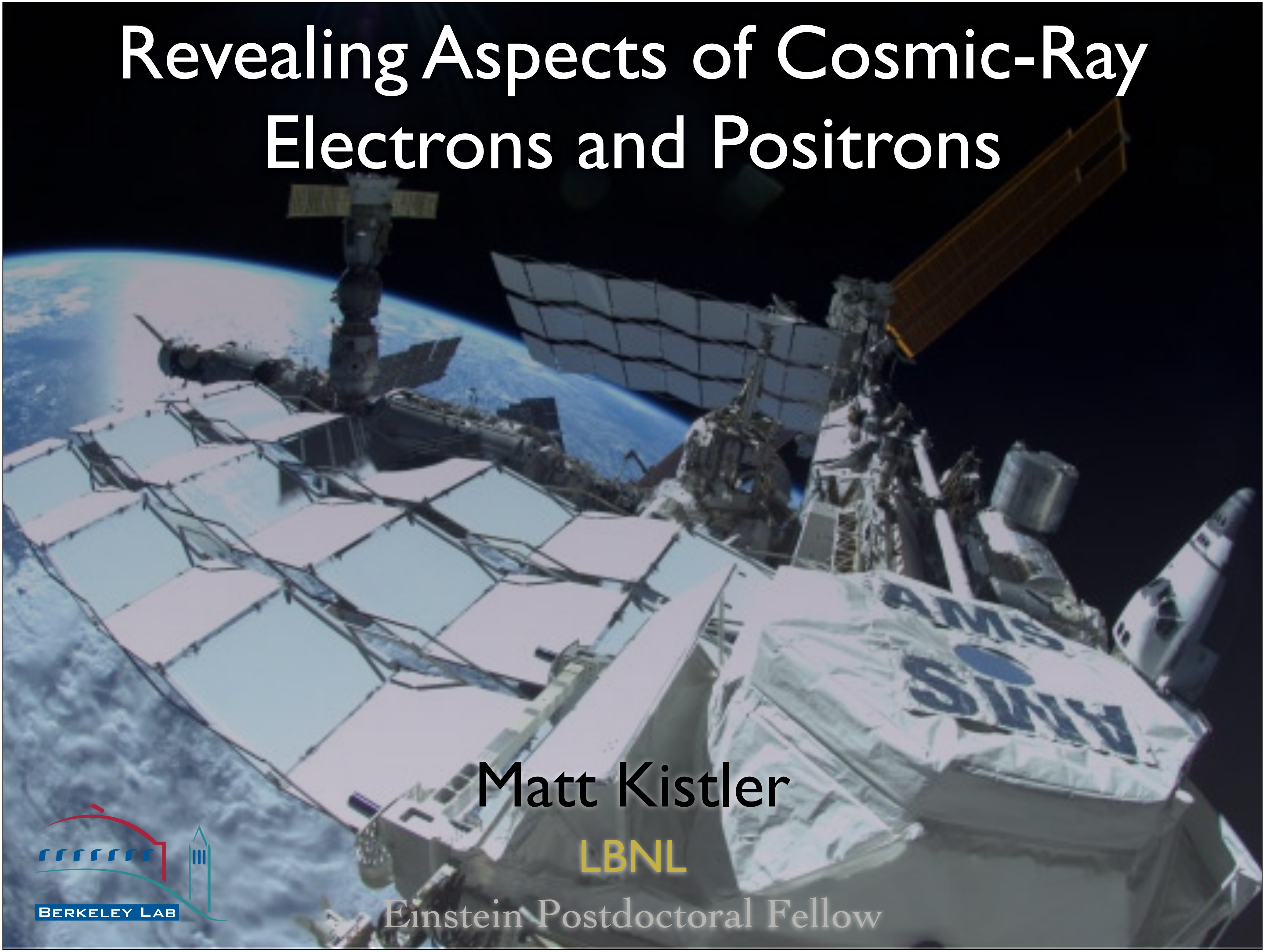
Revealing Aspects of Cosmic-Ray Electrons and Positrons



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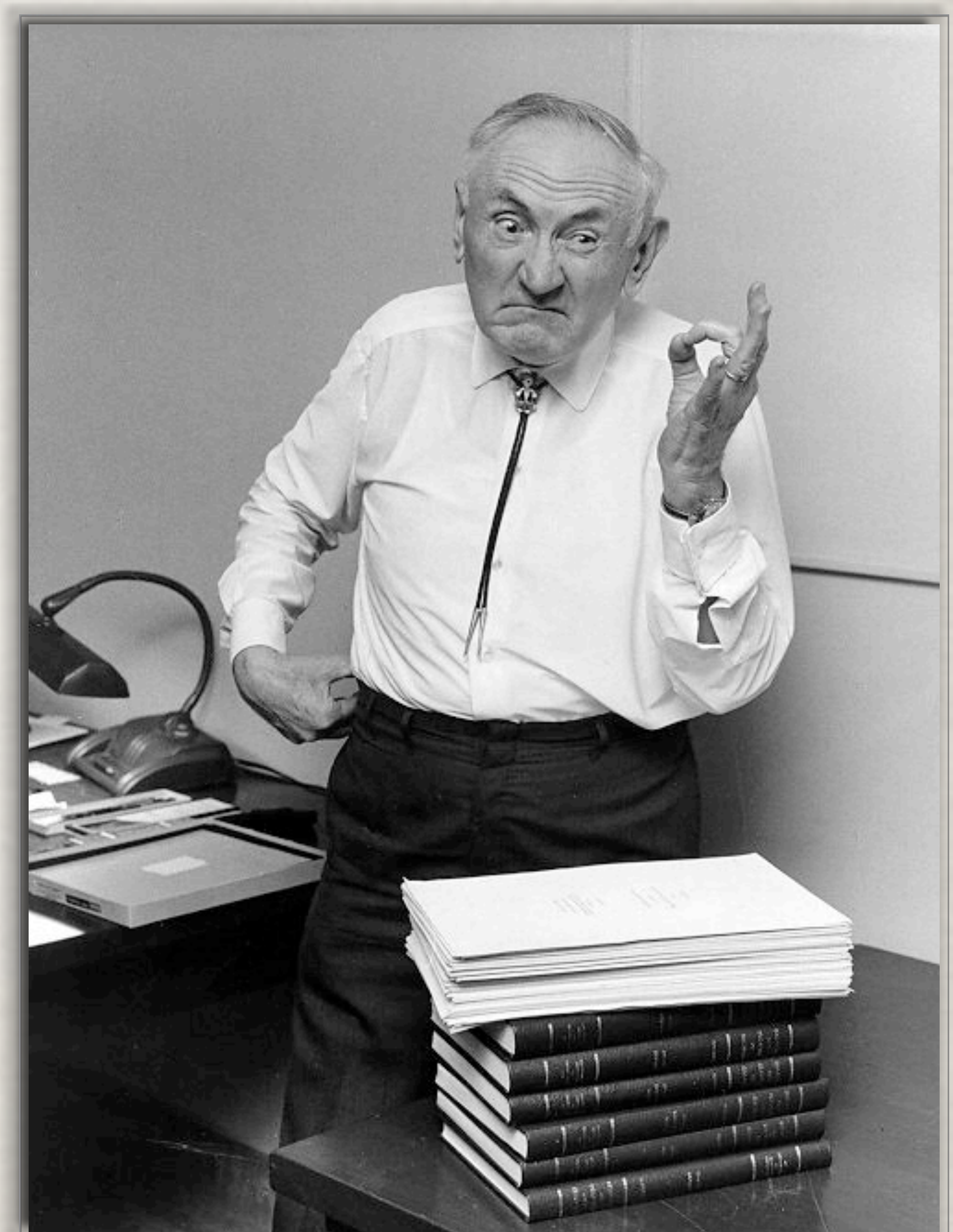
Zwicky

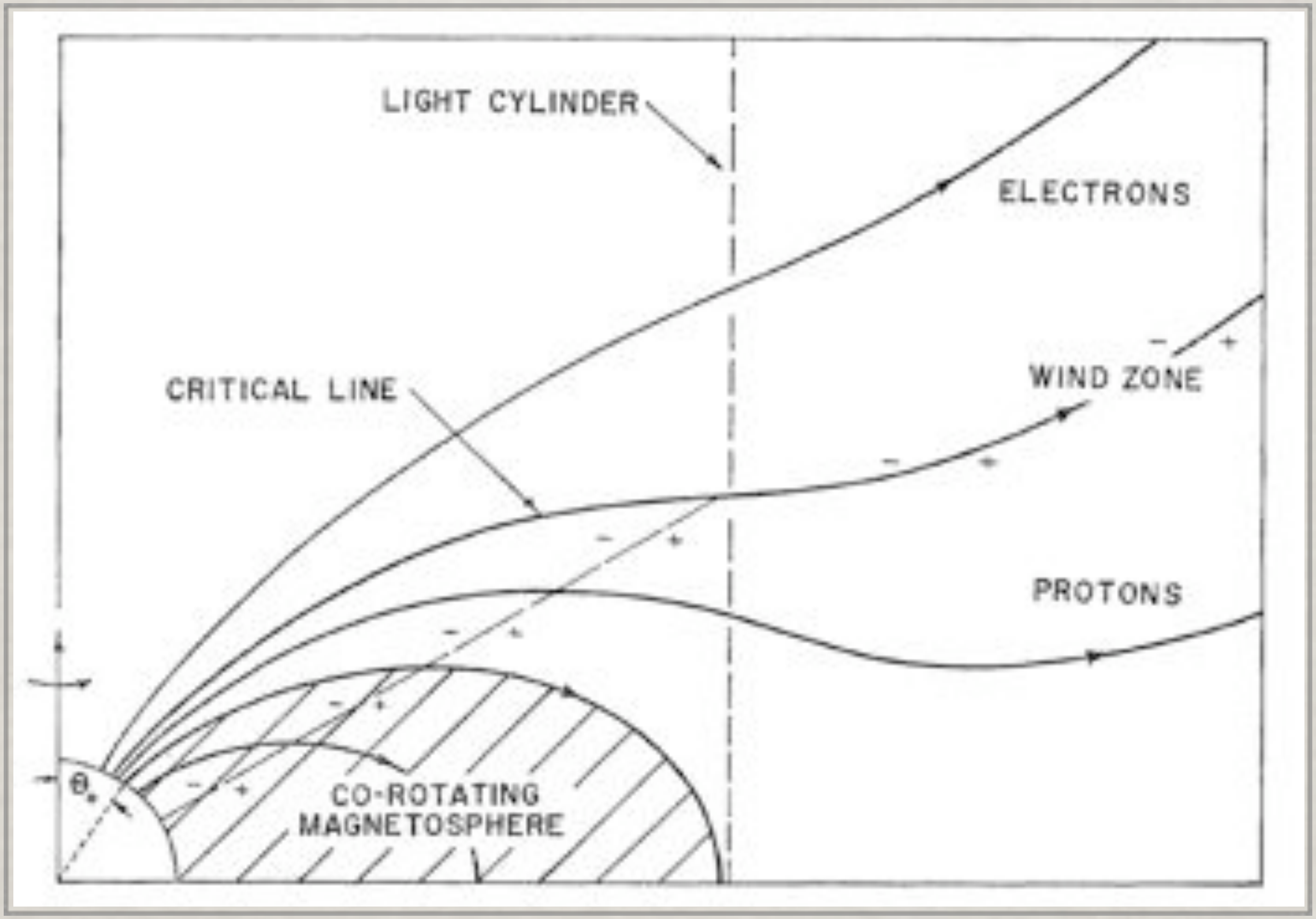
Supernovae as
source of cosmic rays

Neutron stars result
from supernovae

What is the
cosmic ray
output of
neutron stars?



Pulsar wind

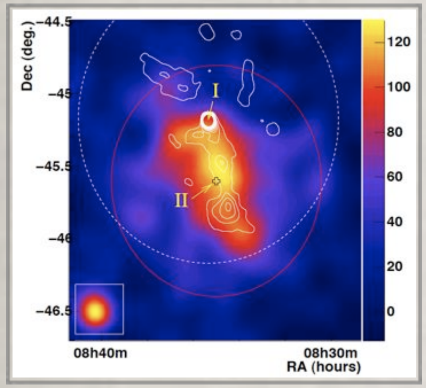


Goldreich and Julian (1969)

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

Electron/positron factories

Vela X

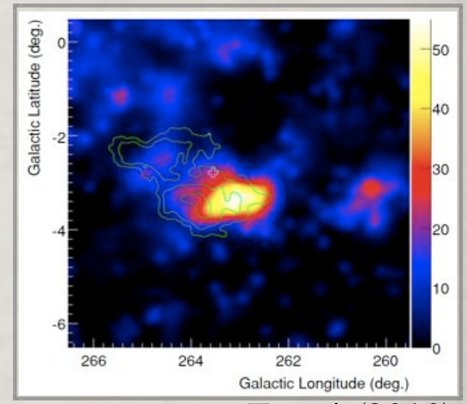


HESS (2006)

Two distinct populations

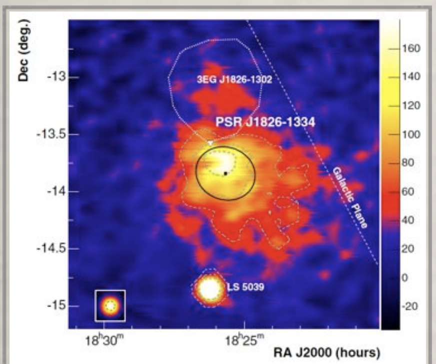
$>10^{46}$ erg in TeV electrons seen, cutoff at ~70 TeV

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



Fermi (2010)

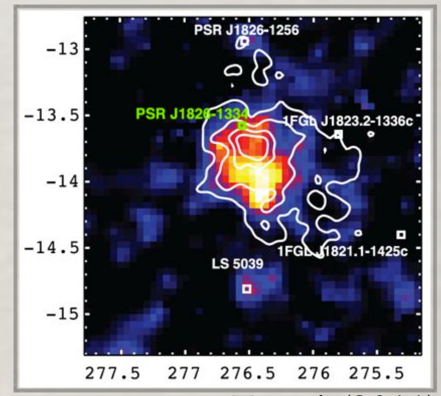
HESS J1825–137



HESS (2006)

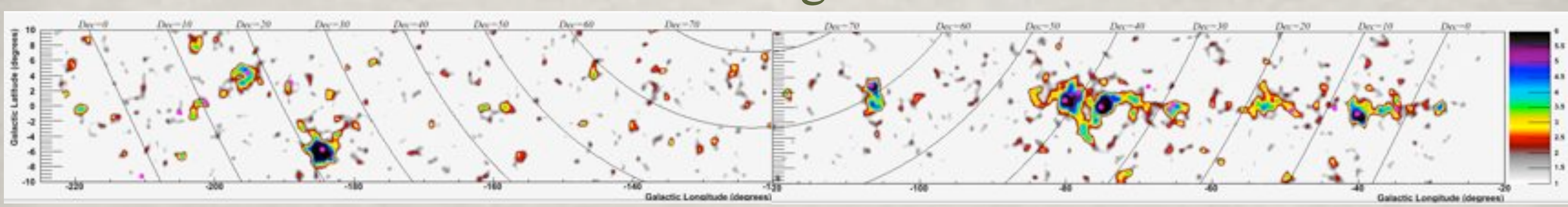
Inferred to travel >100 pc

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



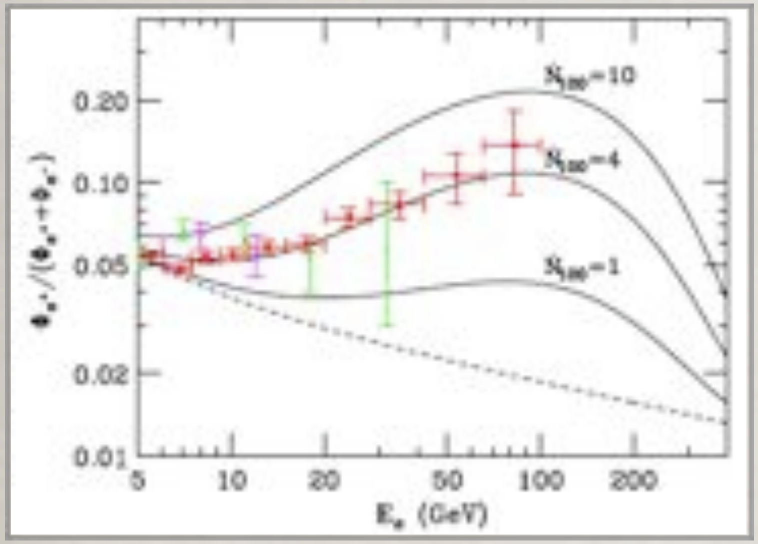
Fermi (2011)

Milagro

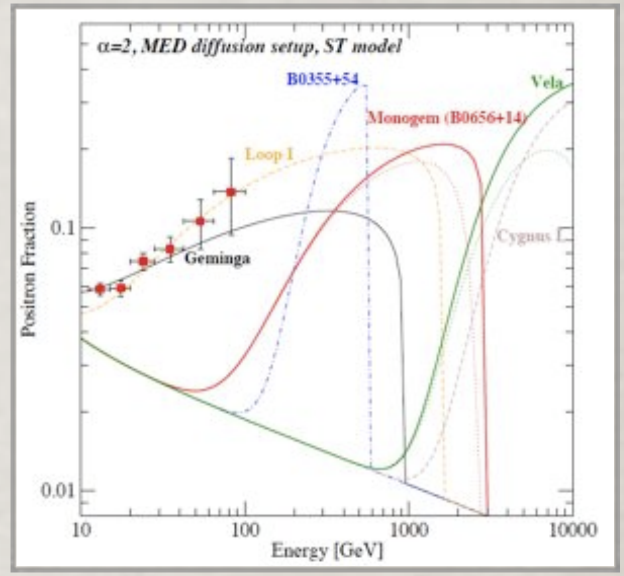


10 out of 17 multi-TeV associations with Fermi GeV pulsars

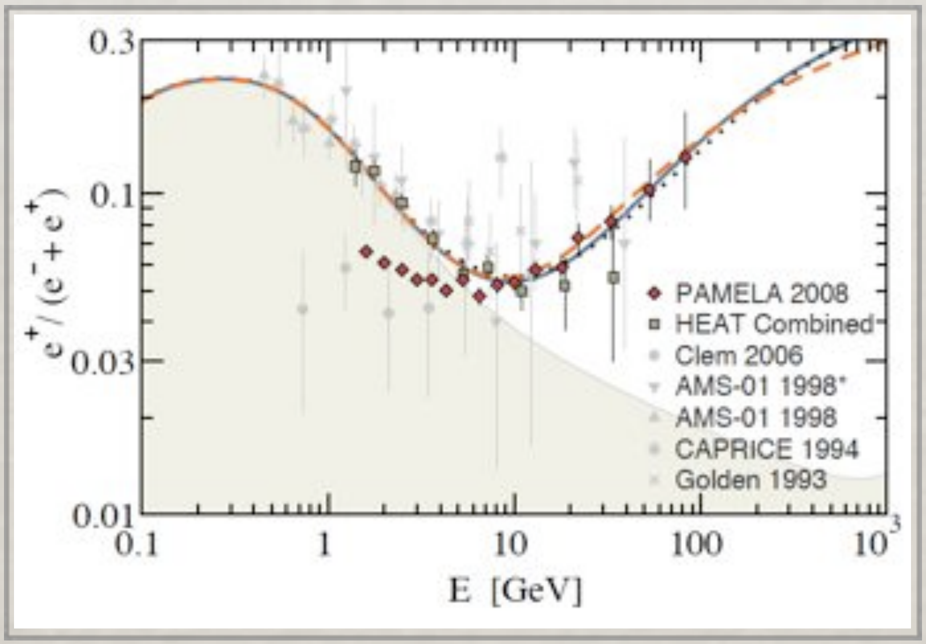
Positrons from pulsars



Hooper, Blasi, Serpico (2008)



Profumo (2008)



Yuksel, Kistler, Stanev (2008)

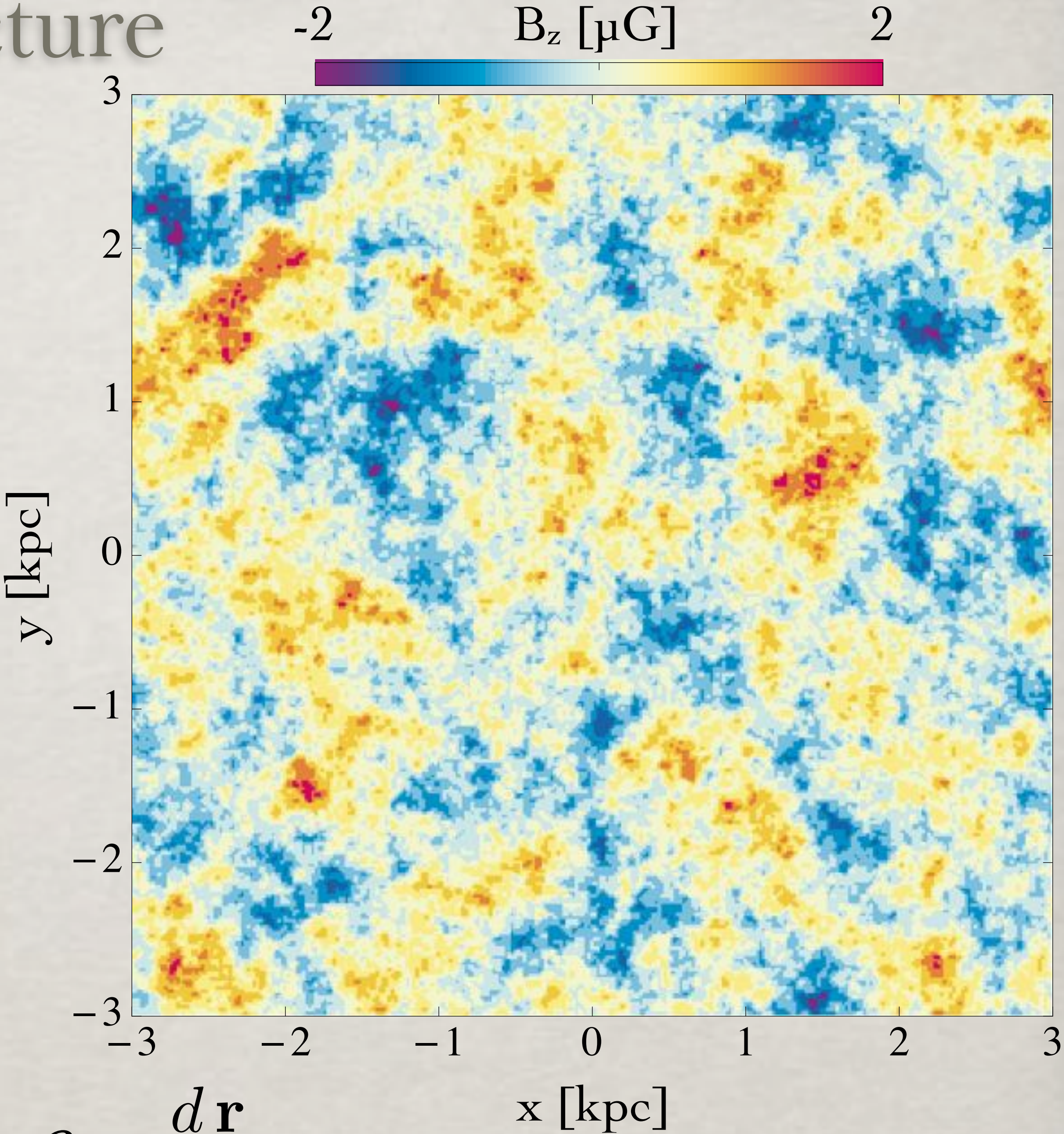
The spherical picture

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

Kolmogorov turbulence

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

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



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

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

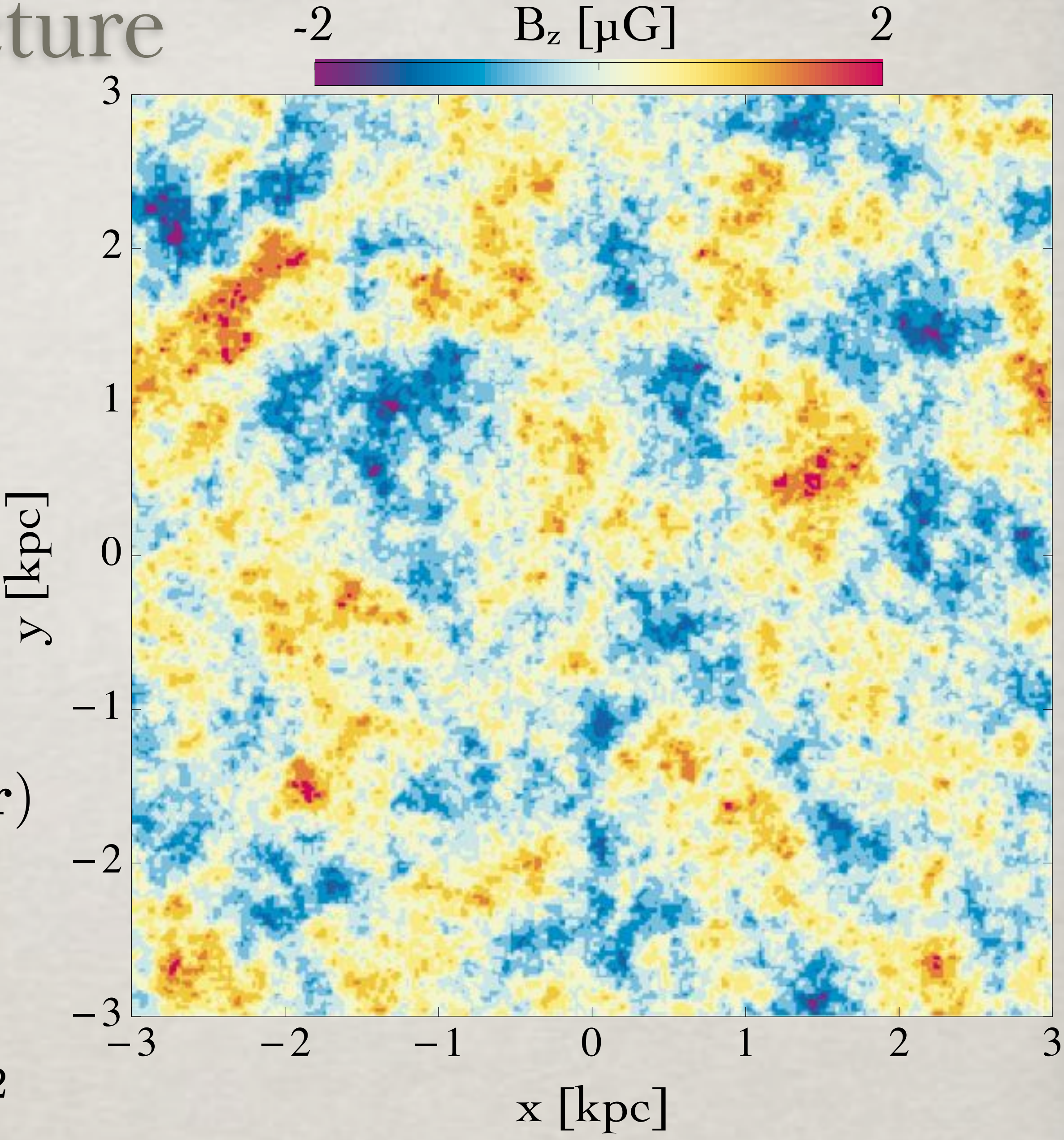
The spherical picture

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

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

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

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



The spherical picture

9 sources

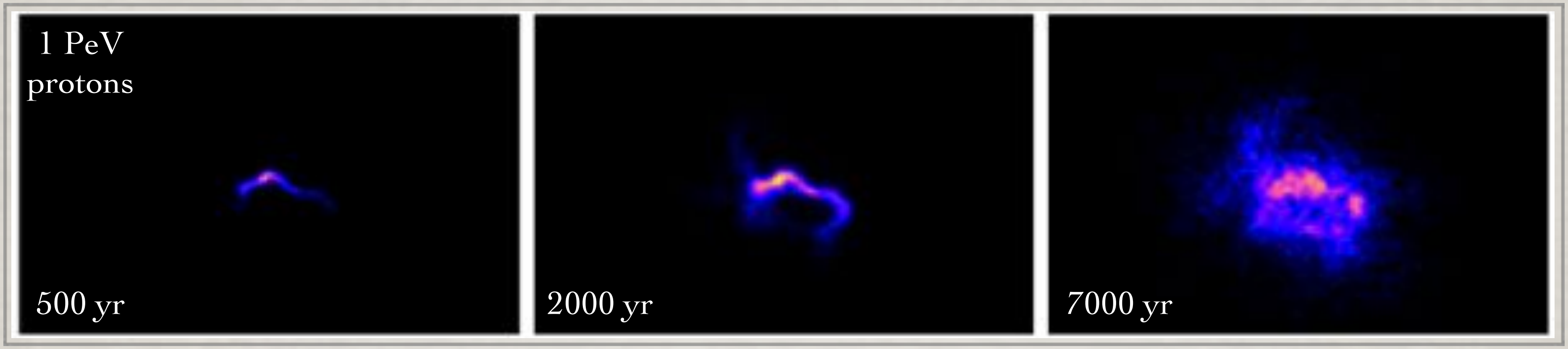
Averaged over many random field configurations

The non-spherical picture

9 sources

Placed throughout a single random field configuration

The non-spherical picture



Giacinti et al. (2012)

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

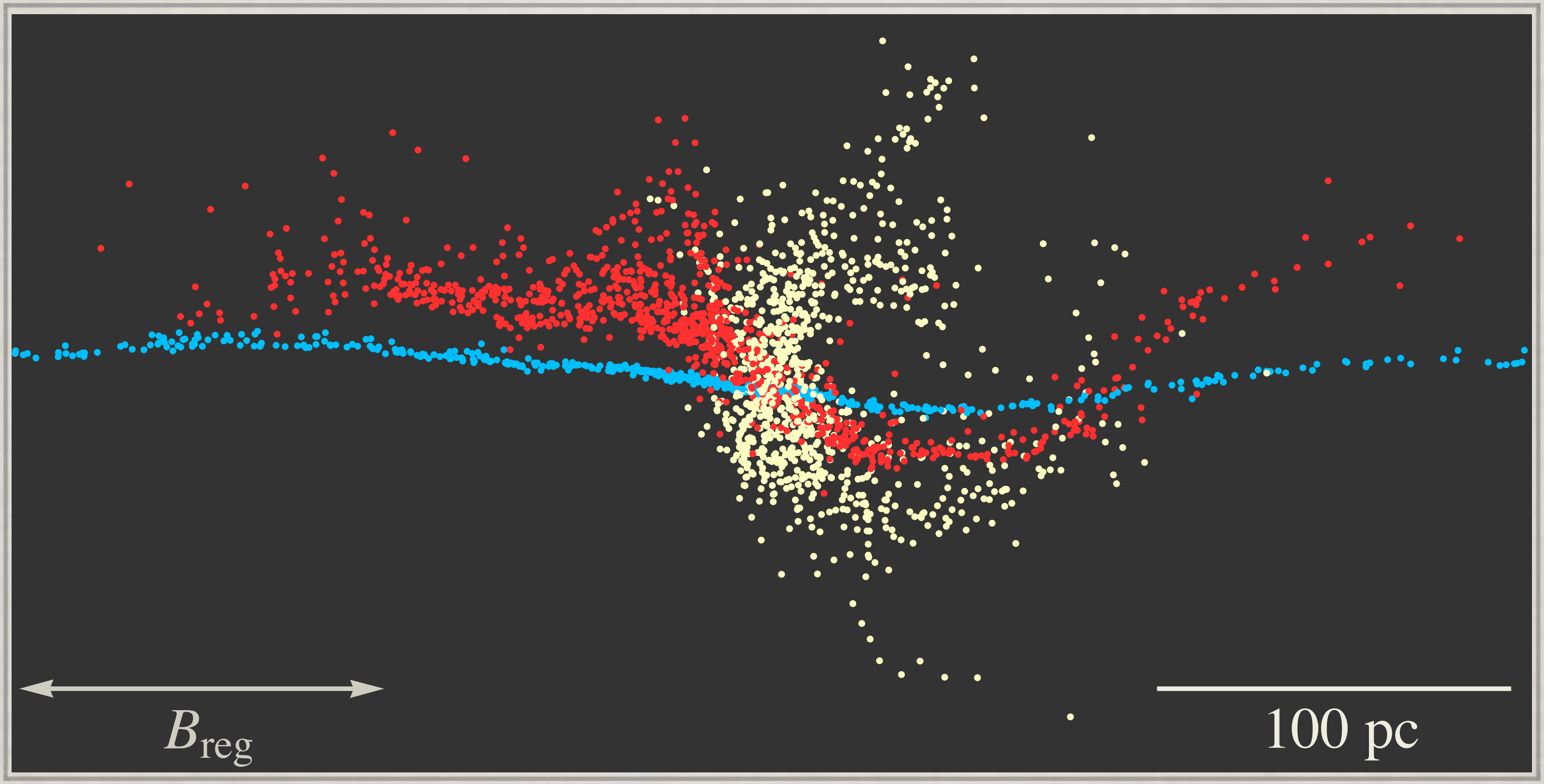
Giacinti et al. (2012)

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

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

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

The non-spherical picture



Kistler et al. (2012)

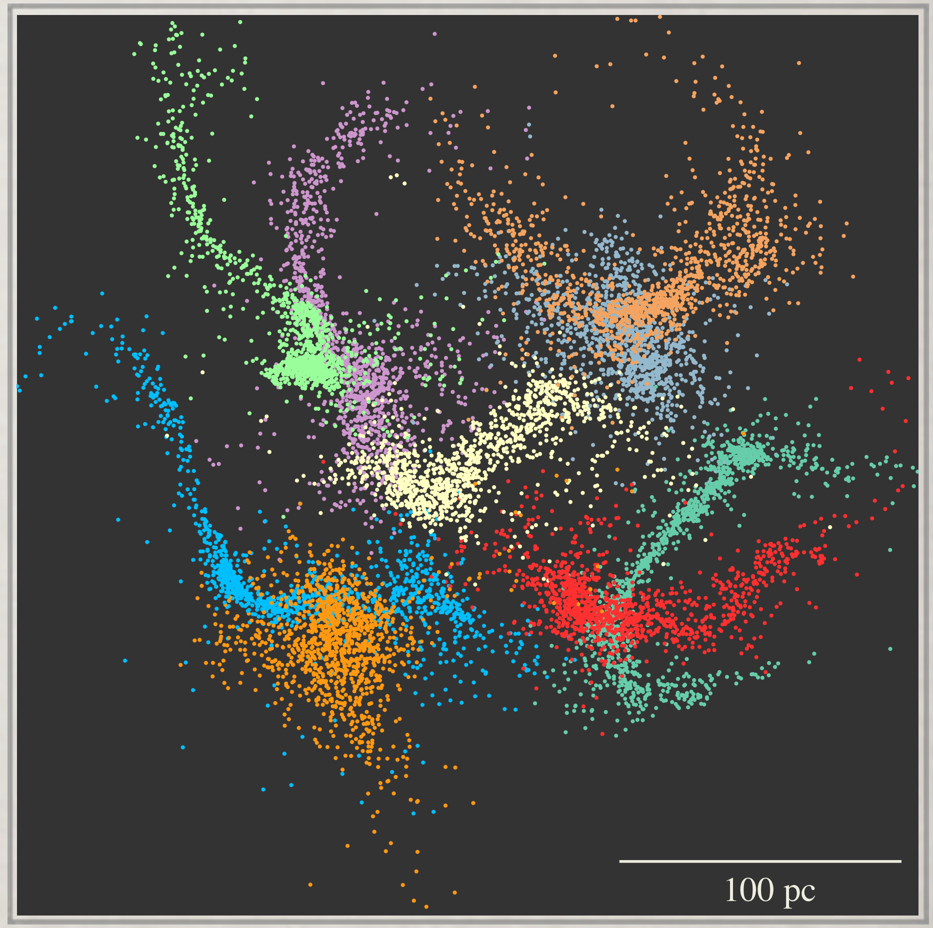
$$B_{\rm reg}/B_{\rm rand} = 0 \text{ (yellow)}, 1 \text{ (red)}, 5 \text{ (blue)}$$

$$B_{\rm reg} + B_{\rm rand} = 3\,\mu\text{G}$$

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

More interesting feedback effects could lead to boring outcome

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