On the possible connection between Fermi bubbles and cosmic rays above 1 PeV

K.S. Cheng, D.Chernyshov, V.Dogiel, C.M.Ko

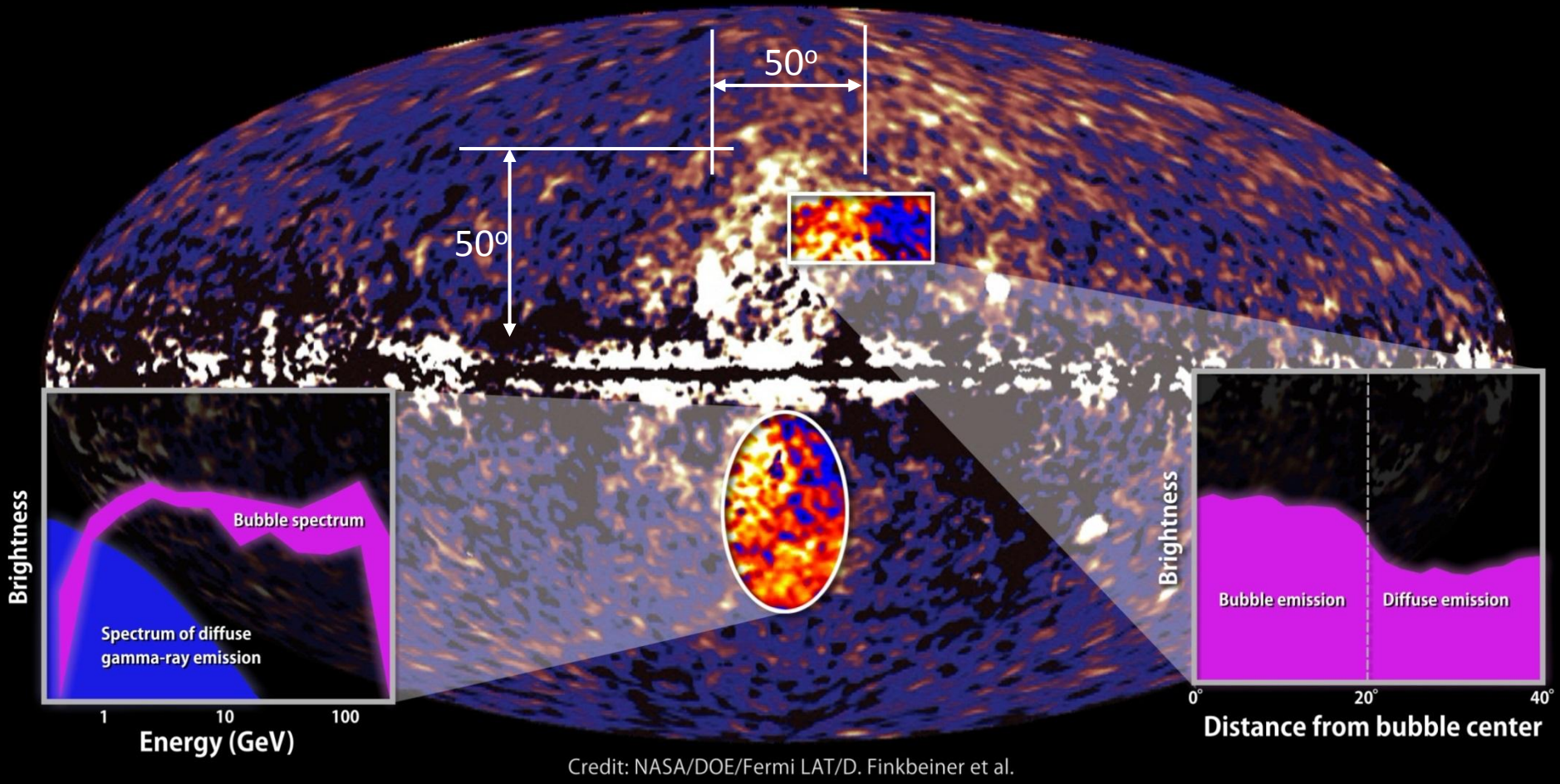
Maximum energy of particles

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

- 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)?

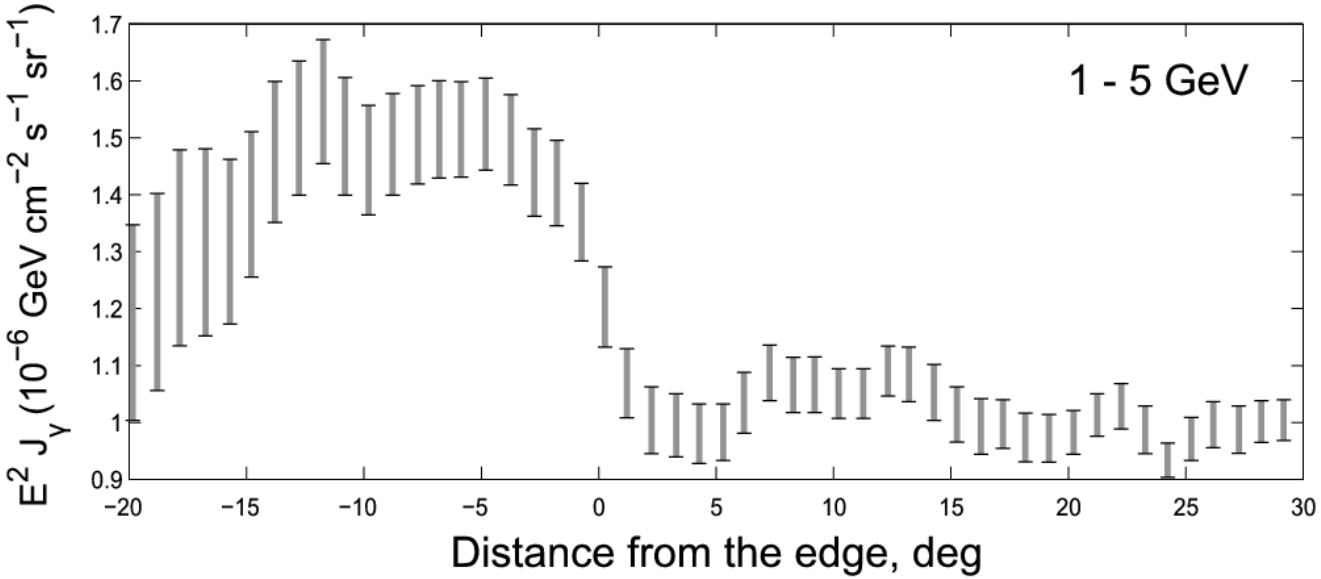
Bubbles show energetic spectrum and sharp edges



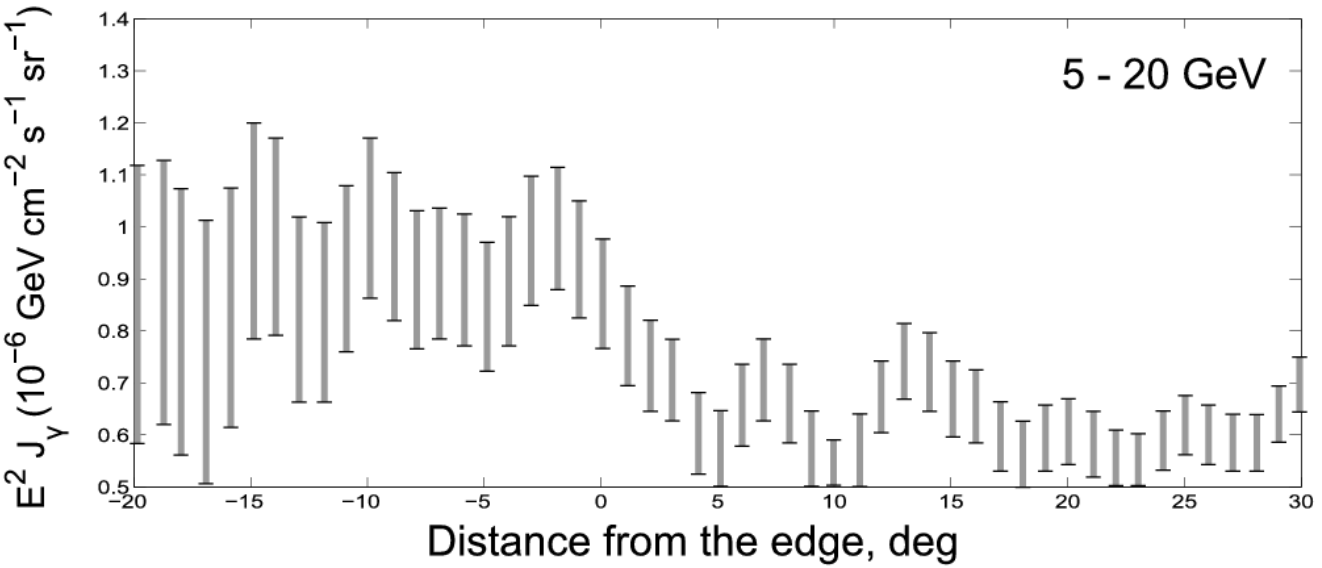
Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

Dobler (2010)
Su+ (2010)

Morphology of Fermi bubbles

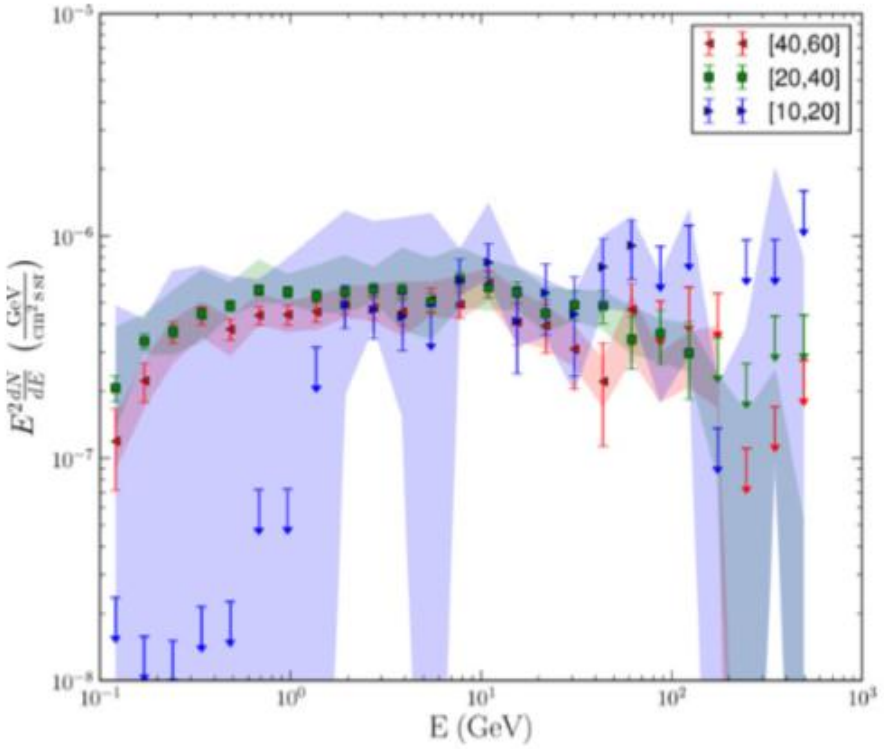


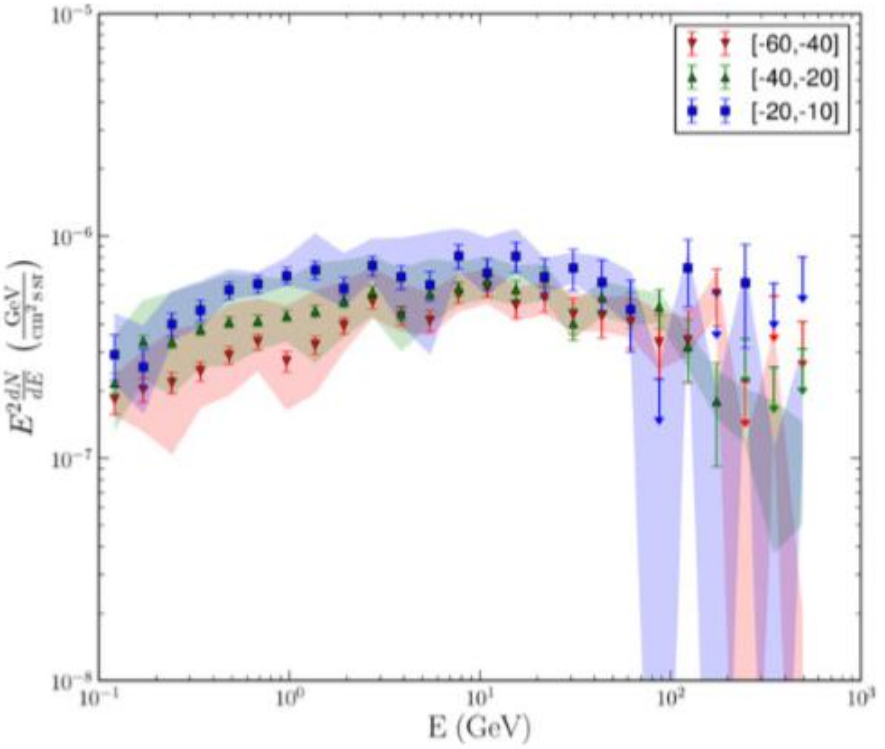
Sharp edges!
< 5°



Su+ (2010)

Morphology of Fermi bubbles

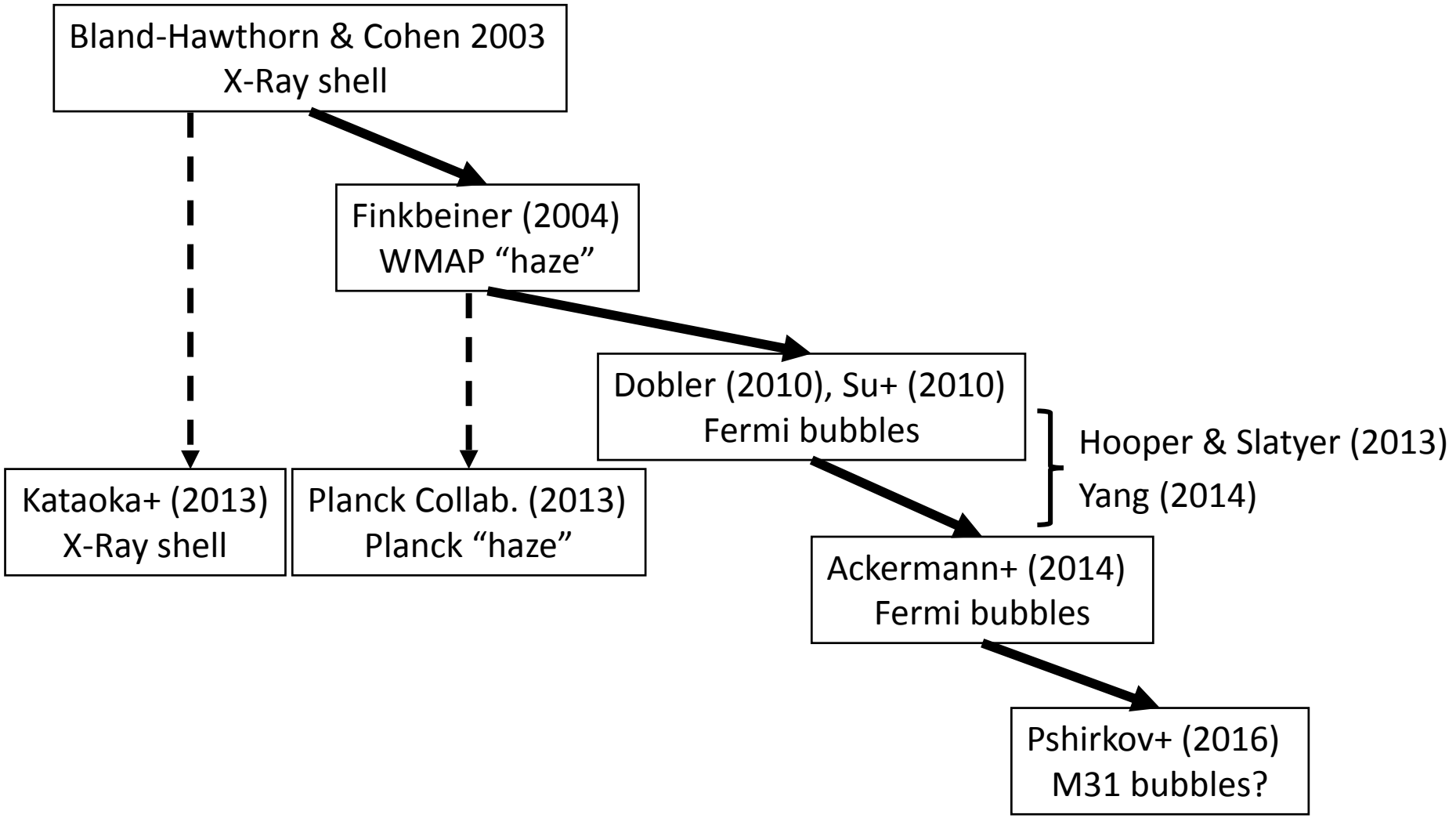




- Uniform brightness => edge-brightened emissivity
- Almost uniform spectrum
- 4×10^{37} erg/s

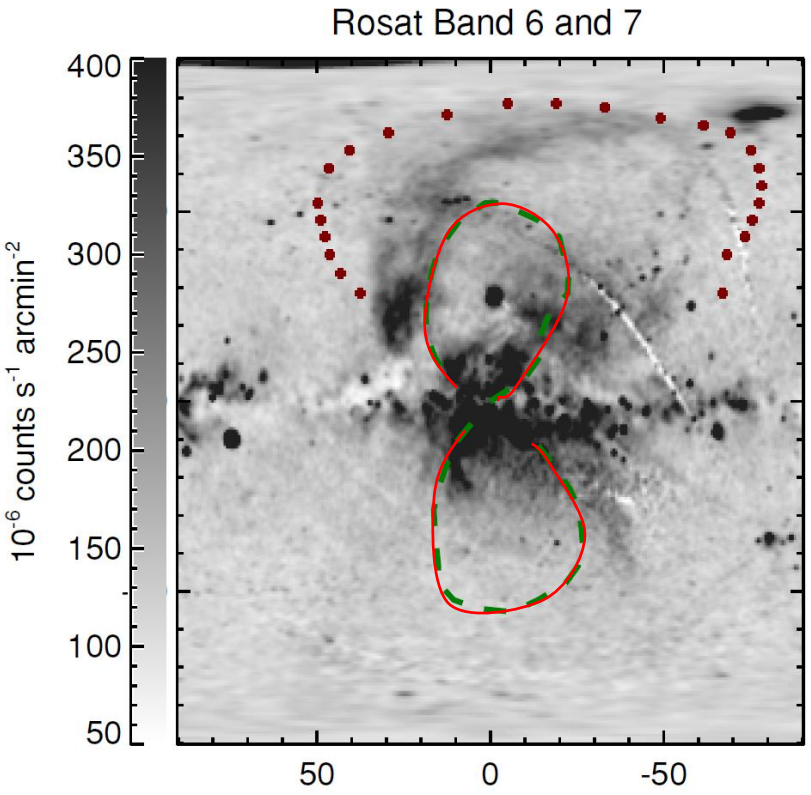
Ackermann+ (2014)

Important observational timestamps



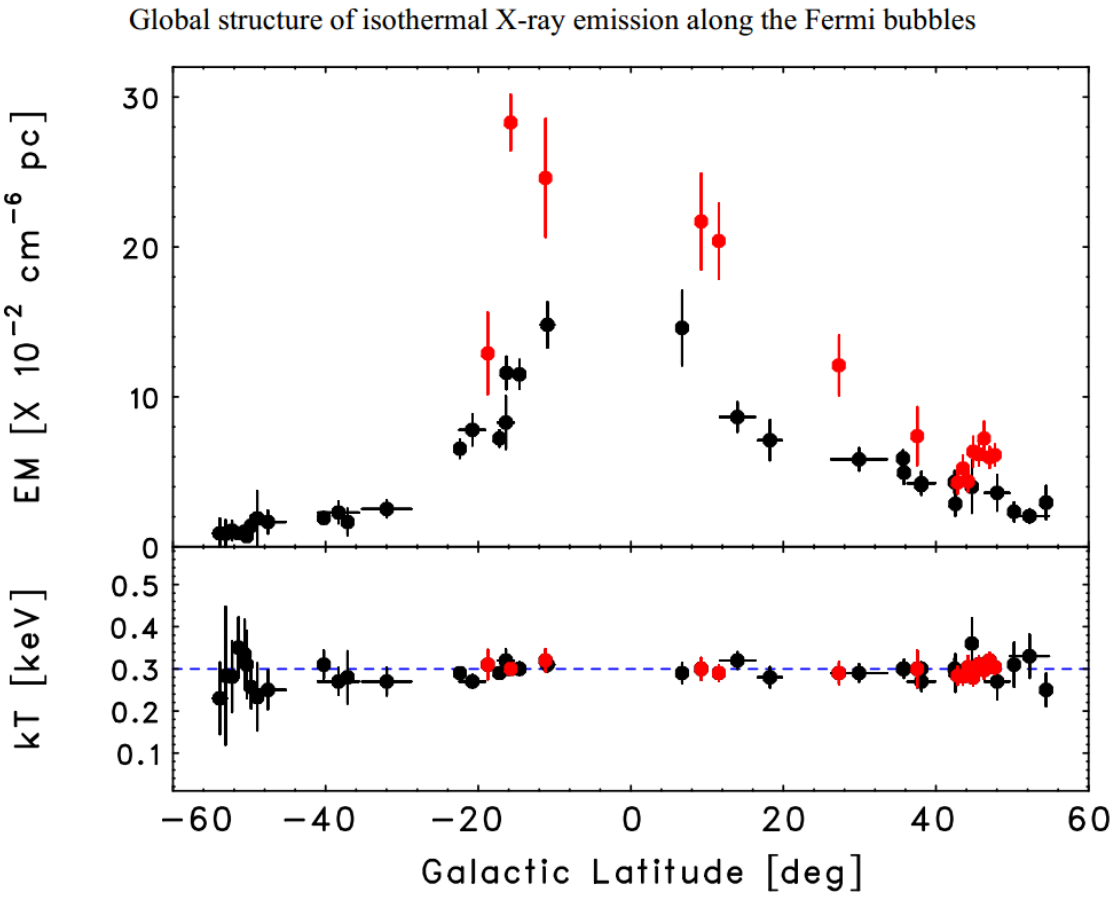
Discovery and counterparts

Bland-Hawthorn & Cohen 2003, ROSAT – X-Rays 1.5 keV.



- X-ray shell near the position of FB
- Limb brightening: no emission from the center
- $n=10^{-2}$ cm^{-3}, T = 2 keV

Discovery and counterparts



Suzaku observation:

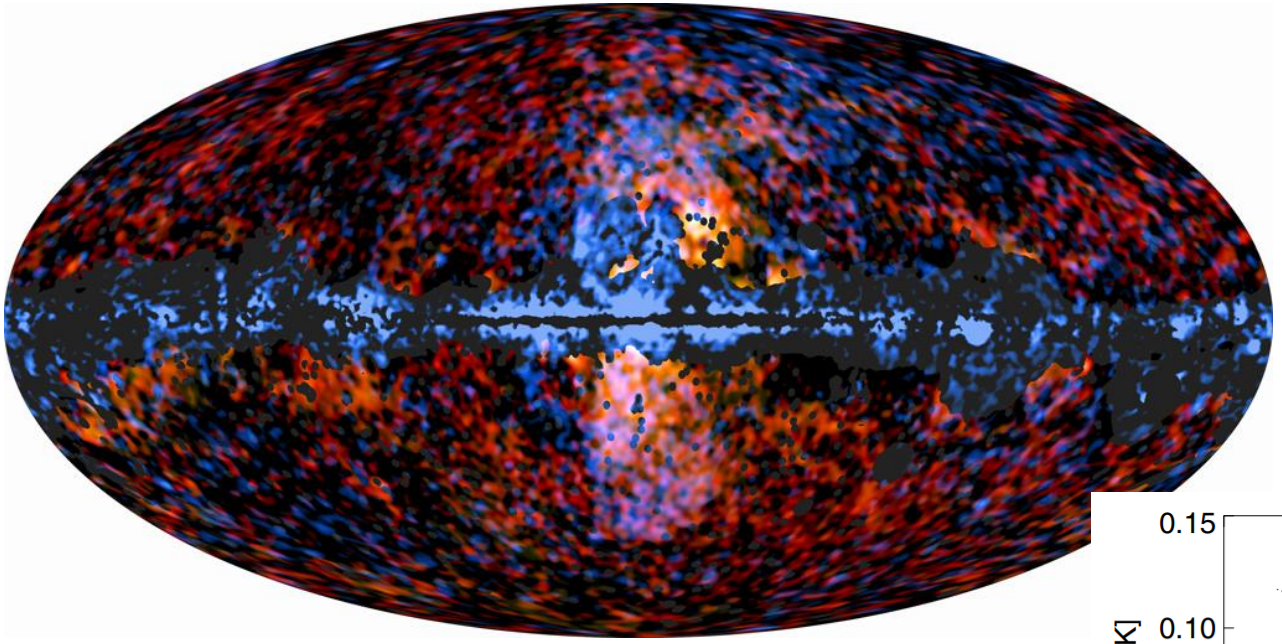
Density gradient
No T gradient

Weak shock?

Kataoka+ (2013, 2015)

Yet >1000 km/s outflows: Bland-Hawthorn+ (2003), Miller+ (2013, 16), Fang+ (2014), Fox+ (2015), Bordoloi+ (2017), Sarkar+ (2017)

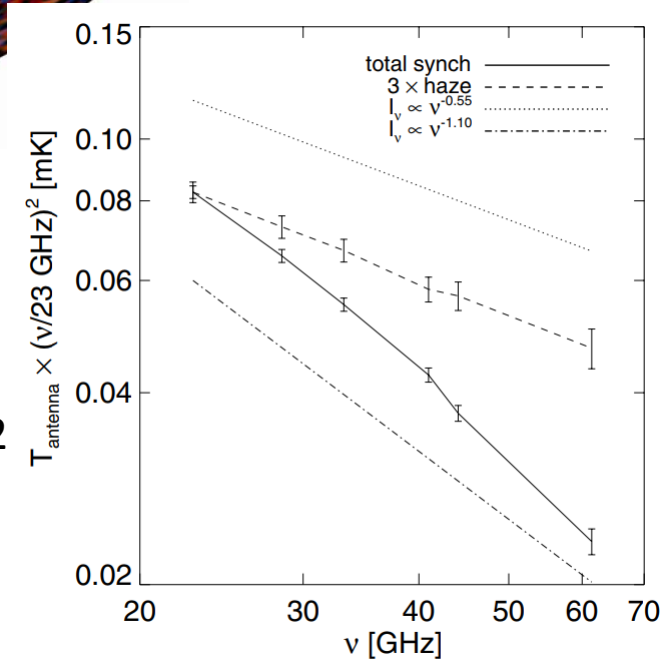
Discovery and counterparts



Blue: gamma-rays
Red and yellow: microwaves

Hard spectrum:
If synch, electrons ~ -2

Planck Collab. (2013)



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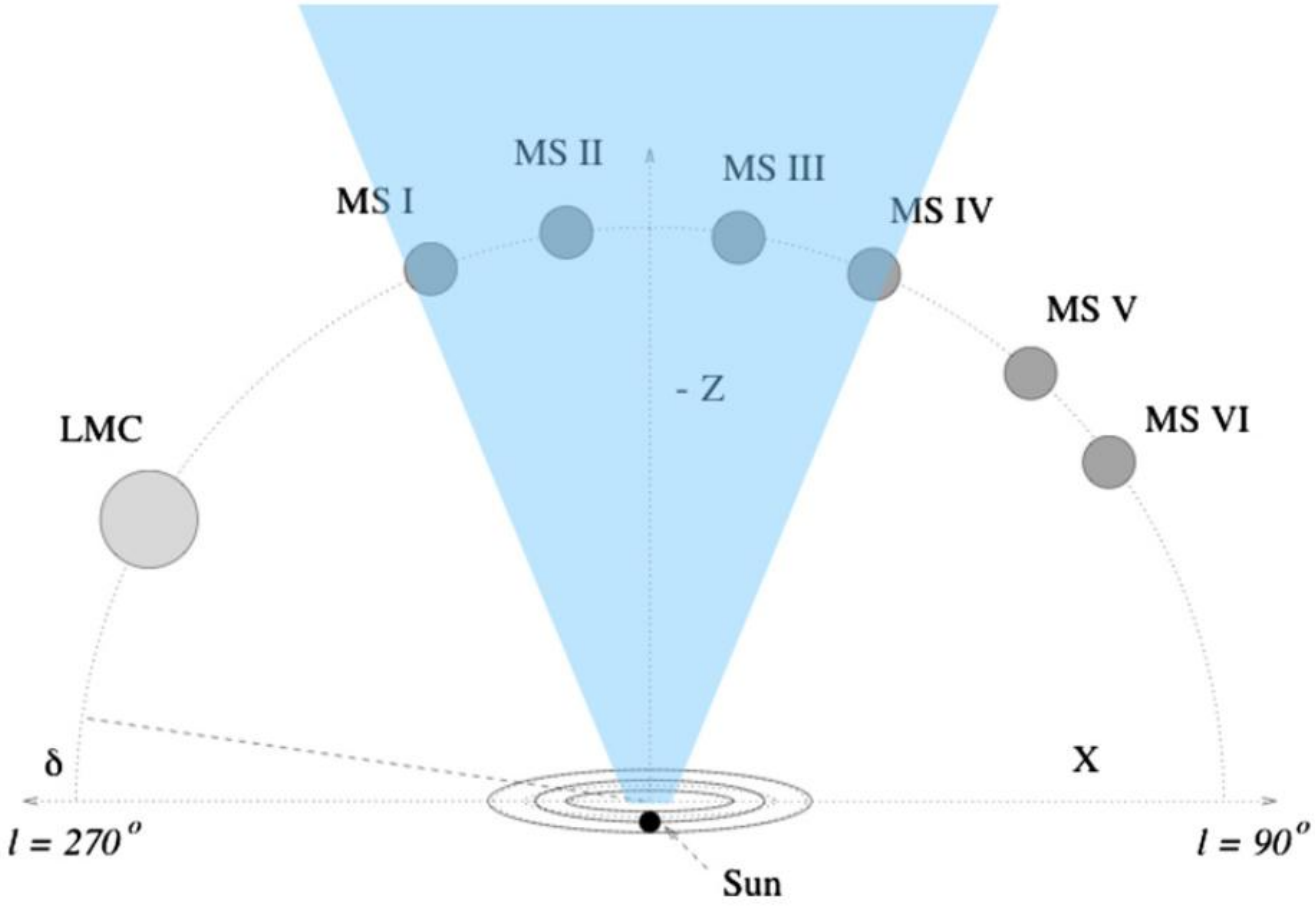
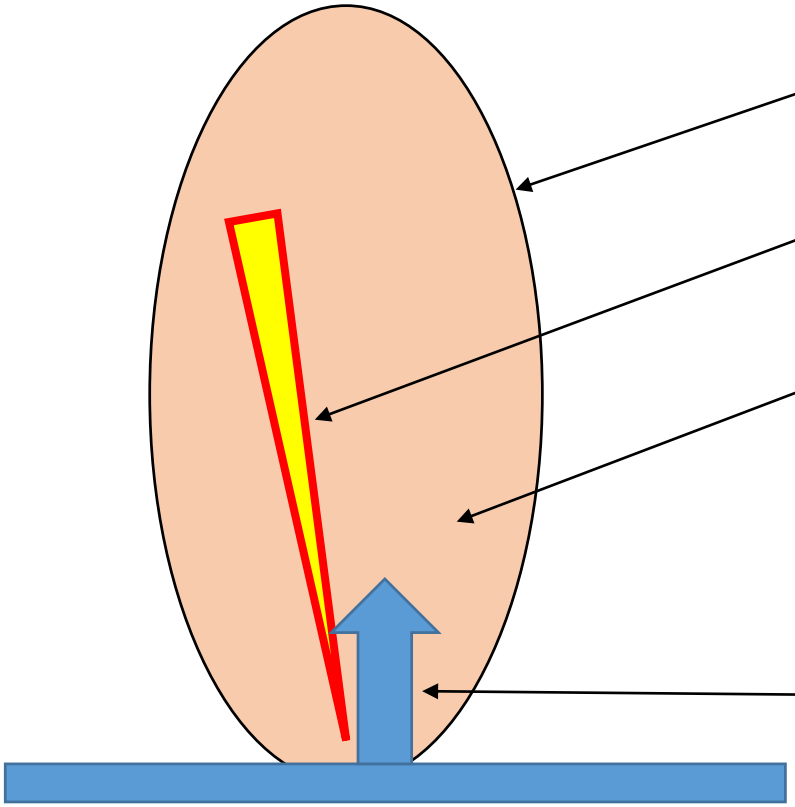


Powerfull activity 1 Myr ago?

Bland-Hawthorn+ (2013)

Models of Fermi bubbles



Kompaneets (1960)

Leptonic/Hadronic jet

Guo+ (2012)
Yang+ (2012,2013)
Barkov+ (2014)

In-situ acceleration

Cheng+ (2011,14,15)
Fujita+ (2013)
Lacki (2014)
Mersch+ (2011)
Sasaki (2015)
Sarkar+ (2015)

Hadronic wind

Crocker+ (2011,2015)
Mou+ (2014,2015)
Zubovas+ (2012)

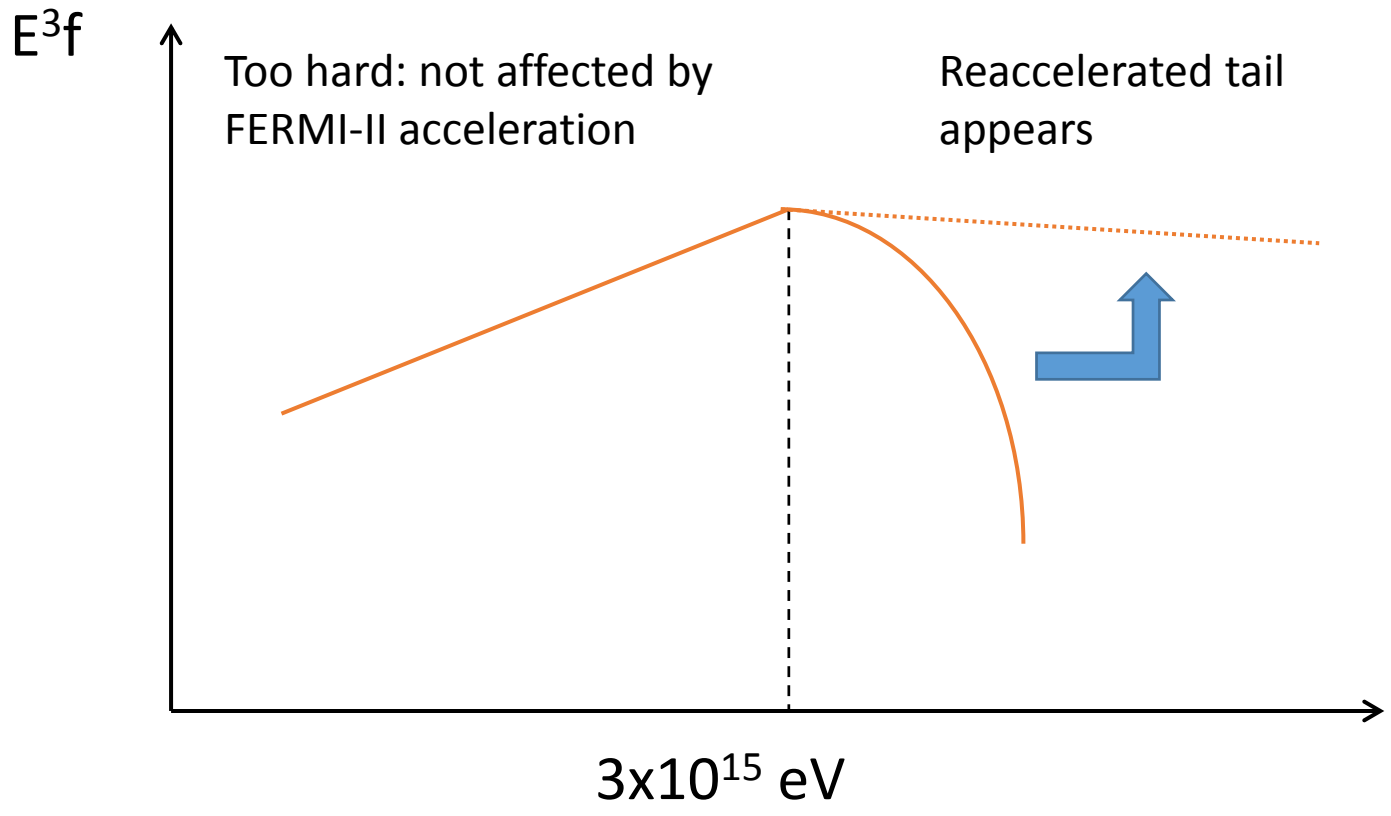
Lifetime of electrons is short < 1 Myr => no “electron wind model”

Yang+ (2018)

Fermi bubbles as giant accelerator

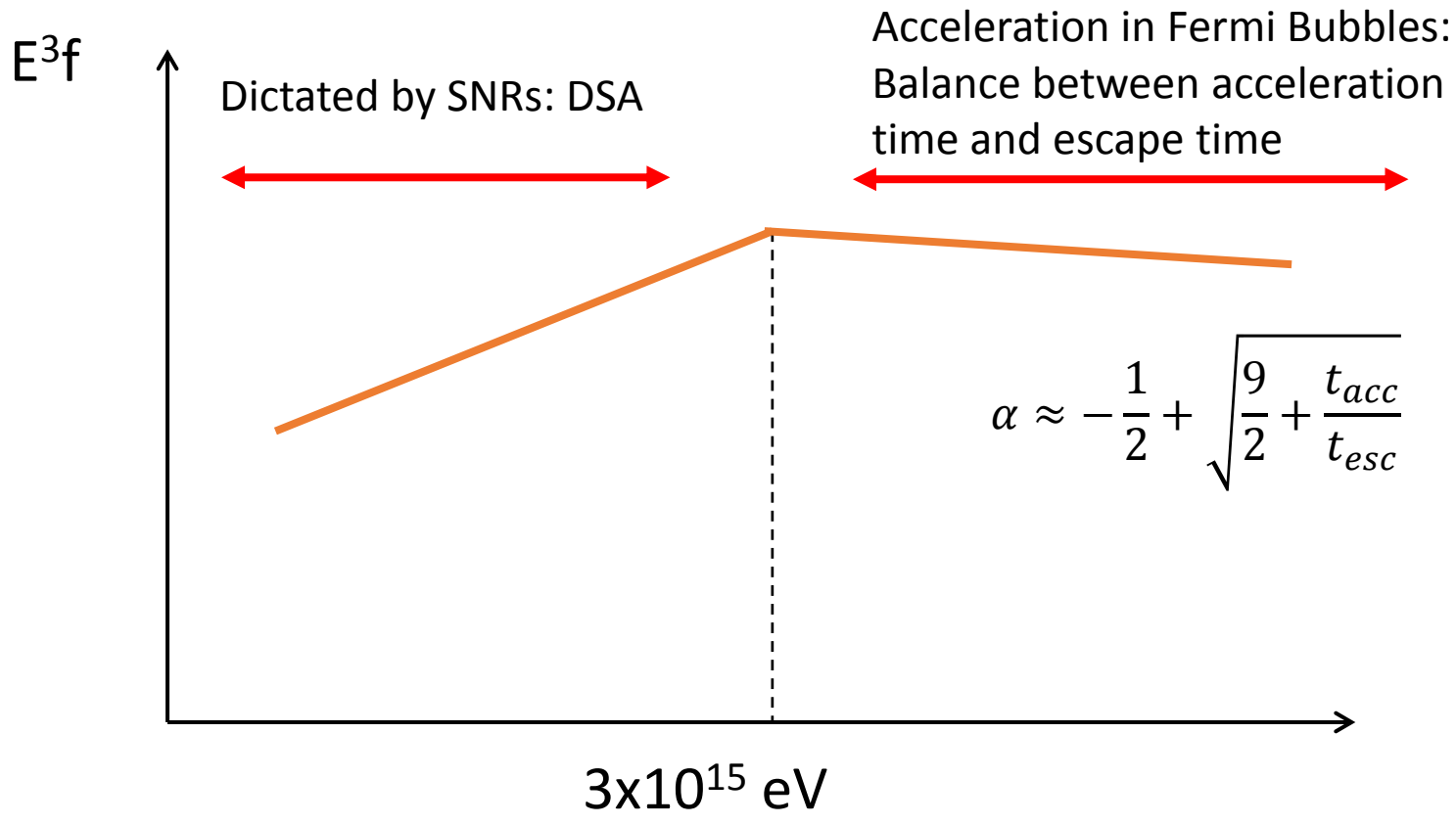
- Hard radio emission require presence of primary electrons
- Too difficult to transfer them from the Galactic sources – they are freshly accelerated
- Weak or non-existent shock (or series of weak shocks) – stochastic acceleration (Bykov & Fleishman 1992, Bykov & Toptygin 1993)
- Acceleration should affect protons! And they live much longer – can even reach the Earth!

Re-acceleration of Galactic CRs



For simplicity assume that all CRs are protons

“Knee” in the spectrum of CRs



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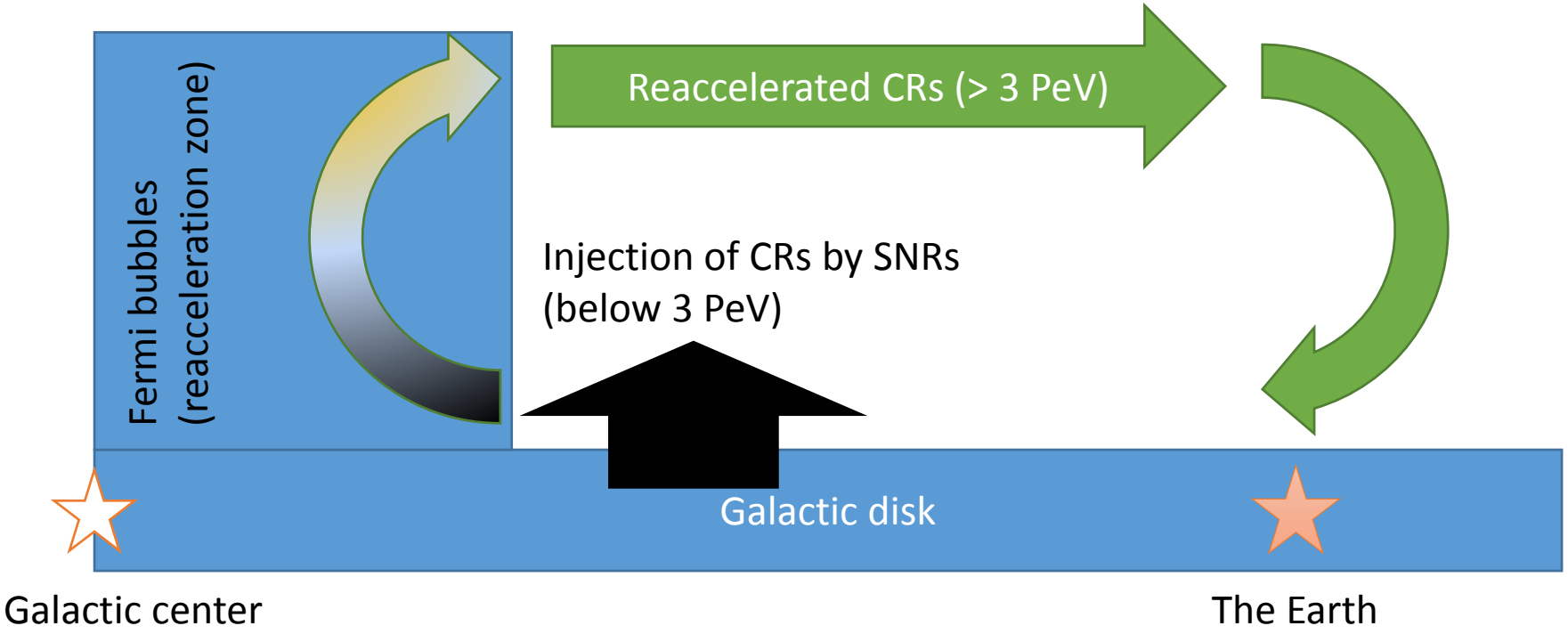
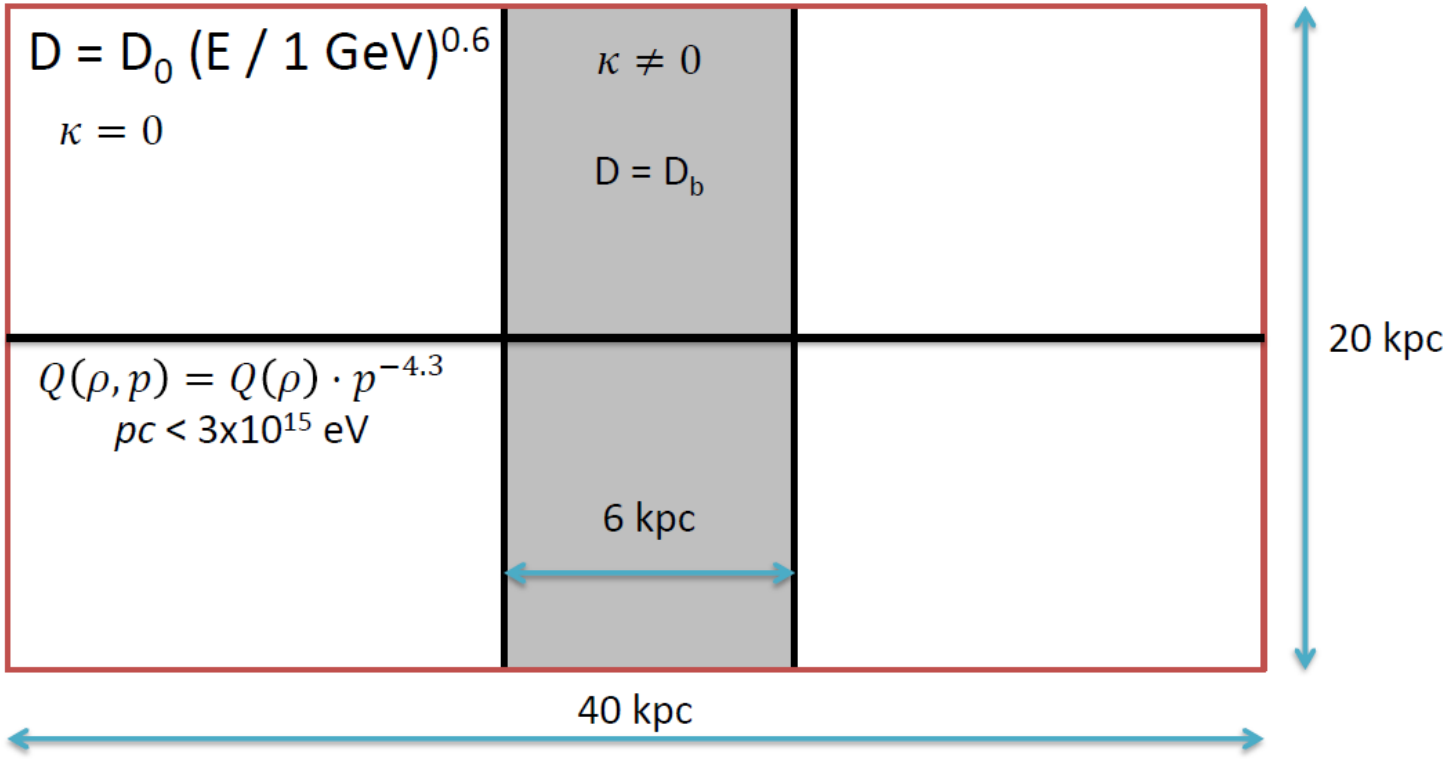


Smooth connection at 3 PeV?

Simulation of the reacceleration

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



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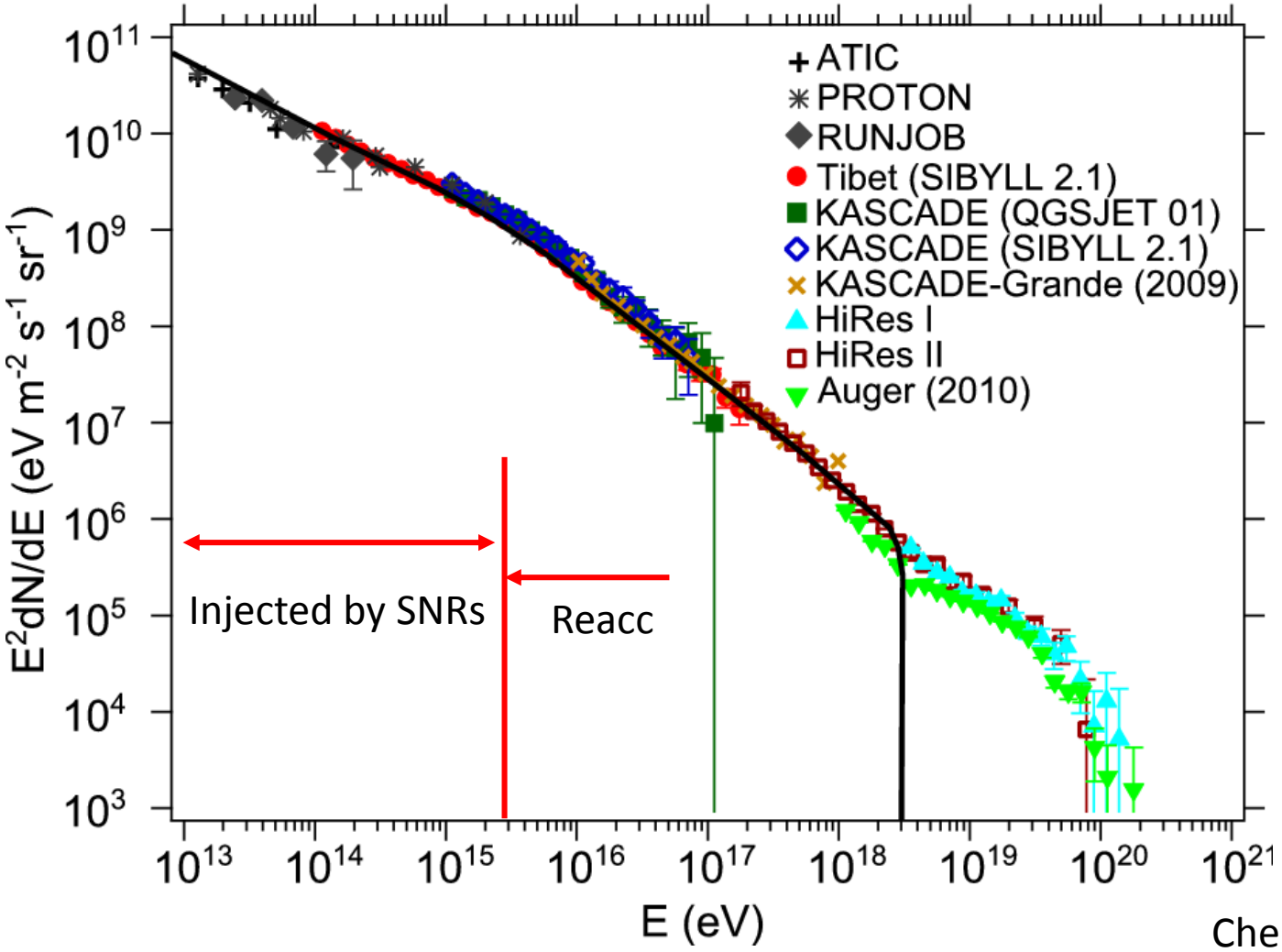
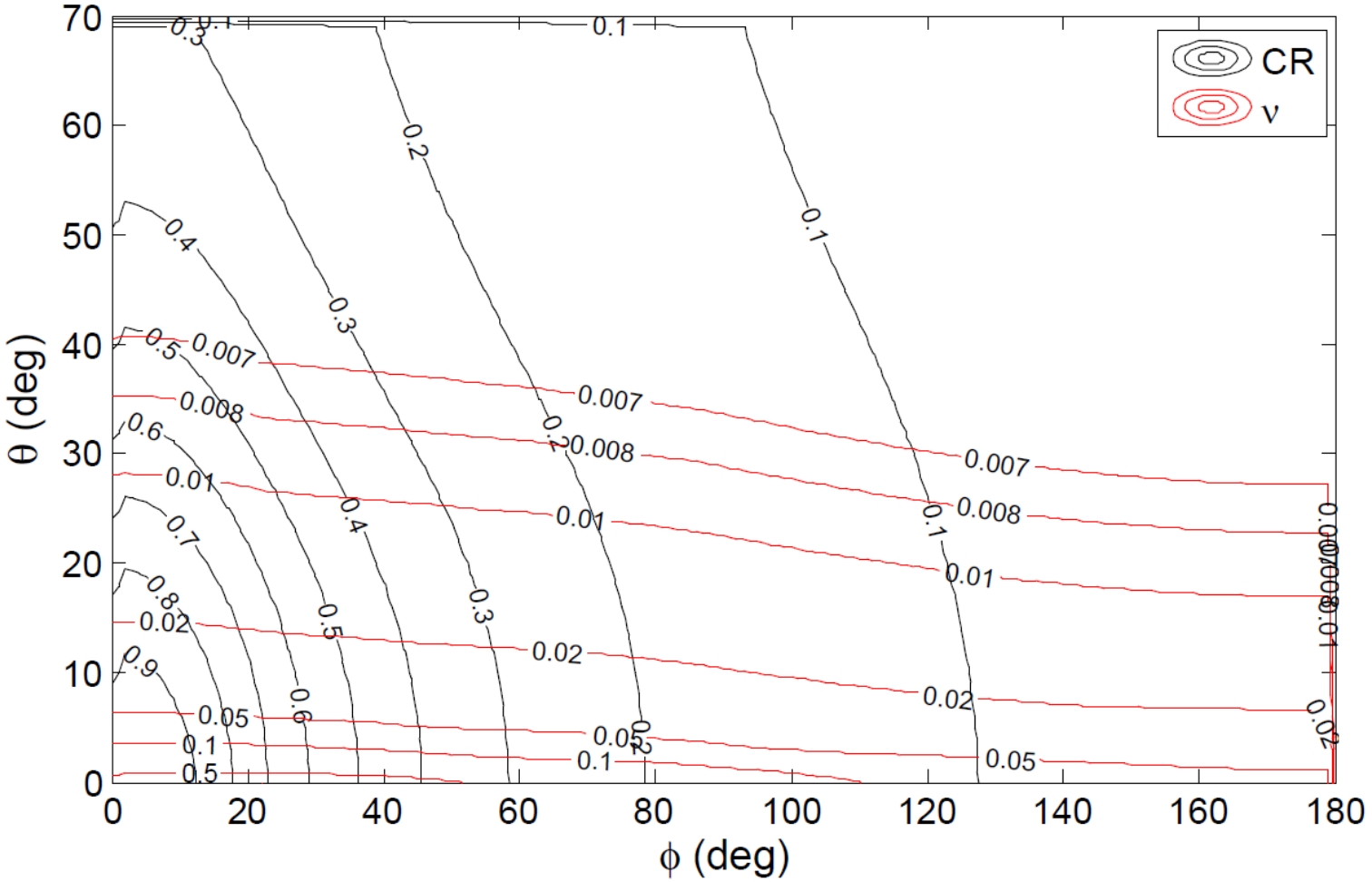


Cheng+ 2012

Distribution of neutrinos and CRs

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



Conclusions

- FB are one of the most interesting gamma-ray phenomena – largest gamma-ray object in the Galaxy
- Nature of FB is still unknown
  - Is it related to past or current activity?
  - Is it hardonic or leptonic?
  - Complex 3D models are required
  - Future observations are required
- 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