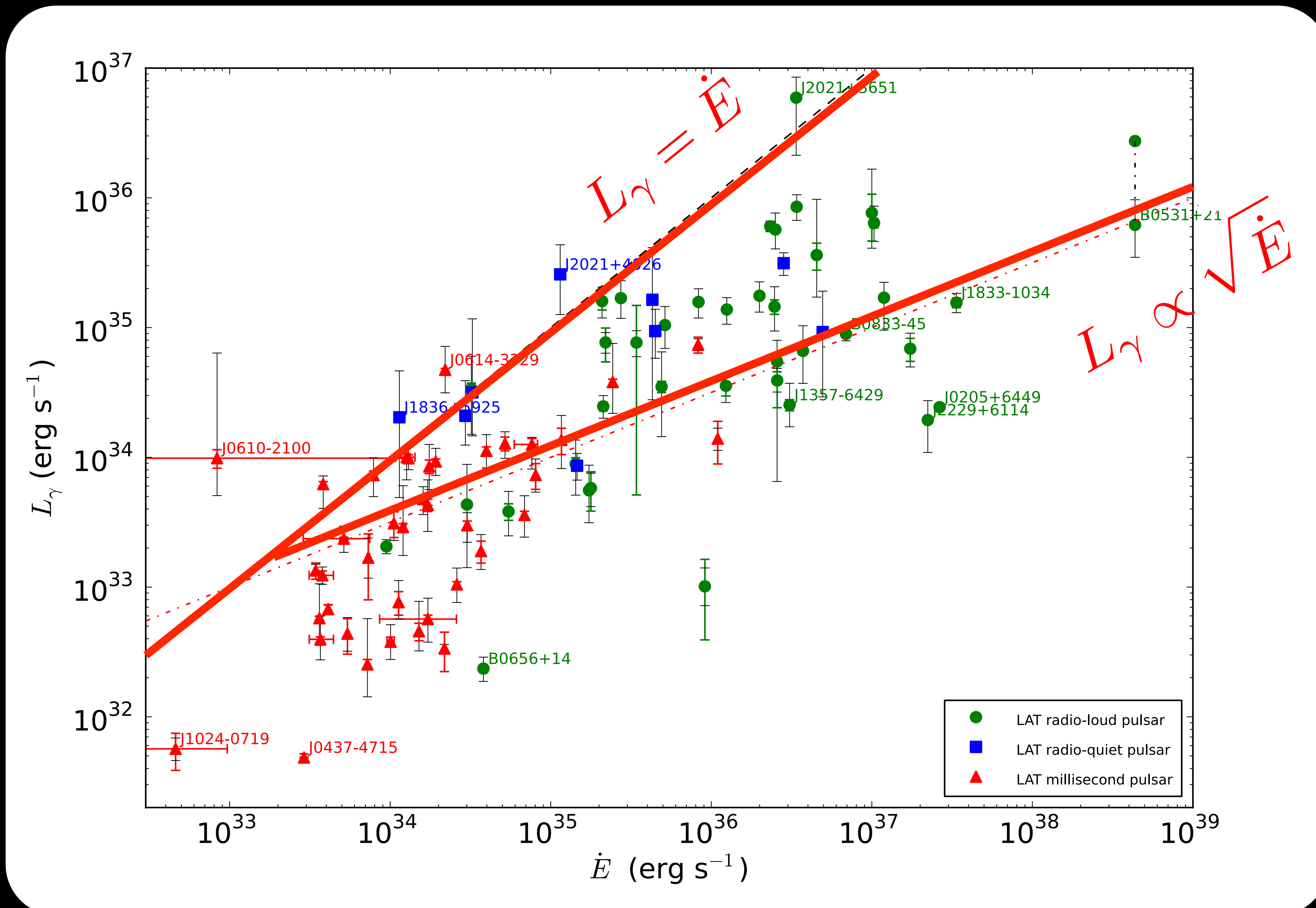


Luminosity

Spin Down Rate

2PC; Abdo et al. 2013

Luminosity scales with $\dot{E}$

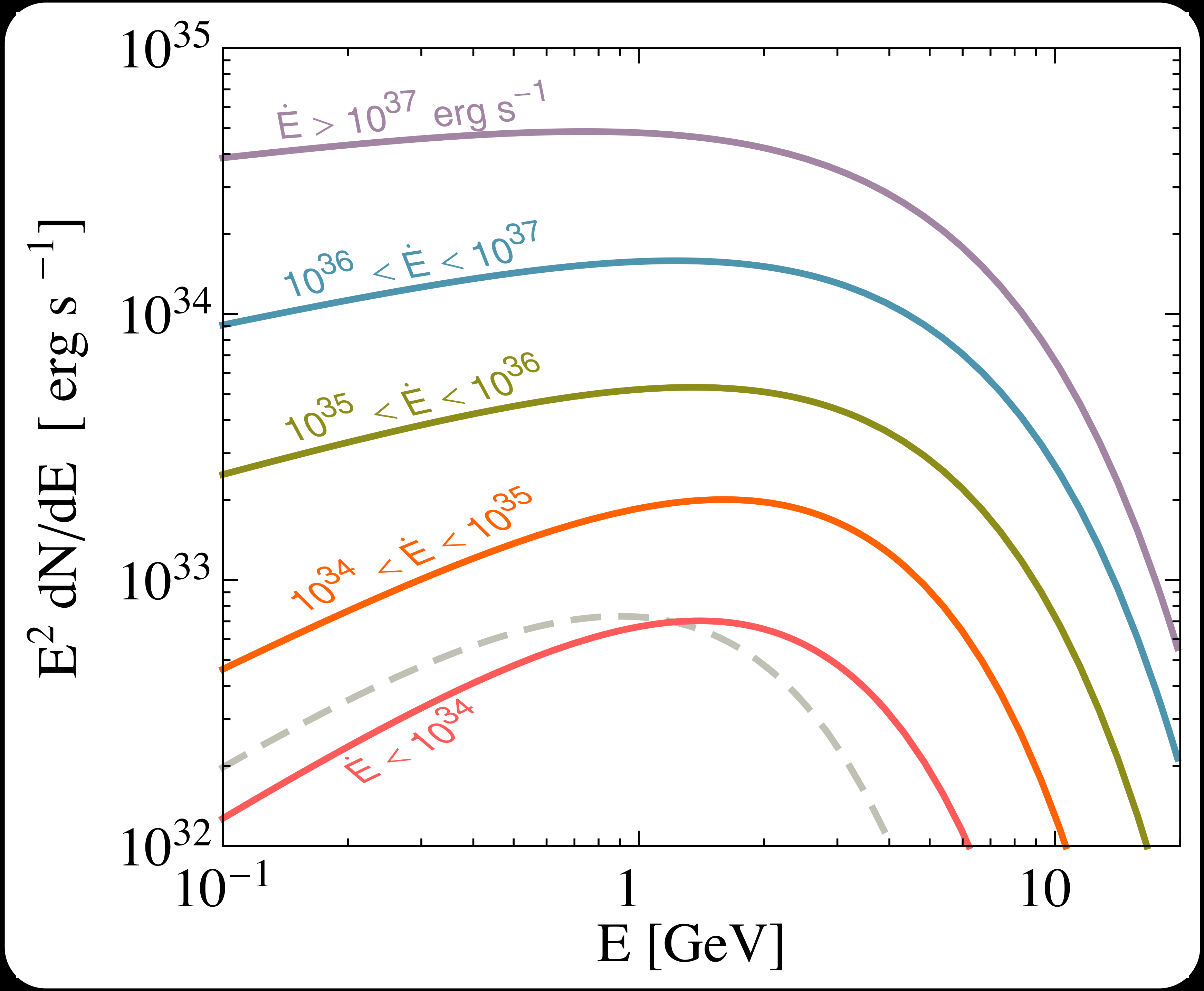


Luminosity

Spin Down Rate

2PC; Abdo et al. 2013

Older Pulsars have harder Spectra



O'Leary+2015b

Forward Modeling

Standard Population Synthesis:

Faucher-Giguere & Kaspi (2006) & Watters & Romani (2011)

- Pulsars are born in spiral arms & *the Galactic Center*
- Pulsars receive a standard kick: $\bar{v}_k \approx 408\,\mathrm{km\,s^{-1}}$

  Hobbs+2005
- Evolve pulsar orbits until present time

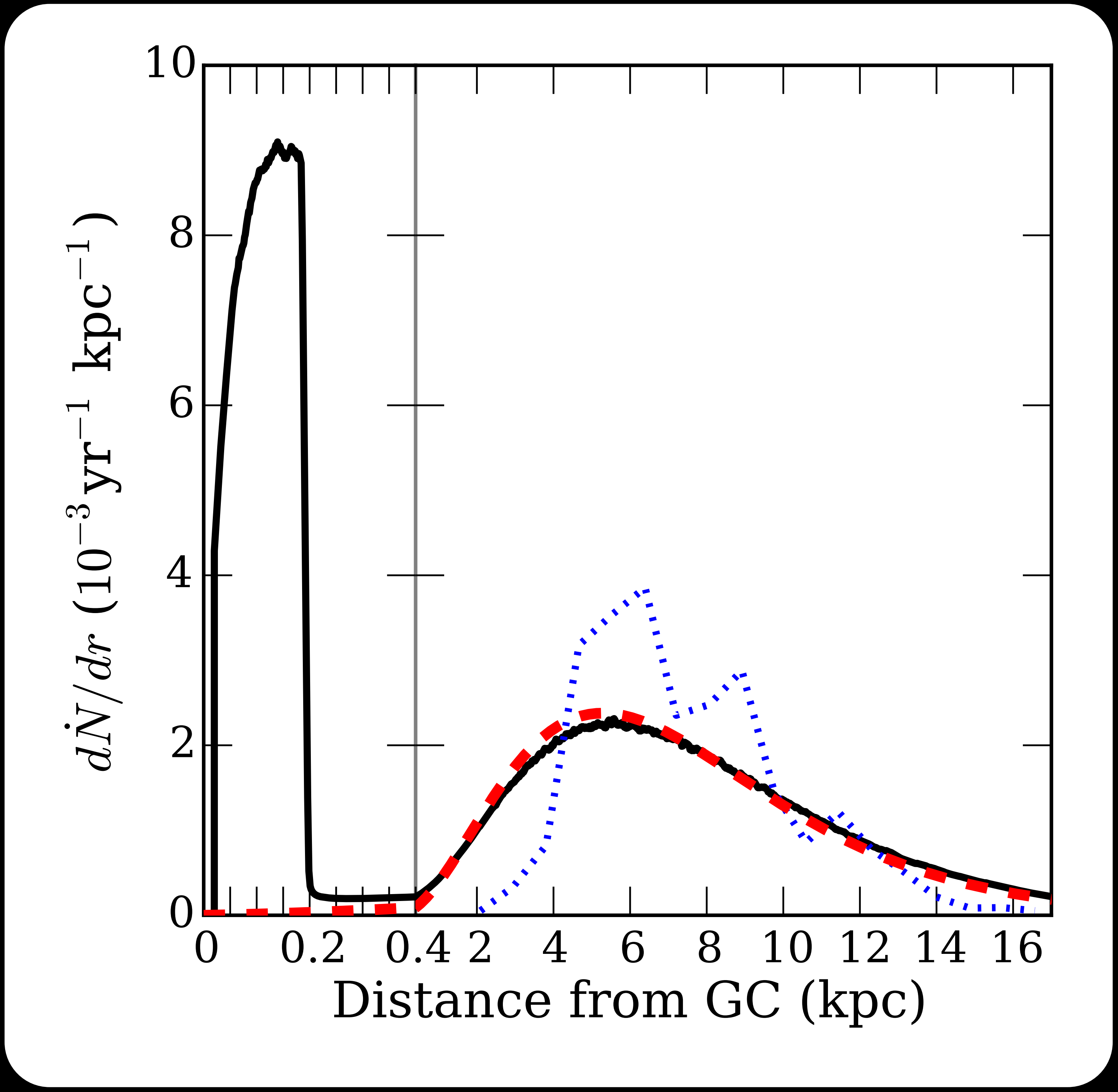
  Galpy - Bovy 2015

Generate the gamma ray maps:

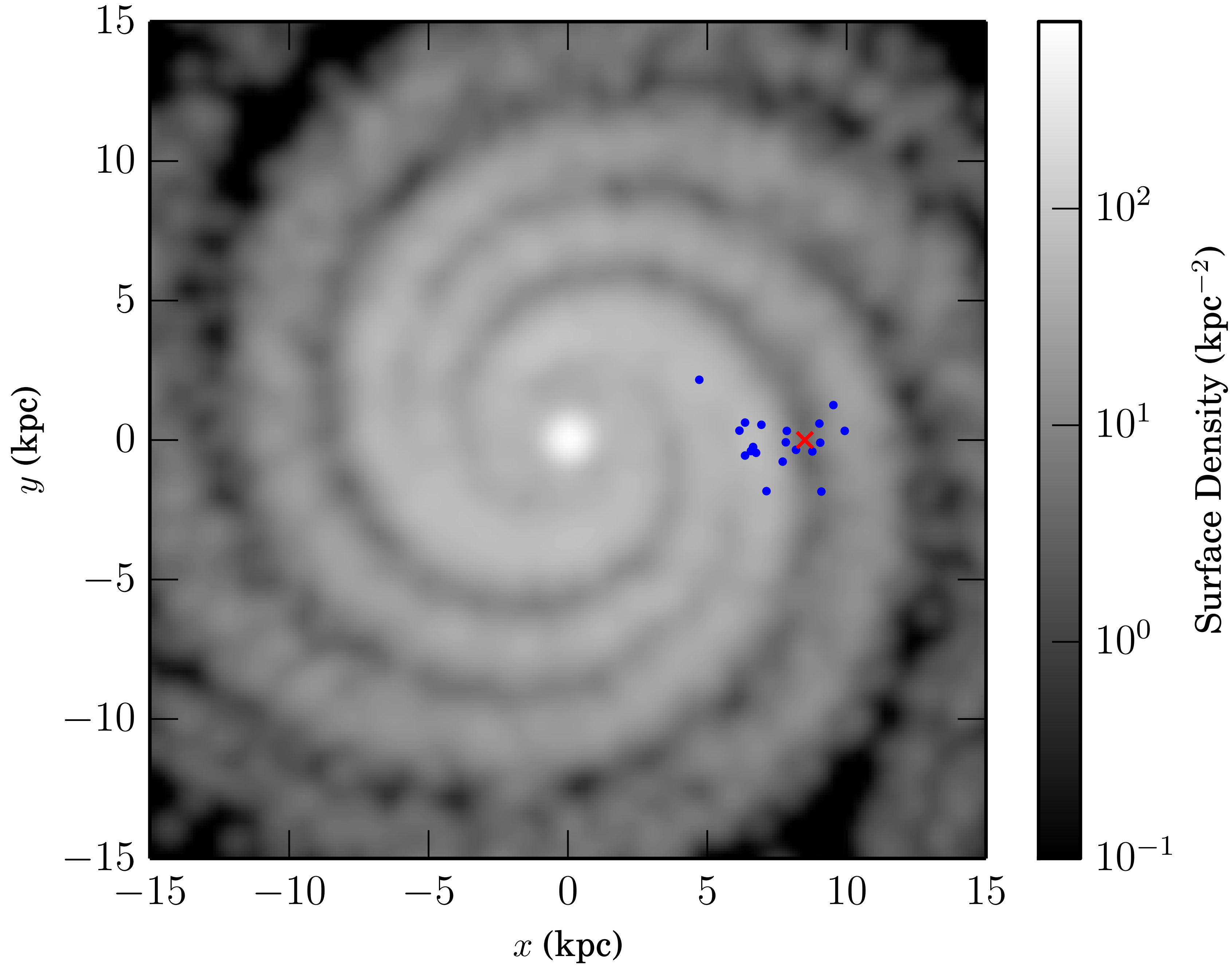
- Spectrum and luminosity depend on $\dot{E}$
- Focus on flux at 2 GeV

See Also Calore+2014

Forward Modeling

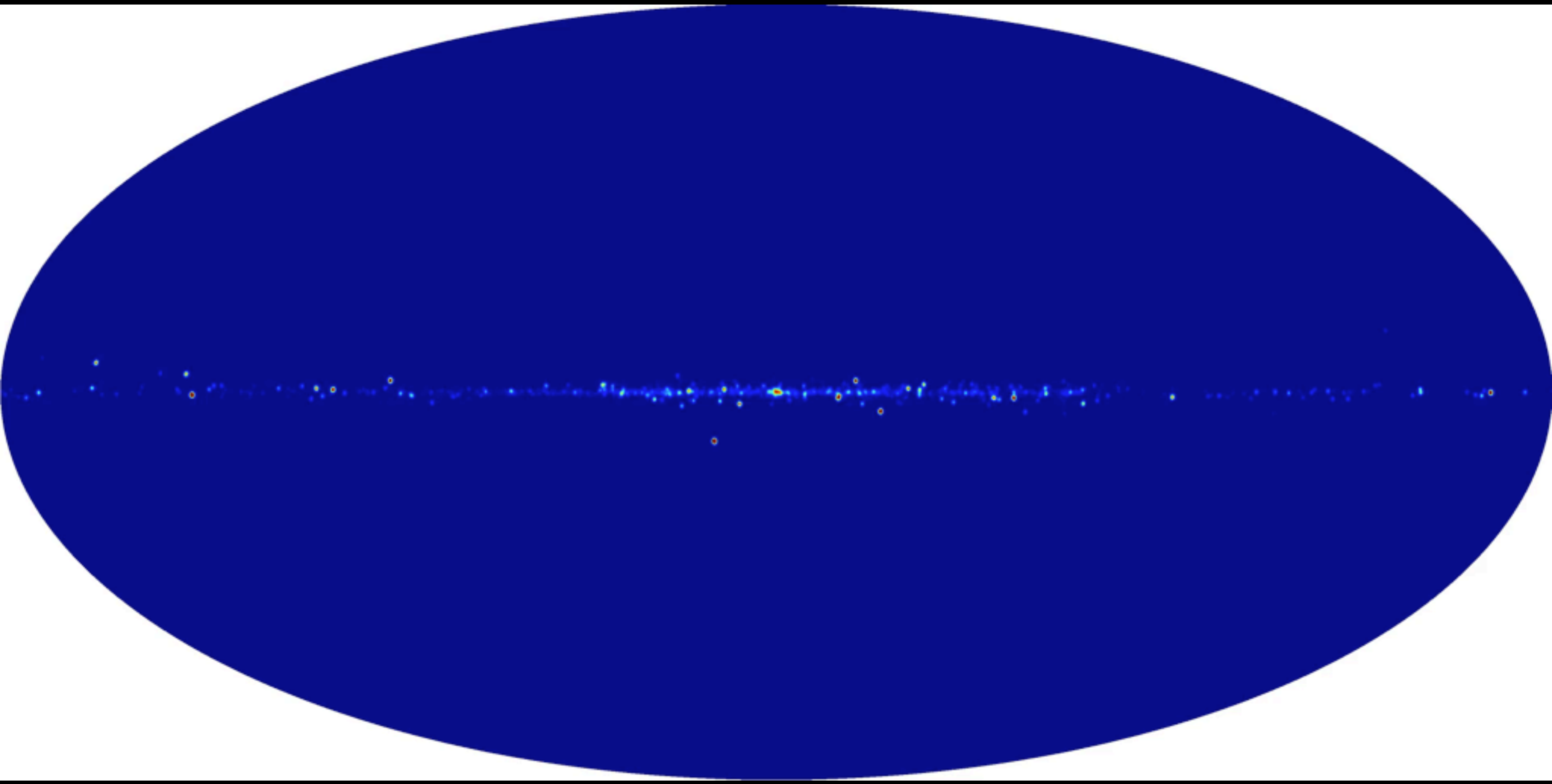


Gamma Ray Pulsar Population

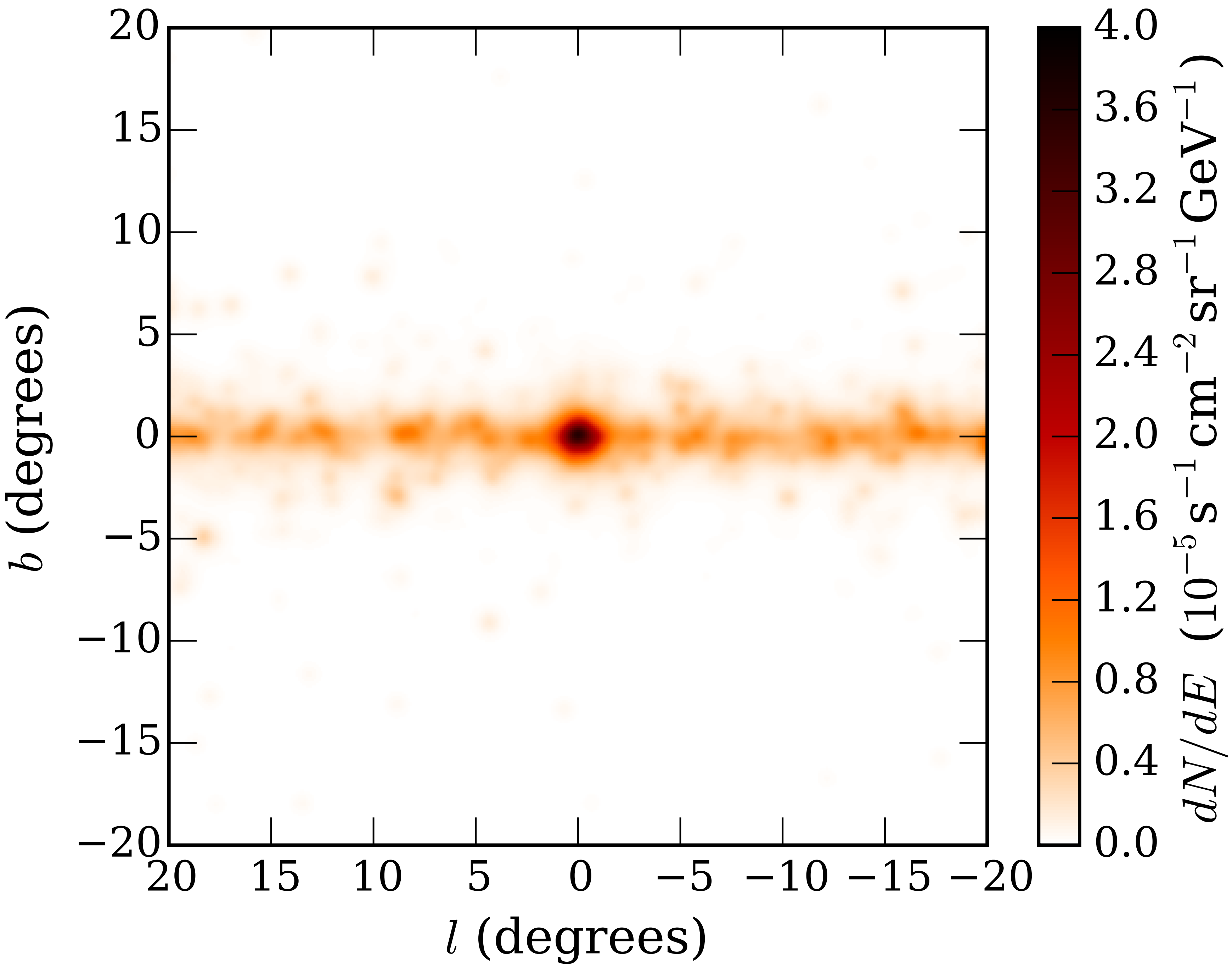


O'Leary+2015b

Young Gamma Ray Pulsars

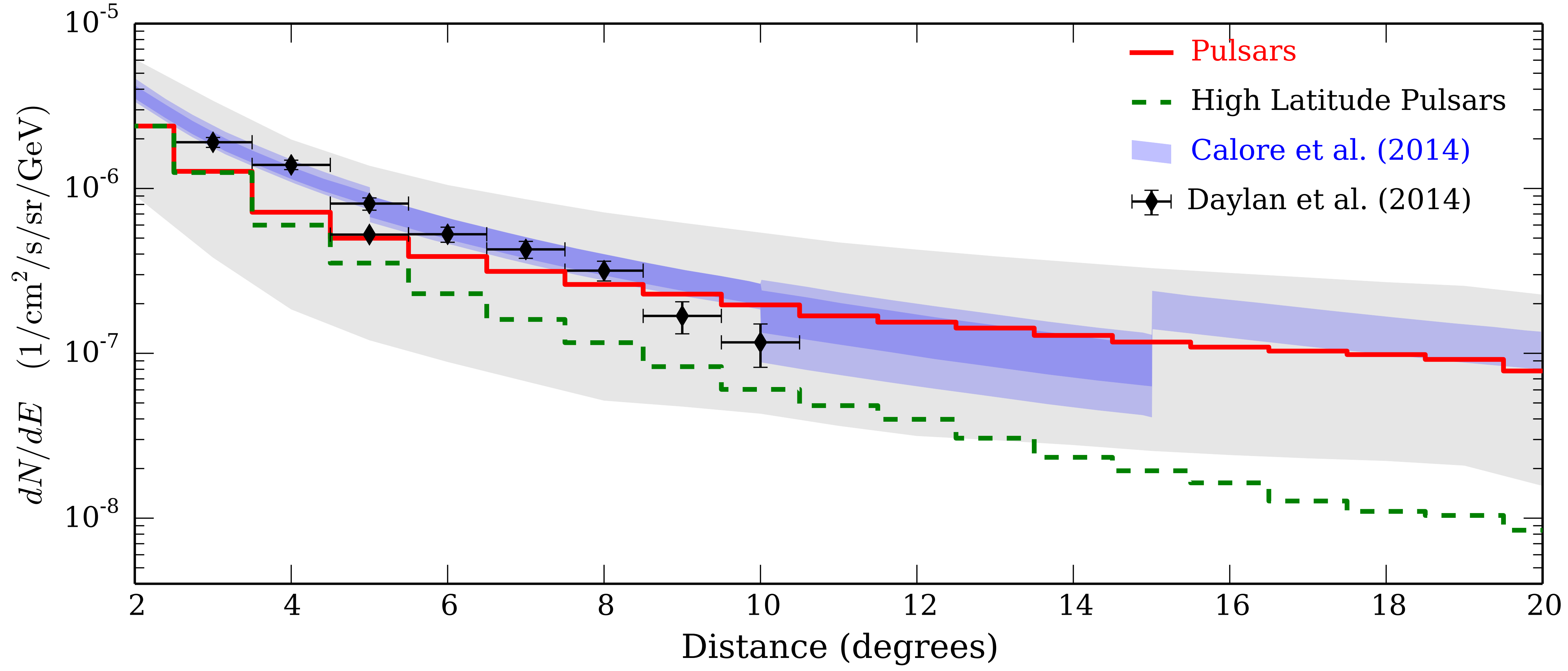


Gamma Ray Pulsar Population



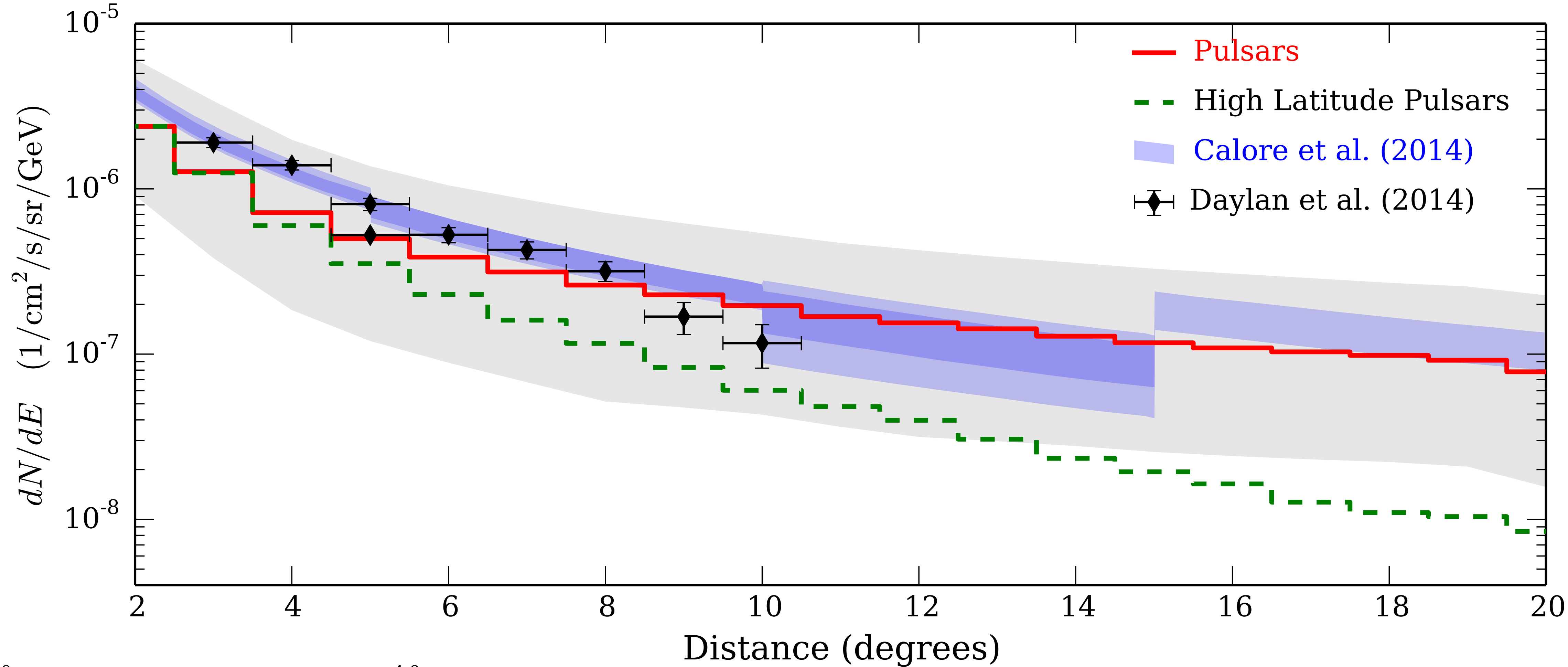
O'Leary+2015a

Main Result



10^{-5}
10^{-6}
10^{-7}
10^{-8}
$dN/dE \quad (1/\mathrm{cm}^2/\mathrm{s}/\mathrm{sr}/\mathrm{GeV})$
2
4
6
8
10
12
14
16
18
20
Distance (degrees)
Pulsars
High Latitude Pulsars
Calore et al. (2014)
Daylan et al. (2014)

Main Result



10^{-5}
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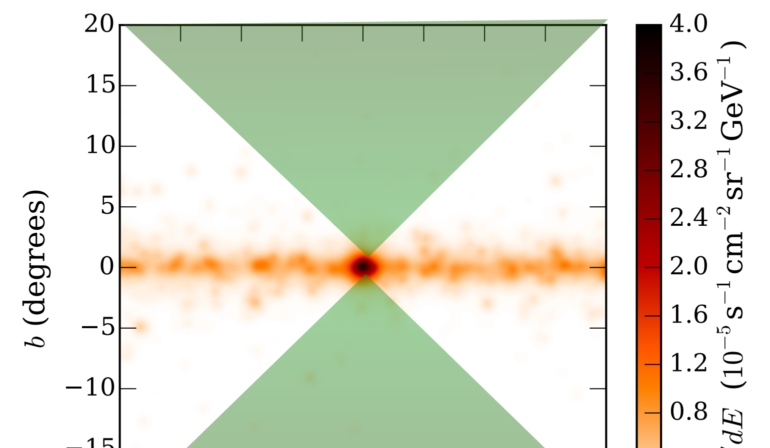
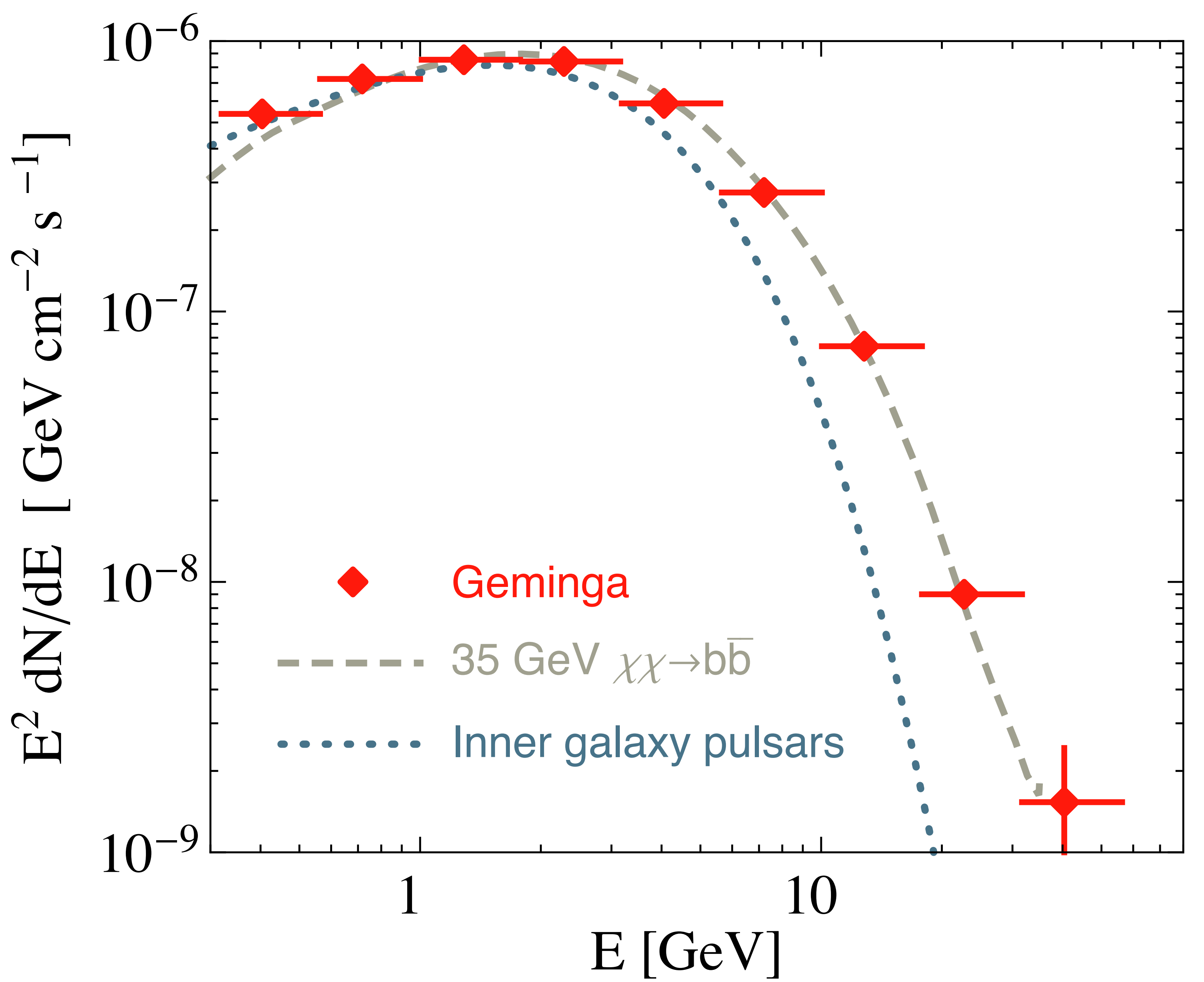
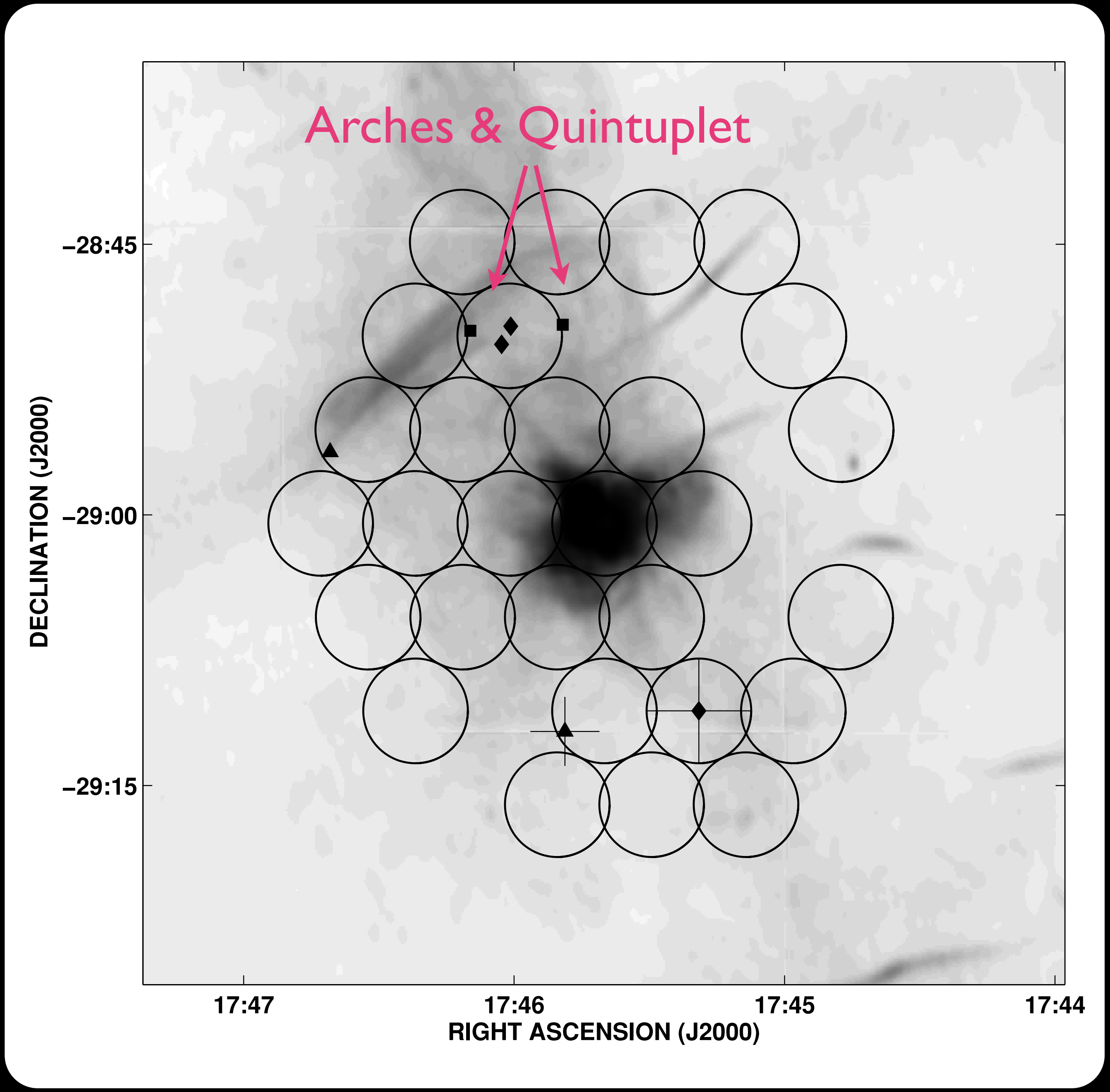


20
15
10
5
0
−5
−10
b (degrees)
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8

Composite Spectrum



Radio Pulsars?



Deneva+2009

5+1 Known Pulsars in CMZ

Deneva+2009; Johnston+2006

Within this survey area we expect ~7-10 detectable *radio* pulsars.

Stolman 1987; Watters & Romani 2011

Inverse Compton from Young Pulsars

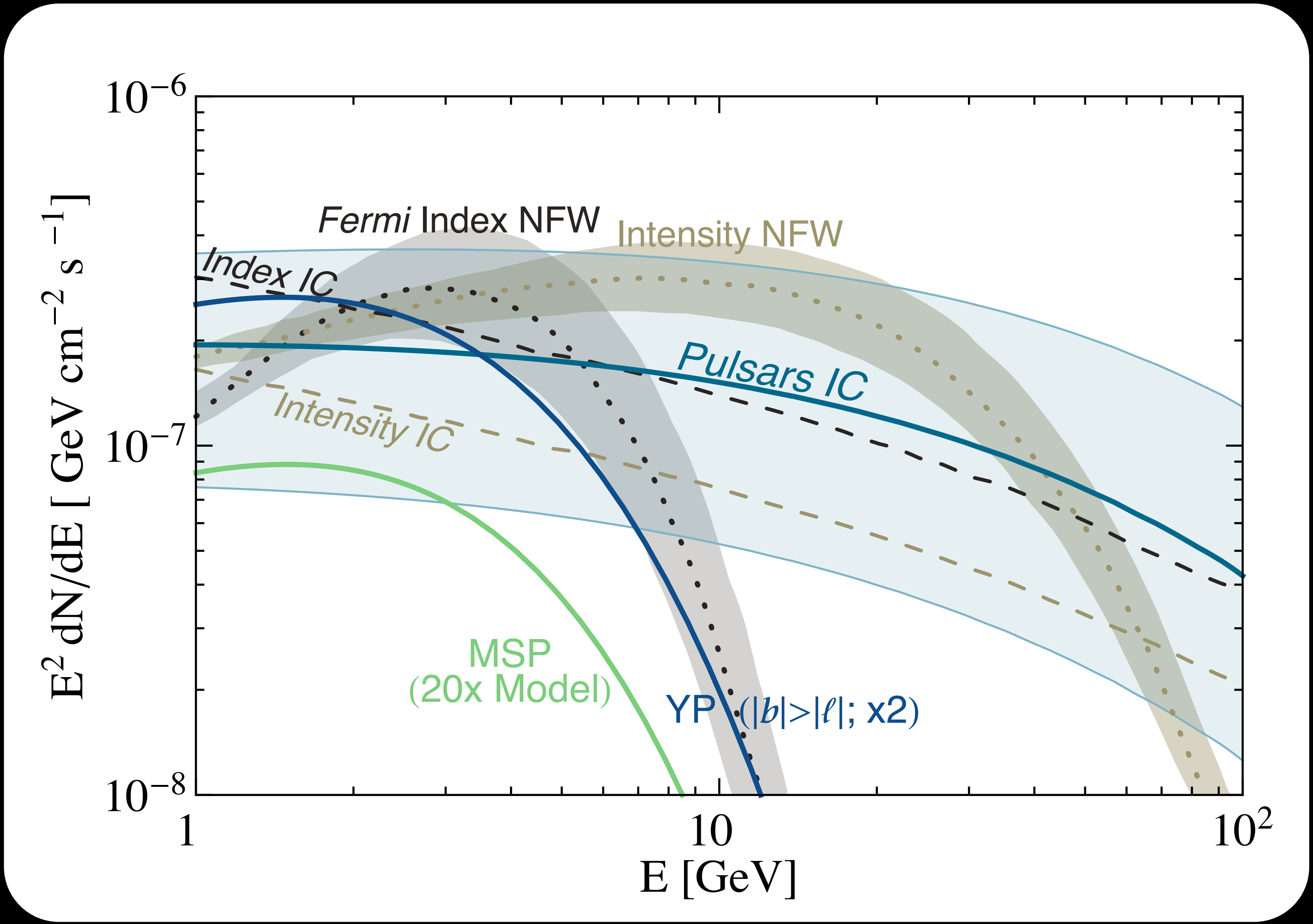
One Zone Model

$$B \approx 25\mu\text{G}$$

$$\mathcal{L}_{e^\pm} = 0.5 \sum \dot{E}$$

Injection Spectrum

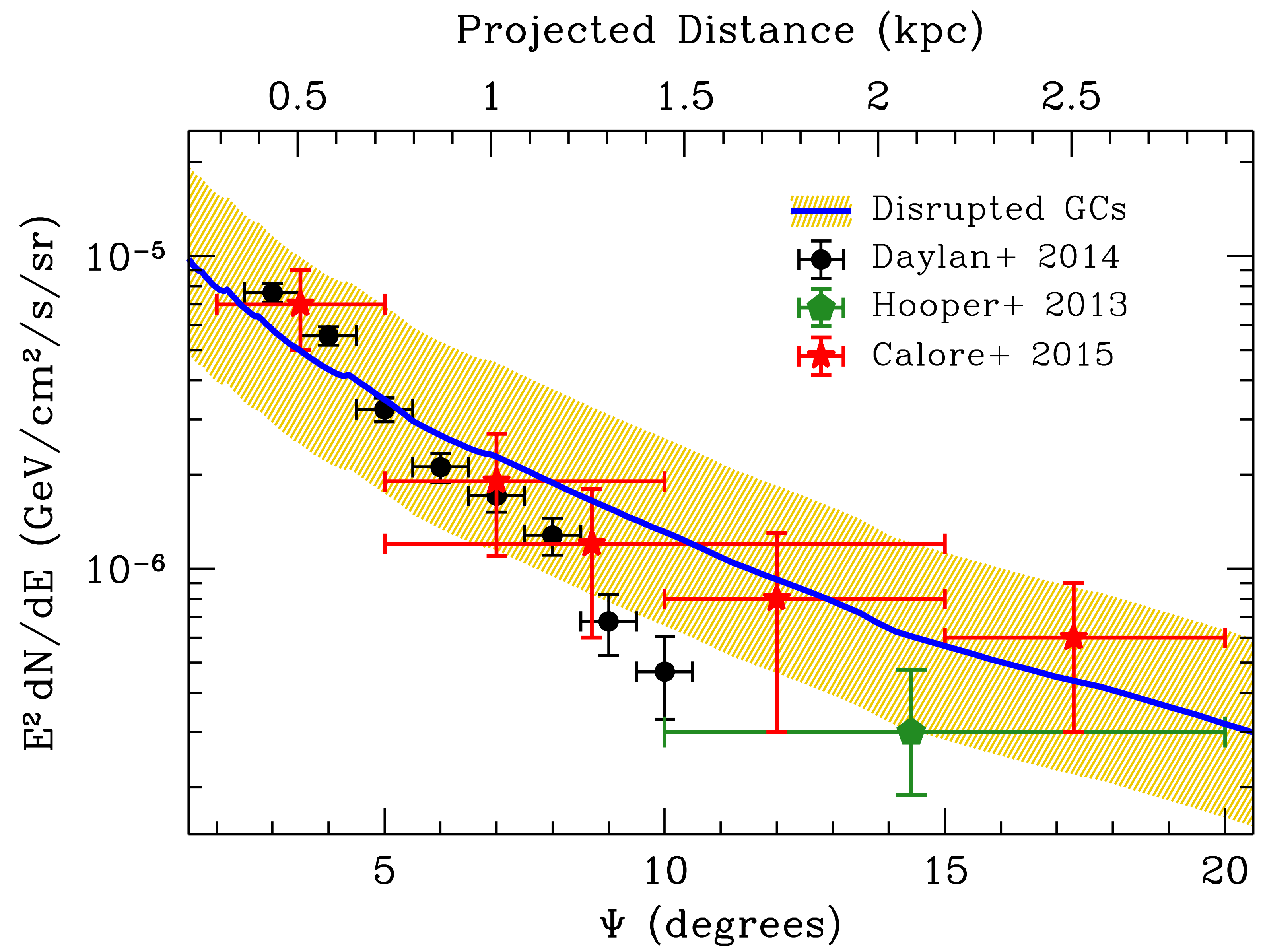
$$\frac{dN}{dE_{e^\pm}} \propto E_{e^\pm}^{-1.8} \exp(-E_{e^\pm}/500\,\text{GeV})$$



c.f. Murgia + Fermi Collaboration

See also Kistler 2015 (arXiv:1511.01159)

Millisecond Pulsars will also contribute



From inspiraling star clusters

Brandt + Kocsis (2015)

Modeling Millisecond Pulsars

Modified Population Synthesis:

MSPs are born following galactic stellar density (bulge+disk)

Pulsars receive a small kick: $\bar{v}_k \approx 80\,\mathrm{km\,s}^{-1}$

Lyne+1998

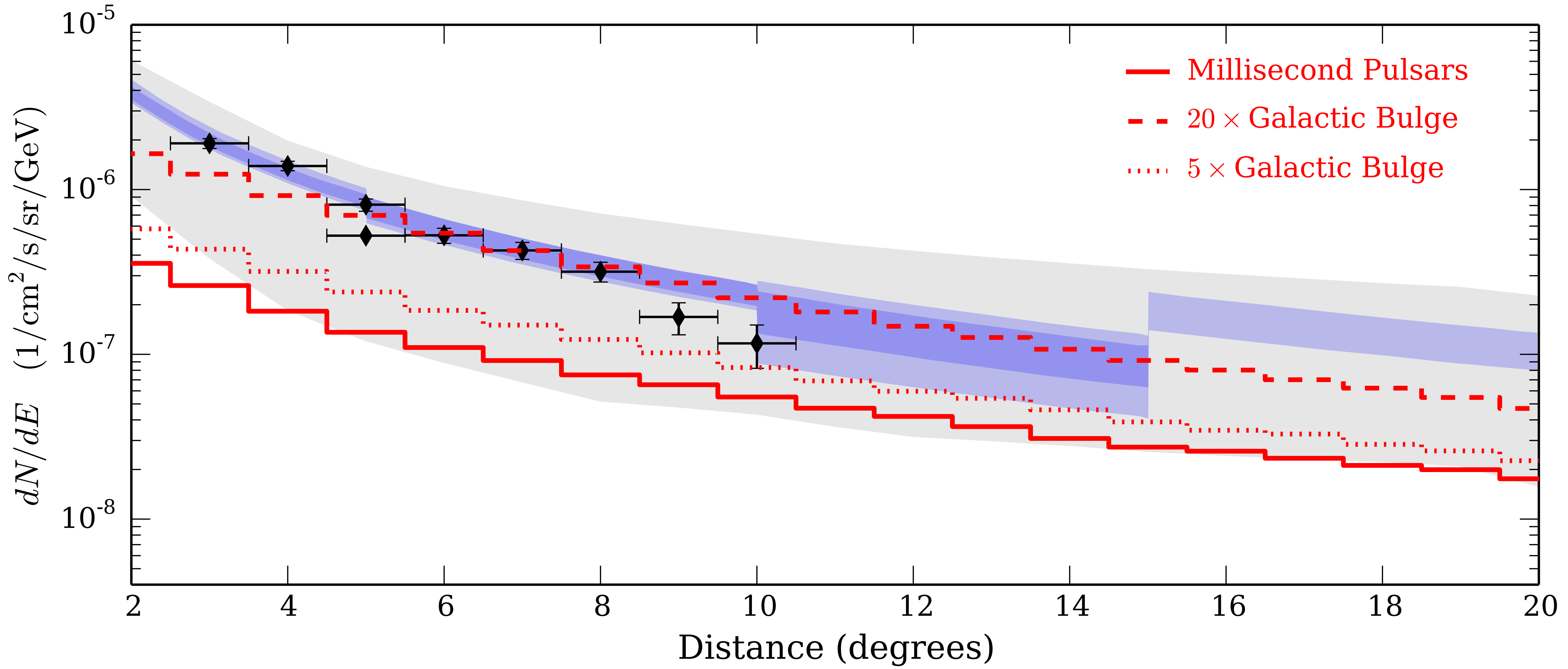
Evolve pulsar orbits until present time

Continuously populate galaxy until match bright population

Vary specific pulsar formation rate of bulge - up to 20x disk

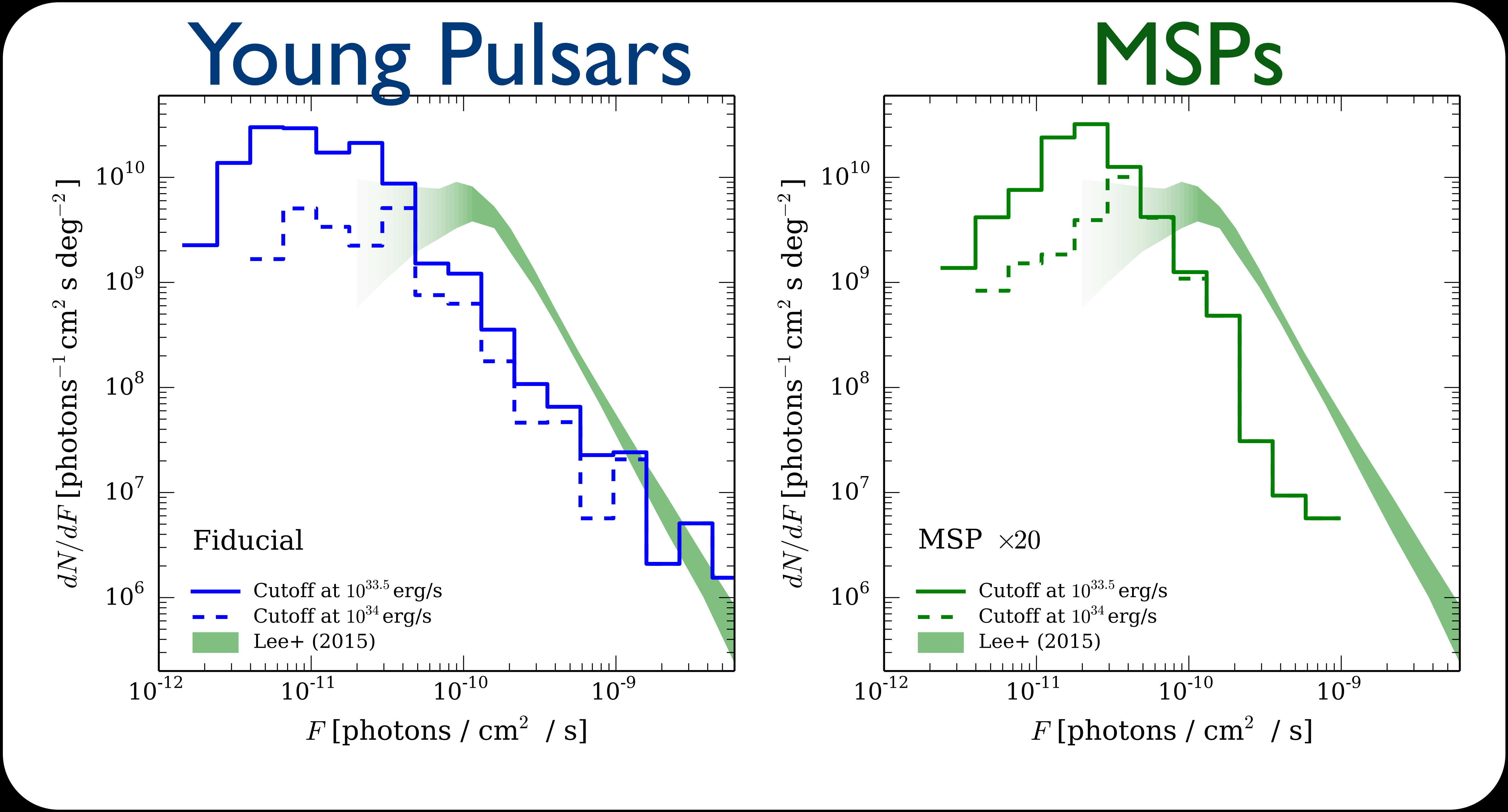
Cf. Brandt + Kocsis (2015)

Modeling Millisecond Pulsars



4% of Bulge = disrupted 47 Tuc's

Comparison with Photon Statistics



Cf. Lee+ 2015

Conclusions

Naturally expect a large population of young pulsars in the GC.

Similar Spectrum, Amplitude, and Morphology to the GeV excess.

Without fitting/tuning the model.

Model is consistent with radio pulsar population near the GC.

Expect spectral evolution in latitude. Unclear how this is affected by template fits between Disk and NFW profiles.

Conclusions

Naturally expect a large population of young pulsars in the GC.

Similar Spectrum, Amplitude, and Morphology to the GeV excess.

Still ~ factor of two uncertainty in the overall amplitude of signal.

Millisecond pulsars require a 6-20x boost in the bulge population

See Brandt + Kocsis 2015

Further *Fermi* observations of the faint pulsar population, the GC, and dwarfs are needed!

What about the ATNF?

e.g., Linden 2015

Within 10 degrees of the GC:
285 Pulsars in ATNF
They don't correlate with the gamma ray hot spots

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285 Pulsars in ATNF
They don't correlate with the gamma ray hot spots

211 with P > 15 ms

48 with P>15 ms and $\dot{E} > 10^{33.5}\,\mathrm{erg\,s^{-1}}$.

28 with P>15 ms and $\dot{E} > 10^{34}\,\mathrm{erg\,s^{-1}}$.

5 were discovered by Fermi in their blind search

What about the ATNF?

e.g., Linden 2015