Fermi gamma-ray `bubbles' from stochastic acceleration of electrons

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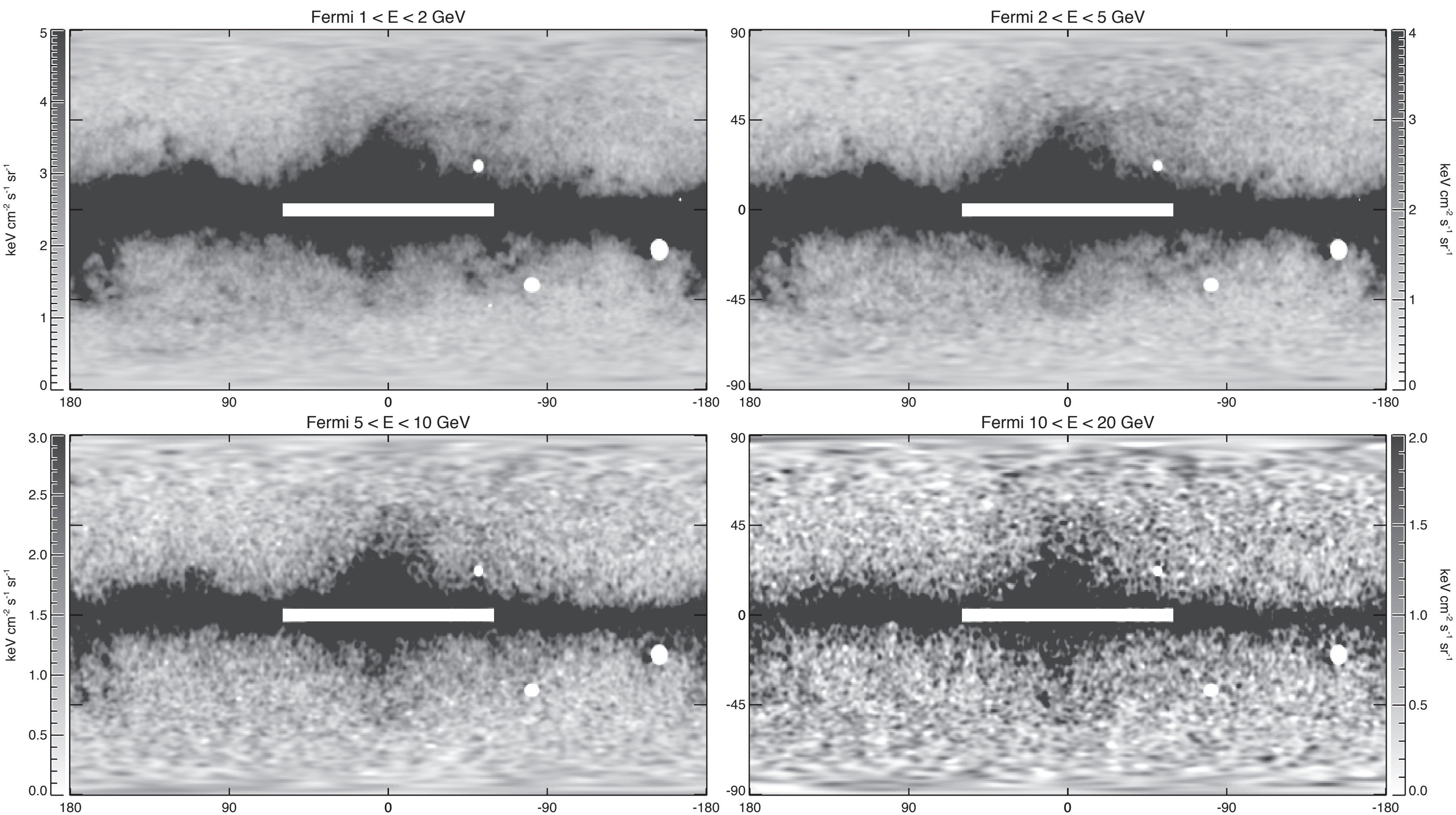
Bubble feature robust

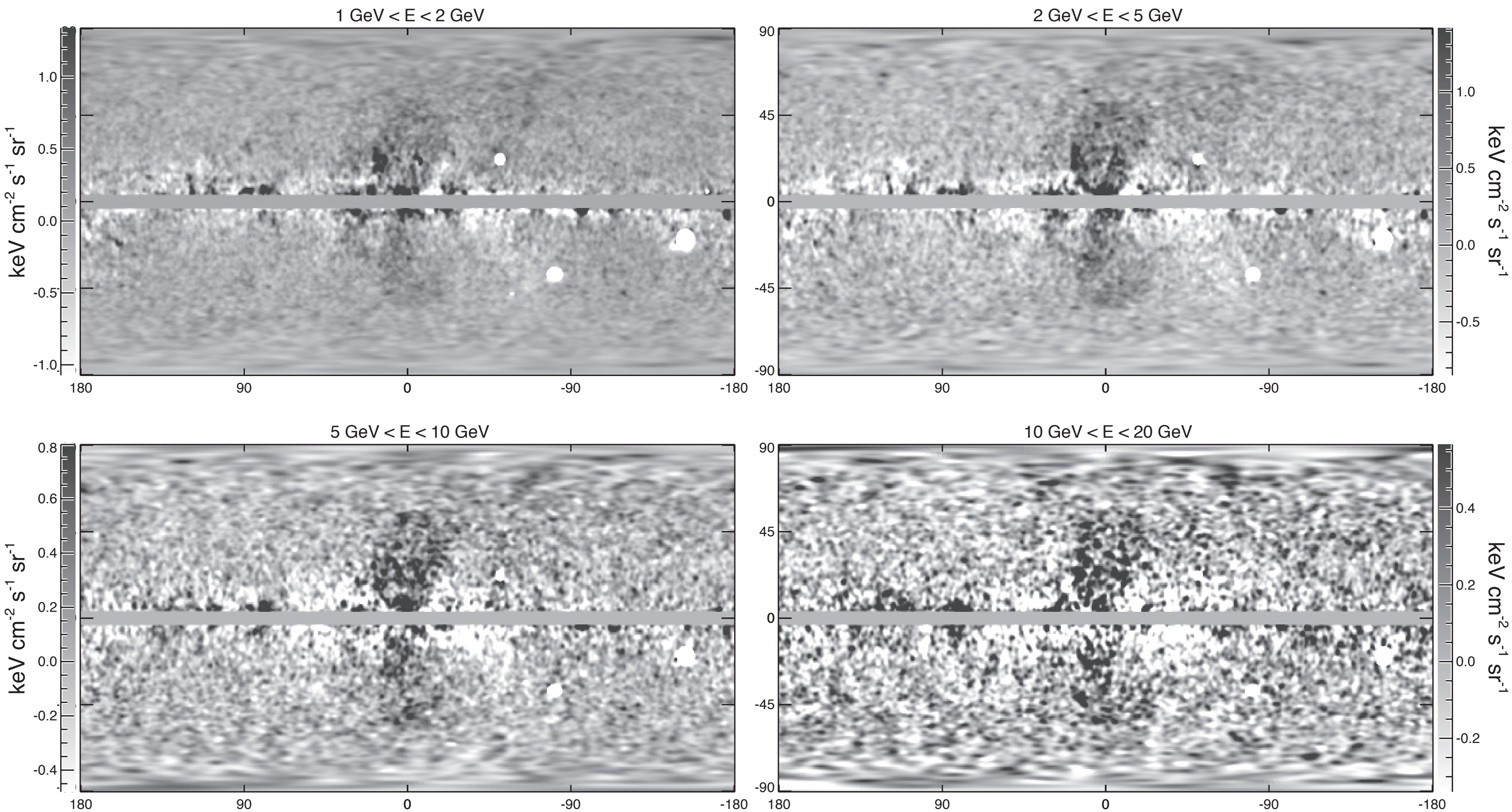
Fermi-LAT skymaps



Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

Bubble feature robust

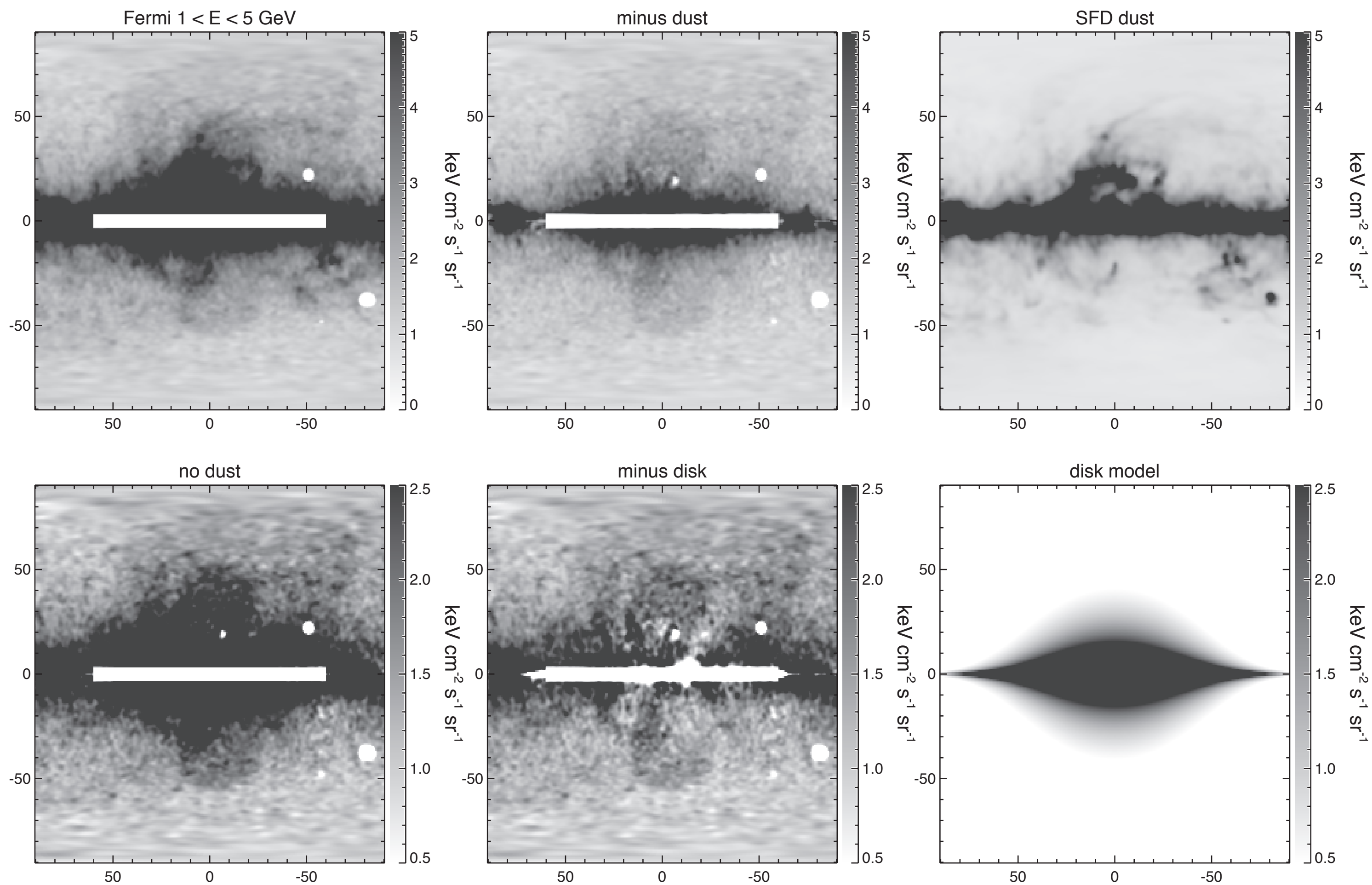
Subtraction of Fermi-LAT model



Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

Bubble feature robust

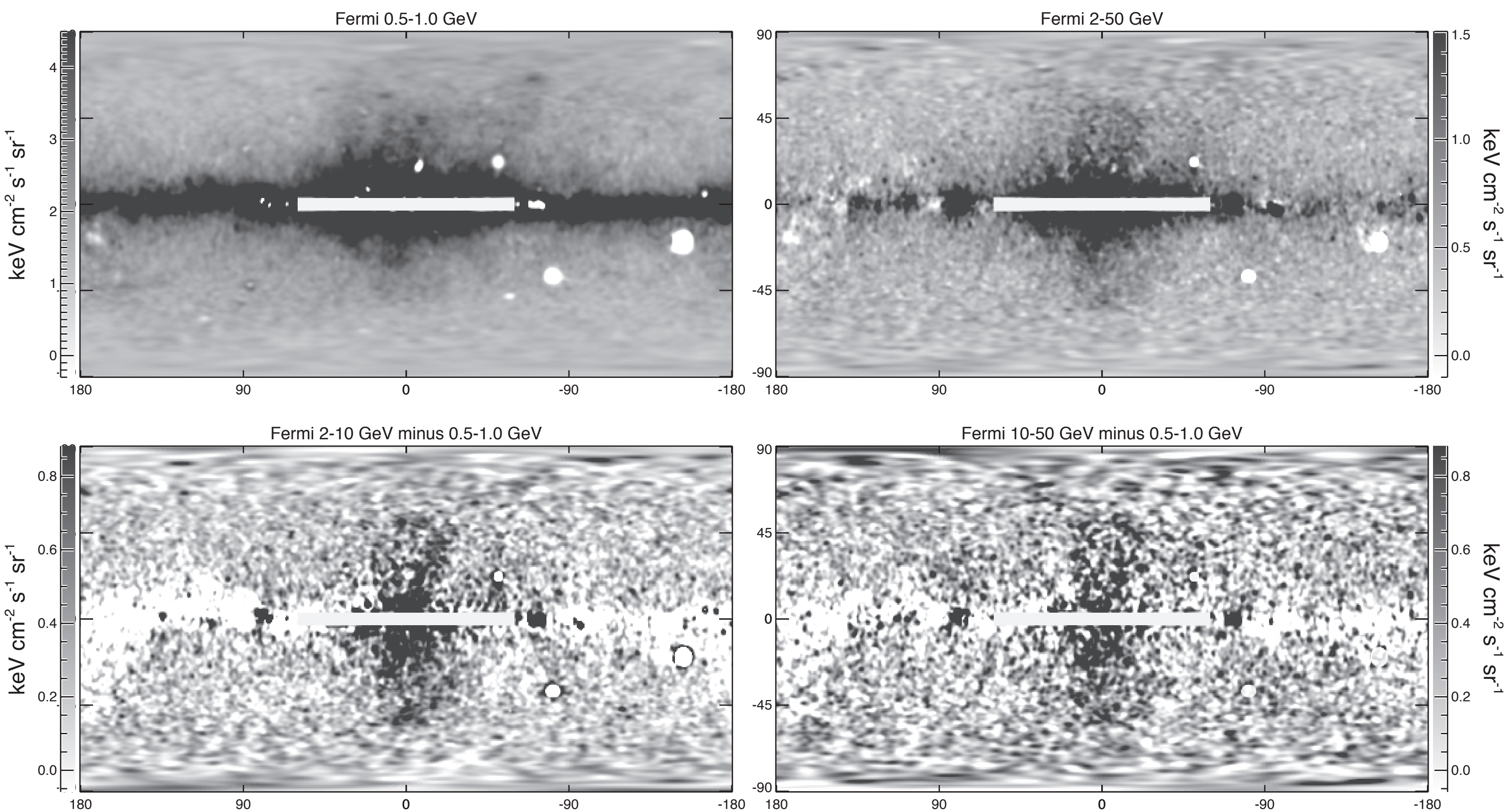
Subtraction of simple π^0 model (dust map) and IC model



Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

Subtraction of low-energy maps

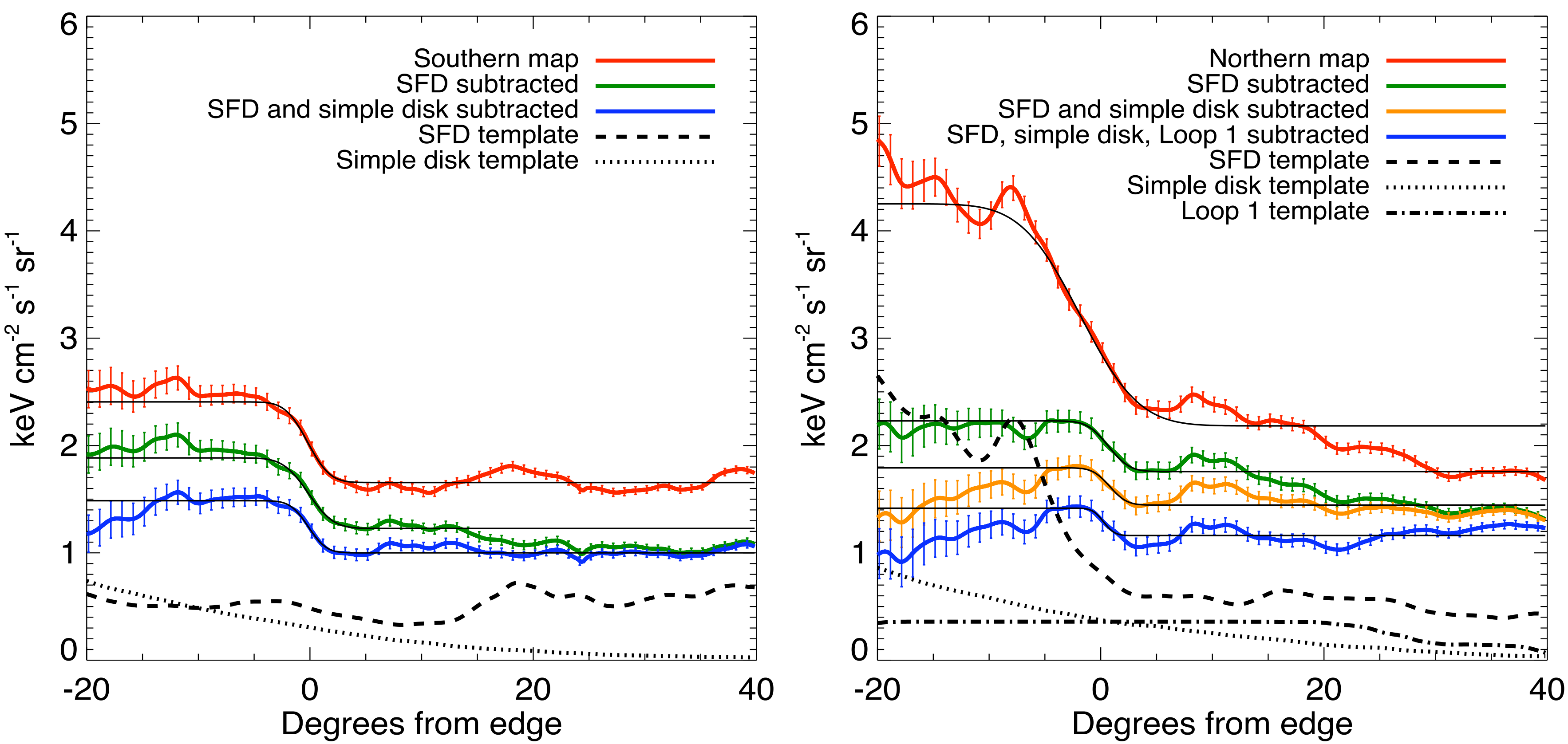
Subtraction of low-energy γ –ray maps maps



Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

Bubbles have sharp edges

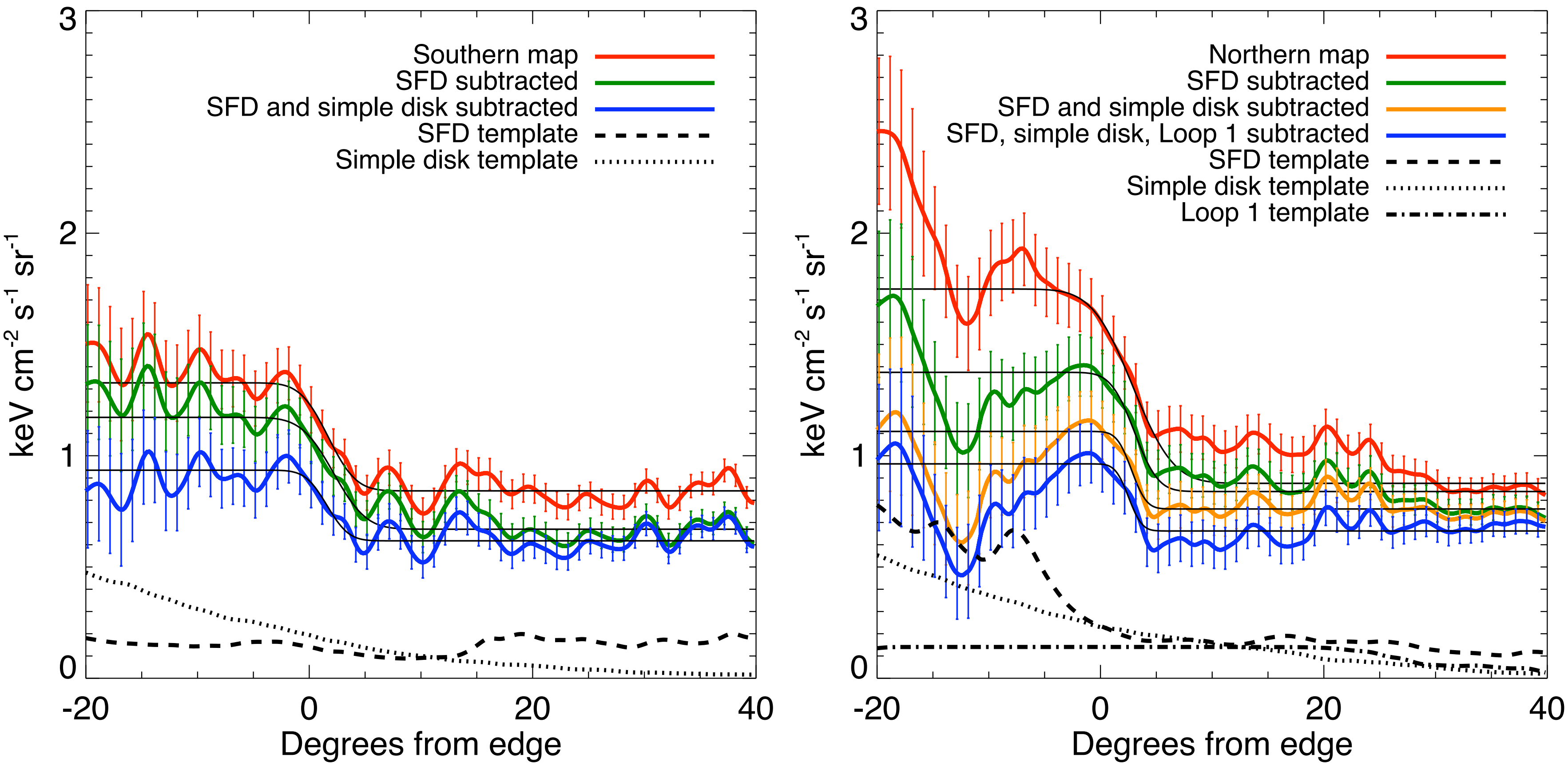
averaged 1-2 and 2-5 GeV maps



Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

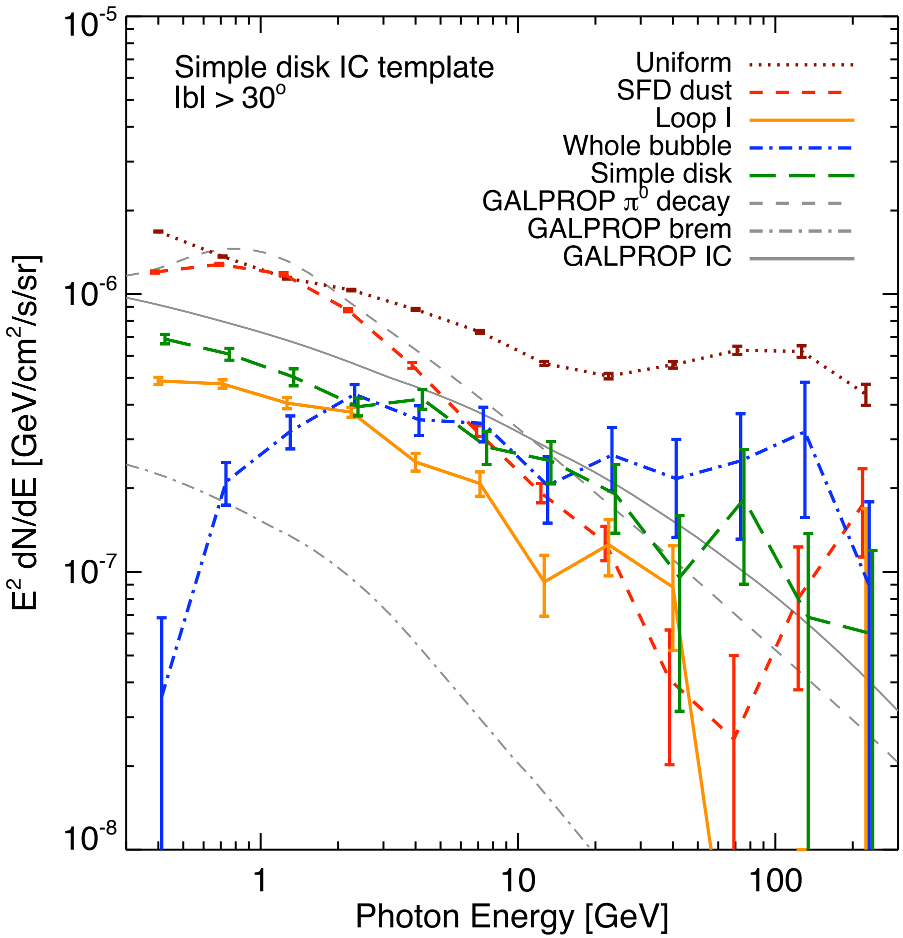
Bubbles have sharp edges

averaged 5-10 and 10-20 GeV maps



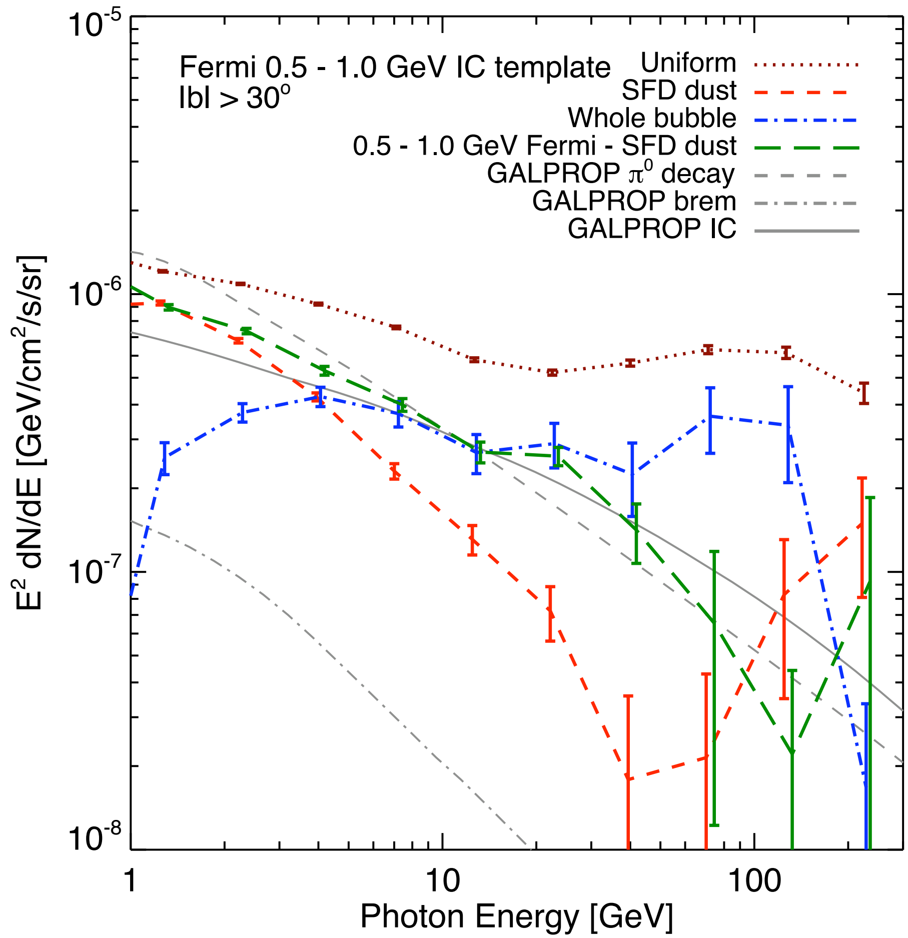
Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

Bubbles have hard spectrum



Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

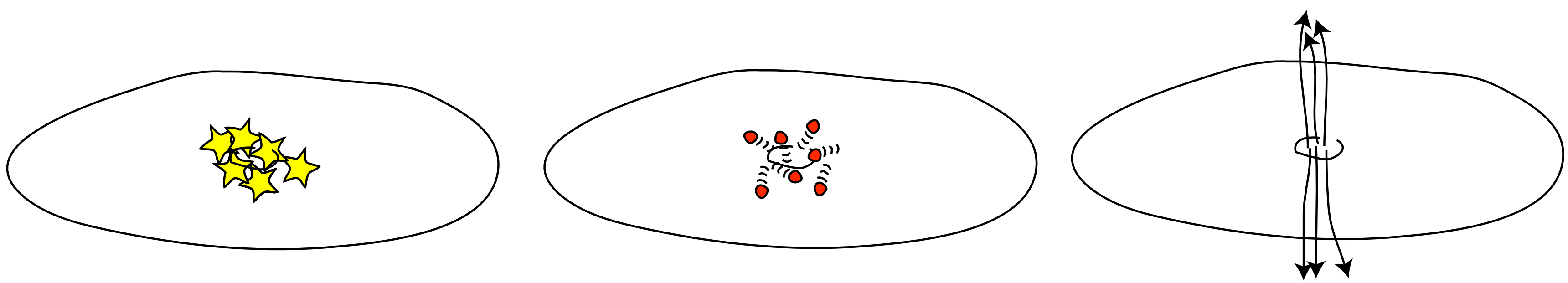
Bubbles have hard spectrum



Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

Hadronic model

Aharonian & Crocker, PRL, **106** (2011) 101102



increased star formation rate close to GC

acceleration of CR protons and nuclei in SNRs

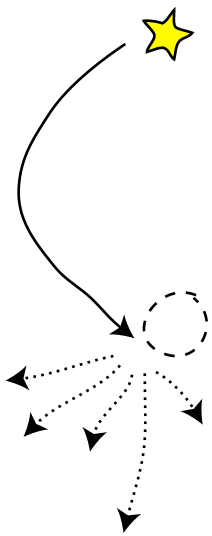
wind convects CRs away from disk

gamma-rays by π^0 on thermal gas

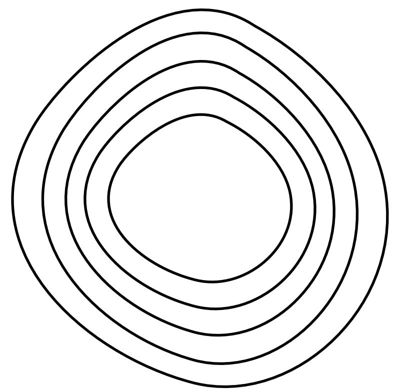
saturation, i.e. $t_{\mathrm{acc}} \ll t_{\mathrm{pp}} < t_{\mathrm{esc}}$ → constant volume emissivity

Leptonic model

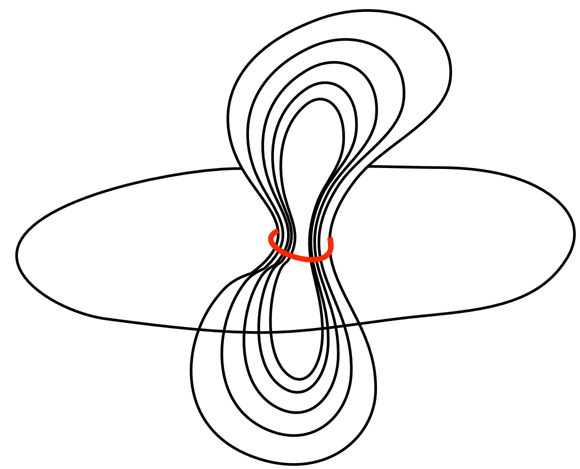
Cheng *et al.*, ApJL **731** (2011) L17



disruption of stars
by central black hole



hundreds of
concentric shock
fronts

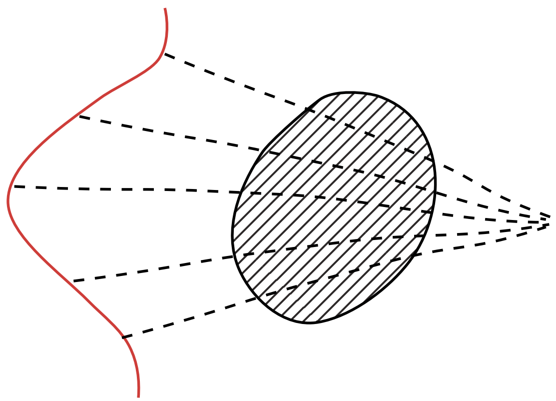


shocks constricted in
galactic disk
→ bubble shape

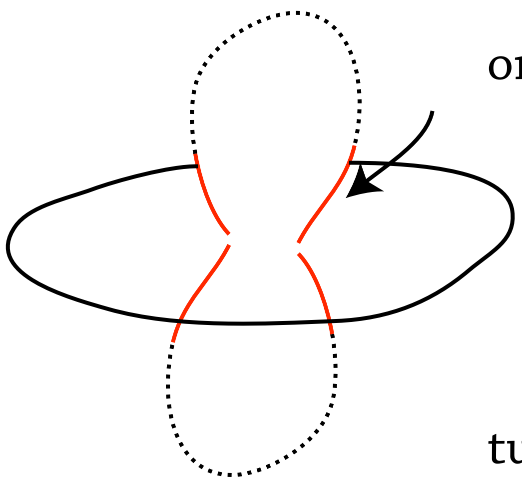
electrons accelerated to E^{-2} spectrum by diffusive shock acceleration

gamma-rays by inverse Compton scattering on radiation fields

Shock(s) and morphology



Even if volume emissivity is homogeneous, in projection this would give a bump-like profile



only evidence for shock at bubble edges (from ROSAT)

turbulence produced at shock and convected downstream

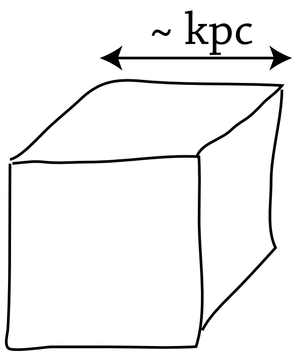
2nd order Fermi acceleration by large-scale, fast-mode turbulence

Mertsch & Sarkar, arXiv:1104.3585

Timescales

Fokker-Planck equation:

$$\frac{\partial n}{\partial t} - \frac{\partial}{\partial p}\left(p^2 D_{pp} \frac{\partial}{\partial p}\frac{n}{p^2}\right) - \frac{n}{t_{\mathrm{esc}}} + \frac{\partial}{\partial p}\left(\frac{\mathrm{d}p}{\mathrm{d}t} n\right) = 0$$

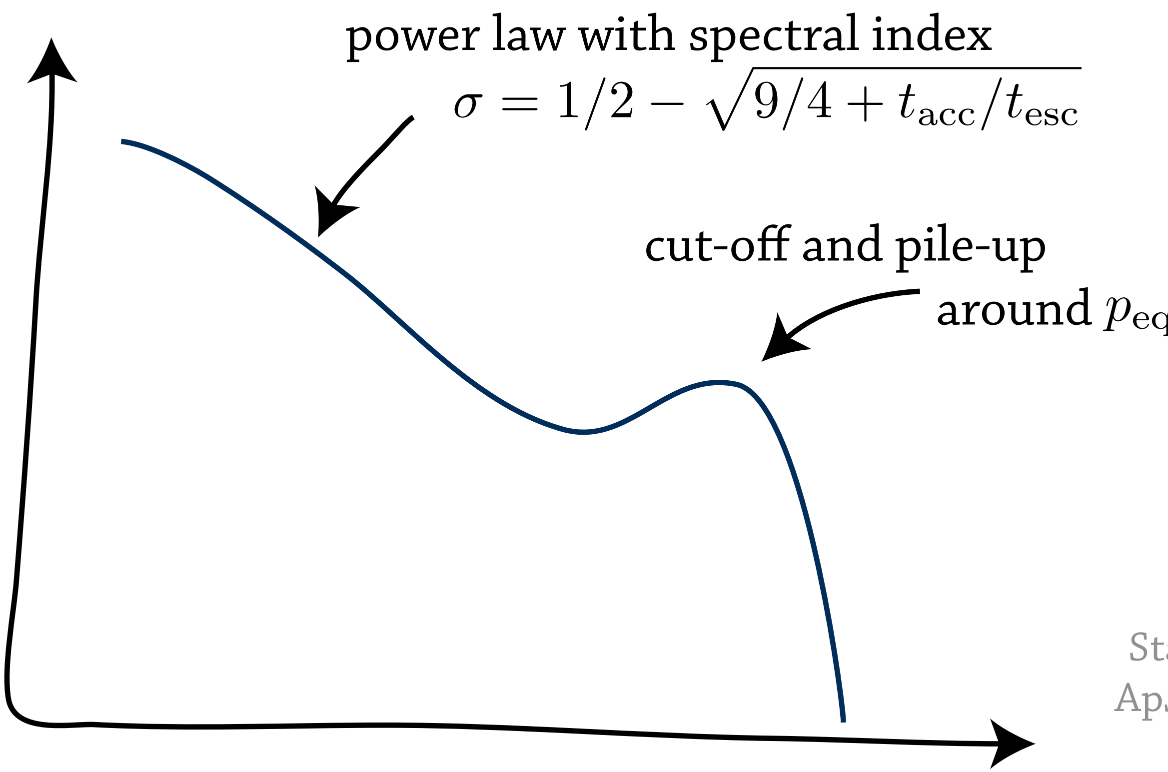


t_{acc}	2nd order Fermi acceleration
t_{esc}	diffusive escape
t_{cool}	synchrotron and inverse Compton
t_{life}	dynamical timescale

steady state solution because of hierarchy of timescales: $t_{\mathrm{acc}}, t_{\mathrm{esc}} \ll t_{\mathrm{life}}$

Mertsch & Sarkar, arXiv:1104.3585

Steady state spectrum

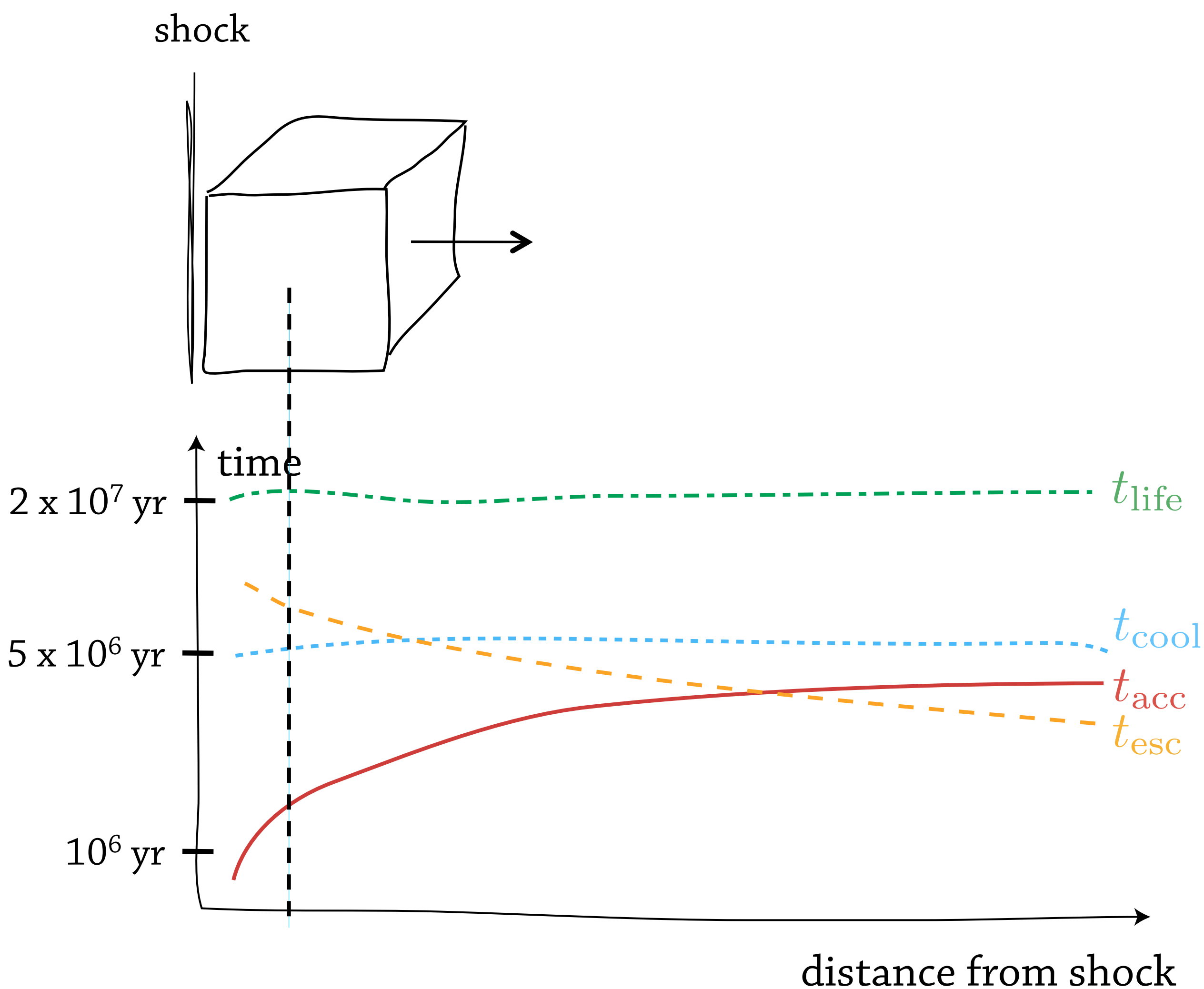


Stawarz & Petrosian, ApJ **681** (2006) 1725

$t_{\rm acc}$ and $t_{\rm esc}$ depend on distance from shock

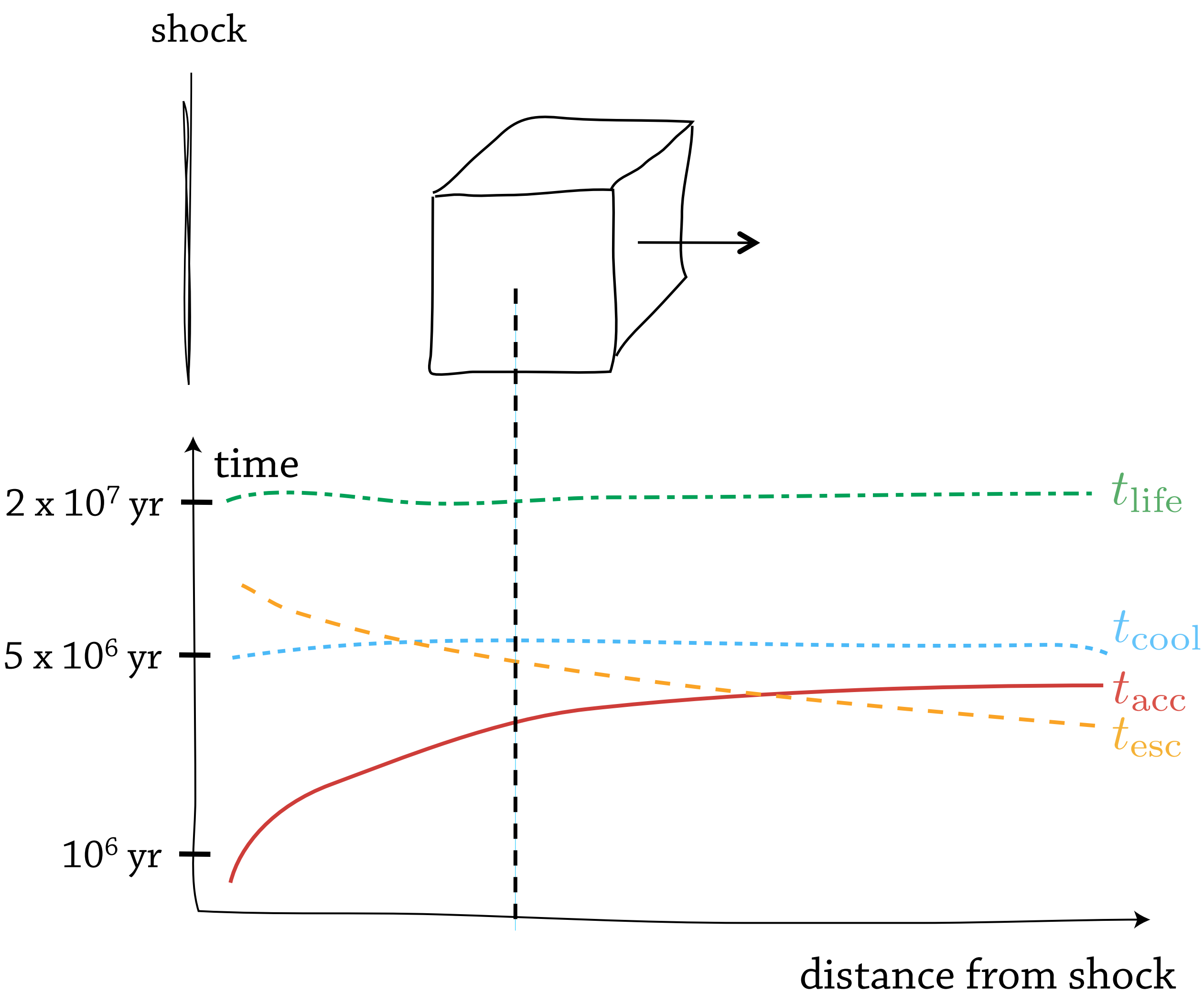
Mertsch & Sarkar, arXiv:1104.3585

Timescales



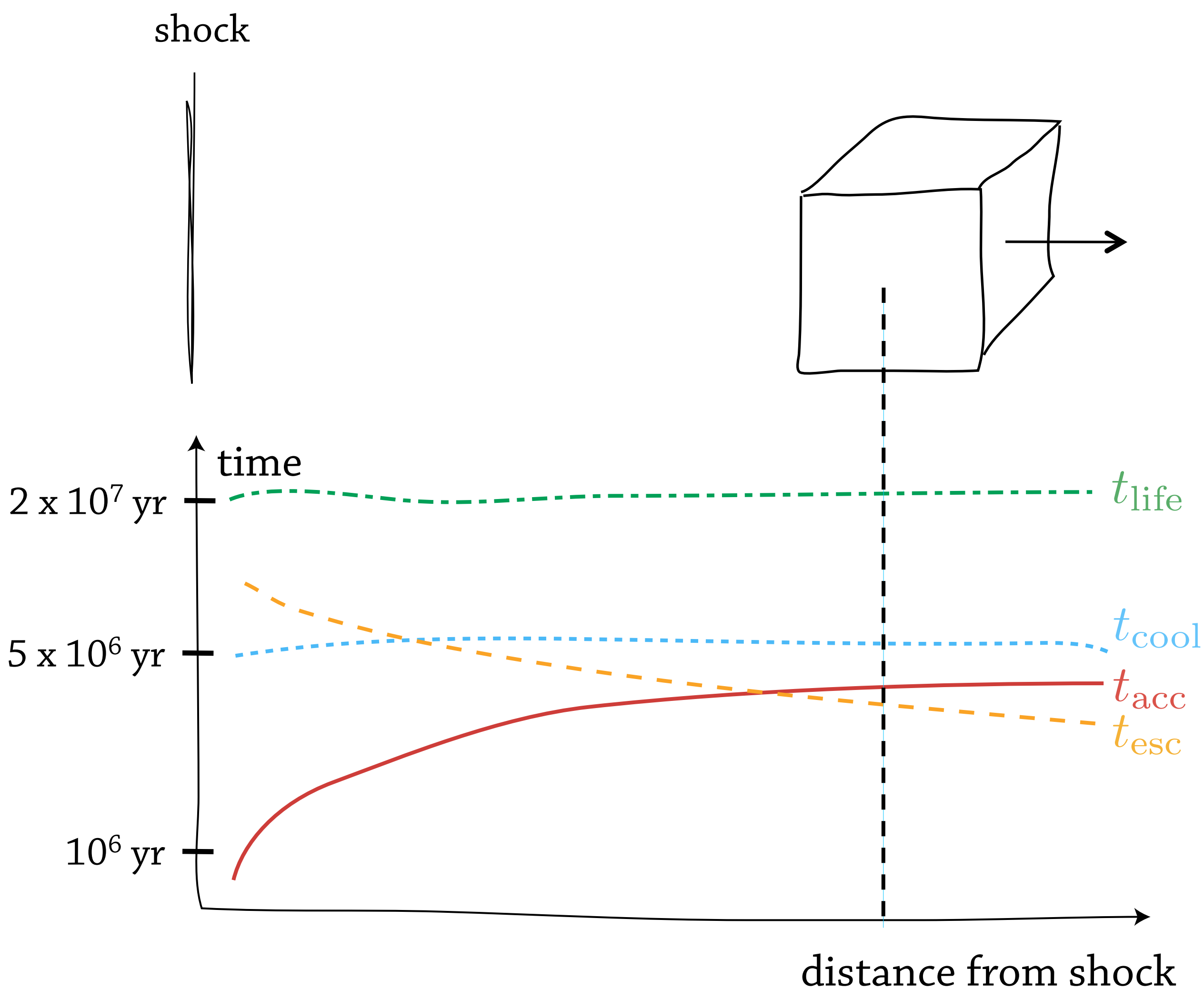
Mertsch & Sarkar, arXiv:1104.3585

Timescales



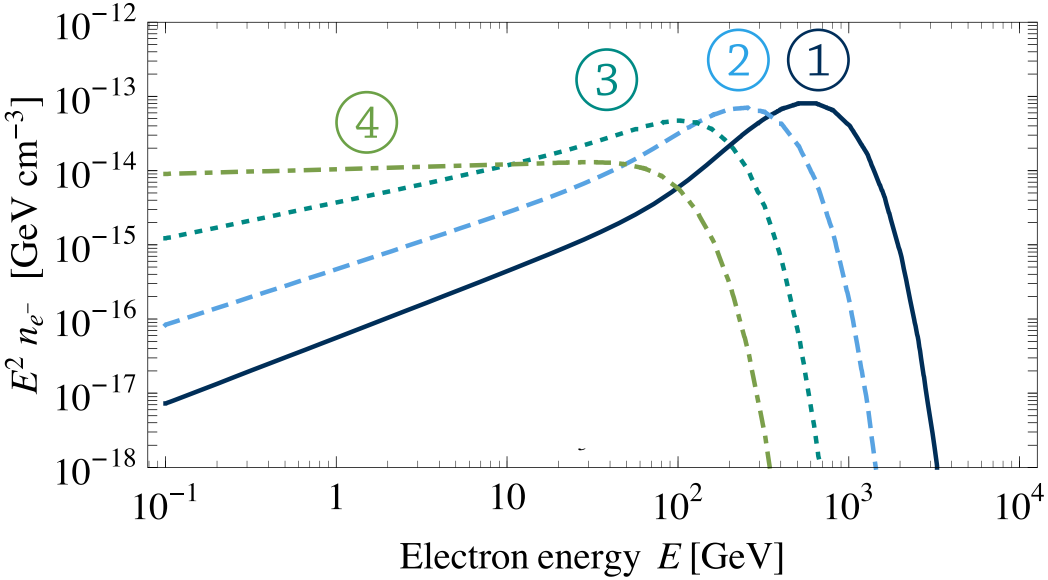
Mertsch & Sarkar, arXiv:1104.3585

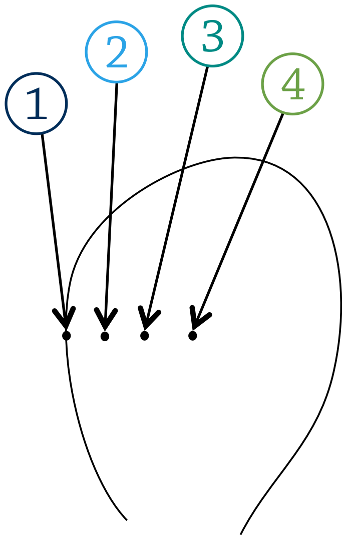
Timescales



Mertsch & Sarkar, arXiv:1104.3585

Electron spectrum



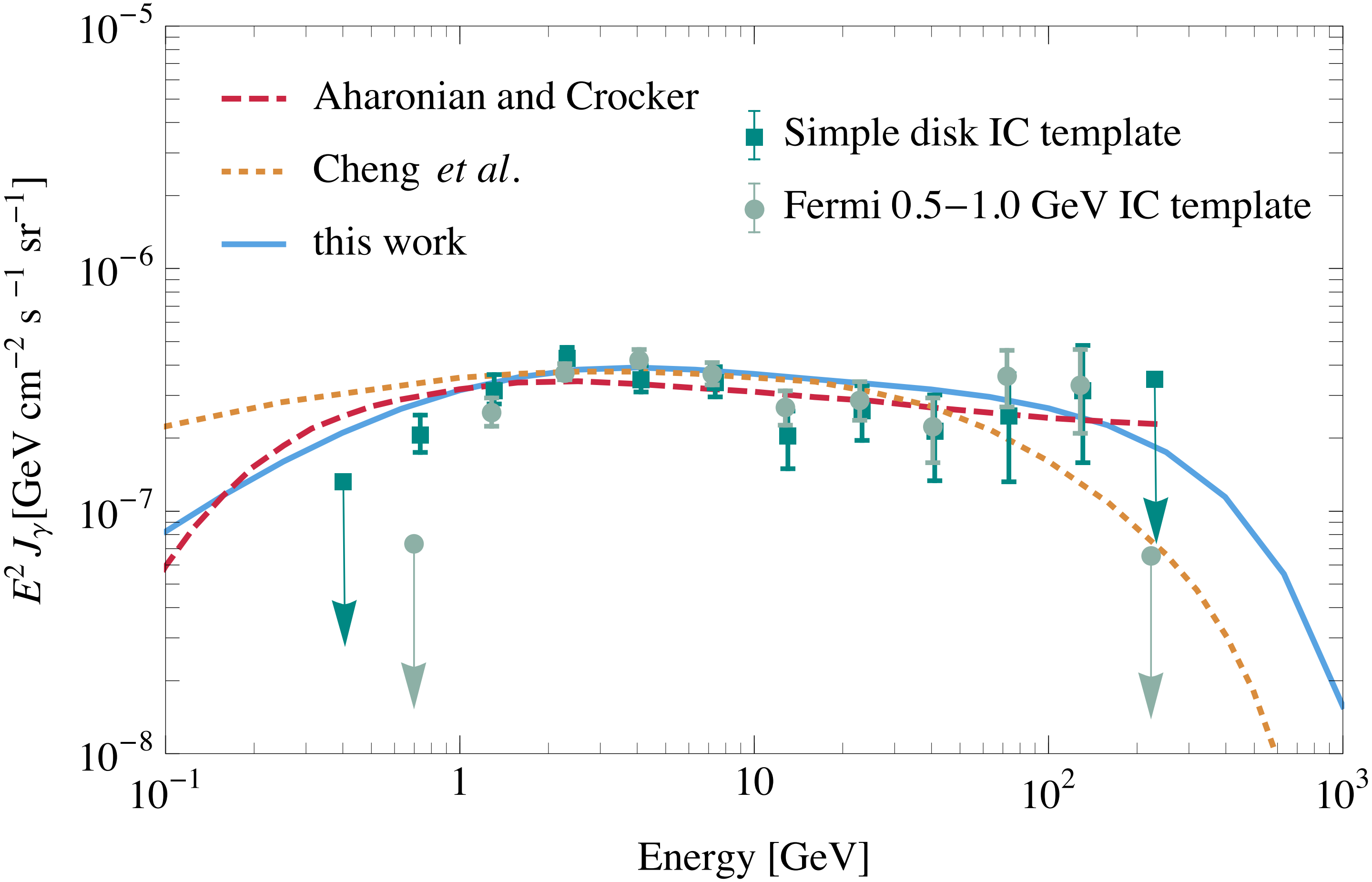


total energy in electrons above 100 MeV: ~ 10^{51} erg

over 5 orders of magnitude smaller than energy of protons in hadronic model

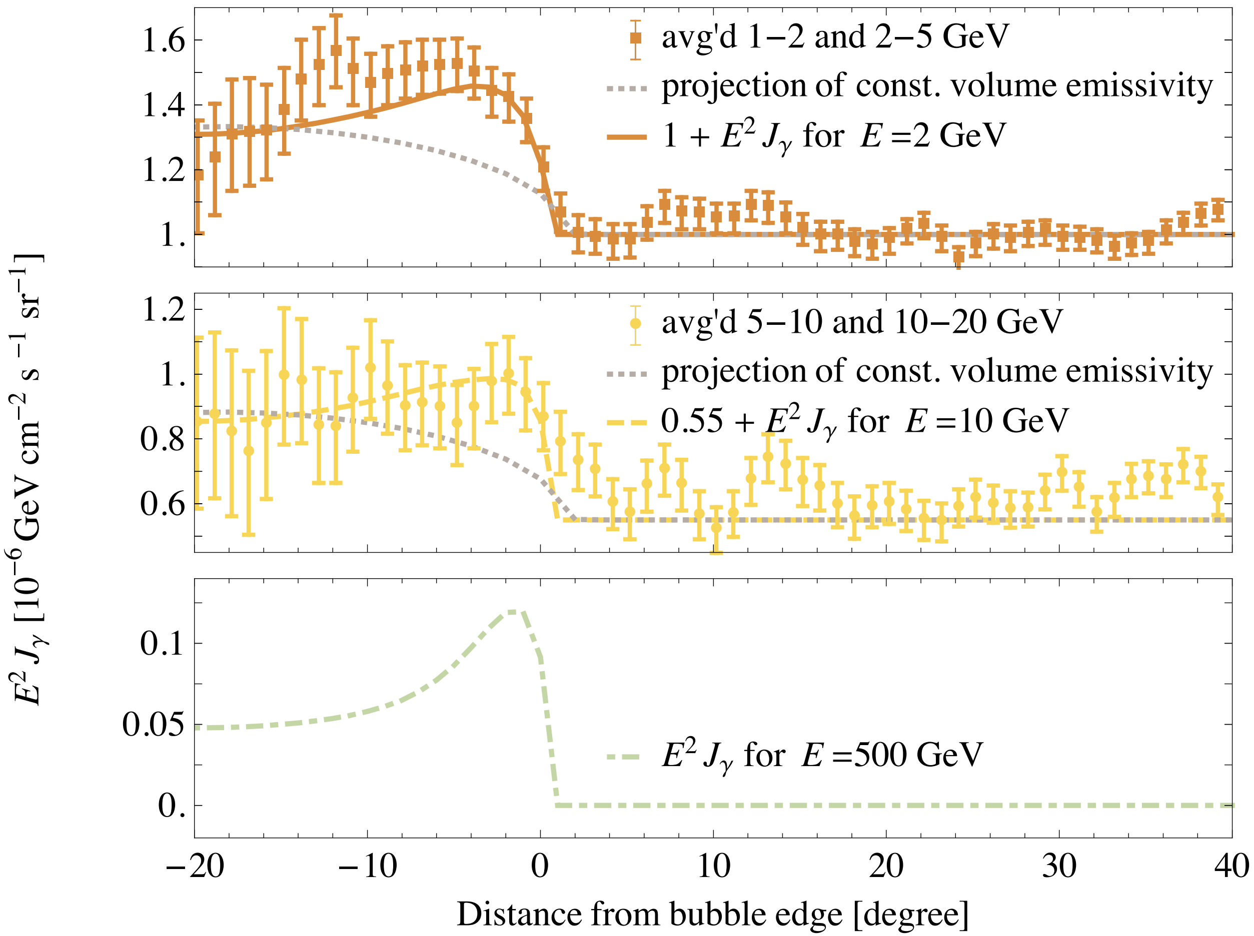
Mertsch & Sarkar, arXiv:1104.3585

Bubble spectrum



Mertsch & Sarkar, arXiv:1104.3585

Bubble profile

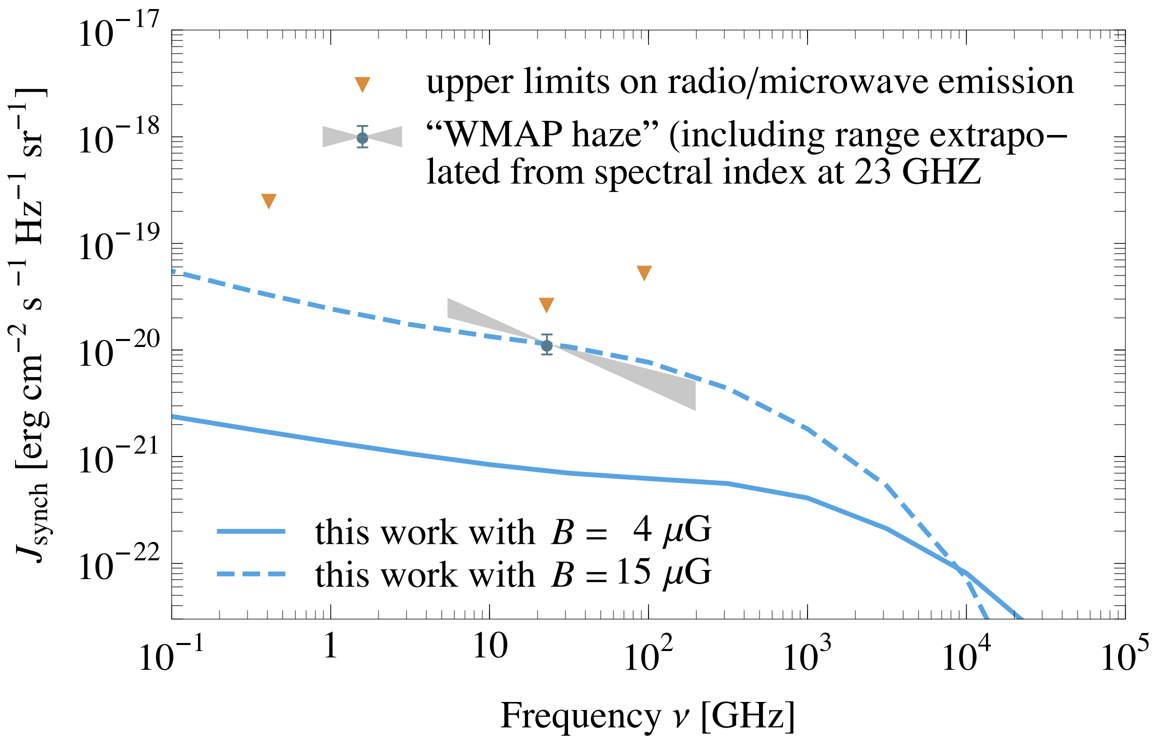


Mertsch & Sarkar, arXiv:1104.3585

Other messengers

leptonic origin of gamma-rays → no neutrinos

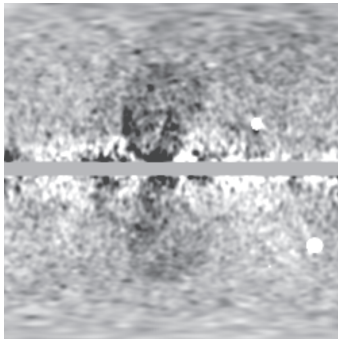
"WMAP haze" can only be matched with unrealistically high B field



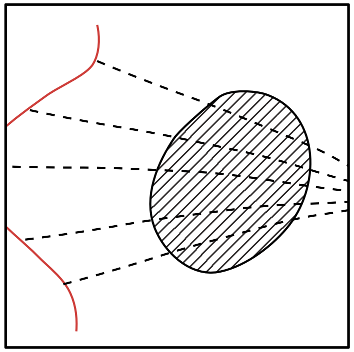
Mertsch & Sarkar, arXiv:1104.3585

BUT: Is the haze real? Mertsch & Sarkar JCAP **10** (2010) 019

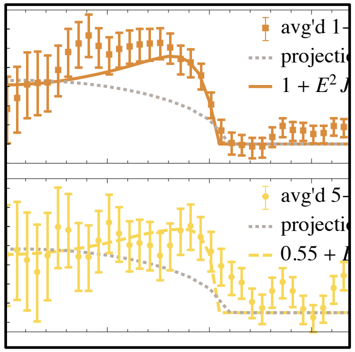
Summary



evidence for Fermi bubbles:
robustness, morphology, spectrum



other models explain gamma-ray emission but don’t match morphology



2nd order Fermi acceleration explains spectrum and sharp edges; moderate energy requirements

Fermi-LAT confirms bubbles

Nov. 09, 2010
RELEASE: 10-295

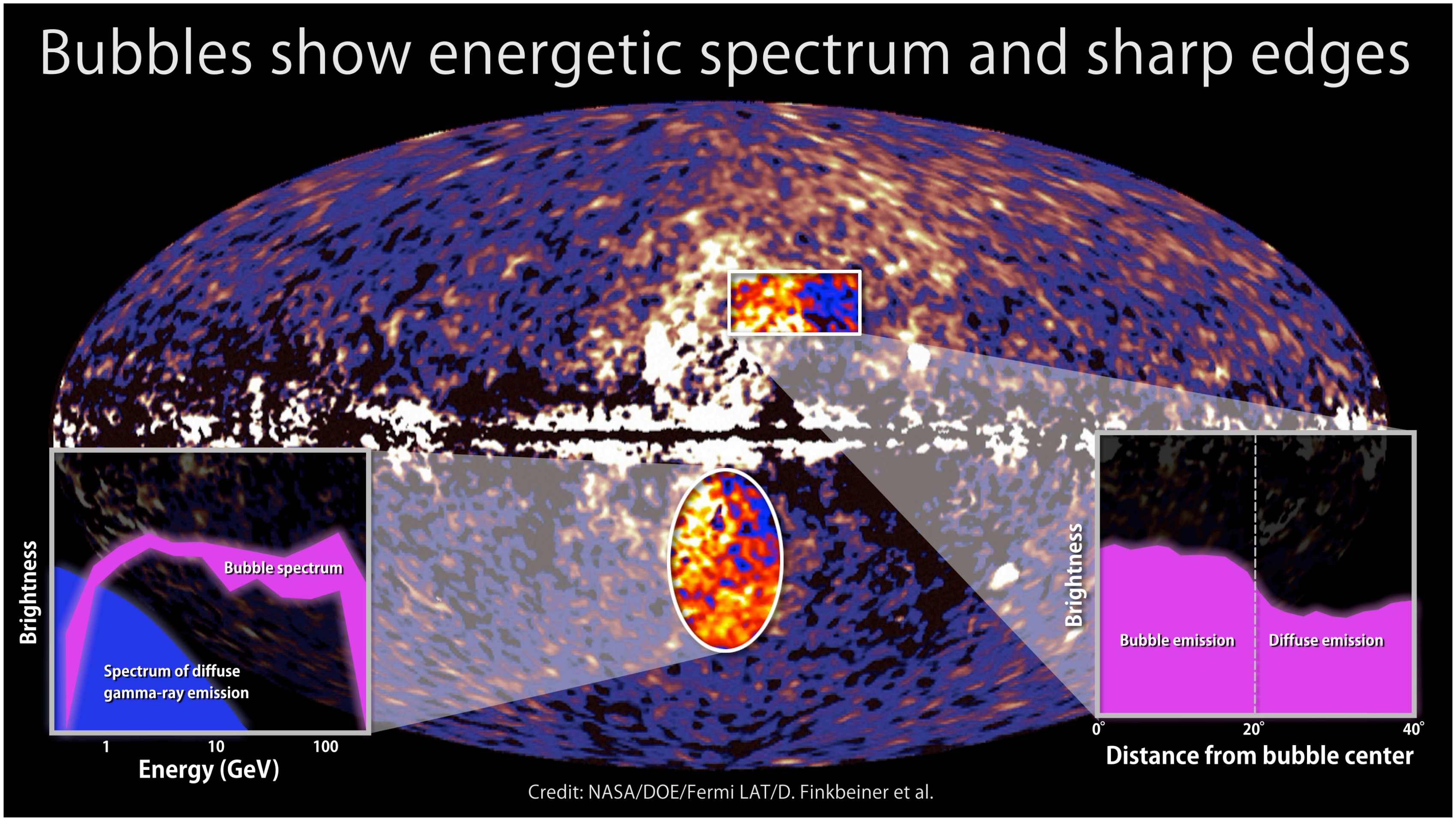
NASA'S FERMI TELESCOPE DISCOVERS GIANT STRUCTURE IN OUR GALAXY

WASHINGTON -- NASA's Fermi Gamma-ray Space Telescope has unveiled a previously unseen structure centered in the Milky Way. The feature spans 50,000 light-years and may be the remnant of an eruption from

much more energetic than the gamma-ray fog seen elsewhere in the Milky Way. The bubbles also appear to have well-defined edges. The structure's shape and emissions suggest it was formed as a result of

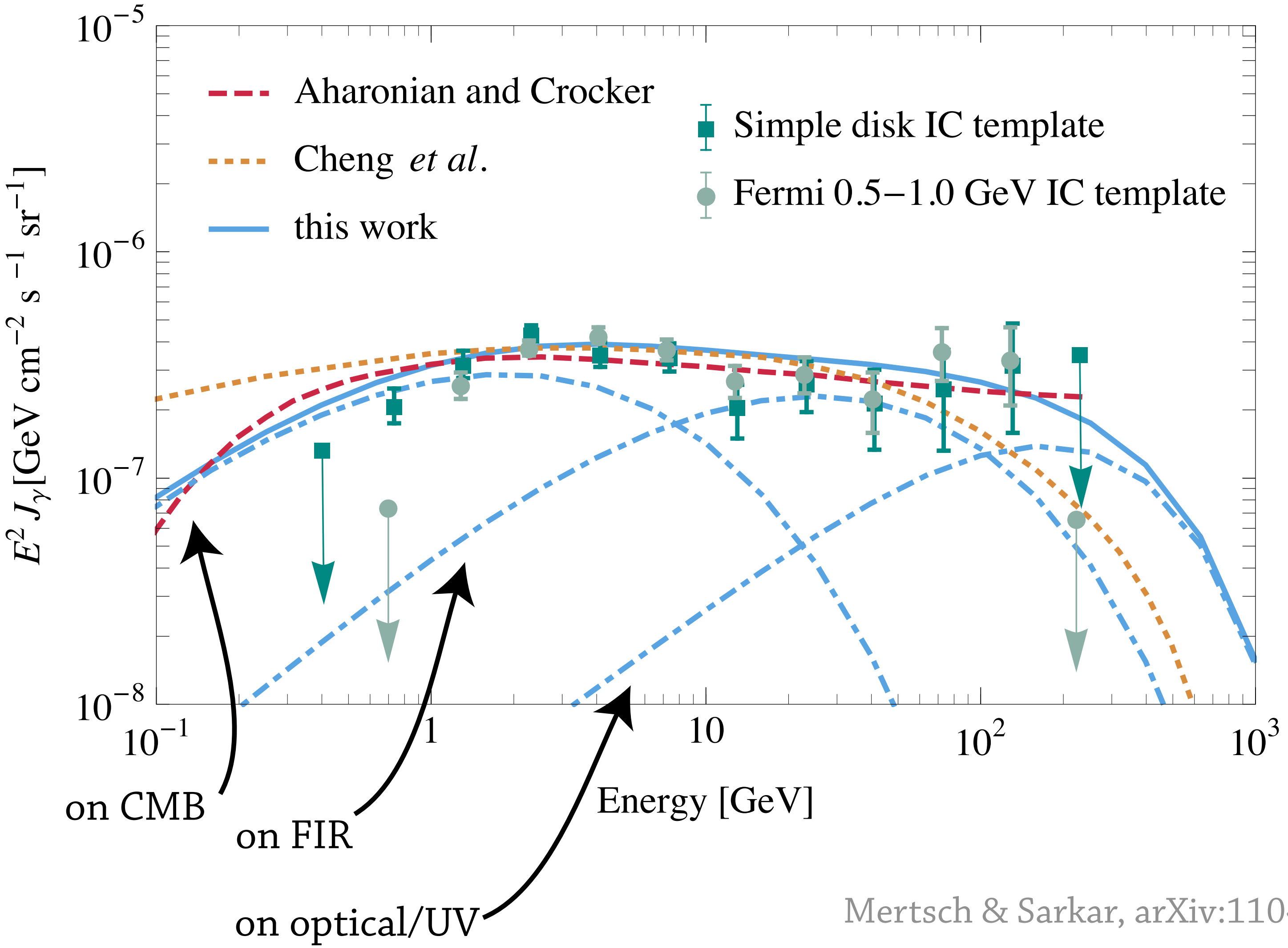
http://www.nasa.gov/home/hqnews/2010/nov/HQ_10-295_FERMI.html

Fermi-LAT confirms bubbles



http://www.nasa.gov/images/content/498886main_DF4_bubbles_graphs.jpg

Bubble spectrum



Mertsch & Sarkar, arXiv:1104.3585