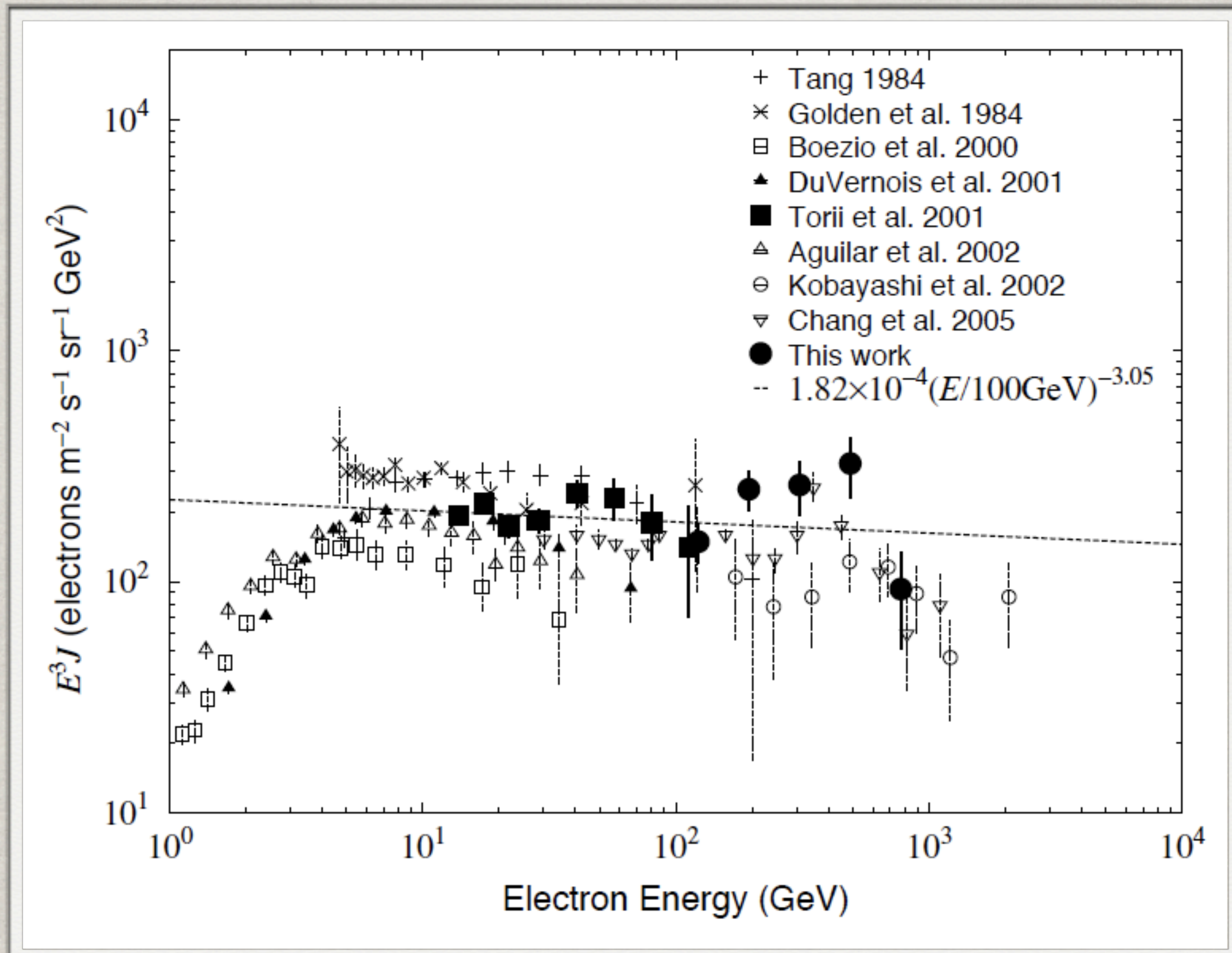
From AMS to Zwicky: Positrons and Dark Matter

Kistler

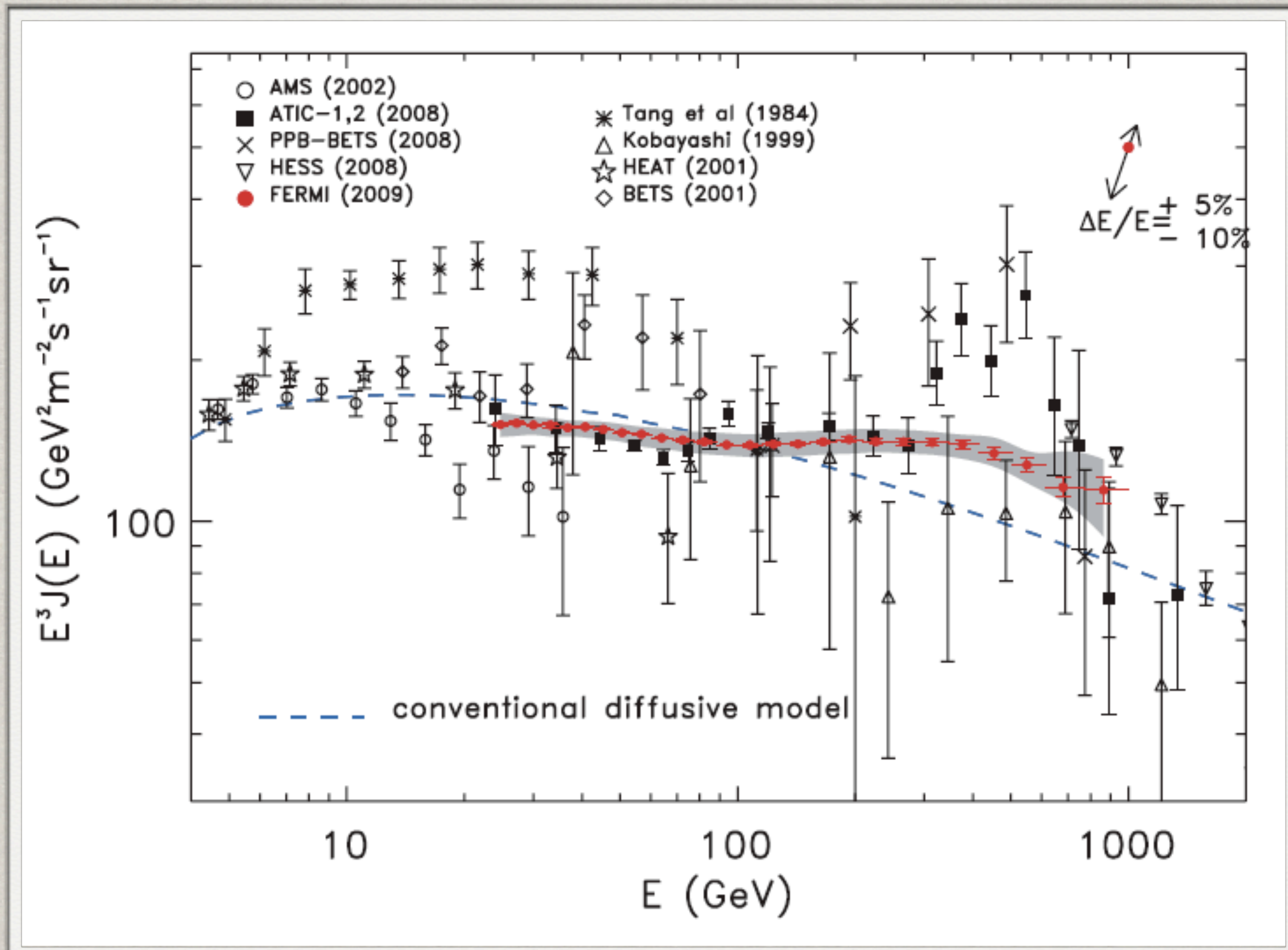
LBNL / UC Berkeley

Cosmic-ray Electrons

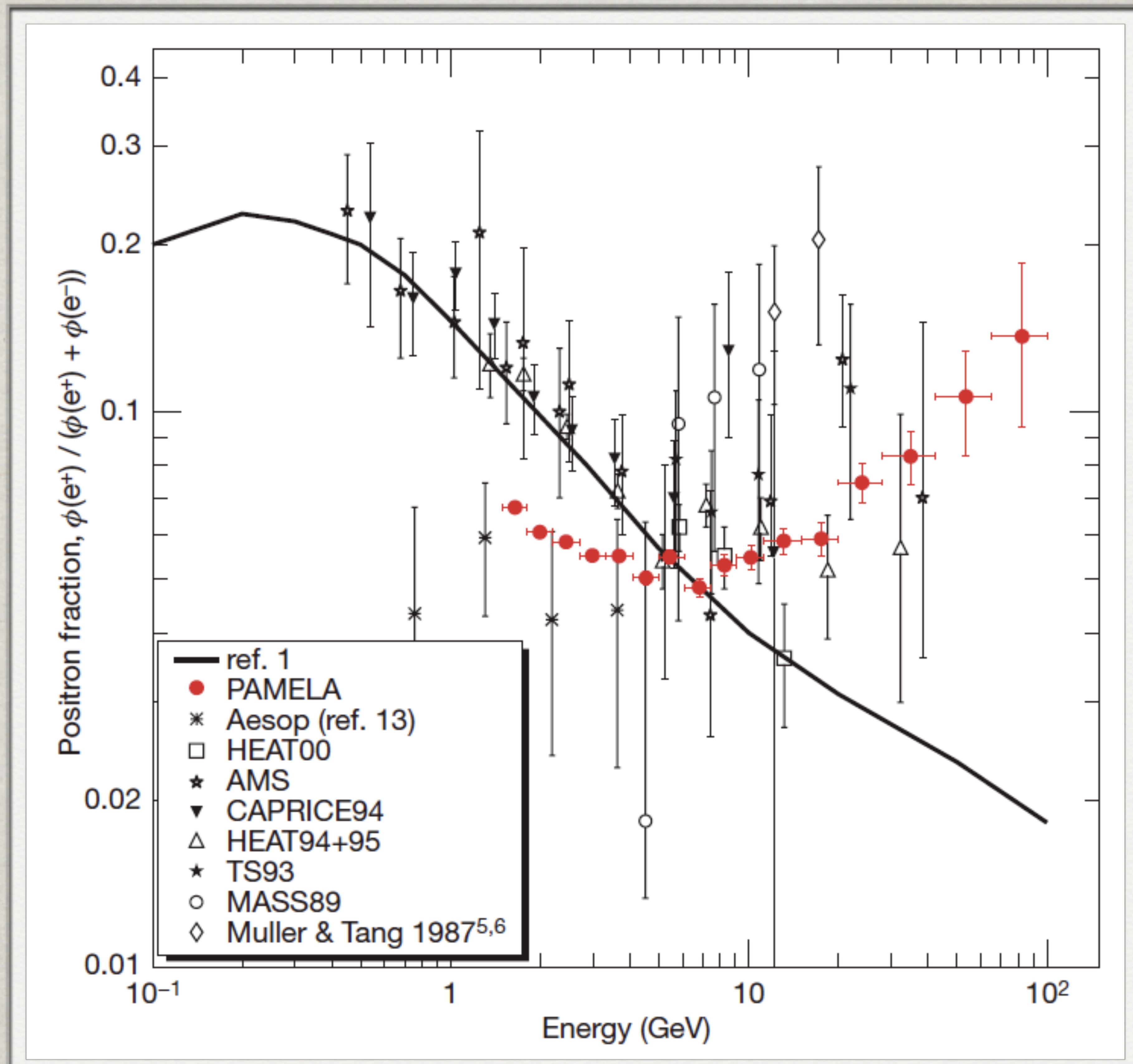


Torii et al. (2008)

Cosmic-ray Electrons

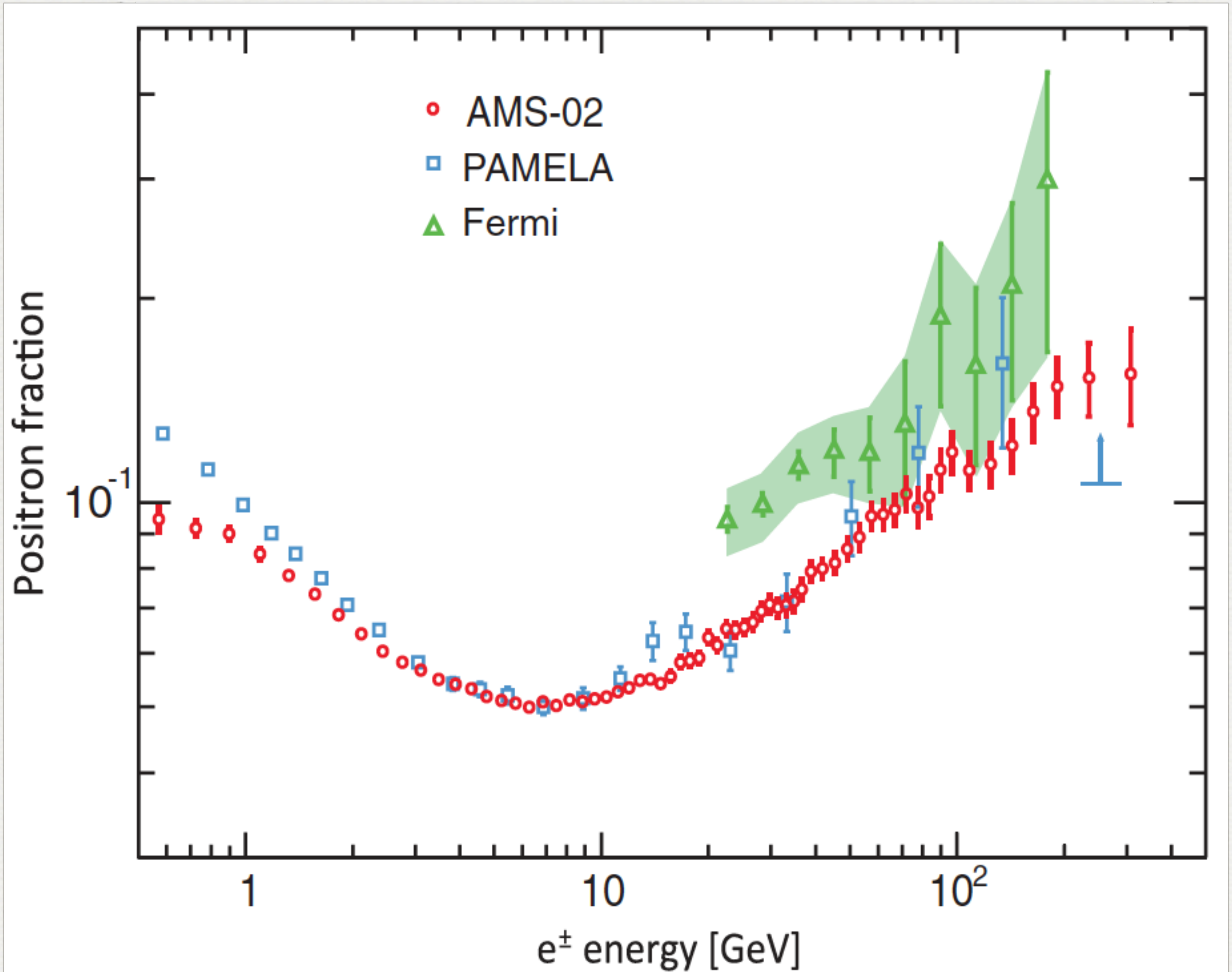


Fermi (2009)



0.4
0.3
0.2
0.1
0.02
0.01
Positron fraction, φ(e⁺) / (φ(e⁺) + φ(e⁻))
10⁻¹
1
10
10²
Energy (GeV)
ref. 1
PAMELA
Aesop (ref. 13)
HEAT00
AMS
CAPRICE94
HEAT94+95
TS93
MASS89
Muller & Tang 1987[5,6]

PAMELA (2008)


AMS-02
PAMELA
Fermi
Positron fraction
10^{-1}
1
10
10^2
e± energy [GeV]

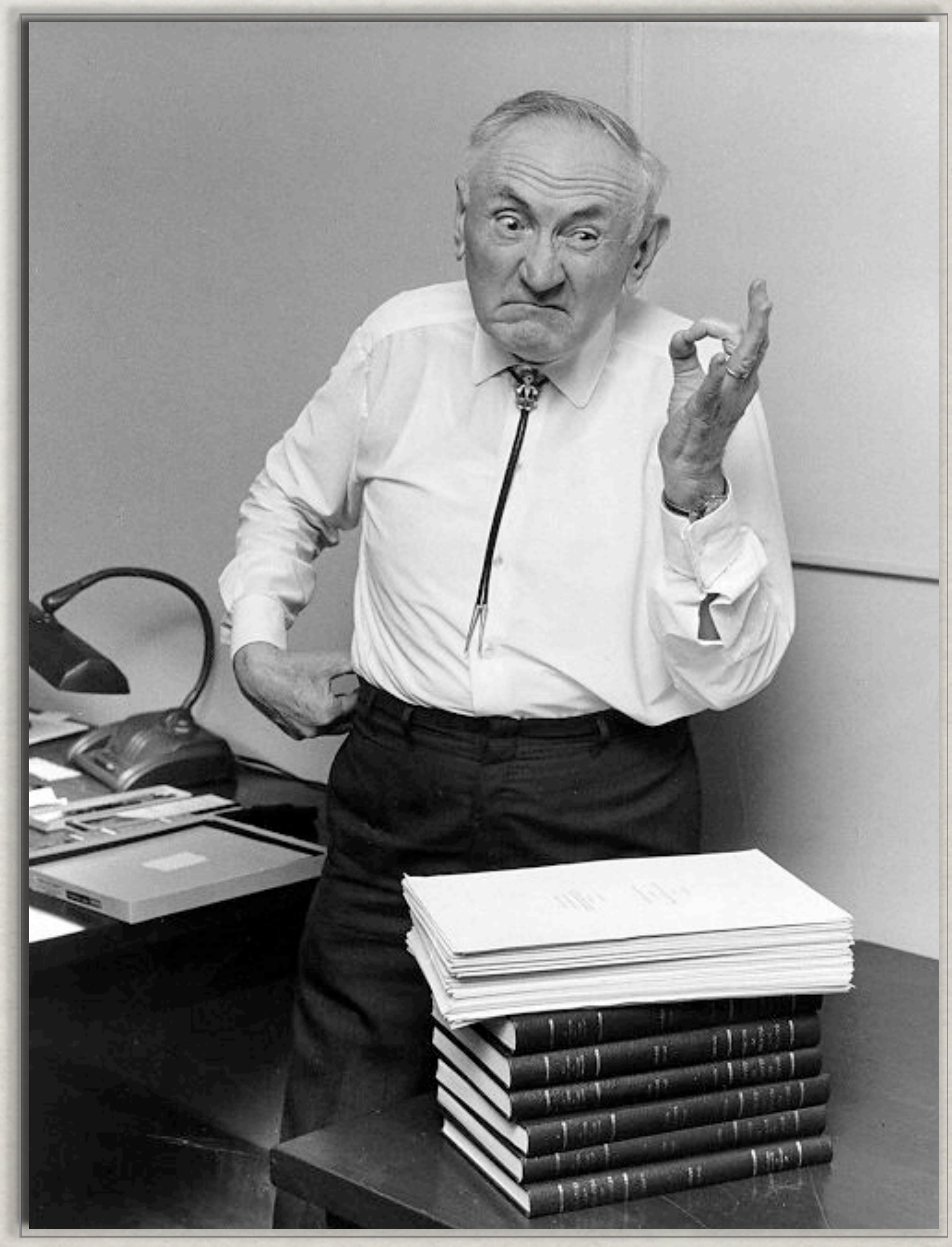
AMS (2013)

Zwicky

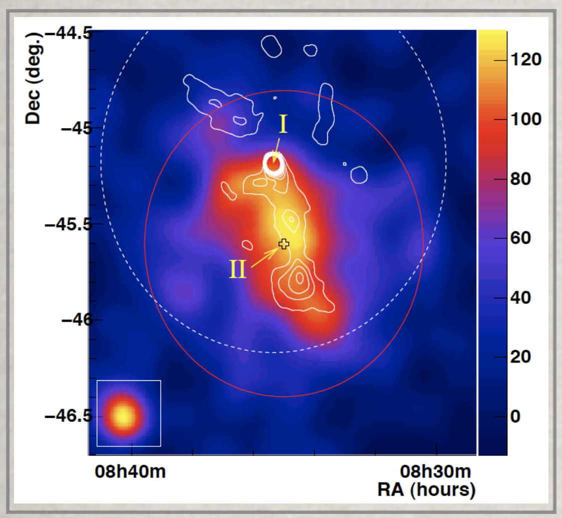
Discovery of dark matter

Neutron stars result from supernovae

What is the cosmic ray output?



Electron/positron factories



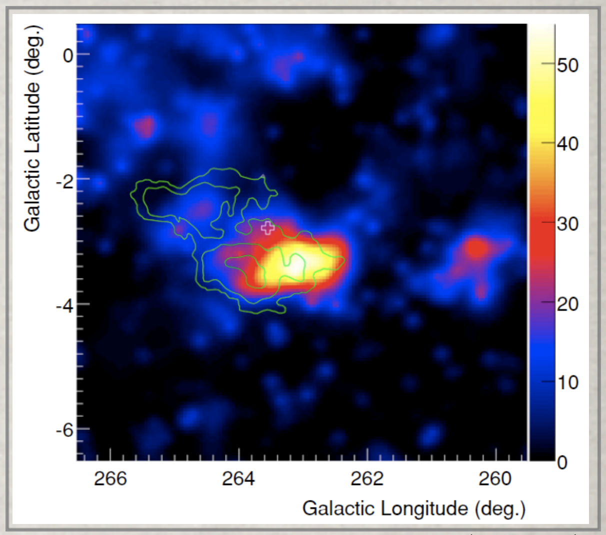
HESS (2006)

Vela X

Two distinct populations

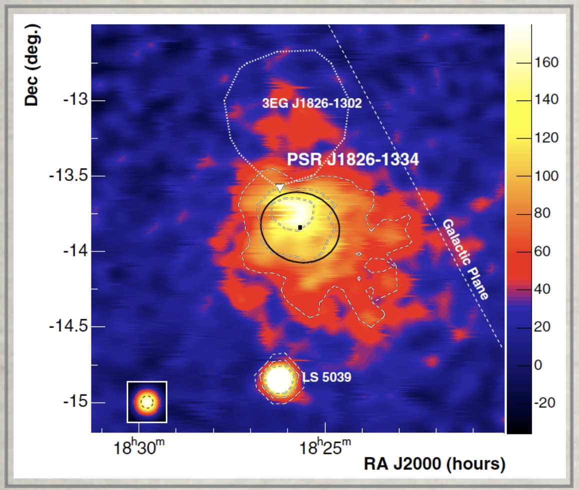
$>10^{46}$ erg in TeV electrons seen, cutoff at ~70 TeV

~4 x 10^{48} erg in GeV electrons/positrons, cutoff at ~100 GeV



Fermi (2010)

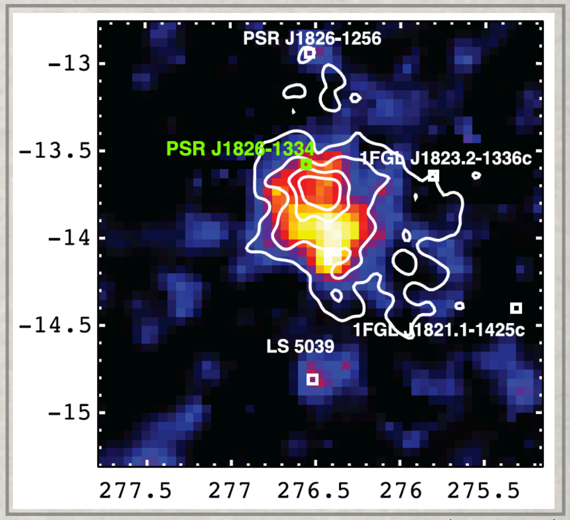
HESS J1825–137



HESS (2006)

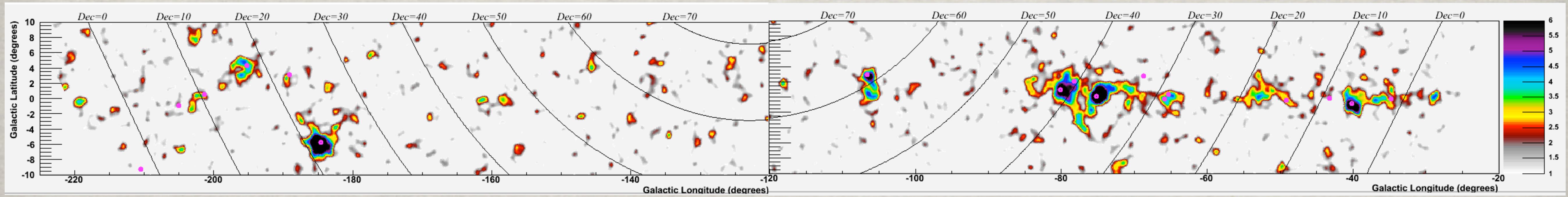
Inferred to travel >100 pc

~5 x 10^{49} erg in electrons/positrons, cutoff at ~60 TeV



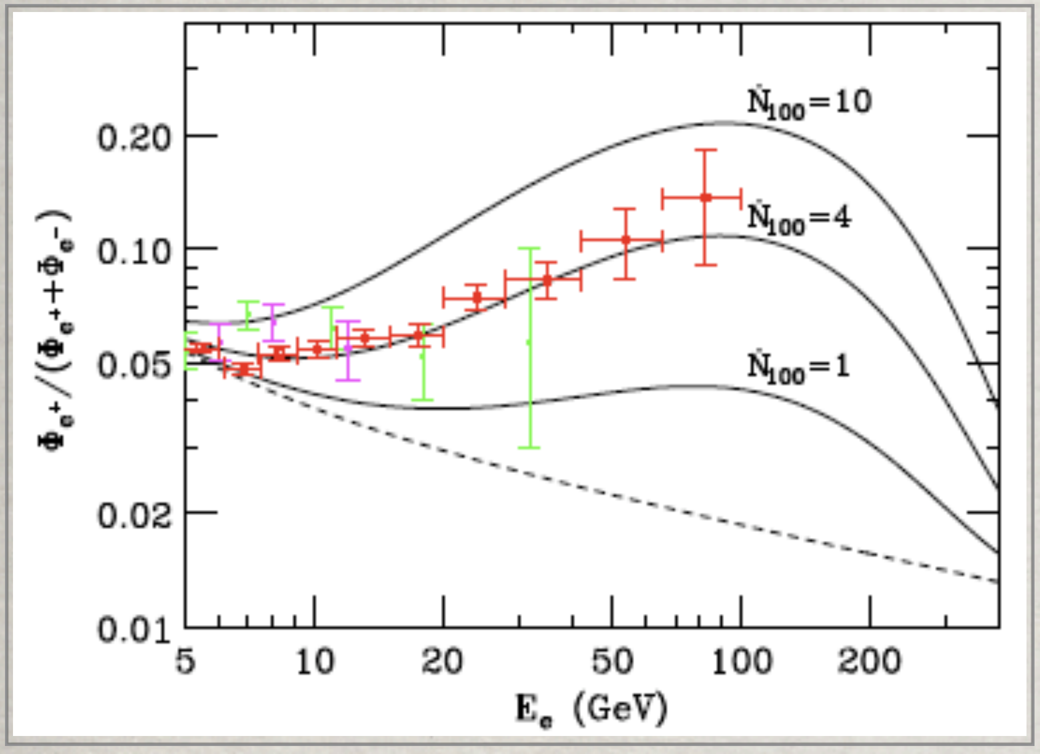
Fermi (2011)

Milagro

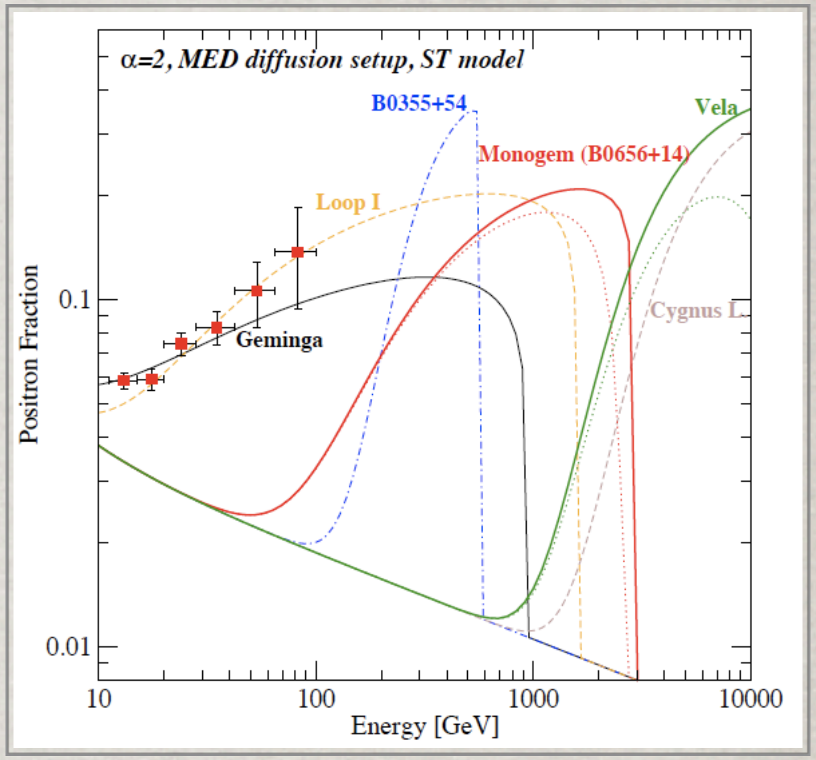


10 out of 17 multi-TeV associations with Fermi GeV pulsars

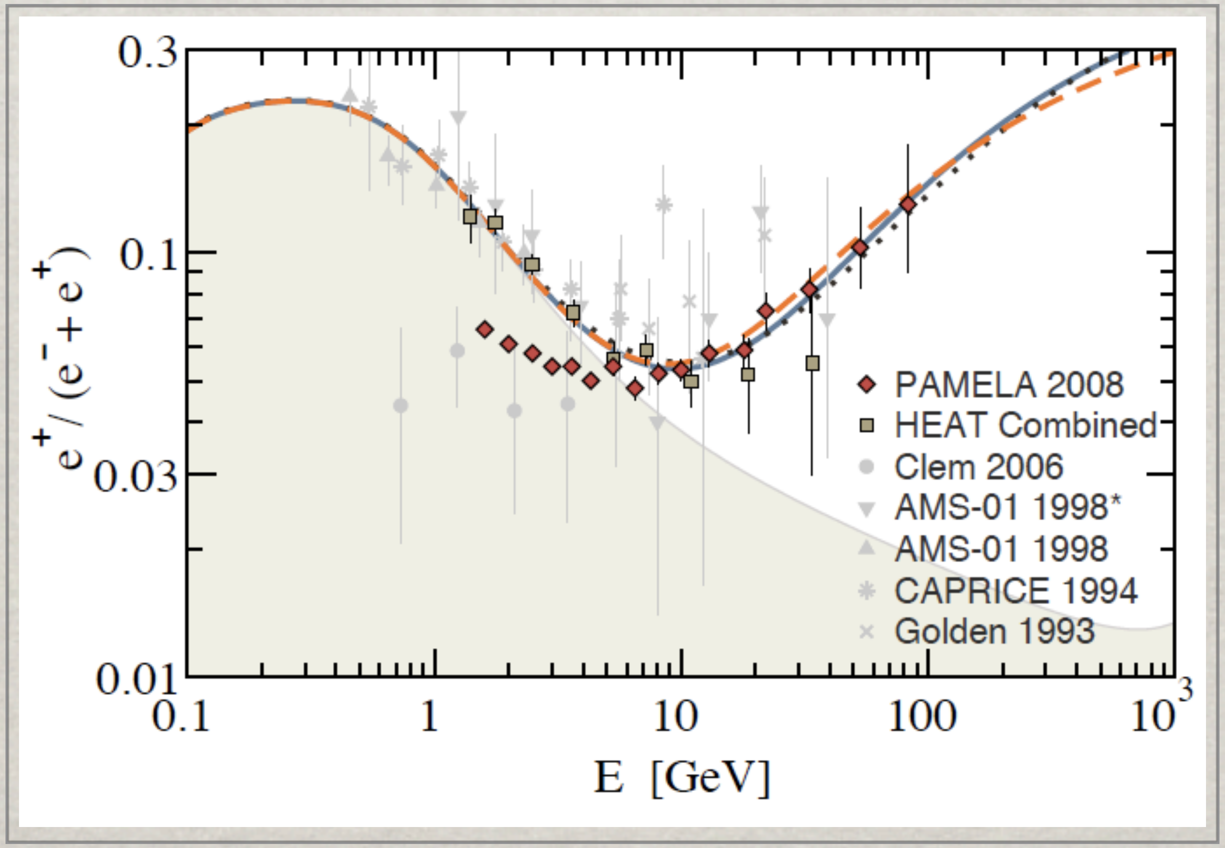
Positrons from pulsars



Hooper, Blasi, Serpico (2008)

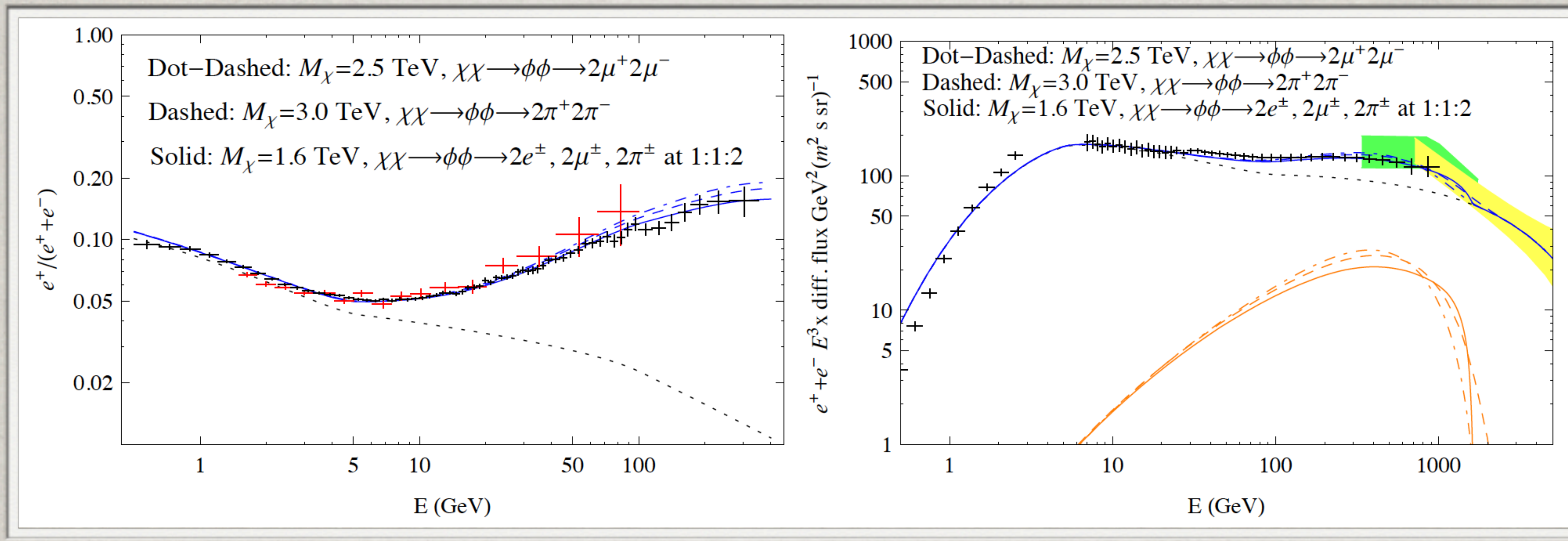


Profumo (2008)

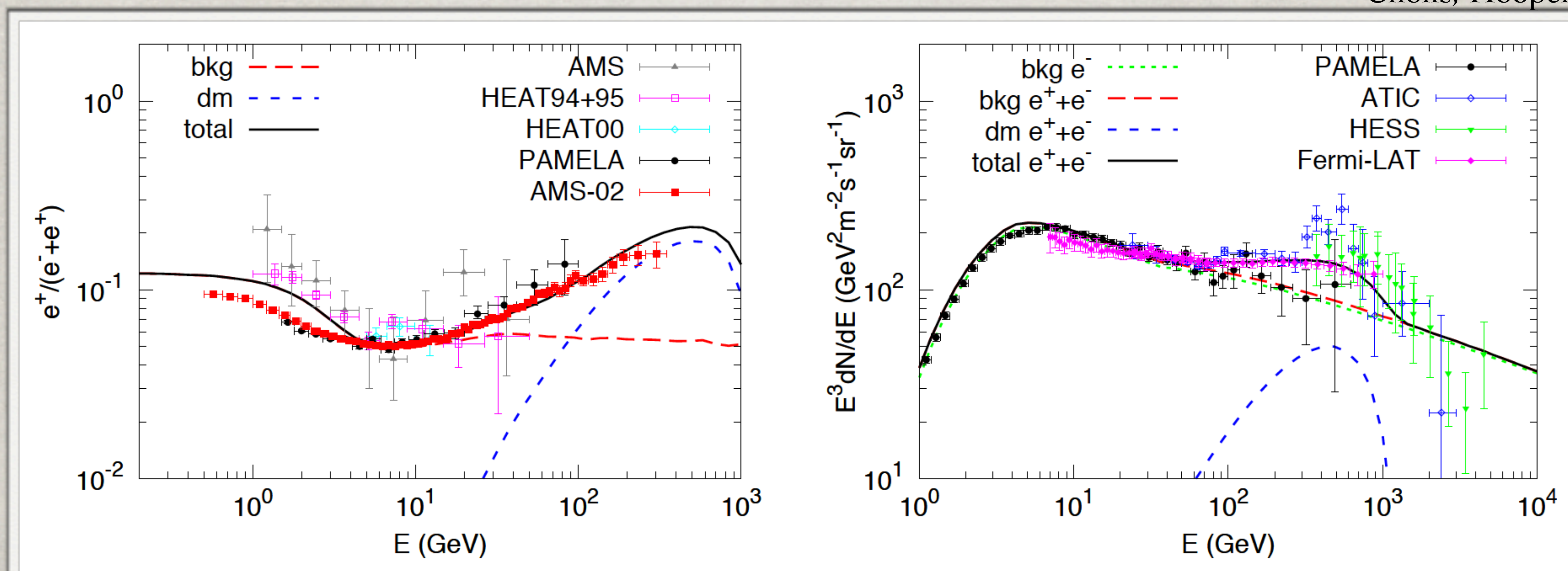


Yuksel, Kistler, Stanev (2008)

Positrons from dark matter

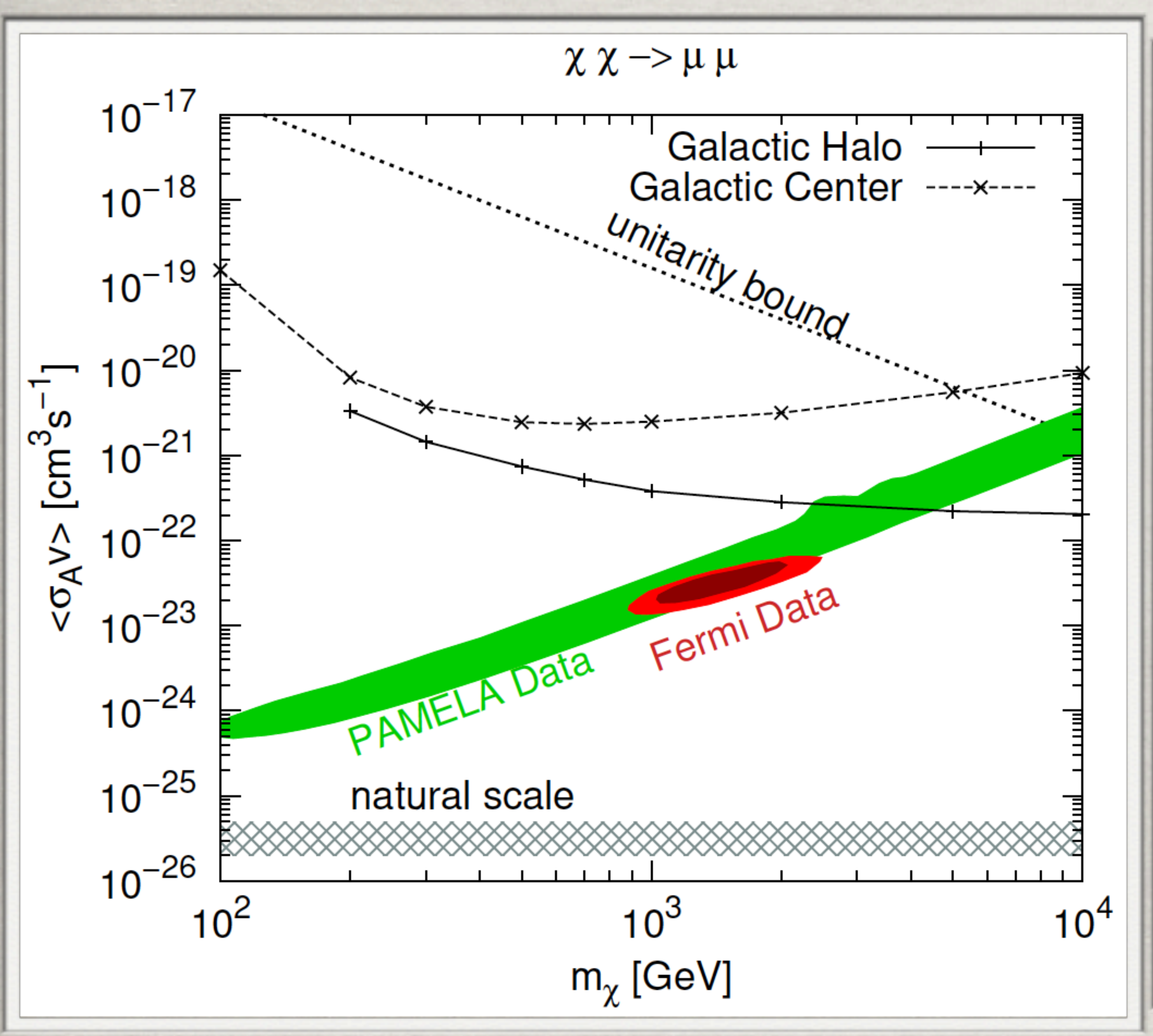


Cholis, Hooper (2013)

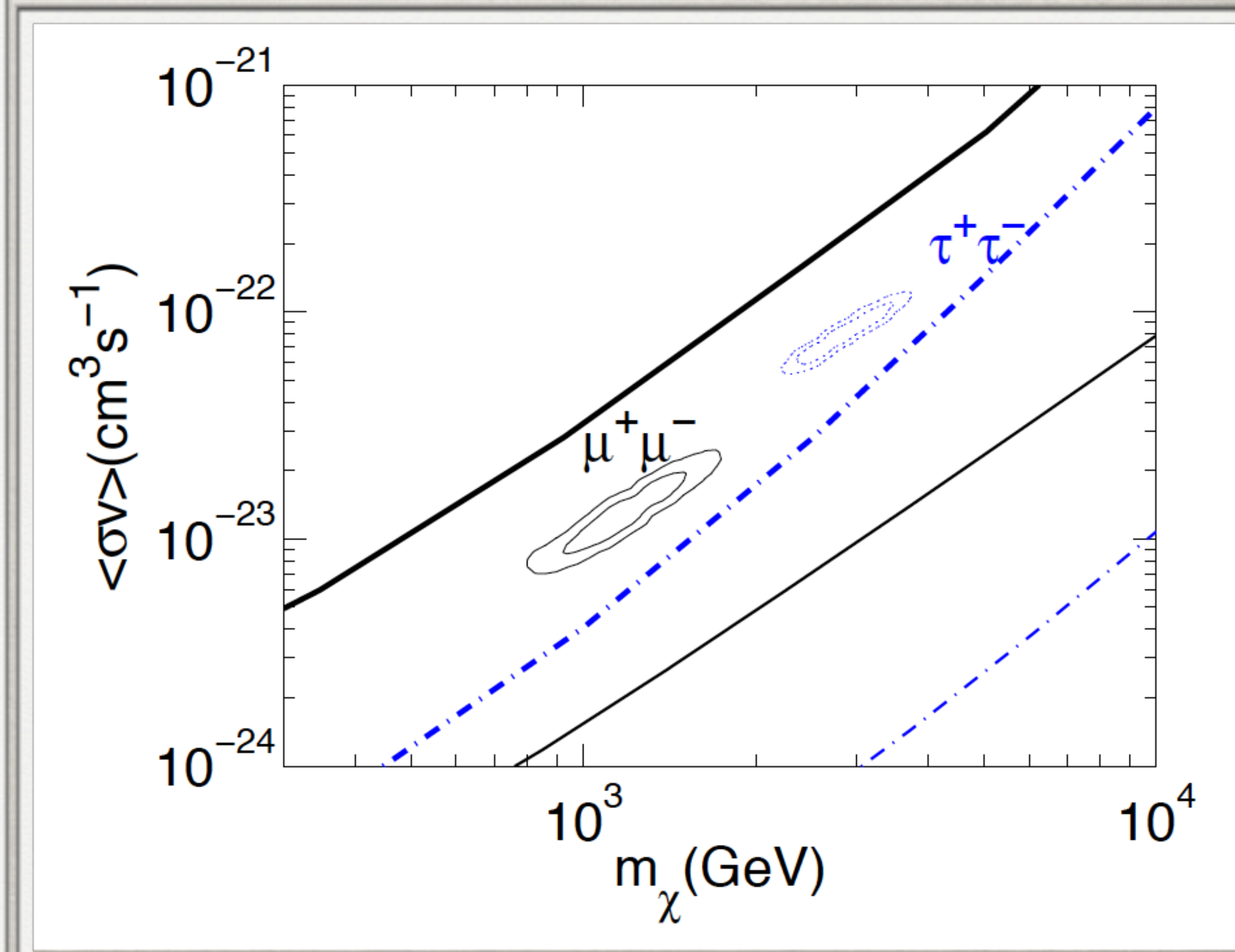


Yuan et al. (2013)

Positrons from dark matter



IceCube (2013)



Yuan et al. (2013)

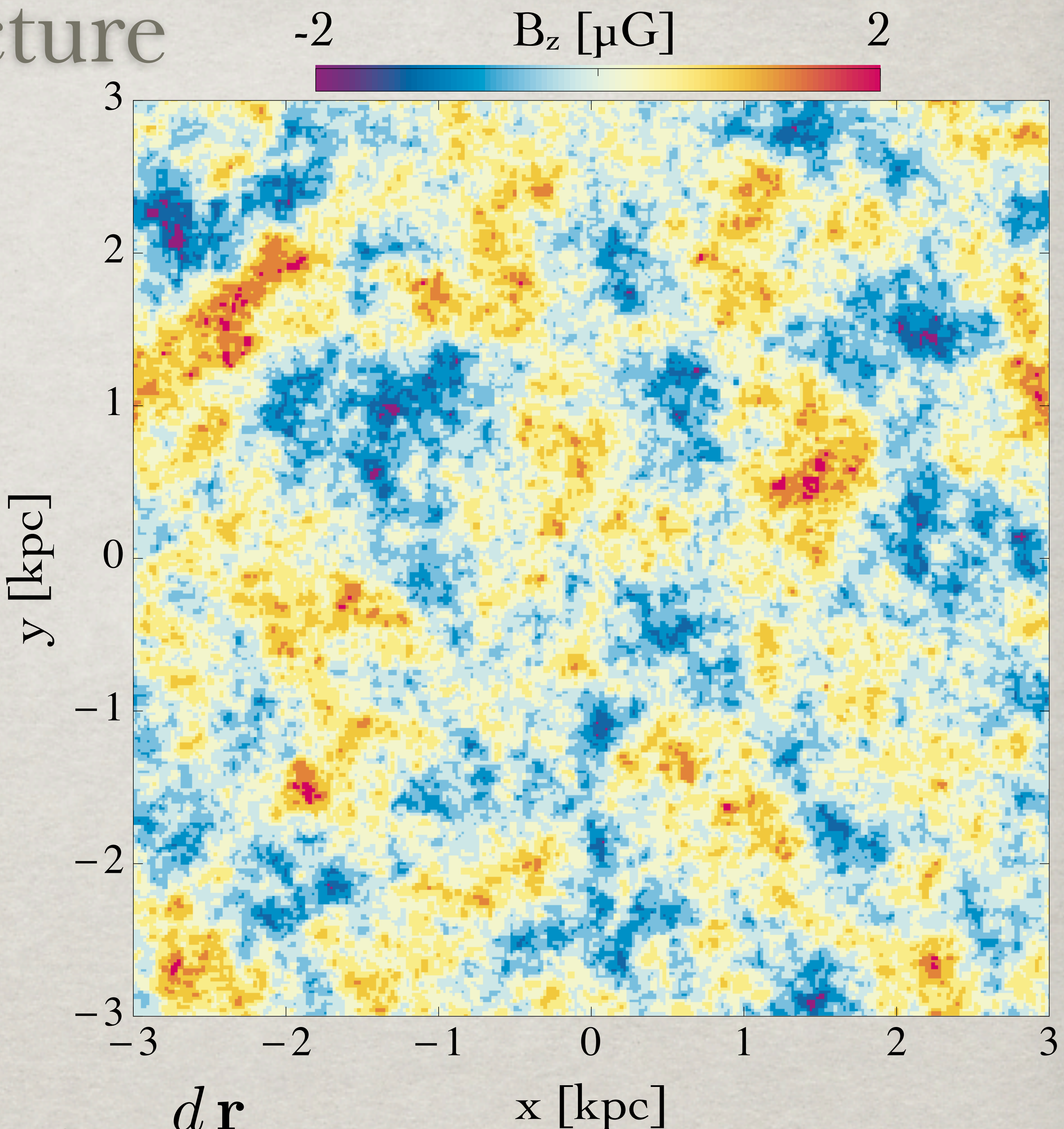
The spherical picture

Goal is to determine anisotropy signals, which get larger at higher energy

Kolmogorov turbulence

$$B_{\rm rms} = 3\,\mu{\rm G}$$

$$l_{max} \propto 1/k_0$$



$$\frac{d\,\boldsymbol{\beta}}{d\,t} \simeq 0.925\,\frac{\boldsymbol{\beta}\times\mathbf{B}}{E}$$

$$\boldsymbol{\beta} = \frac{d\,\mathbf{r}}{d\,t}$$

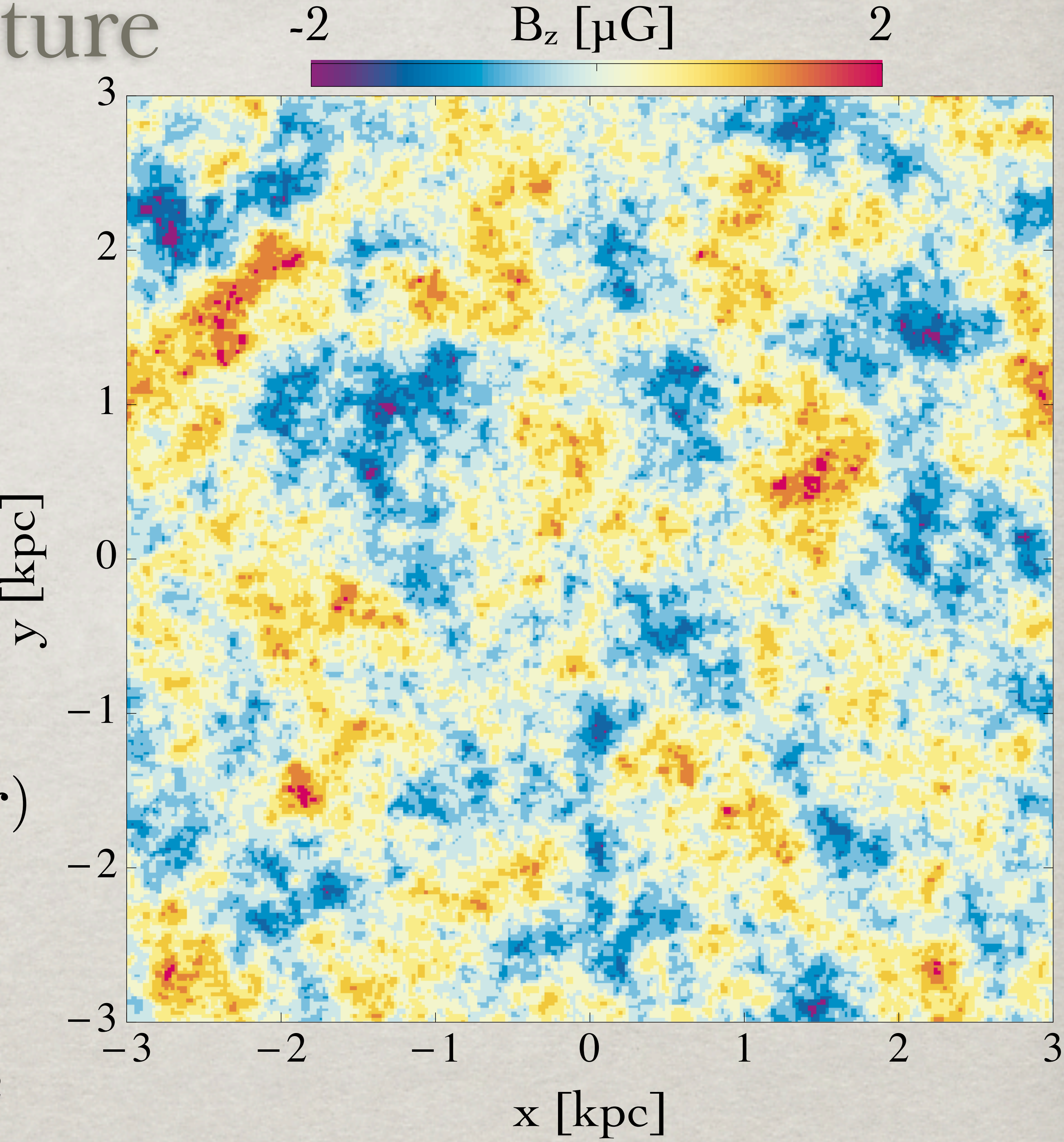
The spherical picture

$$l_{max} = 150 - 250\,\mathrm{pc}$$

$$r_L \simeq 1.08\,\frac{(E/\mathrm{PeV})}{(B/\mu\mathrm{G})}$$

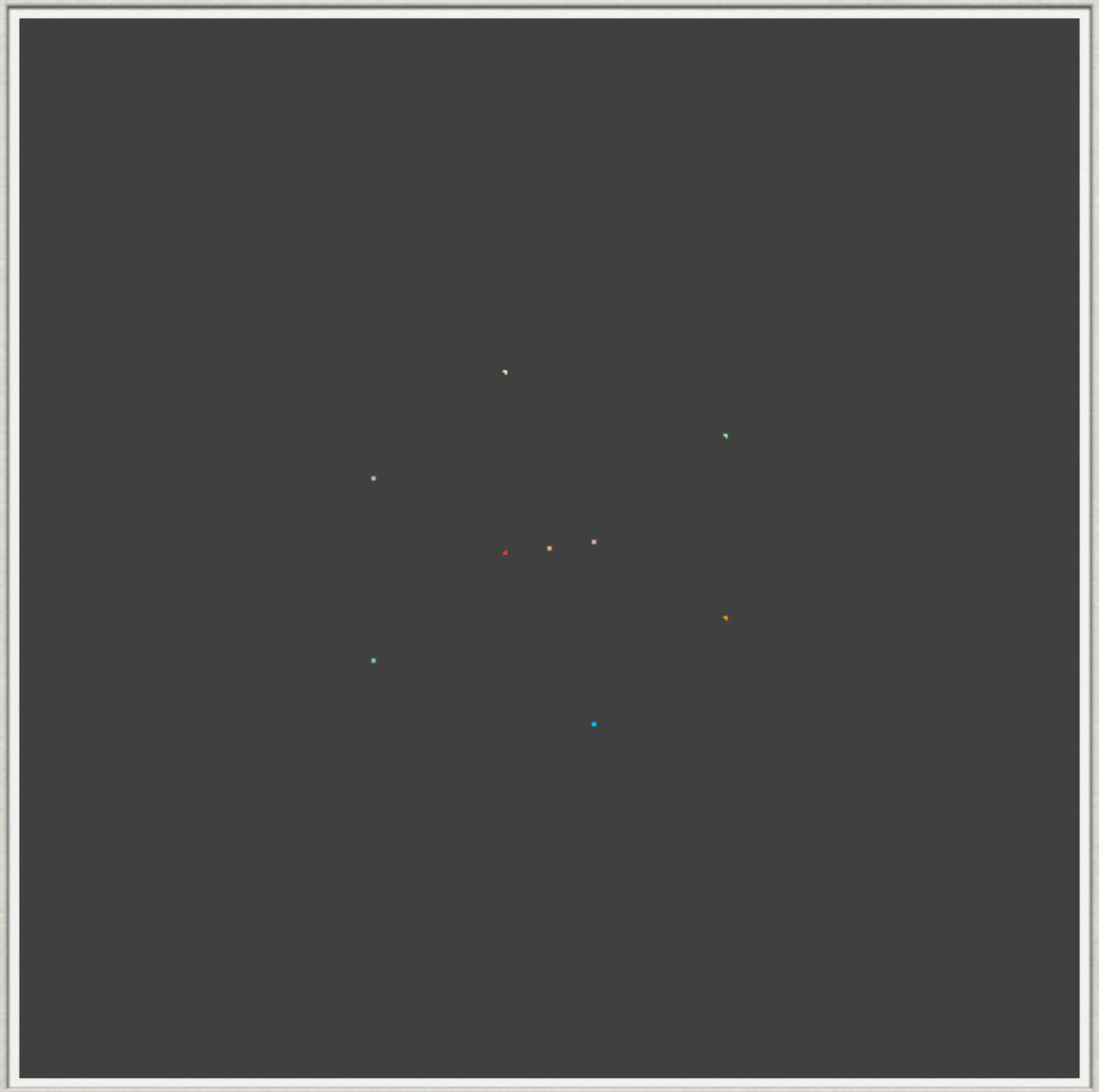
$$\mathbf{B}_{k_0}^{k_N}(\mathbf{r}) \propto \sum_{i=0}^{N} \eta^{-i/2}\,\mathbf{B}_{k_0}^{k_1}(\eta^i \mathbf{r})$$

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



The spherical picture

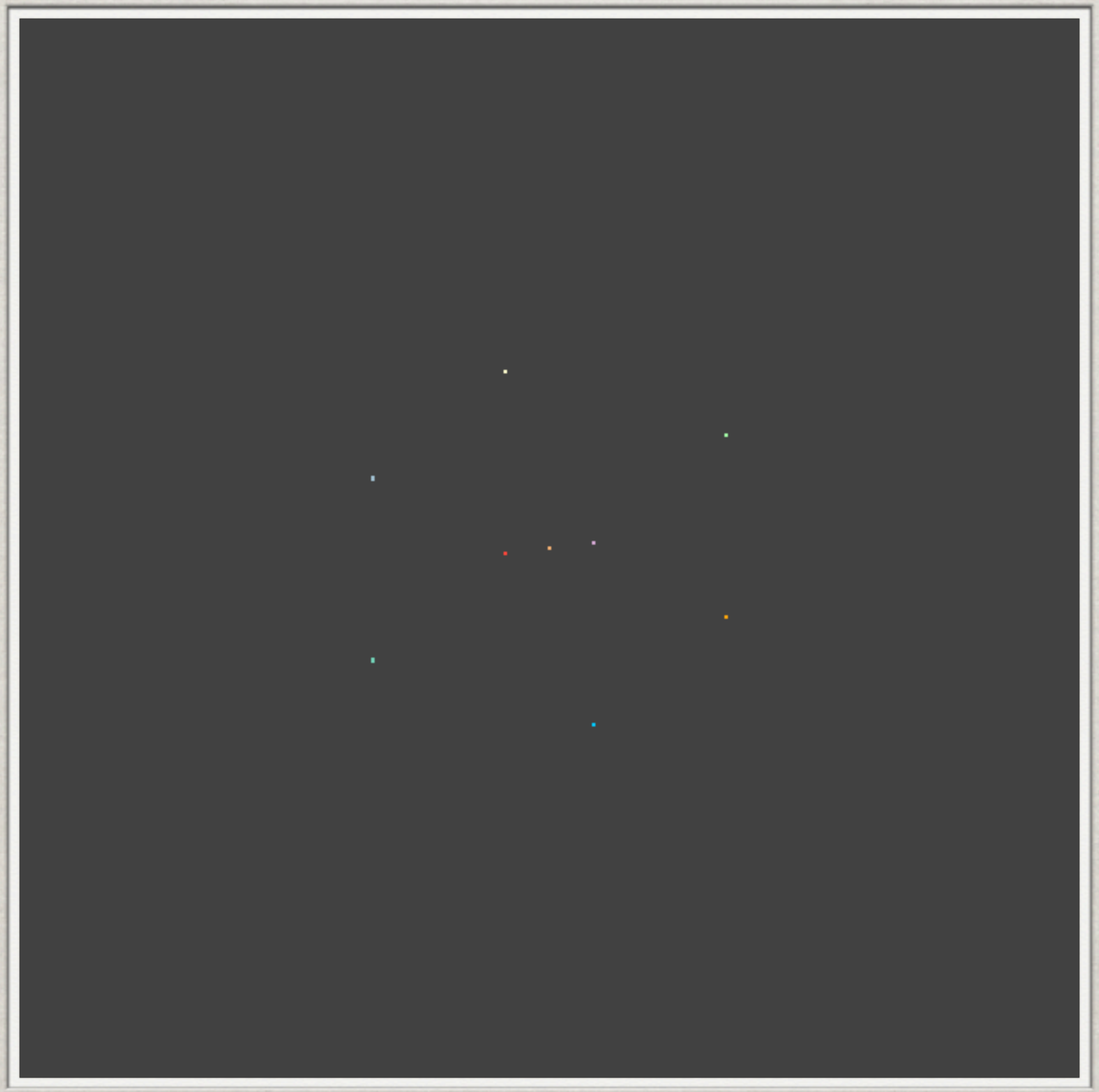
9 sources



Averaged over many random field configurations

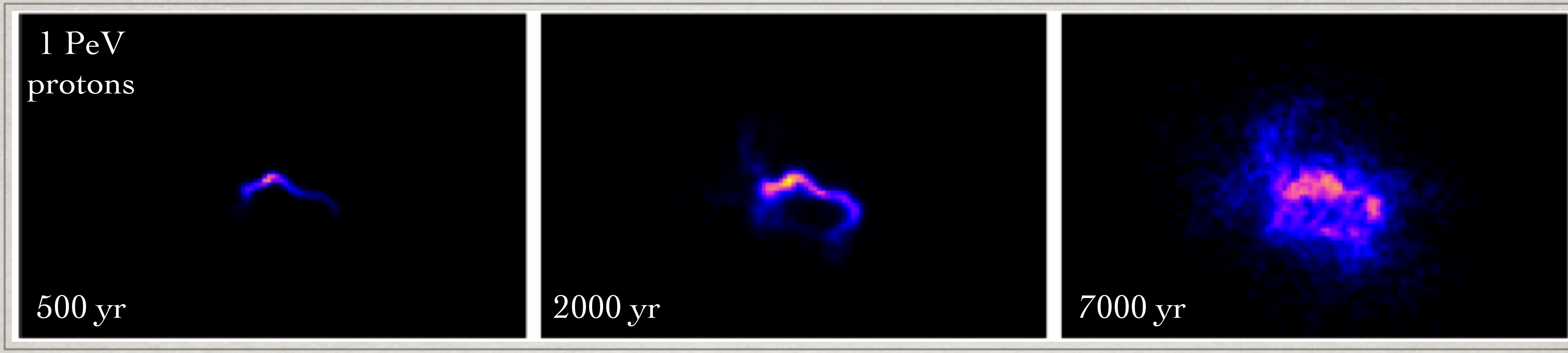
The non-spherical picture

9 sources



Placed throughout a single random field configuration

The non-spherical picture



Giacinti et al. (2012)

$$t_d \sim 10^4 \left(\frac{l_{\rm max}}{150\,{\rm pc}}\right)^{\beta} \left(\frac{1000\ {\rm TeV}}{E}\right)^{\gamma} \left(\frac{B_{\rm rand}}{4\,\mu{\rm G}}\right)^{\gamma} {\rm yr}$$

$$t_l \sim 10^5 \left(\frac{1\ {\rm TeV}}{E}\right) \left(\frac{5\,\mu{\rm G}}{B_{\rm tot}}\right)^{2} \left(\frac{1\,{\rm eV\,cm^{-3}}}{\epsilon_\gamma}\right) {\rm yr}$$

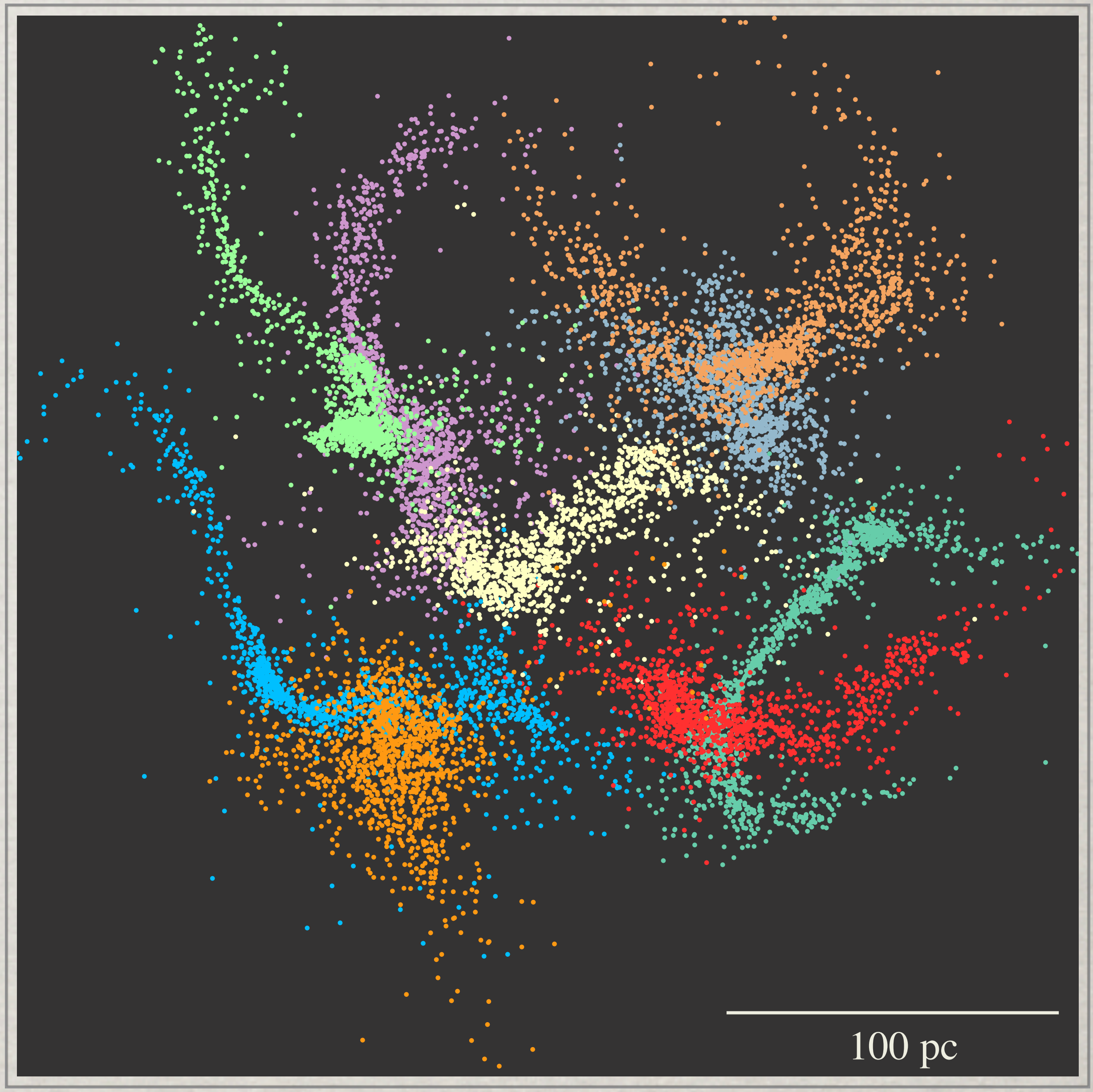
$l_{max} = 150 - 250\,{\rm pc}$ $\quad B_{\rm tot} = 4 - 7.5\,\mu{\rm G}$ $\quad \epsilon_\gamma \sim 1\ {\rm eV\ cm^{-3}}$

$$\boxed{t_l = t_d \ \text{for} \ E_c \approx 10 - 1000\,{\rm GeV}}$$

The non-spherical picture

If cosmic-ray propagation is to be handled using such fields, electrons/positrons above some energy reside in filamentary structures

Very different from protons



Kistler et al. (2012)

Conclusions

Good

Limiting number of sources reaching Earth would lead to featureless spectra

Flux from otherwise unremarkable source could be enhanced

Bad

Number of positron sources reaching Earth could be reduced to zero

Would need alternative source (i.e., dark matter)

Ugly

If anisotropies are seen, do not necessarily point back to source

Feedback, MHD effects not included

In any case, taking energy losses into account leads to a need for improved treatment of electron/positron transport