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

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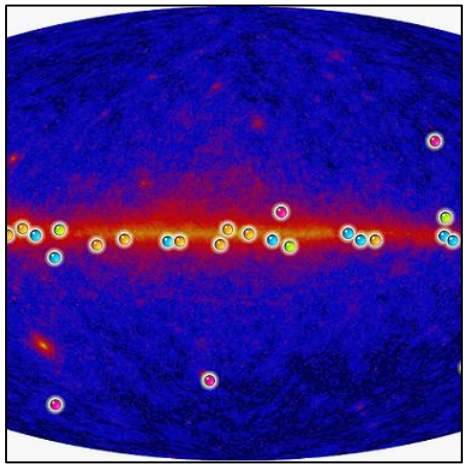
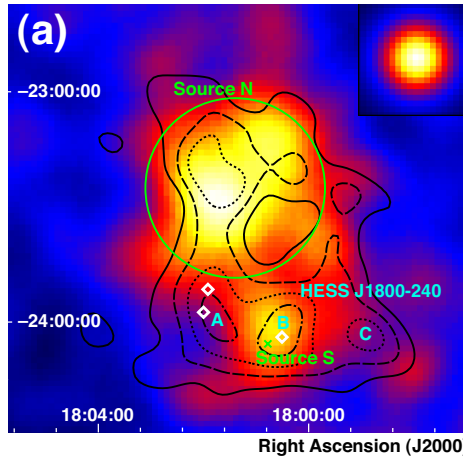
Highlights of Fermi-LAT

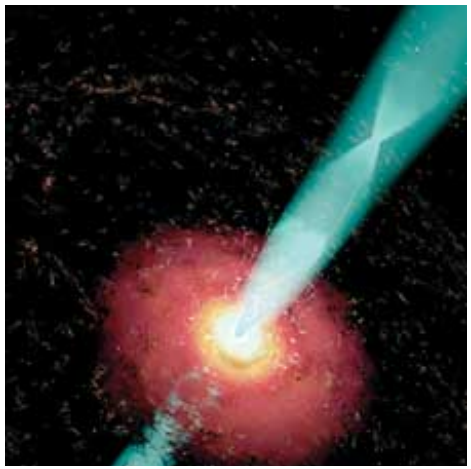
γ-ray pulsars

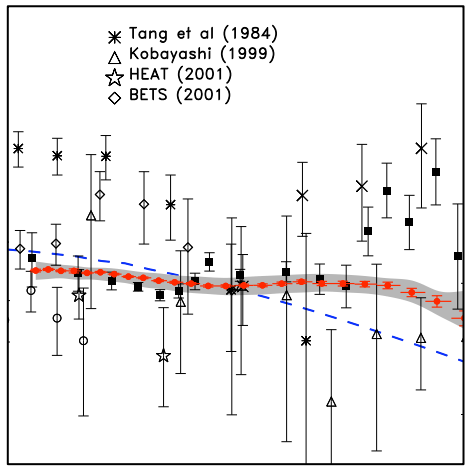




galactic SNRs

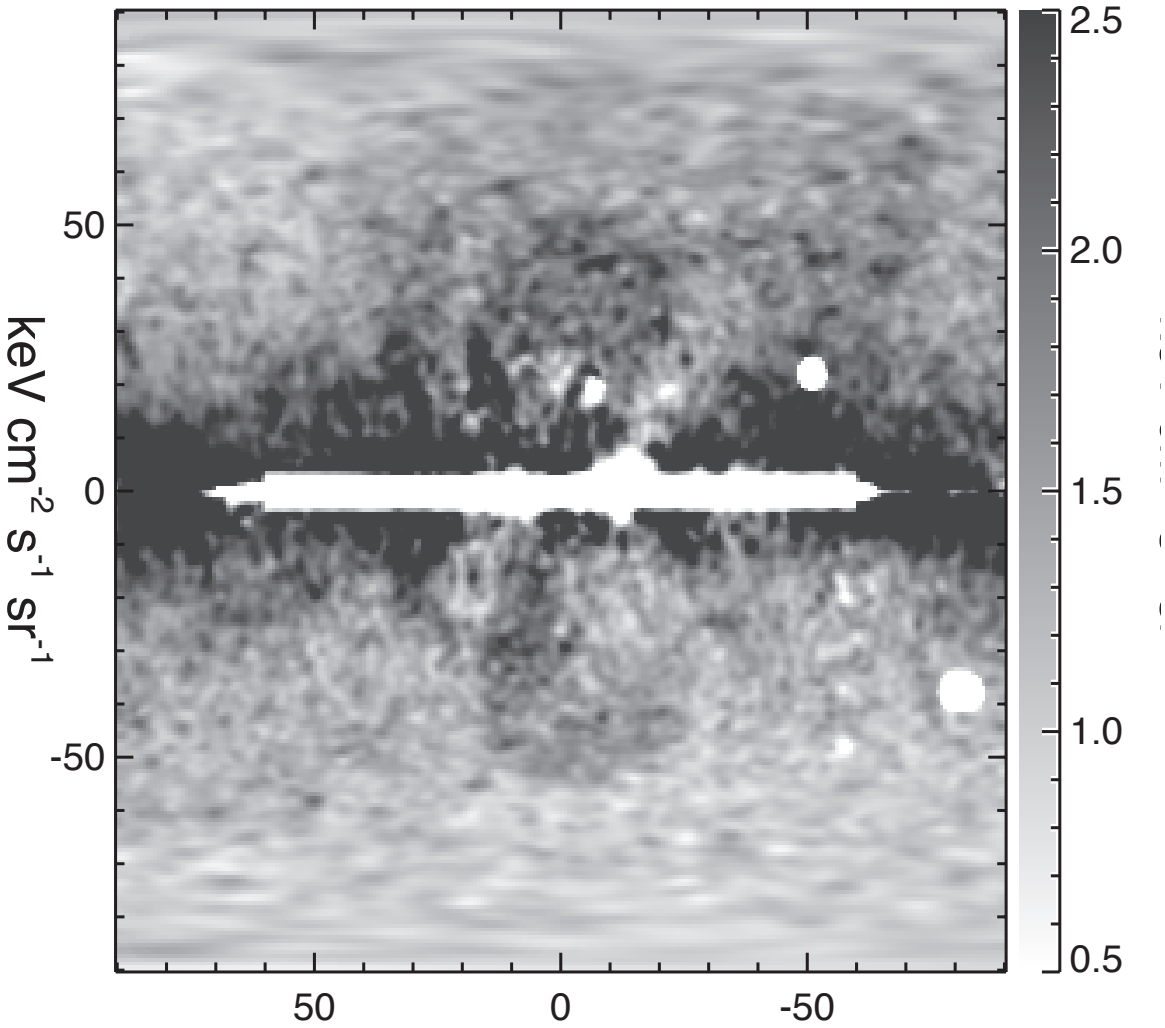
extragalactic γ-ray background





$e^+ + e^-$ flux

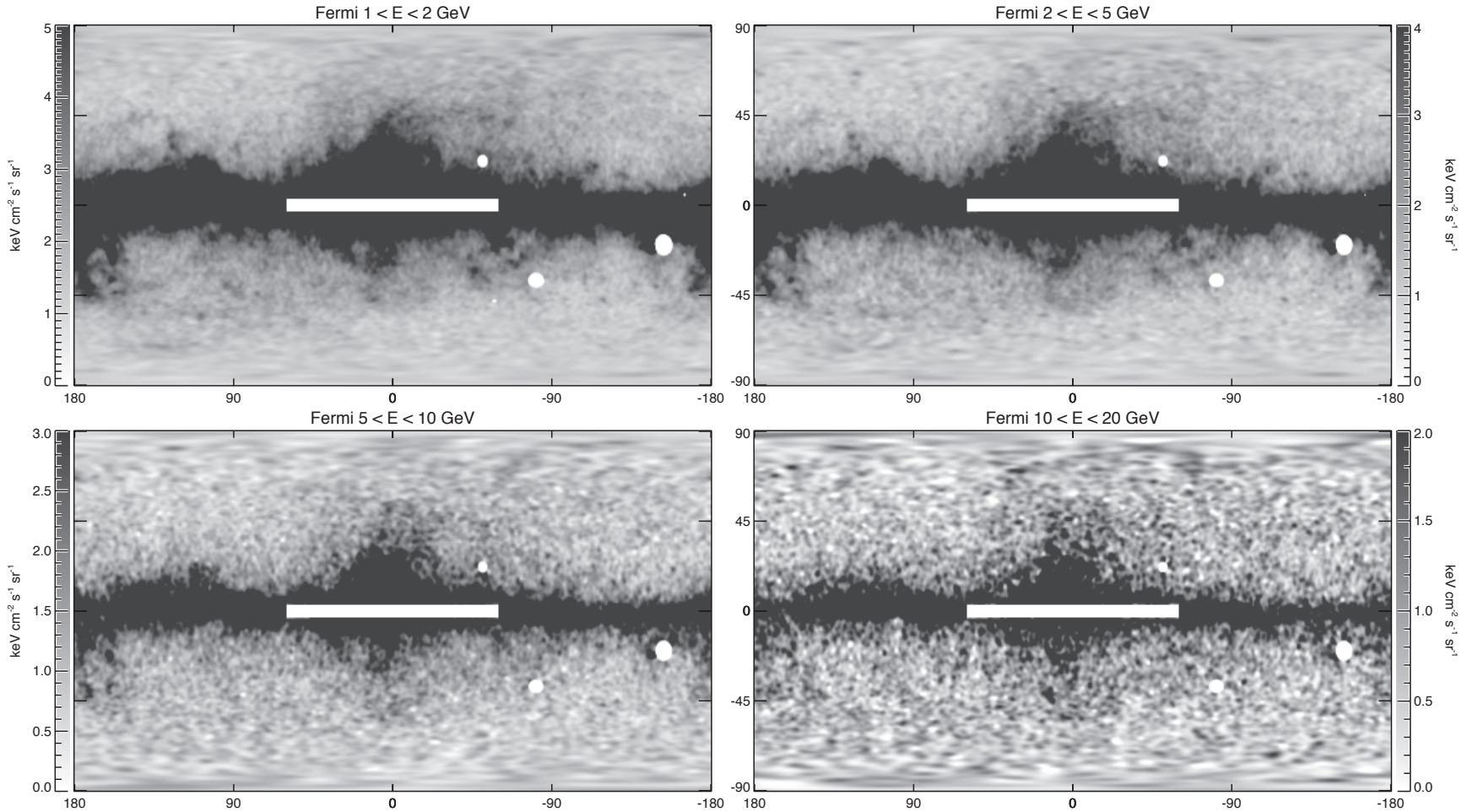
Discovery of the Fermi bubbles



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

Bubble feature robust

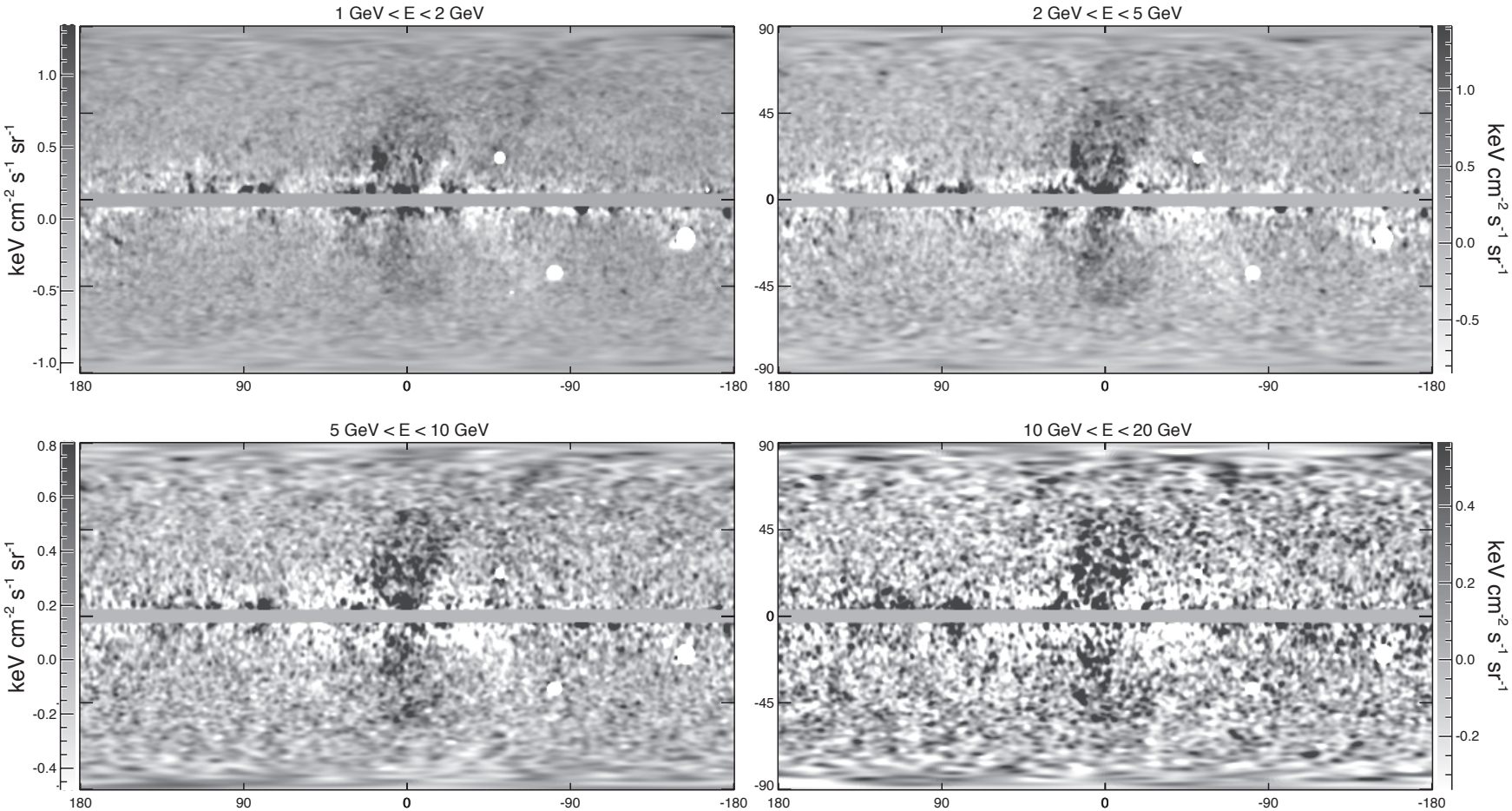
Fermi-LAT skymaps



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

Bubble feature robust

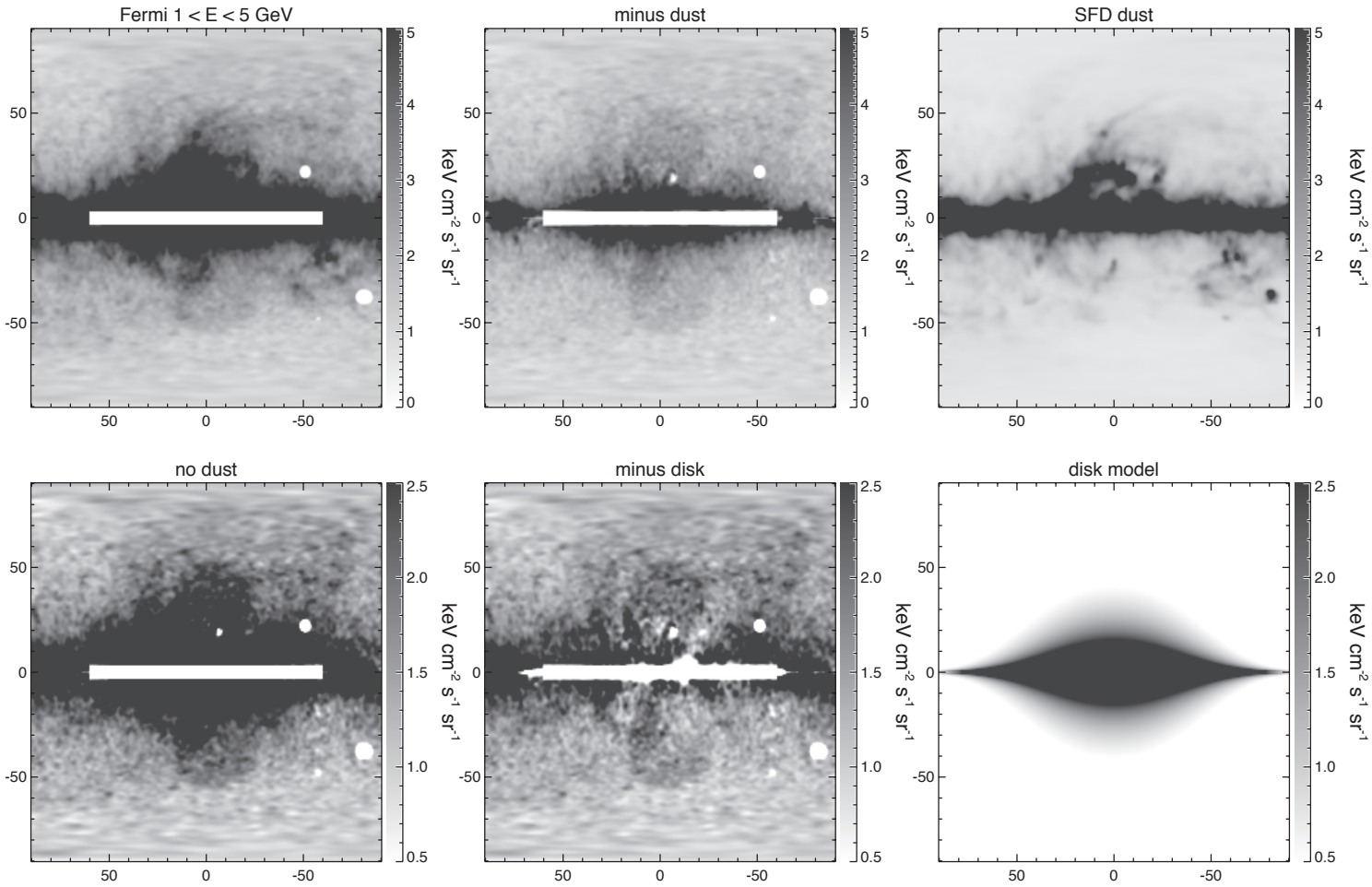
Subtraction of Fermi-LAT model



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

Bubble feature robust

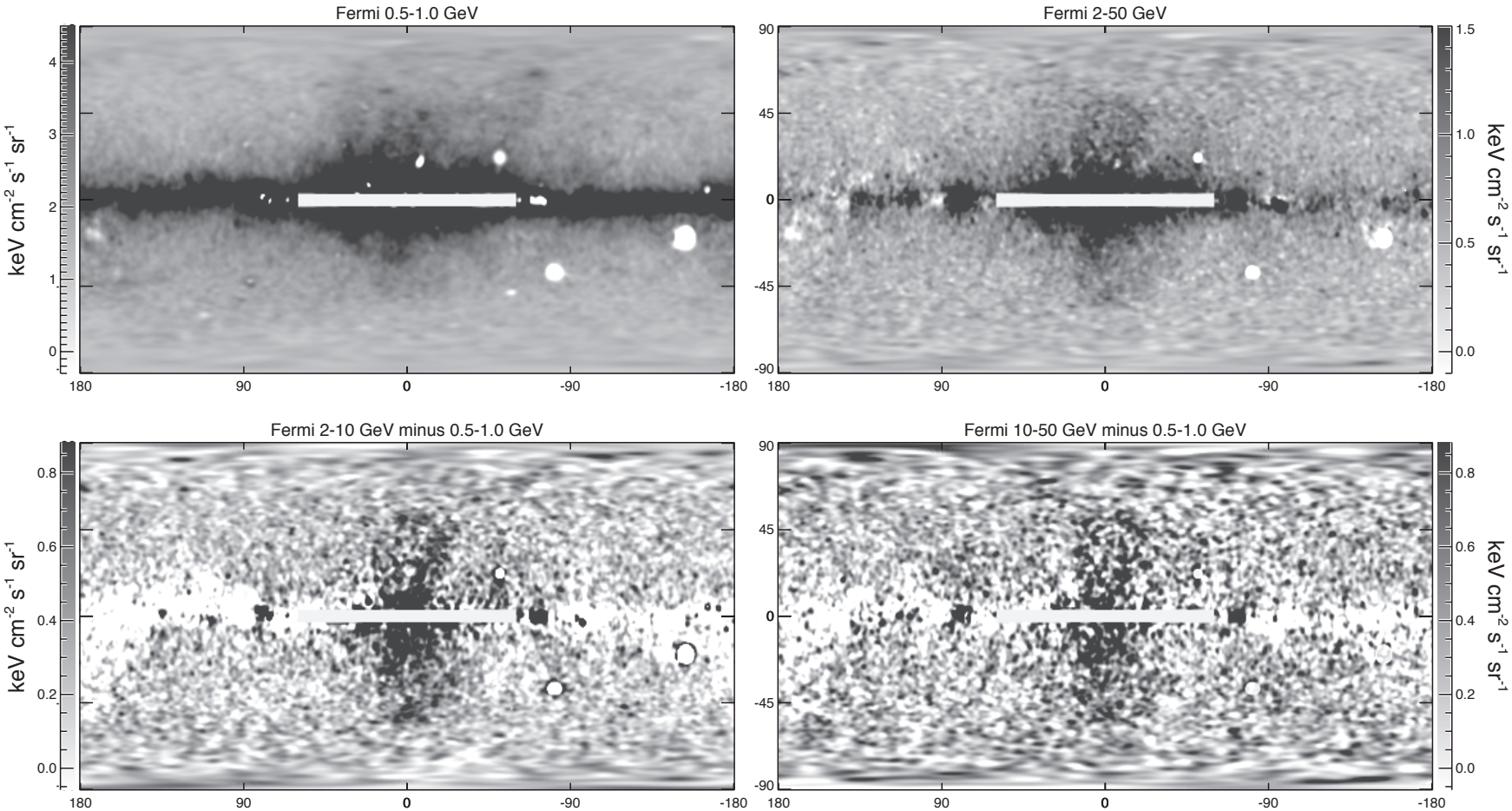
Subtraction of simple π^0 model (dust map) and IC model



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

Subtraction of low-energy maps

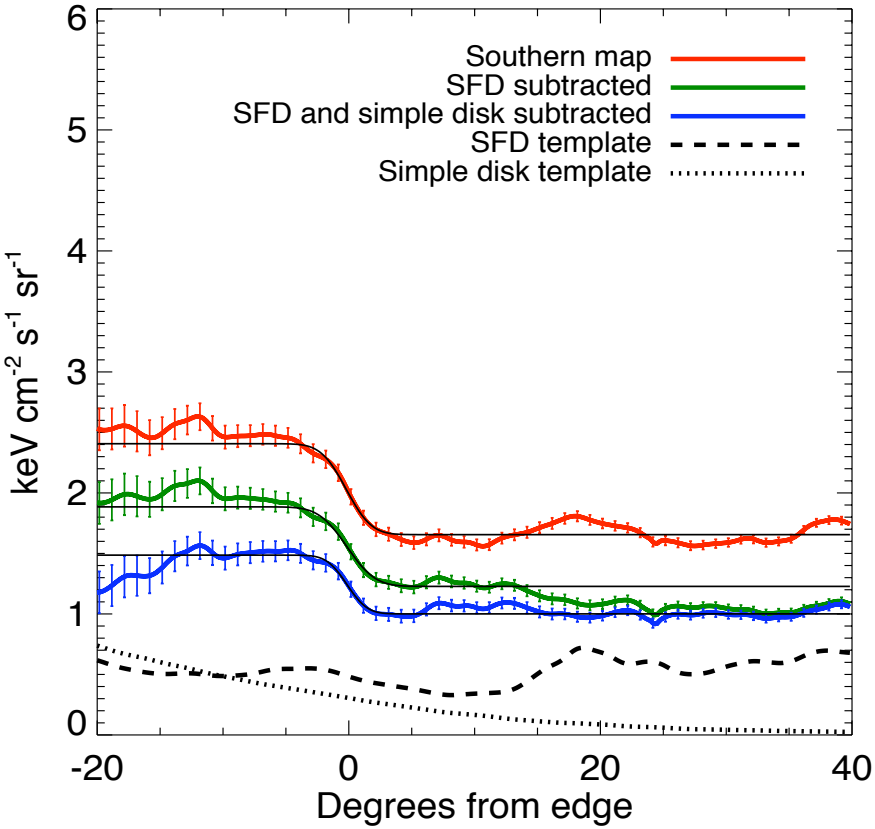
Subtraction of low-energy γ –ray maps maps

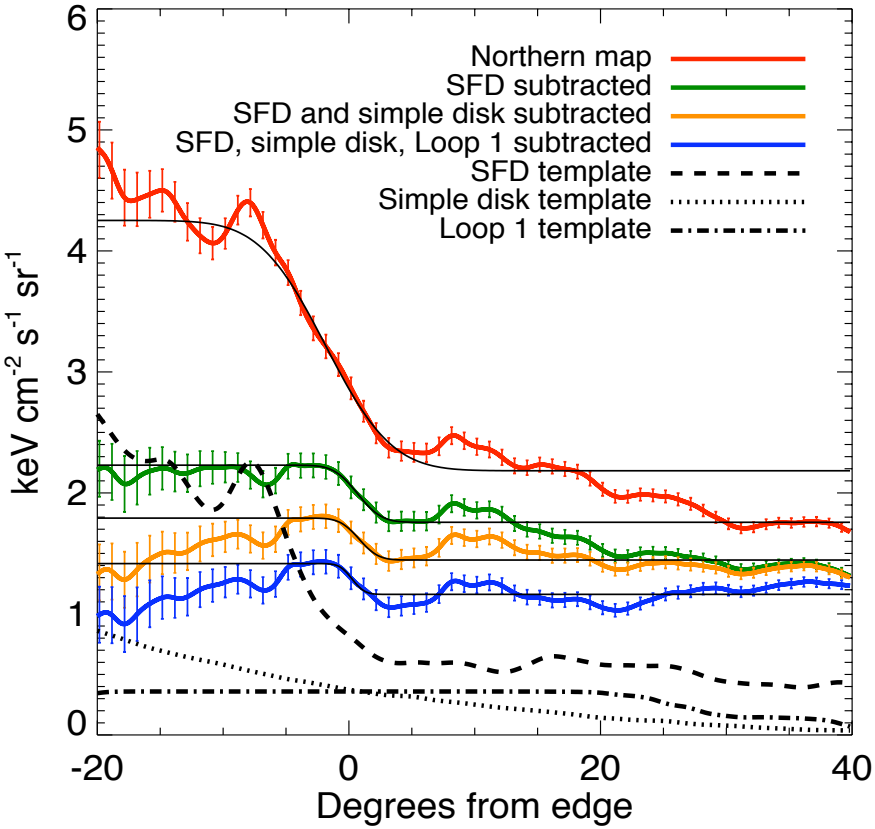


Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

Bubbles have sharp edges

averaged 1-2 and 2-5 GeV maps

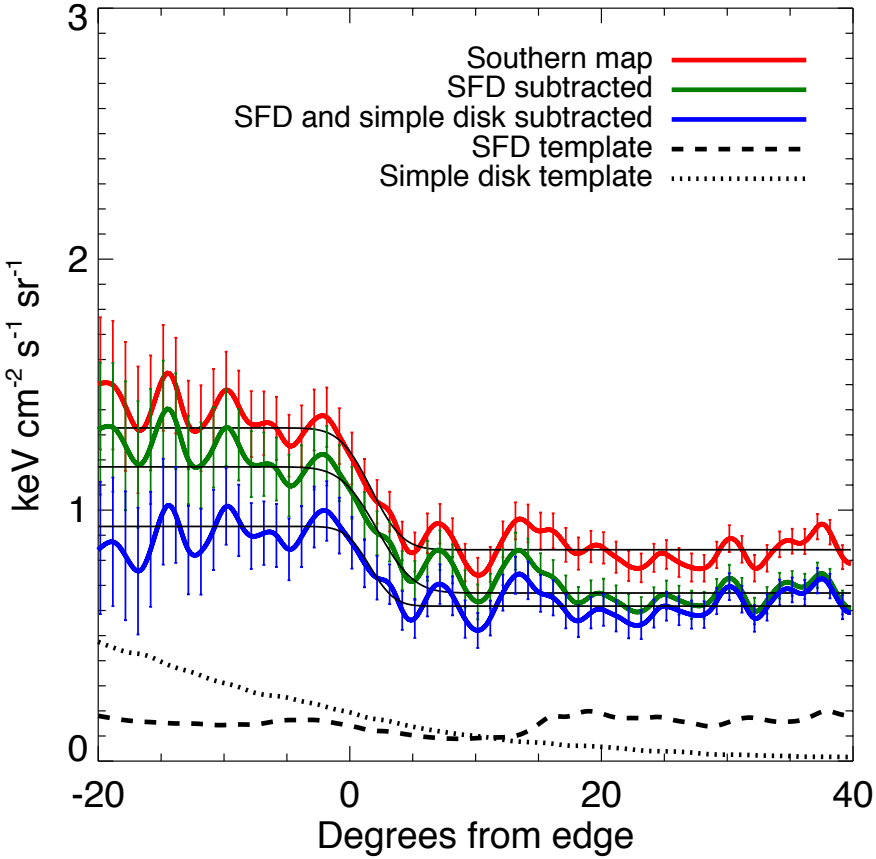


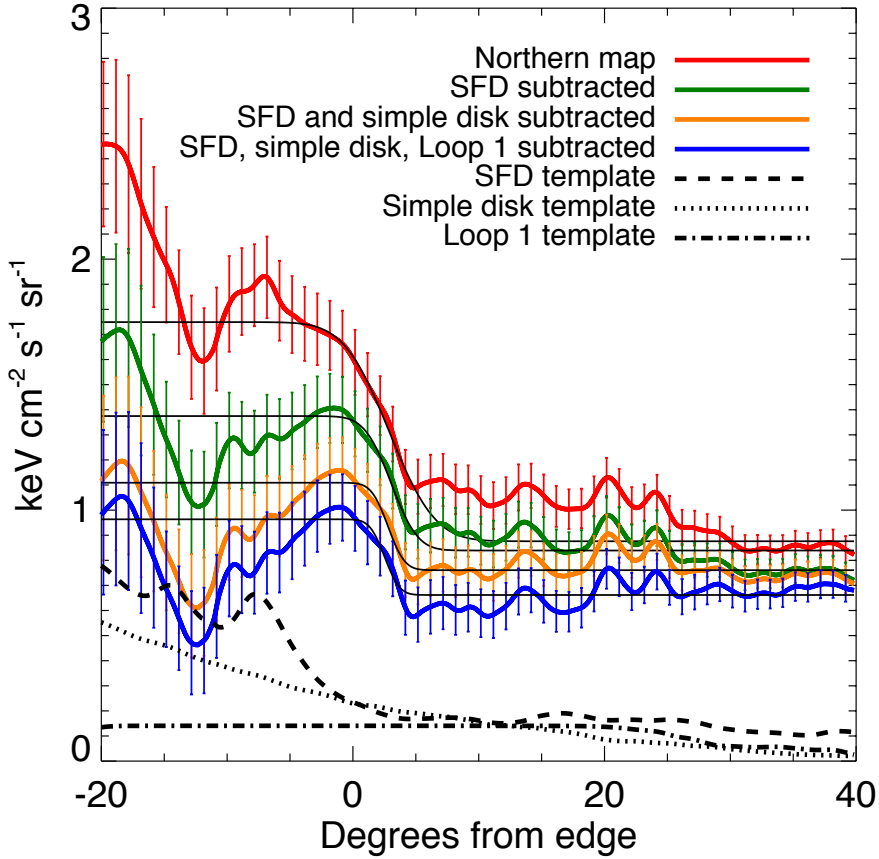


Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

Bubbles have sharp edges

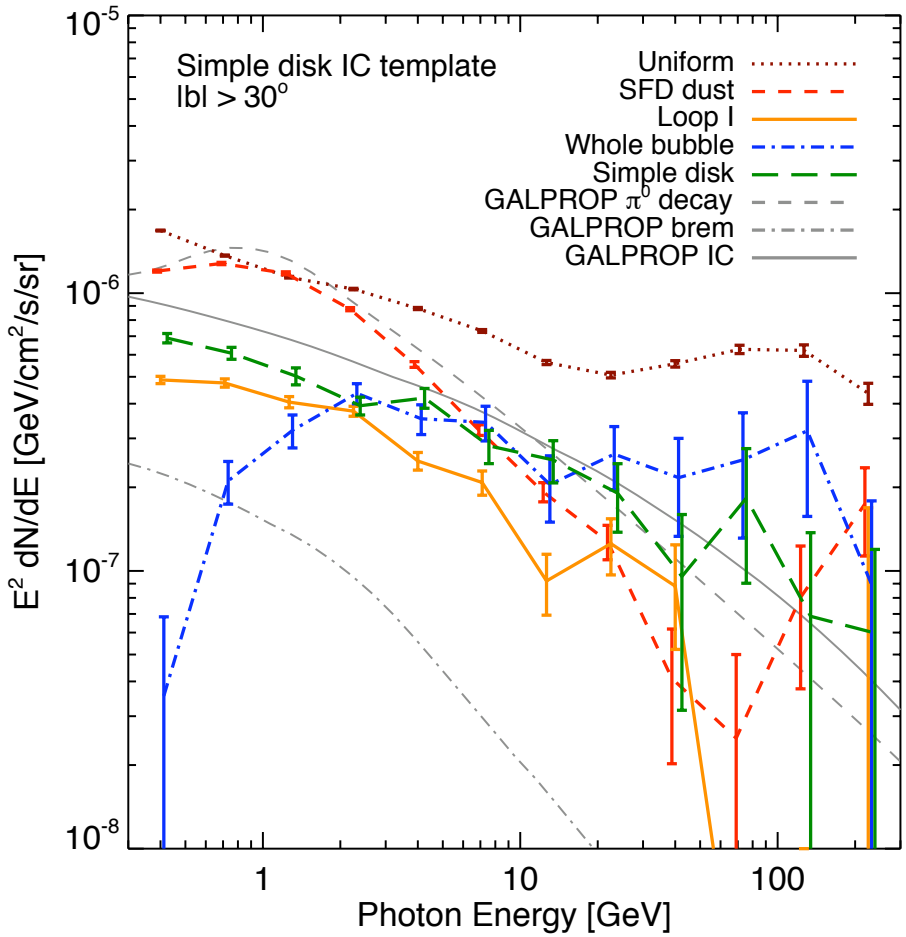
averaged 5-10 and 10-20 GeV maps





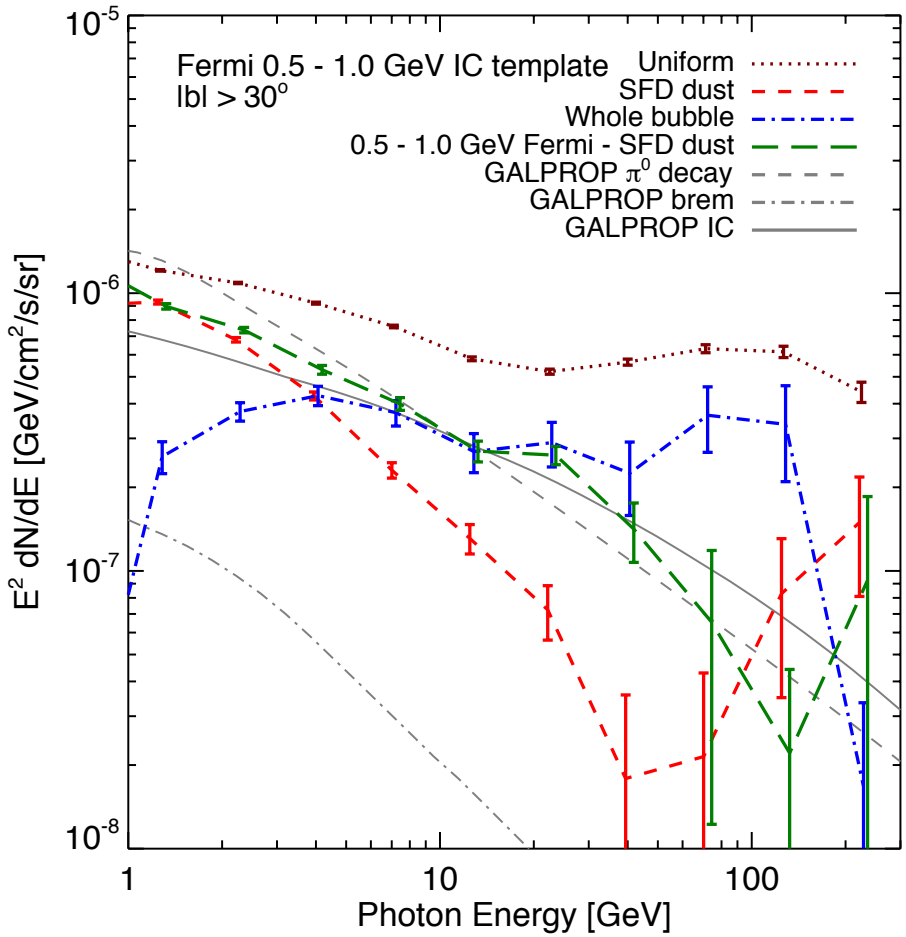
Su, Slatyer, Finkbeiner, ApJ **724** (2010) 1044

Bubbles have hard spectrum



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

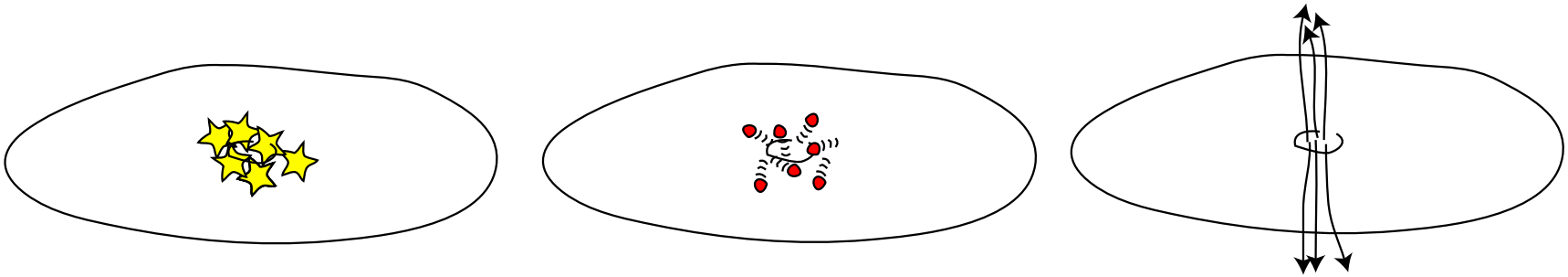
Bubbles have hard spectrum



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

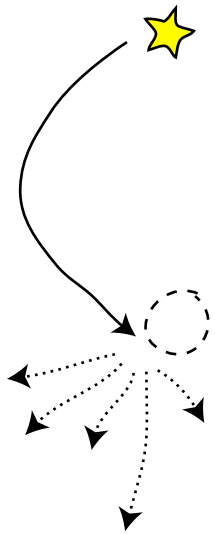
wind convects CRs away from disk

gamma-rays by π^0 on thermal gas

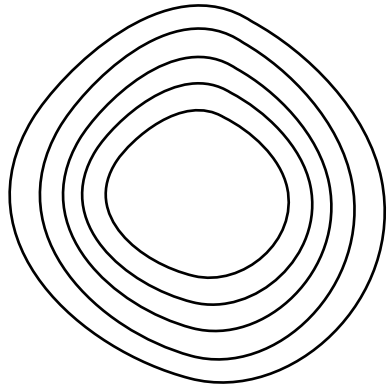
saturation, i.e. $t_{\rm acc} \ll t_{\rm pp} < t_{\rm esc}$ → constant volume emissivity

Leptonic model

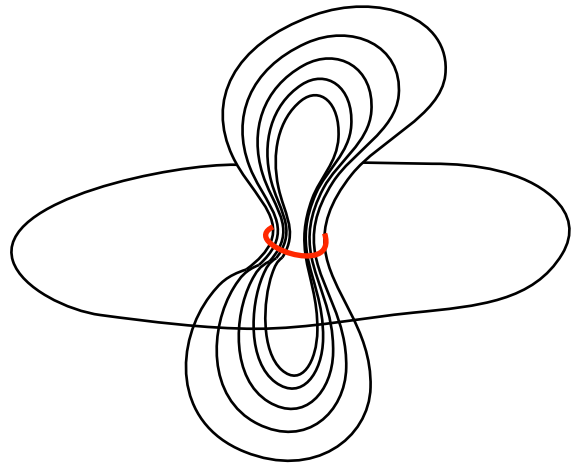
Cheng *et al.*, ApJL **731** (2011) L17



disruption of stars
by central black hole



hundreds of
concentric shock
fronts

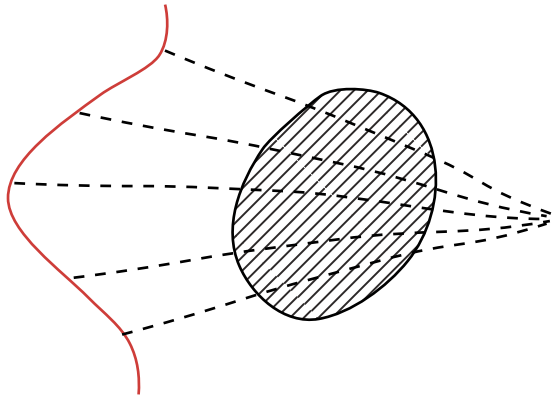


shocks constricted in
galactic disk
→ bubble shape

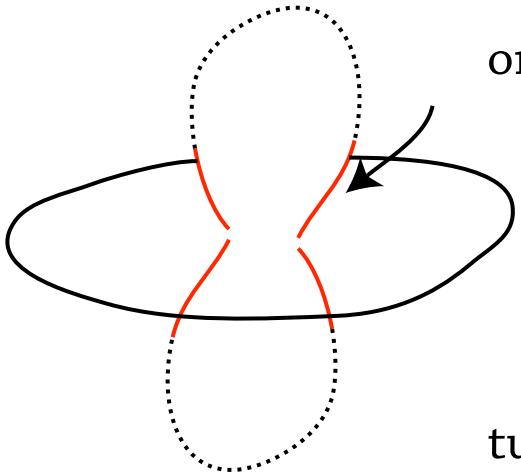
electrons accelerated to E^{-2} spectrum by diffusive shock acceleration

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

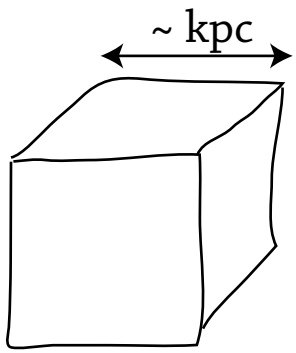
2nd order Fermi acceleration by large-scale, fast-mode turbulence

Mertsch & Sarkar, arXiv:1104.3585

Timescales

Fokker-Planck equation:

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



$t_{\rm acc}$ 2nd order Fermi acceleration

$t_{\rm esc}$ diffusive escape

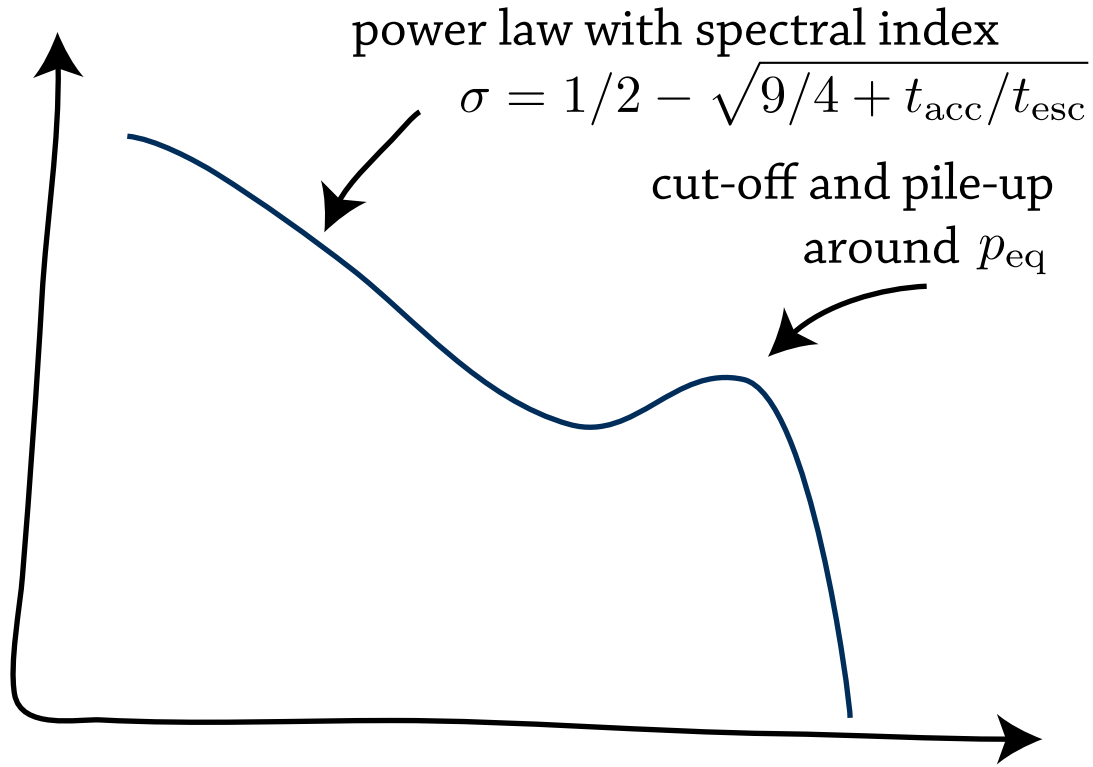
$t_{\rm cool}$ synchrotron and inverse Compton

$t_{\rm life}$ dynamical timescale

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

Mertsch & Sarkar, arXiv:1104.3585

Steady state spectrum

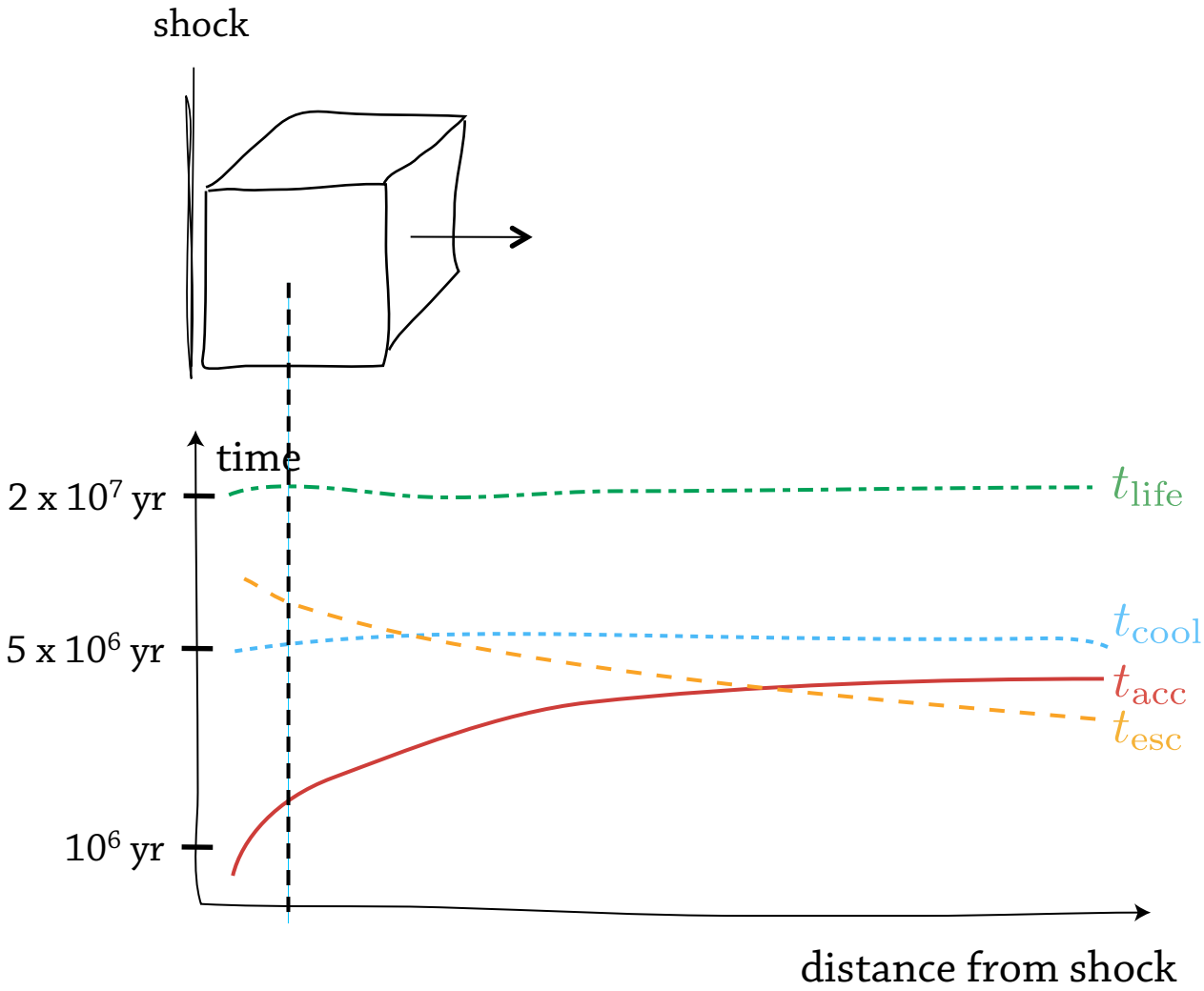


Stawarz & Petrosian,
ApJ **681** (2006) 1725

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

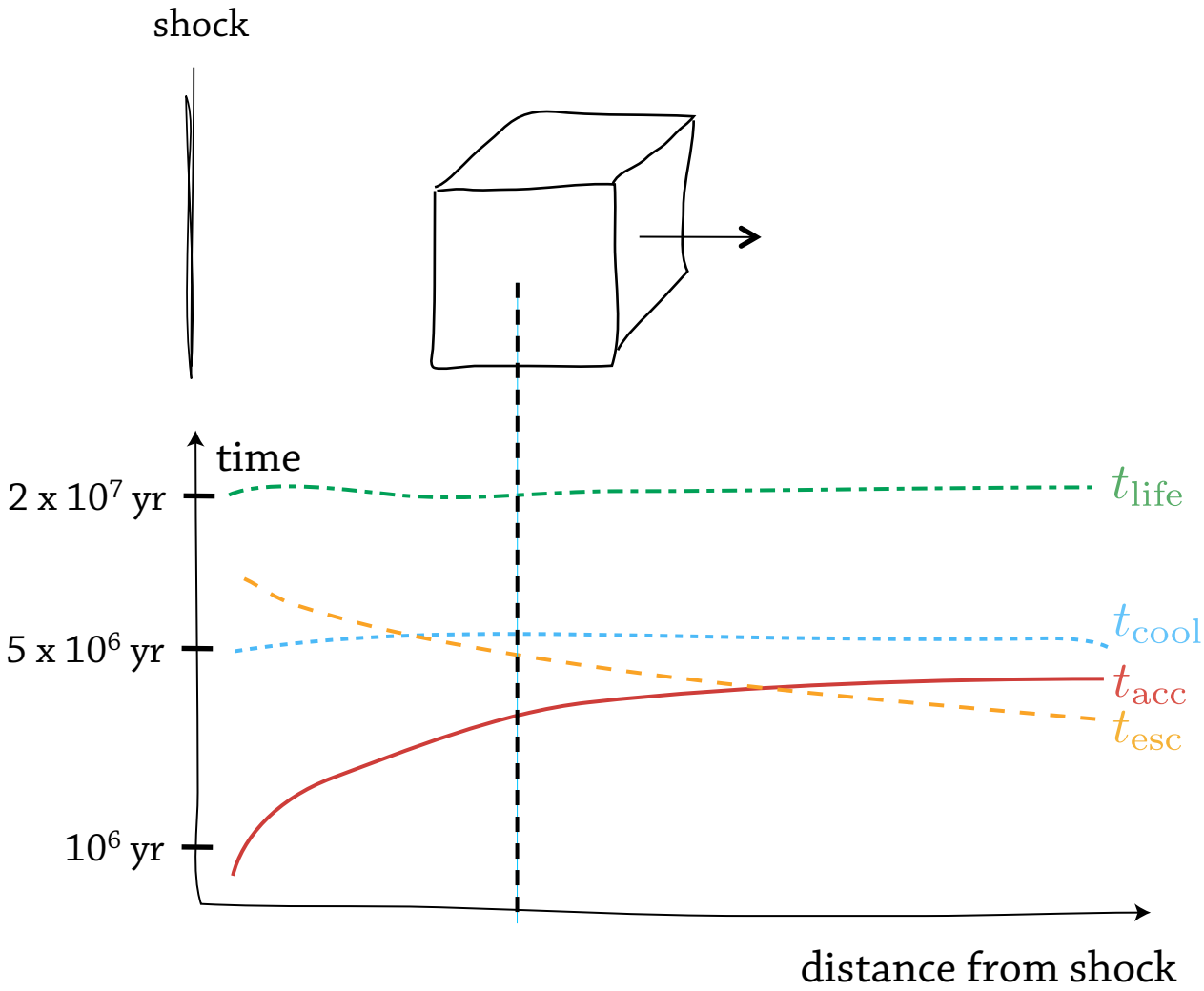
Mertsch & Sarkar, arXiv:1104.3585

Timescales



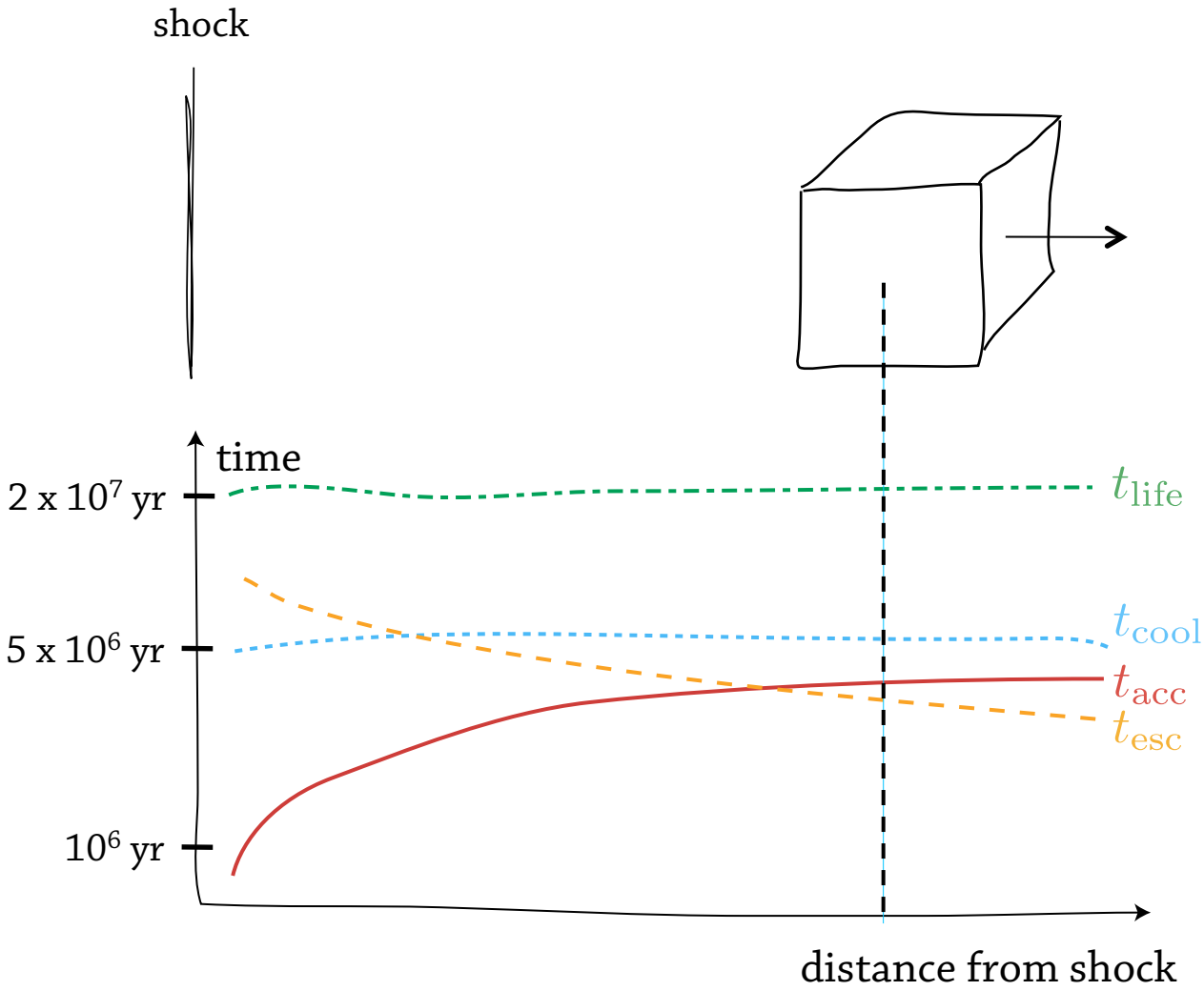
Mertsch & Sarkar, arXiv:1104.3585

Timescales



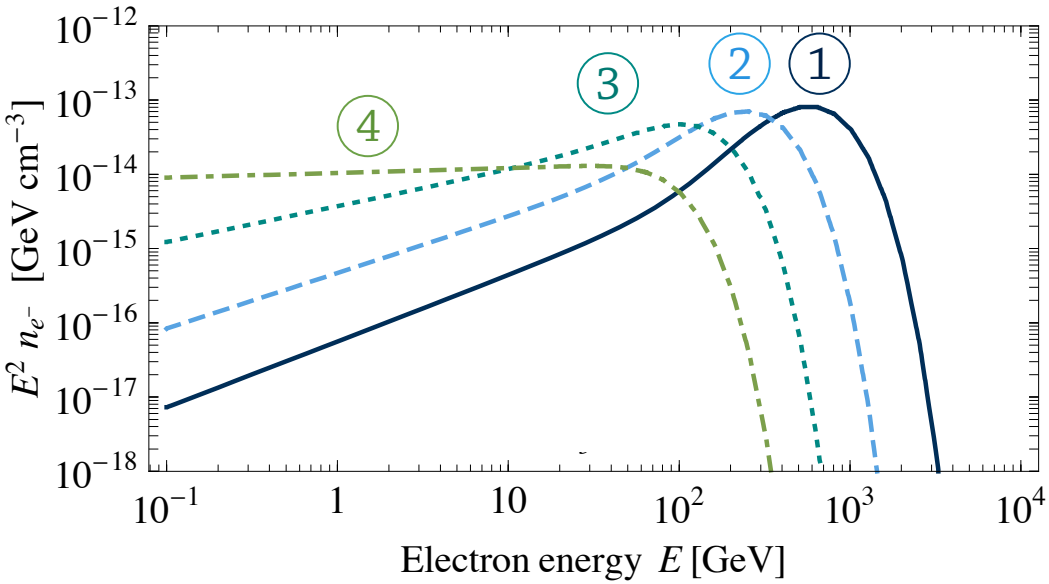
Mertsch & Sarkar, arXiv:1104.3585

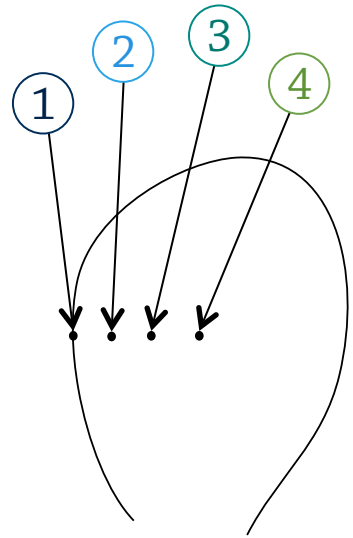
Timescales



Mertsch & Sarkar, arXiv:1104.3585

Electron spectrum



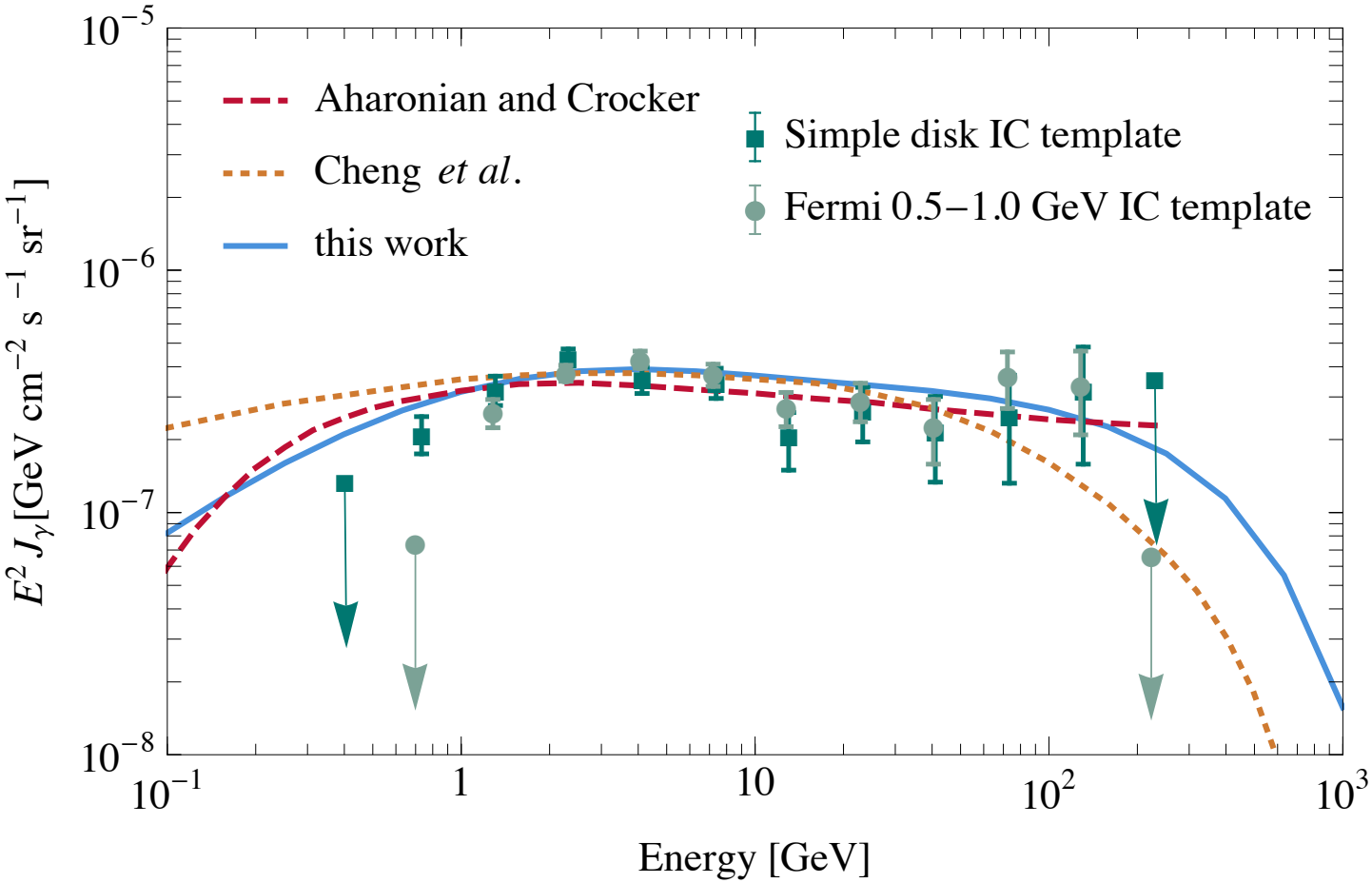


total energy in electrons above 100 MeV: ~ 10^{51} erg

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

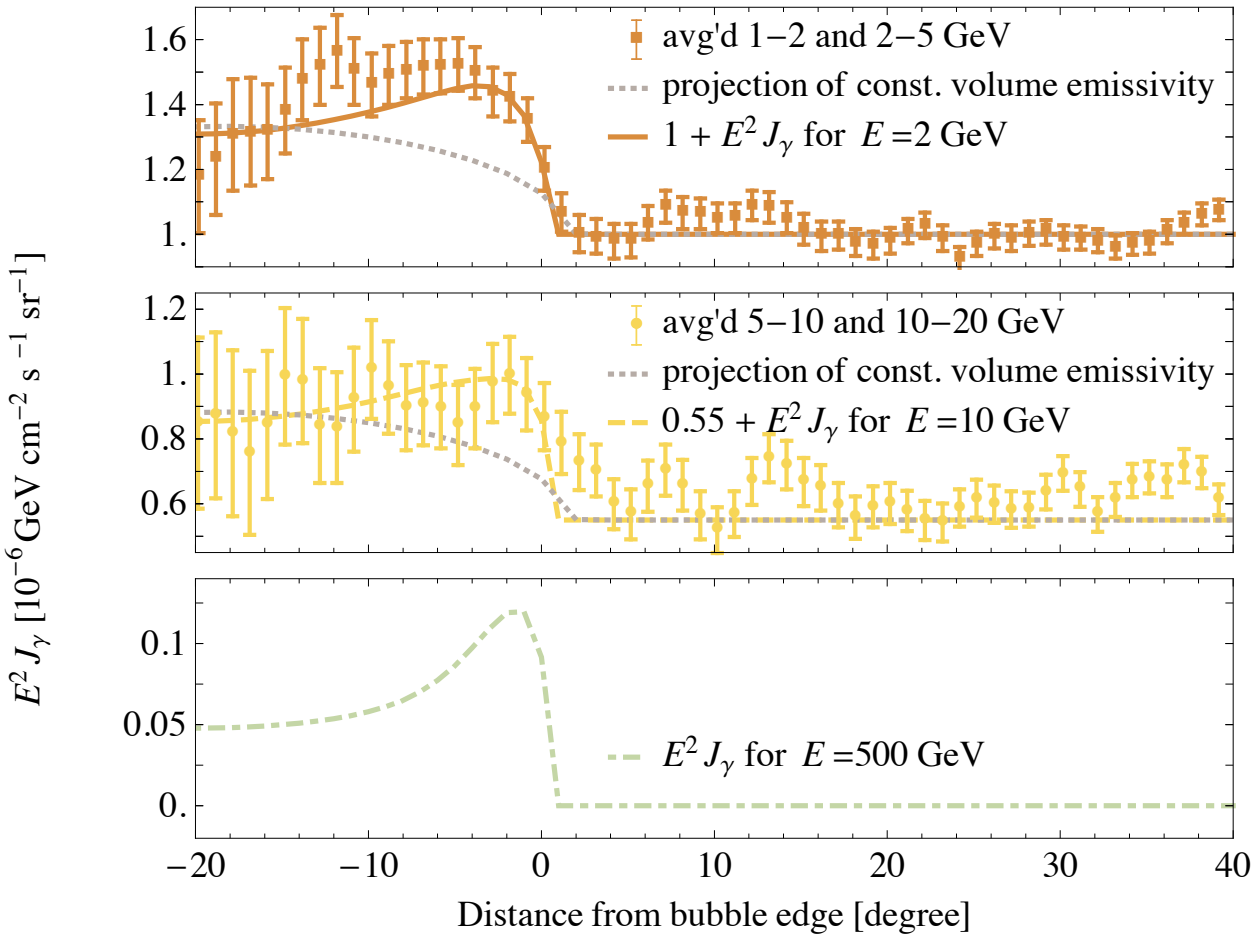
Mertsch & Sarkar, arXiv:1104.3585

Bubble spectrum



Mertsch & Sarkar, arXiv:1104.3585

Bubble profile

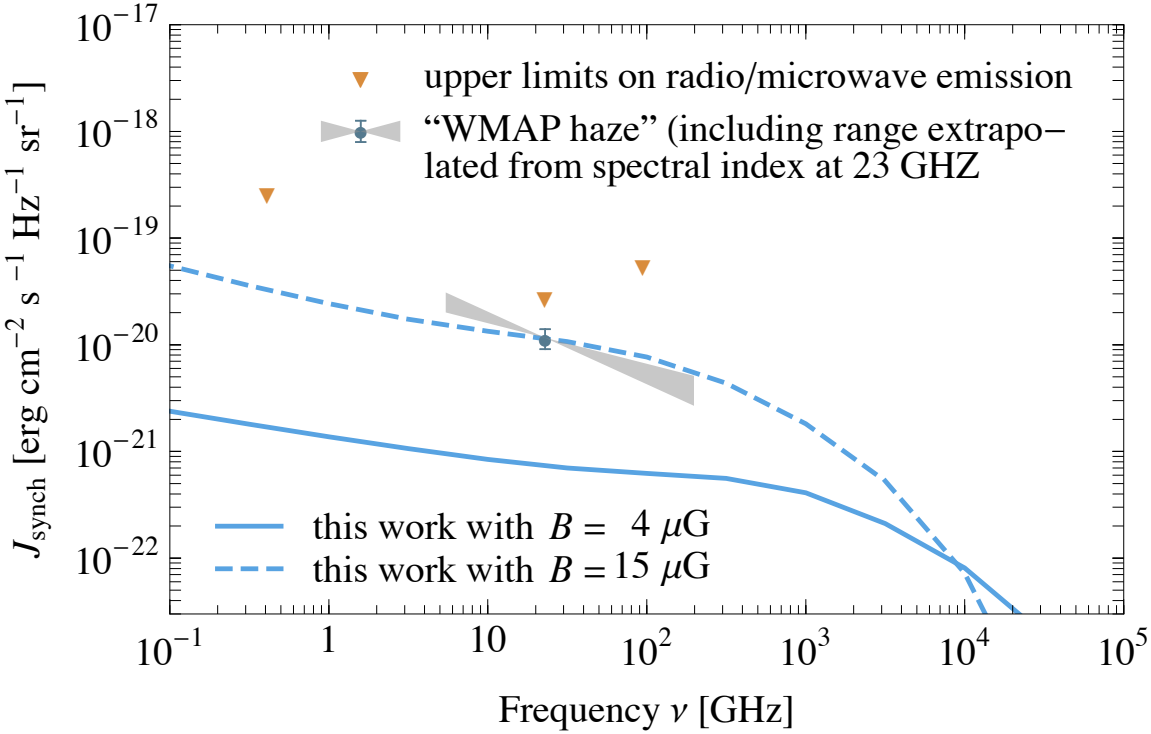


Mertsch & Sarkar, arXiv:1104.3585

Other messengers

leptonic origin of gamma-rays → no neutrinos

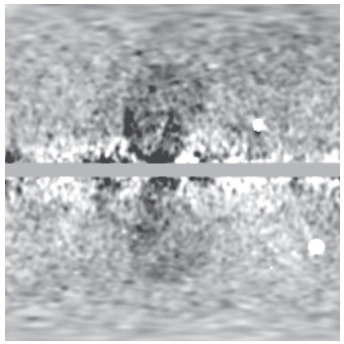
"WMAP haze" can only be matched with unrealistically high B field



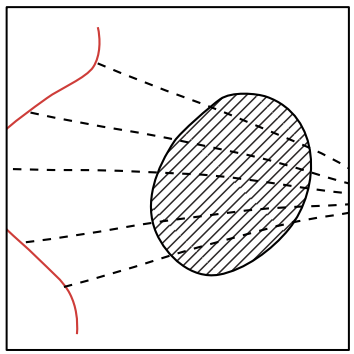
Mertsch & Sarkar, arXiv:1104.3585

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

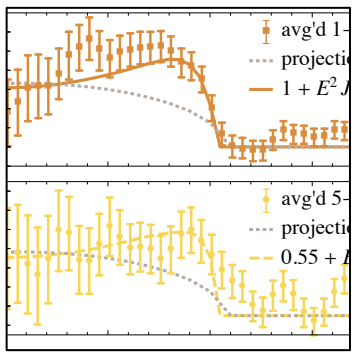
Summary



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