Fermi bubbles as possible sources of cosmic rays above 10^{15} eV

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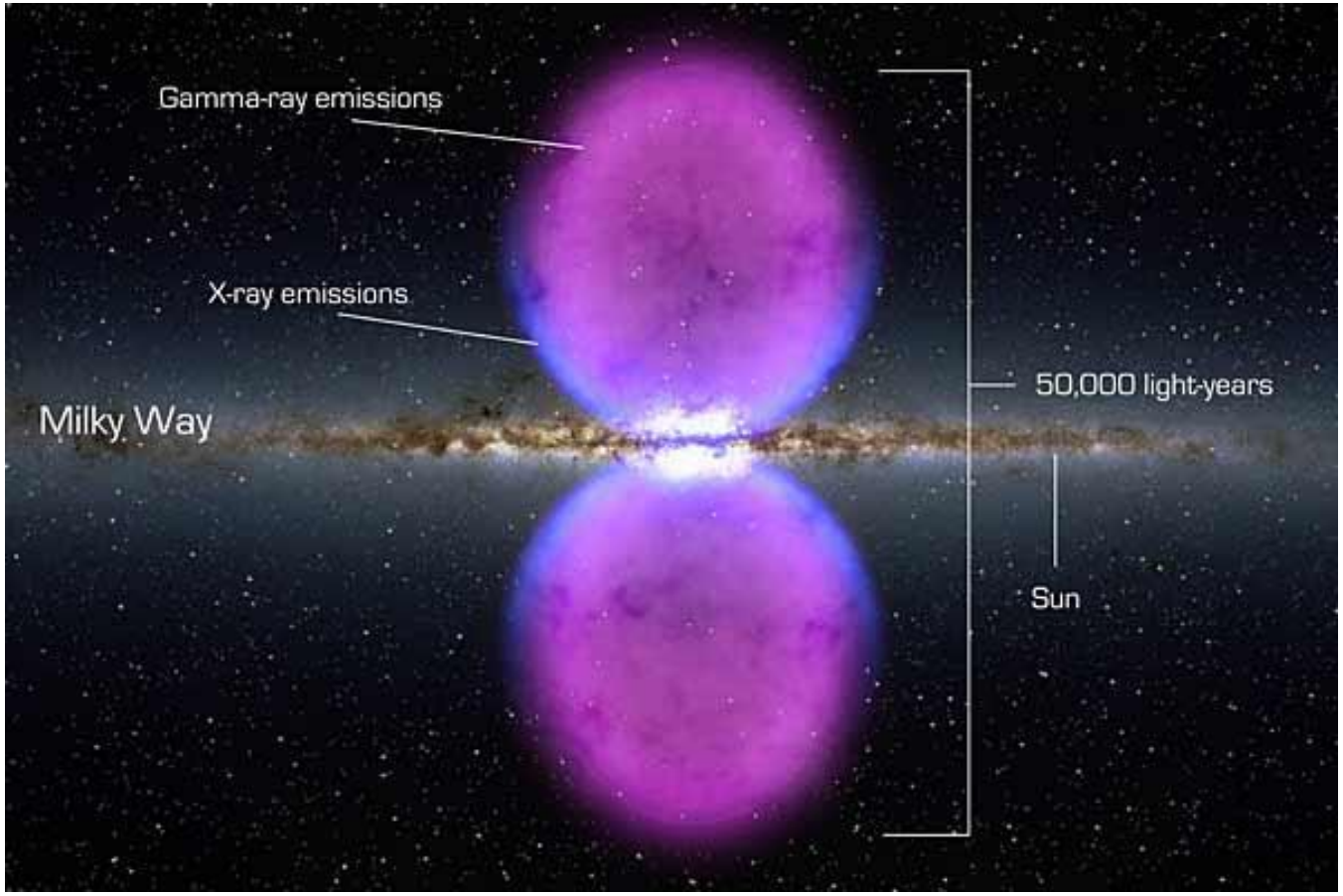
Maximum energy of particles

$$E_{max} \sim Ze\beta_{sh}u_{sh}BT$$

- We are fighting with age and size
- What if there is an acceleration site in the Galaxy
  - 10^3 times older
  - 10^3 times larger

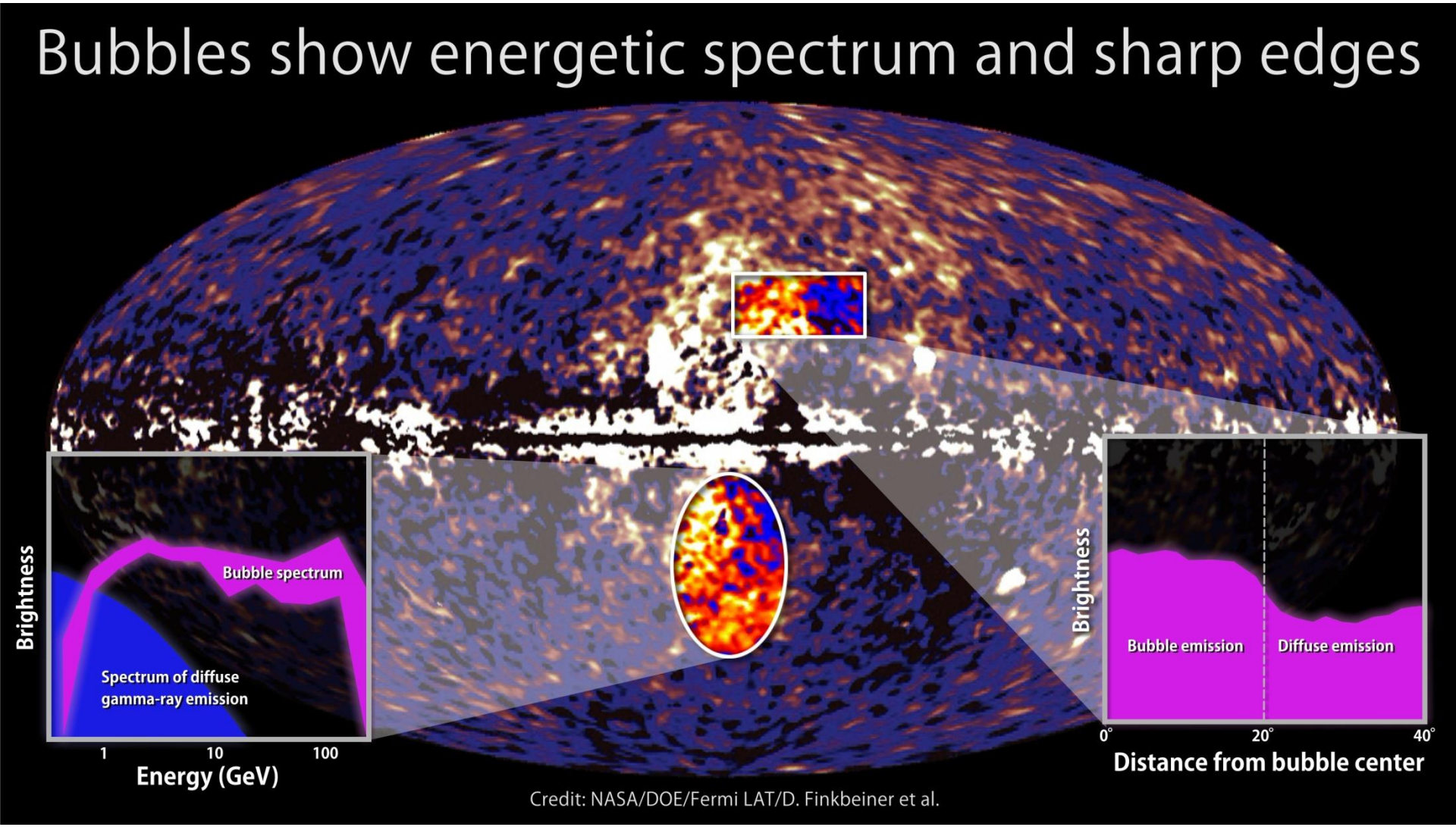
  than typical SNR?
- Will it change everything (anything)?

Fermi bubbles



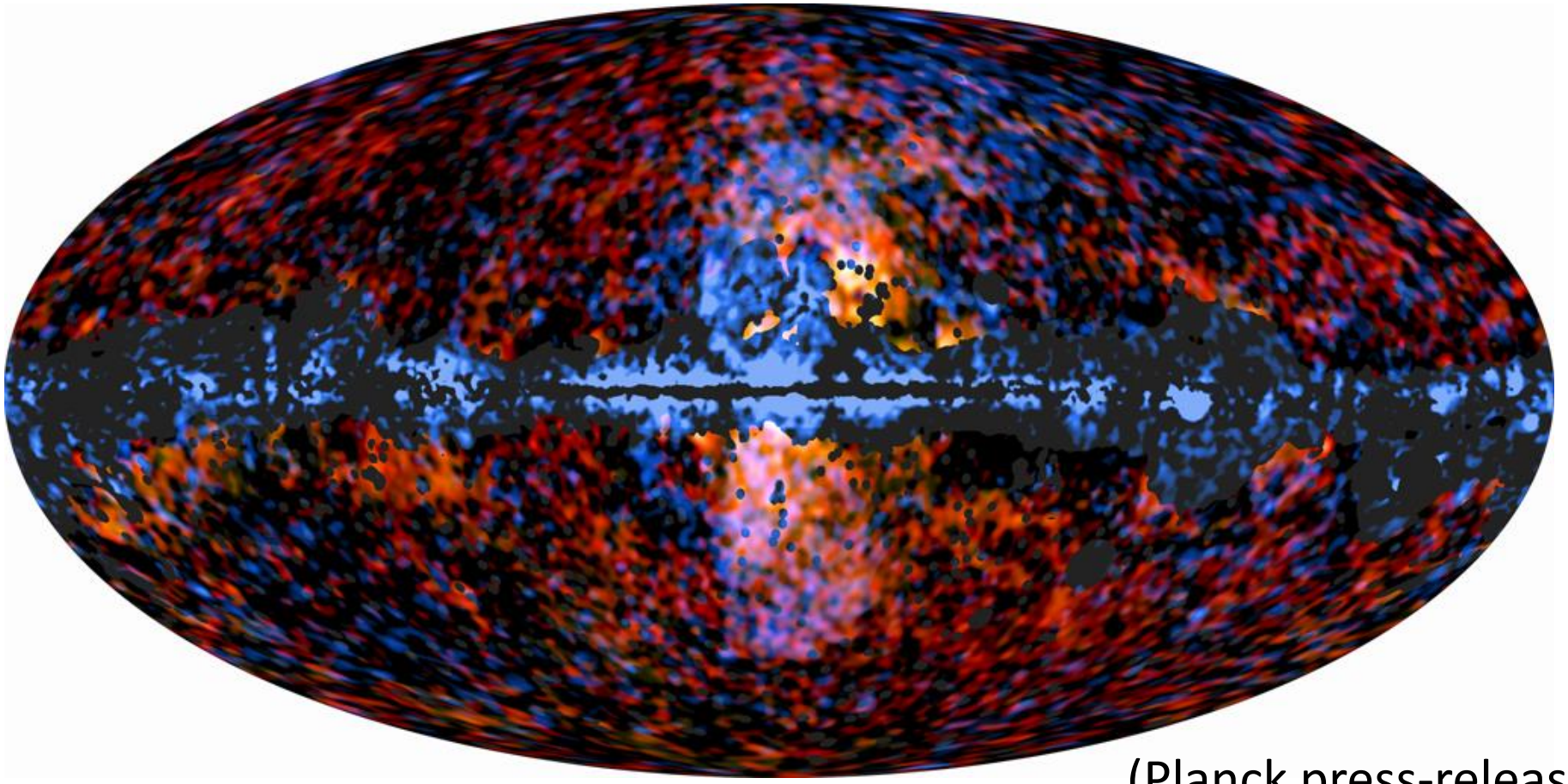
Dobler et al., 2010, Su et al., 2010

Fermi bubbles



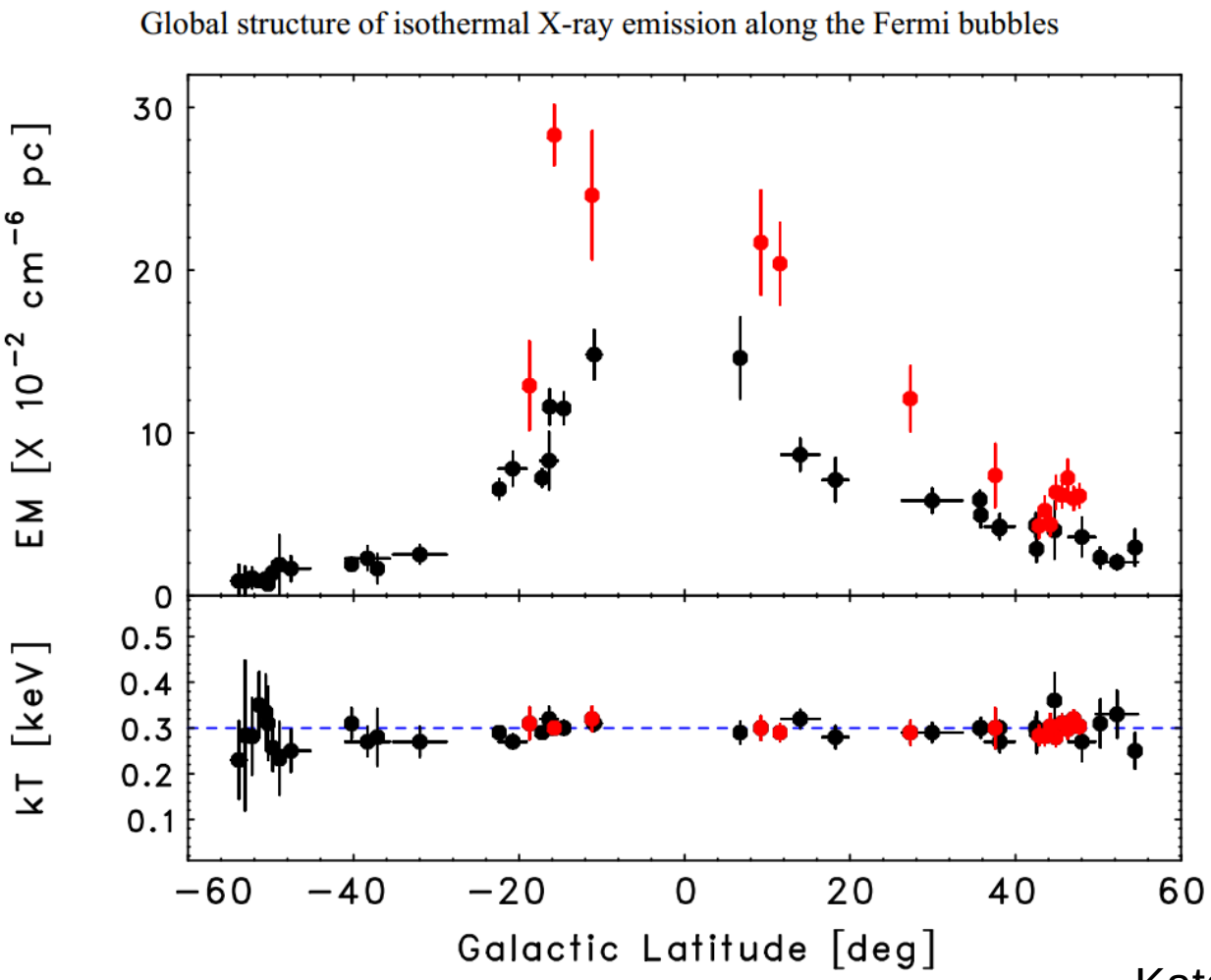
…as seen by Planck

Other wavelength counterparts
30 & 44 GHz (red and yellow) vs gamma-rays (blue)



(Planck press-release)

X-Ray counterpart



Increased density

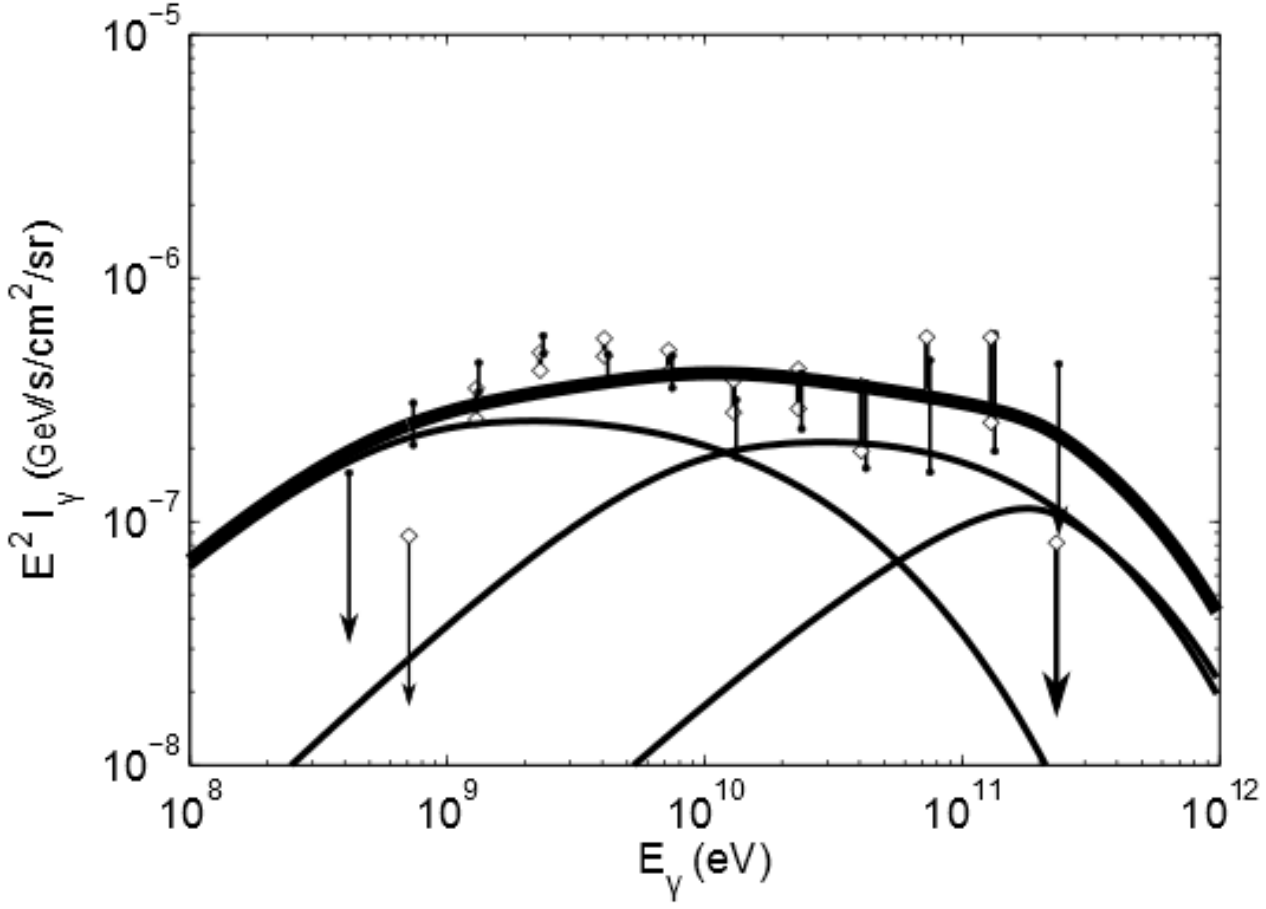
No strong shock

Kataoka et al., 2013, 2015

Origin of Fermi bubbles

Hadronic	Leptonic
$p + p \rightarrow 2\gamma + e^{\pm}$	IC + synchrotron
a) Crocker & Aharonian, 2010 **Crocker, 2012** SN activity + magnetic walls **b) Istomin, 2011** Jet + z-dependent diffusion **c) Fujita et al, 2013** Shock **d) Thoudam, 2013** CR injection	**a)Su et al., 2010** Starburst or jet => giant shock **b)Guo & Mathews,2011; Yang et al., 2012** Jet + anisotropic diffusion, "ballistic" **c)Mertsch & Sarkar, 2011** Fermi-II acceleration **d)Cheng et al., 2011** Stellar captures => series of shocks
Additional leptonic component required	**In-situ acceleration required**

Origin of Fermi bubbles

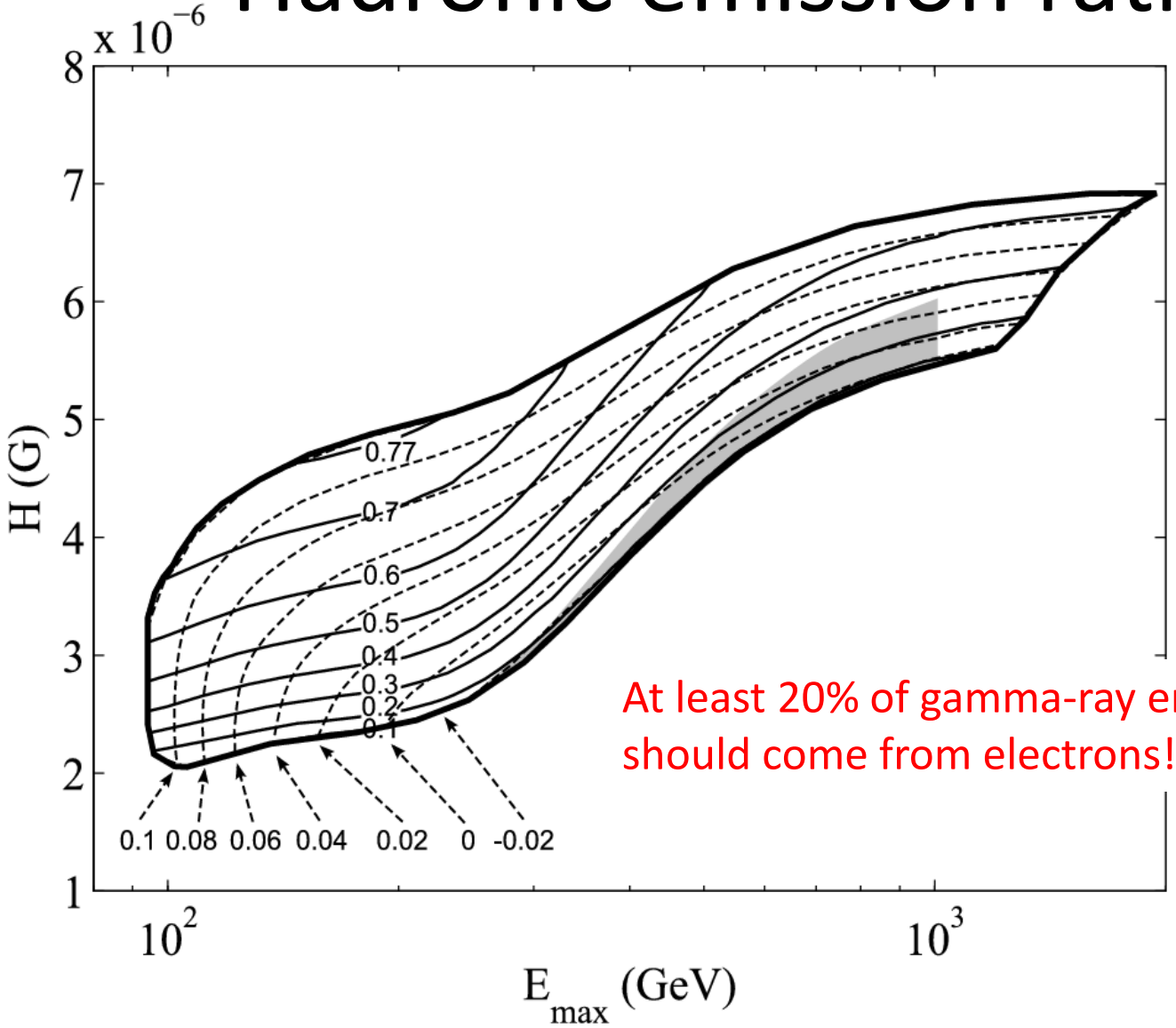


Perfectly fitted by both hadronic and leptonic models!

Hadronic models

- Losses-influenced spectrum of electrons is too steep!
- Adiabatic losses should dominate over synchro-Compton – no way
- Additional primary leptonic component is required (where it comes from? Outflow?)

Hadronic emission ratio

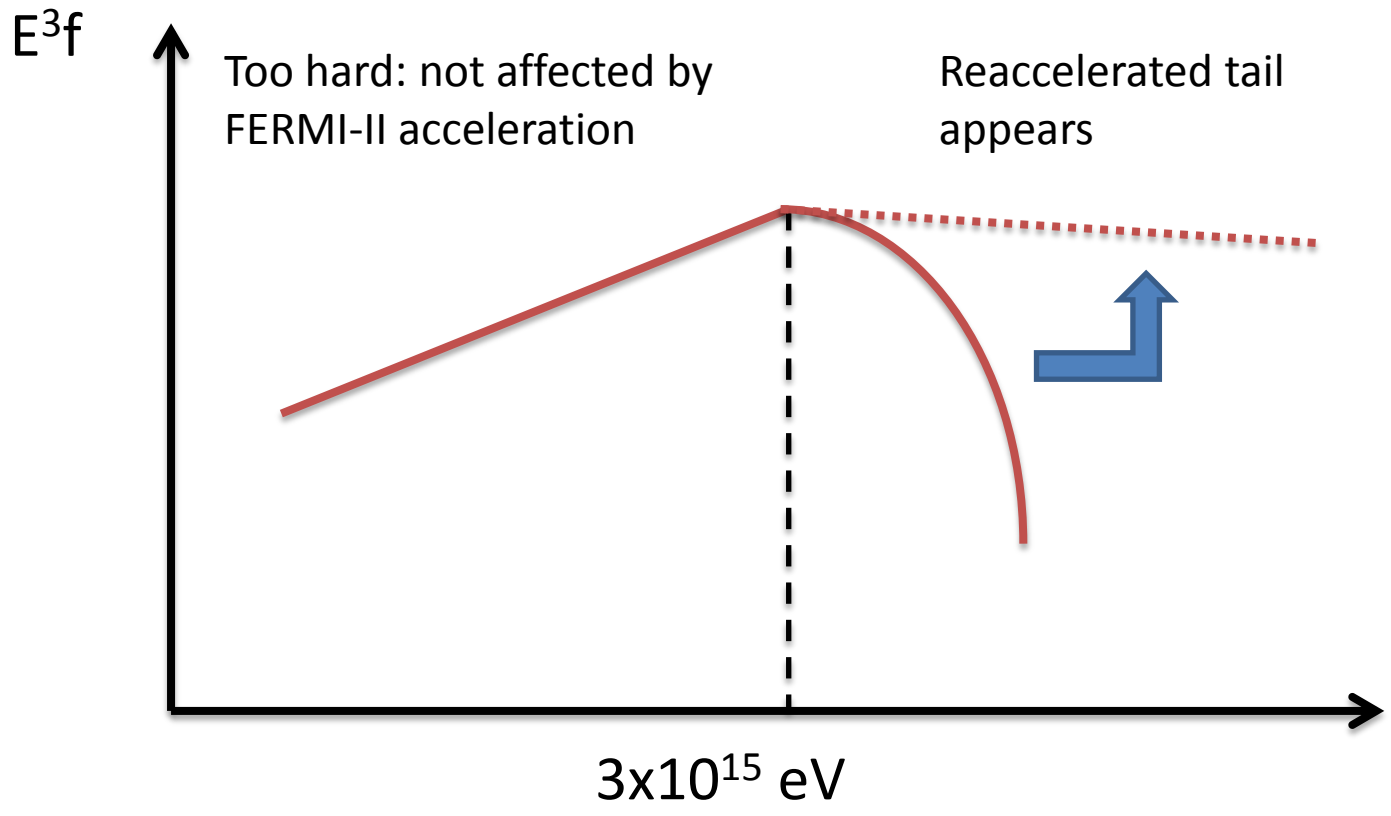


At least 20% of gamma-ray emission should come from electrons!

First part summary

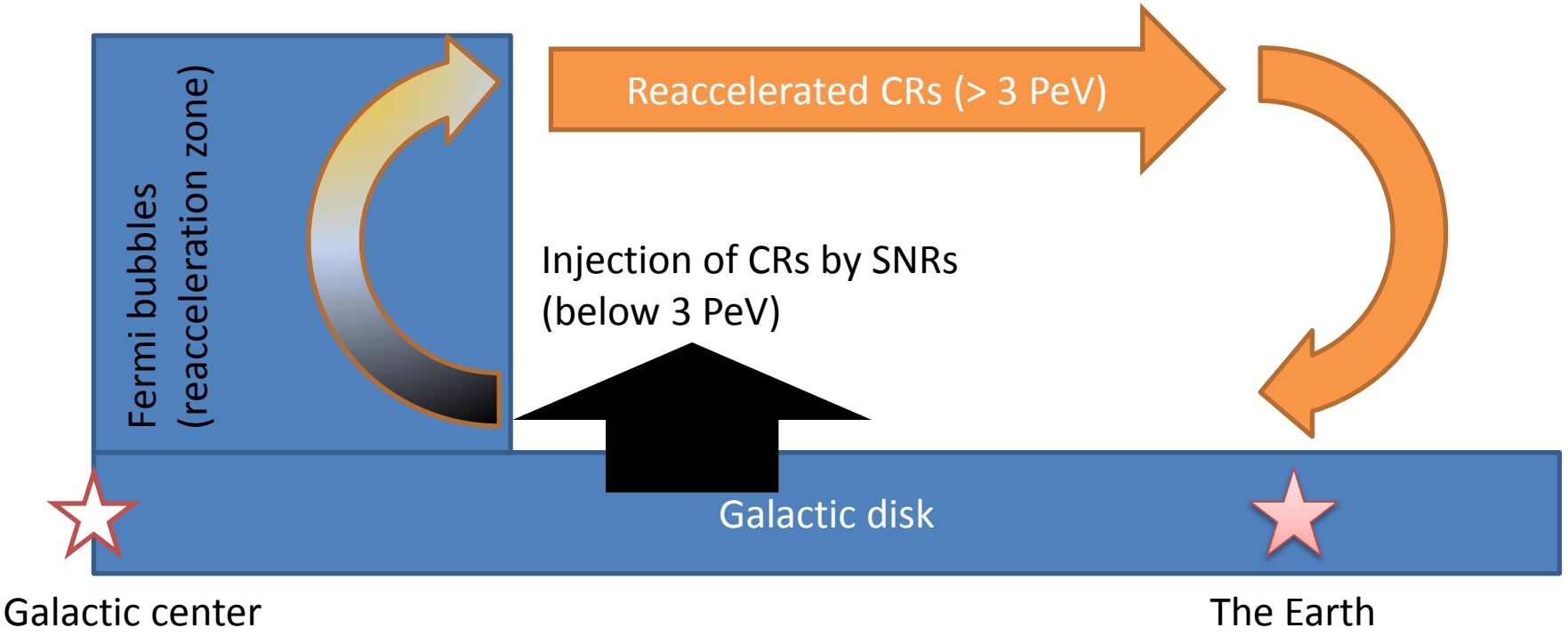
- Gamma-ray and radio emission require leptonic component (in both type of models)
- Life time of electrons is very short – in-situ acceleration is required
- Whole bubble should be a giant acceleration site (no strong shock – Fermi II apparently)
- BUT: it should also affect CR protons!

Effect of acceleration



For simplicity assume that CR are only protons

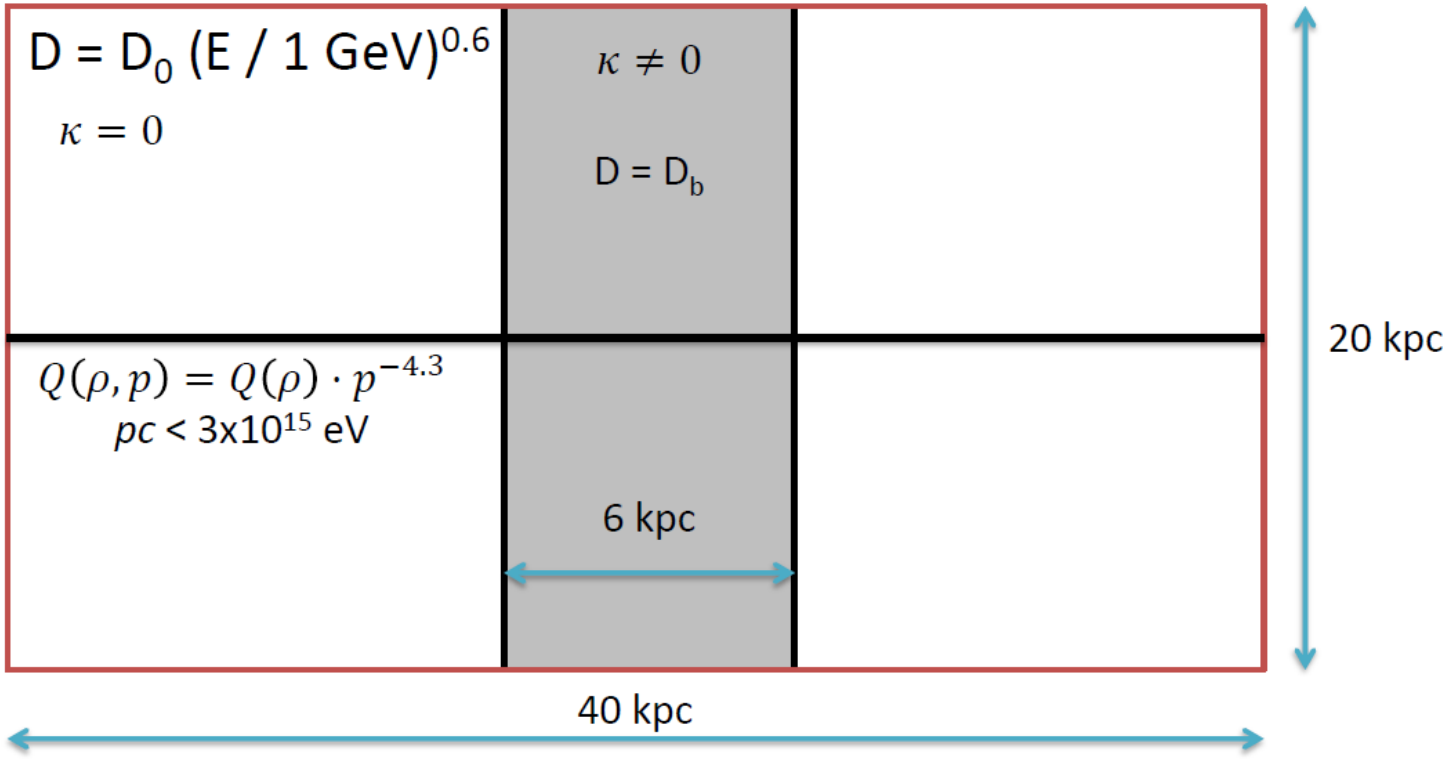
Reacceleration of Galactic CRs



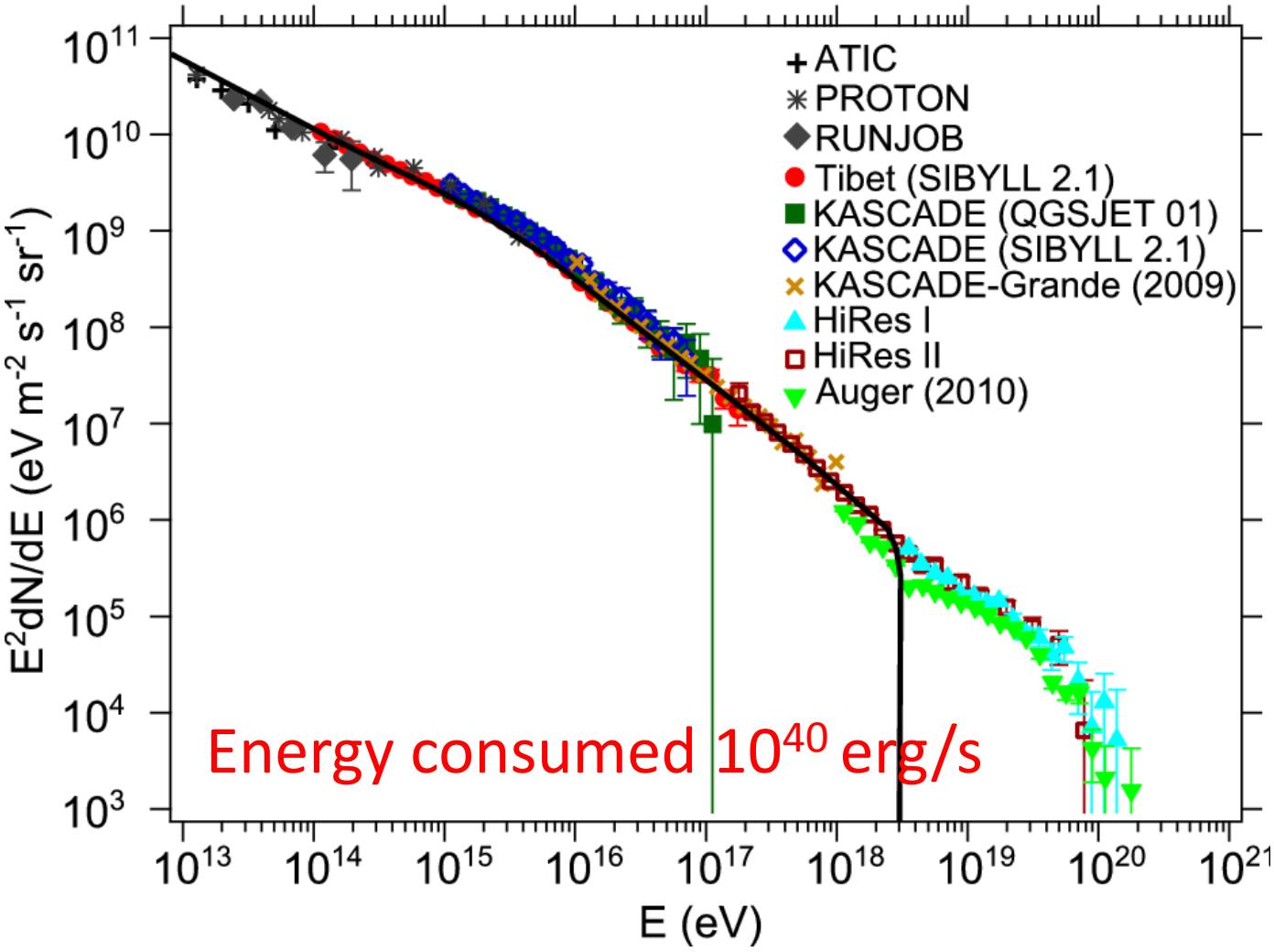
- Will both parts join smoothly at “knee”?

Simulation of the reacceleration

$$D(p)\left(\frac{\partial^2}{\partial z^2}+\frac{1}{\rho}\frac{\partial}{\partial\rho}\rho\frac{\partial}{\partial\rho}\right)f+\frac{1}{p^2}\frac{\partial}{\partial p}\left(\kappa(\rho,p)p^2\frac{\partial f}{\partial p}\right)=-Q(\rho,p)$$



Spectrum of CRs near the Earth

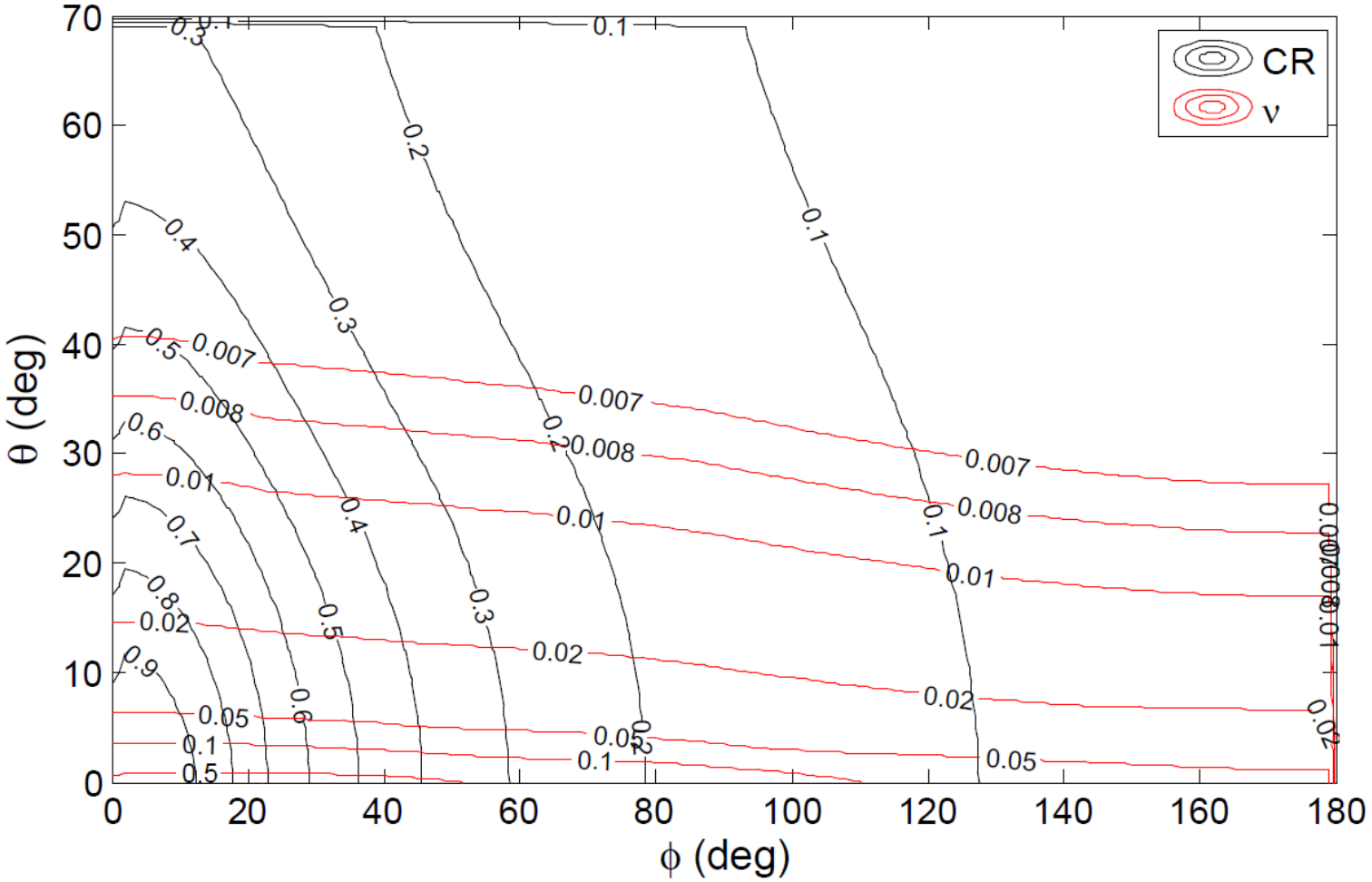


Neutrino emission

- Icecube has detected 4-5 out of 28 events above 30TeV, which may originate from cosmic rays with energies $>10^{15}$eV from FB (Lunardini et al. 2014).
- We expect concentration of CRs towards the Fermi bubbles!

Distribution of neutrinos and CRs

$$n_0 = 10^{-3}\ \mathrm{cm}^{-3}$$



Fluxes from different regions

- We define

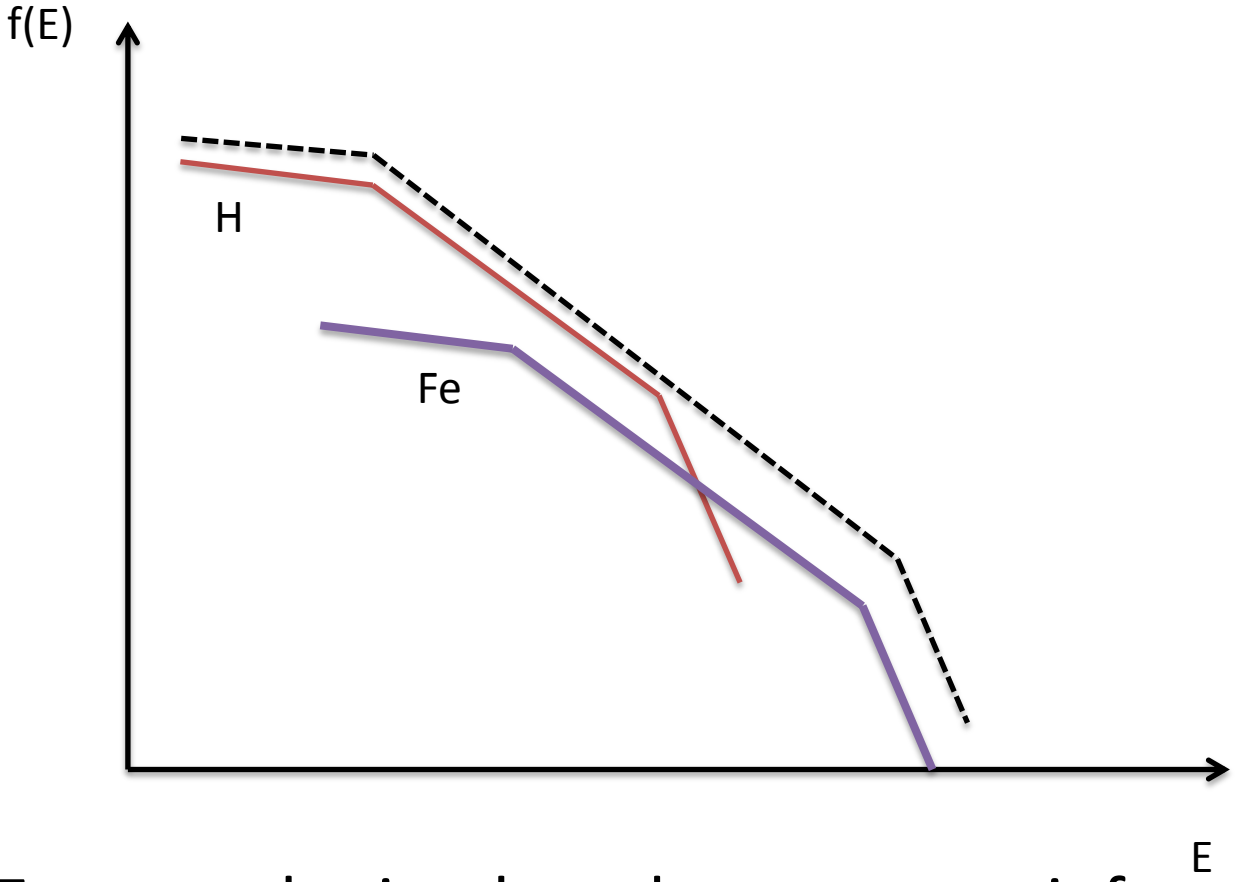
$$I_{GD} = \int_{0^\circ}^{10^\circ} \cos\theta \, d\theta \int_{0^\circ}^{180^\circ} d\phi \; \mathrm{d}I_\nu / d\Omega \, (\phi, \theta)$$

$$I_{FB} = \int_{10^\circ}^{90^\circ} \cos\theta \, d\theta \int_{0^\circ}^{30^\circ} d\phi \; \mathrm{d}I_\nu / d\Omega \, (\phi, \theta)$$

- Then

$$I_{FB}/I_{GD} = \begin{cases} 0.05, & \text{for } n_0 = 10^{-3}\ \mathrm{cm}^{-3} \\ 0.07, & \text{for } n_0 = 10^{-2}\ \mathrm{cm}^{-3} \end{cases}$$

Chemical abundance



To properly simulate the spectrum information about cut-off is required.

In simple model cut-off is badly defined

Conclusion

- Fermi bubbles are large acceleration sites that may accelerate particles
- Since the size of the bubbles is huge they affect the distribution of cosmic rays in the whole Galaxy
- In particular they may form a spectrum of CR above 10^{15} eV
- Neutrino emission is too low