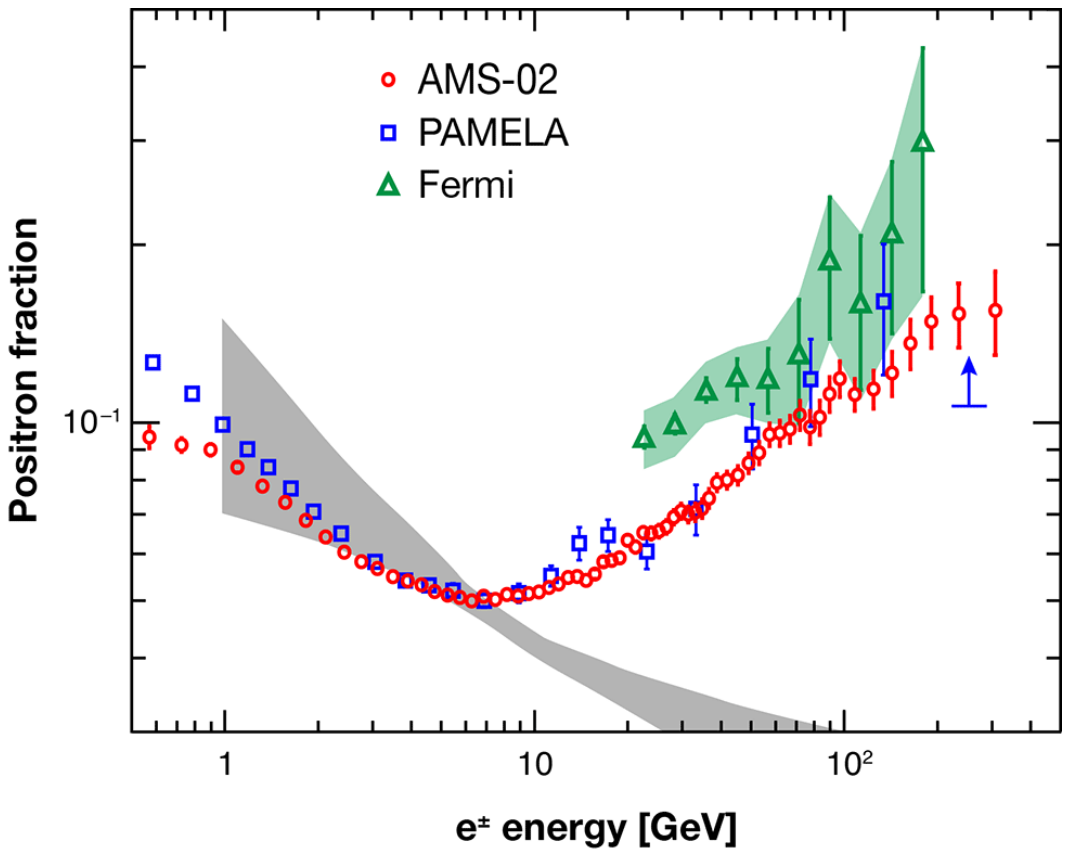
Extended gamma-ray sources around pulsars constrain the origin of the positron flux at Earth

Abeysekara et al. 2017, Science, arXiv:1711.06223

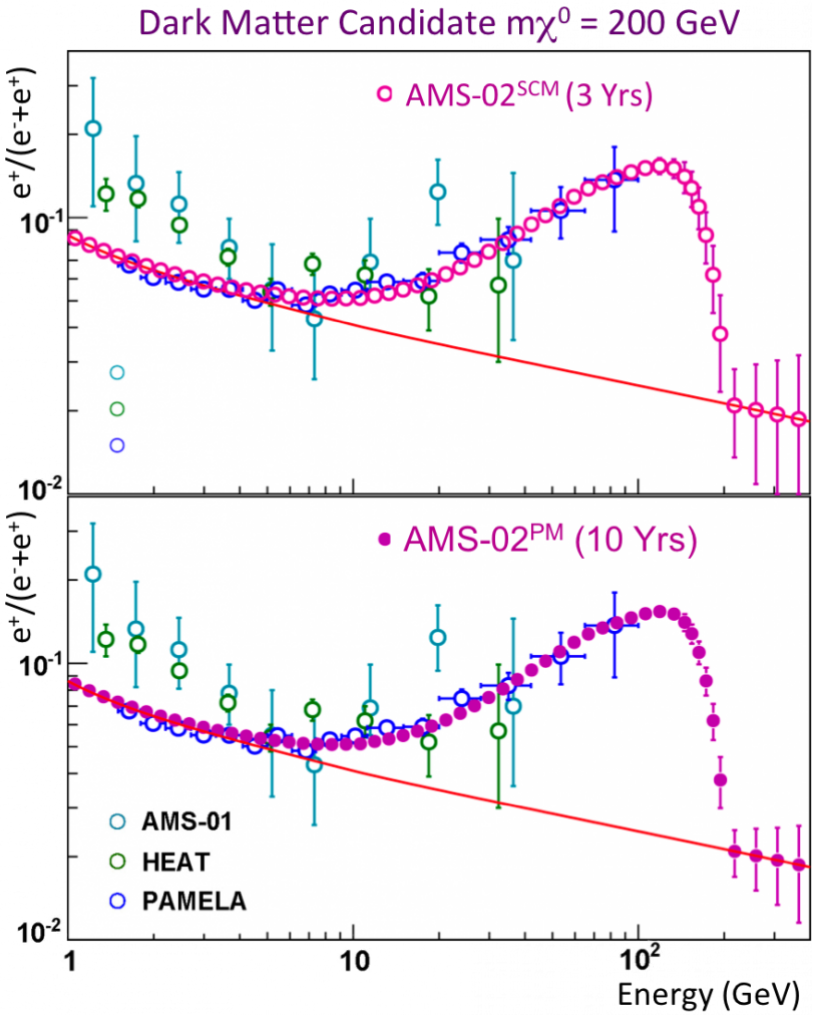
Introduction

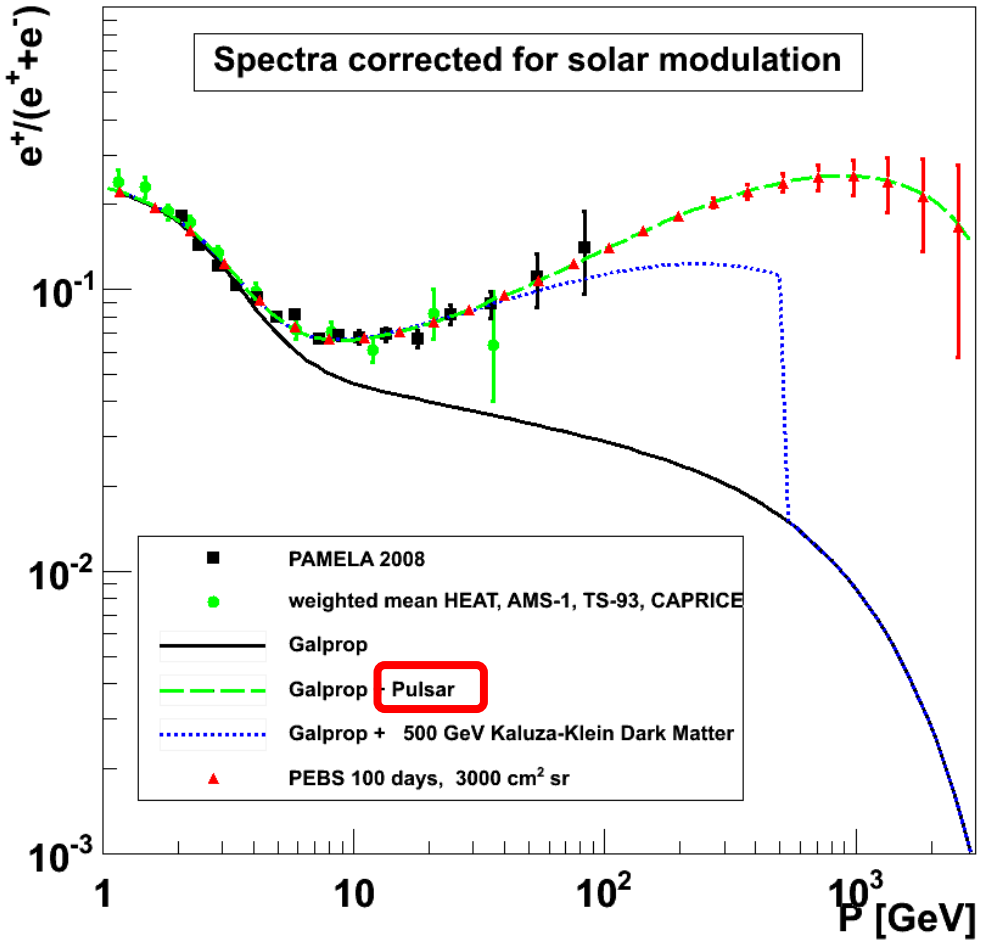
Positron Excess as measured by AMS-02 (PAMELA & Fermi)



Aguila et al. 2013

Dark Matter or Pulsar ? (or sth. Else?)

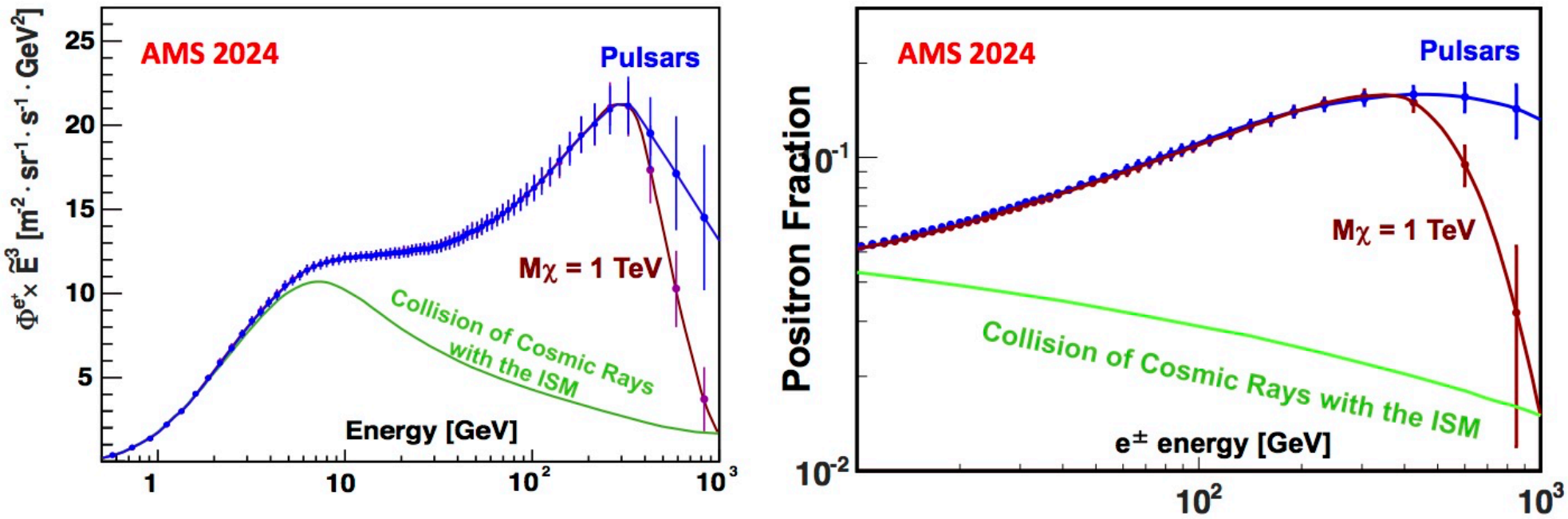




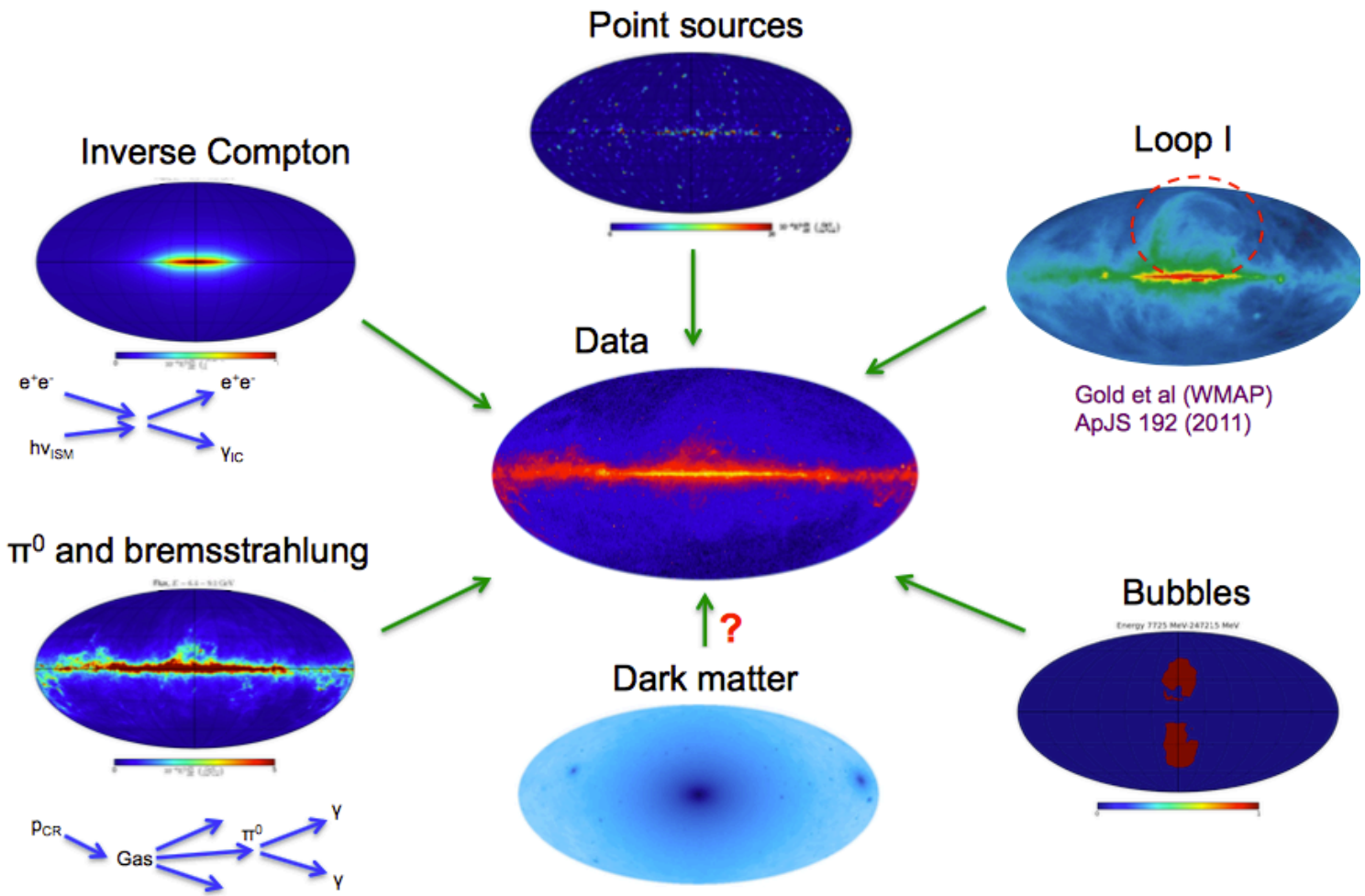
Dark Matter or Pulsar ? (or sth. Else?)

Positron Spectrum **Positron Fraction**

By 2024 we will should be able understand the origin of this unexpected data.



Also Gamma-ray excess at the Galactic Centre (Fermi)



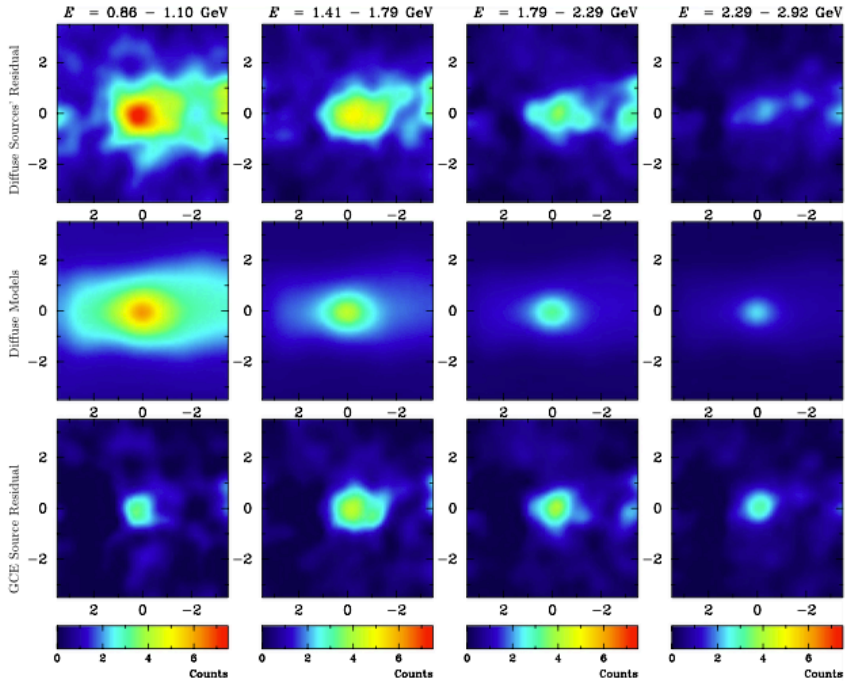
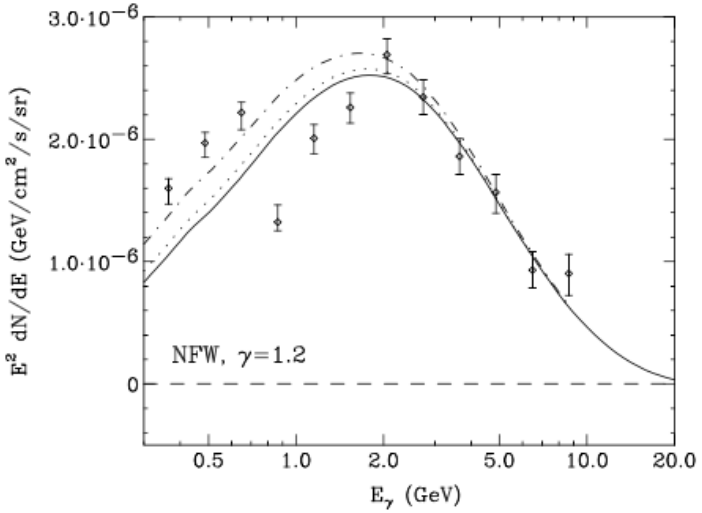
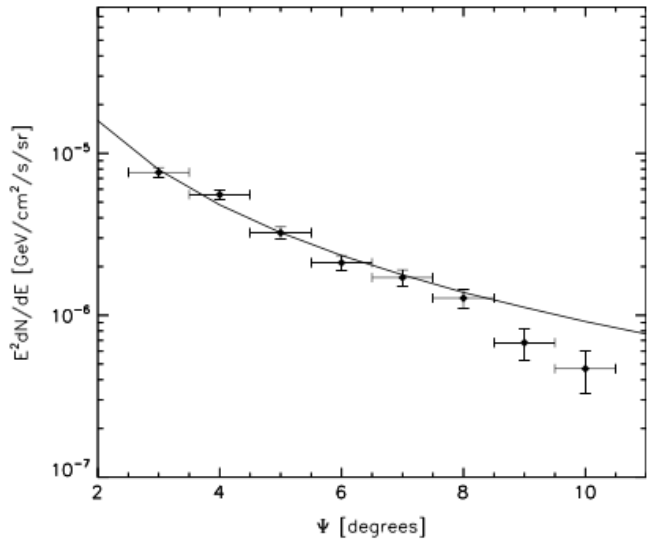


Image: Abazajian+ 2014

Dark Matter Interpretation





Spectral energy distribution

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_0}\right)^{-\zeta} \exp\left(-\frac{E}{E_0}\right)$$

Dark Matter annihilation flux and spatial profile (Abazajian+ 2014; Calore+ 2015; 2016; Hooper+ 2016a,b)

$$\frac{d\Phi}{dE} = \frac{<\sigma v>}{8\pi m_{DM}^2} \frac{J(l,b)}{J_0} \frac{dN_\gamma}{dE}$$

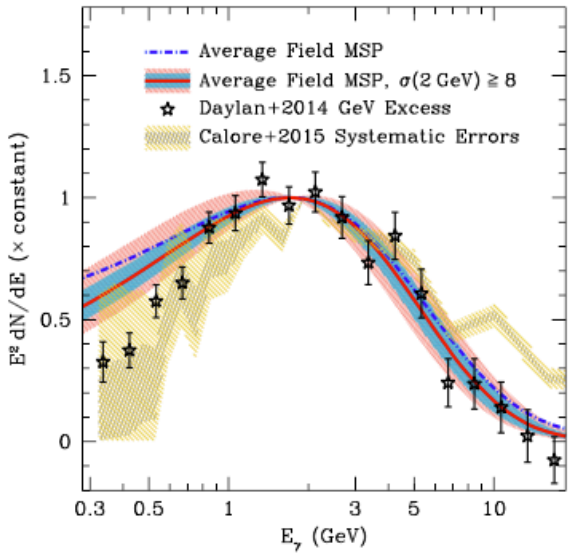
$$J(l,b) = J_0 \int dx \rho^2(r(x,l,b))$$

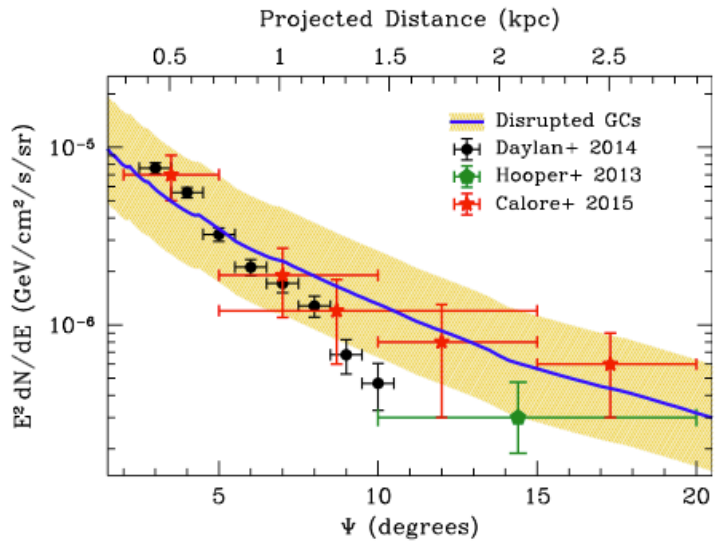
$$\rho(r) = \frac{\rho_s}{(r/r_s)^\gamma (1+(r/r_s))^{3-\gamma}}$$

Images: Daylan+ 2016 ($m_{DM} \approx 35.25$ GeV)

- Not consistent with Fermi's observed distribution of pulsar candidates (Ajello+ 2017)
- No detection from dwarf spheroidal galaxies of the Milky Way (Albert+ 2017)

Or Milli-Second Pulsars ?





First proposed by Bednarek & Sobczak 2013

Spectral energy distribution

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_0}\right)^{-\zeta} \exp\left(-\frac{E}{E_0}\right)$$

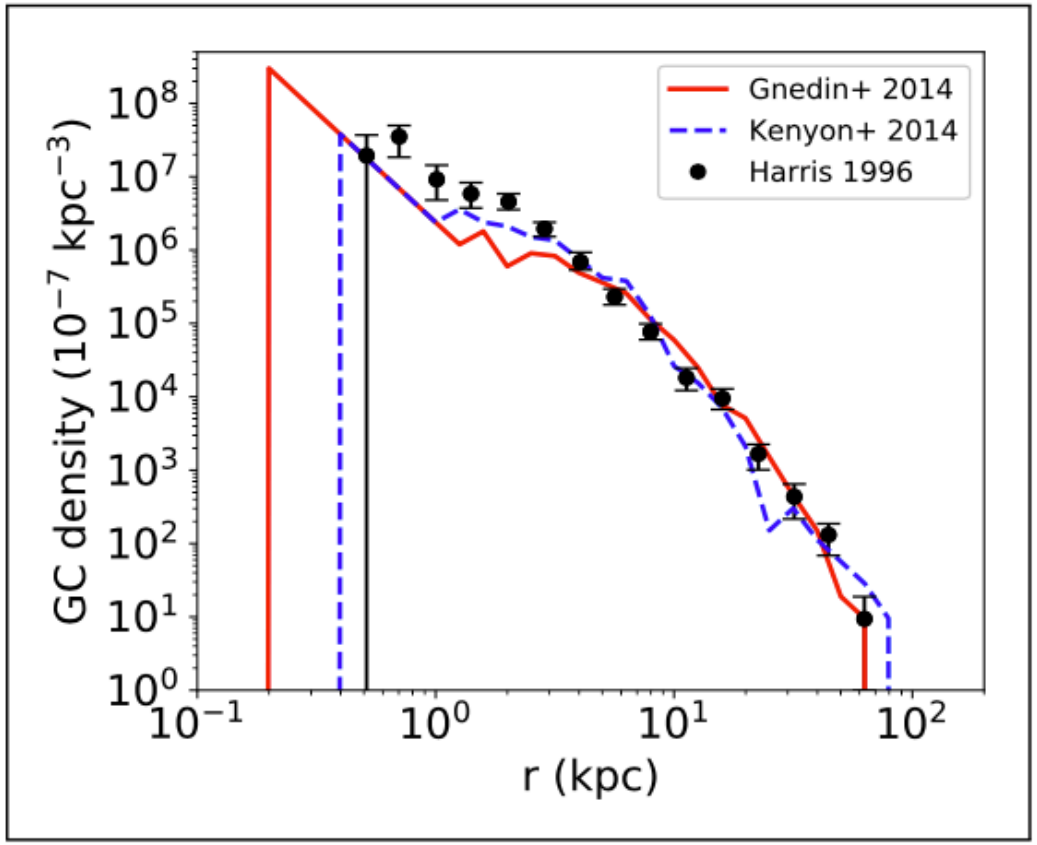
MSP spatial profile

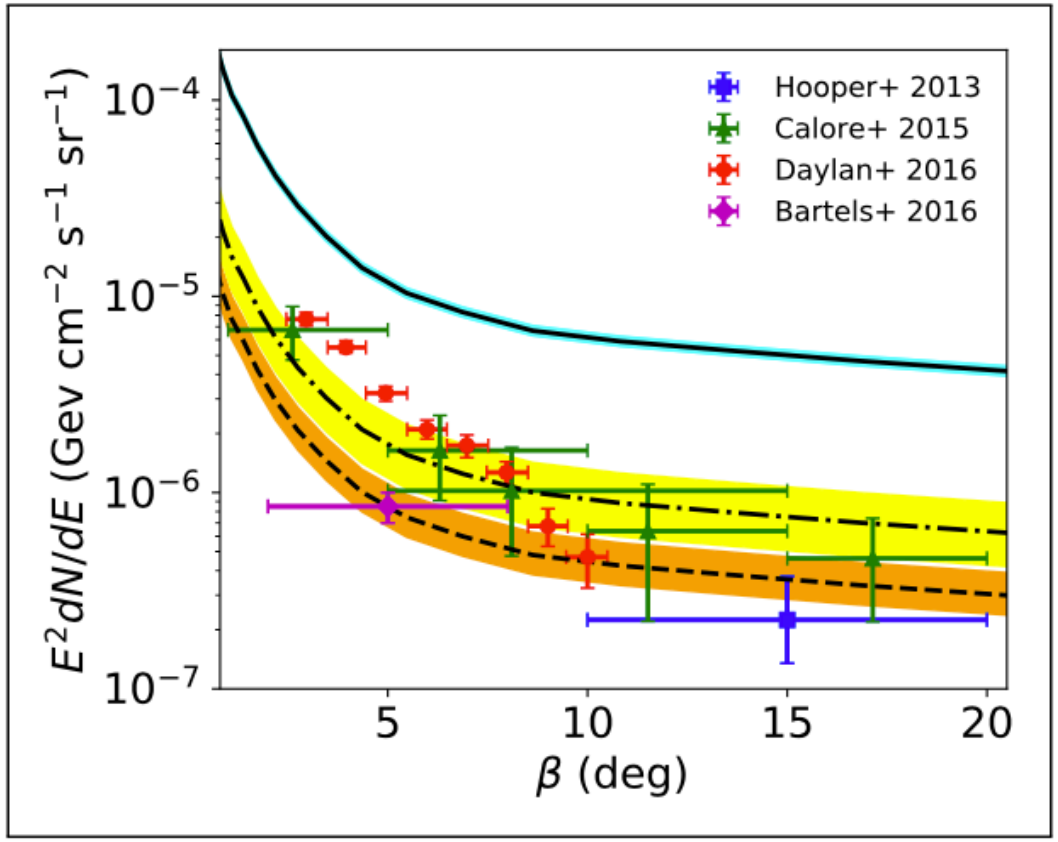
$$\rho(r) \propto r^{-2\gamma}$$

Images: Brandt & Kocsis 2015 (Globular Cluster disruption); see also Lee+ 2015; Bartels+ 2016; Abbate+ 2017; Ajello+ 2017; Arca-Sedda+ 2017

- MSPs can explain only a few percent of the excess because of spin-down (Hooper+ 2016)

MSP in disrupted Globular Cluster





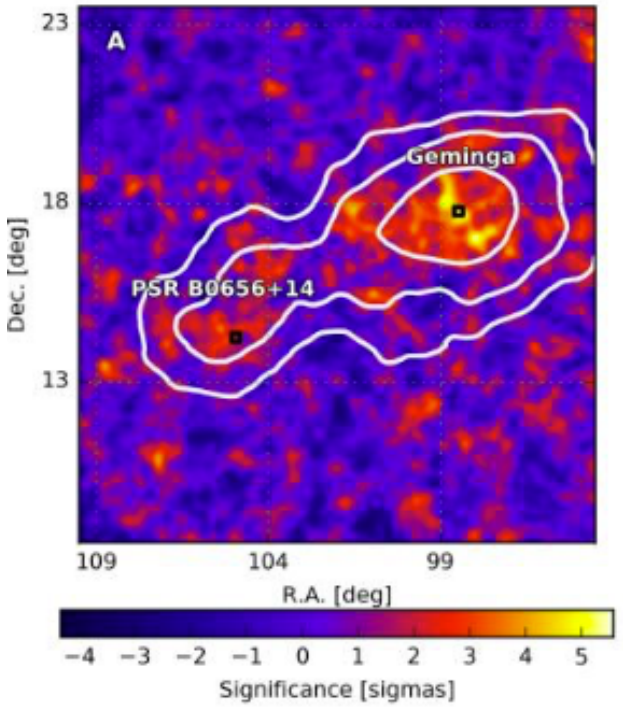
New observations of 2 nearby pulsarsß

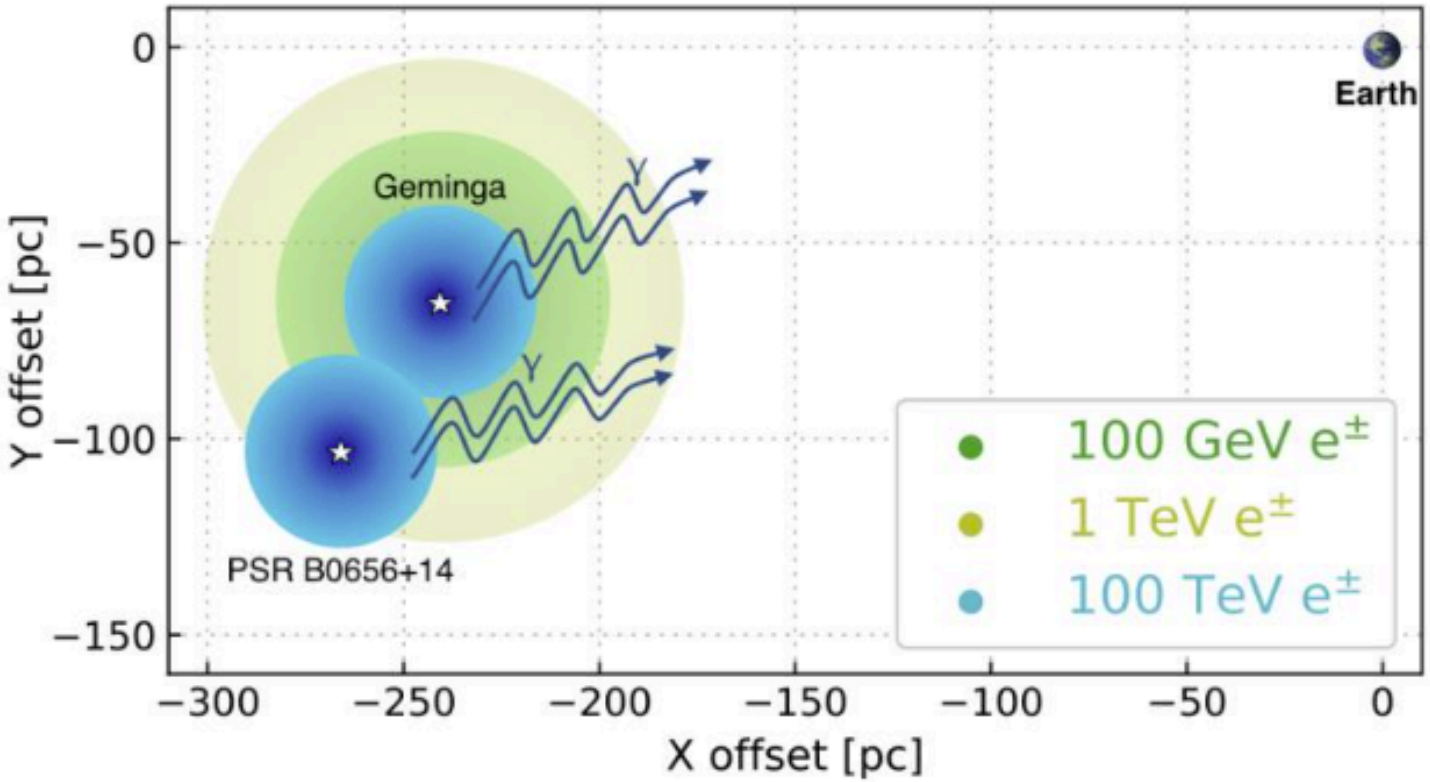
- Observe gamma rays and cosmic rays between 100 GeV and 100 TeV

-Angular res. 1-0.2deg

Geminga and PSR B0656+14

- Observe Gamma-ray to infer the diffusion extend of electron, positron.
- 20 TeV gamma-ray produced from 100 TeV electron/positron IC scatter CMB photon





Parameters and fitting results

- Within a few 100pc required to explain the excess from PWNe
- Middle aged, allow enough diffused time

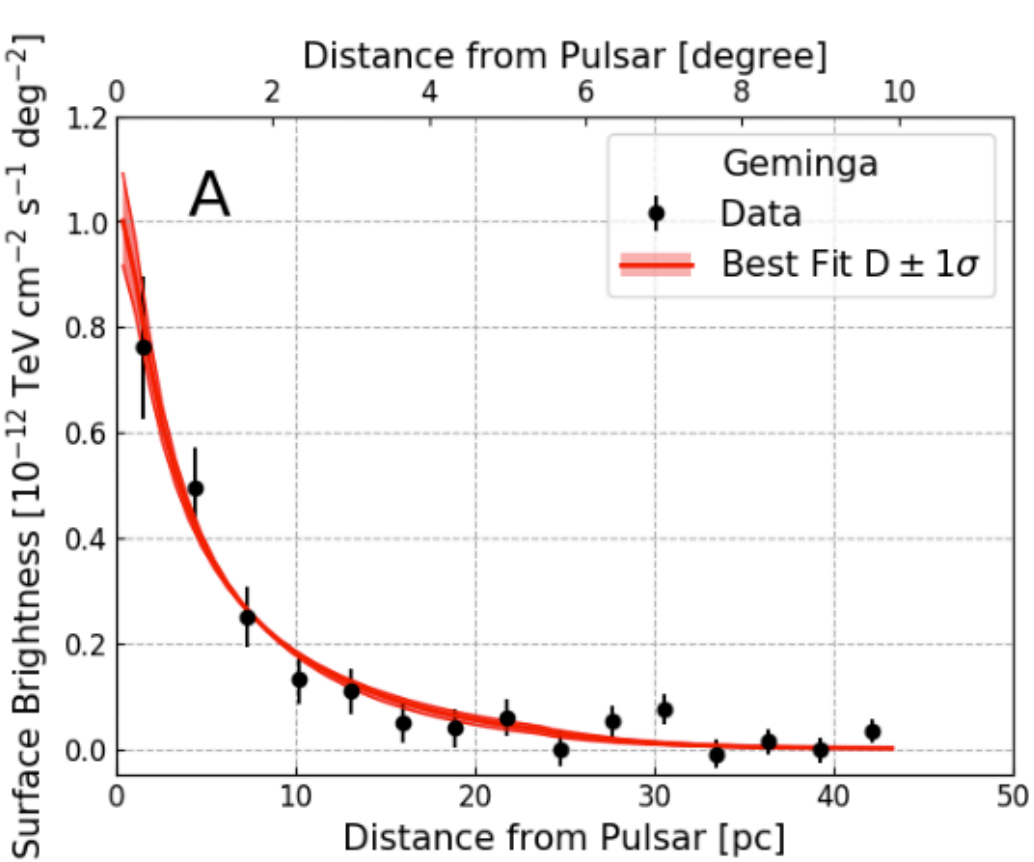
$$r_d = 2\sqrt{D\,t}$$

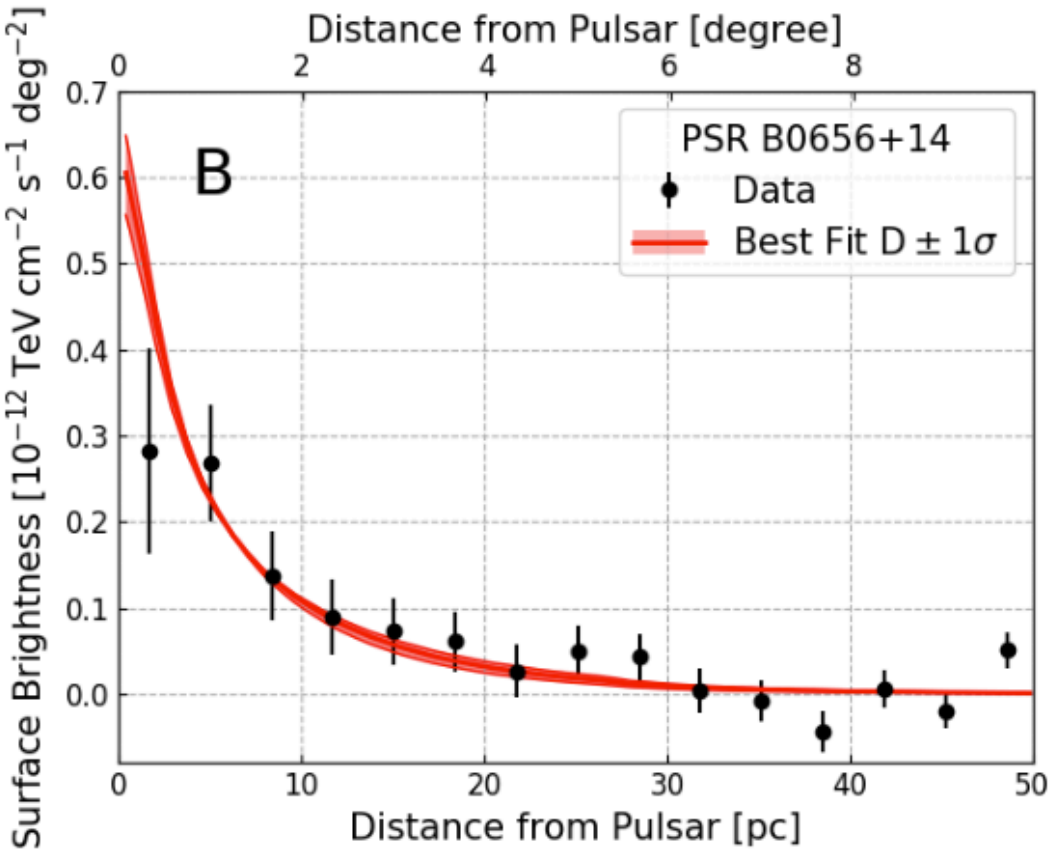
$$\frac{d^2N}{dEd\Omega} = N_0 \left(\frac{E}{20\ \mathrm{TeV}}\right)^{-\alpha} \frac{1.22}{\pi^{3/2}\theta_d(E)(\theta + 0.06\theta_d(E))} \exp(-\theta^2/\theta_d(E)^2)$$

Pulsar Parameters		**Geminga**	**PSR B0656+14**
(Right ascension, declination) (J2000 source location)	[degrees]	(98.48, 17.77)	(104.95, 14.24)
τ_c (characteristic age)	[years]	342,000	110,000
T (spin period)	[seconds]	0.237	0.385
d (distance)	[parsecs]	250^{+120}_{-62}	288^{+33}_{-27}
dE/dt (energy loss rate due to pulsar's spin slowing)	[x10^{34} ergs/sec]	3.26	3.8
Model Values			
θ_0 (θ_d for 20 TeV γ-ray)	[degrees]	5.5 ± 0.7	4.8 ± 0.6
N_0	[x10^{-15} photons/TeV/cm^2 /sec]	$13.6^{+2.0}_{-1.7}$	$5.6^{+2.5}_{-1.7}$
α		2.34 ± 0.07	2.14 ± 0.23
D_{100} (Diffusion coefficient of 100TeV electrons from joint fit of two PWNe)	[x10^{27} cm^2/sec]	4.5 ± 1.2	4.5 ± 1.2
D_{100}(Diffusion coefficient of 100TeV electrons from individual fit of PWN)	[x10^{27} cm^2/sec]	$3.2^{+1.4}_{-1.0}$	15^{+49}_{-9}
Energy Range	[TeV]	8 to 40	8 to 40
Luminosity in gamma-rays over this energy range	[x10^{31} erg/sec]	11x(d/250 parsec)^2	4.5x(d/288 parsec)^2
Assumed Parameters			
L_0 (initial spin down power)	[x10^{36} ergs/sec]	27.8	4.0
W_e (total energy released since pulsar's birth)	[x10^{48} ergs]	11.0	1.5

Table 1: Pulsar parameters, values of parameters from the model fitting to the observed extended gamma-ray emission, and assumed parameters of our model. Pulsar parameters are from (14).

Best-fit diffusion distances





Conclusion → rejected possibility of being PWN

- Geminga and PSR B0656+14 are the oldest pulsars for which TeV nebula has so far been detected.
- Under the assumption of isotropic and homogeneous diffusion, the dominant source of the positron flux above 10 GeV cannot be either Geminga or PSR B0656+14