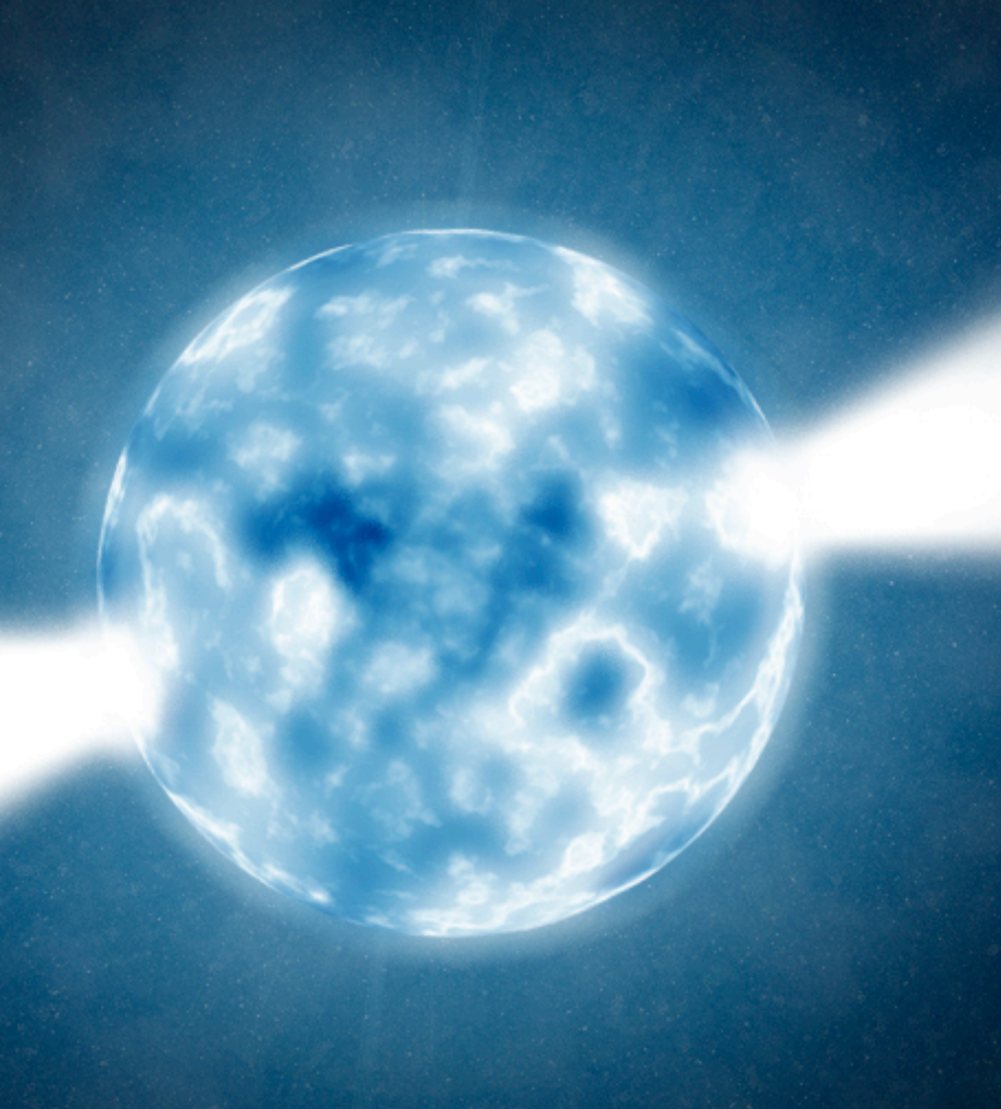
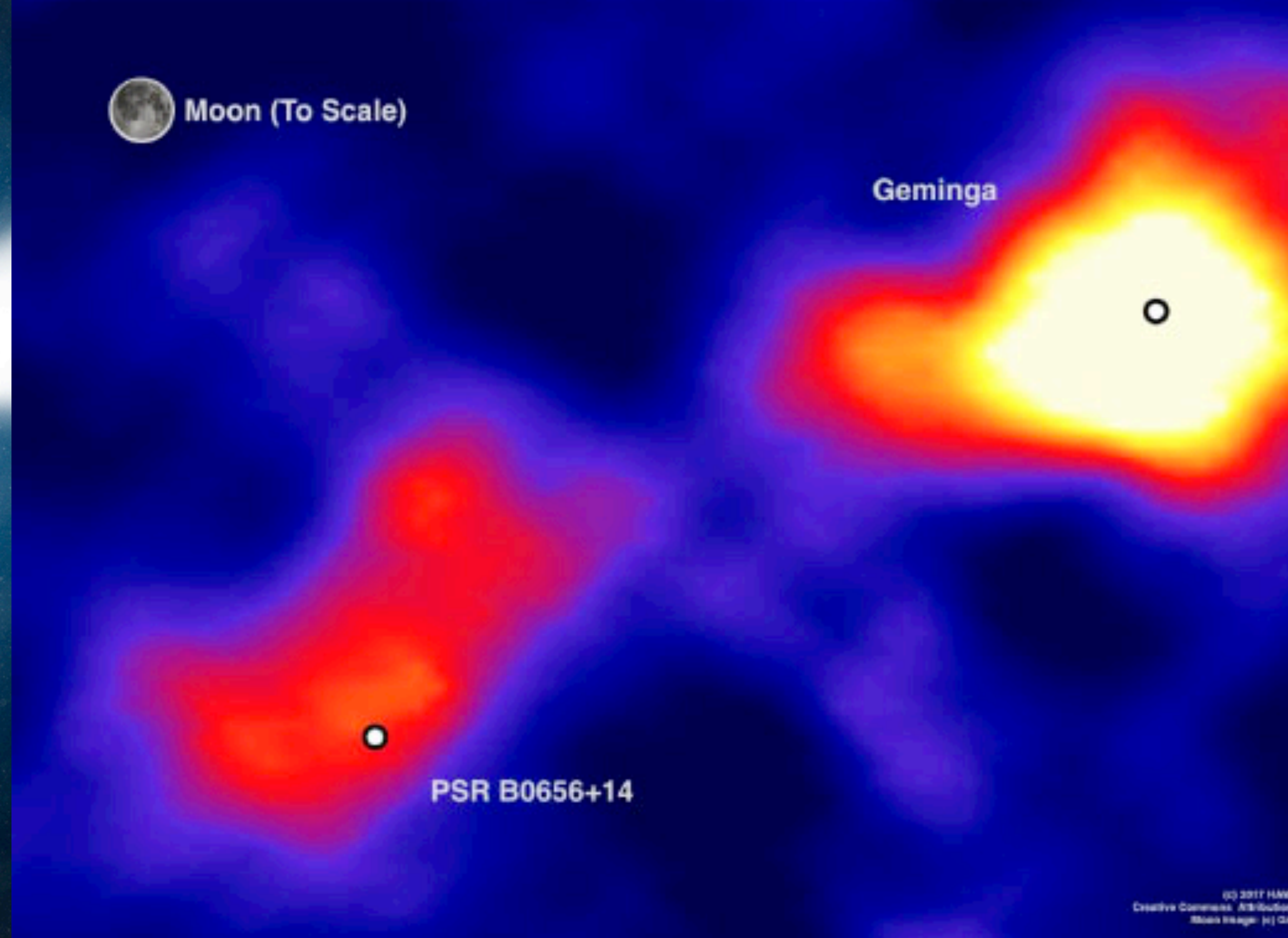




TIM LINDEN

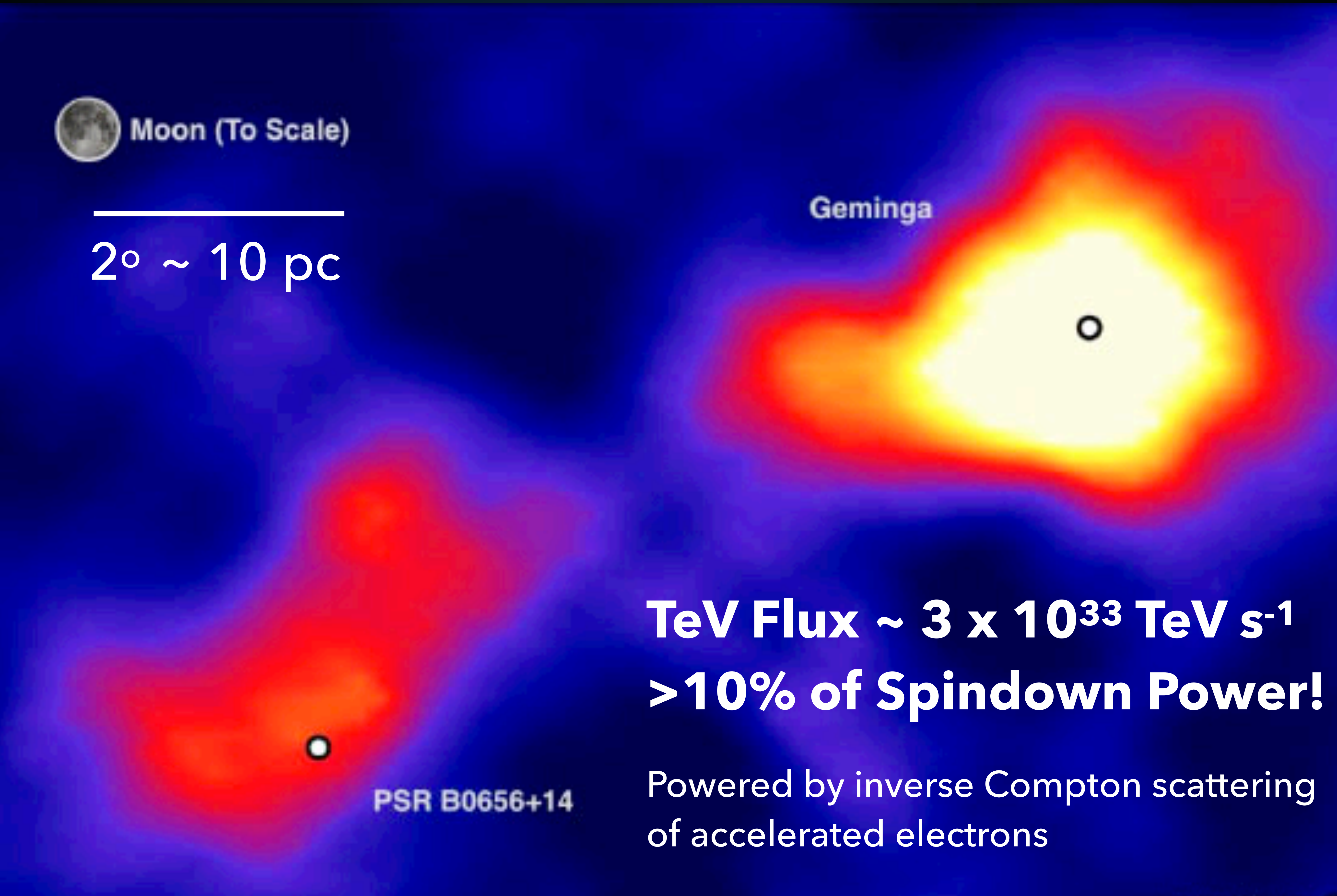
EMISSION FROM PULSARS WILL DOMINATE THE NEXT DECADE OF TEV ASTRONOMY

High Energy Astrophysics in the 2020's and Beyond

THE OHIO STATE UNIVERSITY
CENTER FOR COSMOLOGY AND ASTROPARTICLE PHYSICS

TEV HALOS

HAWC Collaboration (1702.02992)



TeV Flux ~ 3 x 10^{33} TeV s^{-1}

>10% of Spindown Power!

Powered by inverse Compton scattering of accelerated electrons

HESS OBSERVATIONS

HESS Collaboration (1702.08280)

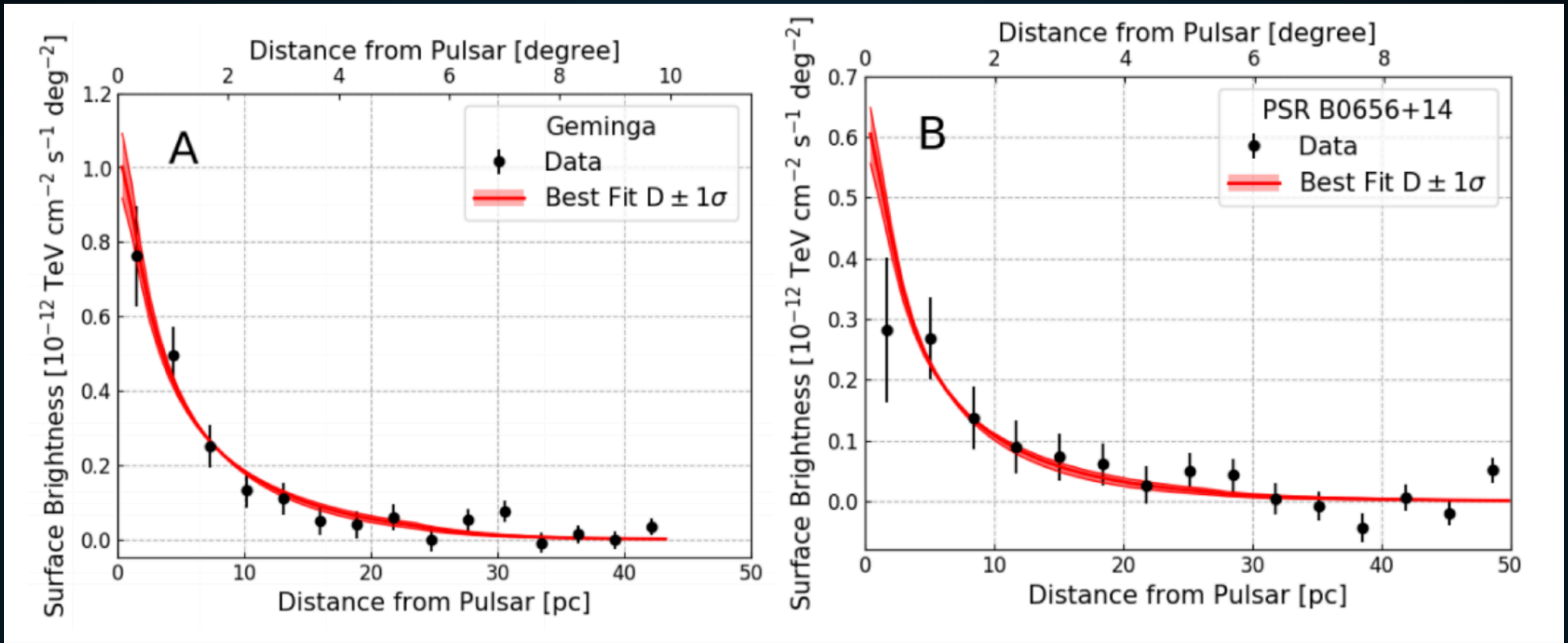
- **“TeV PWN” observed by HESS have similar fluxes and extensions.**

Table 1 HGPS sources considered as firmly identified pulsar wind nebulae in this paper.

HGPS name	ATNF name	Canonical name	$\lg \dot{E}$	τ_c (kyr)	d (kpc)	PSR offset (pc)	Γ	R_{PWN} (pc)	$L_{1-10\,TeV}$ (10^{33} erg s^{-1})
J1813−178[1]	J1813−1749		37.75	5.60	4.70	< 2	2.07 ± 0.05	4.0 ± 0.3	19.0 ± 1.5
J1833−105	J1833−1034	G21.5−0.9[2]	37.53	4.85	4.10	< 2	2.42 ± 0.19	< 4	2.6 ± 0.5
J1514−591	B1509−58	MSH 15−52[3]	37.23	1.56	4.40	< 4	2.26 ± 0.03	11.1 ± 2.0	52.1 ± 1.8
J1930+188	J1930+1852	G54.1+0.3[4]	37.08	2.89	7.00	< 10	2.6 ± 0.3	< 9	5.5 ± 1.8
J1420−607	J1420−6048	Kookaburra (K2)[5]	37.00	13.0	5.61	5.1 ± 1.2	2.20 ± 0.05	7.9 ± 0.6	44 ± 3
J1849−000	J1849−0001	IGR J18490−0000[6]	36.99	42.9	7.00	< 10	1.97 ± 0.09	11.0 ± 1.9	12 ± 2
J1846−029	J1846−0258	Kes 75[2]	36.91	0.728	5.80	< 2	2.41 ± 0.09	< 3	6.0 ± 0.7
J0835−455	B0833−45	Vela X[7]	36.84	11.3	0.280	2.37 ± 0.18	1.89 ± 0.03	2.9 ± 0.3	0.83 ± 0.11*
J1837−069[8]	J1838−0655		36.74	22.7	6.60	17 ± 3	2.54 ± 0.04	41 ± 4	204 ± 8
J1418−609	J1418−6058	Kookaburra (Rabbit)[5]	36.69	10.3	5.00	7.3 ± 1.5	2.26 ± 0.05	9.4 ± 0.9	31 ± 3
J1356−645[9]	J1357−6429		36.49	7.31	2.50	5.5 ± 1.4	2.20 ± 0.08	10.1 ± 0.9	14.7 ± 1.4
J1825−137[10]	B1823−13		36.45	21.4	3.93	33 ± 6	2.38 ± 0.03	32 ± 2	116 ± 4
J1119−614	J1119−6127	G292.2−0.5[11]	36.36	1.61	8.40	< 11	2.64 ± 0.12	14 ± 2	23 ± 4
J1303−631[12]	J1301−6305		36.23	11.0	6.65	20.5 ± 1.8	2.33 ± 0.02	20.6 ± 1.7	96 ± 5

Table 4 Candidate pulsar wind nebulae from the pre-selection.

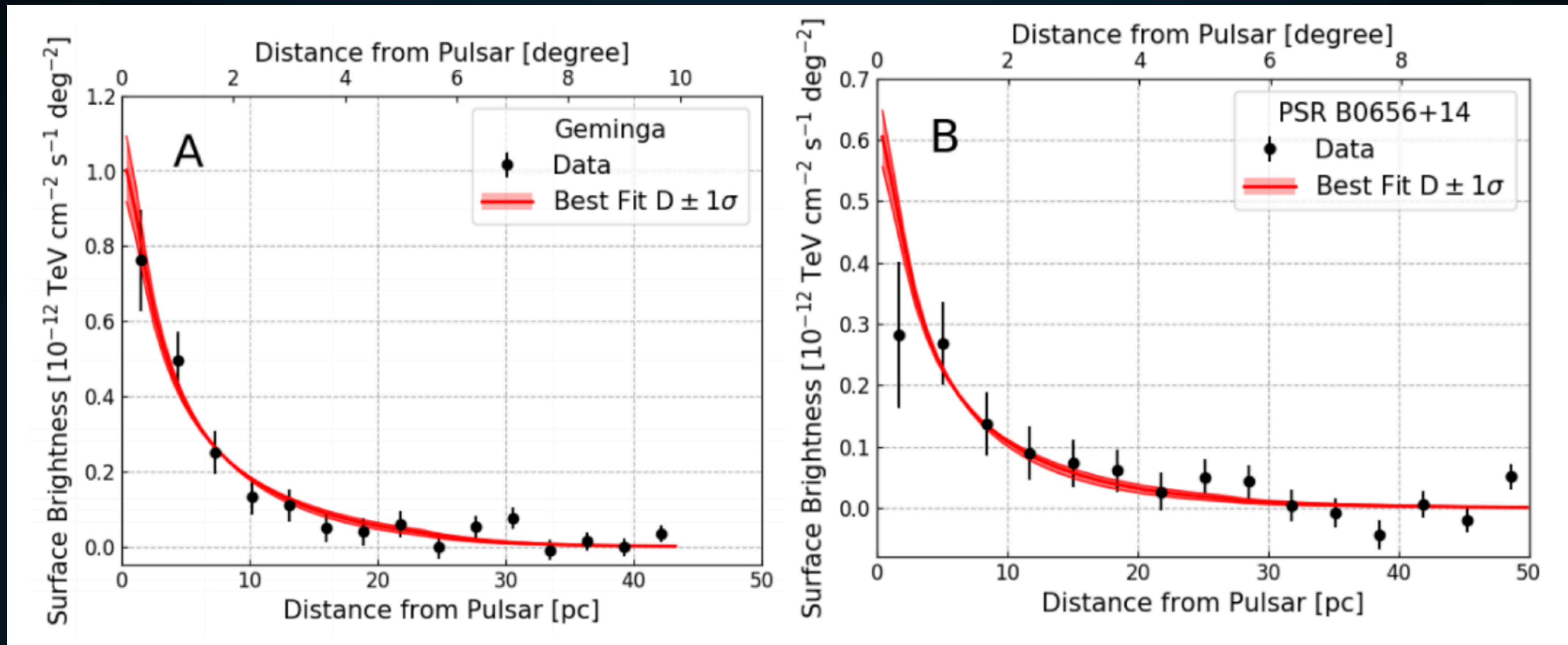
HGPS name	ATNF name	$\lg \dot{E}$	τ_c (kyr)	d (kpc)	PSR offset (pc)	Γ	R_{PWN} (pc)	$L_{1-10\,TeV}$ (10^{33} erg s^{-1})	Rating 1	2	3	4
J1616−508 (1)	J1617−5055	37.20	8.13	6.82	< 26	2.34 ± 0.06	28 ± 4	162 ± 9	★	★	★	★
J1023−575	J1023−5746	37.04	4.60	8.00	< 9	2.36 ± 0.05	23.2 ± 1.2	67 ± 5	★	★	★	★
J1809−193 (1)	J1811−1925	36.81	23.3	5.00	29 ± 7	2.38 ± 0.07	35 ± 4	53 ± 3	★	★	★	↯
J1857+026	J1856+0245	36.66	20.6	9.01	21 ± 6	2.57 ± 0.06	41 ± 9	118 ± 13	★	★	★	★
J1640−465	J1640−4631 (1)	36.64	3.35	12.8	< 20	2.55 ± 0.04	25 ± 8	210 ± 12	★	★	★	★
J1641−462	J1640−4631 (2)	36.64	3.35	12.8	50 ± 5	2.50 ± 0.11	< 14	17 ± 4	↯	⋆	★	⋆
J1708−443	B1706−44	36.53	17.5	2.60	17 ± 3	2.17 ± 0.08	12.7 ± 1.4	6.6 ± 0.9	★	★	★	★
J1908+063	J1907+0602	36.45	19.5	3.21	21 ± 3	2.26 ± 0.06	27.2 ± 1.5	28 ± 2	★	★	★	★
J1018−589A	J1016−5857 (1)	36.41	21.0	8.00	47.5 ± 1.6	2.24 ± 0.13	< 4	8.1 ± 1.4	↯	⋆	★	⋆
J1018−589B	J1016−5857 (2)	36.41	21.0	8.00	25 ± 7	2.20 ± 0.09	21 ± 4	23 ± 5	★	★	★	★
J1804−216	B1800−21	36.34	15.8	4.40	18 ± 5	2.69 ± 0.04	19 ± 3	42.5 ± 2.0	★	★	★	★
J1809−193 (2)	J1809−1917	36.26	51.3	3.55	< 17	2.38 ± 0.07	25 ± 3	26.9 ± 1.5	★	★	★	★
J1616−508 (2)	B1610−50	36.20	7.42	7.94	60 ± 7	2.34 ± 0.06	32 ± 5	220 ± 12	↯	★	★	★
J1718−385	J1718−3825	36.11	89.5	3.60	5.4 ± 1.6	1.77 ± 0.06	7.2 ± 0.9	4.6 ± 0.8	★	★	★	★
J1026−582	J1028−5819	35.92	90.0	2.33	9 ± 2	1.81 ± 0.10	5.3 ± 1.6	1.7 ± 0.5	↯	★	★	★
J1832−085	B1830−08 (1)	35.76	147	4.50	23.3 ± 1.5	2.38 ± 0.14	< 4	1.7 ± 0.4	↯	↯	★	⋆
J1834−087	B1830−08 (2)	35.76	147	4.50	32.3 ± 1.9	2.61 ± 0.07	17 ± 3	25.8 ± 2.0	↯	★	★	↯
J1858+020	J1857+0143	35.65	71.0	5.75	38 ± 3	2.39 ± 0.12	7.9 ± 1.6	7.1 ± 1.5	↯	★	★	↯
J1745−303	B1742−30 (1)	33.93	546	0.200	1.42 ± 0.15	2.57 ± 0.06	0.62 ± 0.07	0.014 ± 0.003	↯	↯	★	↯
J1746−308	B1742−30 (2)	33.93	546	0.200	< 1.1	3.3 ± 0.2	0.56 ± 0.12	0.009 ± 0.003	⋆	↯	★	↯



- **Why TeV Halos?**
  - **These sources are <u>much larger</u> than PWN**

$$R_{\rm PWN} \simeq 1.5 \left(\frac{\dot{E}}{10^{35}\,{\rm erg/s}}\right)^{1/2} \times \left(\frac{n_{\rm gas}}{1\,{\rm cm}^{-3}}\right)^{-1/2} \left(\frac{v}{100\,{\rm km/s}}\right)^{-3/2} {\rm pc}$$

HAWC Collaboration (Nature; 1711.06223)



- **Why TeV Halos?**
  - **These sources are <u>much smaller</u> than ISM diffusion**

$\tau_{loss} \approx 30\ \text{kyr} \qquad D_0 \approx 5 \times 10^{28}\ \text{cm}^2\,\text{s}^{-1}$

$$L = \sqrt{Dt} \approx 2000\ \text{pc}$$

THE GLOBAL POPULATION OF TEV HALOS

- Extrapolate to the full population.

- The following correlation is consistent with the data.

$$\phi_{\rm TeV\ halo} = \left(\frac{\dot{E}_{\rm psr}}{\dot{E}_{\rm Geminga}}\right)\left(\frac{d^2_{\rm Geminga}}{d^2_{\rm psr}}\right)\phi_{\rm Geminga}$$

- Note: Using Monogem would increases fluxes by nearly a factor of 2. The power law of this correlation doesn't greatly affect the results.

HAWC OBSERVATIONS OF TEV HALO LUMINOSITIES

ATNF Name	Dec. (°)	Distance (kpc)	Age (kyr)	Spindown Lum. (erg s^{-1})	Spindown Flux (erg s^{-1} kpc^{-2})	2HWC
J0633+1746	17.77	0.25	342	3.2e34	4.1e34	2HWC J0631+169
B0656+14	14.23	0.29	111	3.8e34	3.6e34	2HWC J0700+143
B1951+32	32.87	3.00	107	3.7e36	3.3e34	—
J1740+1000	10.00	1.23	114	2.3e35	1.2e34	—
J1913+1011	10.18	4.61	169	2.9e36	1.1e34	2HWC J1912+099
J1831-0952	-9.86	3.68	128	1.1e36	6.4e33	2HWC J1831-098
J2032+4127	41.45	1.70	181	1.7e35	4.7e33	2HWC J2031+415
B1822-09	-9.58	0.30	232	4.6e33	4.1e33	—
B1830-08	-8.45	4.50	147	5.8e35	2.3e33	—
J1913+0904	9.07	3.00	147	1.6e35	1.4e33	—
B0540+23	23.48	1.56	253	4.1e34	1.4e33	—

- Can produce a ranked list of the 57 ATNF pulsars in the HAWC field of view.
- 5 of the brightest 7 have been detected.
- No dimmer systems have been detected.

Linden et al. (PRD; 1703.09704)

HAWC OBSERVATIONS OF TEV HALO LUMINOSITIES

ATNF Name	Dec. (°)	Distance (kpc)	Age (kyr)	Spindown Lum. (erg s^{-1})	Spindown Flux (erg s^{-1} kpc^{-2})	2HWC
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B0656+14	14.23	0.29	111	3.8e34	3.6e34	2HWC J0700+143
B1951+32	32.87	3.00	107	3.7e36	3.3e34	—
J1740+1000	10.00	1.23	114	2.3e35	1.2e34	—
J1913+1011	10.18	4.61	169	2.9e36	1.1e34	2HWC J1912+099
J1831-0952	-9.86	3.68	128	1.1e36	6.4e33	2HWC J1831-098
J2032+4127	41.45	1.70	181	1.7e35	4.7e33	2HWC J2031+415
B1822-09	-9.58	0.30	232	4.6e33	4.1e33	—
B1830-08	-8.45	4.50	147	5.8e35	2.3e33	—
J1913+0904	9.07	3.00	147	1.6e35	1.4e33	—
B0540+23	23.48	1.56	253	4.1e34	1.4e33	**2HWC J0543+233**

HAWC detection of TeV emission near PSR B0540+23

ATel #10941; *Colas Riviere (University of Maryland), Henrike Fleischhack (Michigan Technological University), Andres Sandoval (Universidad Nacional Autonoma de Mexico) on behalf of the HAWC collaboration*
on 9 Nov 2017; 23:11 UT
Credential Certification: Colas Riviere (riviere@umd.edu)

Subjects: Gamma Ray, TeV, VHE, Pulsar

Tweet | Recommend 5

The High Altitude Water Cherenkov (HAWC) collaboration reports the discovery of a new TeV gamma-ray source HAWC J0543+233. It was discovered in a search for extended sources of radius 0.5° in a dataset of 911 days (ranging from November 2014 to August 2017) with a test statistic value of 36 (6σ pre-trials), following the method presented in Abeysekara et al. 2017, ApJ, 843, 40. The measured J2000.0 equatorial position is RA=85.78°, Dec=23.40° with a statistical uncertainty of 0.2°. HAWC J0543+233 was close to passing the selection criteria of the 2HWC catalog (Abeysekara et al. 2017, ApJ, 843, 40, see HAWC J0543+233 in 2HWC map), which it now fulfills with the additional data.
HAWC J0543+233 is positionally coincident with the pulsar PSR B0540+23 (Edot = 4.1e+34 erg s-1, dist = 1.56 kpc, age = 253 kyr). It is the third low Edot, middle-aged pulsar announced to be detected with a TeV halo, along with Geminga and B0656+14. It was predicted to be one of the next such detection by HAWC by Linden et al., 2017, arXiv:1703.09704.
Using a simple source model consisting of a disk of radius 0.5°, the measured spectral index is -2.3 ± 0.2 and the differential flux at 7 TeV is (7.9 ± 2.3) × 10^-15 TeV-1 cm-2 s-1. The errors are

EMISSION FROM PULSARS WILL DOMINATE THE NEXT DECADE OF TEV ASTRONOMY

- **5 / 39 sources in the 2HWC catalog are correlated with bright, middle-aged (100 – 400 kyr) pulsars.**

2HWC Name	ATNF Name	Distance (kpc)	Angular Separation	Projected Separation	Expected Flux ($\times 10^{-15}$)	Actual Flux ($\times 10^{-15}$)	Flux Ratio	Expected Extension	Actual Extension	Age (kyr)	Chance Overlap
J0700+143	B0656+14	0.29	0.18°	0.91 pc	43.0	23.0	1.87	2.0°	1.73°	111	0.0
J0631+169	J0633+1746	0.25	0.89°	3.88 pc	48.7	48.7	1.0	2.0°	2.0°	342	0.0
J1912+099	J1913+1011	4.61	0.34°	27.36 pc	13.0	36.6	0.36	0.11°	0.7°	169	0.30
J2031+415	J2032+4127	1.70	0.11°	3.26 pc	5.59	61.6	0.091	0.29°	0.7°	181	0.002
J1831-098	J1831-0952	3.68	0.04°	2.57 pc	7.70	95.8	0.080	0.14°	0.9°	128	0.006

- **12 others with young pulsars**
  - **2.3 chance overlaps**
  - **TeV emission may be contaminated by SNR**

2HWC Name	ATNF Name	Distance (kpc)	Angular Separation	Projected Separation	Expected Flux ($\times 10^{-15}$)	Actual Flux ($\times 10^{-15}$)	Flux Ratio	Expected Extension	Actual Extension	Age (kyr)	Chance Overlap
J1930+188	J1930+1852	7.0	0.03°	3.67 pc	23.2	9.8	2.37	0.07°	0.0°	2.89	0.002
J1814-173	J1813-1749	4.7	0.54°	44.30 pc	243	152	1.60	0.11°	1.0°	5.6	0.61
J2019+367	J2021+3651	1.8	0.27°	8.48 pc	99.8	58.2	1.71	0.28°	0.7°	17.2	0.04
J1928+177	J1928+1746	4.34	0.03°	2.27 pc	8.08	10.0	0.81	0.11°	0.0°	82.6	0.002
J1908+063	J1907+0602	2.58	0.36°	16.21 pc	40.0	85.0	0.47	0.2°	0.8°	19.5	0.26
J2020+403	J2021+4026	2.15	0.18°	6.75 pc	2.48	18.5	0.134	0.23°	0.0°	77	0.01
J1857+027	J1856+0245	6.32	0.12°	13.24 pc	11.0	97.0	0.11	0.08°	0.9°	20.6	0.06
J1825-134	J1826-1334	3.61	0.20°	12.66 pc	20.5	249	0.082	0.14°	0.9°	21.4	0.14
J1837-065	J1838-0655	6.60	0.38°	43.77 pc	12.0	341	0.035	0.08°	2.0°	22.7	0.48
J1837-065	J1837-0604	4.78	0.50°	41.71 pc	8.3	341	0.024	0.10°	2.0°	33.8	0.68
J2006+341	J2004+3429	10.8	0.42°	80.07 pc	0.48	24.5	0.019	0.04°	0.9°	18.5	0.08

- Tauris and Manchester (1998) calculated the beaming angle from a population of young and middle-aged pulsars.

$$f = \left[1.1 \left(\log_{10}\left(\frac{\tau}{100\ \mathrm{Myr}}\right)\right)^2 + 15\right]\%$$

- This varies between 15-30%.
- 1/f pulsars are unseen in radio surveys.

MISSING TEV HALOS

Linden et al. (PRD; 1703.09704)

2HWC Name	ATNF Name	Distance (kpc)	Angular Separation	Projected Separation	Expected Flux ($\times 10^{-15}$)	Actual Flux ($\times 10^{-15}$)	Flux Ratio	Expected Extension	Actual Extension	Age (kyr)	Chance Overlap
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J1912+099	J1913+1011	4.61	0.34°	27.36 pc	13.0	36.6	0.36	0.11°	0.7°	169	0.30
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2HWC Name	ATNF Name	Distance (kpc)	Angular Separation	Projected Separation	Expected Flux ($\times 10^{-15}$)	Actual Flux ($\times 10^{-15}$)	Flux Ratio	Expected Extension	Actual Extension	Age (kyr)	Chance Overlap
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J1928+177	J1928+1746	4.34	0.03°	2.27 pc	8.08	10.0	0.81	0.11°	0.0°	82.6	0.002
J1908+063	J1907+0602	2.58	0.36°	16.21 pc	40.0	85.0	0.47	0.2°	0.8°	19.5	0.26
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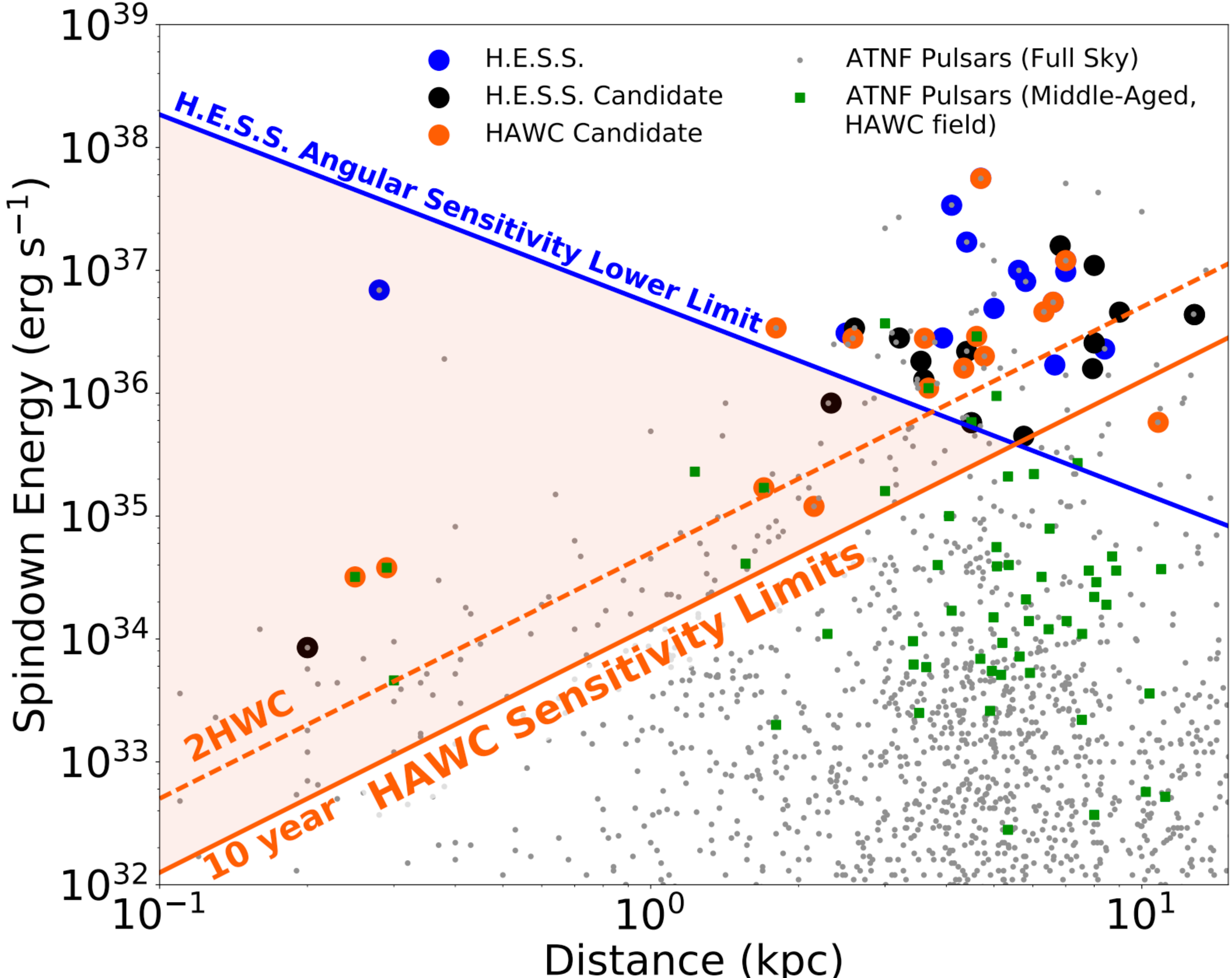
J2006+341	J2004+3429	10.8	0.42°	80.07 pc	0.48	24.5	0.019	0.04°	0.9°	18.5	0.08

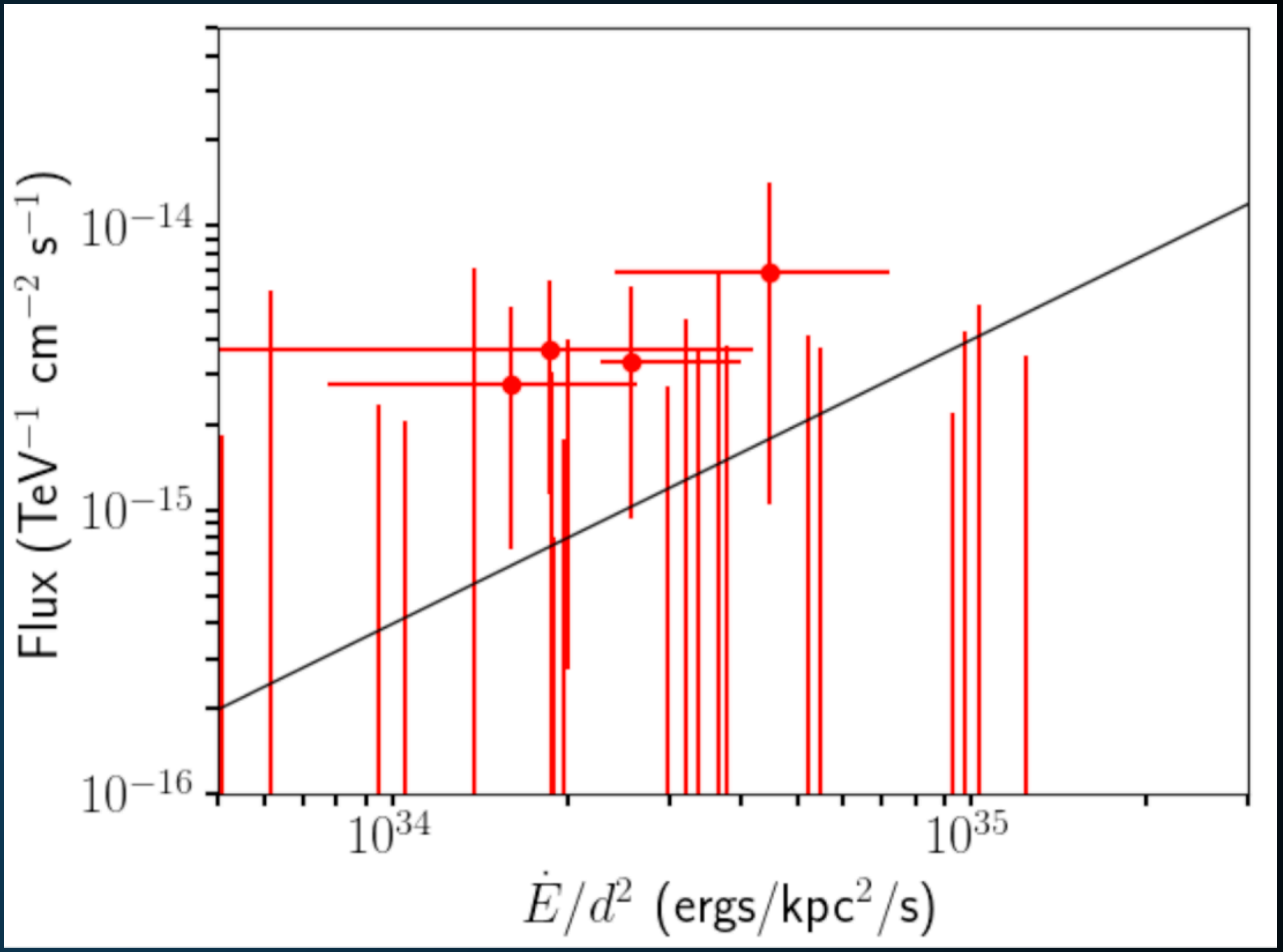
- Correcting for the beaming fraction implies that 56^{+15}_{-11} TeV halos are currently observed by HAWC.
- However, only 39 HAWC sources total.
- Chance overlaps, SNR contamination must be taken into account.



H.E.S.S.
H.E.S.S. Candidate
HAWC Candidate
ATNF Pulsars (Full Sky)
ATNF Pulsars (Middle-Aged, HAWC field)
H.E.S.S. Angular Sensitivity Lower Limit
2HWC
10 year HAWC Sensitivity Limits
Spindown Energy (erg s^{-1})
Distance (kpc)
10^{32}
10^{33}
10^{34}
10^{35}
10^{36}
10^{37}
10^{38}
10^{39}
10^{-1}
10^{0}
10^{1}

 Hooper & Linden (TBS)

- Unknown if MSPs follow the same correlation.



- Even brightest MSPs slightly too dim to be individually detected.

- Stacking a population of 24 MSPs provides moderate (~3σ) evidence that MSPs also produce TeV halos, further increasing the population.

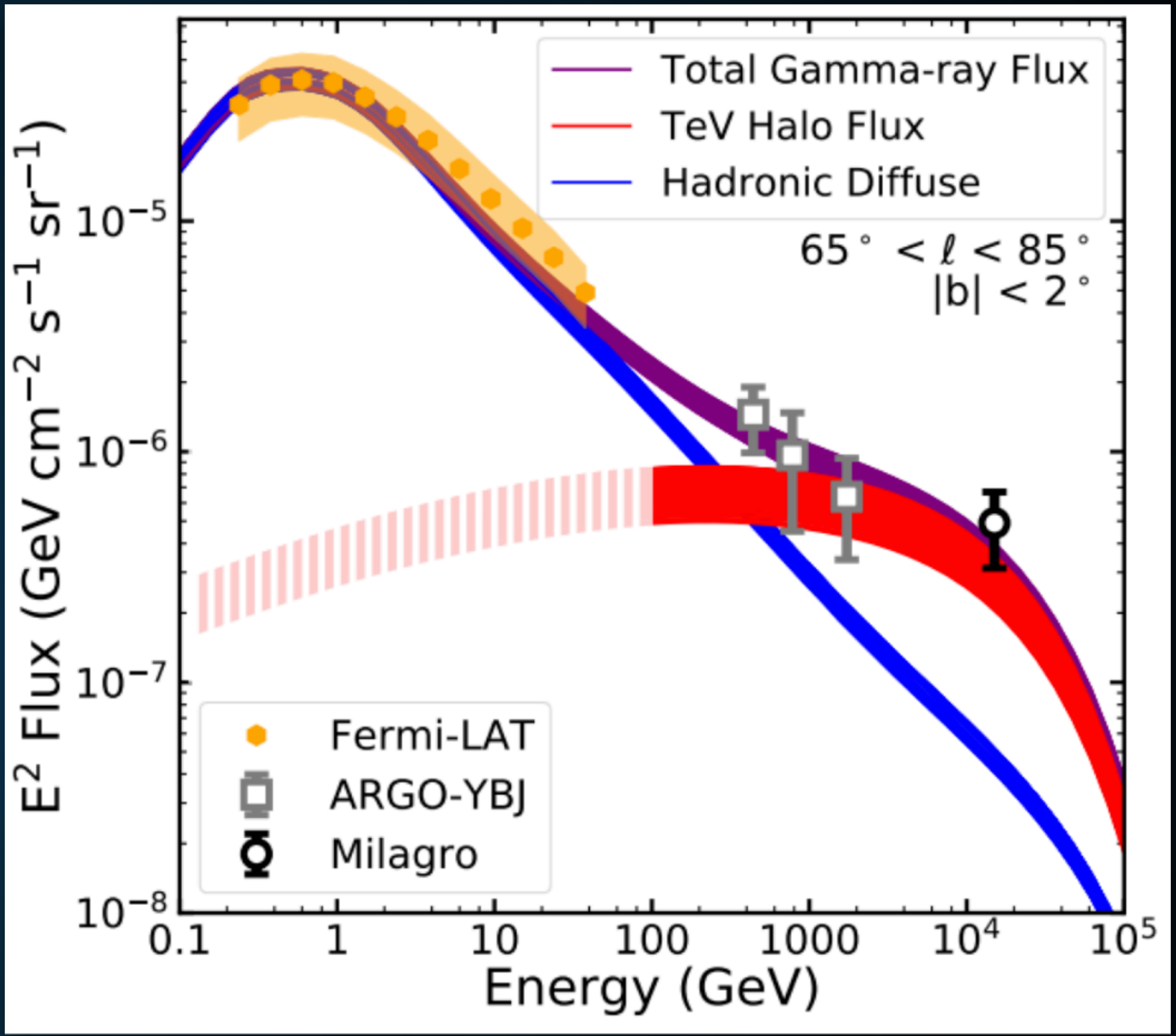
IMPLICATIONS

IMPLICATION I: THE TEV EXCESS

Linden & Buckman (PRL; 1707.01905)

- Milagro detects bright diffuse TeV emission along the Galactic plane.

- Difficult to explain with pion decay, due to steeply falling local hadronic CR spectrum.

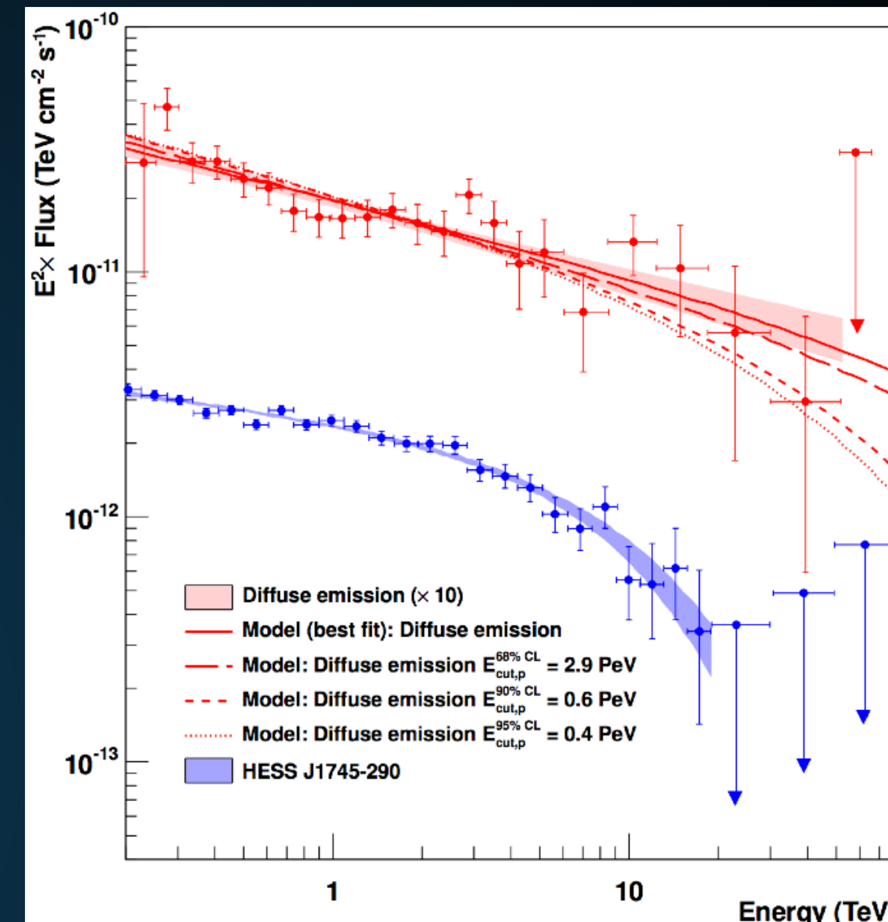


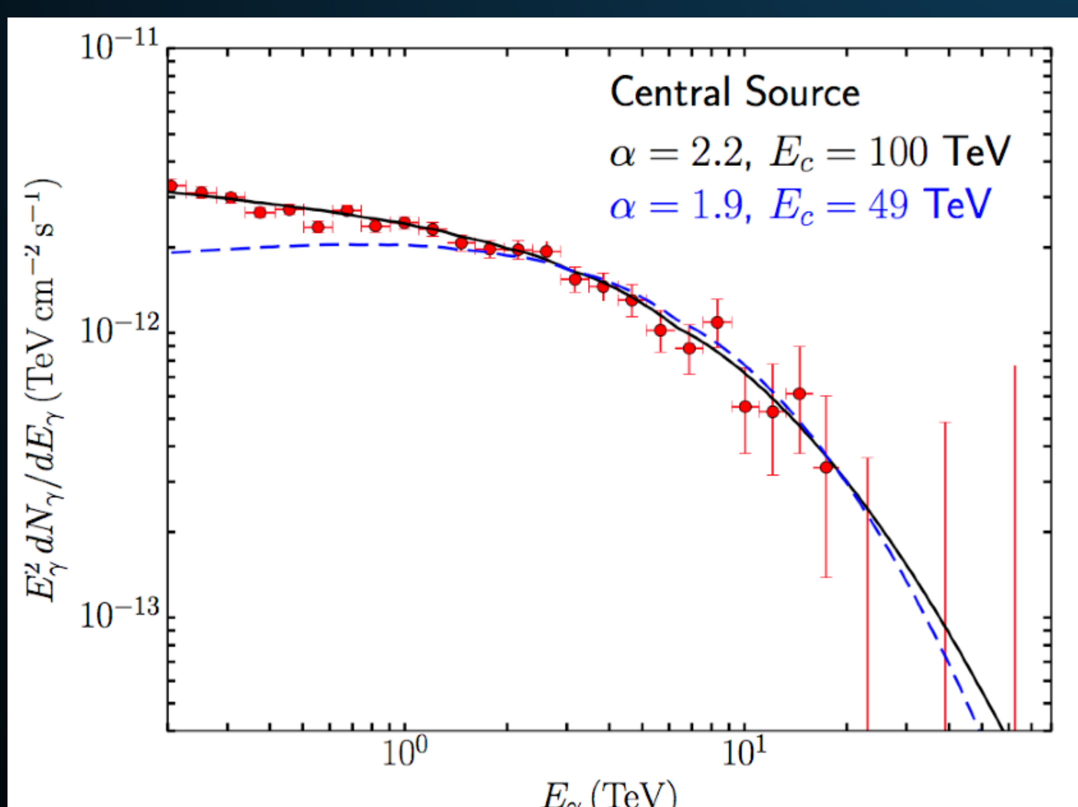
- The Geminga and Monogem TeV halo spectra naturally explain both the spectrum and intensity of this emission.

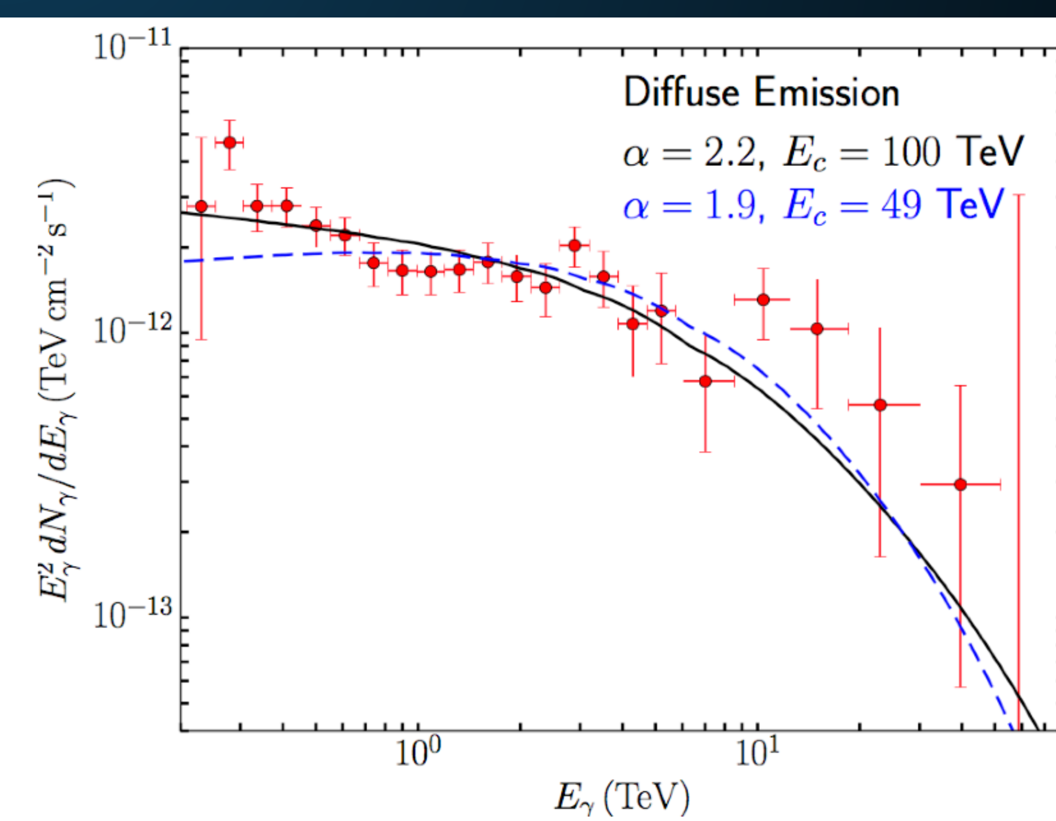
IMPLICATION II: THE GALACTIC CENTER PEVATRON

Hooper, Cholis, TL (1603.07730)
HESS Collaboration (1603.07730)

- HESS observes ~50 TeV diffuse emission from the Galactic center.
- If this is hadronic, it is evidence for PeV proton acceleration.
- TeV halos from Geminga and Monogem explain the spectrum and intensity of this emission.

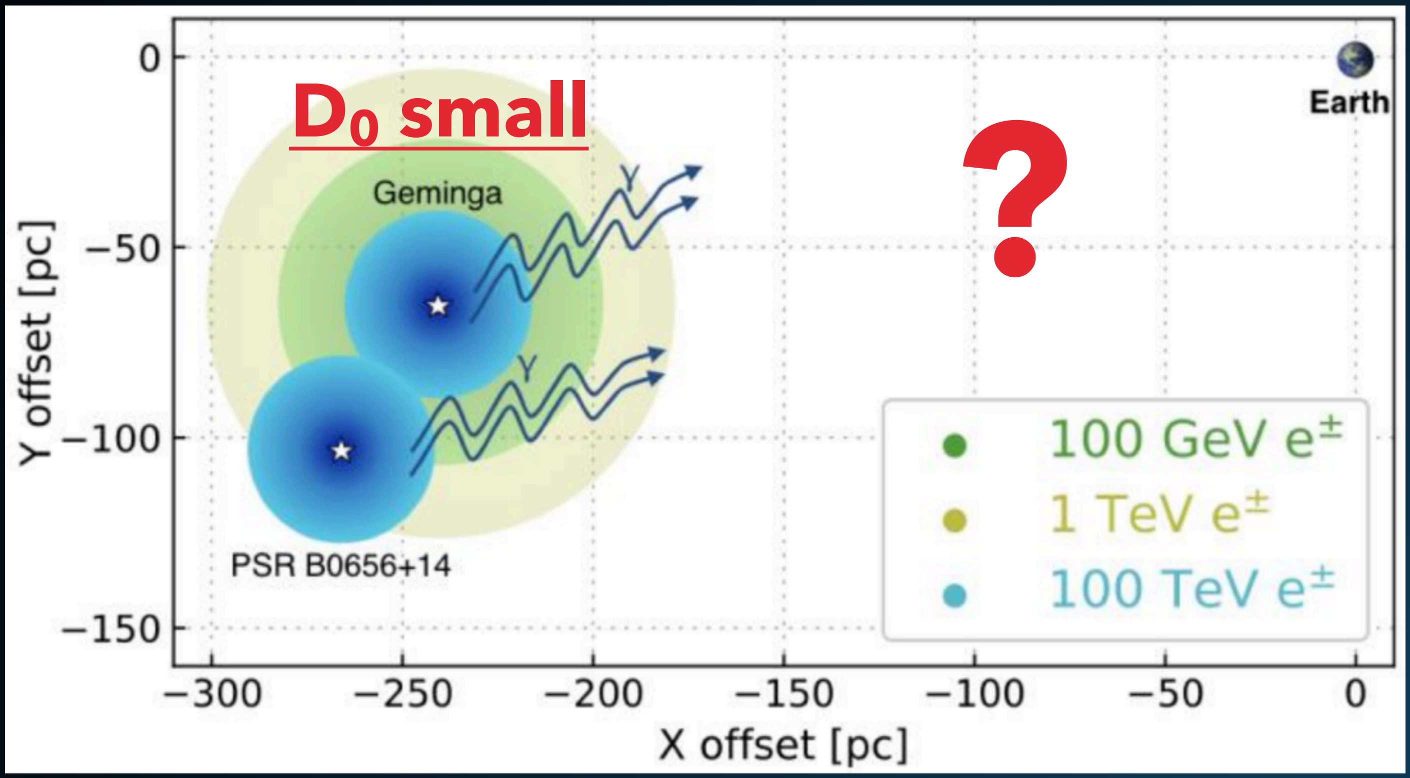




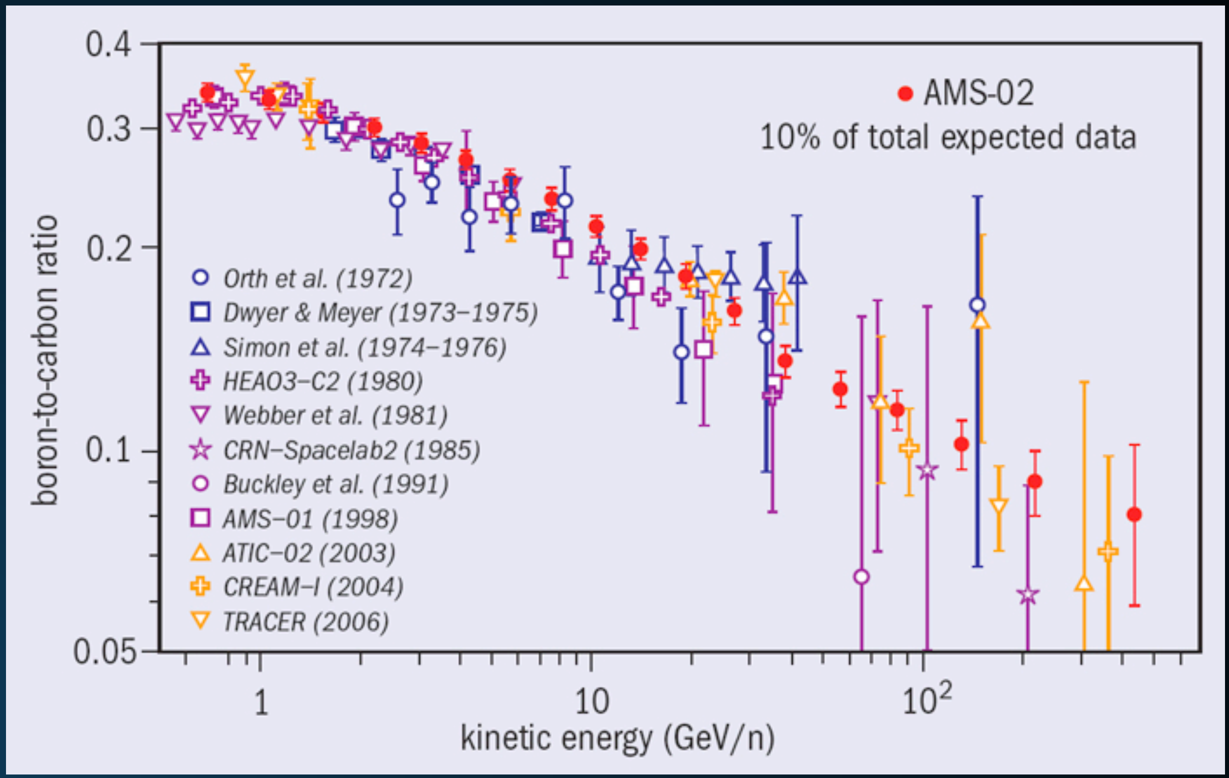


IMPLICATION III: THE POSITRON EXCESS

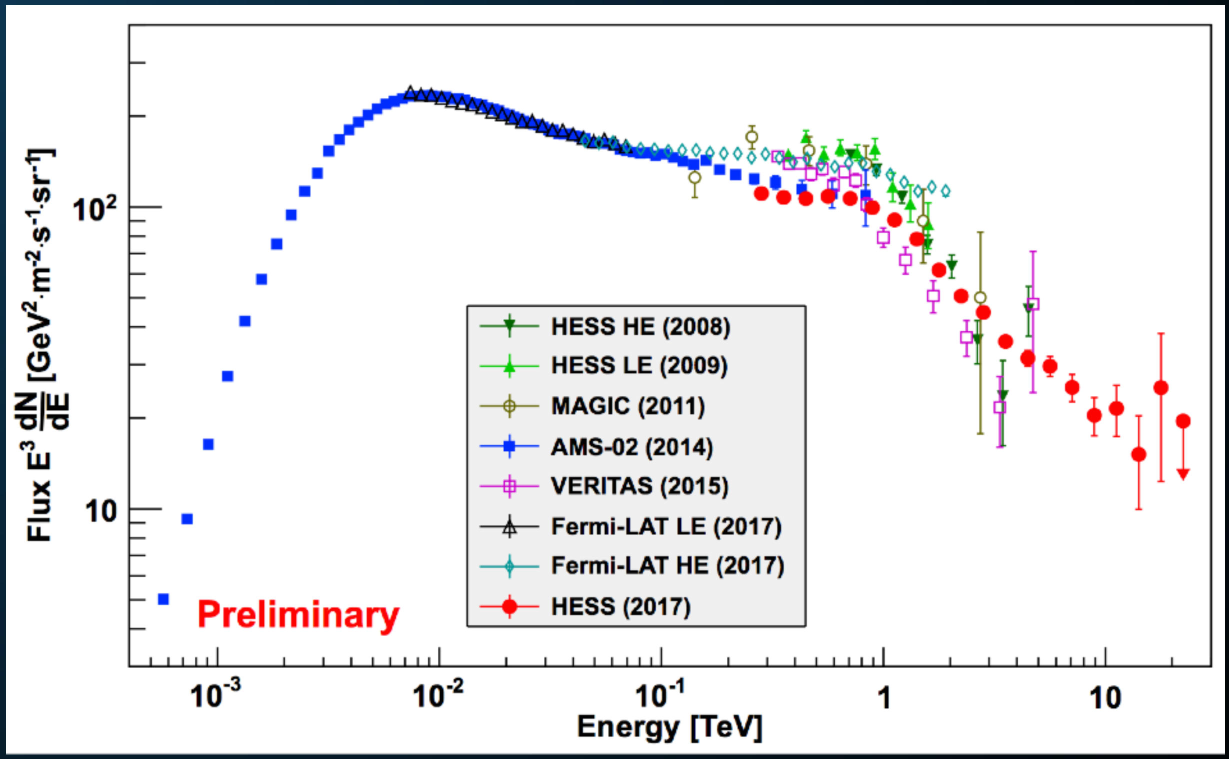
HAWC Collaboration (Nature; 1711.06223)



AMS-02 Collaboration



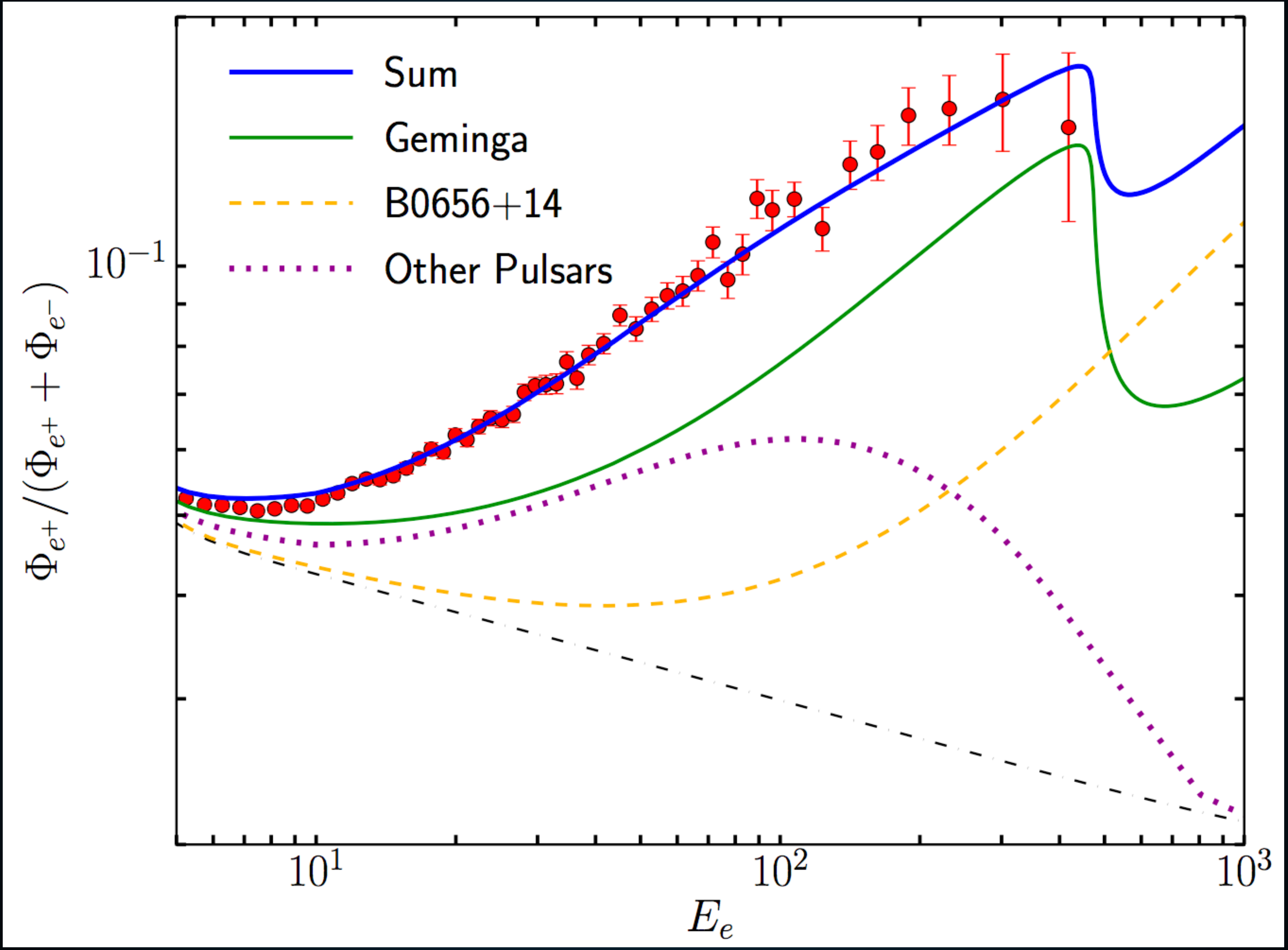
- TeV halo observations indicate that diffusion constant in halo is low.
- Local CR observations (e.g. AMS-02) indicate that global diffusion constant is high.
- Observations of TeV electrons near Earth indicates that diffusion constant increases drastically outside of TeV halo.



HESS Collaboration

IMPLICATION III: THE POSITRON EXCESS

Hooper et al. (JCAP; 1702.08436)



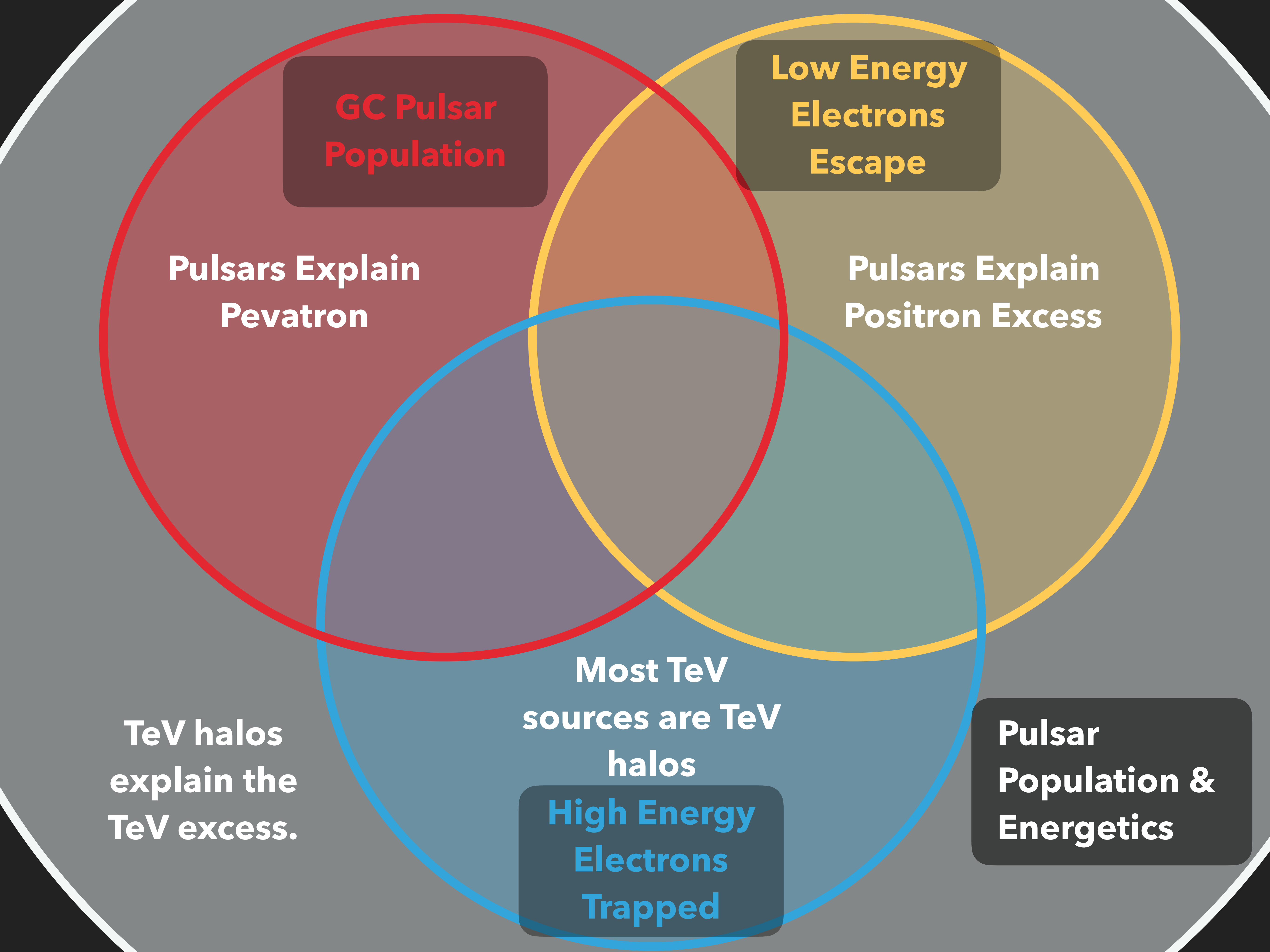
CONCLUSIONS (1/2)

- **TeV halos are a new dynamical object.**
- **Have already observed ~20 objects; >100 inevitable**
- **Simple extrapolations of observed systems imply:**
  - **TeV halos dominate the TeV source number.**
  - **TeV halos dominate Milky Way diffuse emission.**
  - **TeV halos produce the positron excess.**

CONCLUSIONS (2/2)

- **TeV Halos will provide new insight into pulsar birth, death, and evolution, providing a new handle into the multi-wavelength study of neutron star dynamics.**

- **TeV halos provide the first evidence for significant inhomogeneities in Galactic cosmic-ray propagation — new insights into cosmic-ray observations (e.g. AMS-02).**


GC Pulsar Population
Low Energy Electrons Escape
Pulsars Explain Pevatron
Pulsars Explain Positron Excess
Most TeV sources are TeV halos
TeV halos explain the TeV excess.
High Energy Electrons Trapped
Pulsar Population & Energetics

WHAT HAPPENS TO THE LOW-ENERGY E^+E^-?

Two Zone Model: First electrons escape from halo

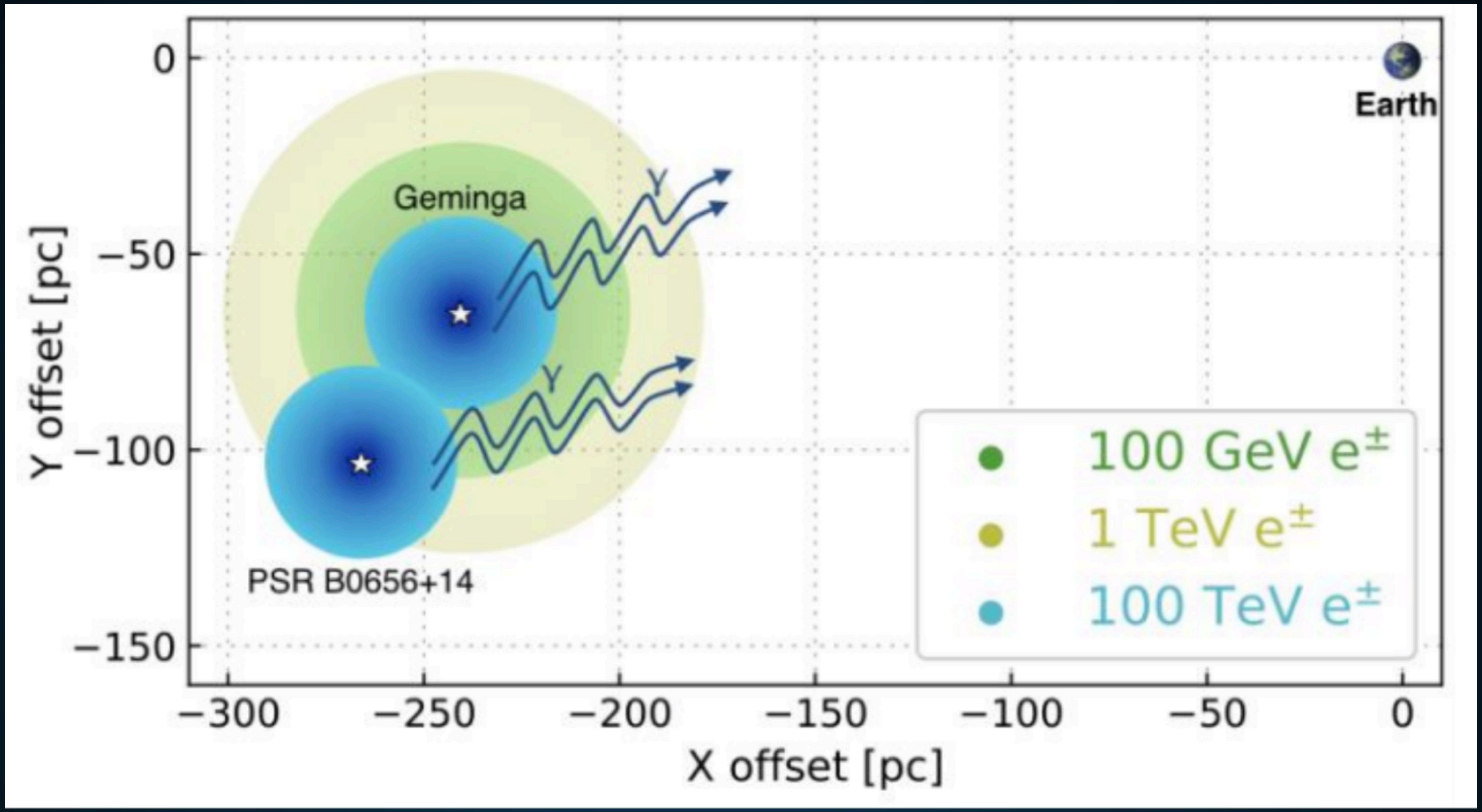
$$\tau_{diff} \propto \frac{L^2}{D_0 E^\delta} \qquad \tau_{loss} \propto E^{-1}$$

$$\left(\frac{\Delta E}{E}\right) \propto \frac{\tau_{diff}}{\tau_{loss}} \propto E^{1-\delta}$$

- **Low-energy electrons lose energy slower, lose less energy before exiting the TeV halo.**
- **If 10 TeV electrons lose 90% of their energy, 100 GeV electrons lose 10% of their energy.**

TWO POSSIBLE ASSUMPTIONS

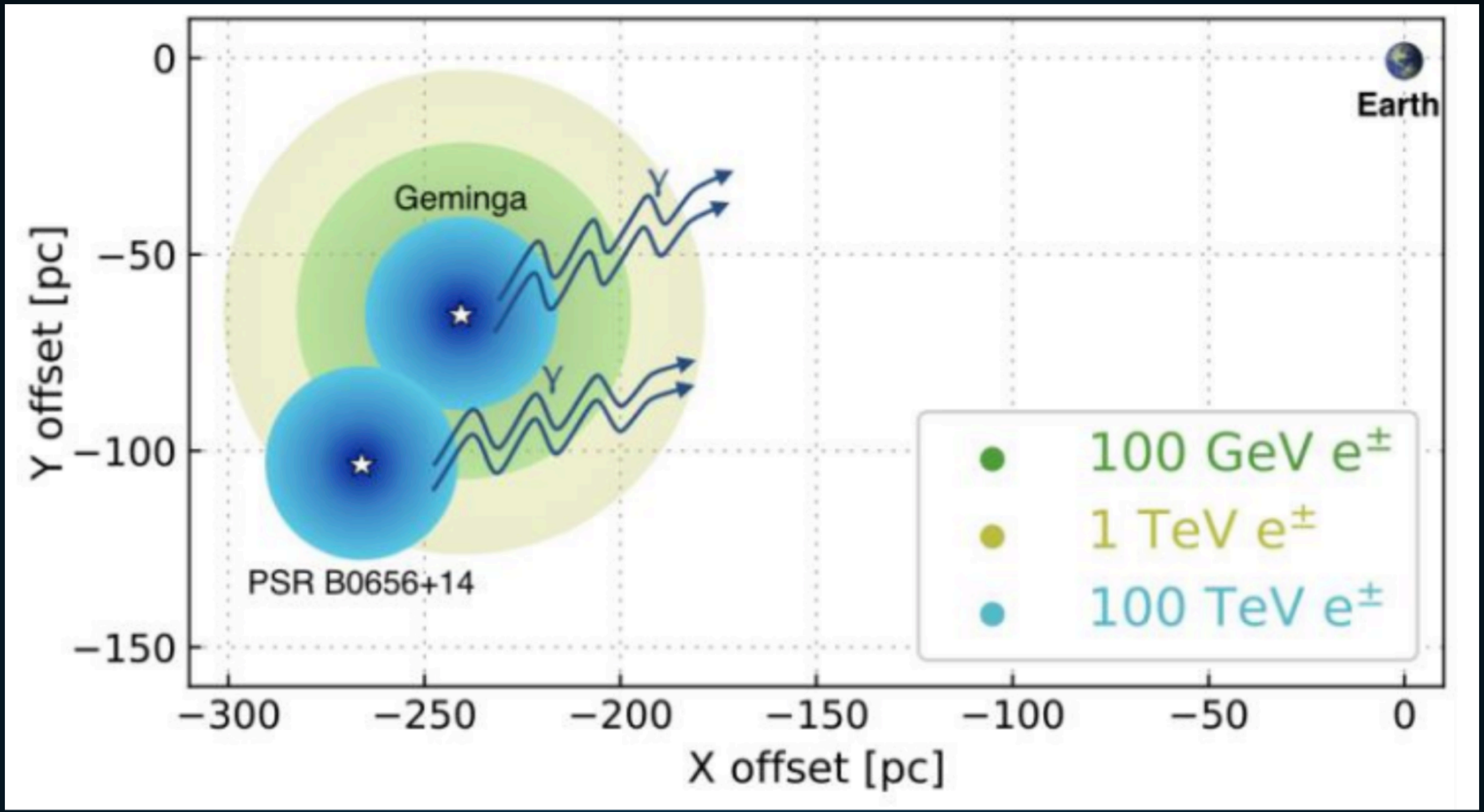
HAWC Collaboration (1711.06223)



- **<u>Assumption 1:</u> The diffusion constant measured near Geminga and Monogem stands as the first measurement of the diffusion constant near Earth**

TWO POSSIBLE ASSUMPTIONS

HAWC Collaboration (1711.06223)



- **Methodology:** **Apply the low** $(D_0 \sim 1 \times 10^{26}\ cm^2\ s^{-1})$ **diffusion constant for the full positron journey.**

TWO POSSIBLE ASSUMPTIONS

$$\tau_{diff} \propto \frac{L^2}{D_0 E^{\delta}} \qquad \tau_{loss} \propto E^{-1}$$

$$L(E) \propto \sqrt{D_0 E^{\delta - 1}}$$

- <u>Implication:</u> **Assuming Kolmogorov Diffusion (δ = 0.33), 100 GeV e^+e^- propagate about 4.5x as far.**

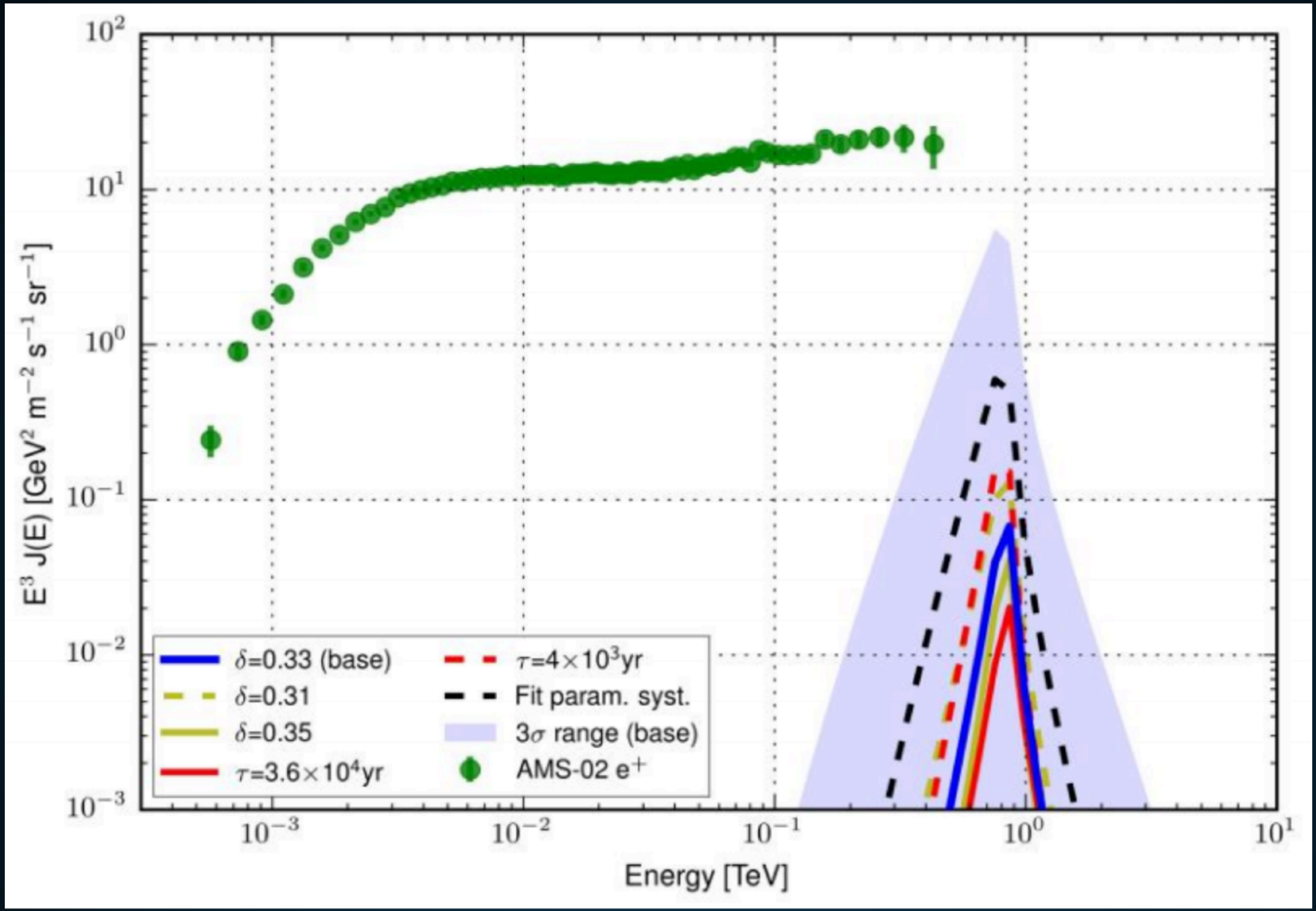
TWO POSSIBLE ASSUMPTIONS

$$L(10\ \text{TeV}) = 20\ \text{pc}$$

$$L(100\ \text{GeV}) = 92\ \text{pc}$$

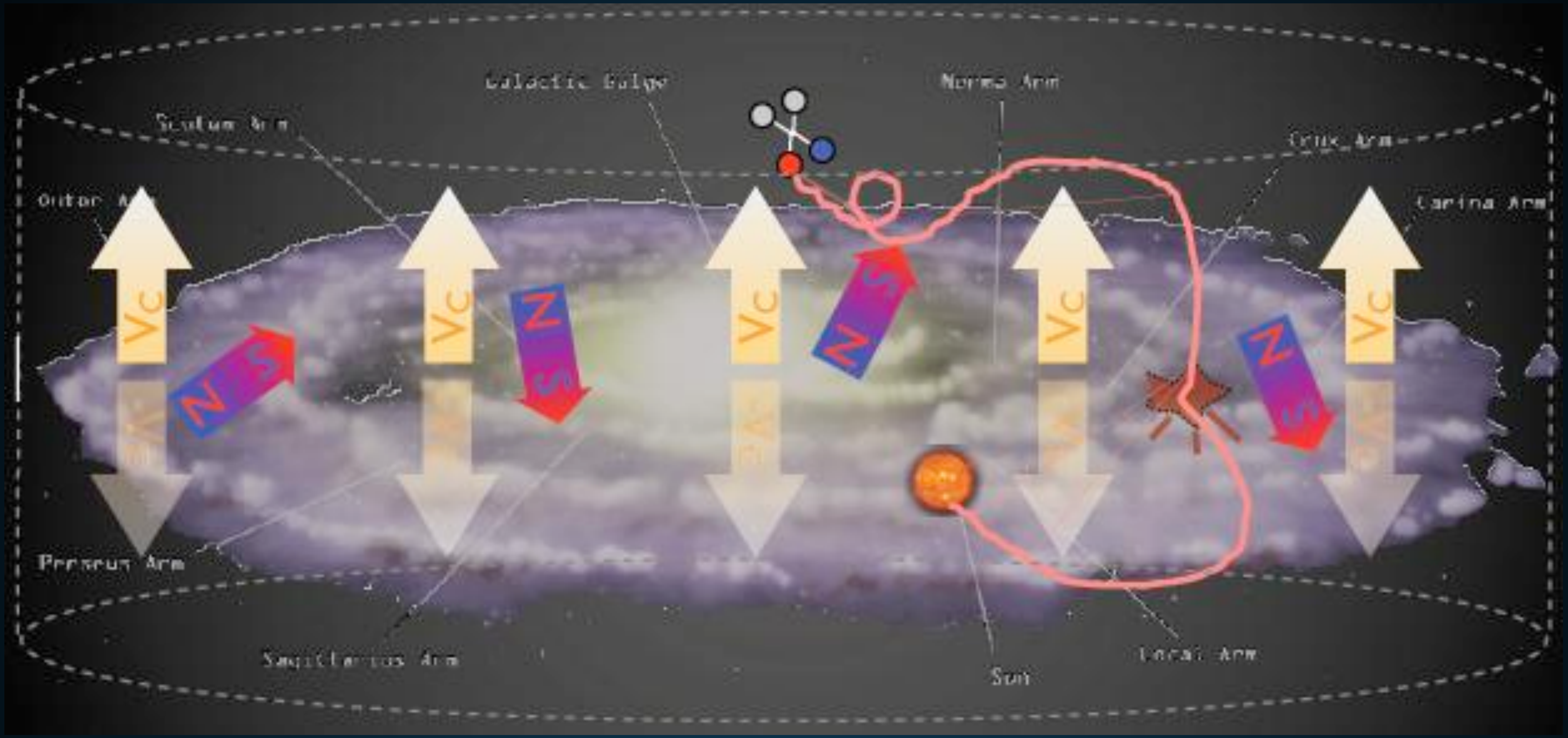
- **Implication:** Assuming Kolmogorov Diffusion ($\delta = 0.33$), 100 GeV electrons propagate about 4.5x as far.
- Earth is ~250 pc away

TWO POSSIBLE ASSUMPTIONS



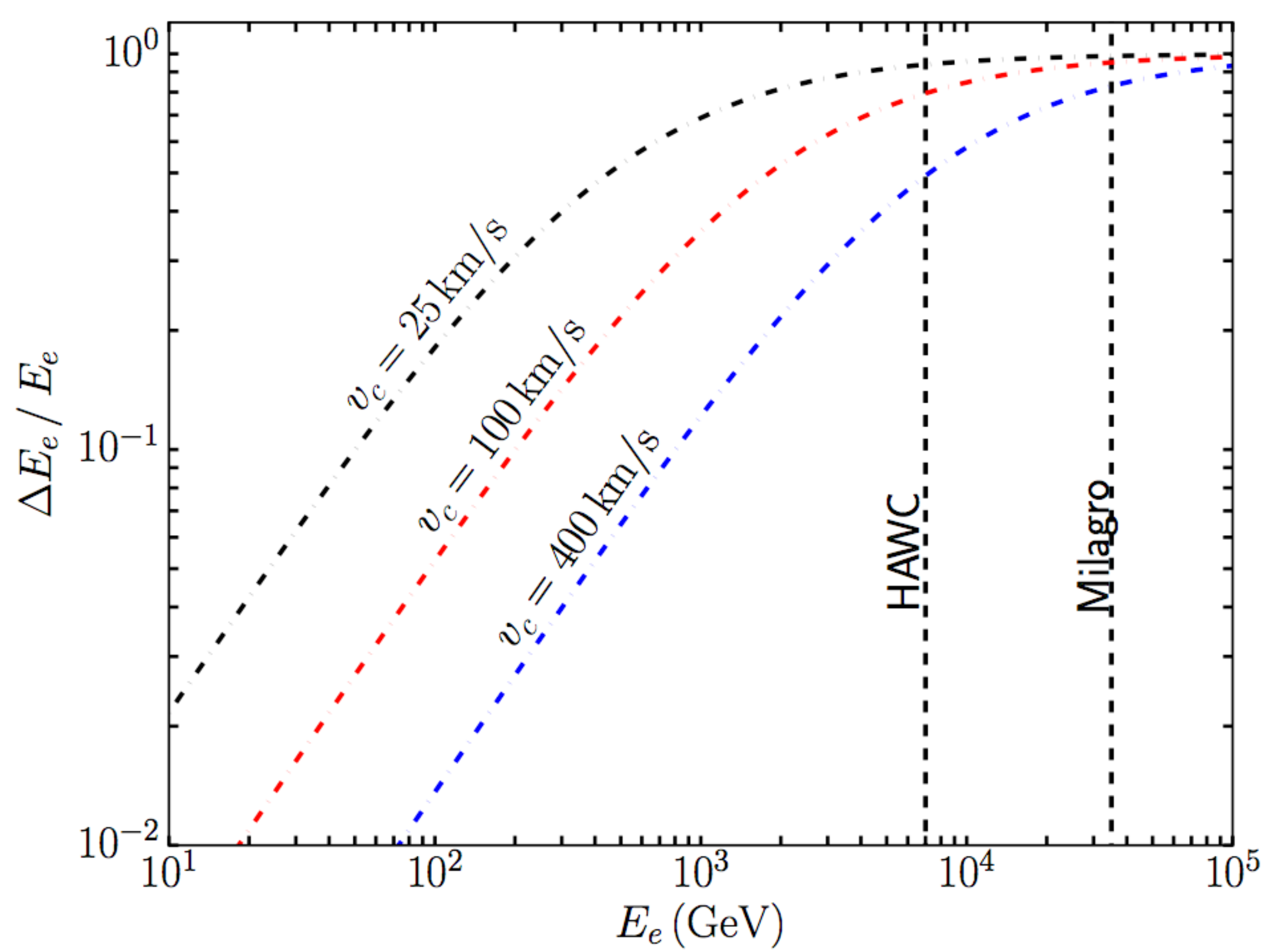
- **Implication:** **Geminga and Monogem do not explain the positron excess.**

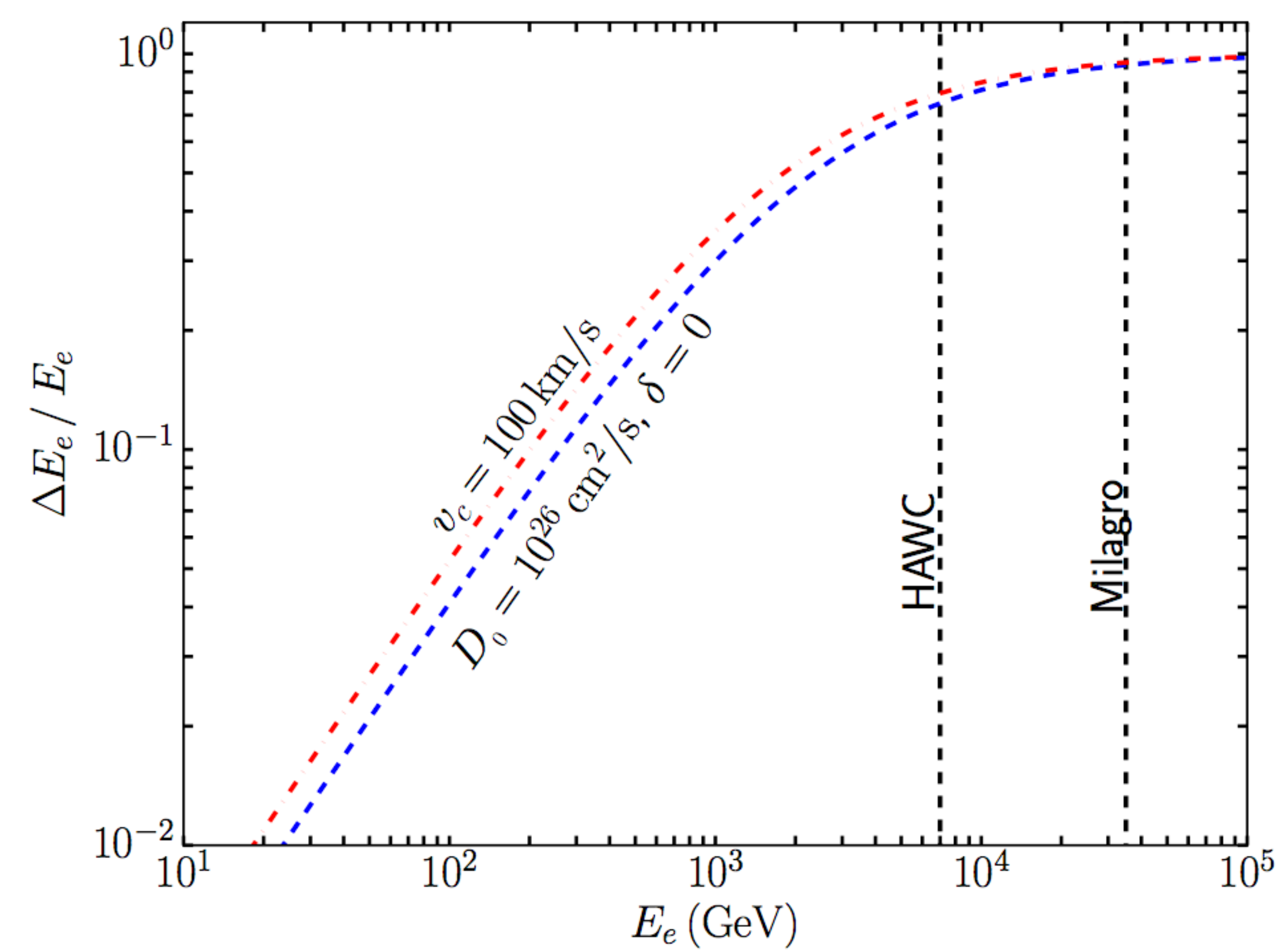
TWO POSSIBLE ASSUMPTIONS



- <u>Assumption 2:</u> **Measurements of cosmic-ray primary to secondary ratios (e.g. by AMS-02) imply that the local diffusion constant is high. The diffusion constant near Geminga and Monogem is local to those sources.**

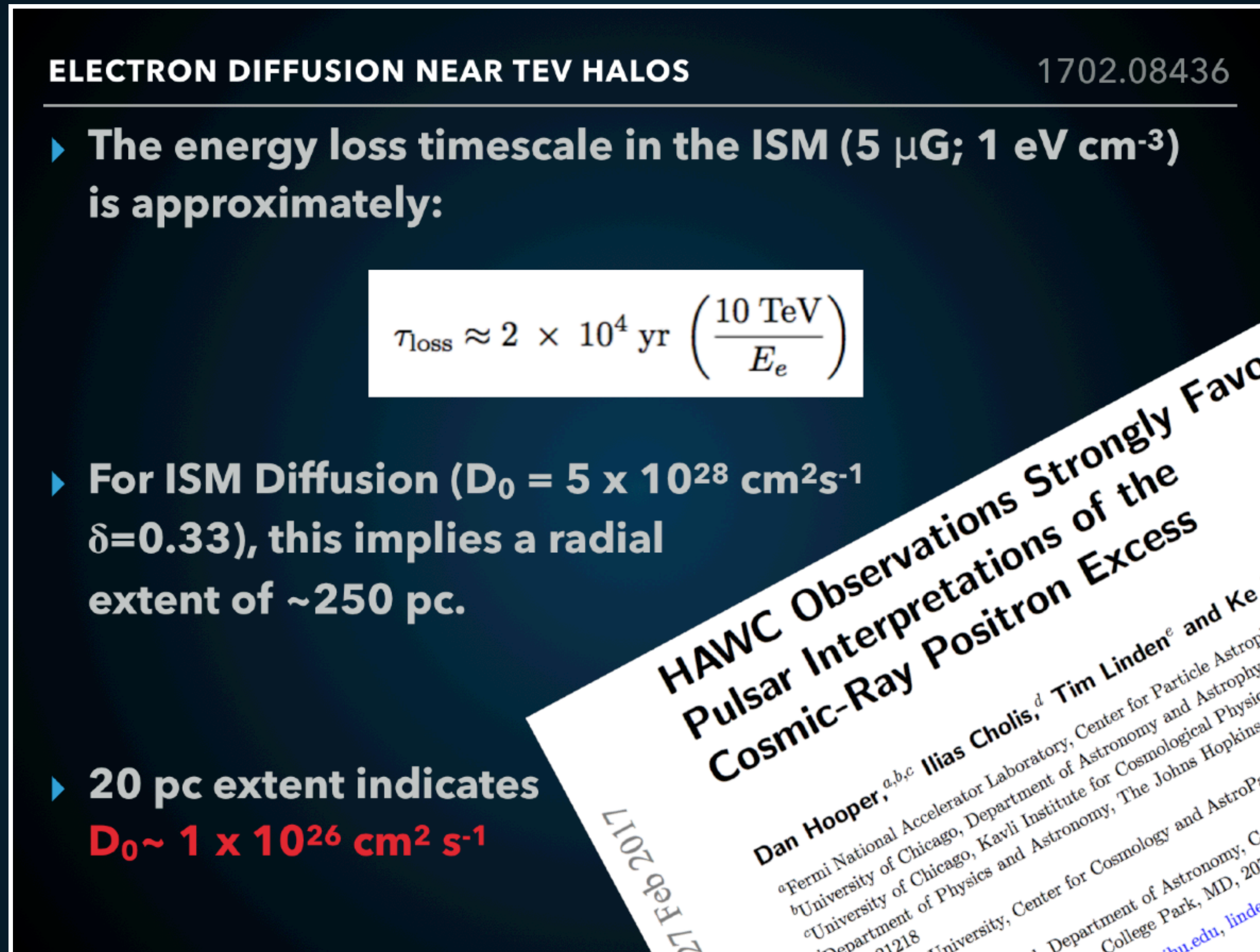
Two Zone Model: First electrons escape from halo





- **Low-energy electrons lose energy slower, lose less energy before exiting the TeV halo.**
- **If 10 TeV electrons lose 90% of their energy, 100 GeV electrons lose 10% of their energy.**

Two Zone Model: Then electrons propagate through ISM



- **Outside the TeV halo, diffusion is 500x more efficient.**

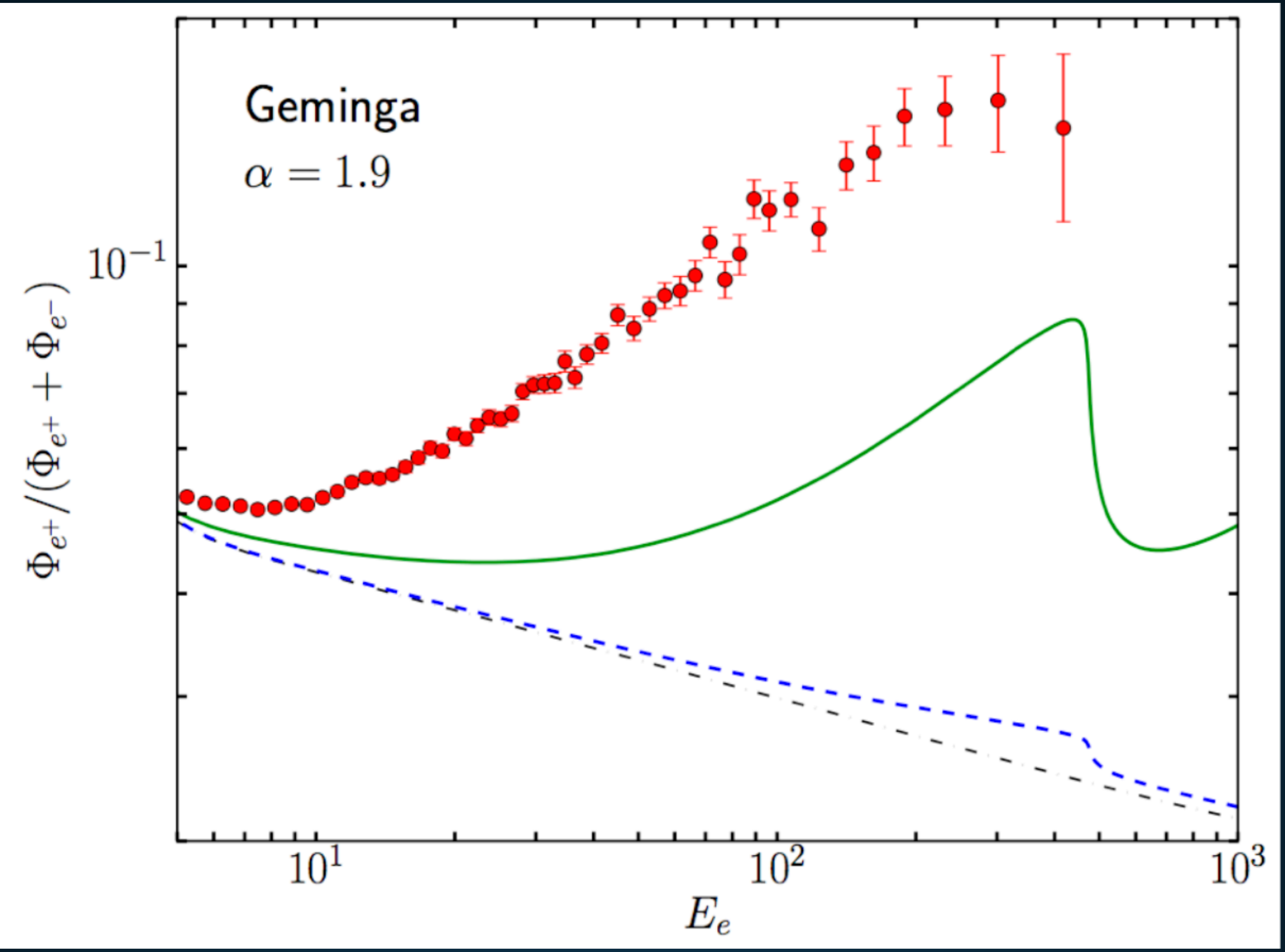
Two Zone Model: Then electrons propagate through ISM

$$\tau_{diff} \propto \frac{L^2}{D_0 E^\delta} \qquad \tau_{loss} \propto E^{-1}$$

$$L(E) \propto \sqrt{D_0 E^{\delta-1}}$$

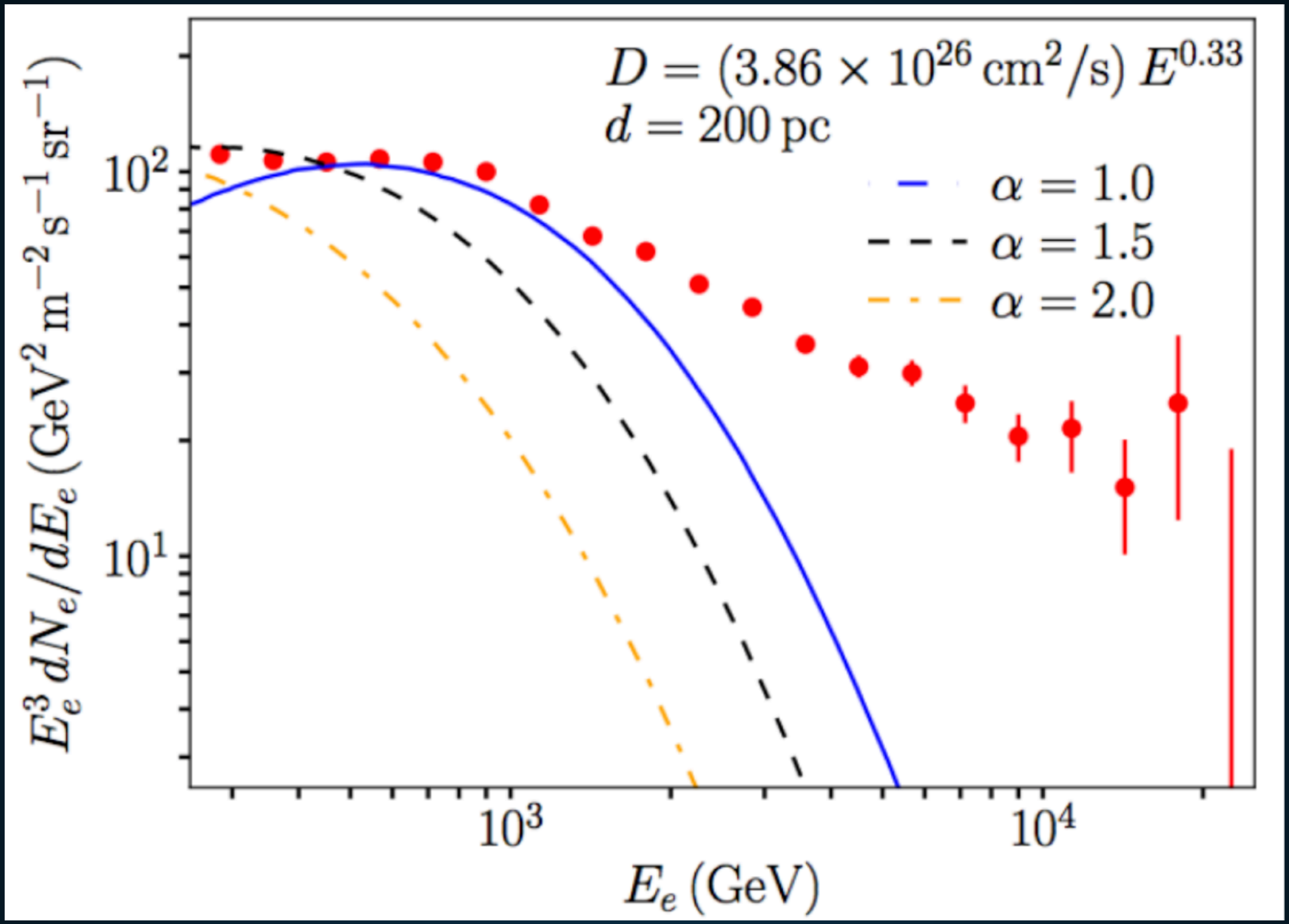
- Instead of 100 GeV electrons propagating ~90 pc, they now propagate 2000 pc.

Hooper et al. (1702.08436)



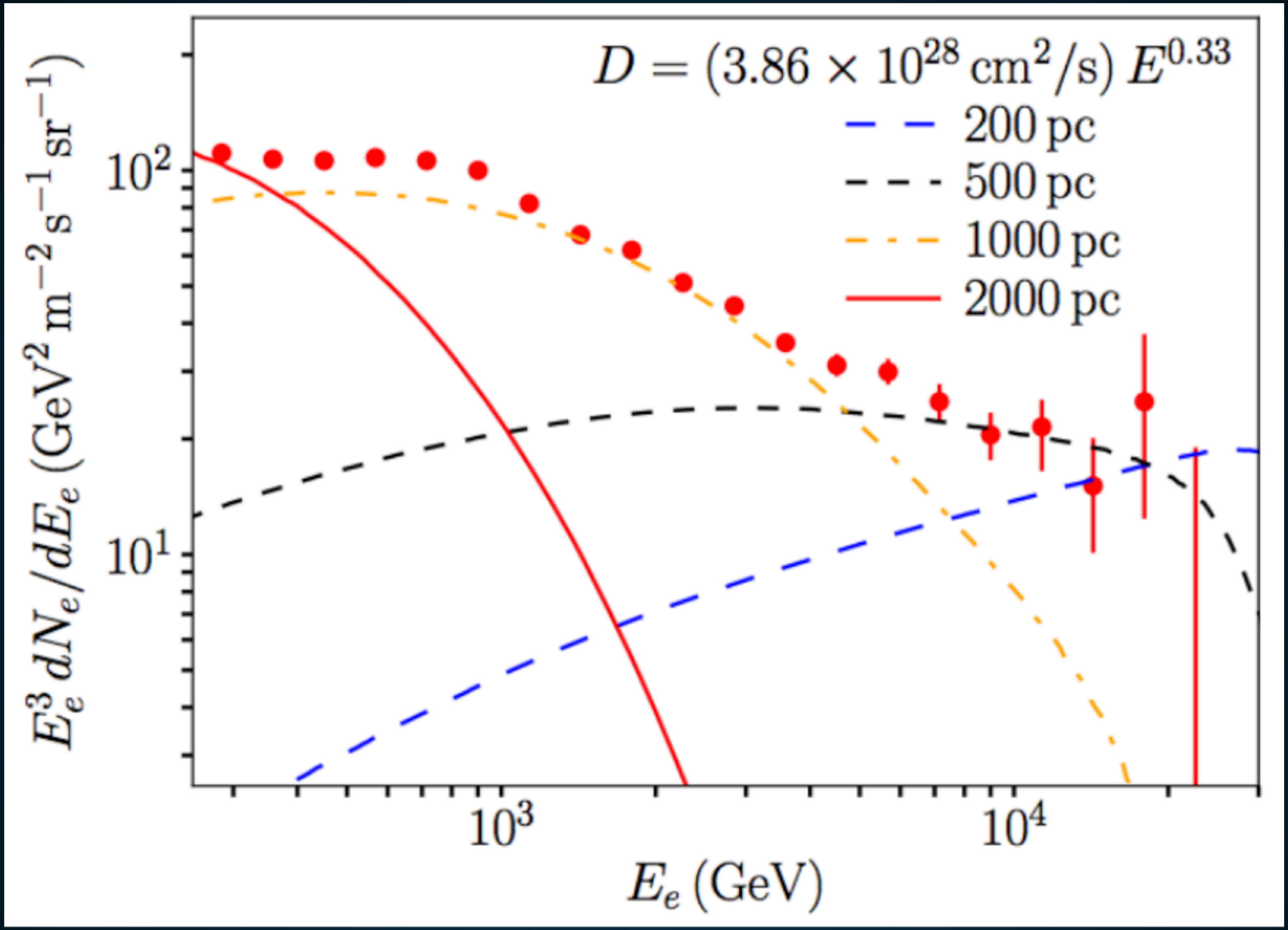
- **<u>Implication:</u> Low energy positrons make it to Earth and explain the positron excess.**

WHAT HAPPENS TO THE LOW-ENERGY E^+E^-?



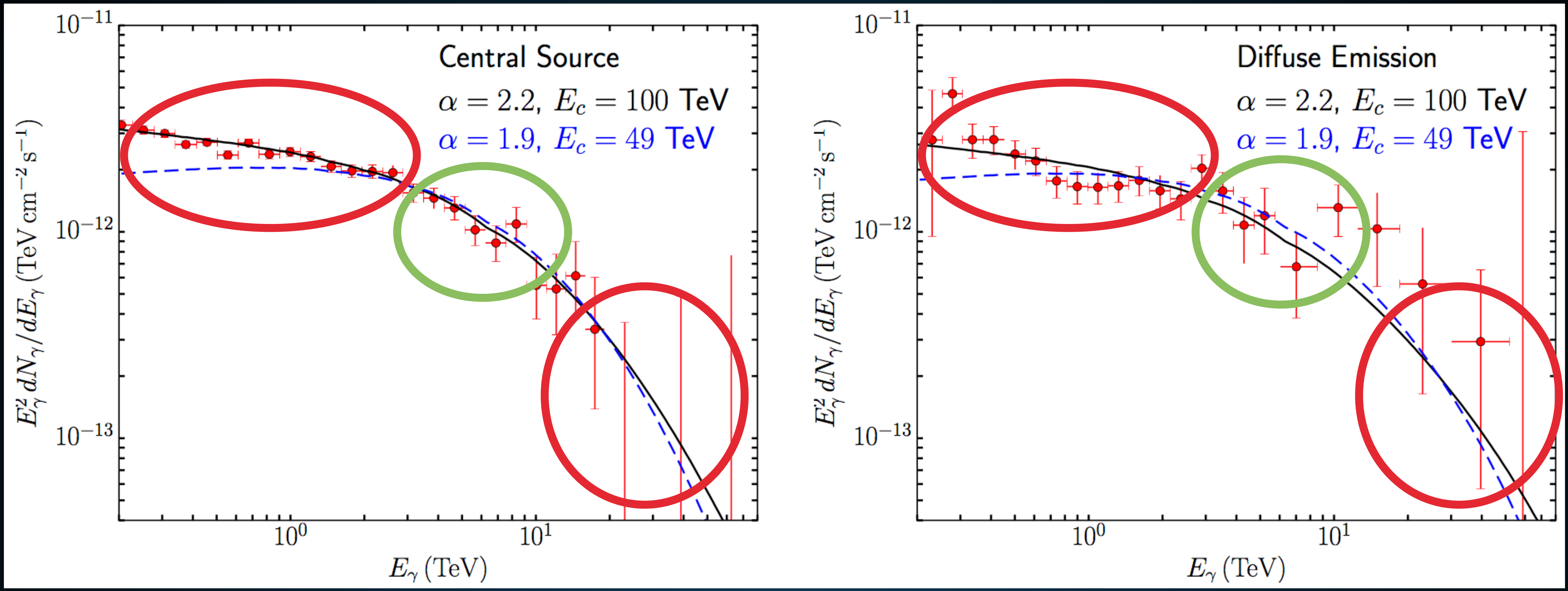
- <u>Assumption 1:</u> **If diffusion constant near Earth is low, any source explaining the electron flux must be within ~30 pc of Earth.**

WHAT HAPPENS TO THE LOW-ENERGY E+E-?



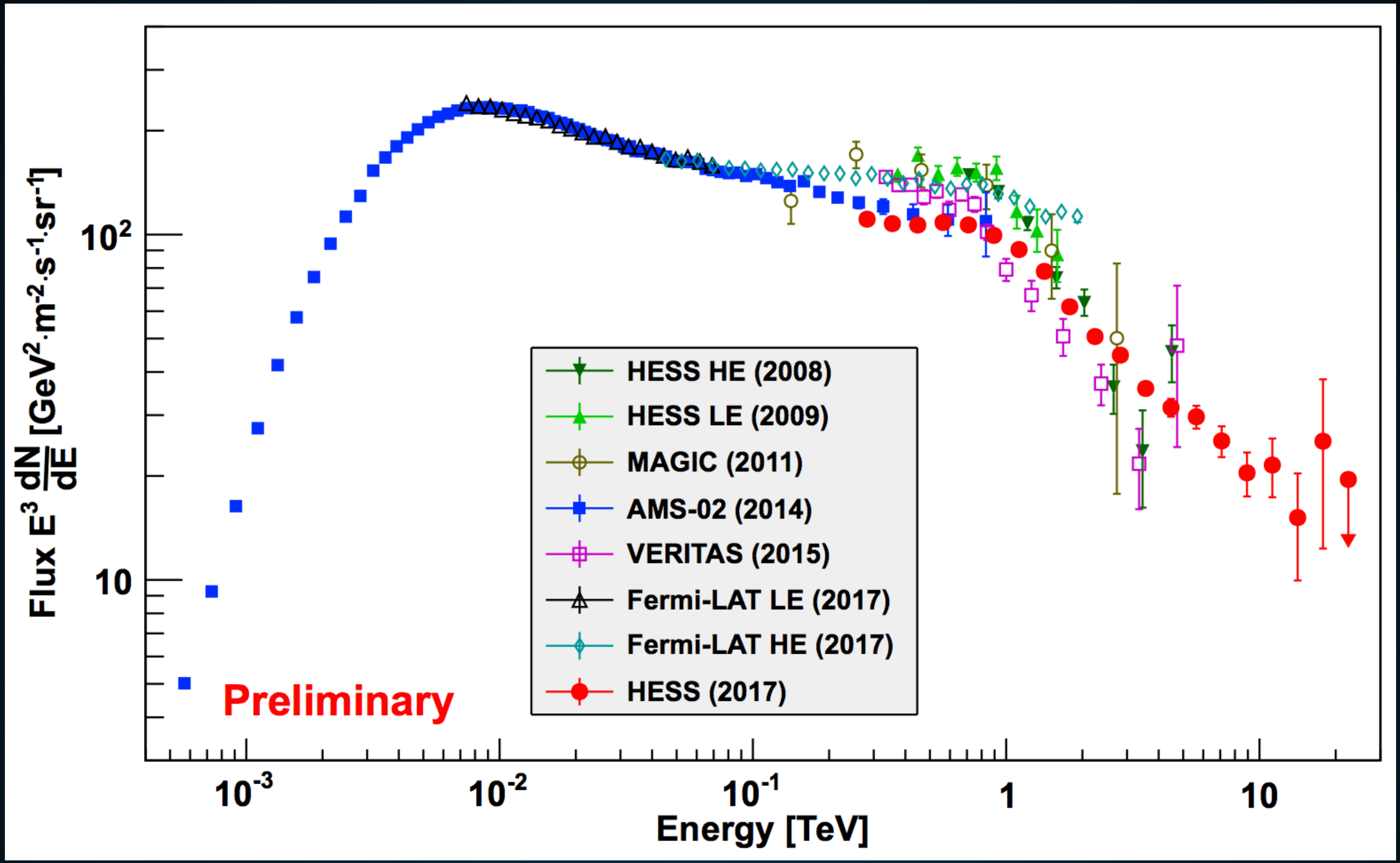
- <u>Assumption 2:</u> **If diffusion is high, the nearest 10 TeV source can be ~500 pc away.**

INTENSITY OF TEV HALO EMISSION IN GALACTIC CENTER



- Assumptions: Standard values for the pulsar birthrate and kick velocity
    - Birth rate between 100-750 pulsars/Myr
    - Pulsar kicks ~ 400 km/s
- We reproduce the intensity and morphology of the HESS emission.

WHAT HAPPENS TO THE LOW-ENERGY E+E-?



- **Recent H.E.S.S. observations have extended the observed e^++e^- spectrum to energies exceeding 20 TeV.**

https://indico.snu.ac.kr/indico/event/15/session/5/contribution/694/material/slides/0.pdf