Testing the msec Pulsar Scenario of the Galactic Center γ-Ray Excess with Very High Energy γ-Rays

Qiang YUAN (UMass)

Kunihito IOKA (KEK, Sokendai)

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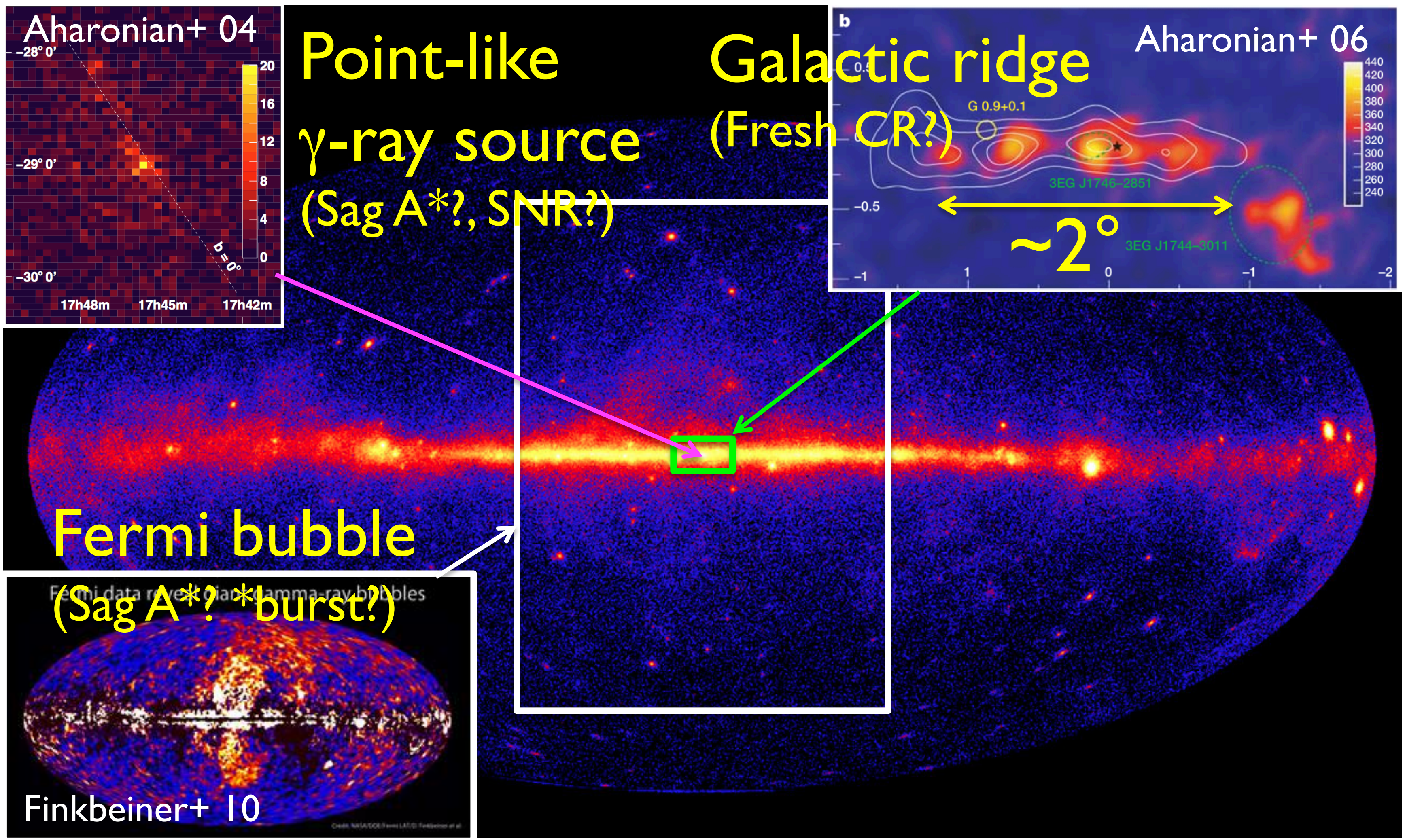
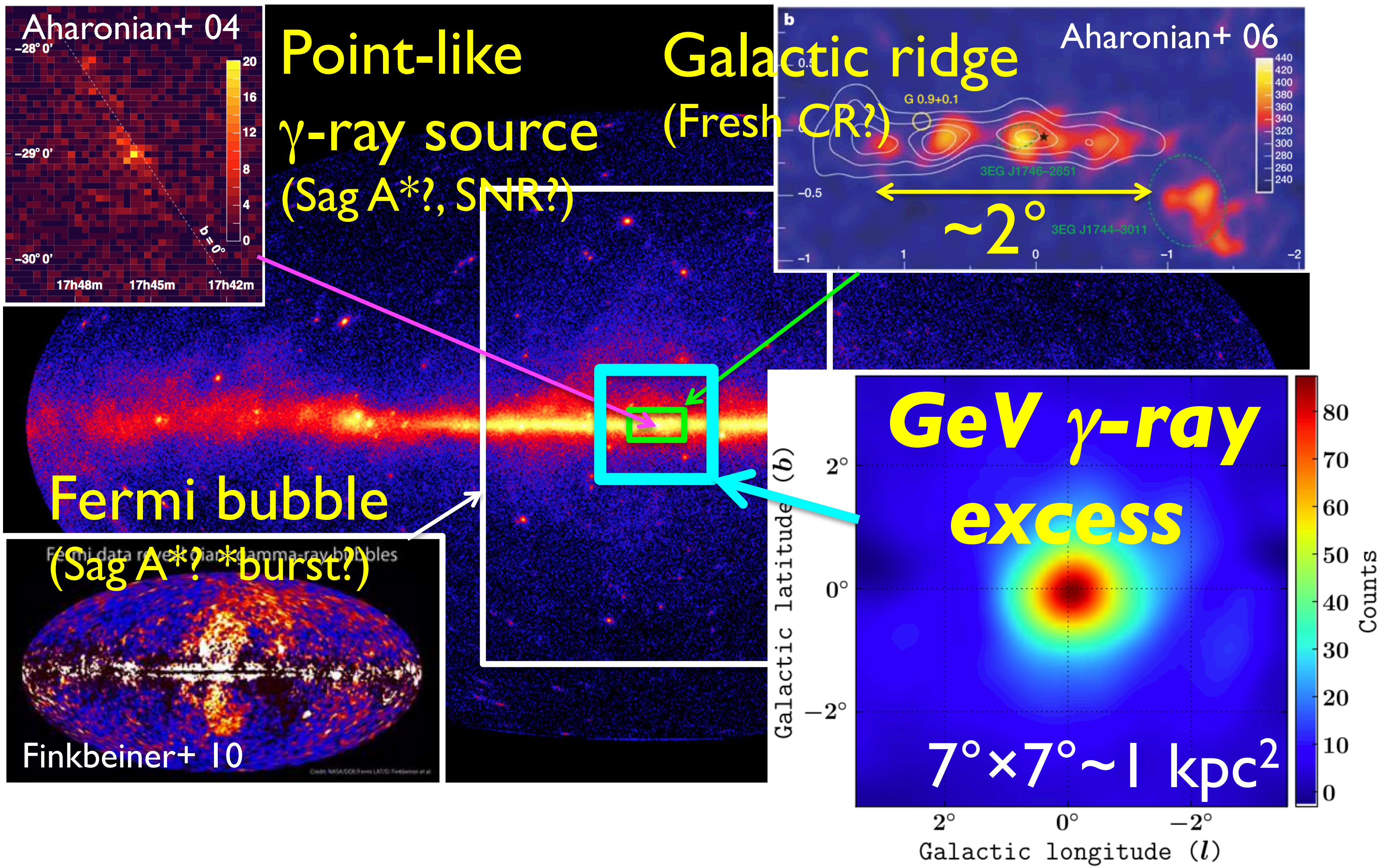
KEK
HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

The Graduate University for Advanced Studies
Sokendai

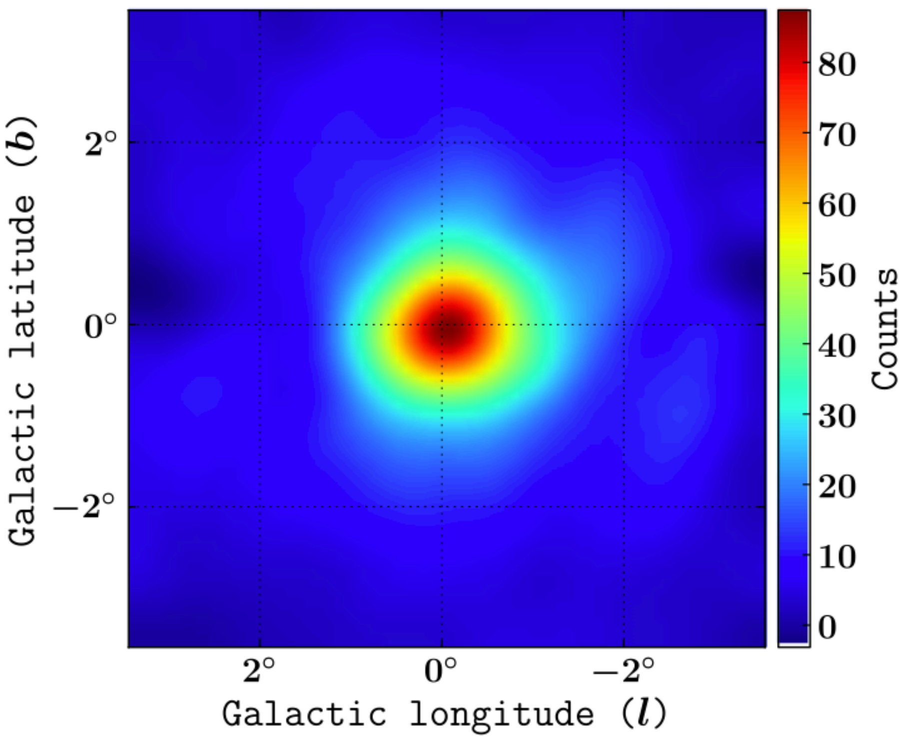
Galactic Center



Galactic Center



GeV γ-ray Excess

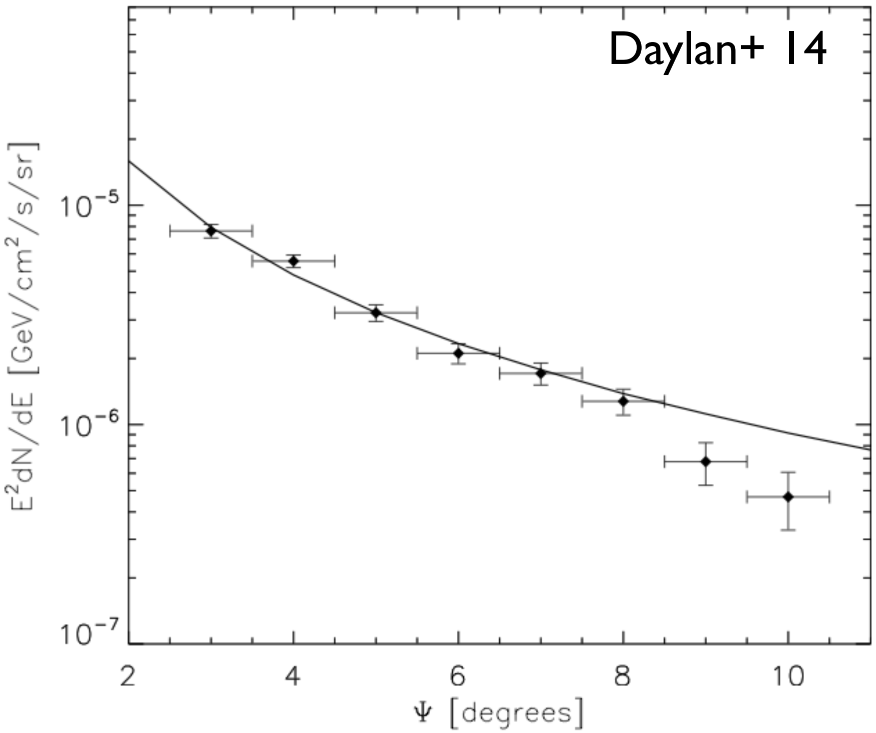


Goodenough & Hooper 09
Vitale & Morselli 09
Hooper & Goodenough 11
Boyarsky+ 11
Hooper & Linden 11
Abazajian & Kaplinghat 12
Gordon & Macias 13
Huang+ 13
Abazajian+ 14
Daylan+ 14
Zhou+ 14
Calore+ 14
Bertone+ 15 …

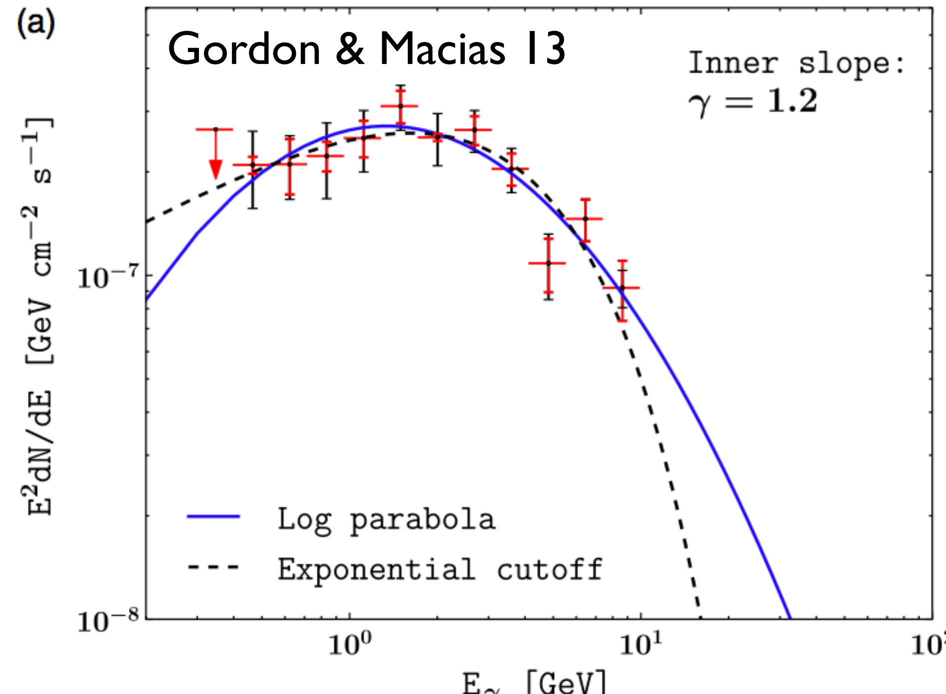
Caveat: Background model systematics is not small

GeV Excess Characteristic

Spatially Extended



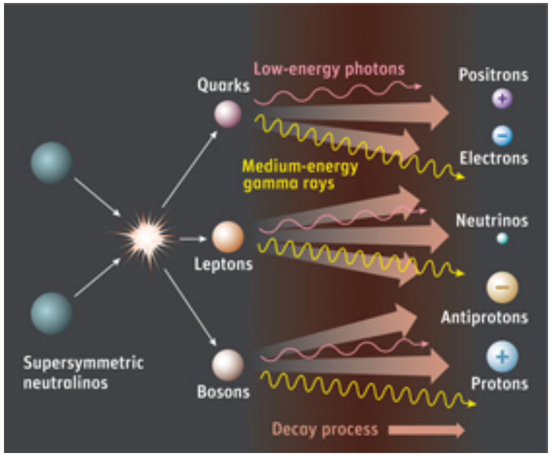
Spectral Peak at GeV

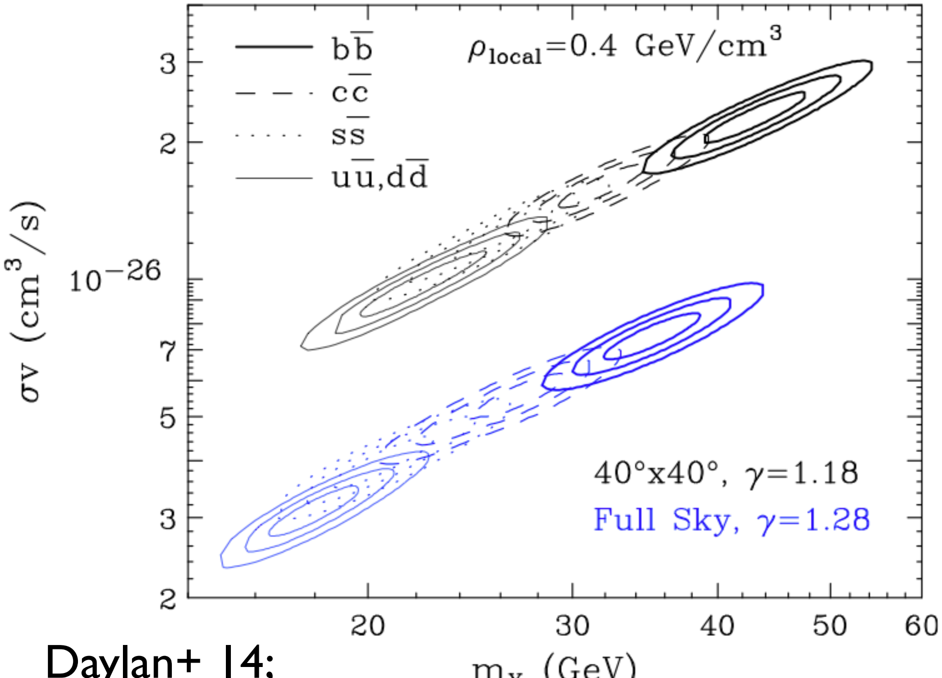


Spherical (Axis ratio within 20%)
Flux~$r^{-2.5}$ (gen NFW γ~1.3)
Extend to >1.5kpc (10°)

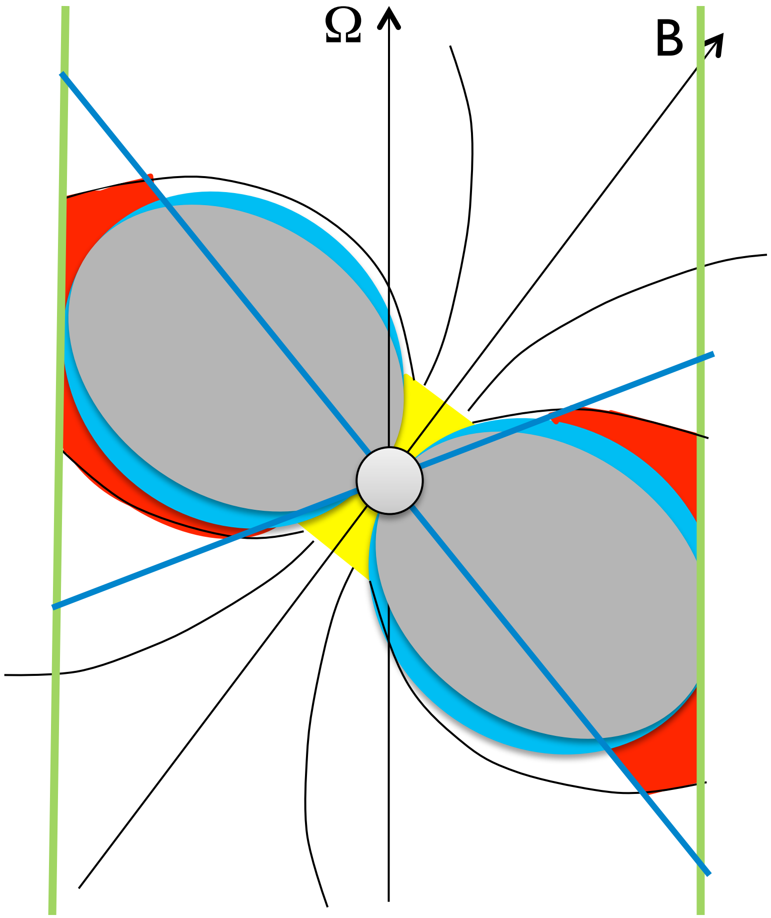
~30 GeV WIMP annihilation
~msec pulsar spectrum

Dark Matter v.s. Pulsar





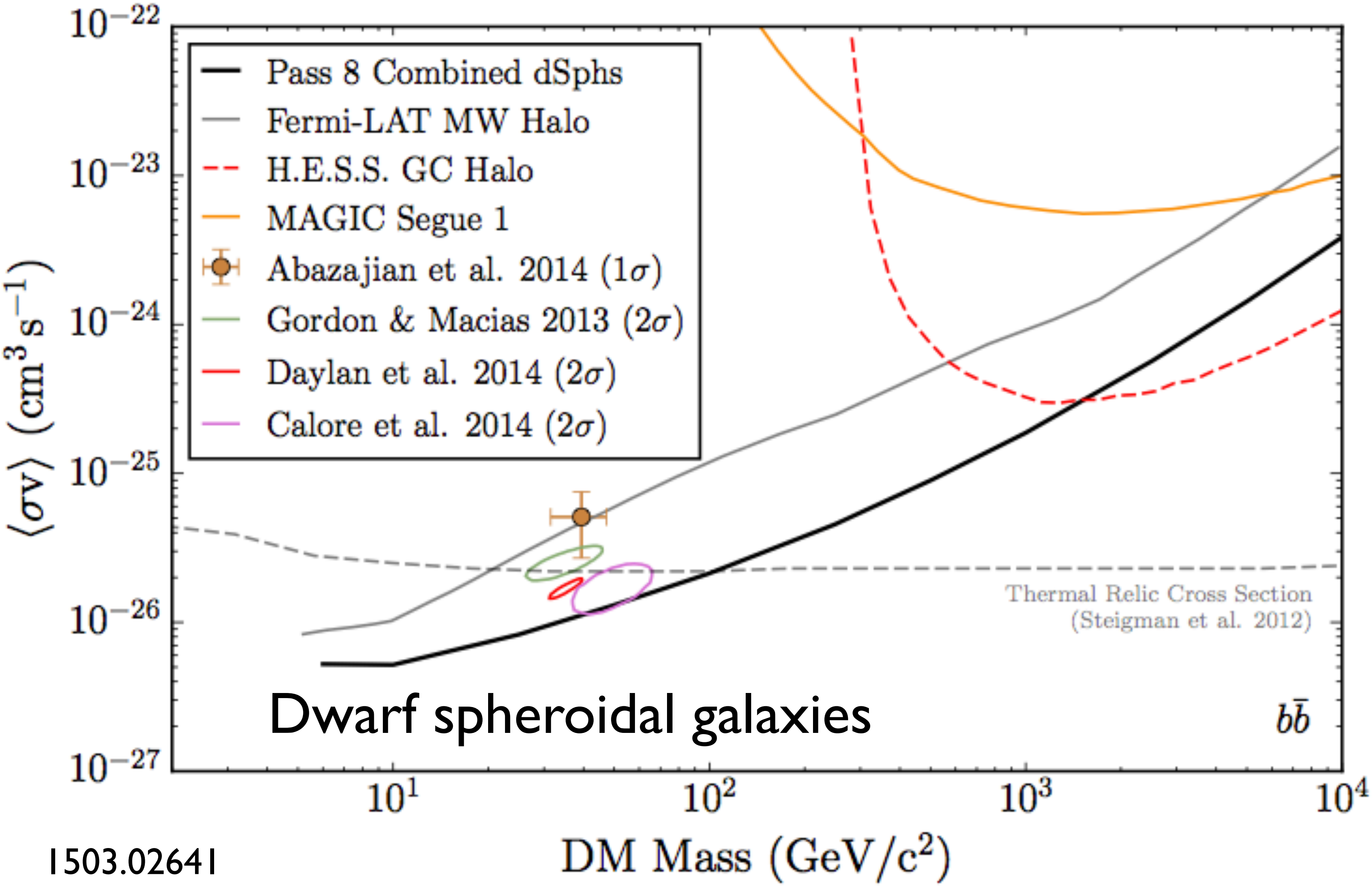
Daylan+ 14;



$$\Delta V \approx \frac{\Omega^2 B R^3}{2c^2} \sim 10^{14}\,\mathrm{V}\left(\frac{\Omega}{100\ \mathrm{s}^{-1}}\right)^2\left(\frac{B}{10^8\,\mathrm{G}}\right)\left(\frac{R}{10^6\,\mathrm{cm}}\right)^3$$

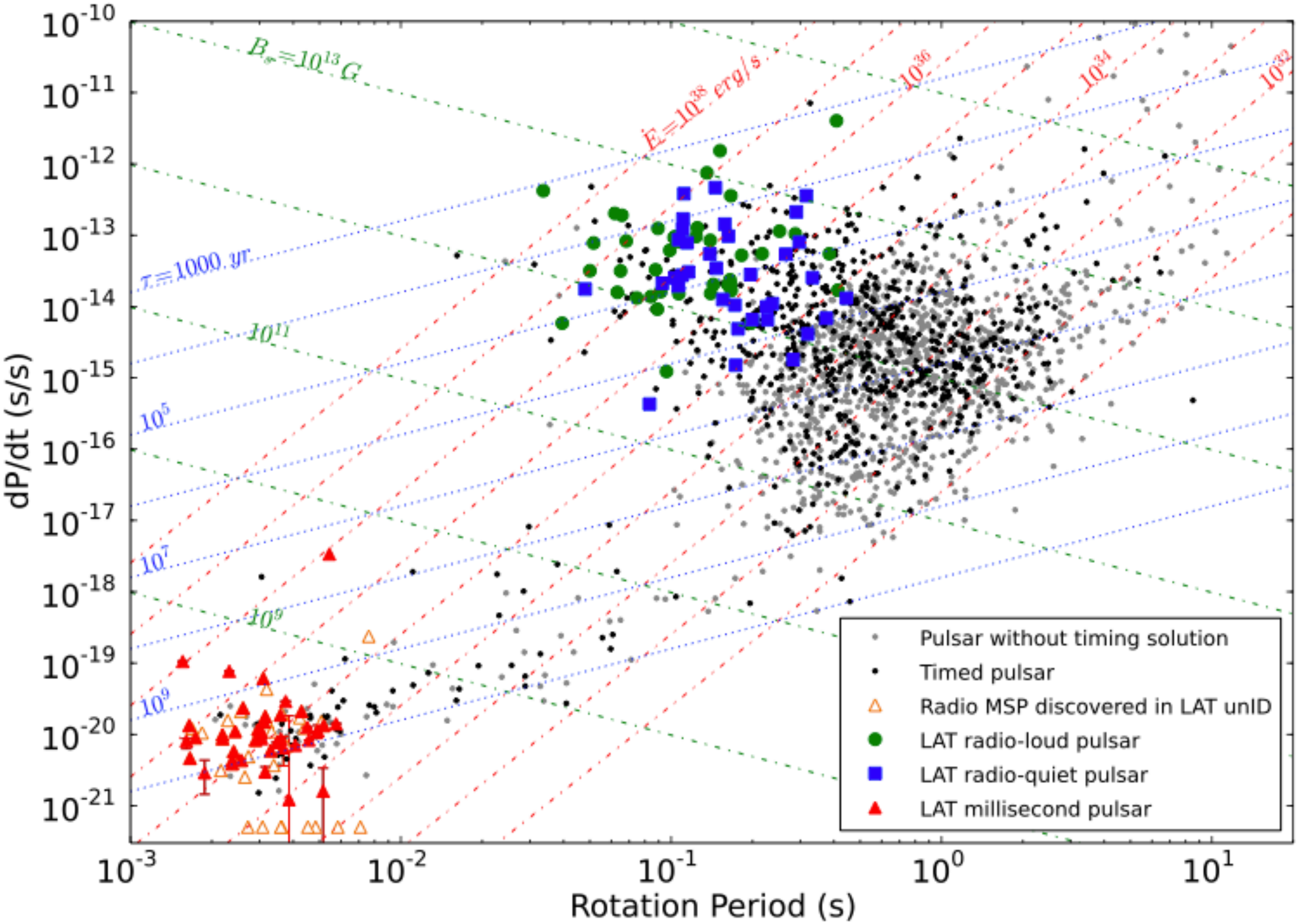
Or cosmic-ray bursts? (Carlson & Profumo 14; Petrovic+ 2014; Cholis+ 15)

6yr Fermi Limits on DM



1503.02641

γ-ray Pulsars



Fermi:

γ-ray PSRs

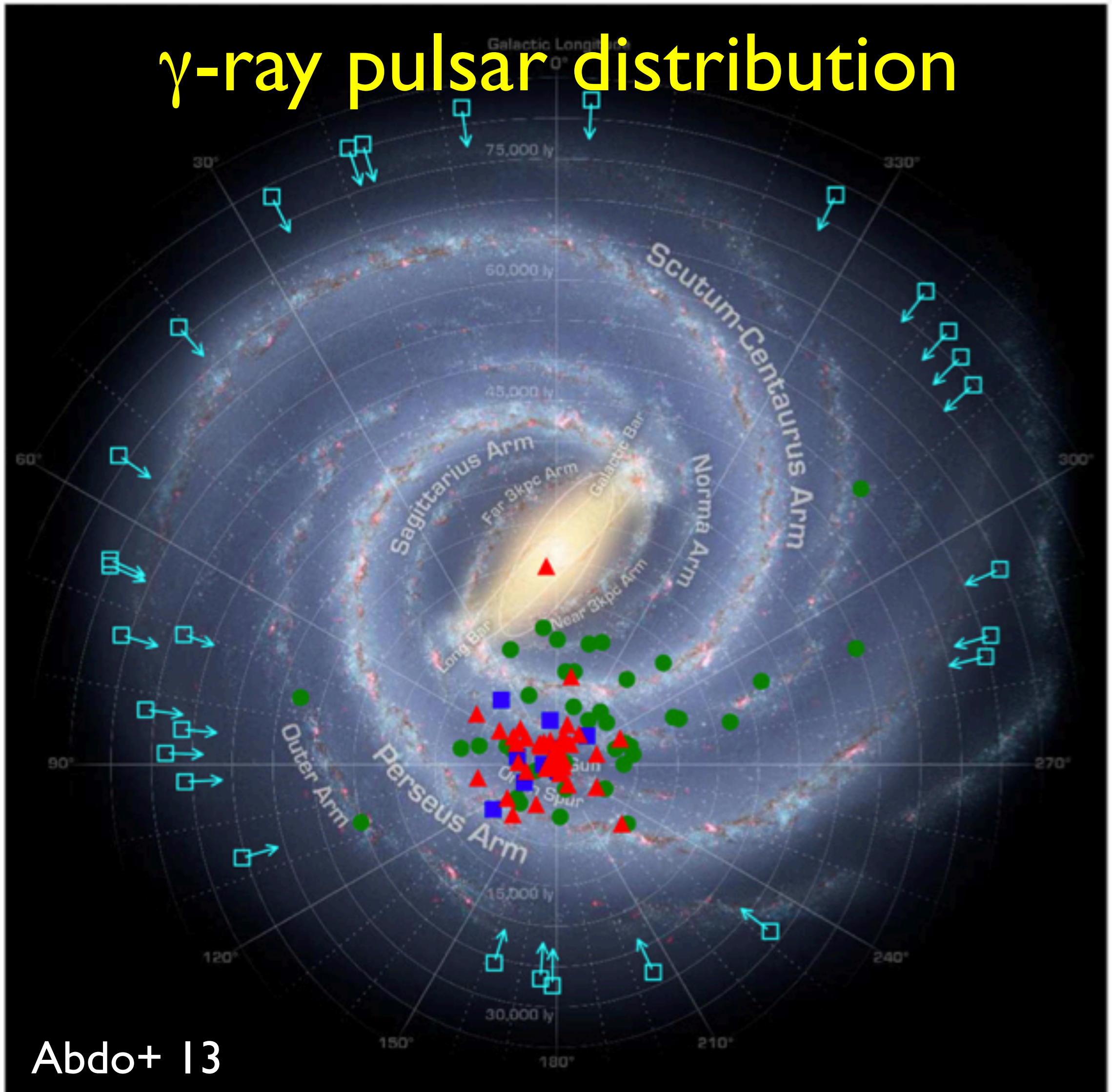
6 → >160

γ-ray MSPs

0 → >60

Abdo+ 13

Most Pulsars are Unseen



We are observing only nearby pulsars

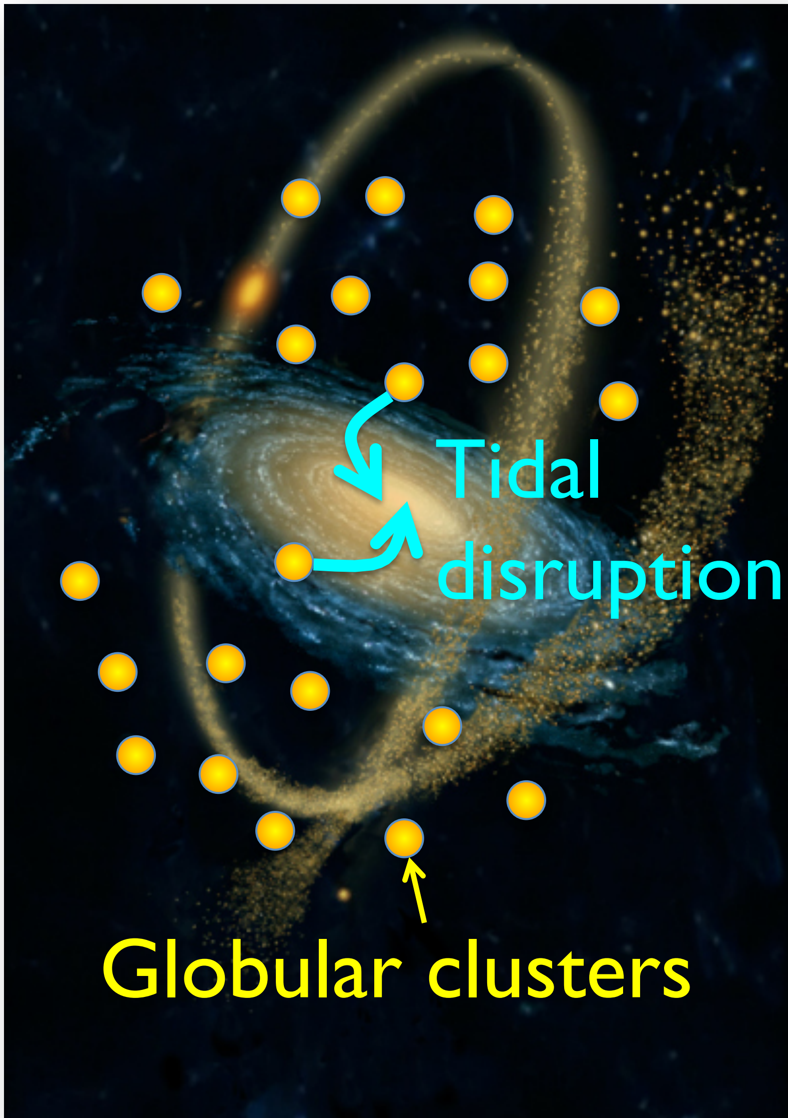
MSPs are faint

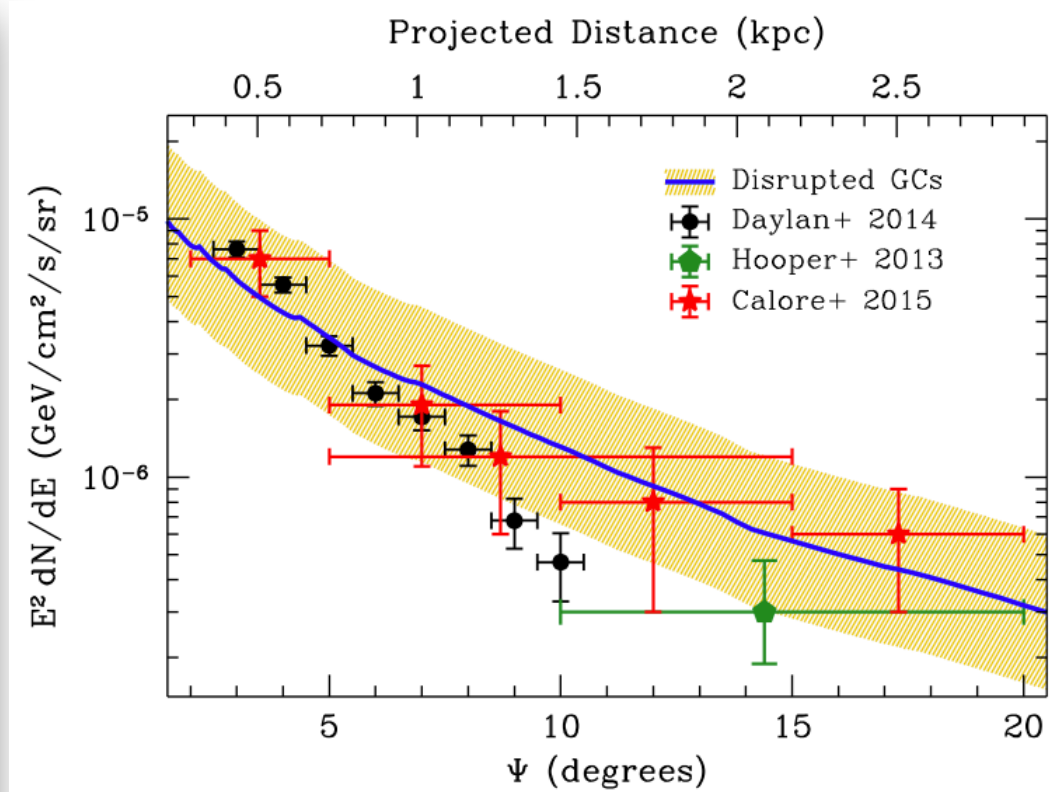
Galactic center may have ***O(10$^{3\text{-}4}$)*** MSPs ⇒ GeV excess?

Abazajian 11; Gordon & Macias 13; Yuan & Zhang 14; Petrovic+ 15; Bartels+ 15; Lee+ 15
Hooper+ 13; Cholis+ 15

▲MSP; ●Radio-loud; ■Radio-quiet

Possible Origin of Pulsars





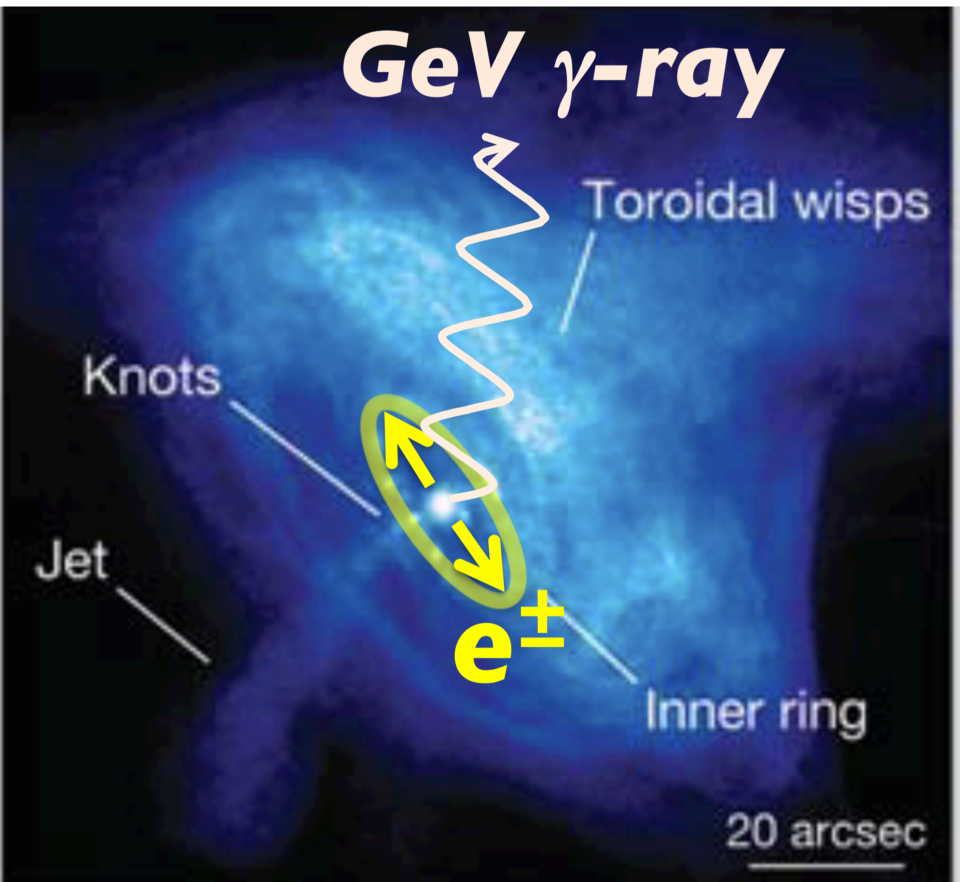
Brandt & Kocsis 15
Bednarek & Sobczak 13

Low Mass X-ray Binaries are rare in the bulge

Pulsar Energy Budget

Most spin-down energy ⇒ Pulsar wind

(Relativistic plasma of magnetized $e^{\pm}$)

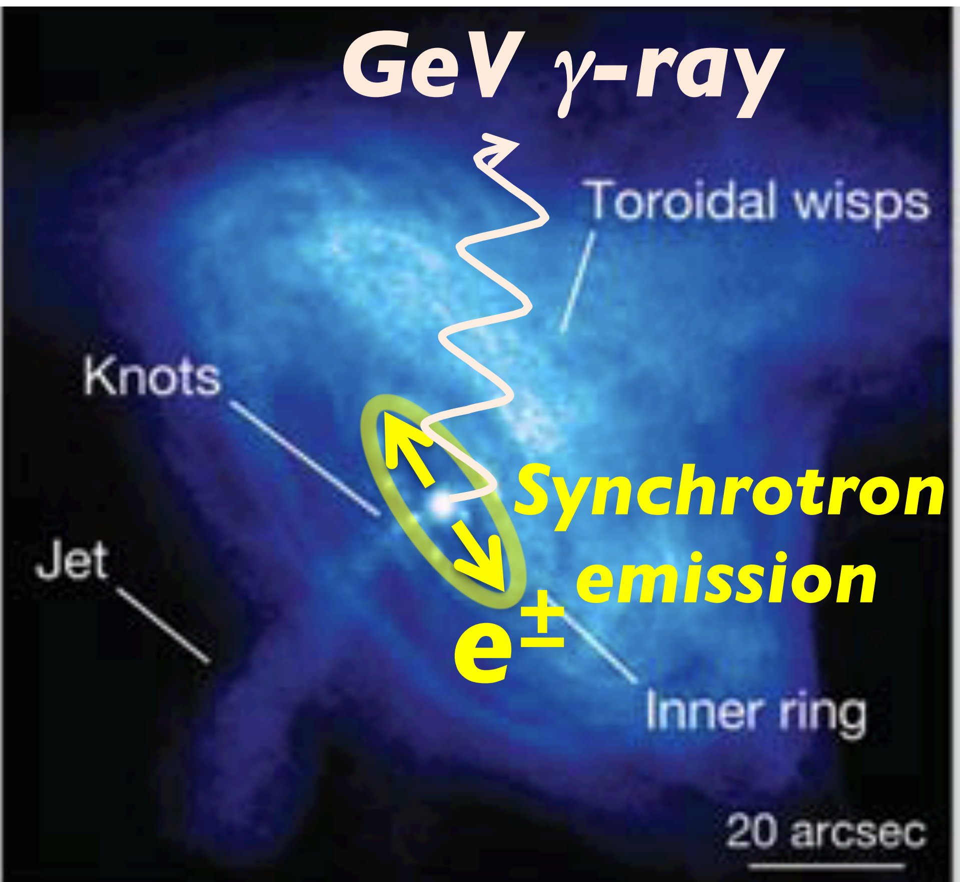


$$L_{e^{\pm}} \sim 10 L_{\gamma}$$

$e^{\pm}$ has ~TeV energy
with power law spectrum
via shock acceleration

Inverse Compton

In young pulsars
Pulsar wind ⇒ Synchrotron emission



msec pulsars are old
⇒ Pulsar wind nebula becomes large
⇒ B becomes weak
⇒ Synchrotron is weak

Kashiyama+ 11

⇒ $e^{\pm}$ escape to ISM
⇒ Inverse Compton

GALPROP

Moskalenko & Strong 98

B=5μG

Stellar photon density ~10 eV cm^{-3}

⇒ Inverse Compton >> Synchrotron

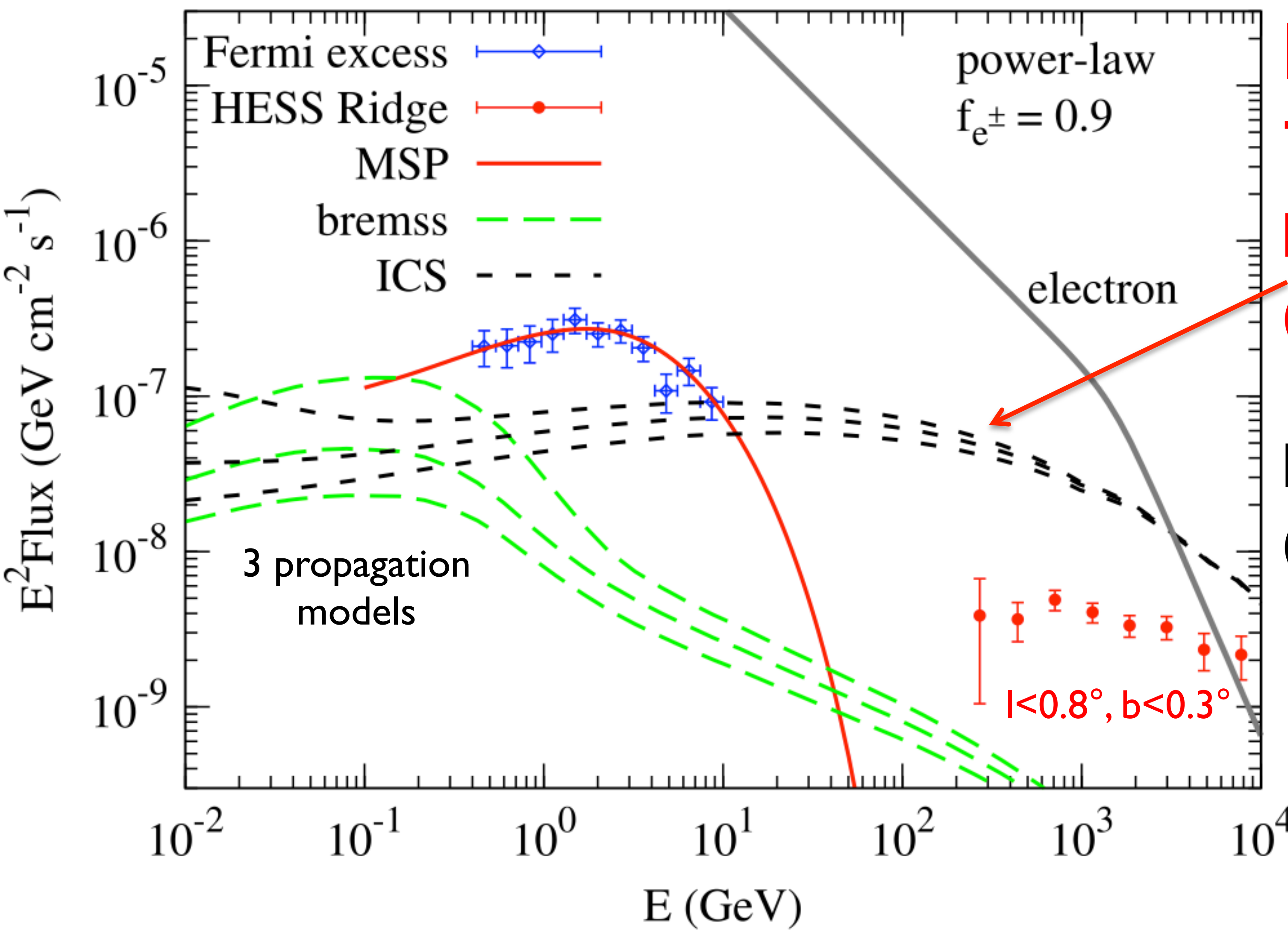
Table 2
Cosmic Ray Propagation Parameters

Yuan & KI 15

	D_0 (10^{28} cm^2 s^{-1})	z_h (kpc)	v_A (km s^{-1})	δ
1	2.7	2	35.0	0.33
2	5.3	4	33.5	0.33
3	9.4	10	28.6	0.33

Note. The columns from left to right are the diffusion coefficient D_0 at the reference rigidity $R = 4$ GV, the height of the propagation halo z_h, the alfven speed v_A which characterizes the reacceleration, and the power-law index δ of the rigidity dependence of the diffusion coefficient.

Inverse Compton Spectrum

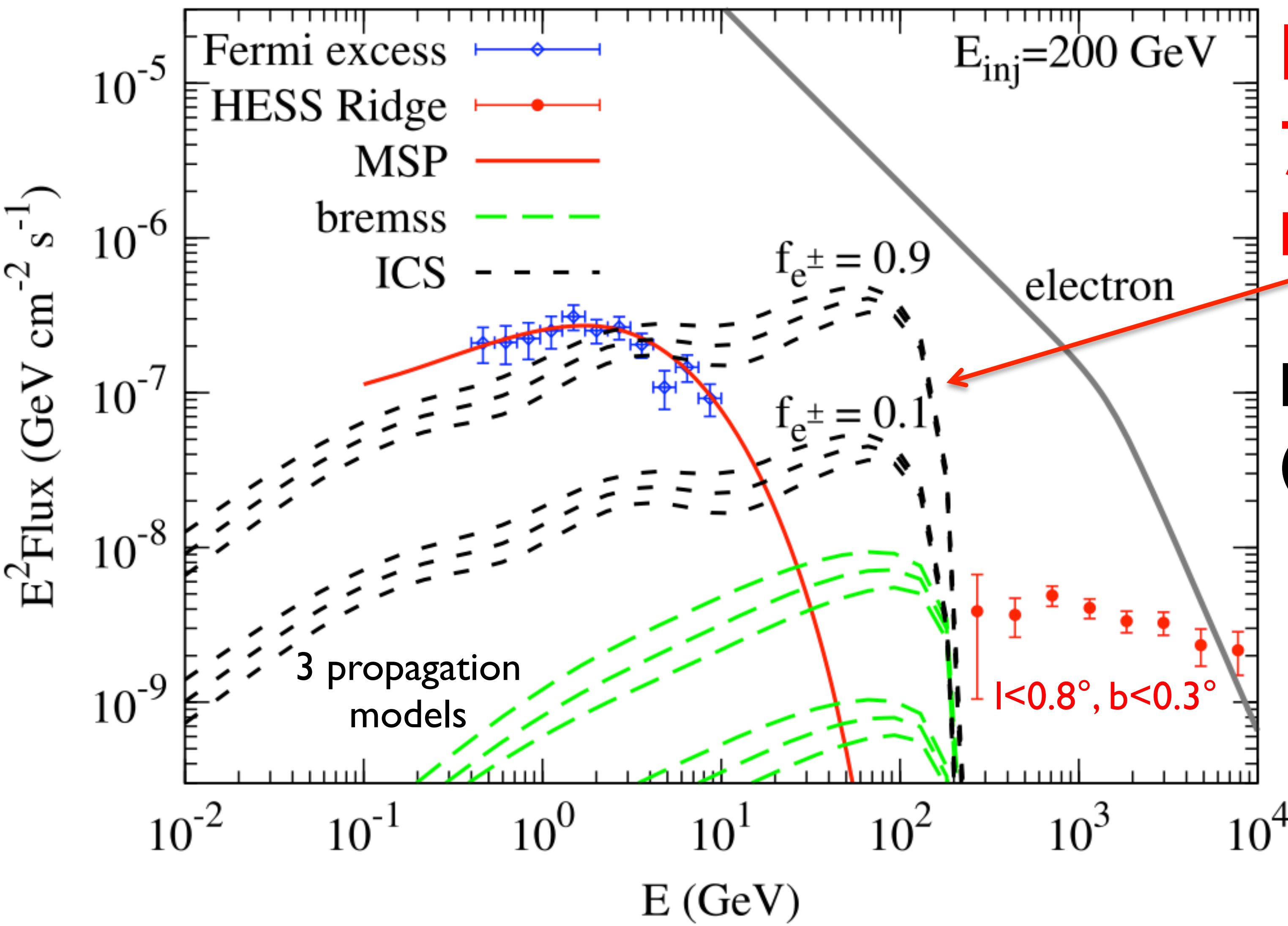


Extended
7°×7°
Power law E^{-2}
(E_{max}=50TeV)

Electron BG
(Isotropic)

Yuan & KI 15

Inverse Compton Spectrum

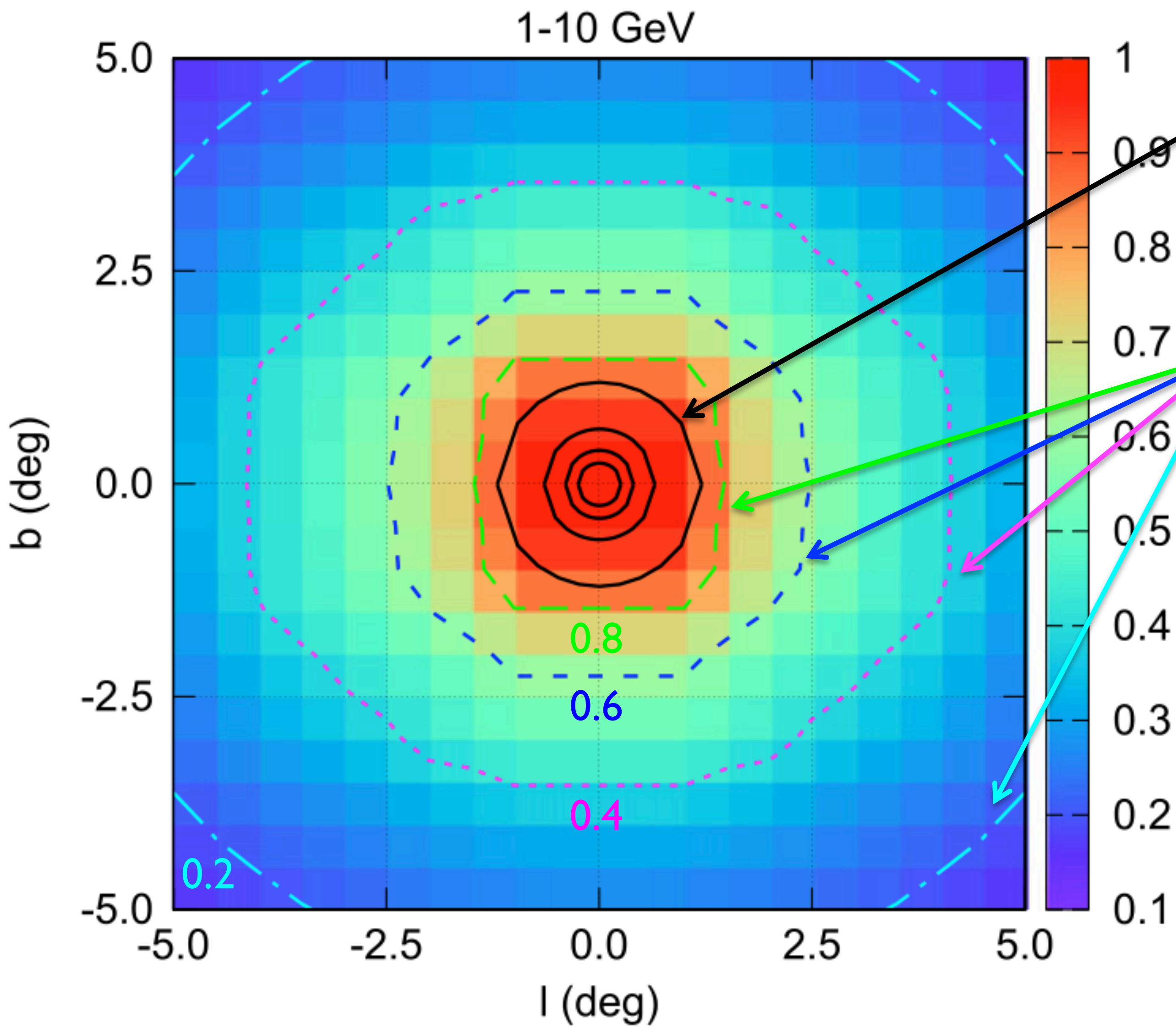


Extended
7°×7°
E_{inj}=200GeV

Electron BG
(Isotropic)

Yuan & KI 15

Skymap

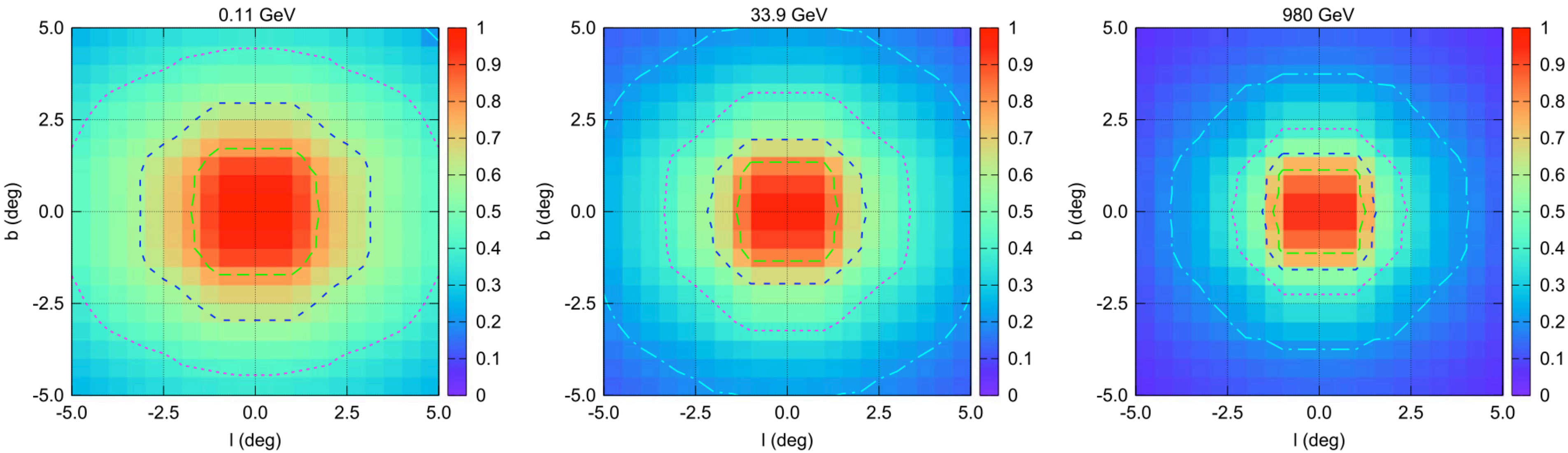


GeV excess
(Directly from pulsars)

Inverse Compton
1-10 GeV
Flux contours
(Propagated $e^{\pm}$)

Yuan & KI 15

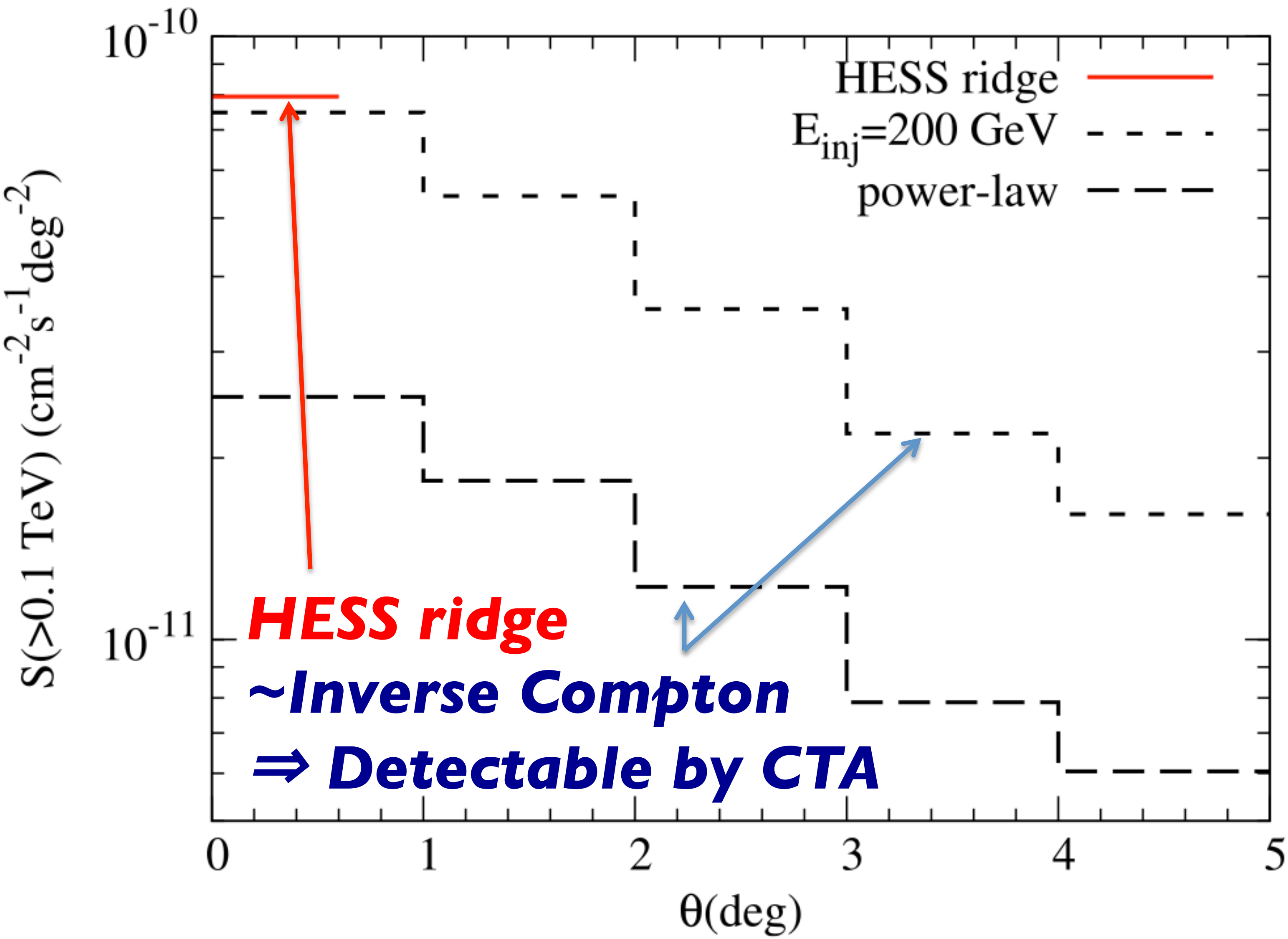
Energy Dependence



More concentrated (More cooling) with increasing energy

Yuan & KI 15

Surface Brightness

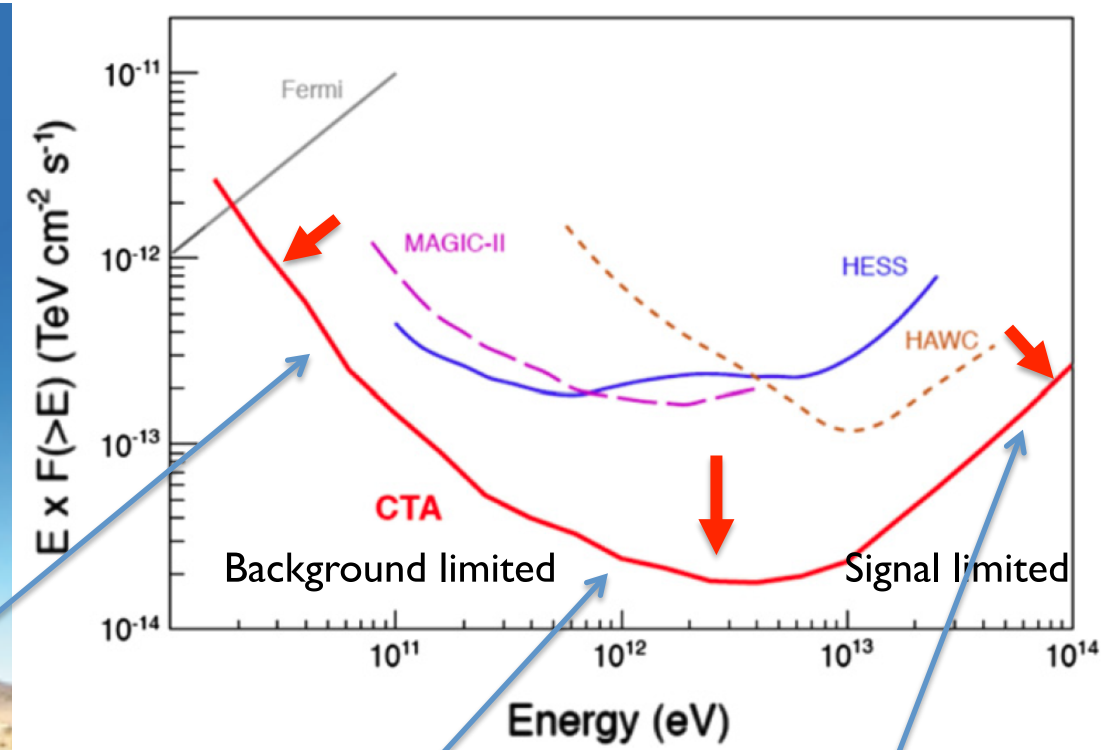


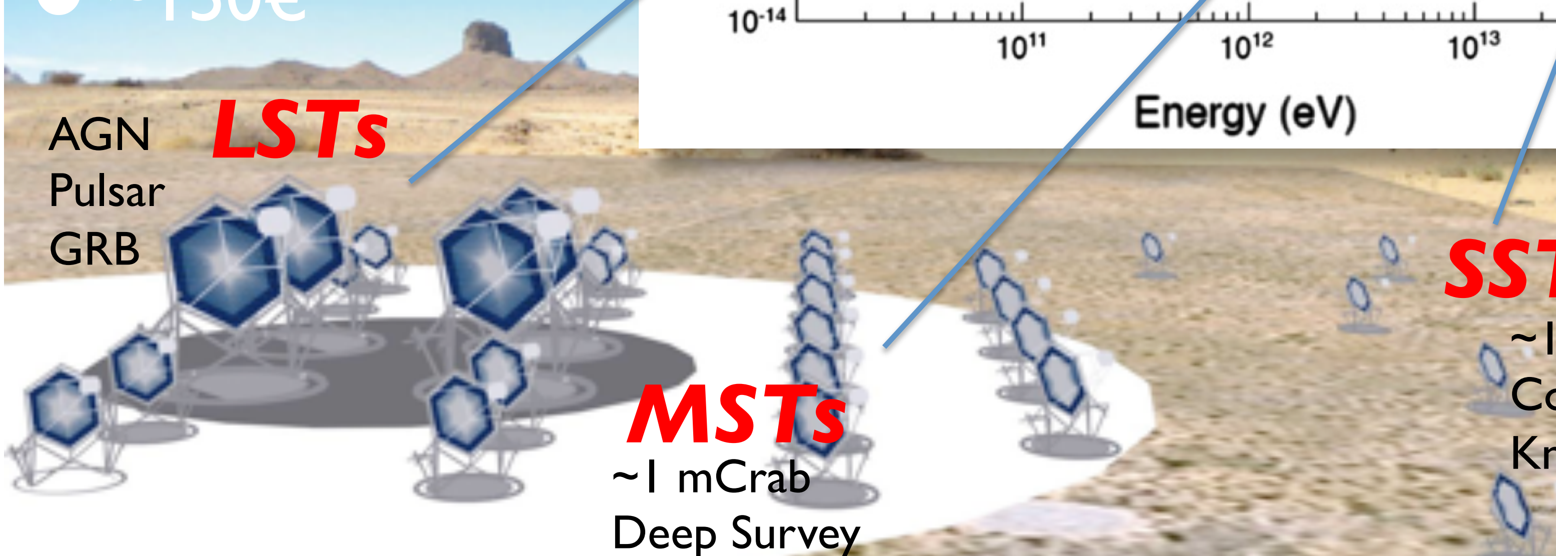
$\sim\theta^{-0.9}$
shallower than GeV

Yuan & KI 15

CTA

- ~20GeV-100TeV
- x10 Sensitivity
- Δθ~1-2 min
- FOV~5-10 deg
- ~20 s slew (LST)
- ~2016-
- ~150€



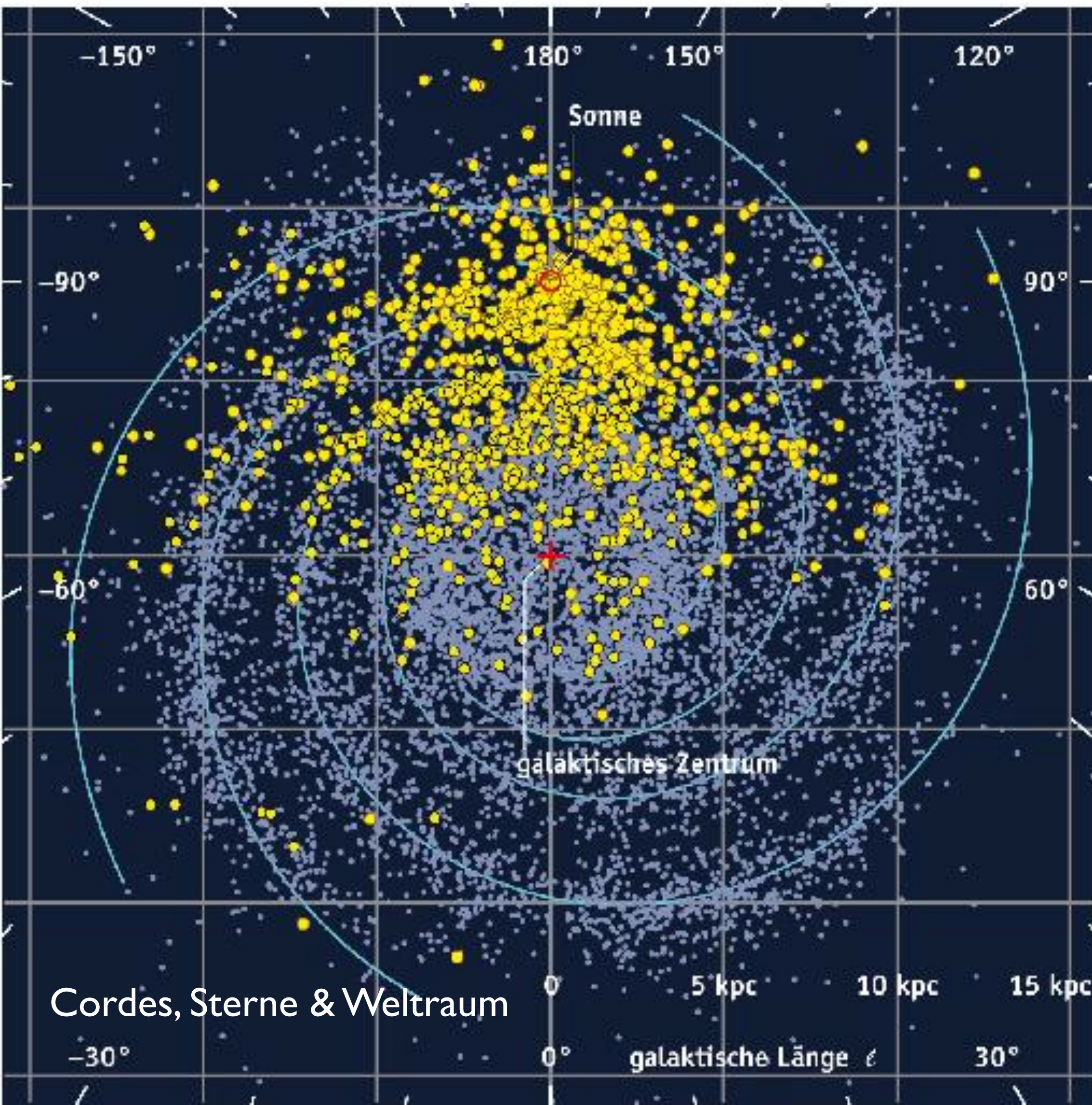


AGN
Pulsar
GRB
LSTs

MSTs
~1 mCrab
Deep Survey

SSTs
~10km^2
Cosmic Ray Knee

SKA



Complete census of Galactic pulsars

~160,000 normal PSR

~40,000 MSP

× breaming ~20%

– Test strong gravity

– Pulsar timing array

Summary

- ***GeV γ-ray excess***
  - Dark matter v.s. msec Pulsars
- ***Most energy ⇒ $e^{\pm}$ wind***
- ***Inverse Compton***
  - Extended TeV γ-rays
  - ***CTA!***

Bechtol's talk: Fermi already suggests IC
6-30× stronger than baseline models

Advertisement

- ***Yutaka OHIRA (Aoyama Gakuin University)***
  - Cosmic-ray hardenings in the light of AMS-02
- ***Kazunori KOHRI (KEK)***
  - Can we explain AMS-02 antiproton and positron excesses simultaneously?
- ***Norita KAWANAKA (U. Tokyo)***
  - Neutrino Flavor Ratios Modified by Cosmic Ray Secondary-acceleration

Thank You

Yuan & Ioka 2015

$$L_{\rm sd} = \gamma_w \dot{N}_{\rm GJ} m_e c^2 \kappa (1 + \sigma)/f_{e^\pm},$$

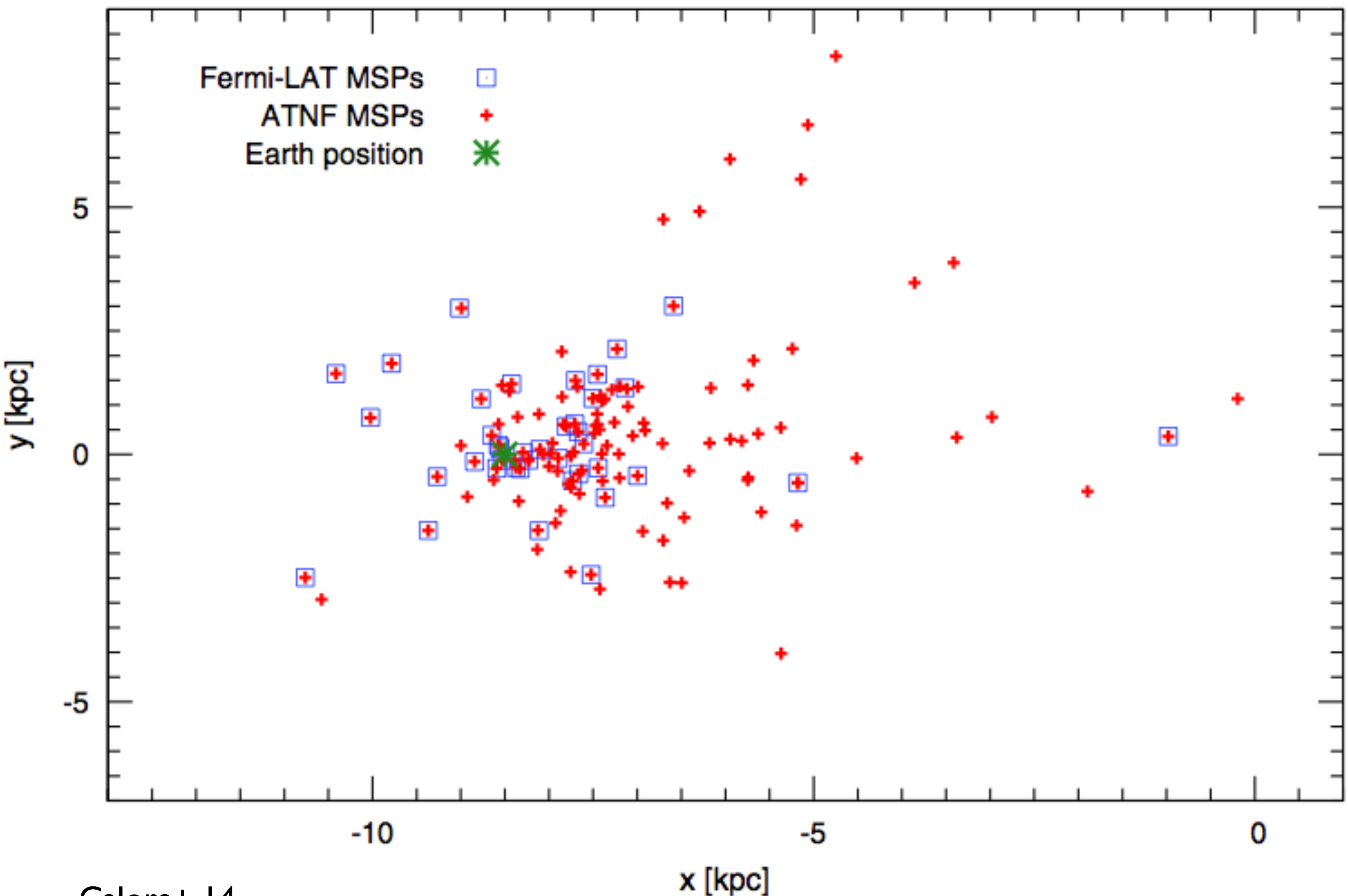
$$\gamma_w = 4 \times 10^5 \left(f_{e^\pm}/\kappa_3\right) L_{34}^{1/2},$$

Table 1

Injection $e^\pm$ Parameters: Injection Energy $E_{\rm inj}$ for the Monochromatic Case, Spectral Index α and Cutoff Energy $E_{\rm max}$ for the Power-law Case, and $e^\pm$ Energy Fraction of the Spindown Power $f_{e^\pm}$

Spectrum	$E_{\rm inj}$ (GeV)	α	$E_{\rm max}$ (GeV)	$f_{e^\pm}$
$\delta(E - E_{\rm inj})$	200	...	...	0.9 or 0.1
$\delta(E - E_{\rm inj})$	20	...	...	0.9 or 0.1
$E^{-\alpha} \exp(-E/E_{\rm max})$	...	2.0	5×10^4	0.9 or 0.1

Fermi-LAT and ATNF catalog MSPs spatial distribution projected on the galactic plane



Calore+ 14