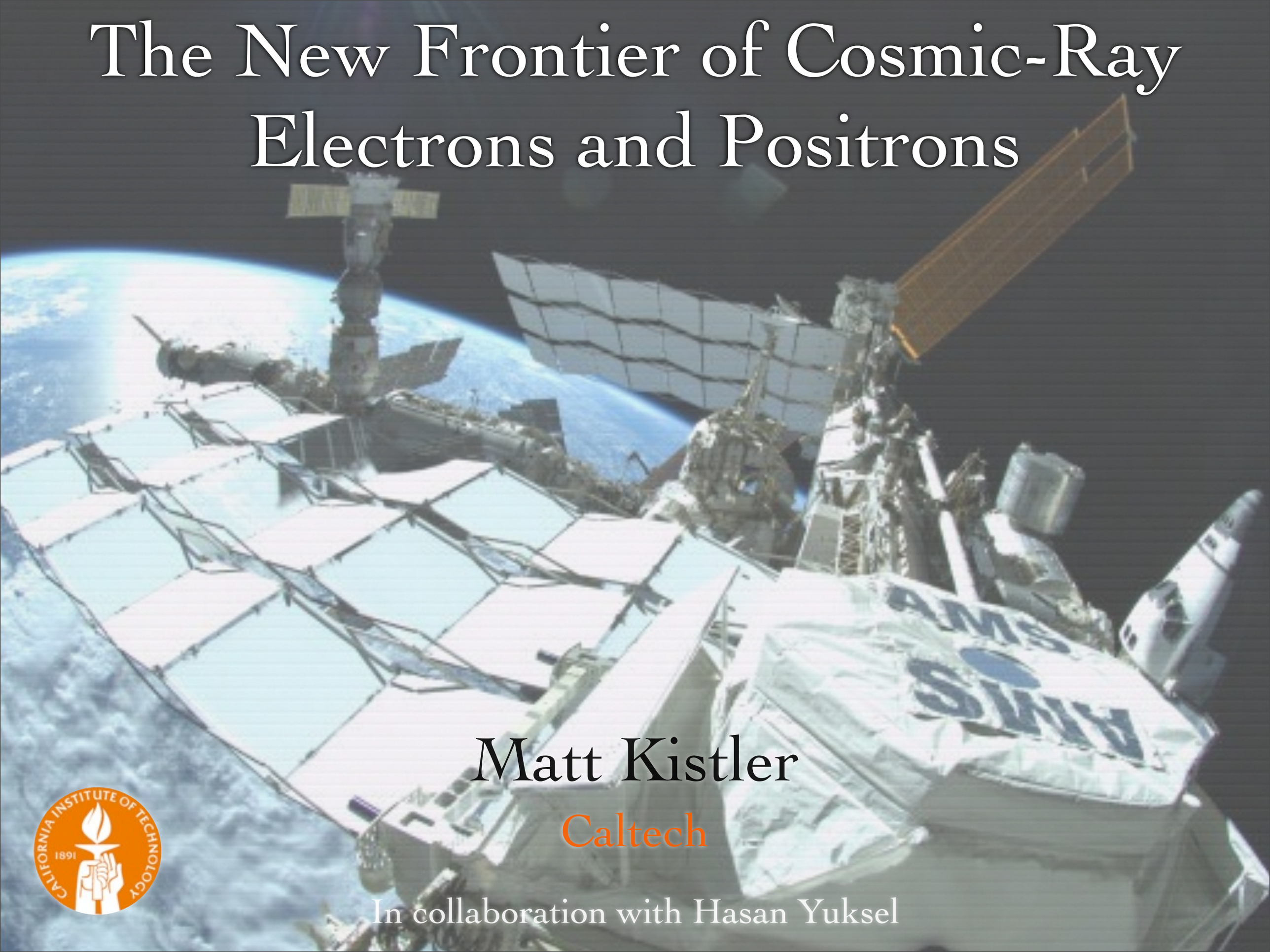
The New Frontier of Cosmic-Ray Electrons and Positrons

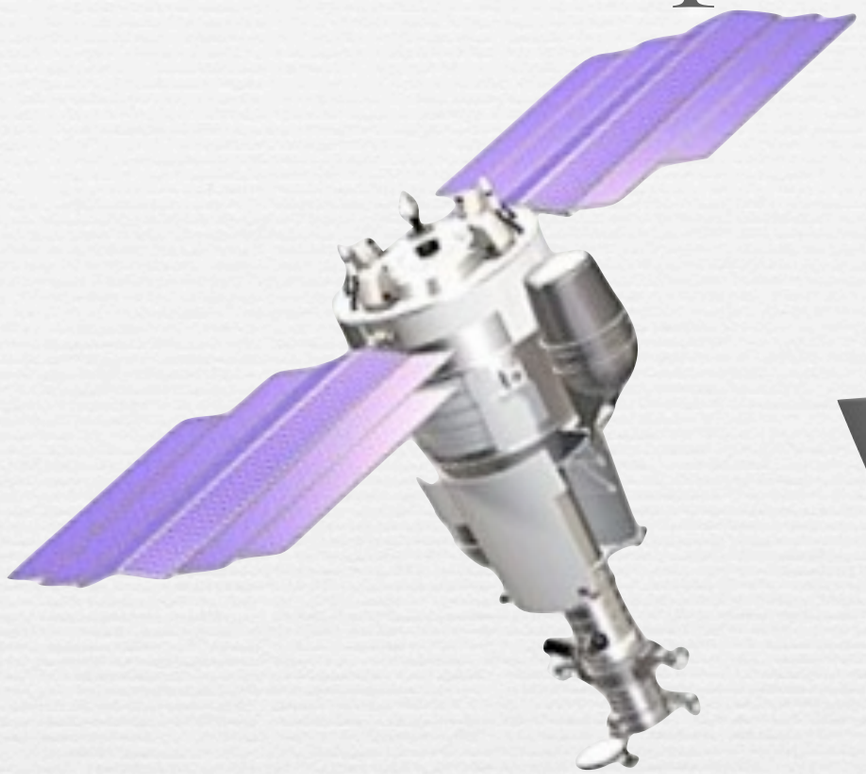


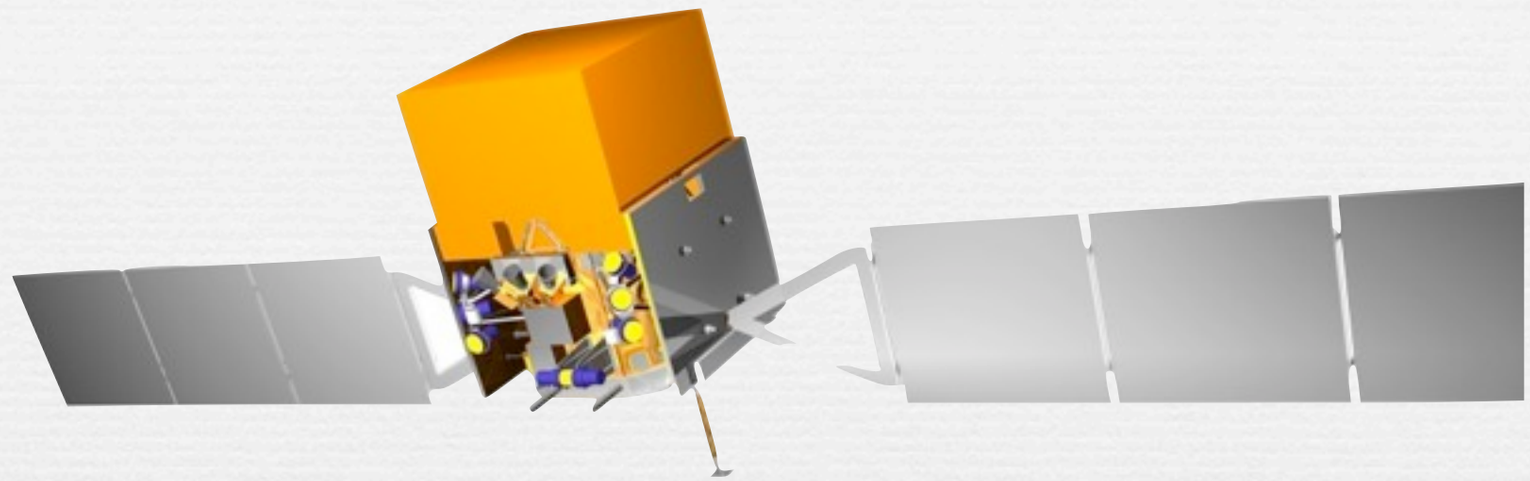
Matt Kistler

Caltech

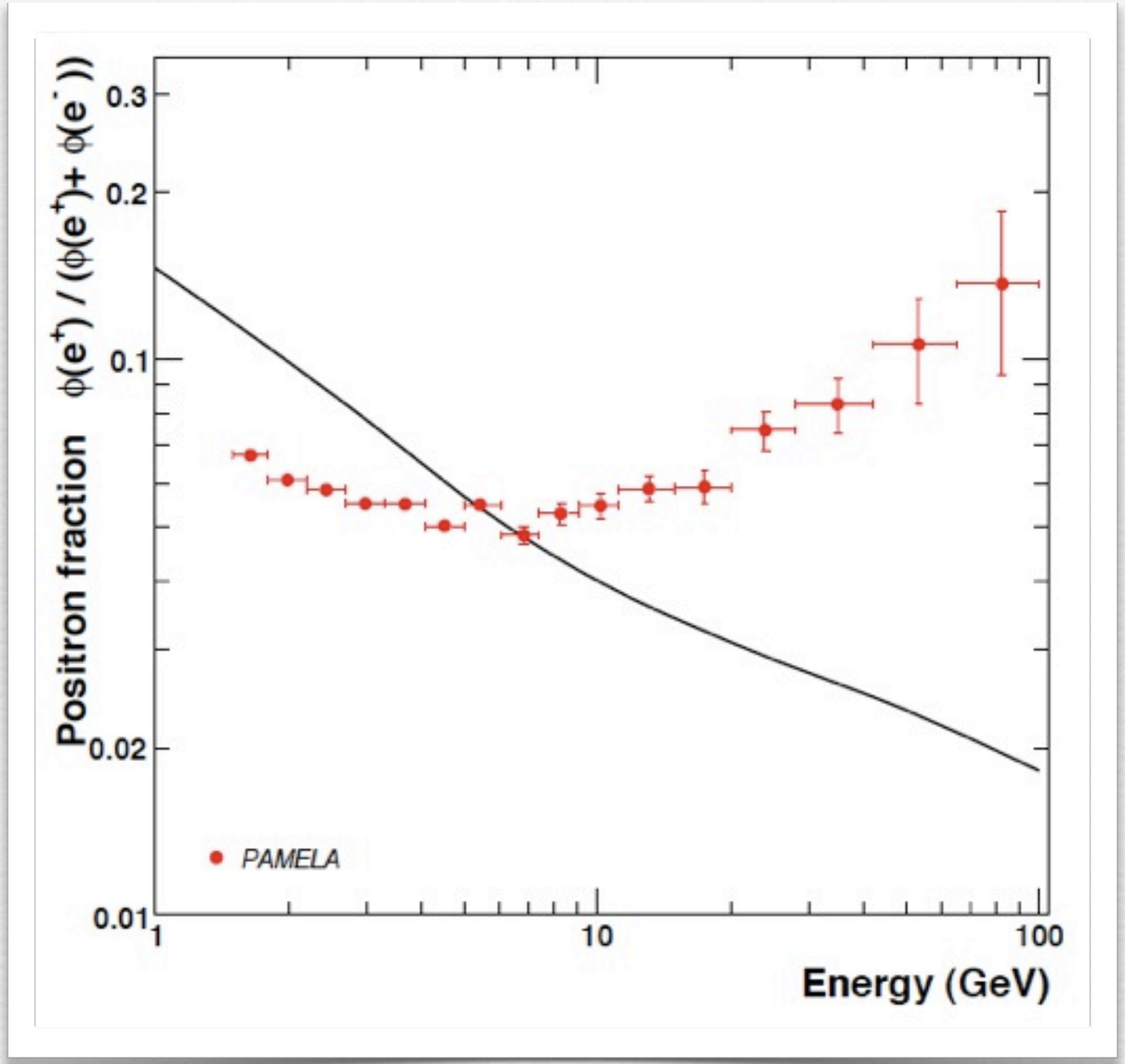
In collaboration with Hasan Yuksel

Electron experiments



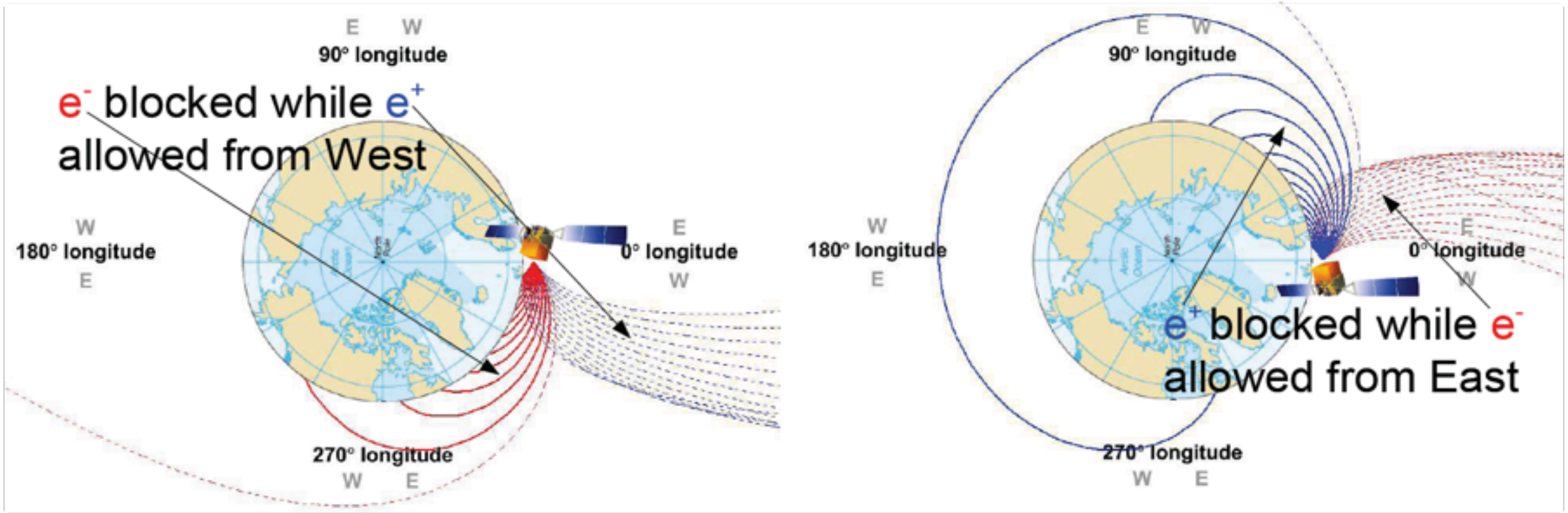


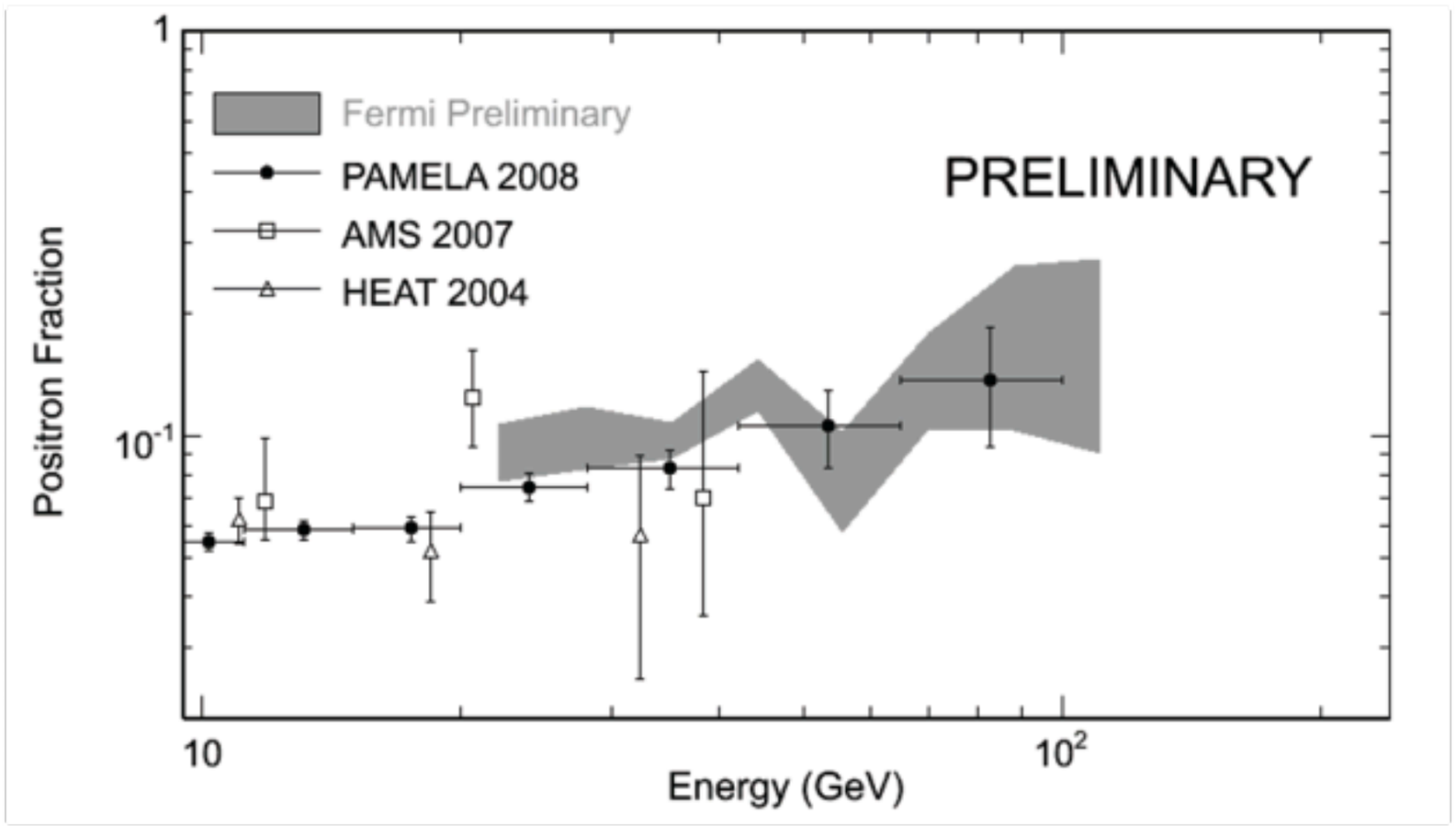
Physicists aflutter about data



PAMELA (2008)

Latest from Fermi





Talk by W. Mitthumsiri at Fermi Symposium 2011

Photo: UFO Snapped Near UK Cathedral!

Posted in Photos, UFOs with tags aliens, hot pick, new ufo picture, top post, ufo near ely cathedral, ufo picture 2009 on April 2, 2009 by ghostradioworld

Nice shot. Here are the details from the Ely Standard:

A WOMAN in Ely has taken phone footage of what she believes is a flying saucer hovering over Ely Cathedral.

The woman, who was walking her dog on Tuesday evening, sent us this footage last night and we immediately put it up on our website this morning (April 1).

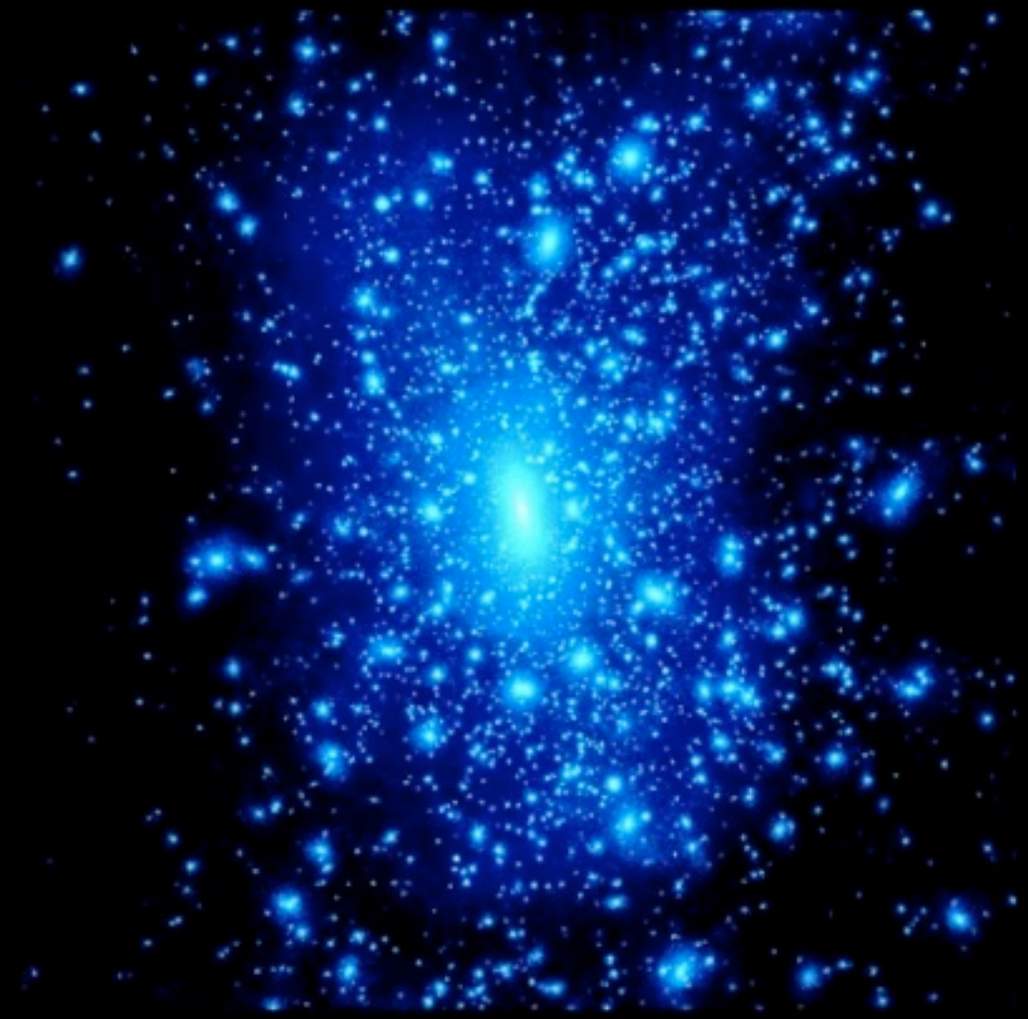
A dog walker told us she was with her pet Labrador Massie down near to riverside when she looked up and saw an oval mass hovering over the cathedral.

"Maisie started quivering," the woman in her fifties told the Ely Standard, "and that's when I knew something was wrong."

The resident took out her camera phone to capture this e once-in-a lifetime event and sent the result to the Ely Standard. "The result was a bit blurry," she said, "because by that time I was almost as nervous as Maisie. You certainly don't prepare yourself for that sort of thing – I'm a natural sceptic about the existence of extra-terrestrial life and had always poured scorn on the conspiracy theorists who thought we would all be beamed up into spaceships by 2010. However, it was soon clear that whatever the object was, it was not hostile, and it had obviously homed in on the cathedral as a major landmark for the area and I think that's rather nice. I go to evensong at the cathedral fairly regularly and am unsure about what the Church of England's view on alien life forms is, but the fact that they didn't do me, Maisie or that spectacular building any harm – so as far as I'm concerned – if they are aliens, they are welcome on my planet."

Dark Matter Found?

Posted in Weird Science with tags cool, dark energy, dark matter, quantum, satellite, science news, space, telltale signs of dark matter on April 2, 2009 by ghostradioworld



From Yahoo News:

PARIS (AFP) – European astronomers said on Wednesday that an anomalous energy signal detected by an orbiting satellite could be a telltale of the enigmatic substance known as dark matter.

The researchers, in a study appearing in the British journal Nature, say the hunch is that they picked up a signature of this strange phenomenon, but more work is needed.

Some years ago, astrophysicists calculating the amount of matter in the Universe arrived at the startling discovery that ordinary material — atoms — comprises perhaps as little as five percent of the stuff in the cosmos.

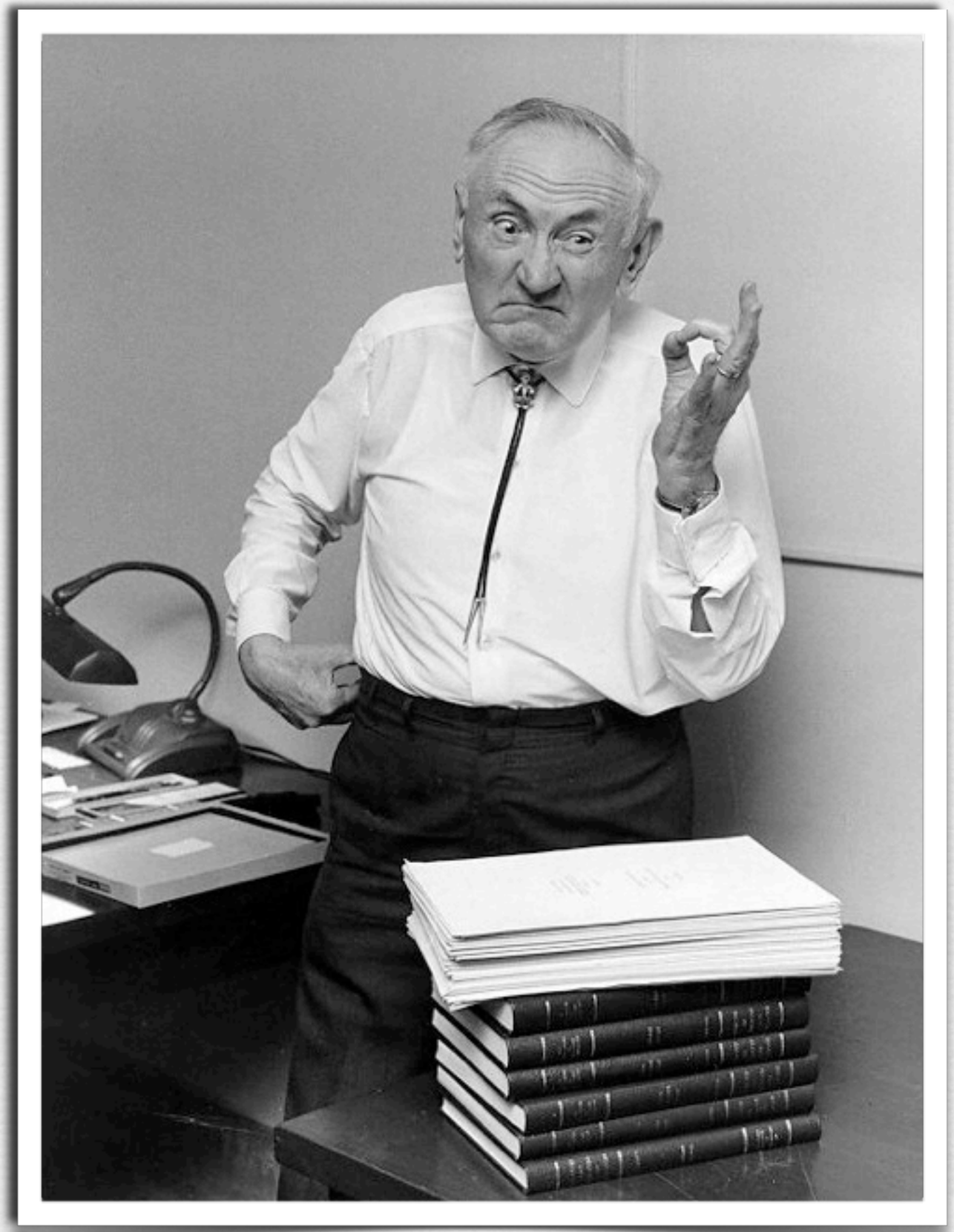
The rest, they believe, comes from the "dark" sector: matter and energy that appear to be pervasive but whose nature remains a puzzle.

Zwicky

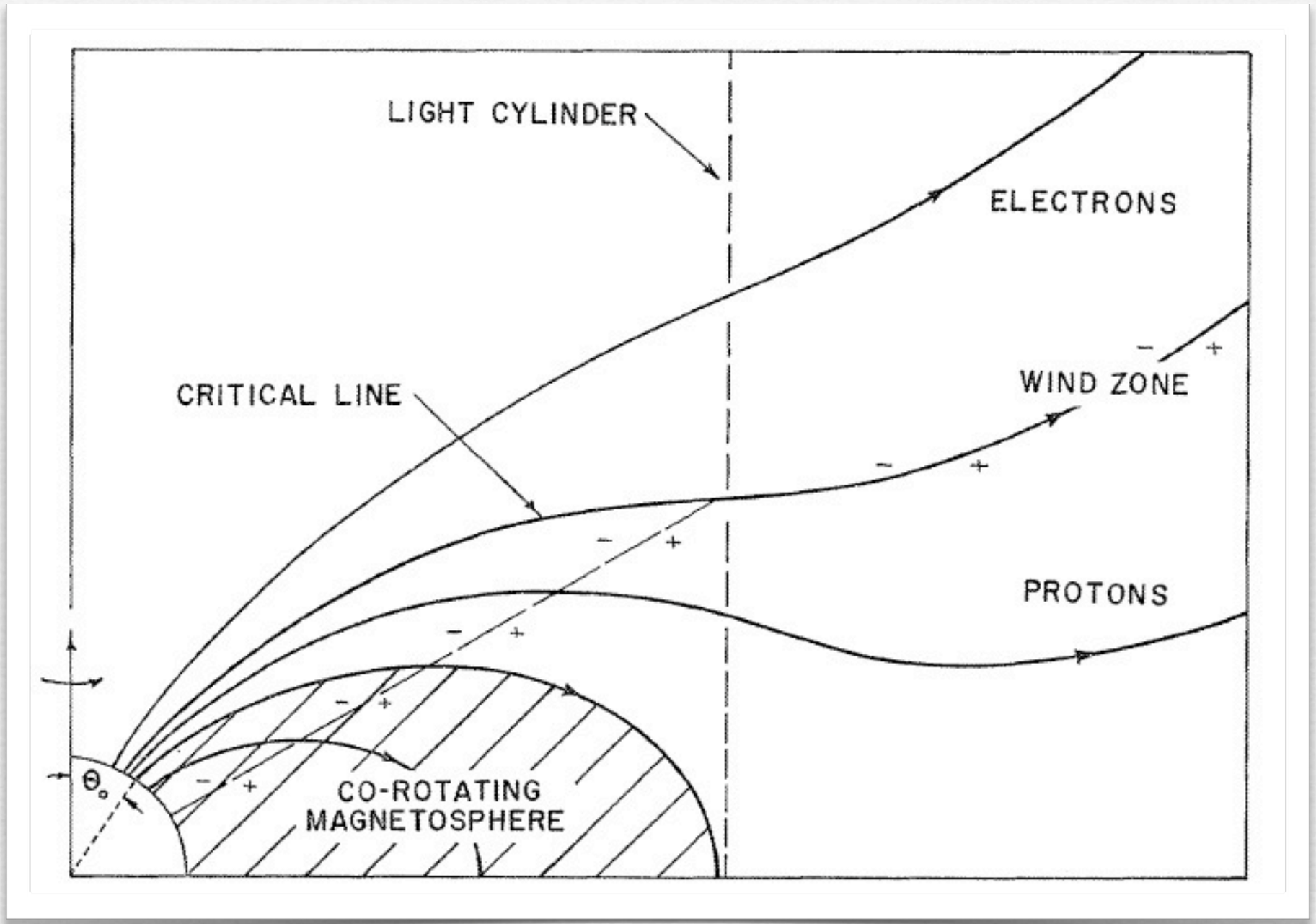
Supernovae as source of cosmic rays

Neutron stars result from supernovae

What is the cosmic ray output of neutron stars?

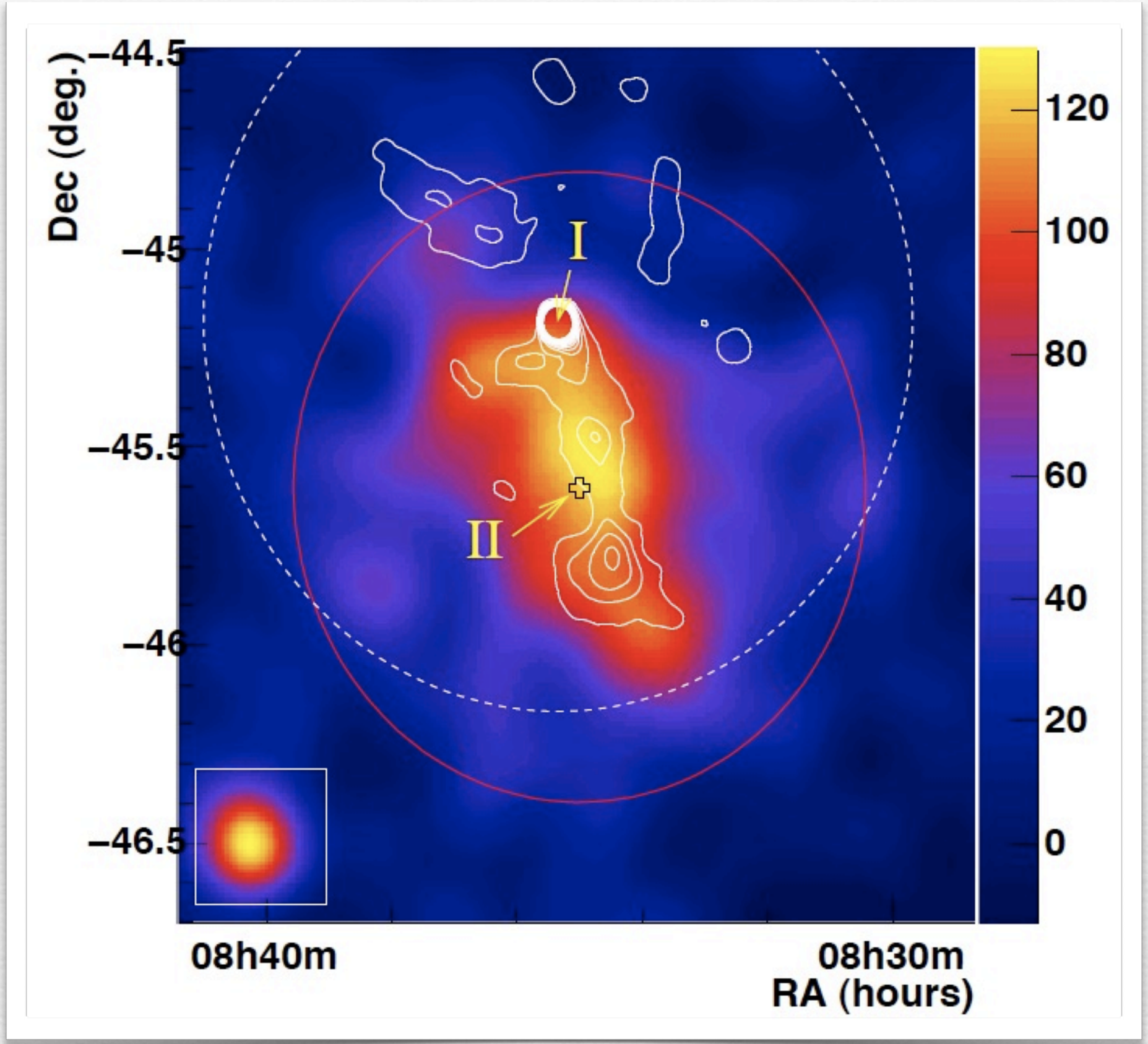


Pulsar wind



Goldreich and Julian (1969)

$$\dot{N}_{GJ} \simeq B\,\Omega^2 R^3/ec$$



HESS (2006)

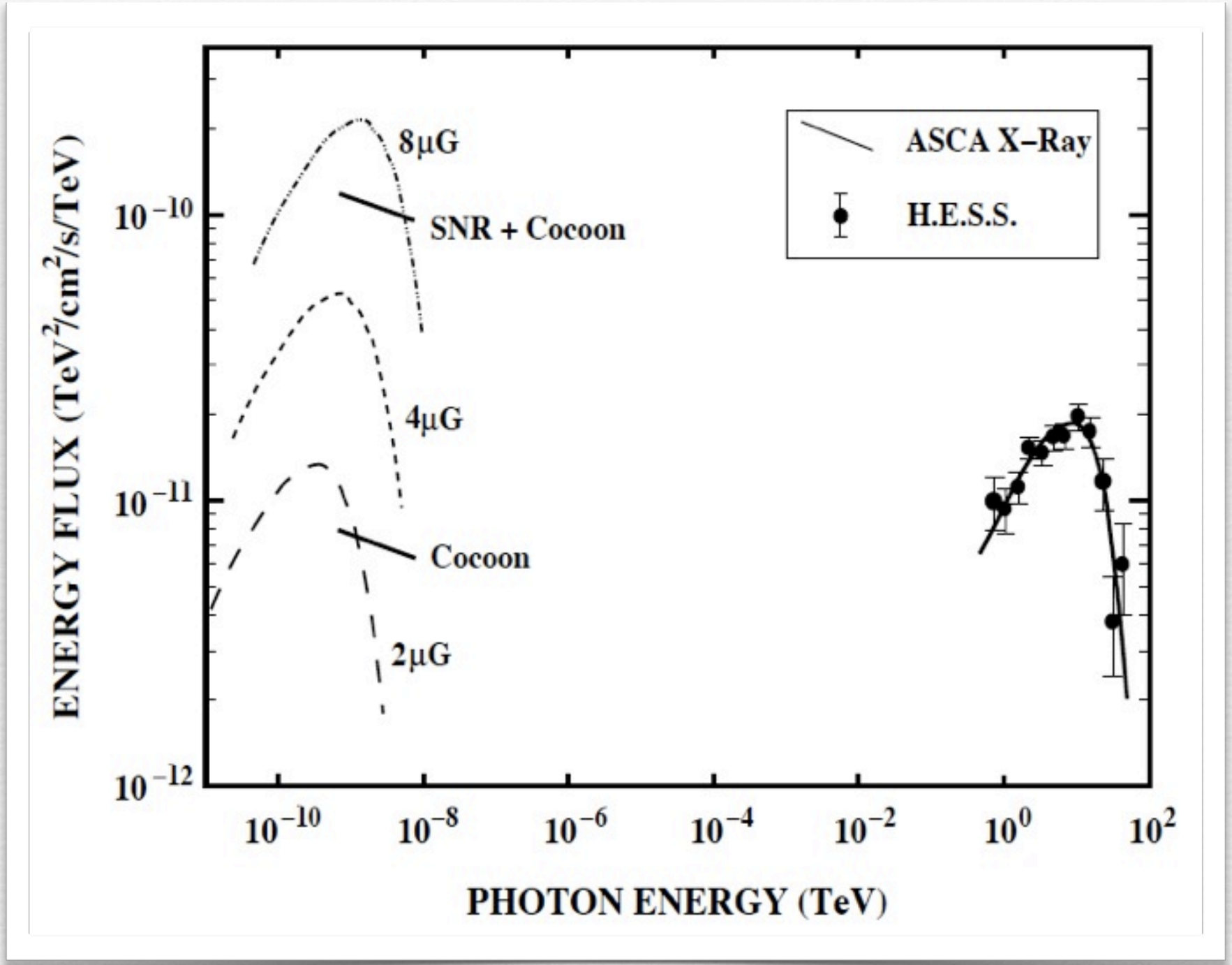
Vela X

11,000 yr

290 pc

Larger radio nebula not shown

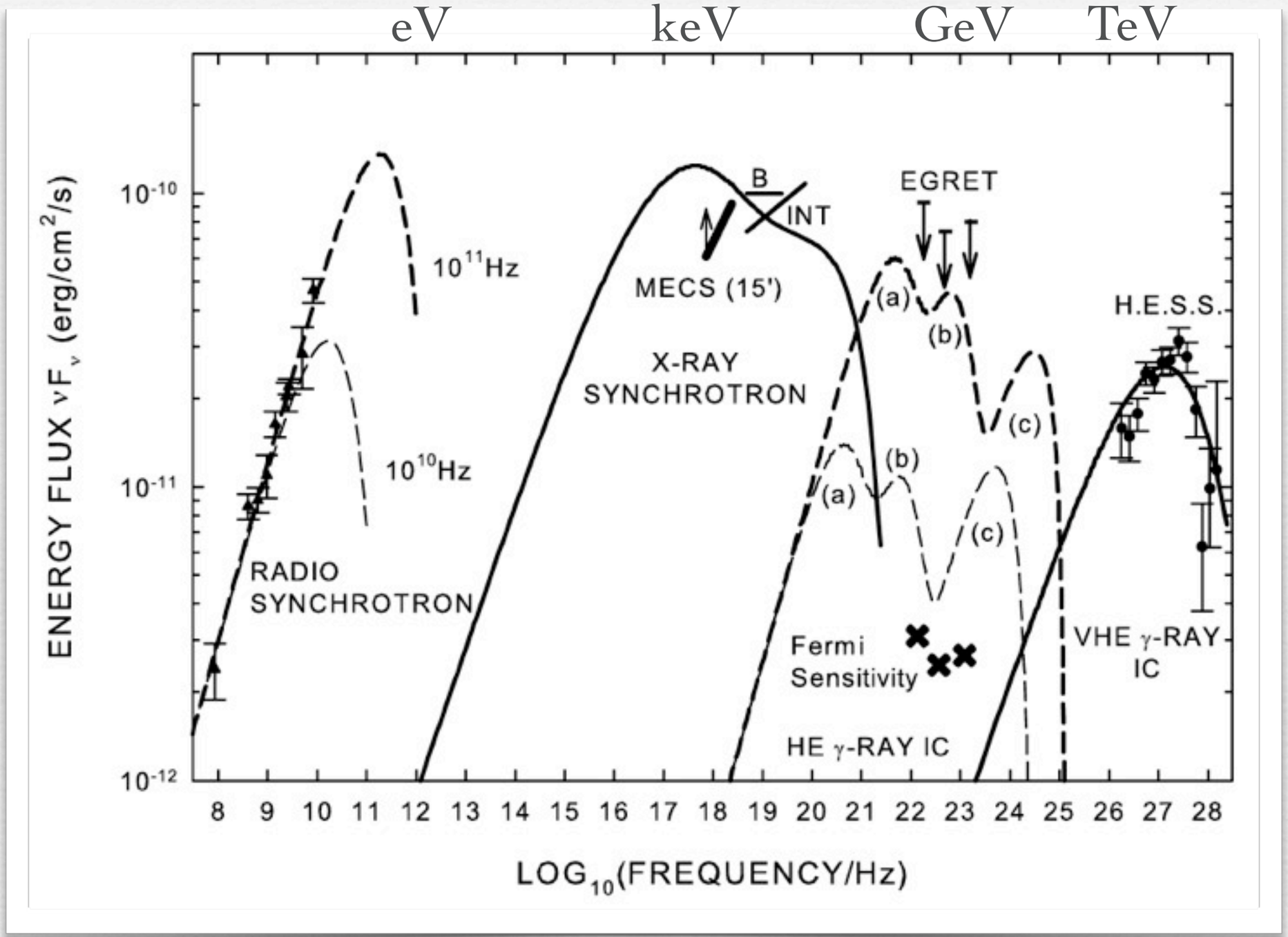
Vela X



HESS (2006)

Electron spectrum consistent with E^{-2} with exponential cutoff at ~70 TeV

~10^{46} erg in TeV electrons seen, more if escape allowed for



Vela X

Radio implies electron spectrum of form $E^{-1.8}$

Cutoff at ~100 GeV?

~4 x 10^{48} erg in radio population

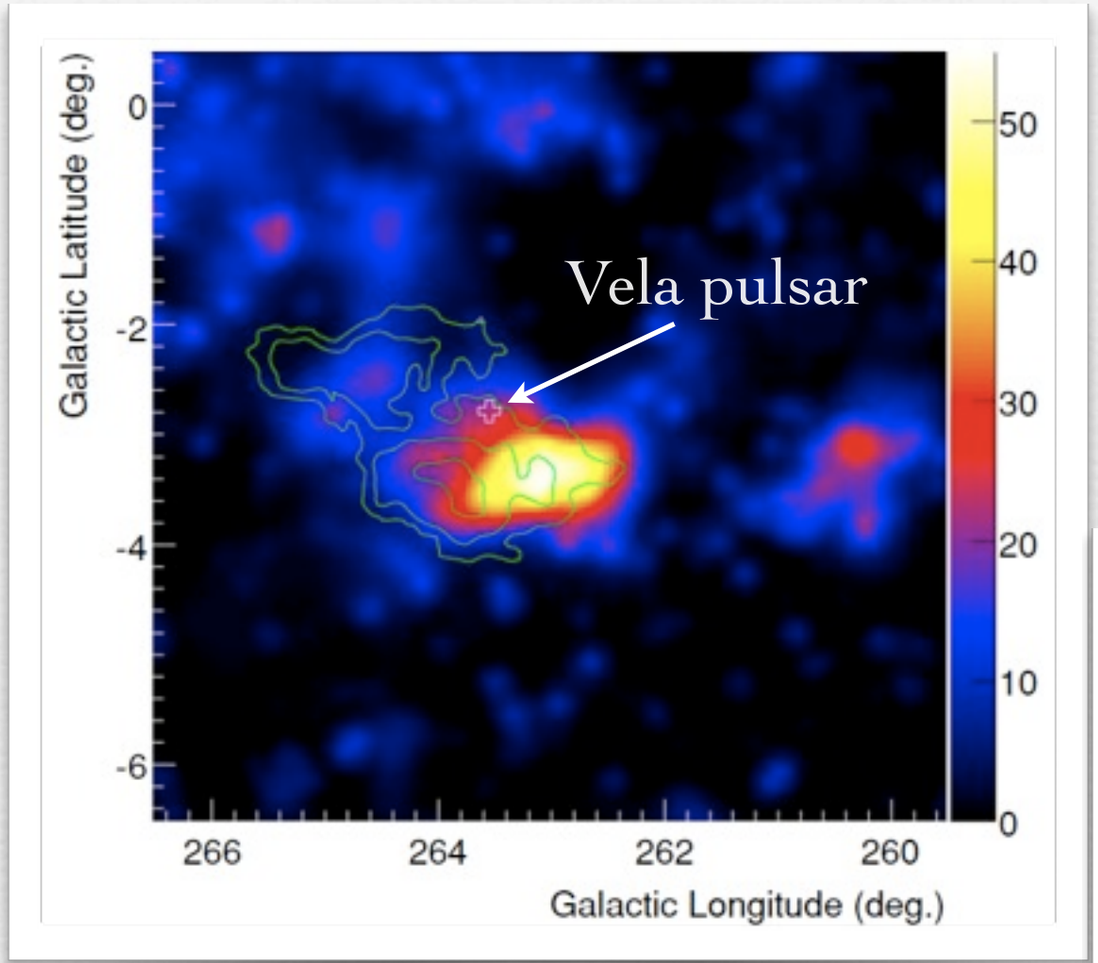
>10% of pulsar spin-down energy

de Jager, Slane, Lamassa (2008)

$$\dot{N}_{GJ} \simeq B\,\Omega^2 R^3/ec$$

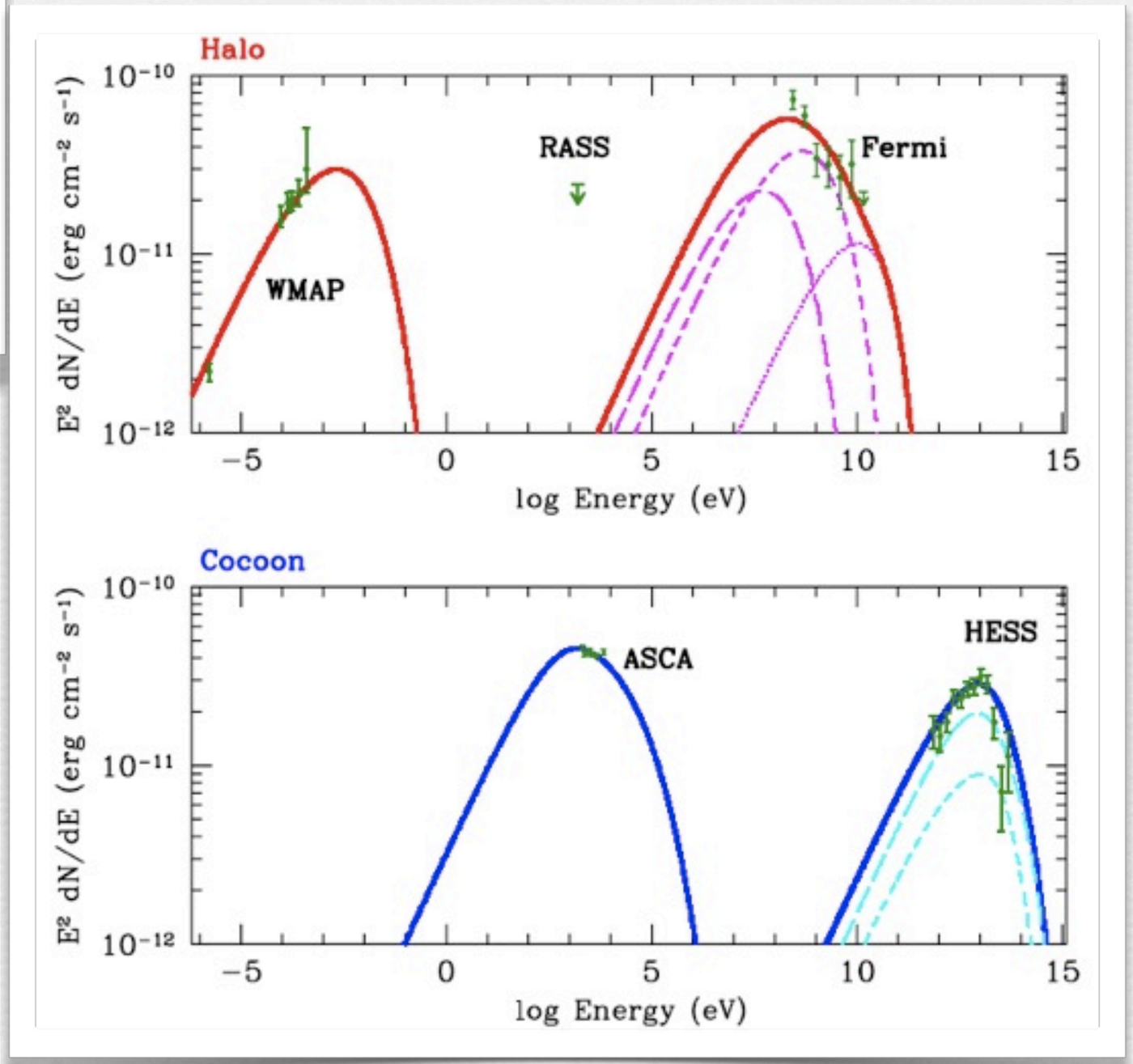
$$\mathcal{M} = \dot{N}_{e^\pm}/\dot{N}_{GJ}$$

Vela X



Confirmed!

also detected by AGILE

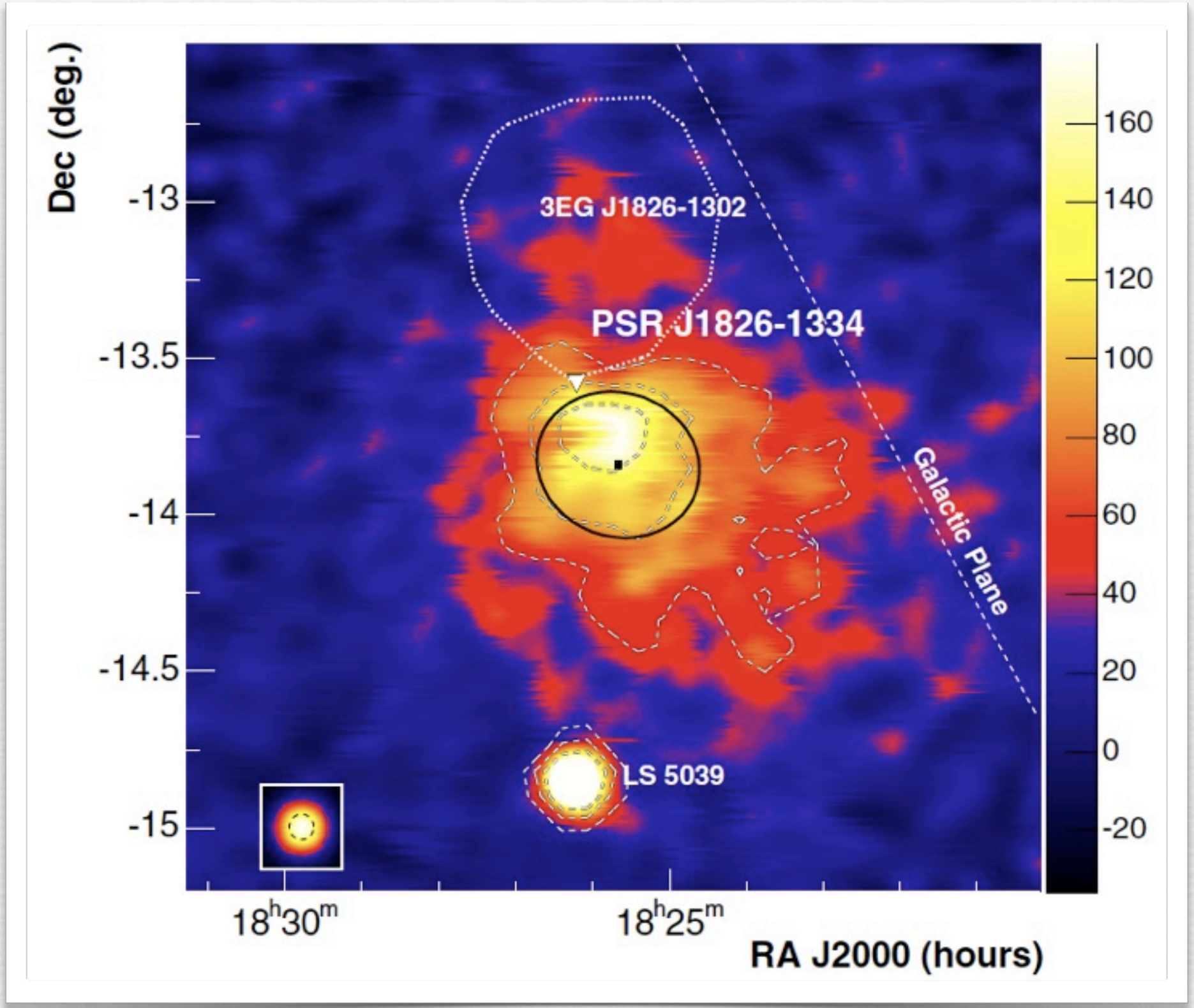


Cutoff at ~100 GeV

Two distinct electron/ positron populations

Fermi (2010)

HESS J1825–137



21,400 yr

3.9 ± 0.4 kpc

$>10^{48}$ erg of electrons

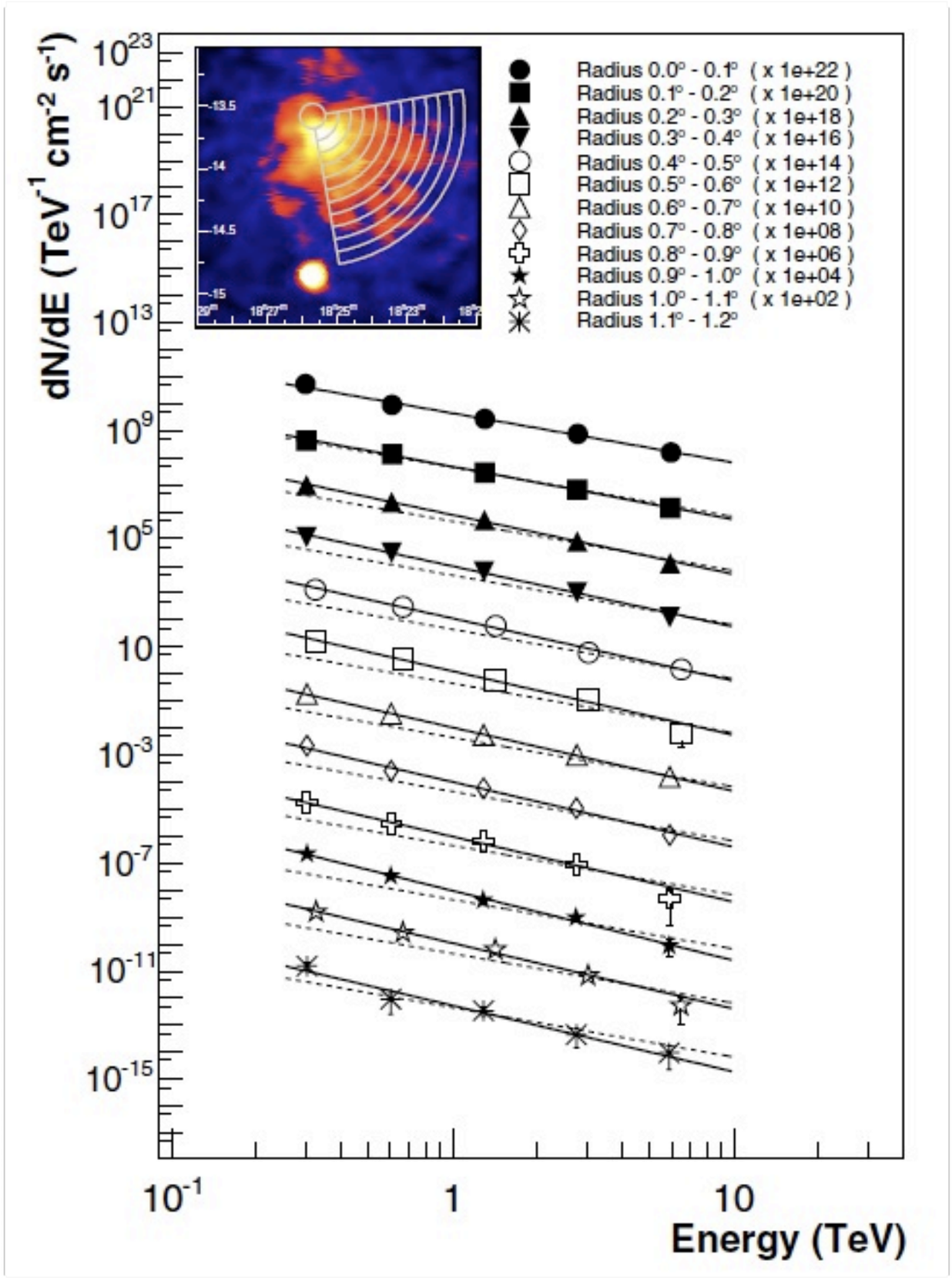
HESS (2006)

HESS J1825–137

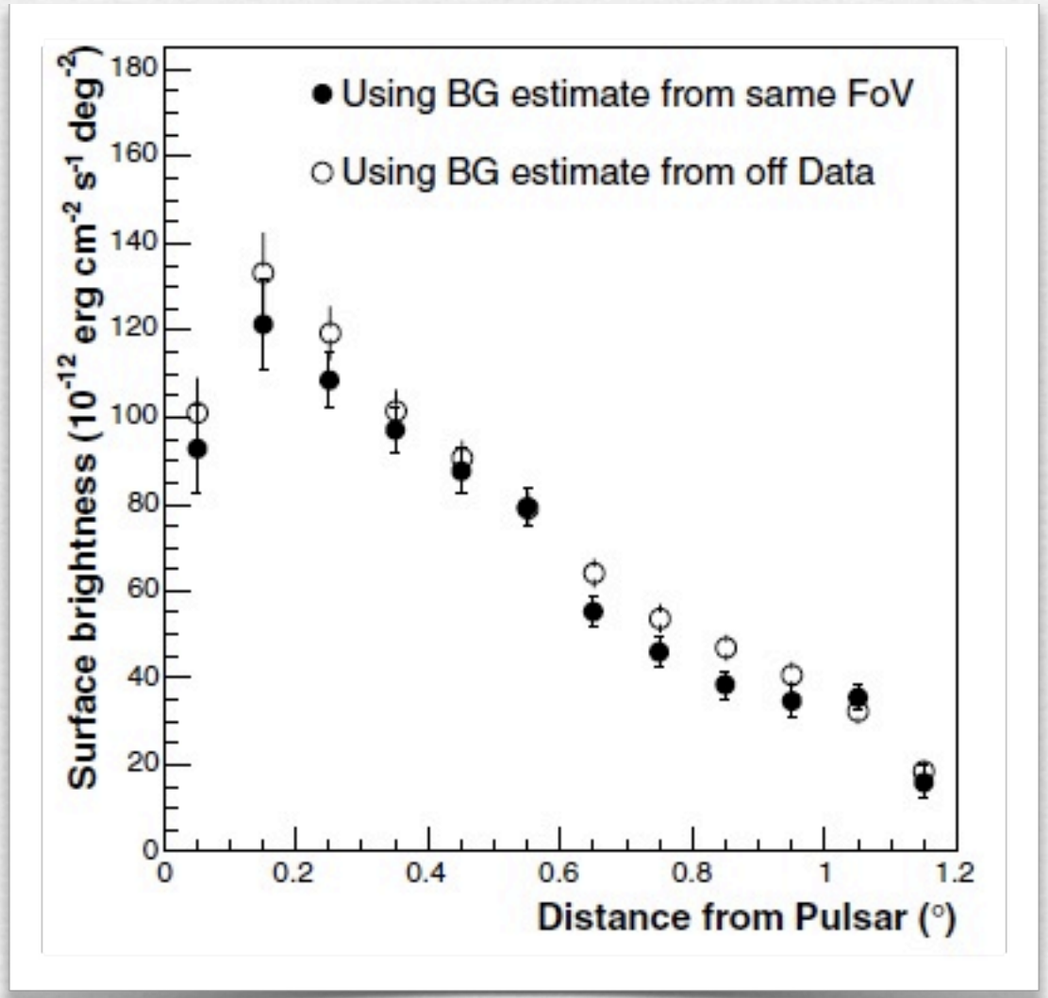
Deep observations due to nearby LS 5039

Multi-TeV electrons being measured

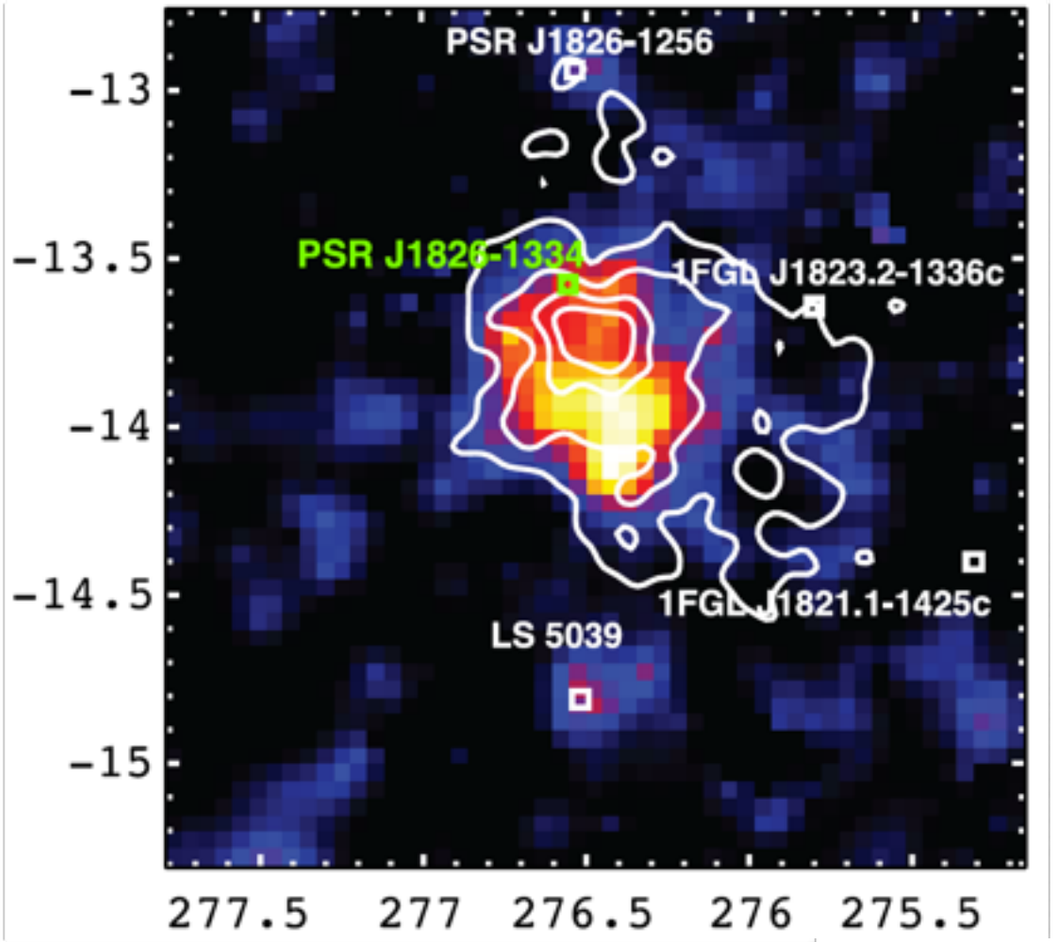
Is this common?



HESS (2006)



HESS J1825–137

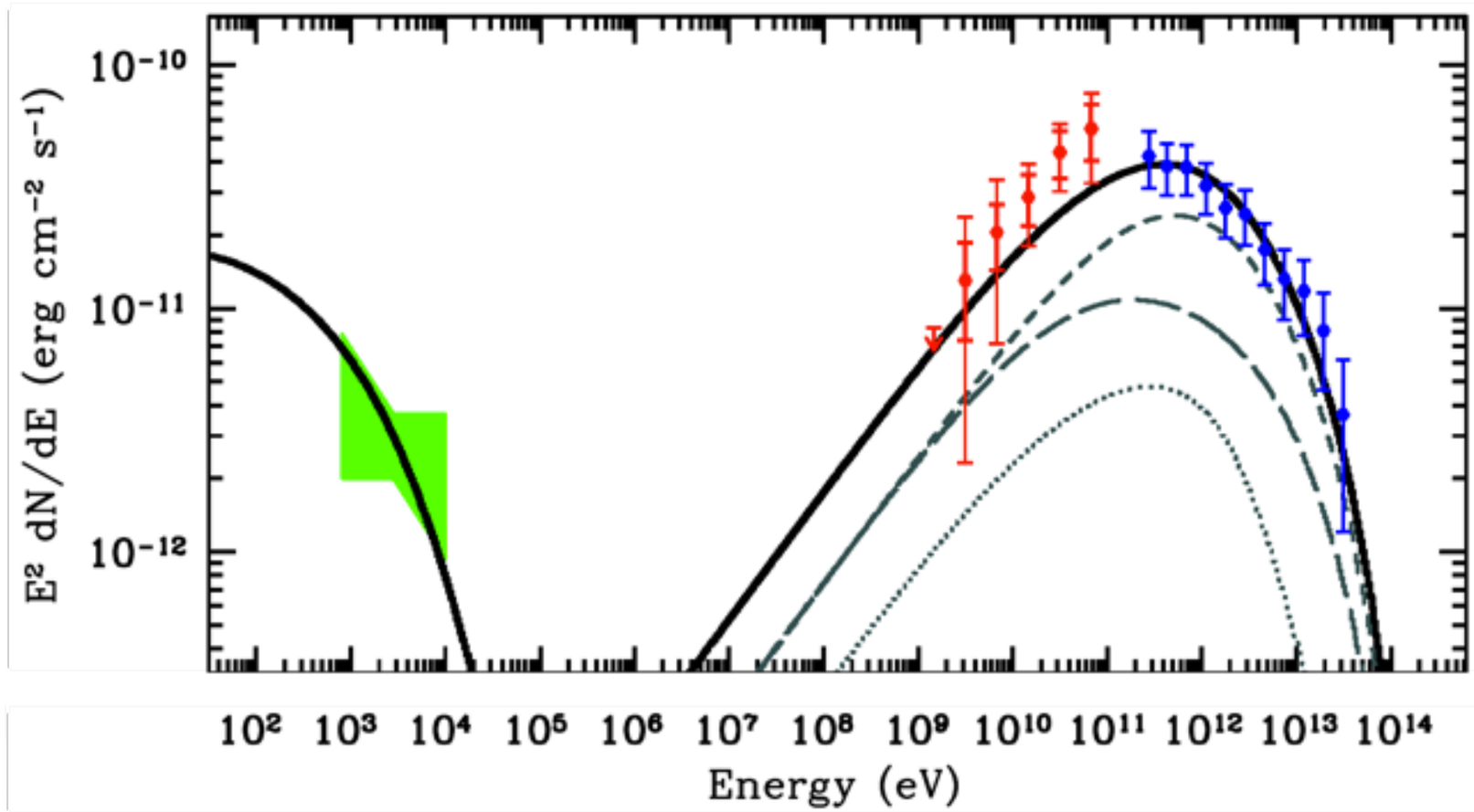


Now detected by Fermi

Electron spectrum of form $E^{-1.9}$

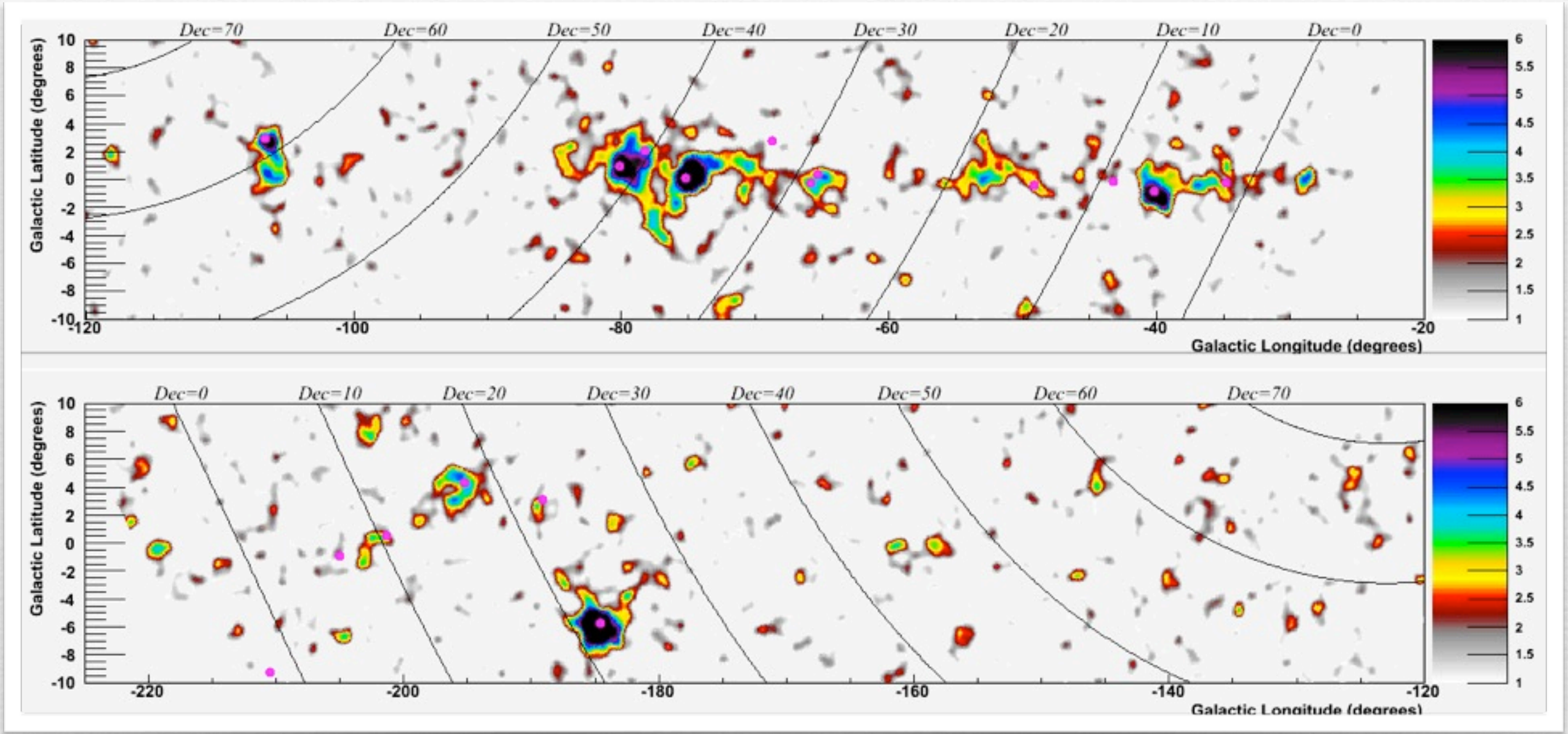
Cutoff at ~60 TeV

~5 x 10^{49} erg of electrons/ positrons!



Fermi (2011)

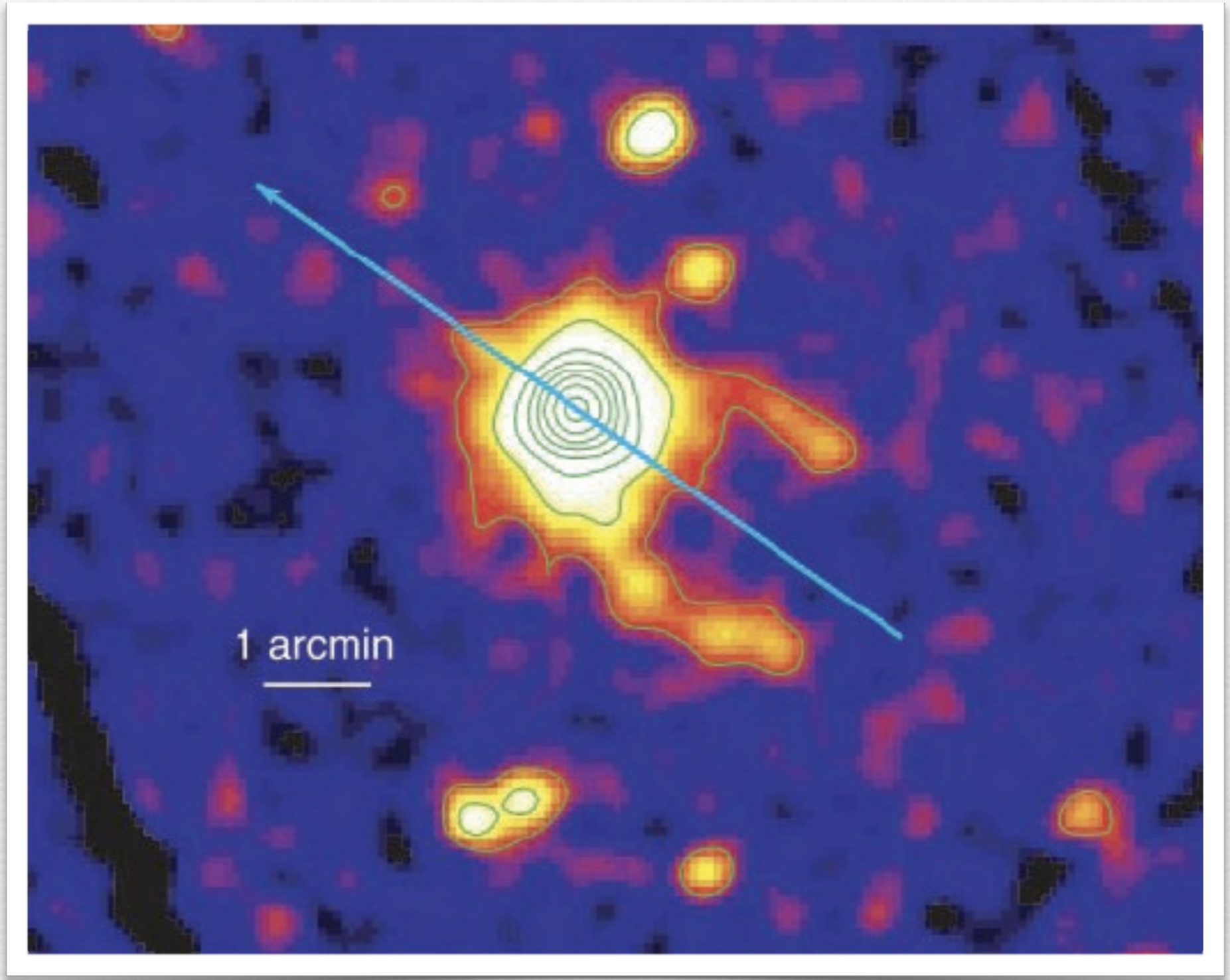
Look to the TeV



Milagro (from talk by B. Dingus)

10 out of 17 multi-TeV associations with Fermi GeV pulsars

Geminga



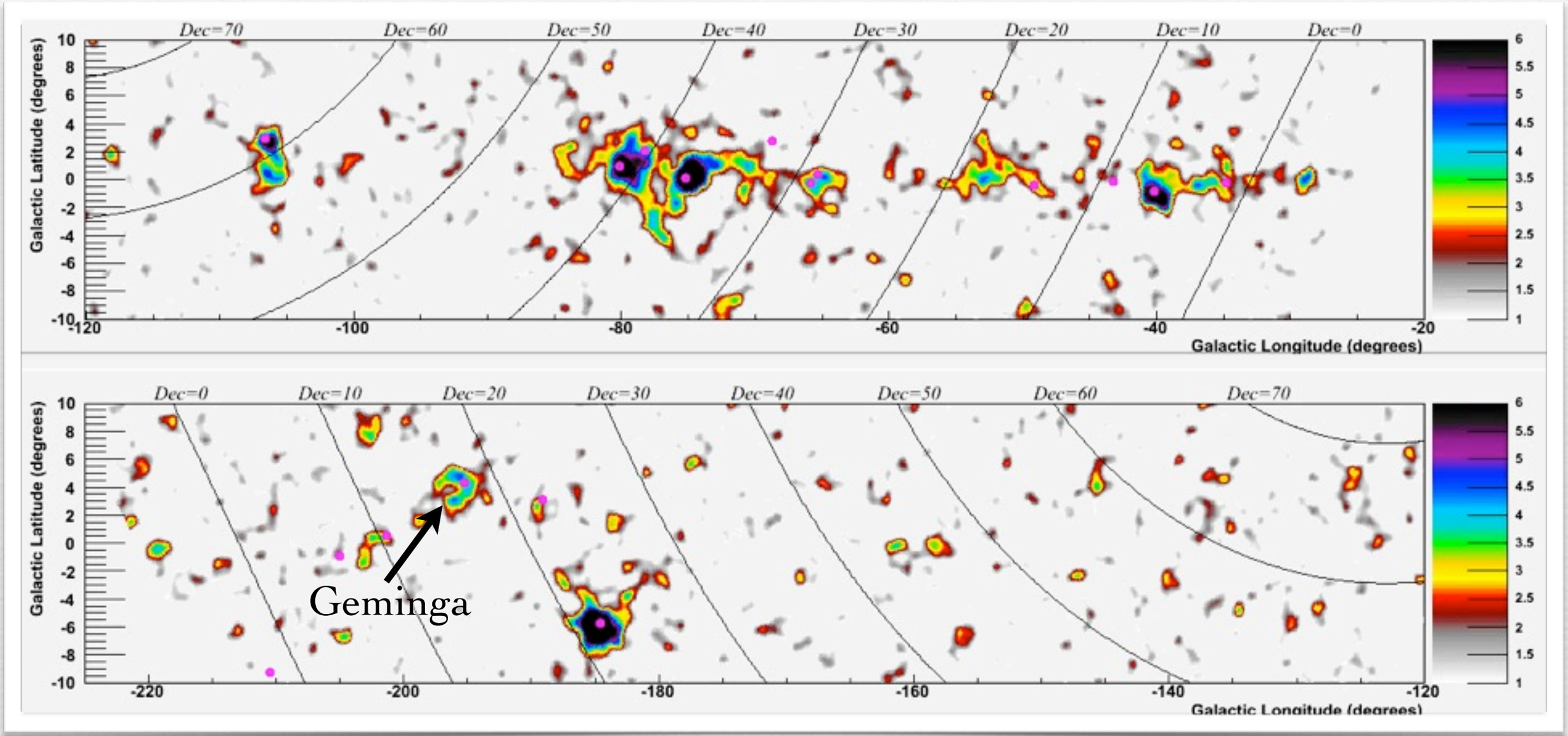
Caraveo et al. (2003)

~300,000 yr

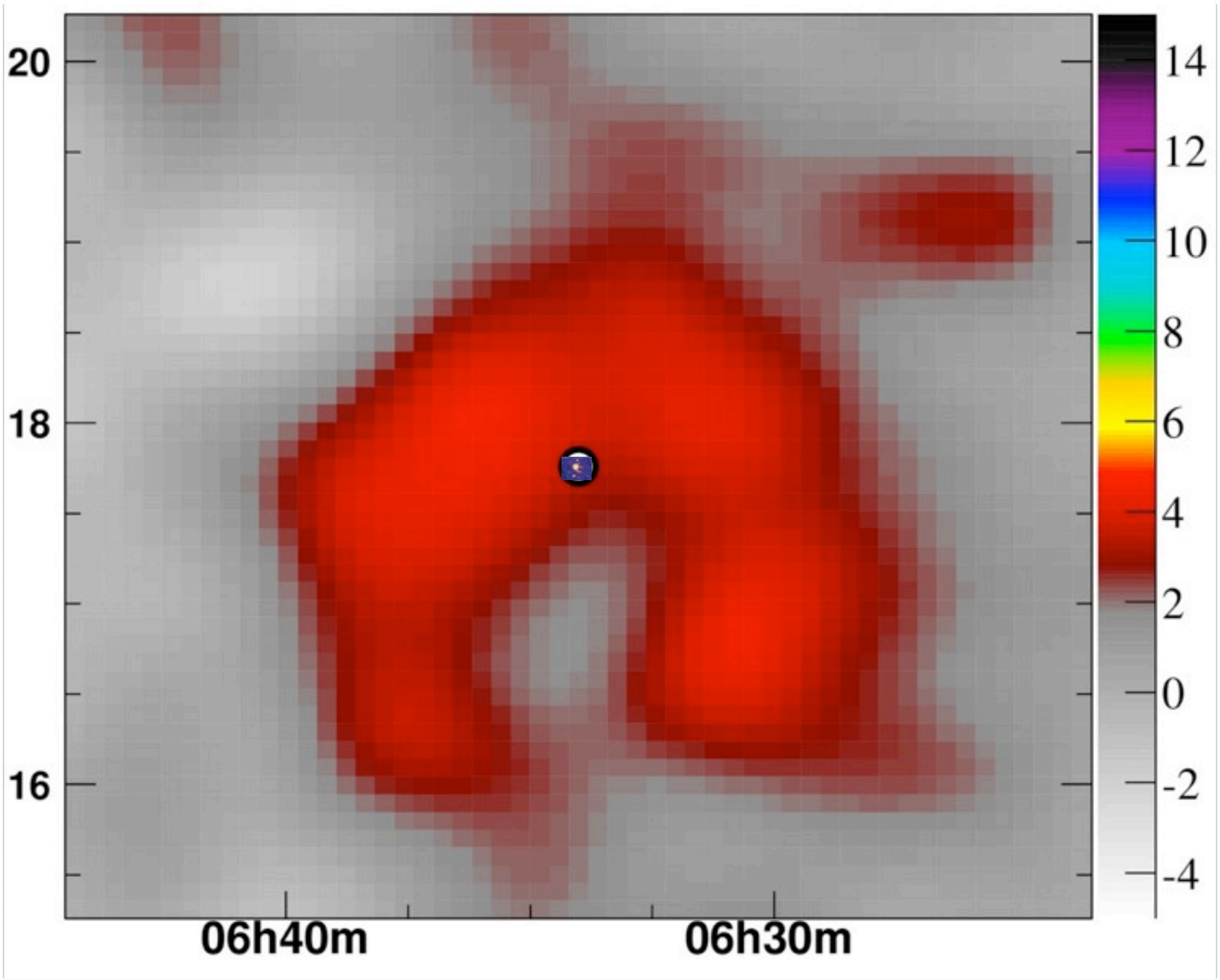
~200 pc

Not seen in radio

Look to the TeV



Milagro (from talk by B. Dingus)



Milagro (2009)

Geminga detected in ~35 TeV gamma rays

Extended source

VERITAS constrains point source

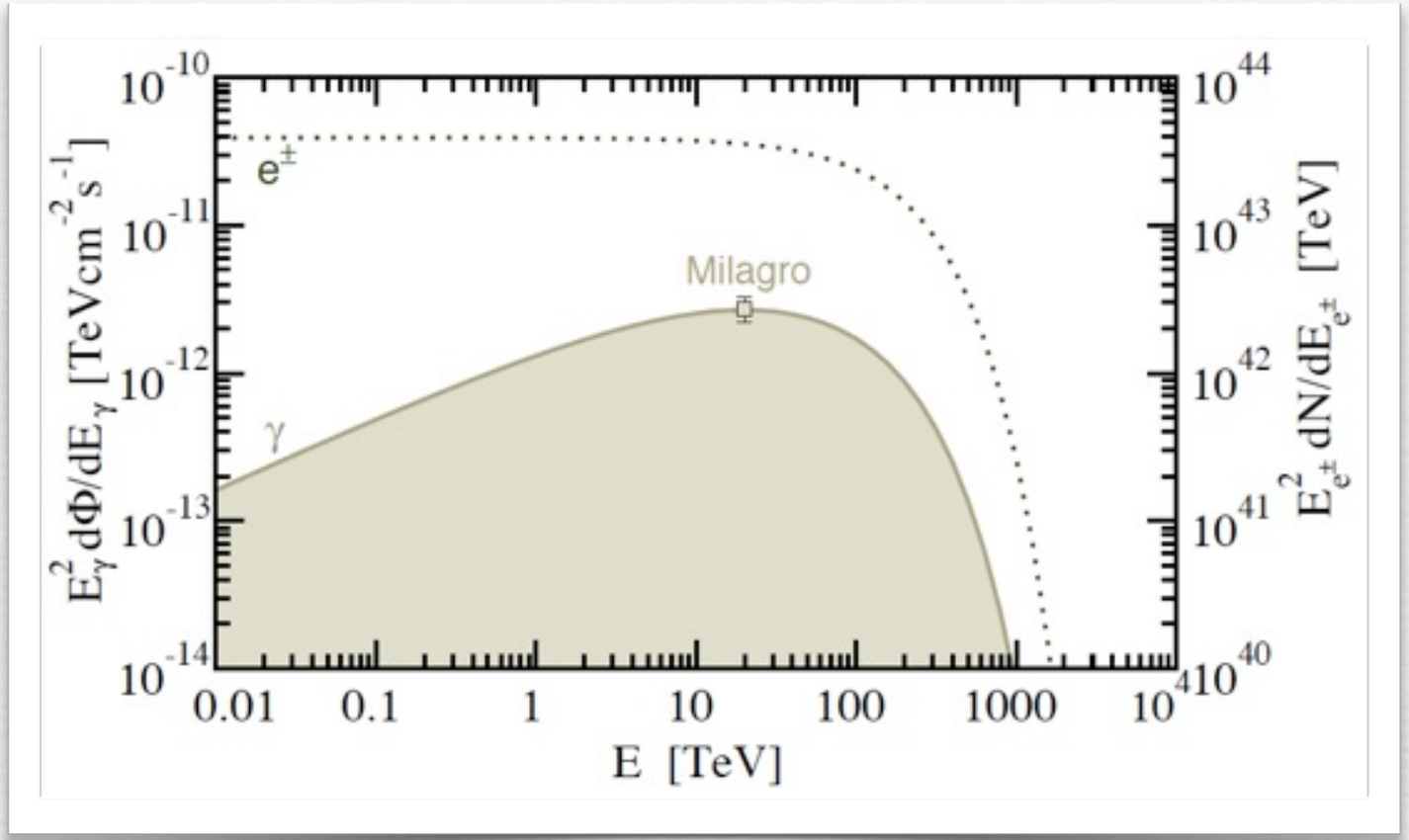
$$\gtrsim 100 \text{ TeV } e^{\pm} \text{ needed}$$

$$\tau_{IC} \sim 10^4 (100\,\text{TeV}/E_e)\,\text{yr}$$

$$t_G \sim 3 \times 10^5\,\text{yr}$$

→ Fresh particle acceleration

$$\dot{\mathcal{E}}_{\gamma,\text{TeV}} \sim 10^{32}\,\text{erg s}^{-1}$$



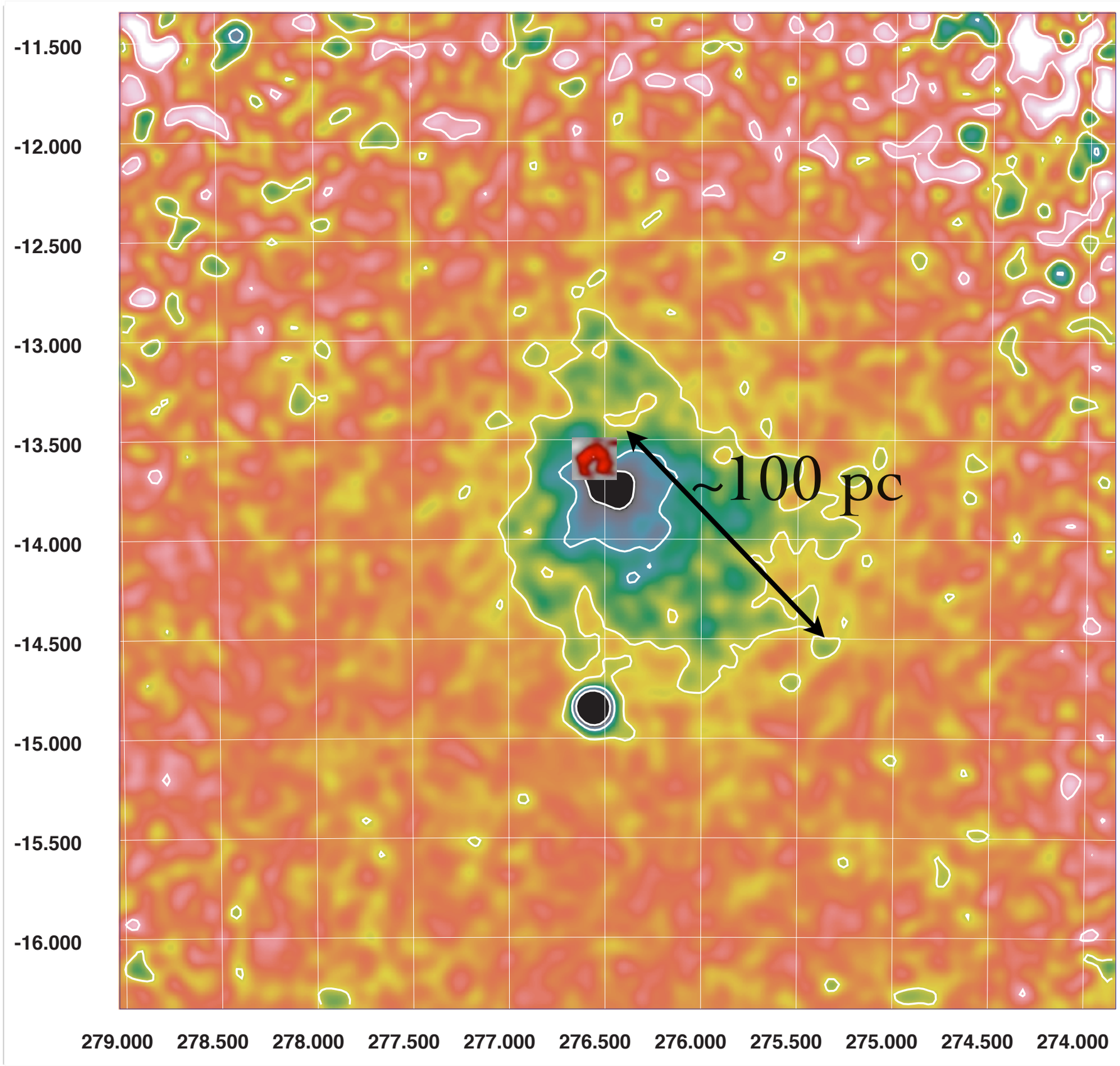
Yuksel, Kistler, Stanev (2008)

$$\frac{d\Phi}{dE_\gamma} = \frac{c}{4\pi r_G^2} \int d\gamma \int dE_b \frac{dN}{d\gamma}\, n_b(E_b)\, \sigma_{\text{KN}}(\gamma, E_b, E_\gamma)$$

$$\dot{\mathcal{E}}_{e^\pm} \approx \dot{N}_{e^\pm} \langle E_{e^\pm} \rangle \approx \mathcal{M}\, \dot{N}_{\text{GJ}} \langle E_{e^\pm} \rangle \approx 2 \times 10^{30}\, \mathcal{M}\, \text{erg s}^{-1}$$

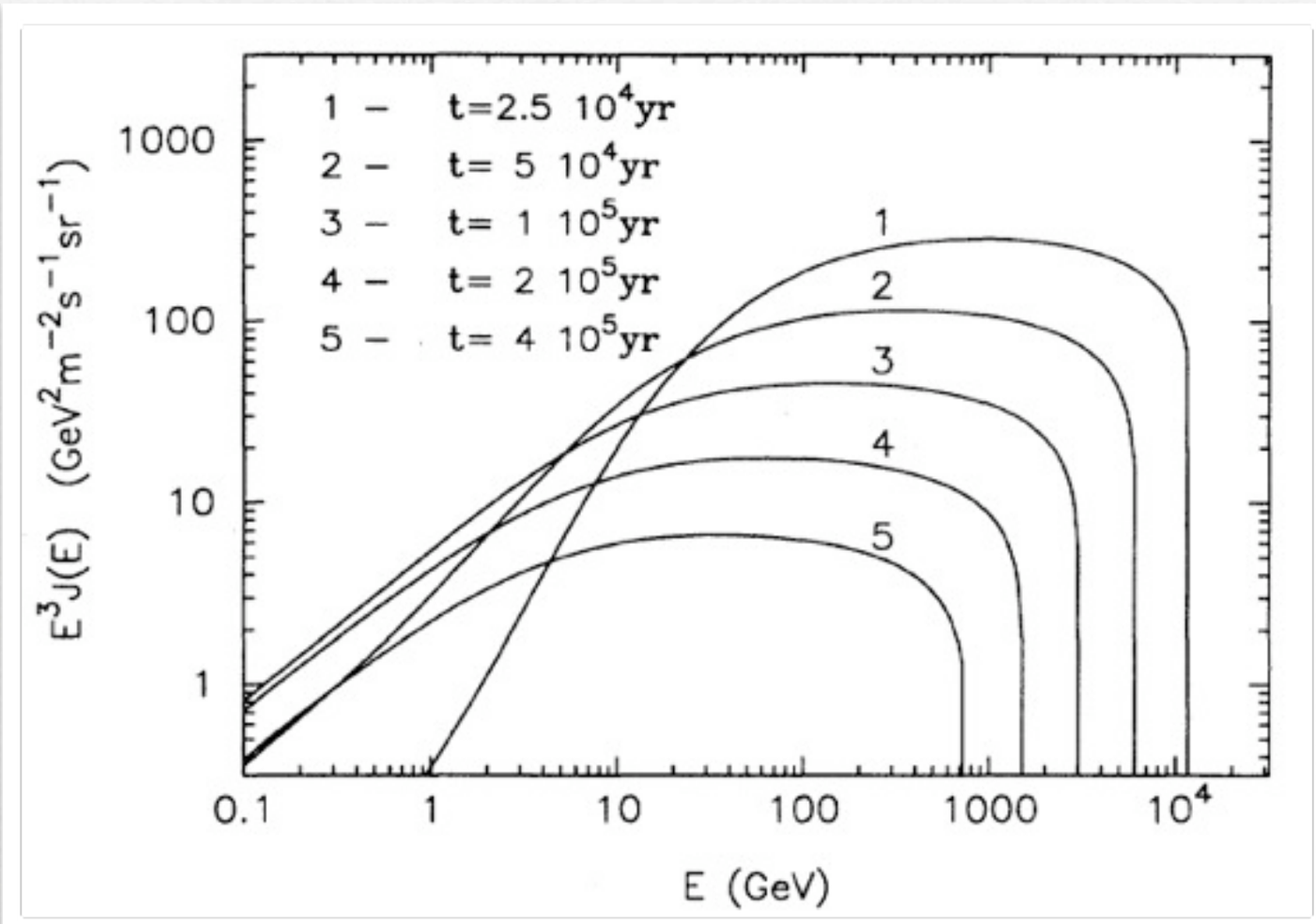
$$\mathcal{M} \gtrsim 100$$

Pair production is required to account for TeV gamma ray luminosity


-11.500
-12.000
-12.500
-13.000
-13.500
-14.000
-14.500
-15.000
-15.500
-16.000
279.000
278.500
278.000
277.500
277.000
276.500
276.000
275.500
275.000
274.500
274.000
~100 pc

Time-dependent propagation from a point source

$$\frac{\partial n}{\partial t} = \frac{D(E)}{r^2}\frac{\partial}{\partial r} r^2 \frac{\partial n}{\partial r} + \frac{\partial}{\partial E}[b(E)\, n] + Q$$



Atoyan, Aharonian and Volk (1995)

$$b(E) = -dE/dt = b_0\, E^2$$

$$Q(r, t, E_g) = \delta(r)\, \delta(t)\, dN/dE_g$$

$$n_S(r, t, E) = \frac{e^{-r^2/r_{dif}^2}}{\pi^{3/2}\, r_{dif}^3} \frac{dN}{dE_g} \frac{dE_g}{dE}$$

$$dE_g/dE = (E_g/E)^2$$

$$r_{dif}(E, t) = 2\sqrt{\lambda(E, t)}$$

$$\lambda(E, t) = \int_0^t dt' D[E(t')] = \int_E^{E_g} dE' \frac{D(E')}{b(E')}$$

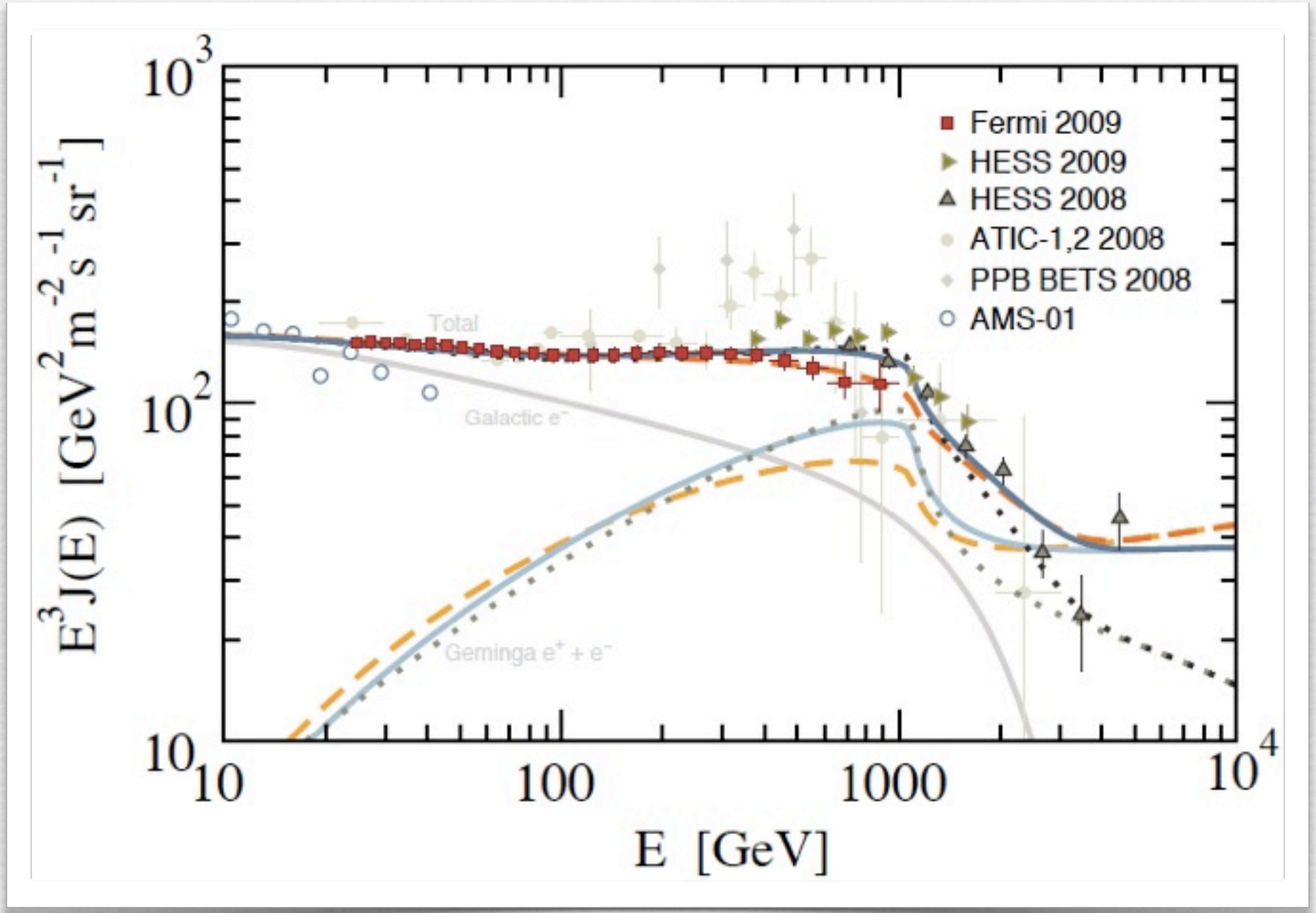
Electron spectrum including Geminga

$$\mathcal{L}_{e^\pm}(t) \propto (1 + t/t_0)^{-2}$$

Dotted, Solid, Dashed lines correspond to

$$\mathcal{E}_G = 1, 2, 3 \times 10^{48} \text{ erg} \qquad \delta = 0.4, 0.5, 0.6$$

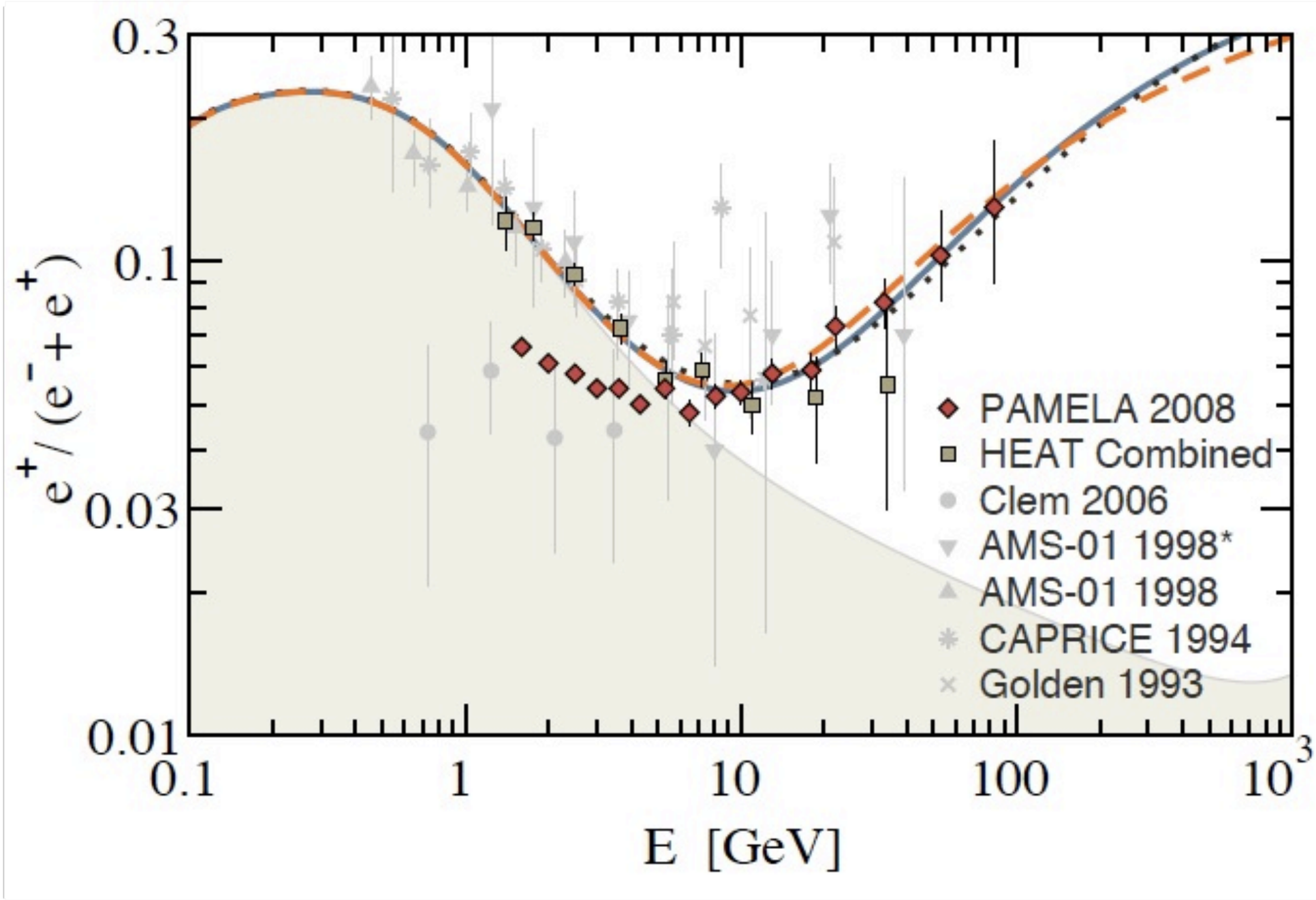
$$r_G = 150 \rightarrow 250 \text{ pc}, 220 \text{ pc}, 250 \rightarrow 200 \text{ pc}$$



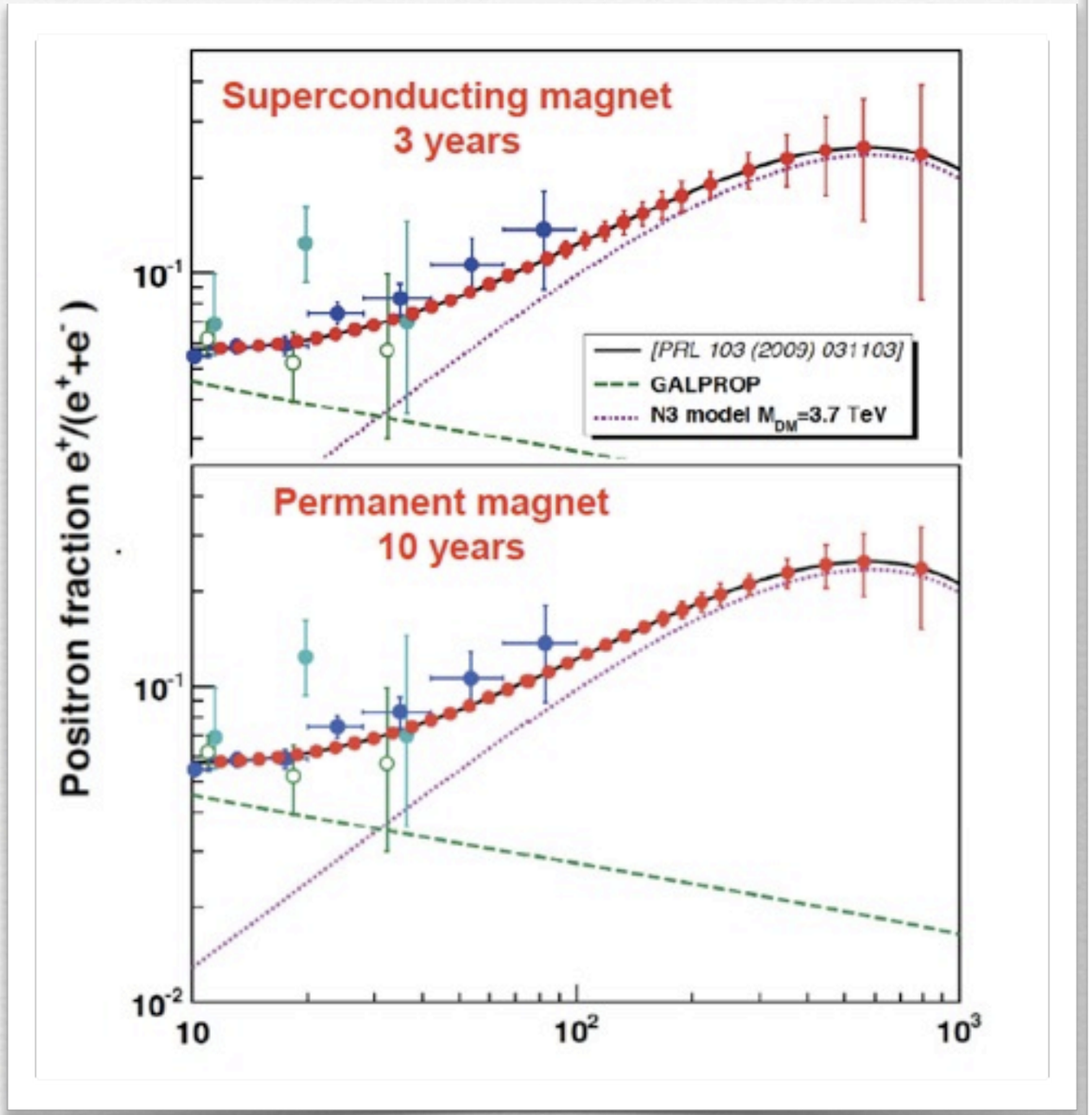
Yuksel, Kistler, Stanev (2008)

TeV Gamma Rays from Geminga and the Origin of the GeV Positron Excess

Hasan Yüksel,[1] Matthew D. Kistler,[2] and Todor Stanev[1]

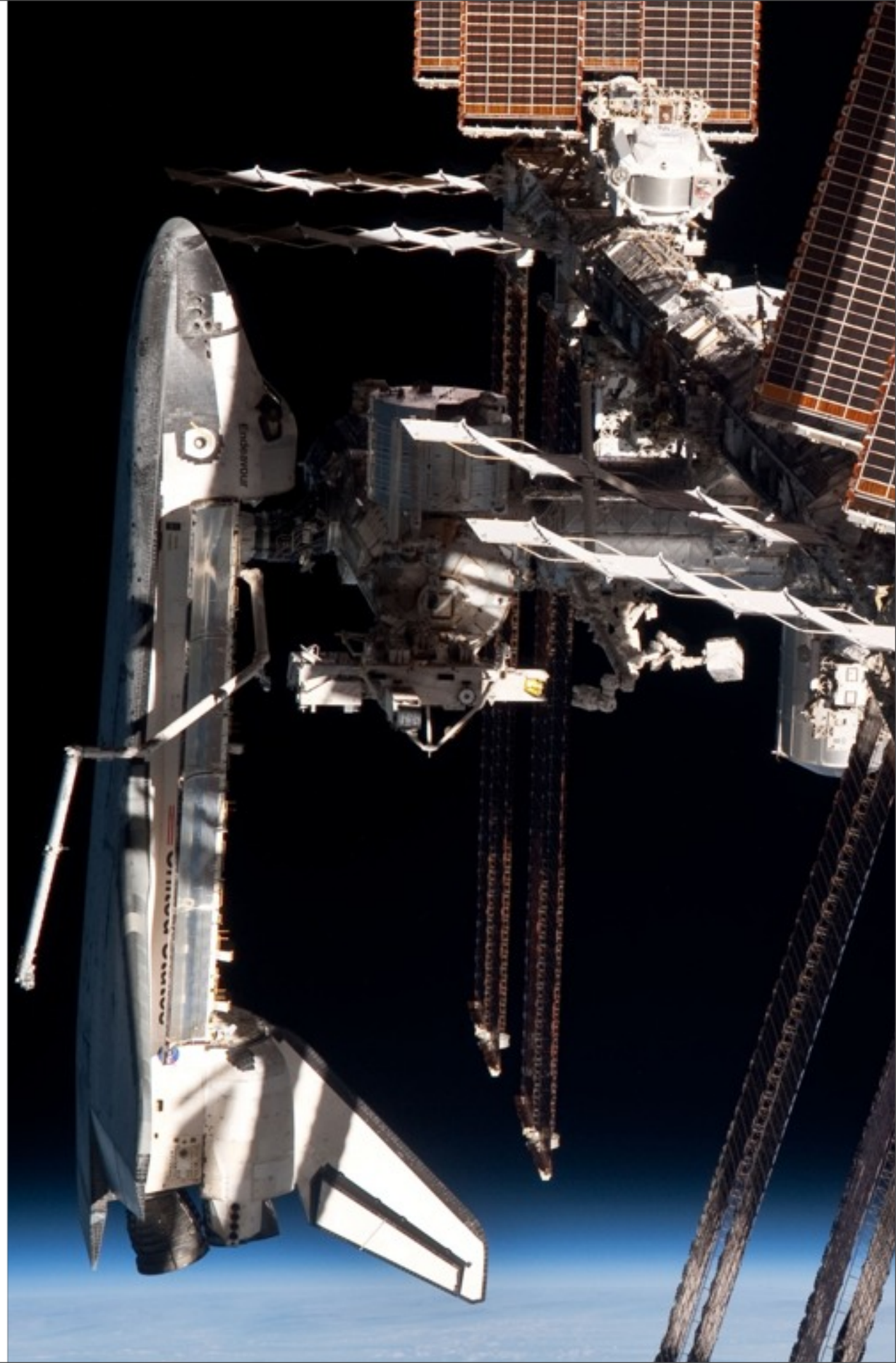


To higher energies

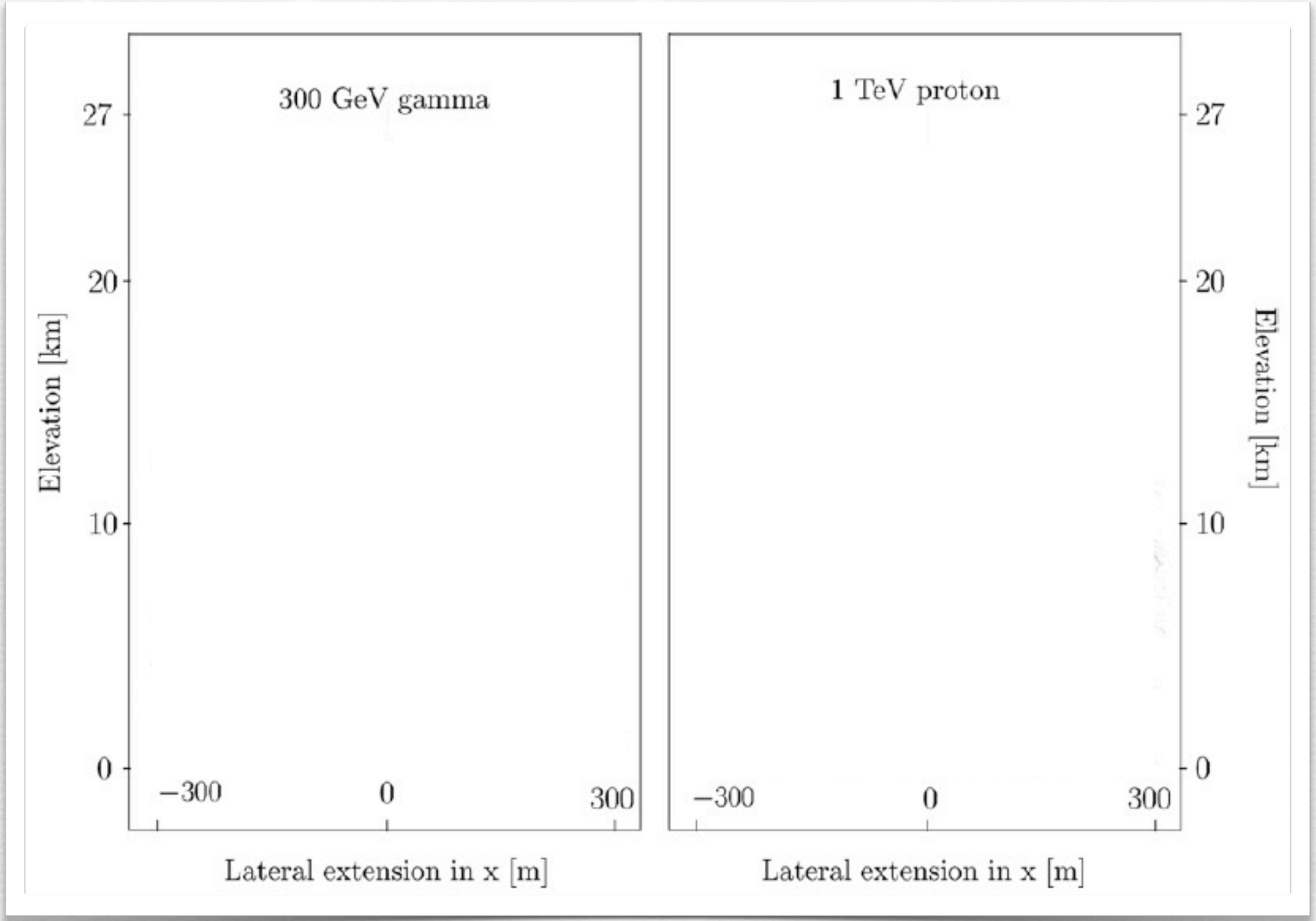


Talk by S. Ting

AMS-02 now up!



To yet higher energies



Aharonian, Buckley, Kifune, Sinnis (2008)

To yet higher energies

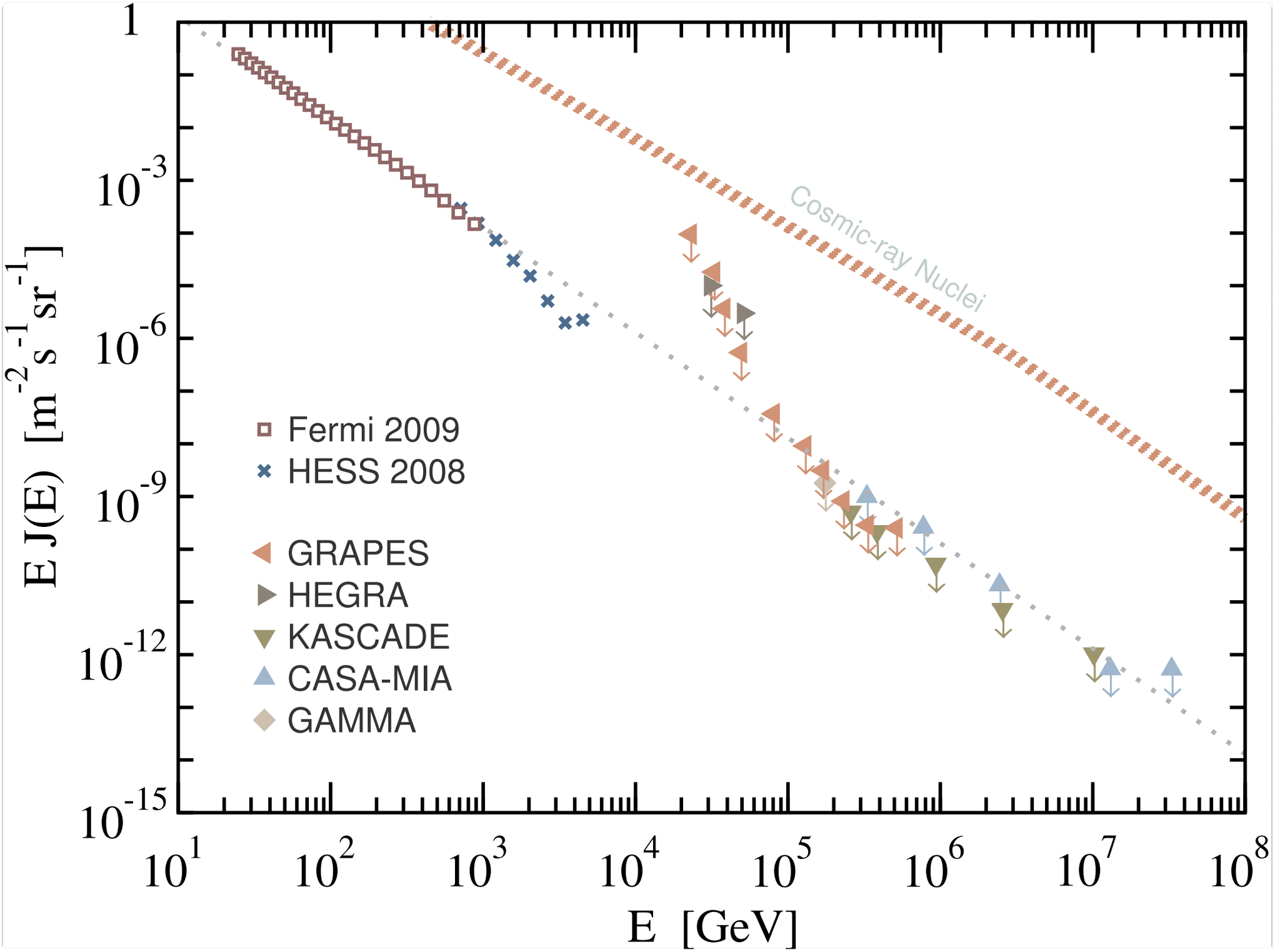
Milagro

KASCADE

CASA-MIA

New Constraints on the Highest-Energy Cosmic-Ray Electrons and Positrons

Matthew D. Kistler[1] and Hasan Yüksel[2]



Time-dependent propagation from a point source redux

$$v_{dif}(t) \;=\; r_{dif}(t)/t \;\simeq\; 2\sqrt{D(E)/t}$$

Phenomenological resolution from Aloisio, Berezinsky, Gazizov (2009)

$$P_M(v) = \left(\frac{m}{2\pi kT}\right)^{3/2} \exp\left(-\frac{mv^2}{2kT}\right)$$

$$v \;\rightarrow\; x$$

$$kT/m \;\rightarrow\; 2Dt$$

$$P_{\rm diff}(r,t) = \frac{1}{(4\pi Dt)^{3/2}} \exp\left(-\frac{r^2}{4Dt}\right)$$

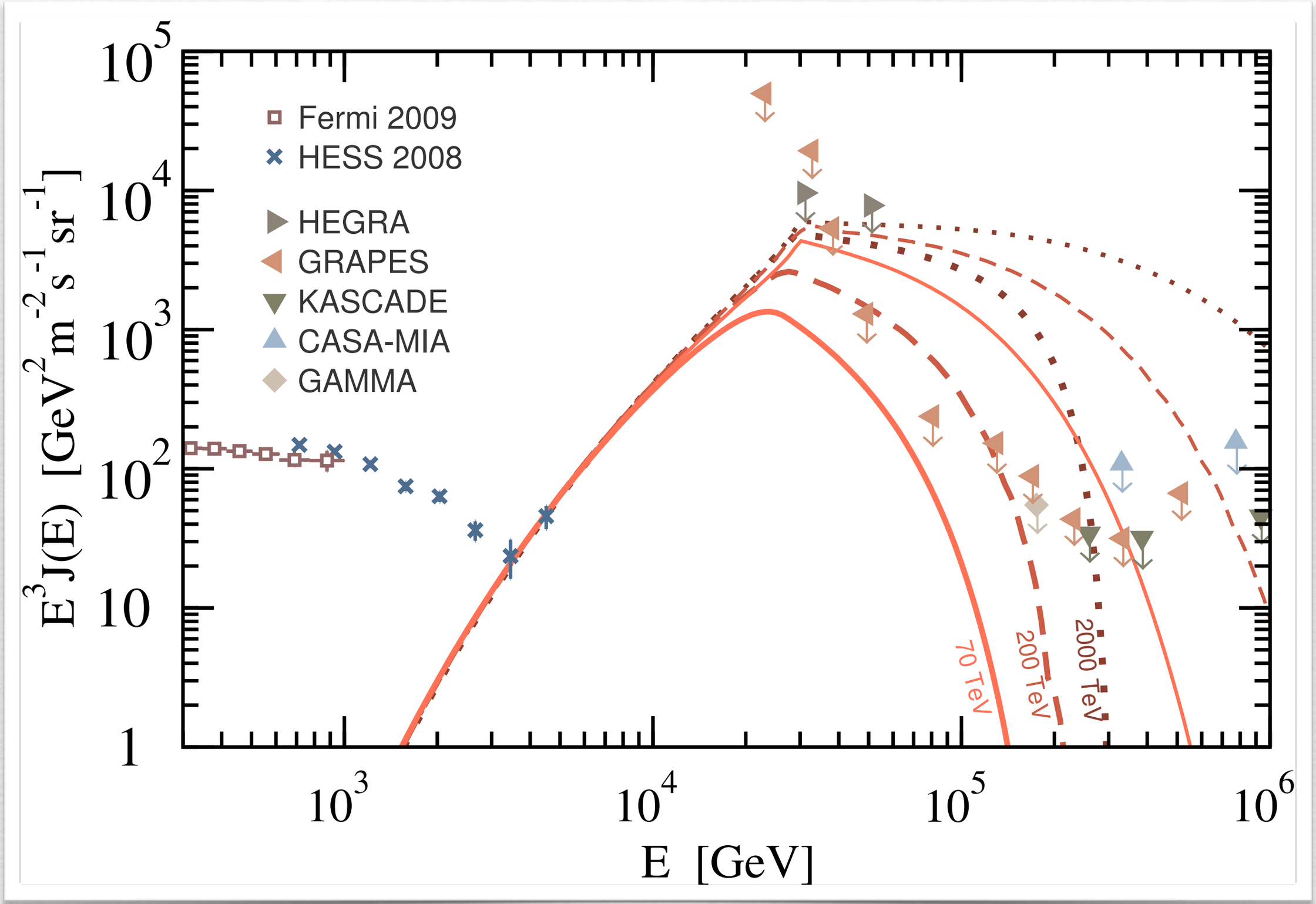
Jüttner particle distribution

$$n_J(r,t,E) = \frac{\theta(1-\xi)}{4\pi(ct)^3} \frac{e^{-\alpha/\sqrt{1-\xi^2}}}{(1-\xi^2)^2} \frac{\alpha}{K_1(\alpha)} \frac{dN}{dE_g} \frac{dE_g}{dE}$$

$$\xi(r,t) = r/ct$$

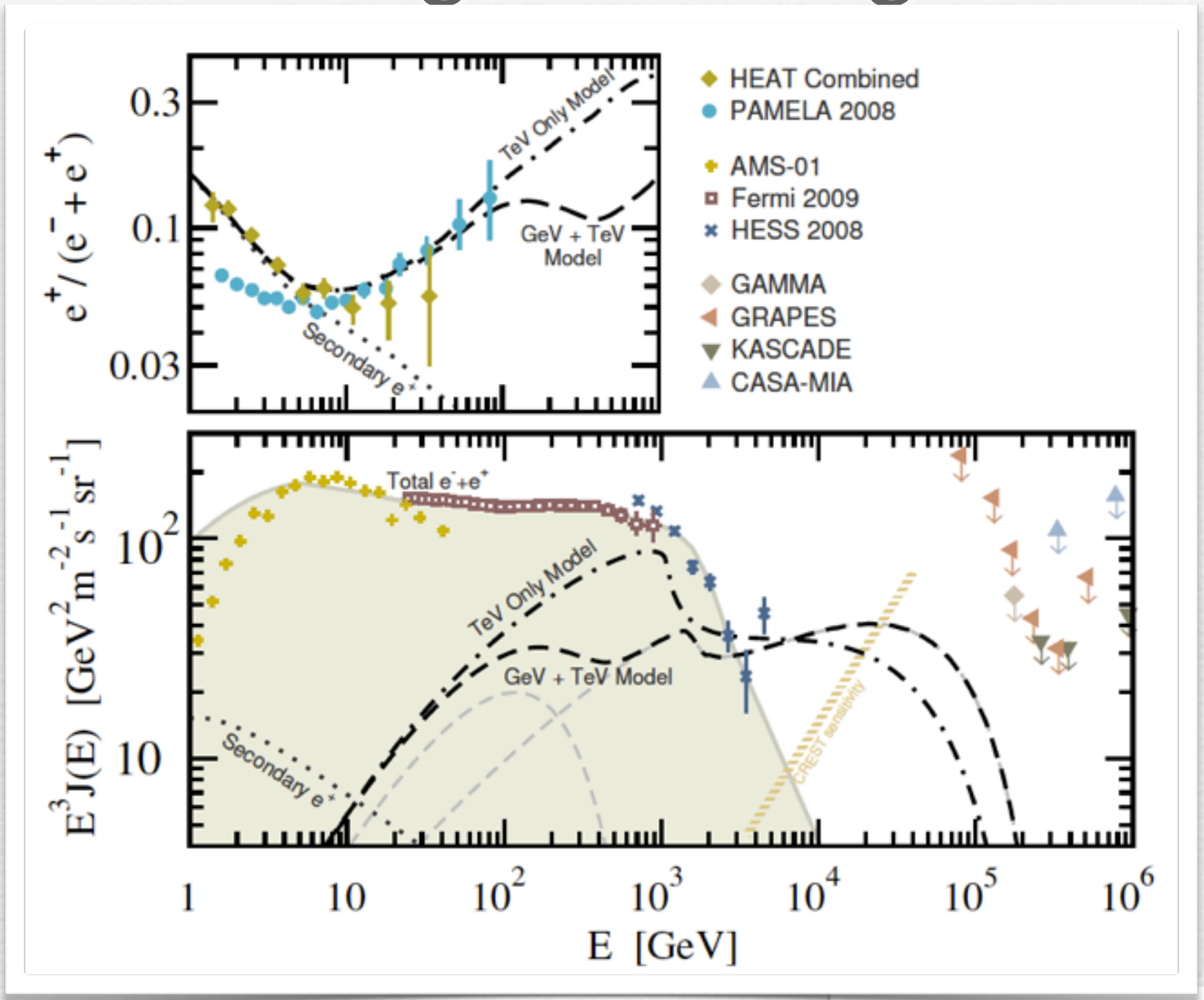
$$\alpha(E,t) = c^2t^2/(2\lambda(E,t))$$

To the highest energies



Kistler & Yuksel (2010)

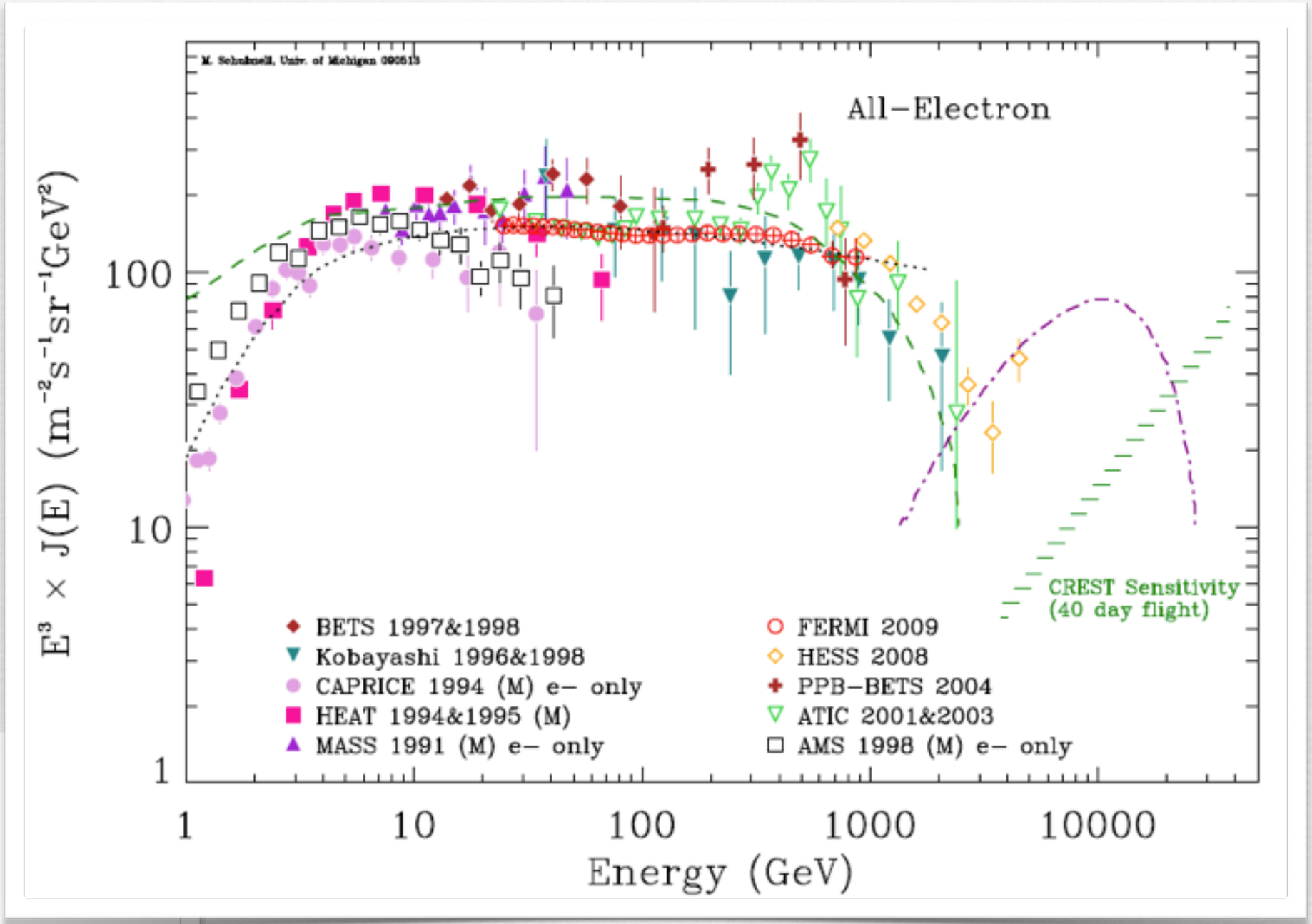
To the highest energies



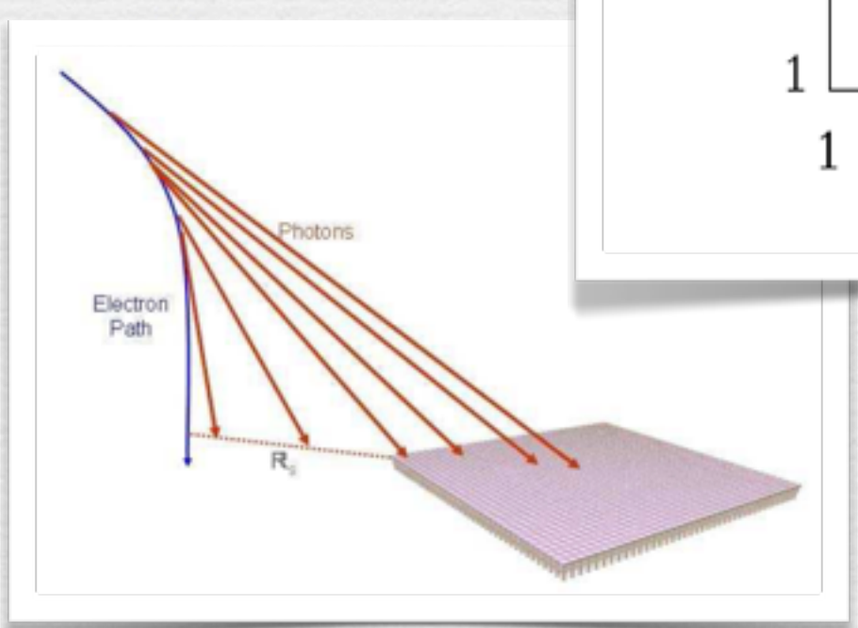
Kistler & Yuksel (2009)

Model	TeV mode (erg)	GeV mode (erg)	Distance (pc)	Age (yr)	Diffusion
TeV	2×10^{48}	0	220	3×10^5	slow
Dual	1.3×10^{48}	1.3×10^{48}	300→200	2×10^5	fast

What's out there?



CREST (2009)



CALET will cover a similar energy range

Conclusions

Gamma-ray data implies production of large quantities of positrons by pulsars

Energy frontier for cosmic-ray electrons/ positrons moving into multi-TeV regime

Will allow to study of the not-too-distant history of nearby sources