Observations of Fermi bubbles and Evidence for Past Activities in the Galactic Center

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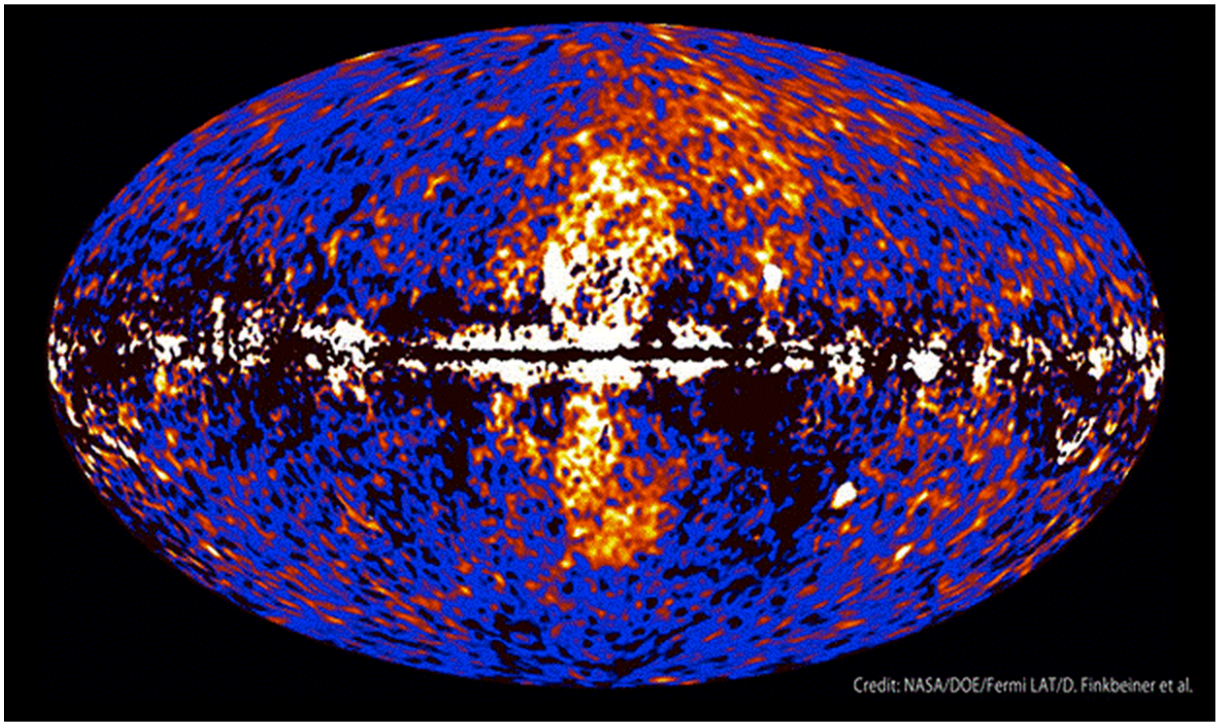
The Fermi Bubbles: Theory and Observations

April 11 - 12, 2013

SLAC National Accelerator Laboratory, Menlo Park, California



The Fermi bubbles are two large structures in gamma-rays above and below the Galactic center. They are associated with the microwave haze around the Galactic center discovered in the WMAP data and recently confirmed in the Planck data. At the moment, there are several theoretical models and simulations developed to explain the shape and the energy spectrum of the bubbles. In order to distinguish among the different models, a detailed comparison between the theory and the observations is necessary. The main purpose of the meeting is to foster a collaboration between the scientists working on the theoretical and observational sides of the problem in order to deepen our understanding of the origin and the emission mechanisms associated with the bubbles. The topics include: observational results related to the Galactic halo region, models and simulations designed to explain the bubbles, and related systems in other galaxies.

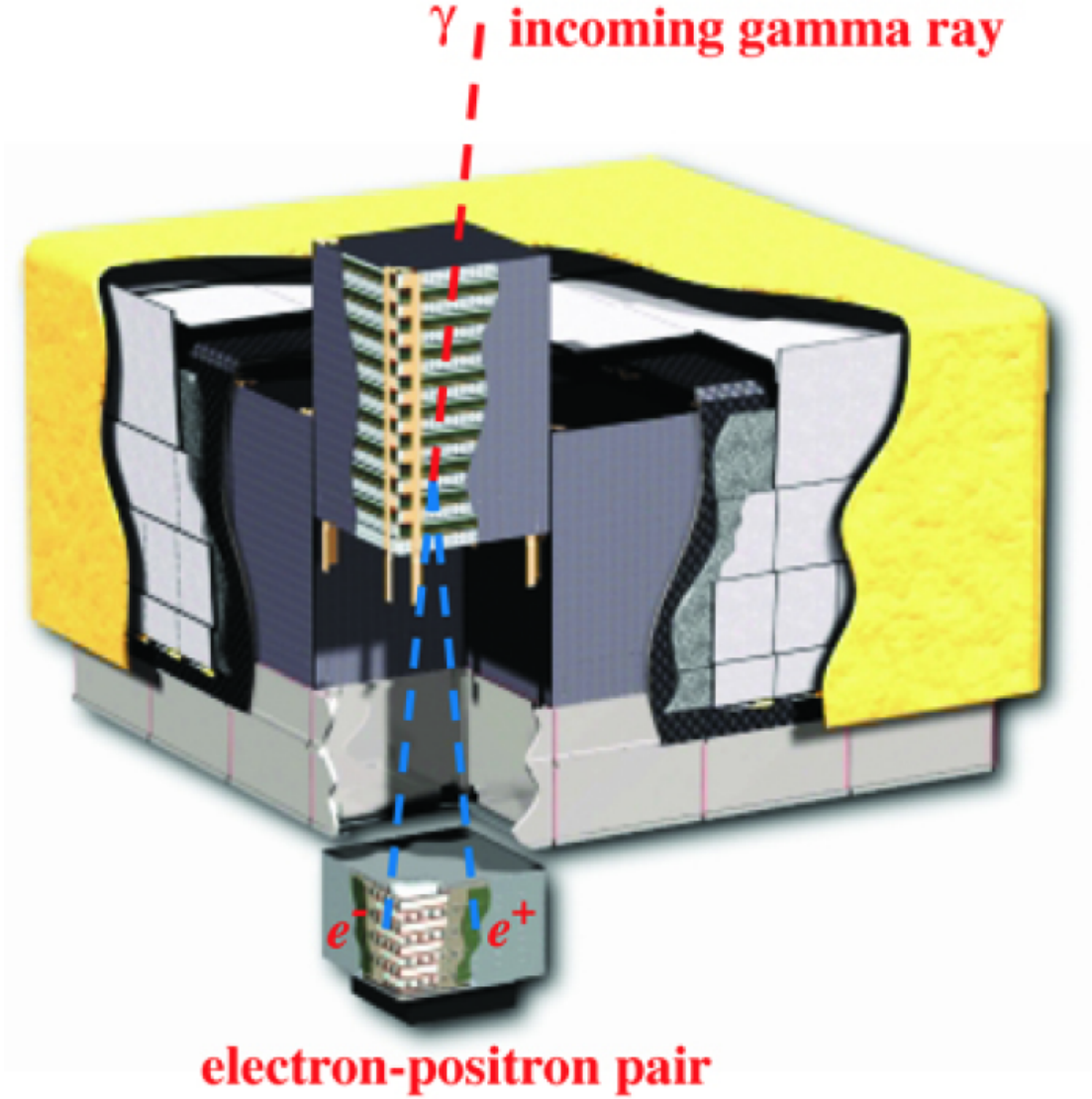
Fermi Bubbles

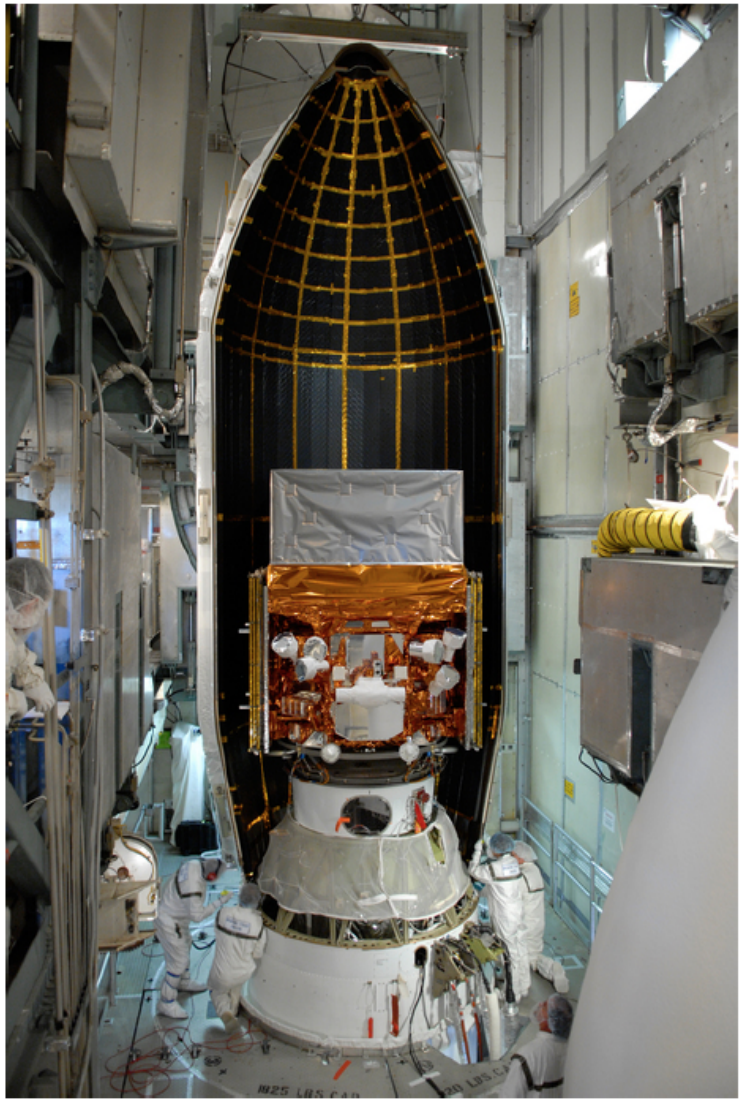
Giant gamma-ray structure with sharp edges
Discovered using data from Large Area Telescope (LAT) on-board Fermi Gamma-ray Space Telescope

Rise up & down from the Galactic center

They are:

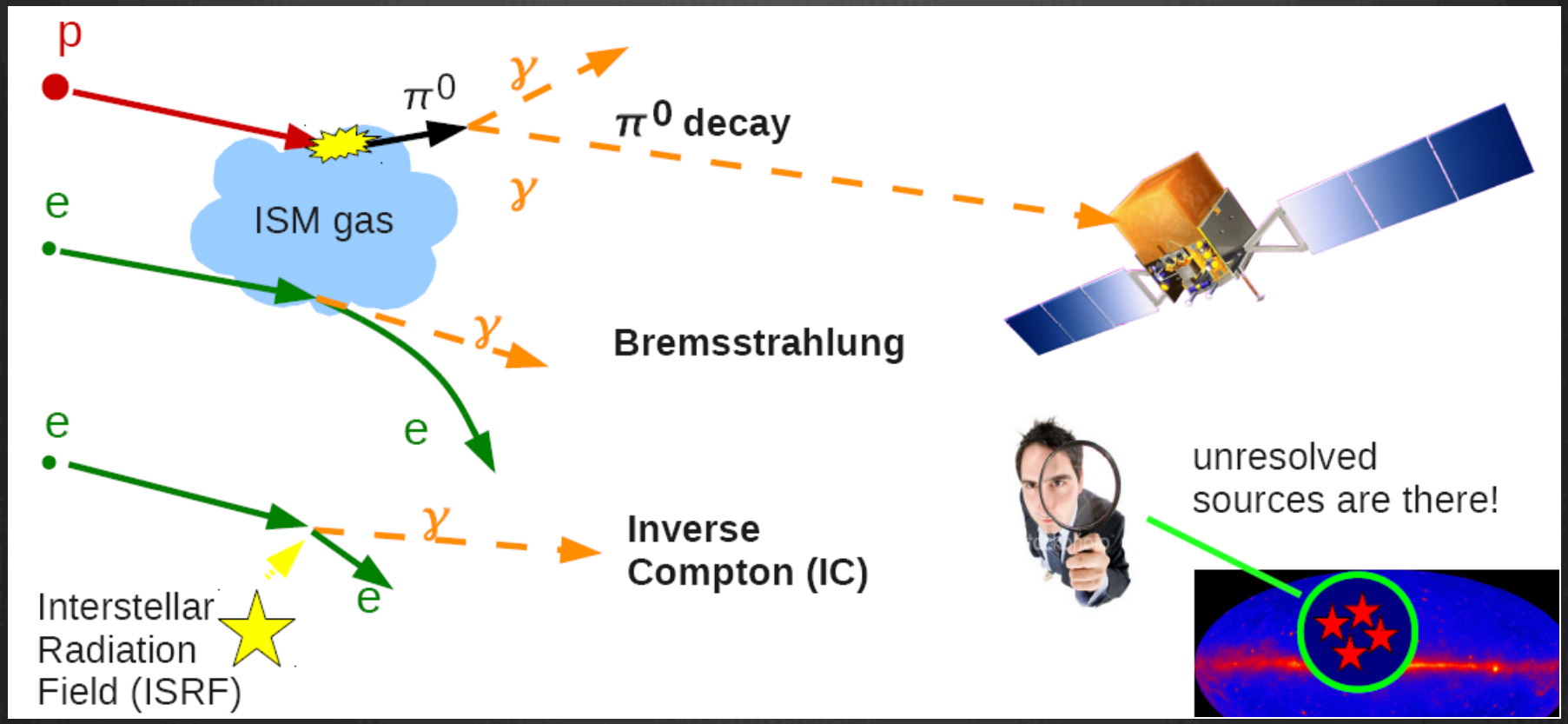
- *50 degrees high (~10 kpc)*
- *Well centered on longitude zero (close to latitude zero)*
- *Imply 100 GeV~TeV cosmic ray electron energy!*





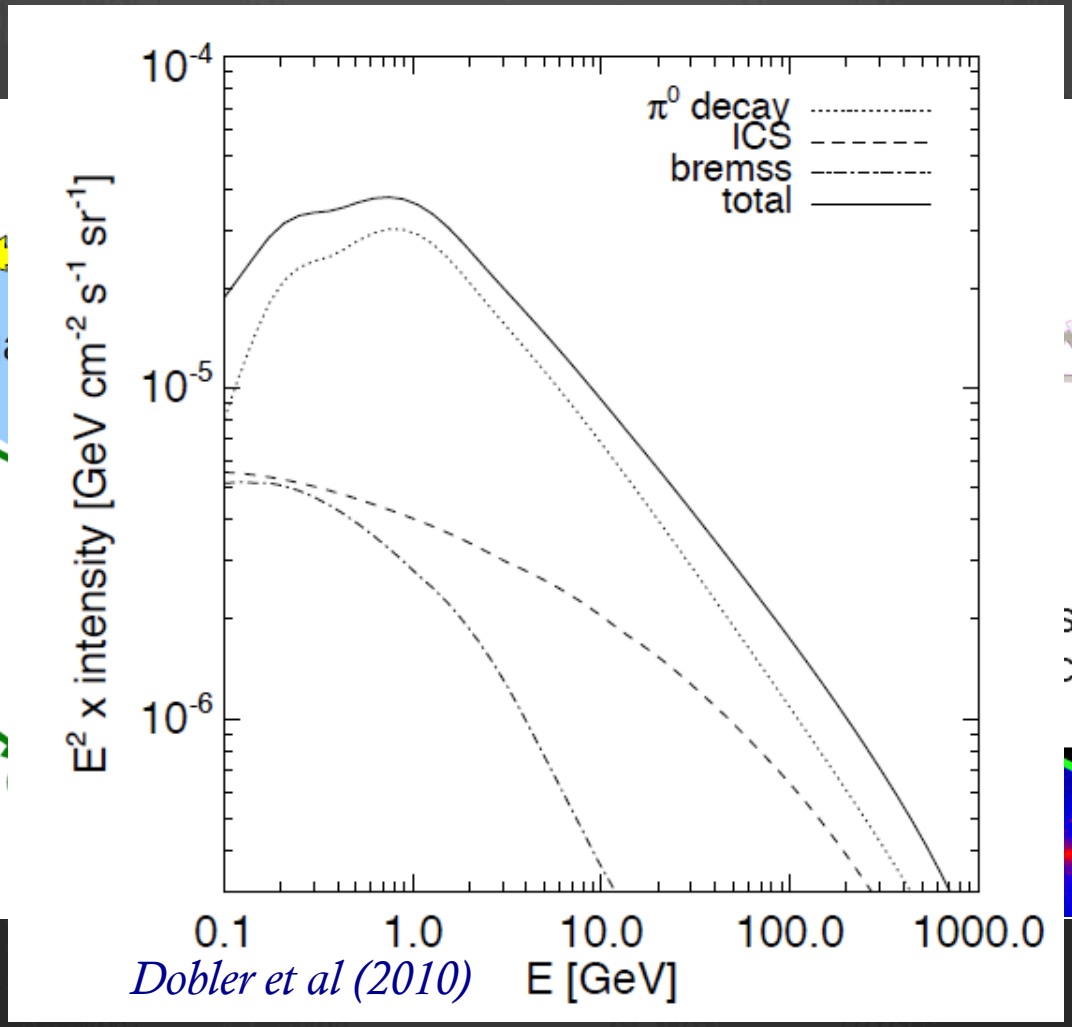
Fermi-LAT collaboration

Galactic Diffuse Gamma-ray Emission

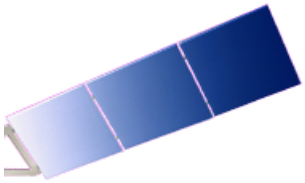


(from Tsunefumi Mizuno)

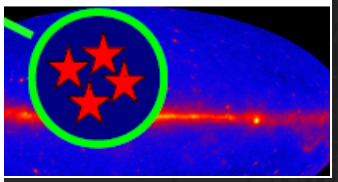
Galactic Diffuse Gamma-ray Emission



Dobler et al (2010)

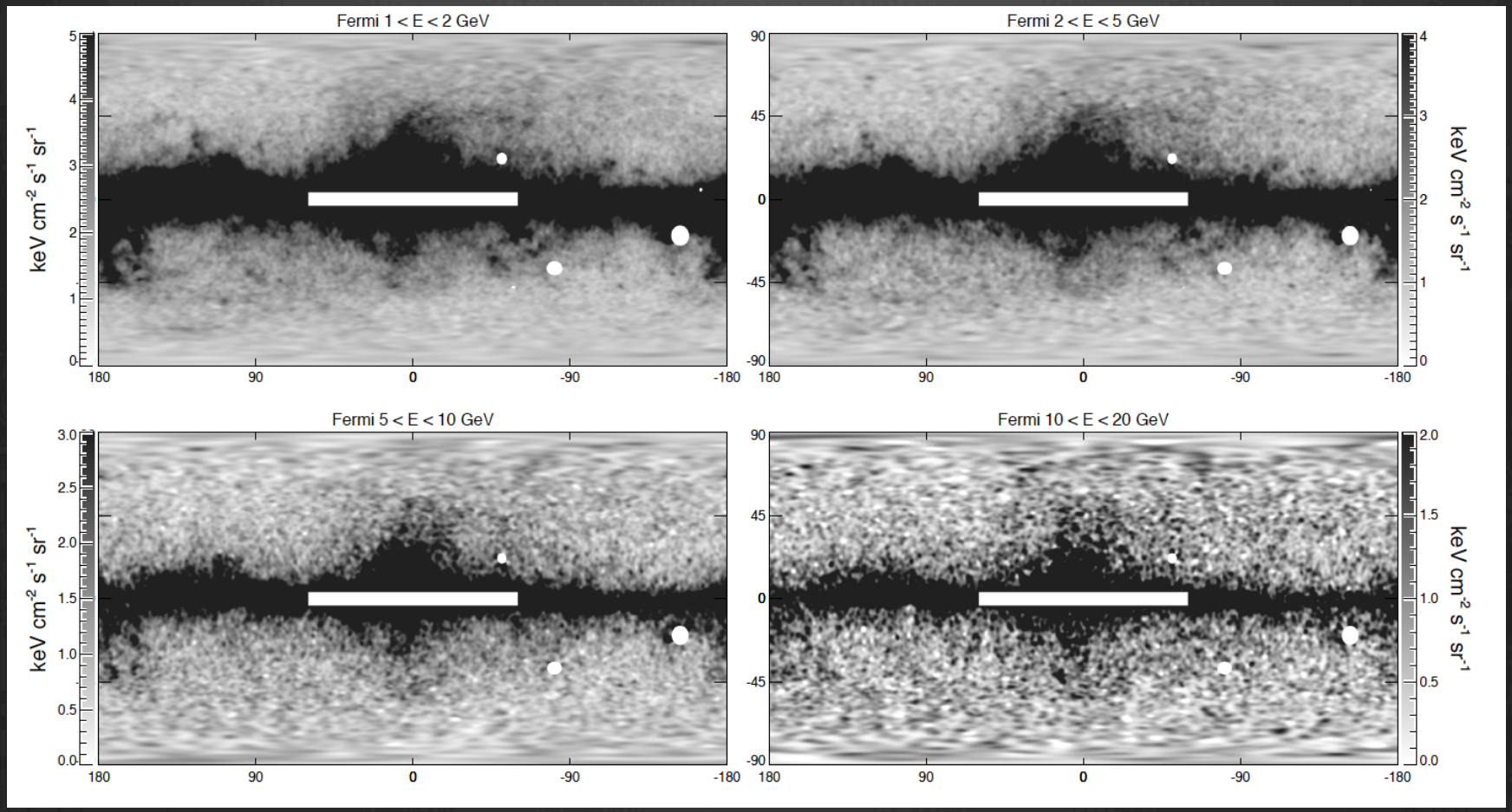


solved
ces are there!



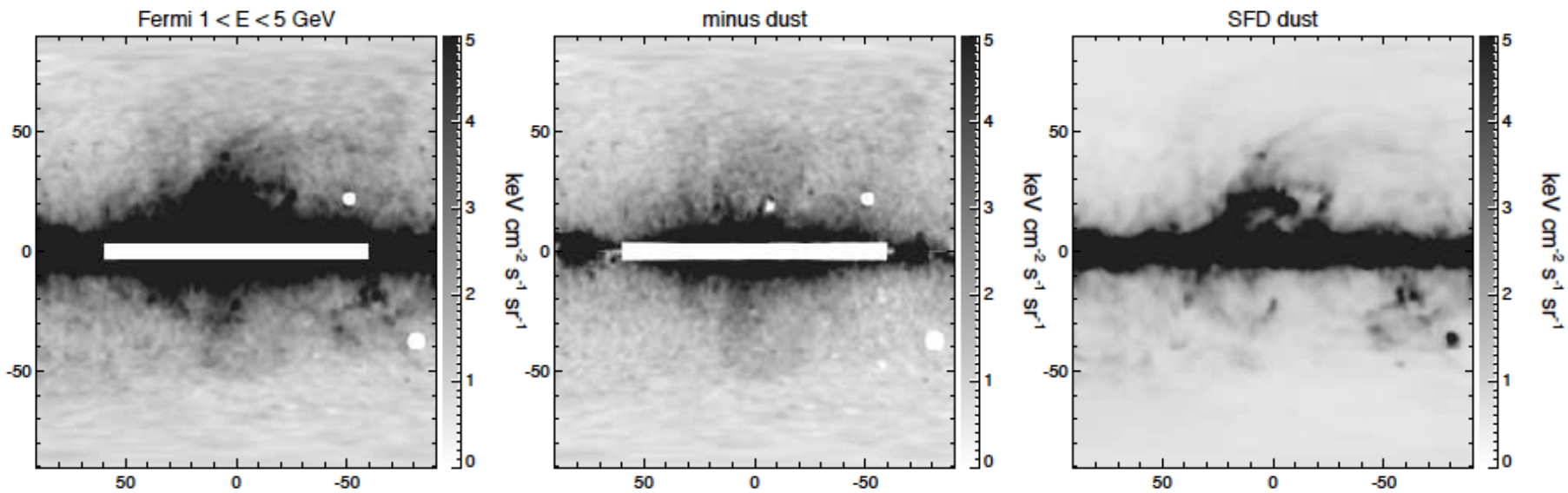
(from Tsunefumi Mizuno)

The Fermi-LAT 1.6 year maps



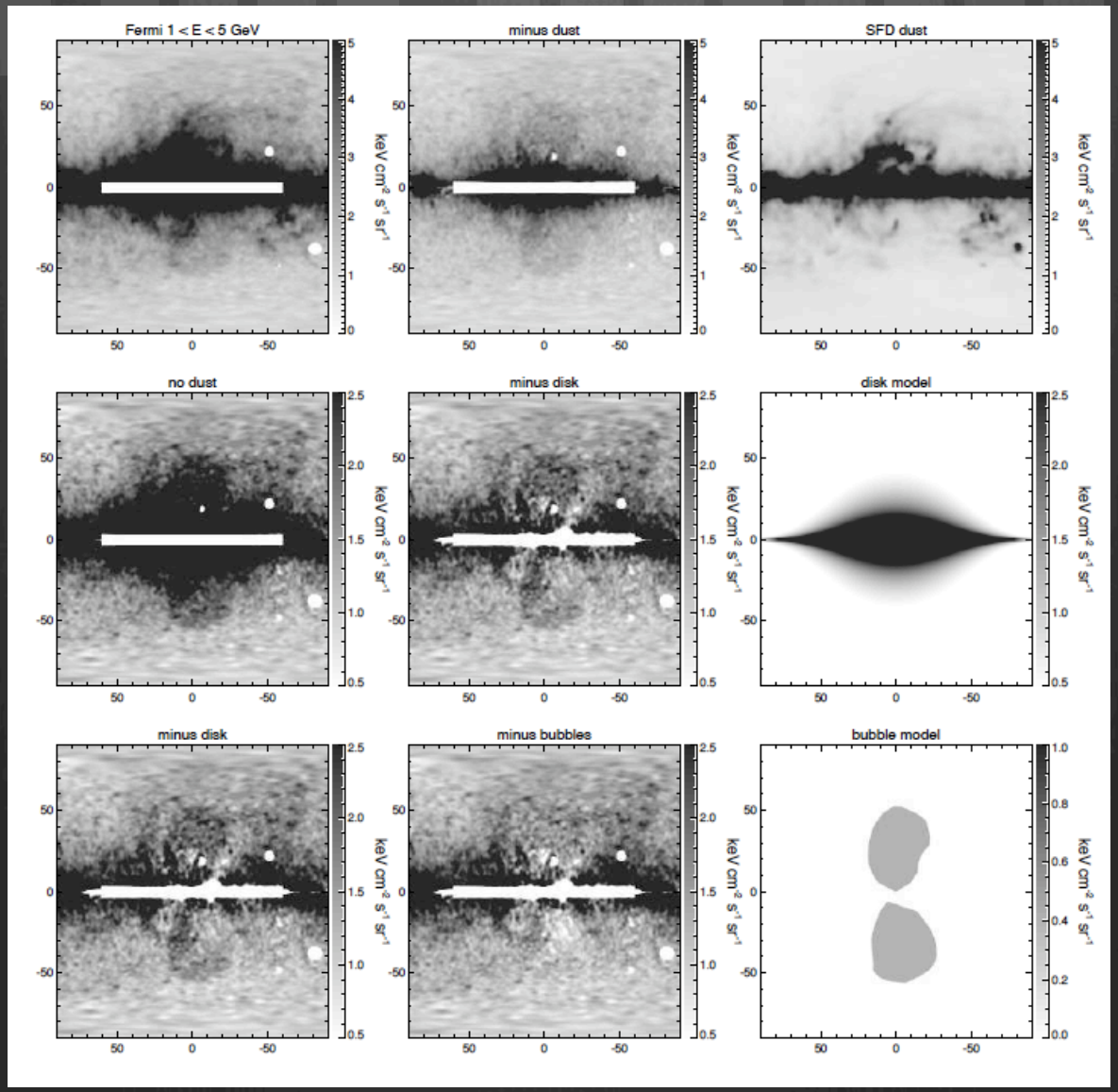
Su, Slatyer, Finkbeiner (2010)

Galactic dust map as a tracer of diffuse π^0 gamma-rays

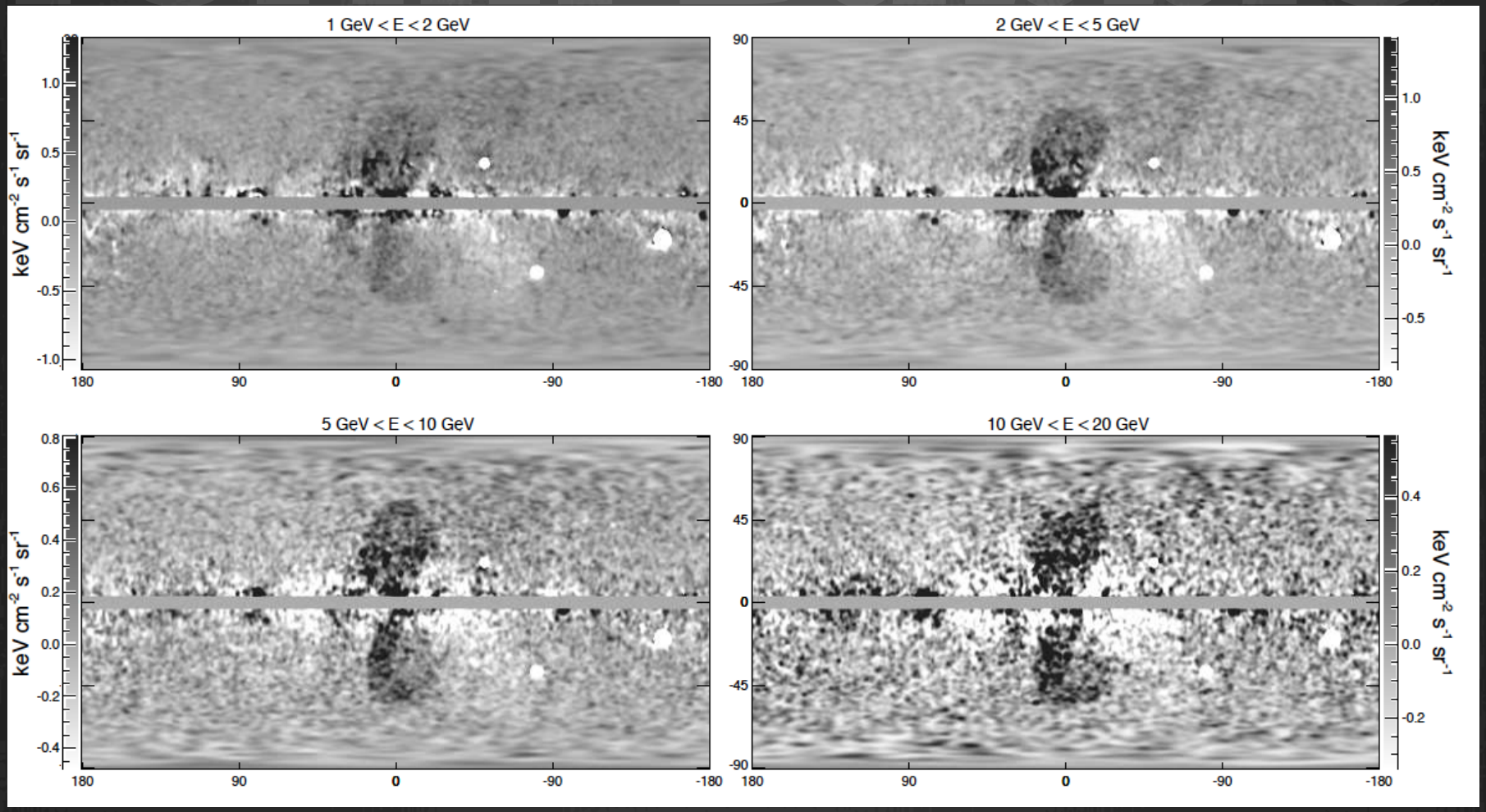


Schlegel, Finkbeiner, Davis (1998)
Su, Slatyer, Finkbeiner (2010)

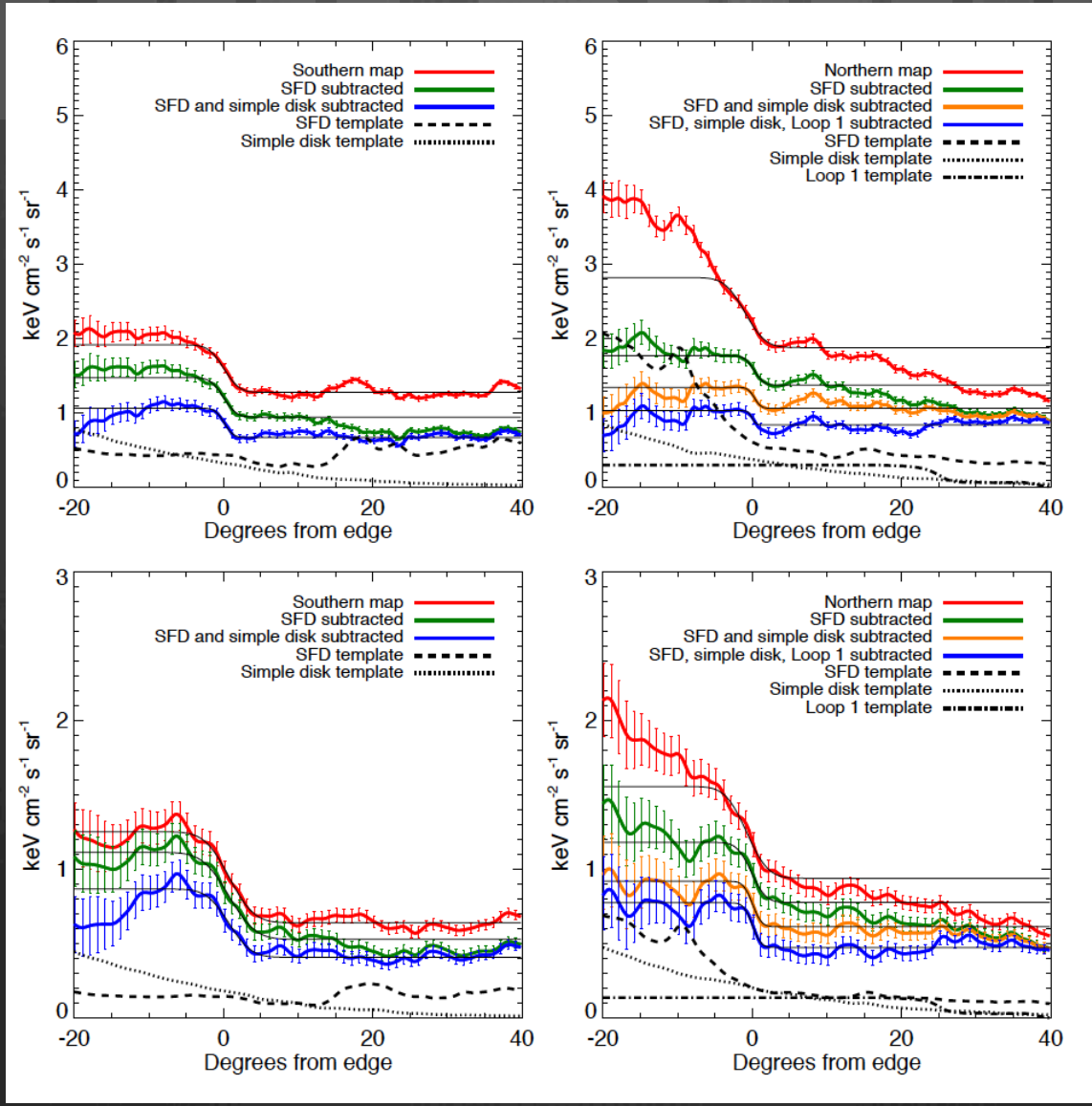
Simple disk model



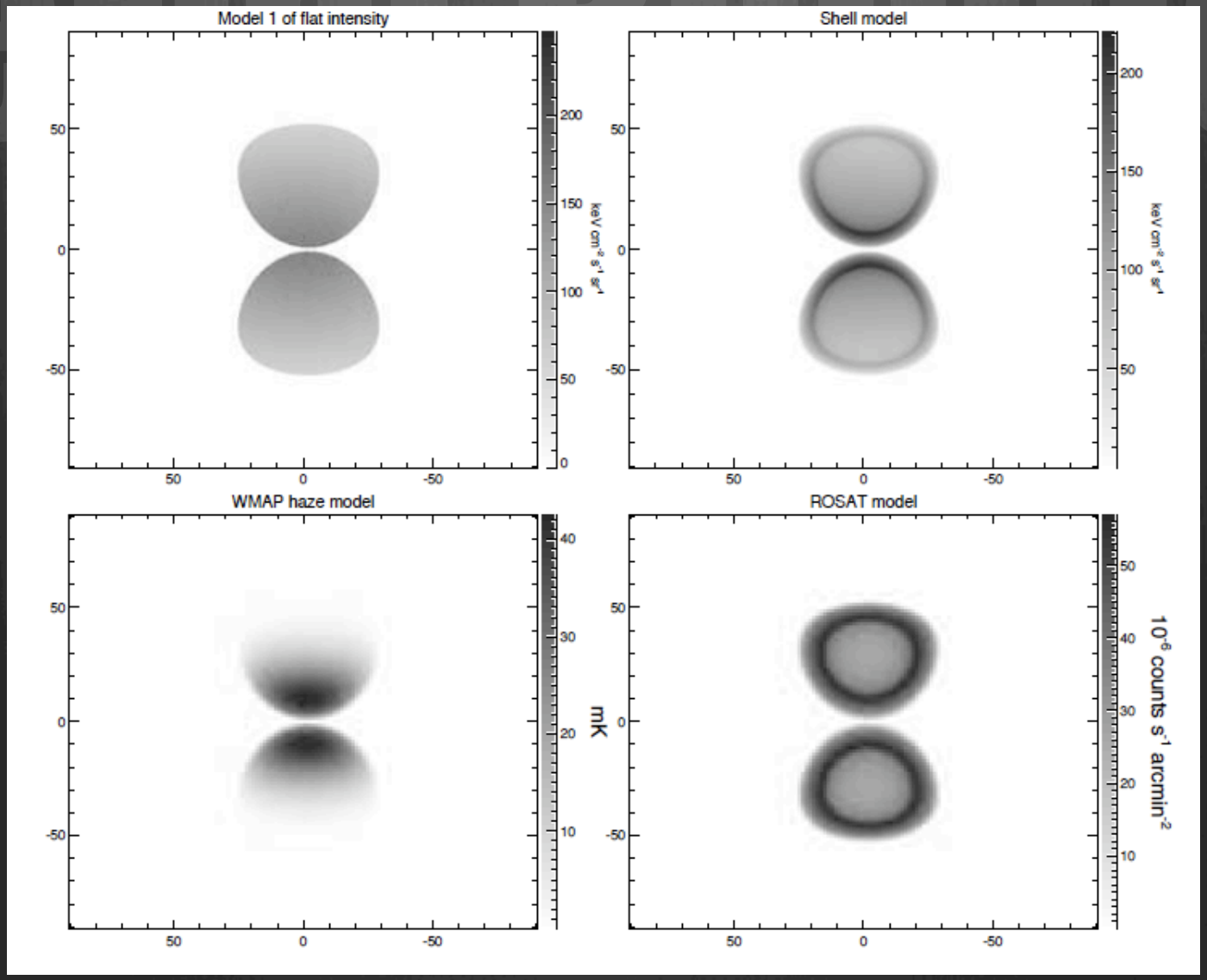
Data minus Fermi diffuse emission model:



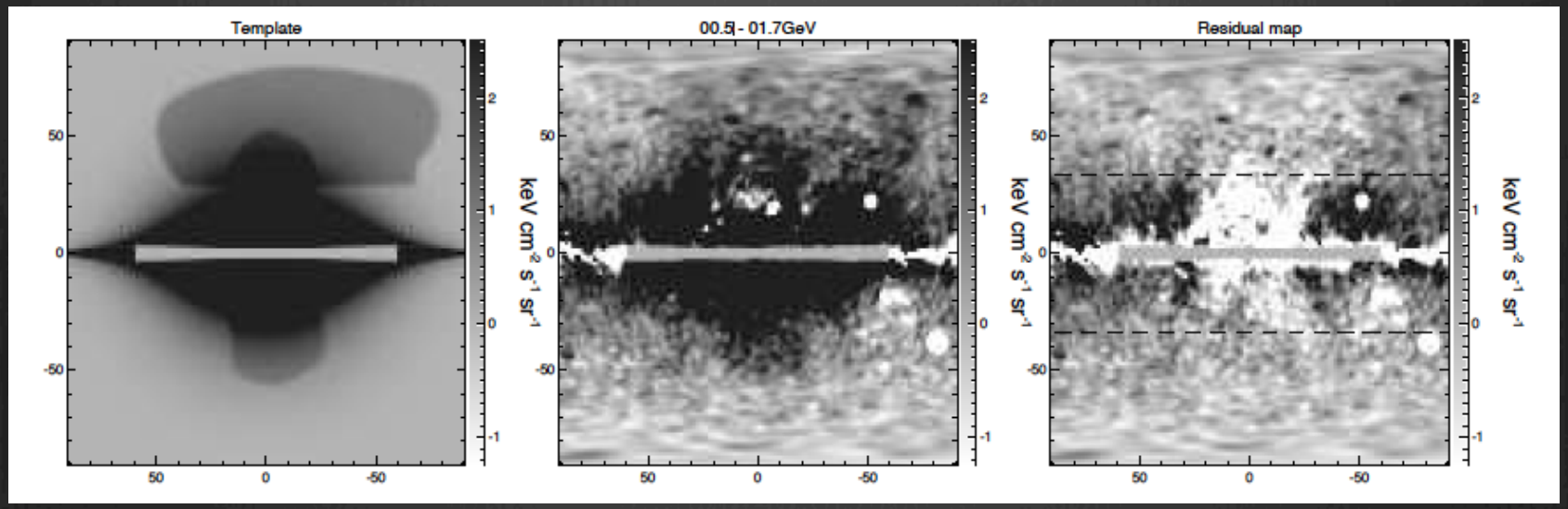
The bubbles have sharp edges!

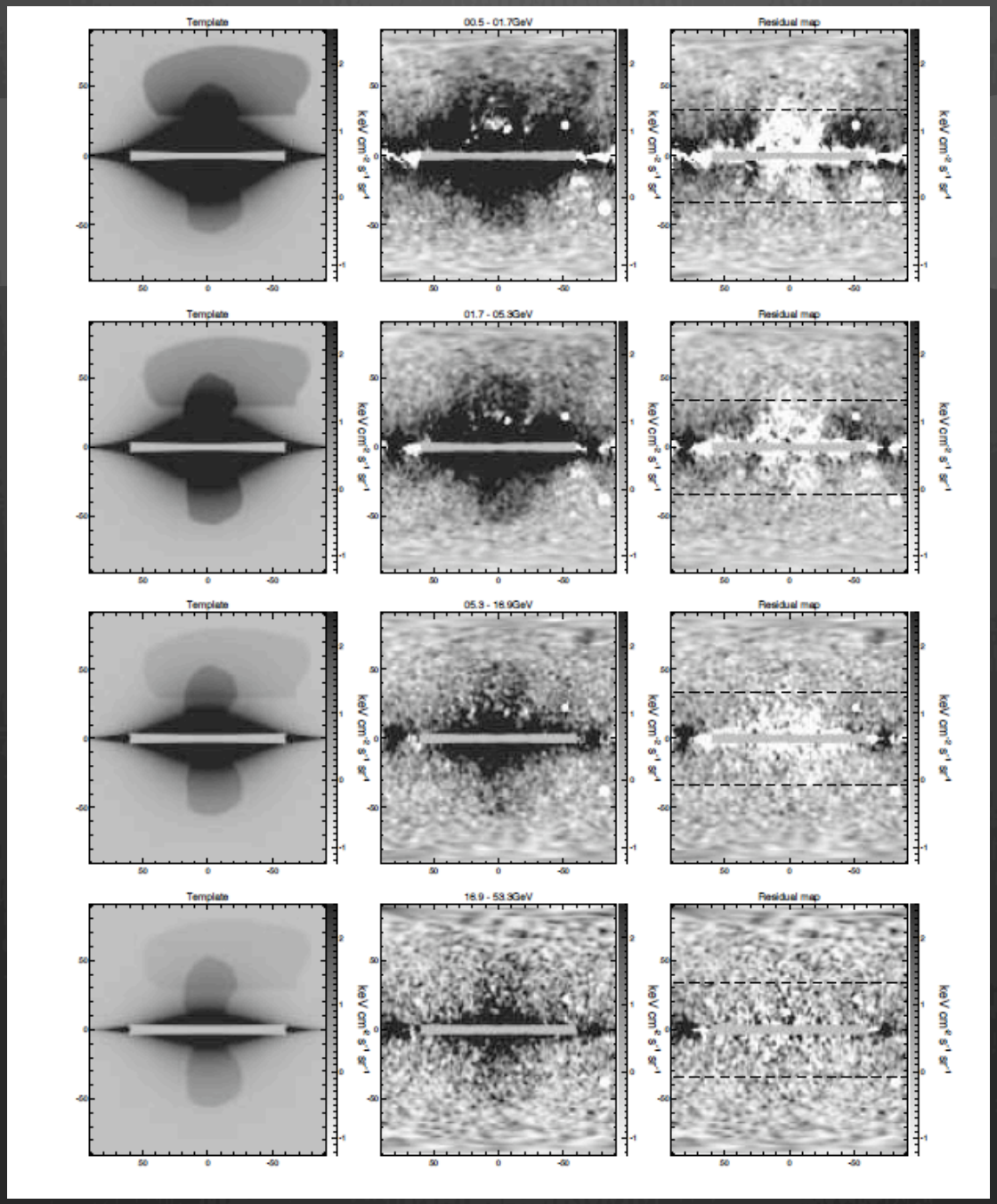


Fermi Bubble

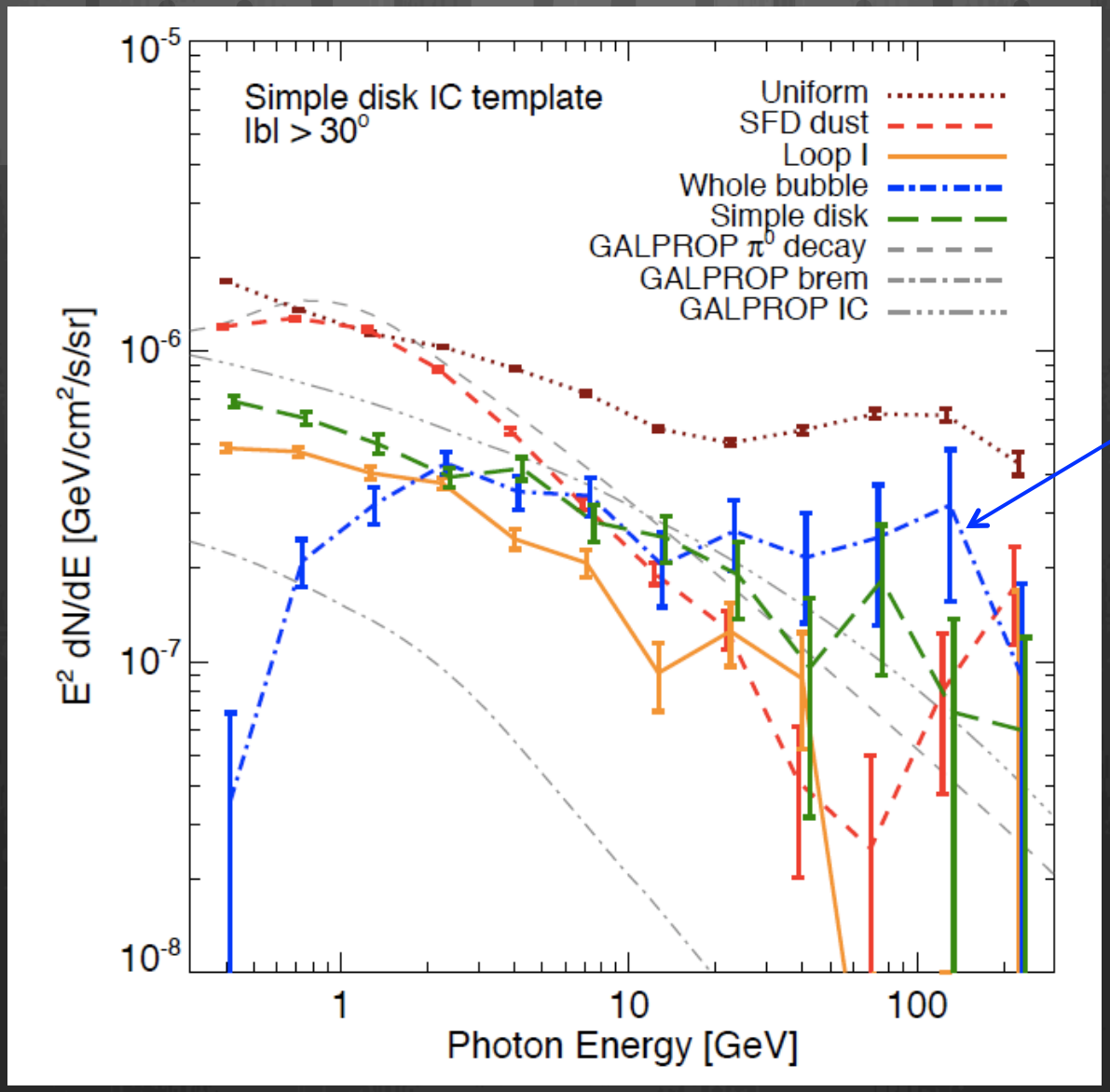


Compare model with data: simple geometric templates

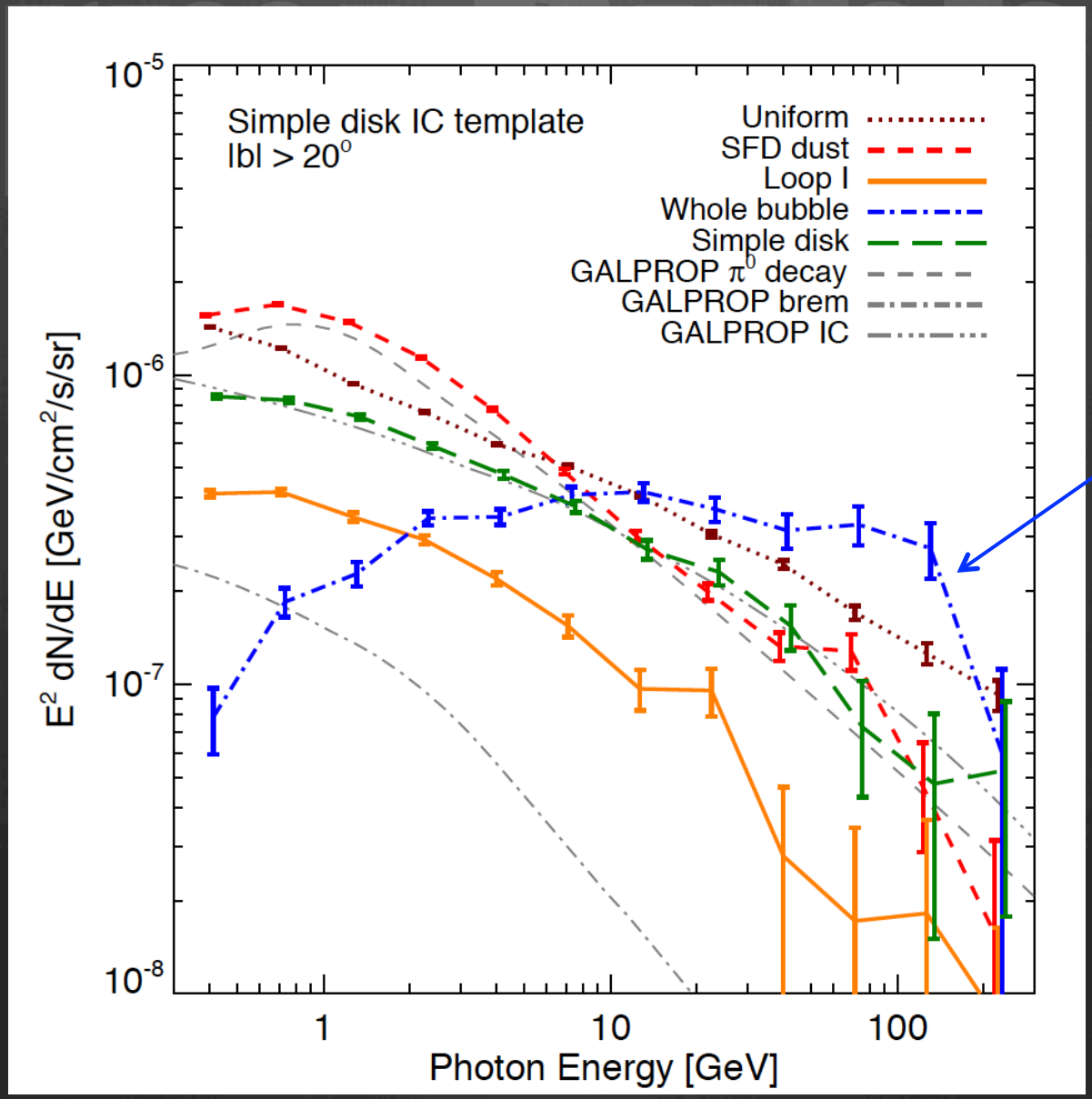



Template
00.5 - 01.7GeV
Residual map
keV cm^{-2} s^{-1} sr^{-1}
Template
01.7 - 05.3GeV
Residual map
keV cm^{-2} s^{-1} sr^{-1}
Template
05.3 - 16.9GeV
Residual map
keV cm^{-2} s^{-1} sr^{-1}
Template
16.9 - 53.3GeV
Residual map
keV cm^{-2} s^{-1} sr^{-1}

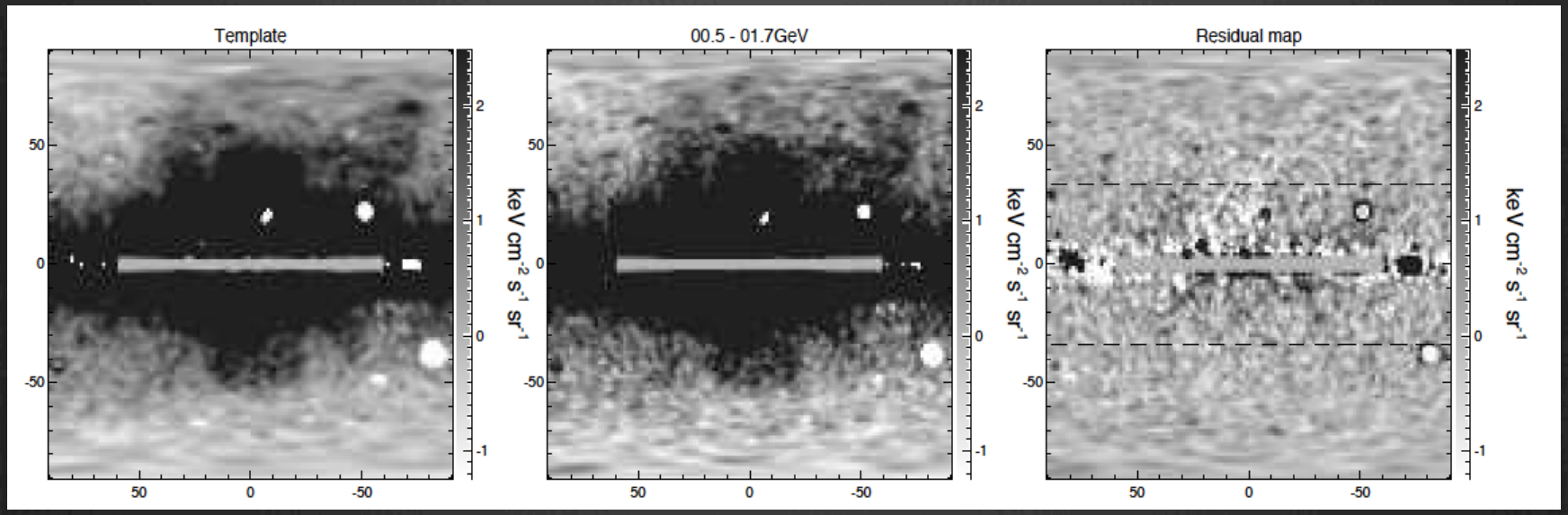
Fermi Bubble

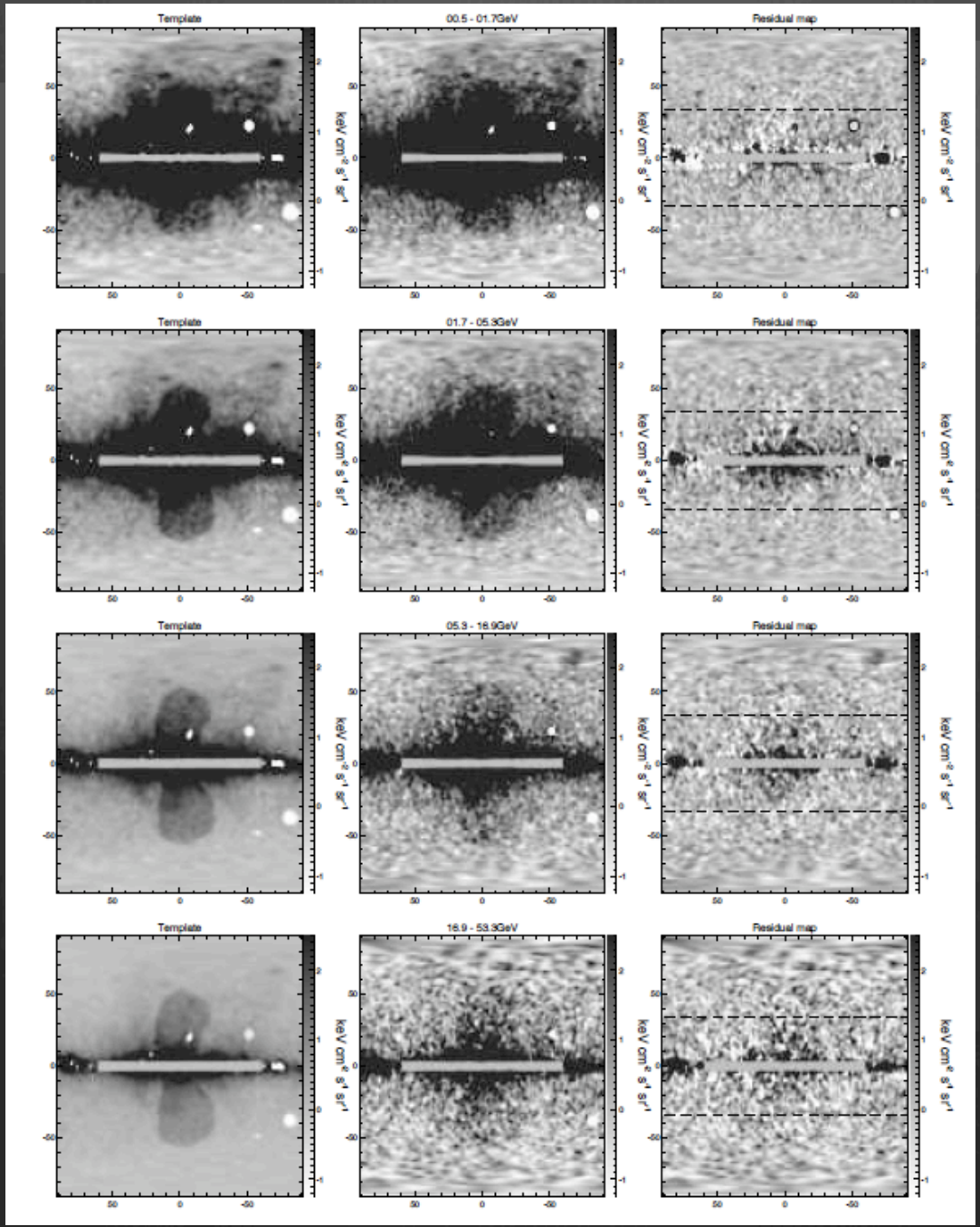


Su et al. (2010)

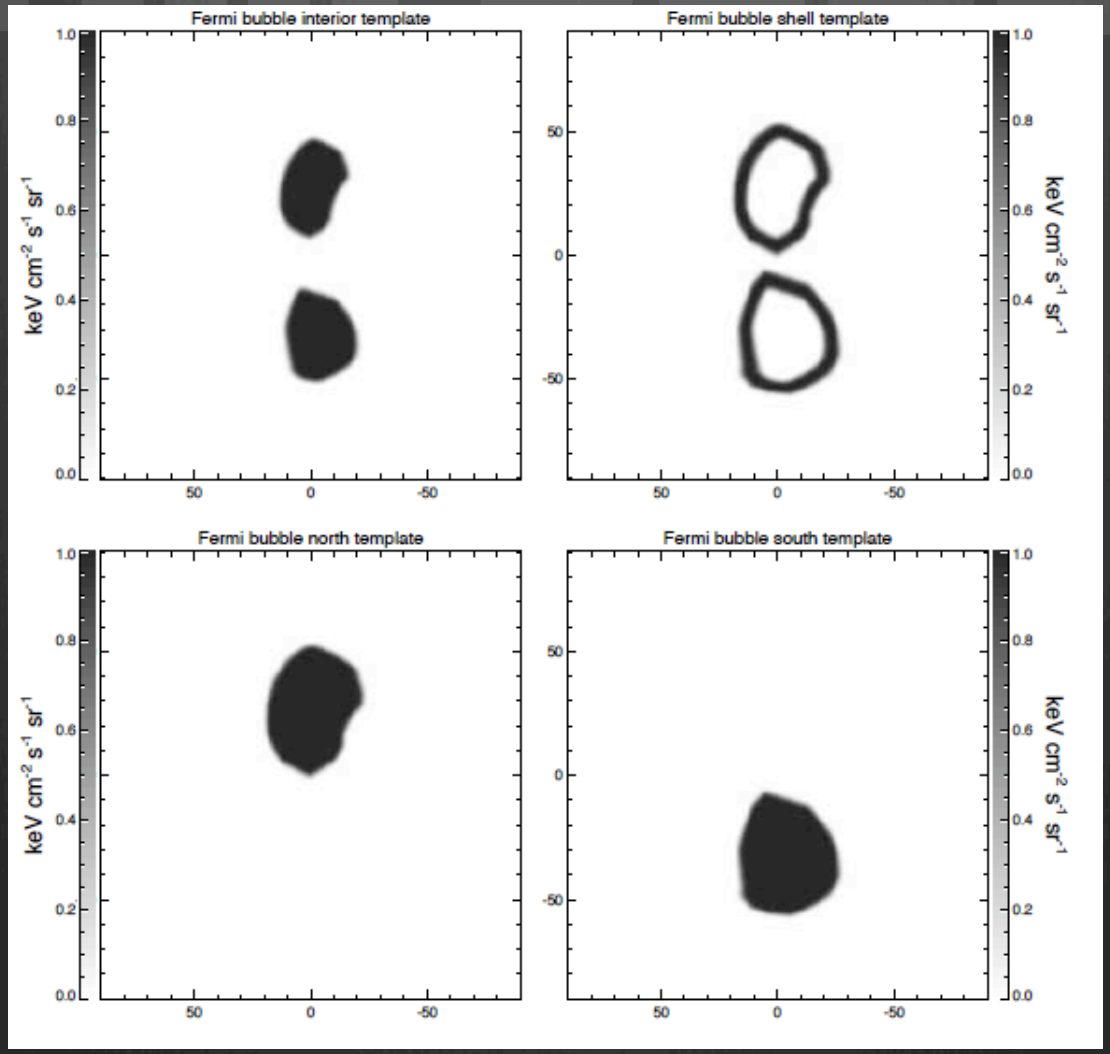

Simple disk IC template
|b| > 20°
Uniform
SFD dust
Loop I
Whole bubble
Simple disk
GALPROP π0 decay
GALPROP brem
GALPROP IC
E2 dN/dE [GeV/cm2/s/sr]
10-5
10-6
10-7
10-8
1
10
100
Photon Energy [GeV]

Compare model with data: Lower energy maps as templates



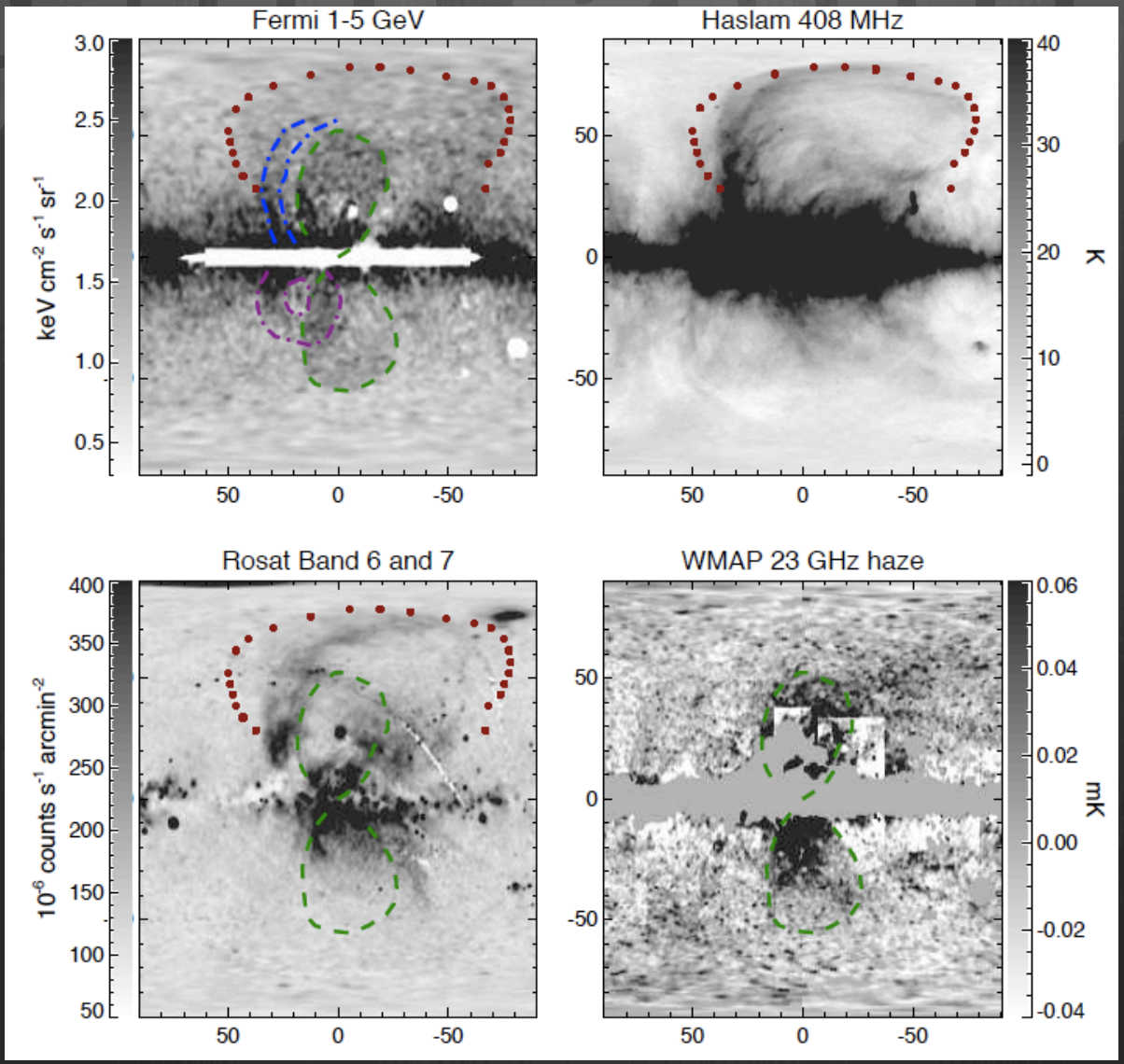

Template
00.5 - 01.7GeV
Residual map
Template
01.7 - 05.3GeV
Residual map
Template
05.3 - 16.9GeV
Residual map
Template
16.9 - 53.3GeV
Residual map
keV cm^{-2} s^{-1} sr^{-1}

Any substructure in the bubbles?



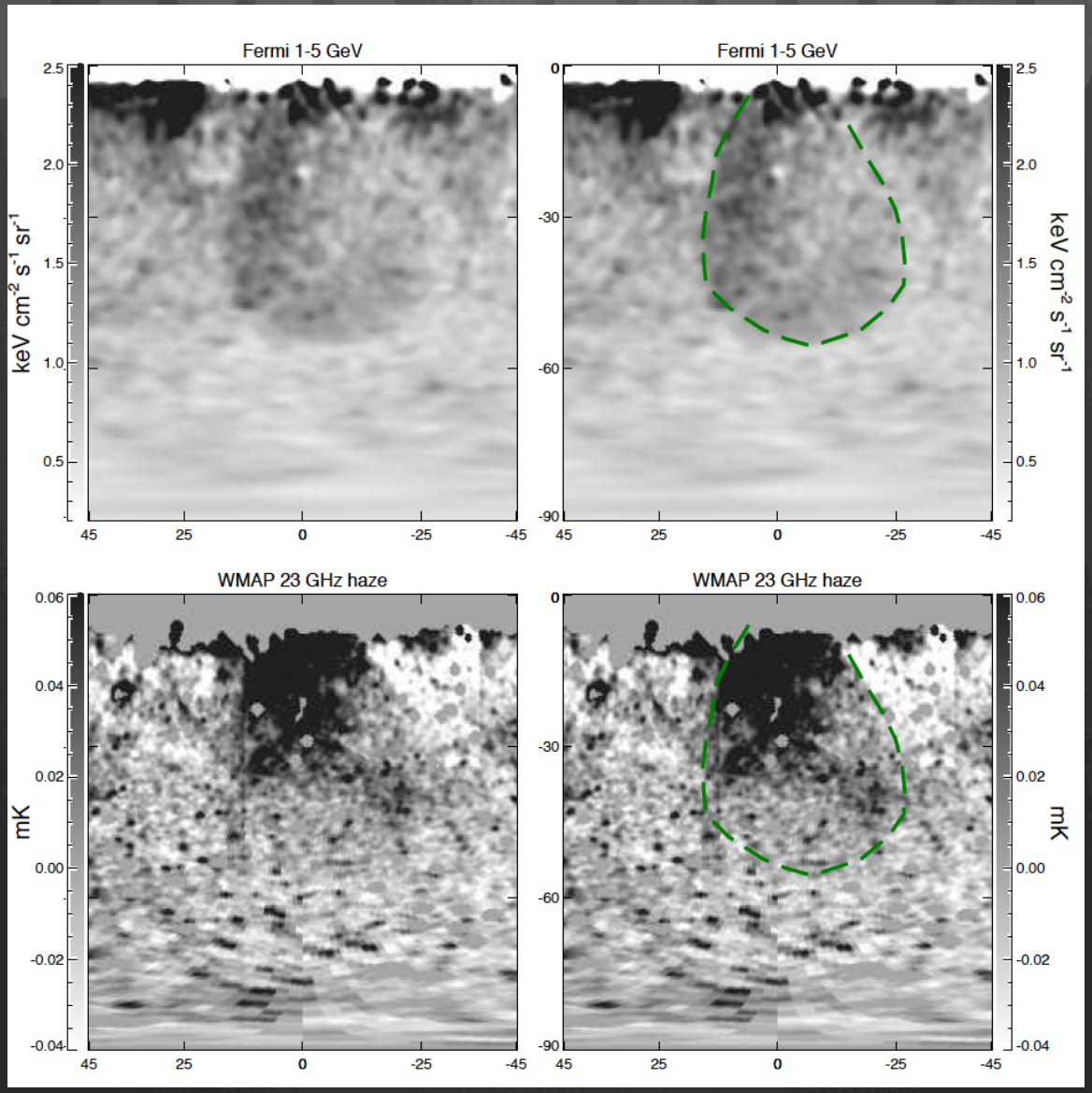
How about other wavelength?

Fermi Bubble



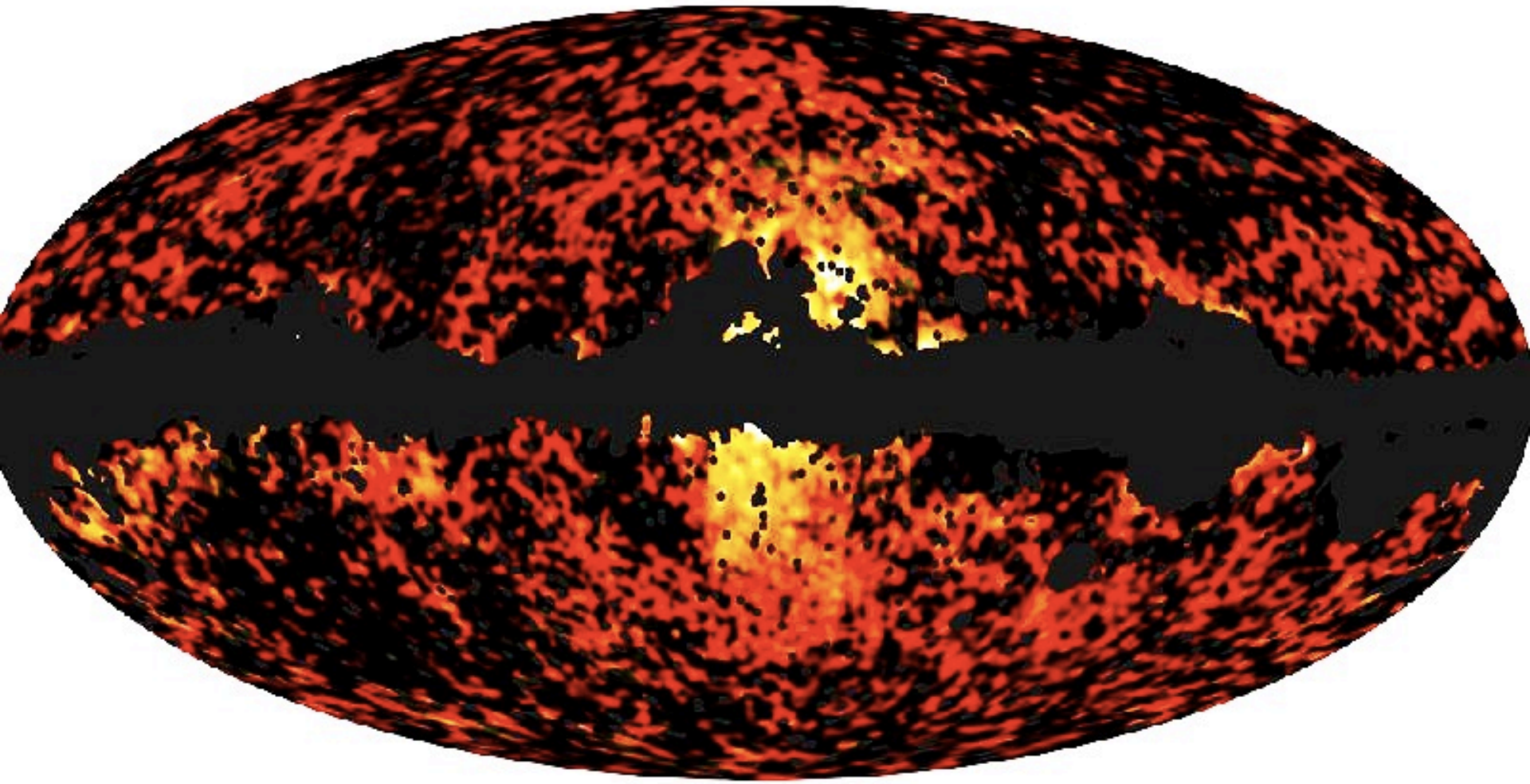
Su et al. (2010)

Compare with WMAP haze

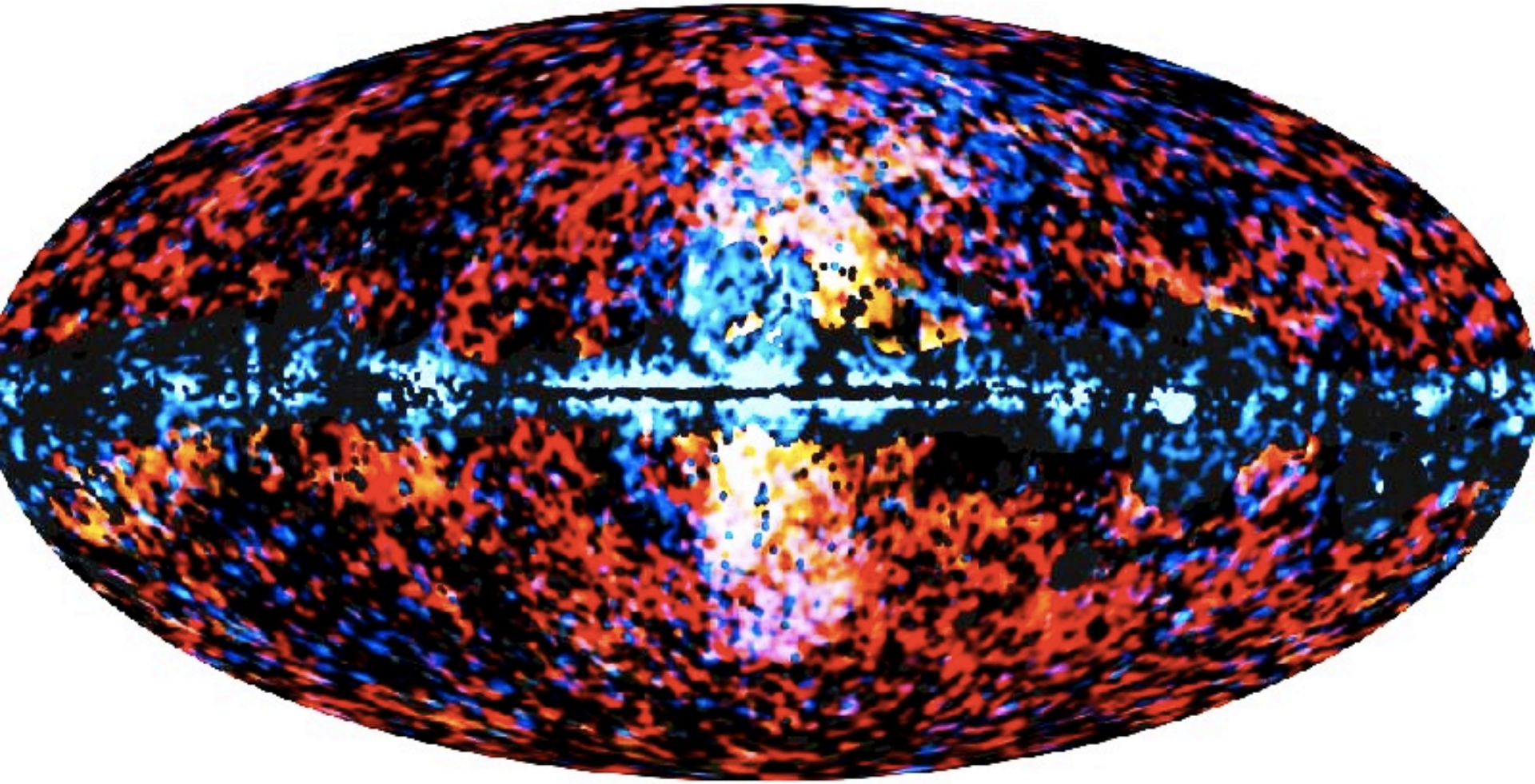


Fermi Bubble

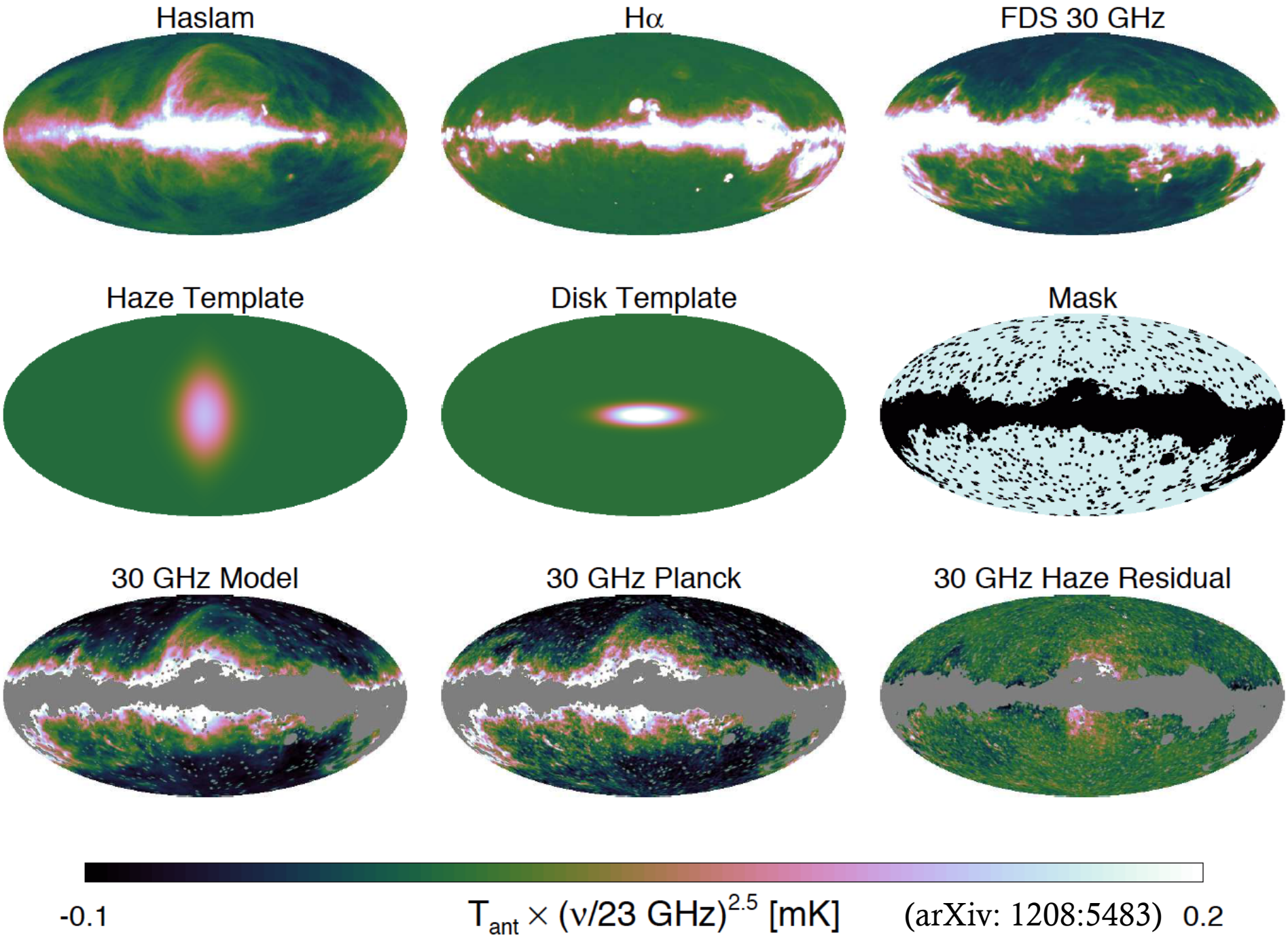
Update from Planck!

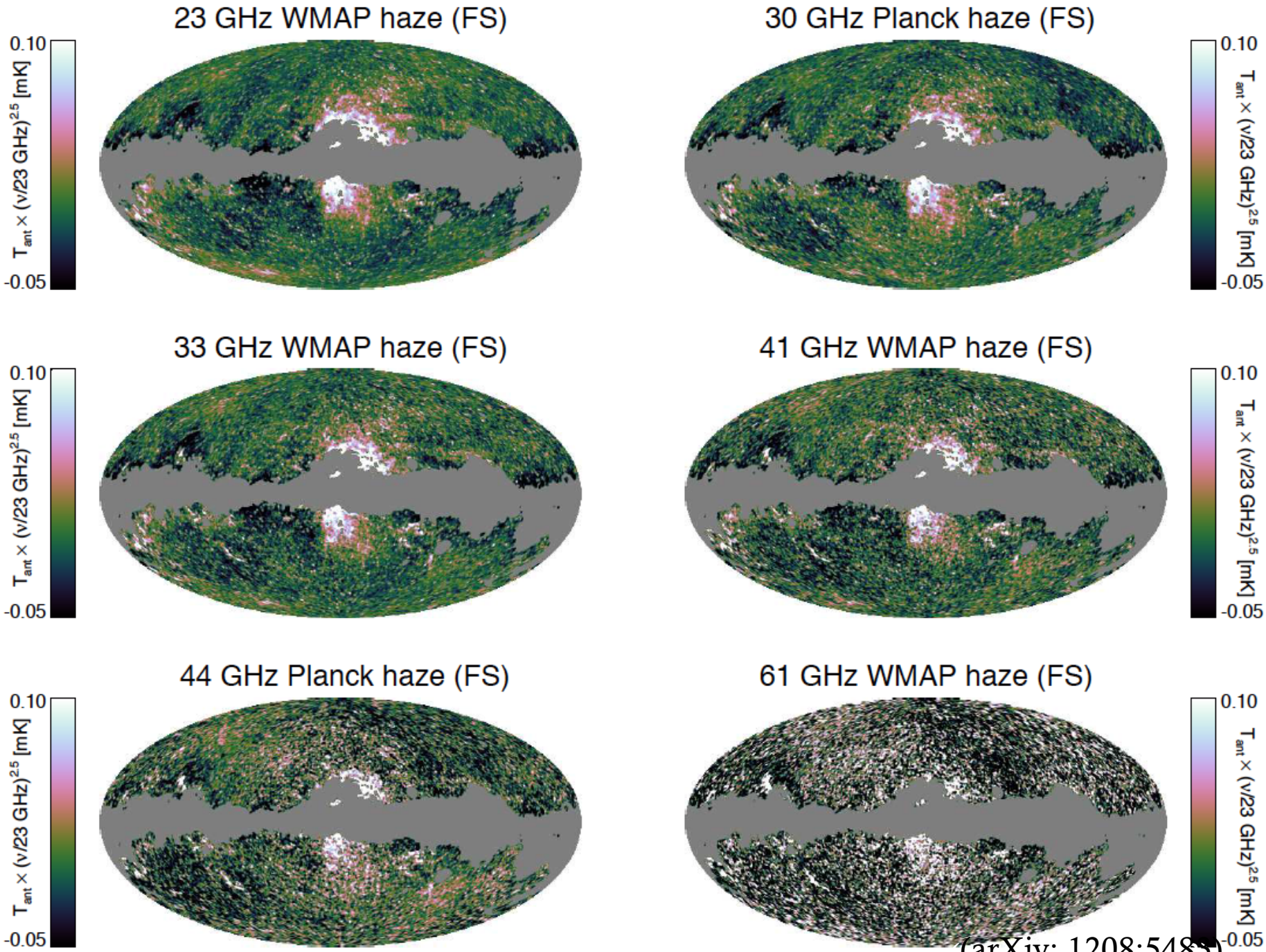


This all-sky image shows the spatial distribution over the whole sky of the galactic haze at 30 and 44 GHz, extracted from the Planck observations. Credits: ESA/Planck Collaboration.

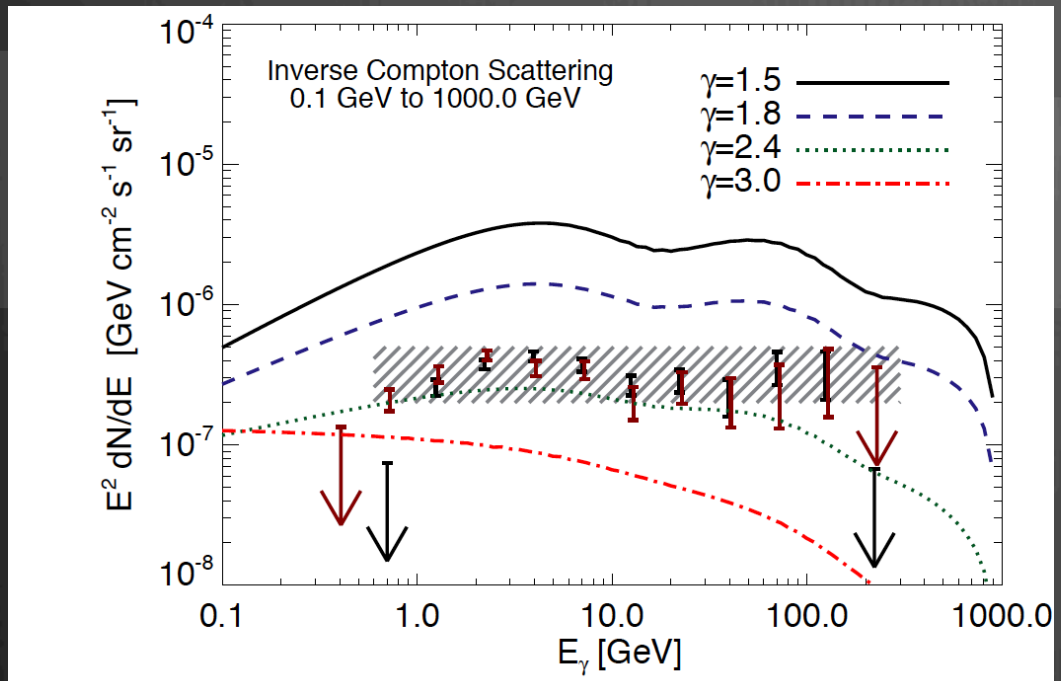


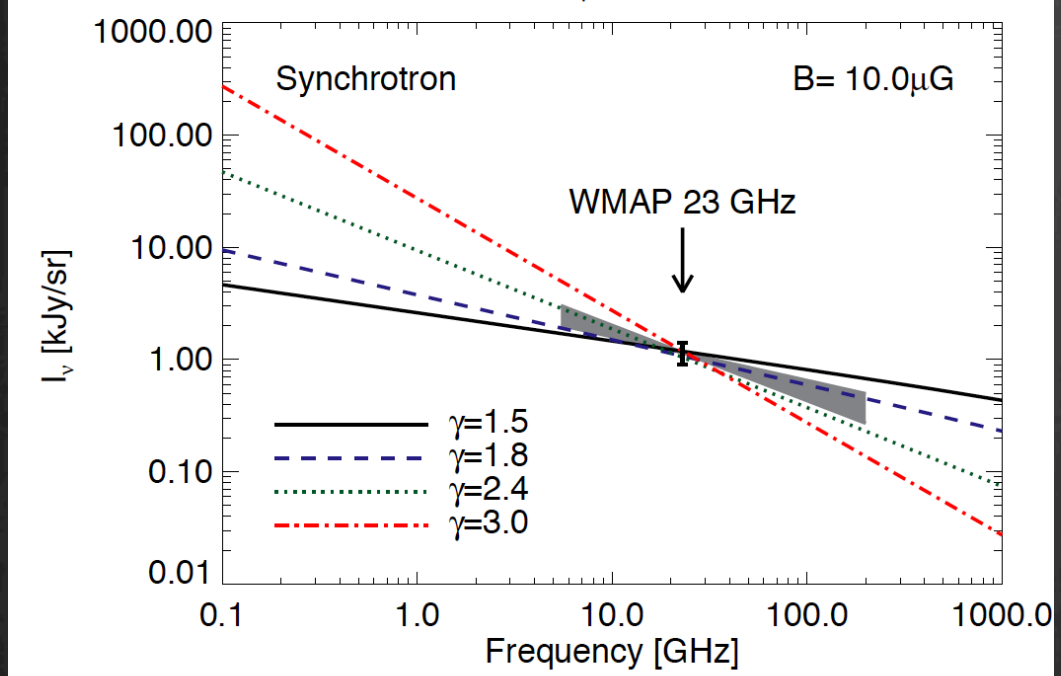
This all-sky image shows the distribution of the galactic haze seen by ESA's Planck mission at microwave frequencies superimposed over the high-energy sky, as seen by NASA's Fermi Gamma-ray Space Telescope. Credits: ESA/Planck Collaboration (microwave); NASA/DOE/Fermi LAT/D. Finkbeiner et al.


Haslam
Hα
FDS 30 GHz
Haze Template
Disk Template
Mask
30 GHz Model
30 GHz Planck
30 GHz Haze Residual
-0.1
$T_{ant} \times (\nu/23\ GHz)^{2.5}$ [mK]
(arXiv: 1208:5483)
0.2



(arXiv: 1208:5483)



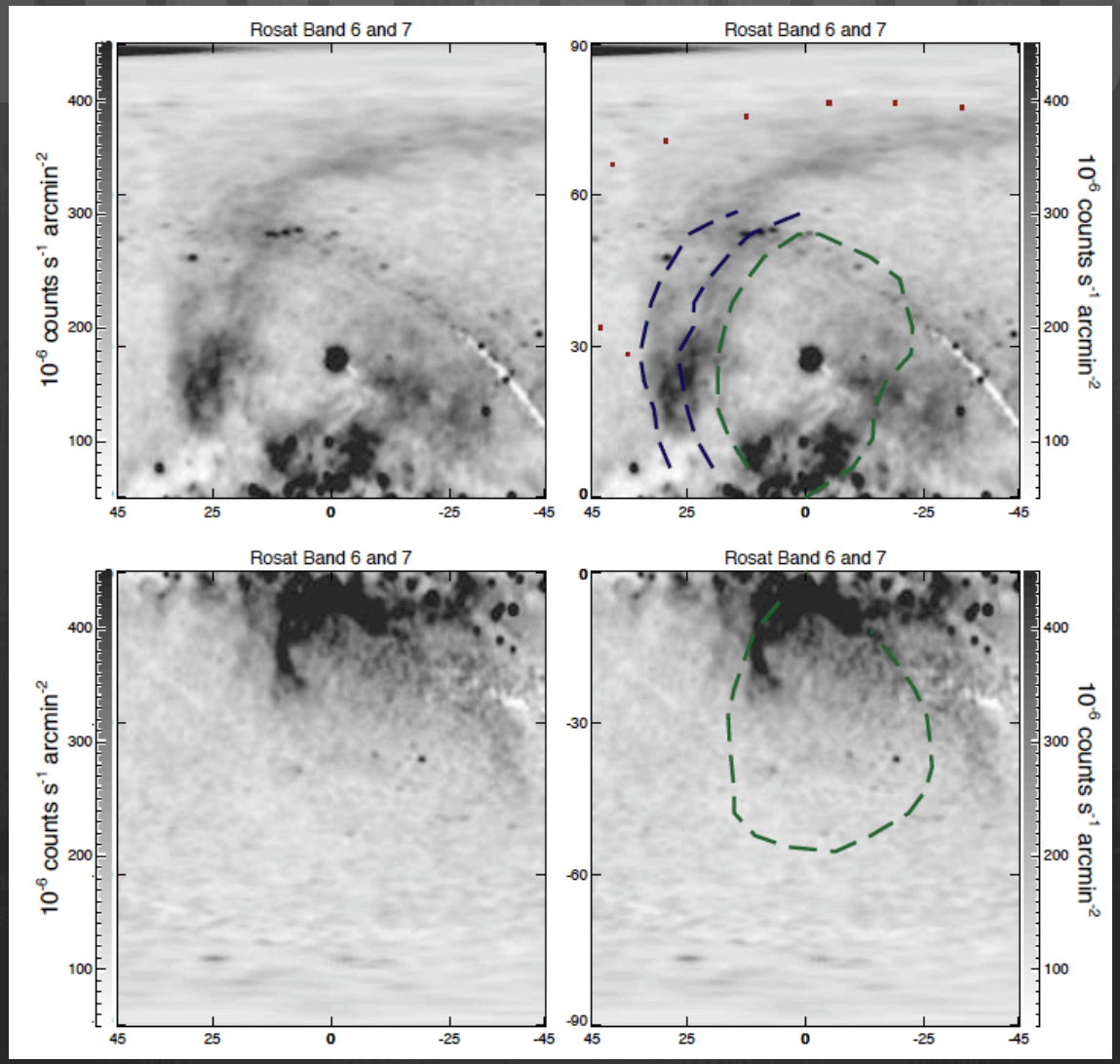


The Fermi bubbles are clearly associated with WMAP haze

The same electron spectrum can easily make both!

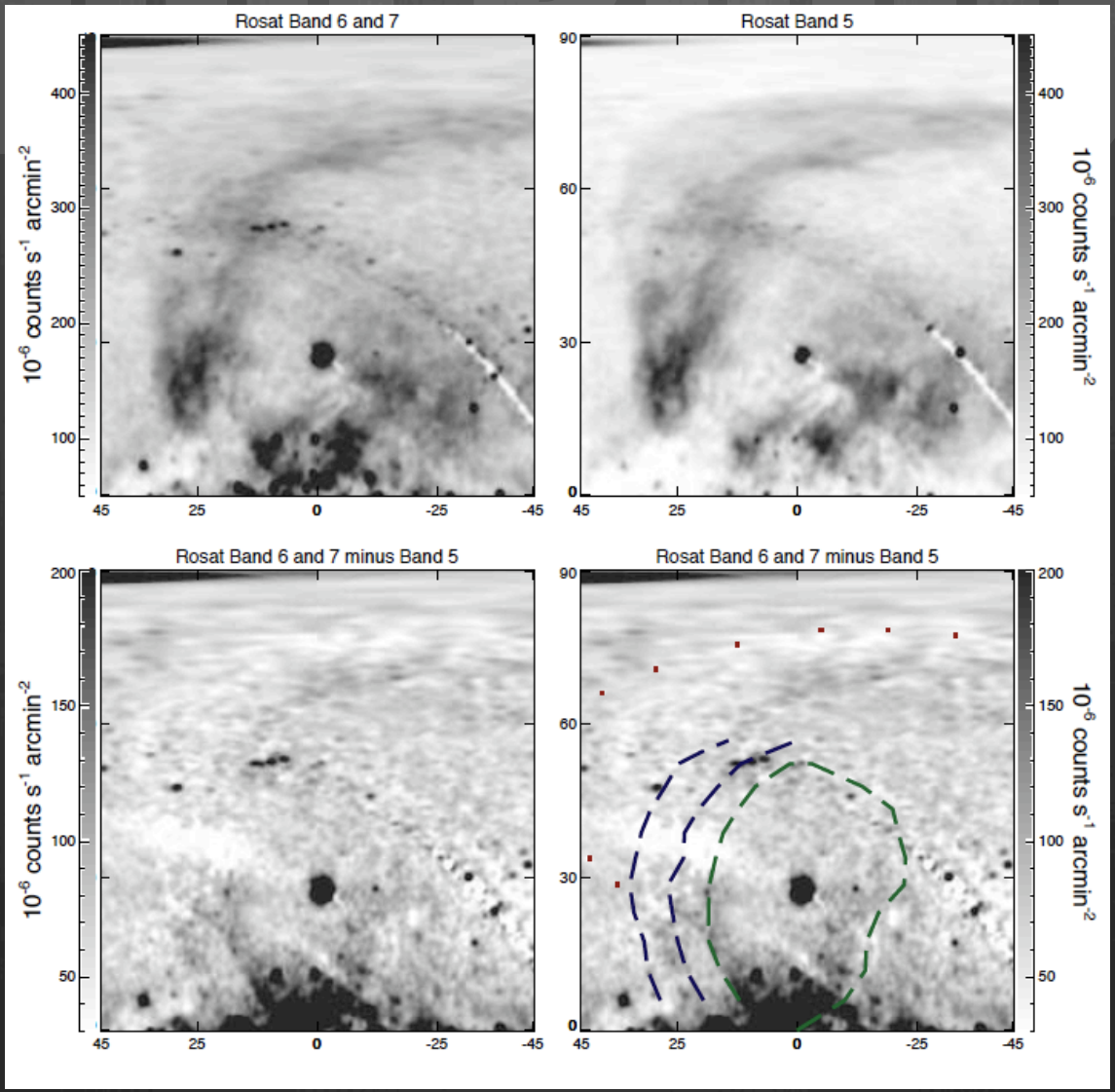
Su et al. (2010)

ROSAT 1.5 keV



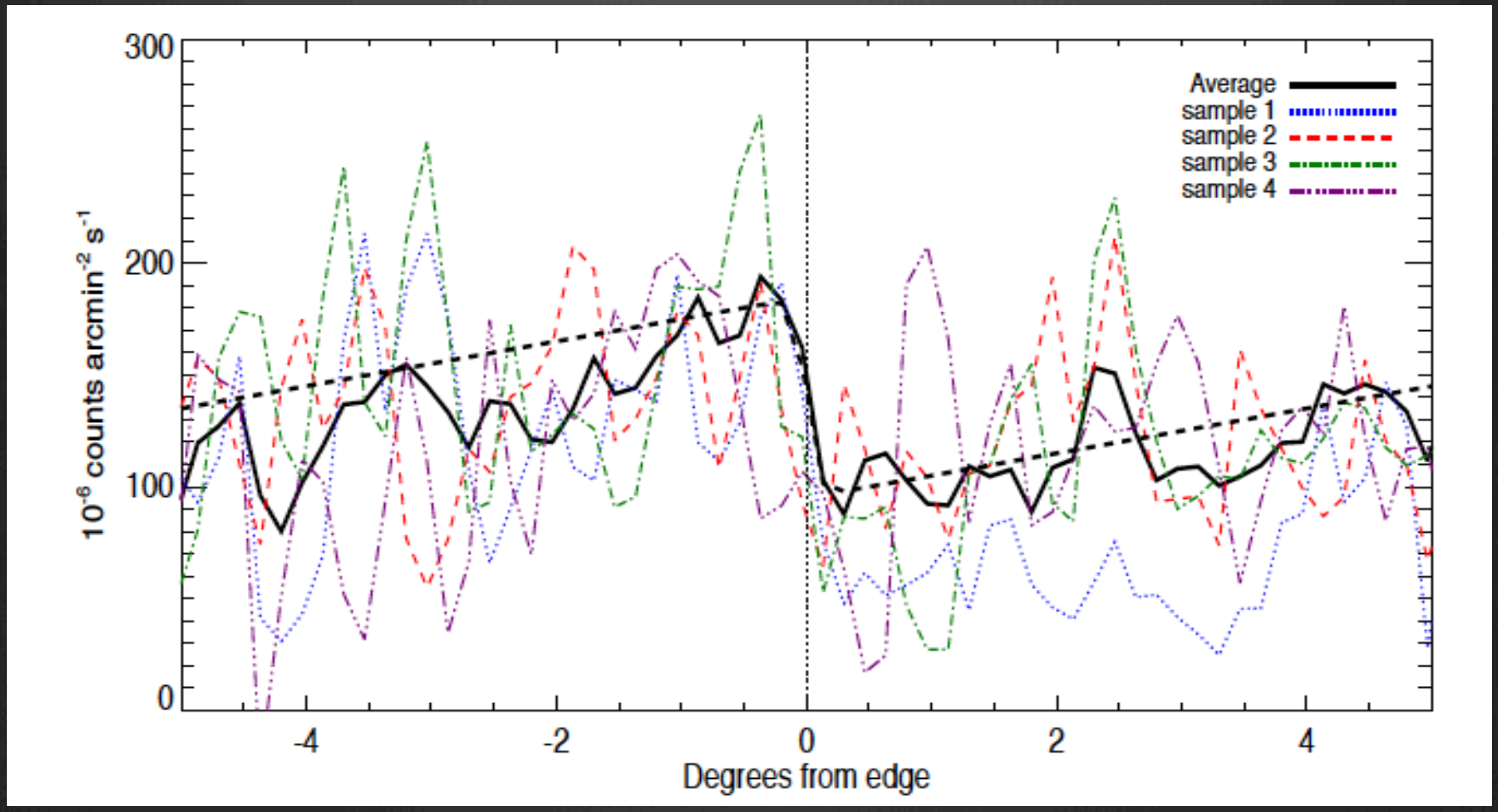
Su et al. (2010)

Fermi Bubble

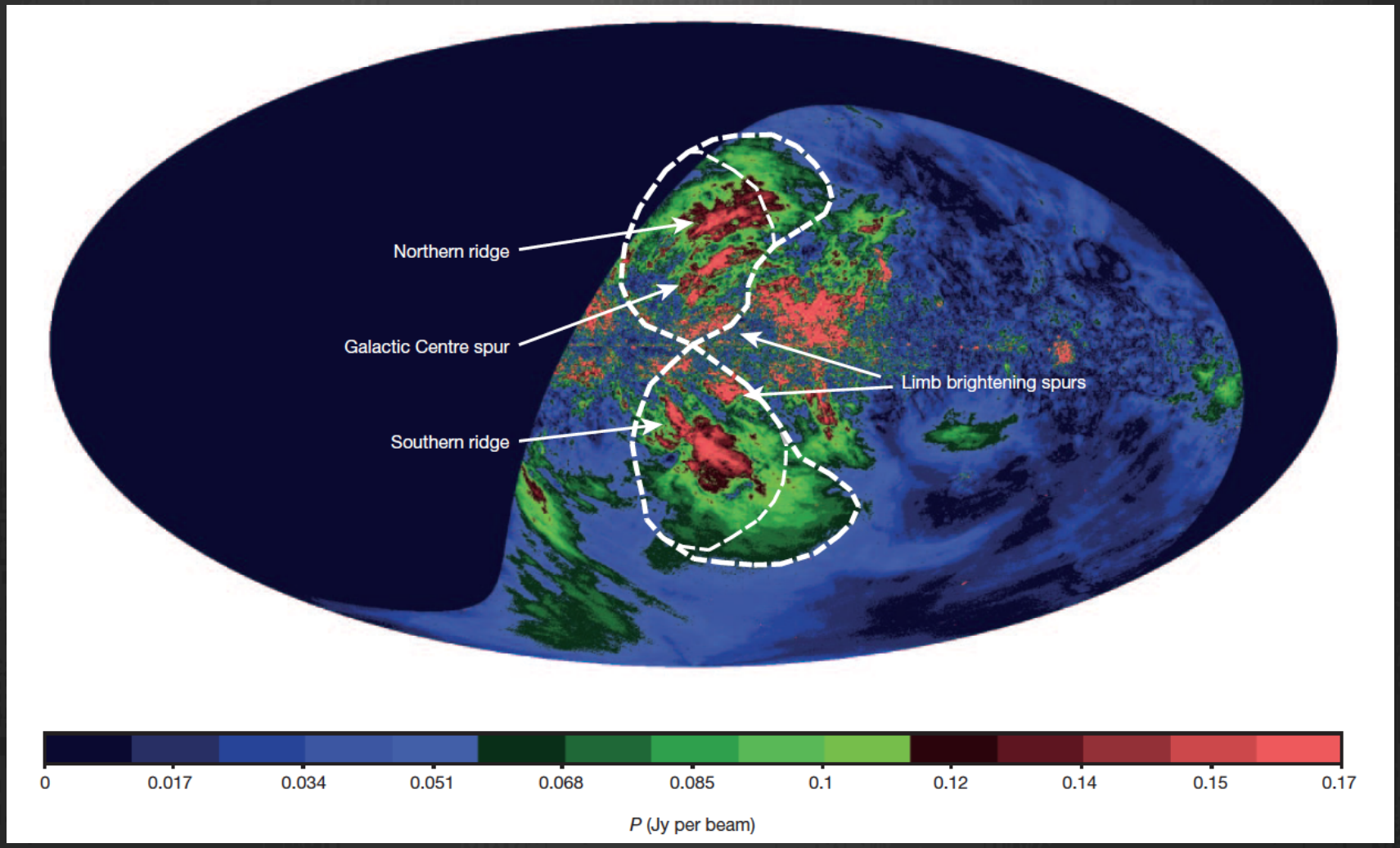


Su et al. (2010)

Sharp edge in X-ray too!



S-PASS observations



Ettore Carretti et al. (2013)

Fermi Bubble

What are they?

- ✔ *Black hole "burp"*
- ✔ *Superwind bubble?*
- ✔ *Dark matter?*

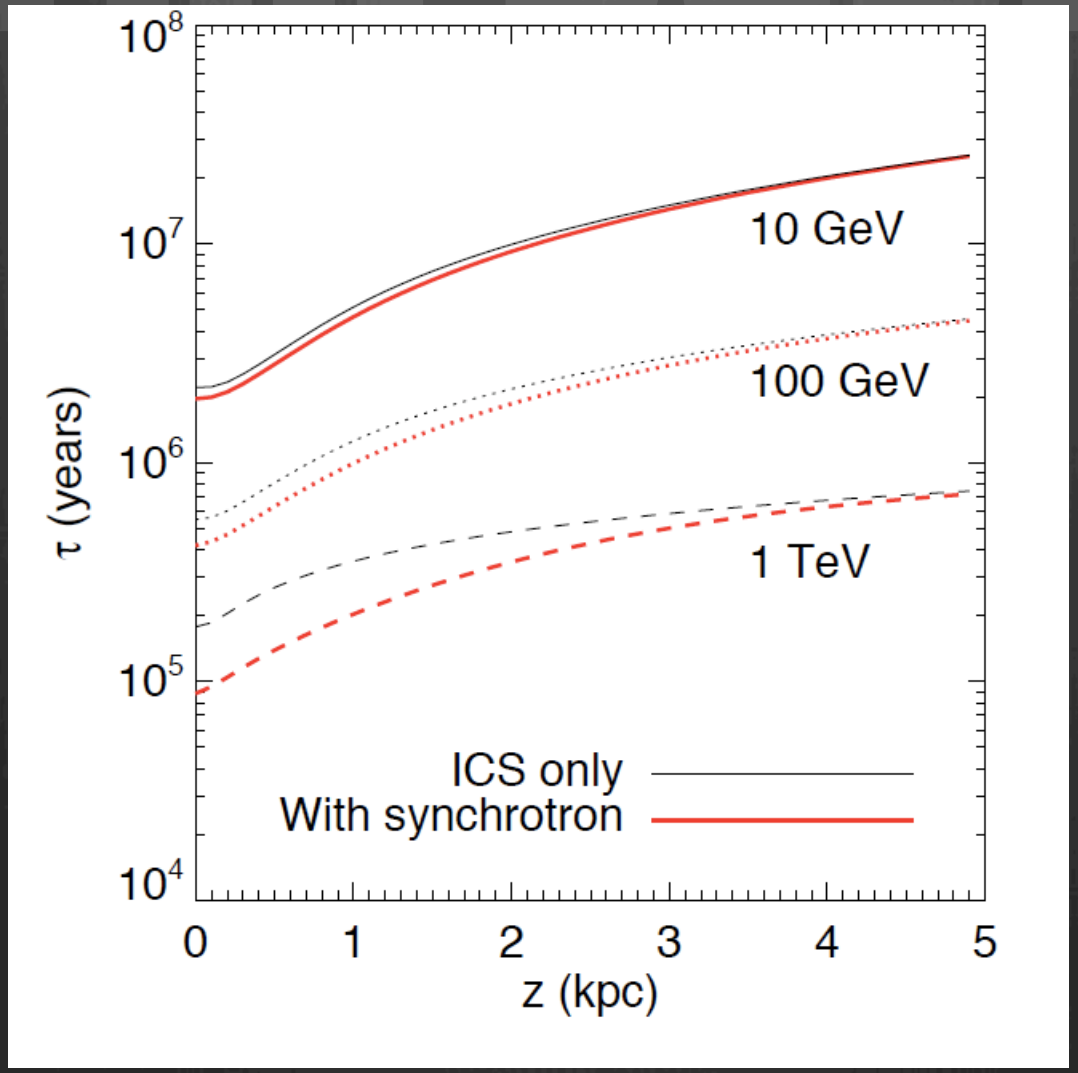
- Mystery: How do we get TeV electrons 10 kpc off the disk in the last < Myr?

- In situ acceleration. Shocks? Reconnection?

- If they are formed quickly by AGN activity, then kinetic energy >> 10^{55} erg. Could do, but this would be an impressive event for our humble little black hole.

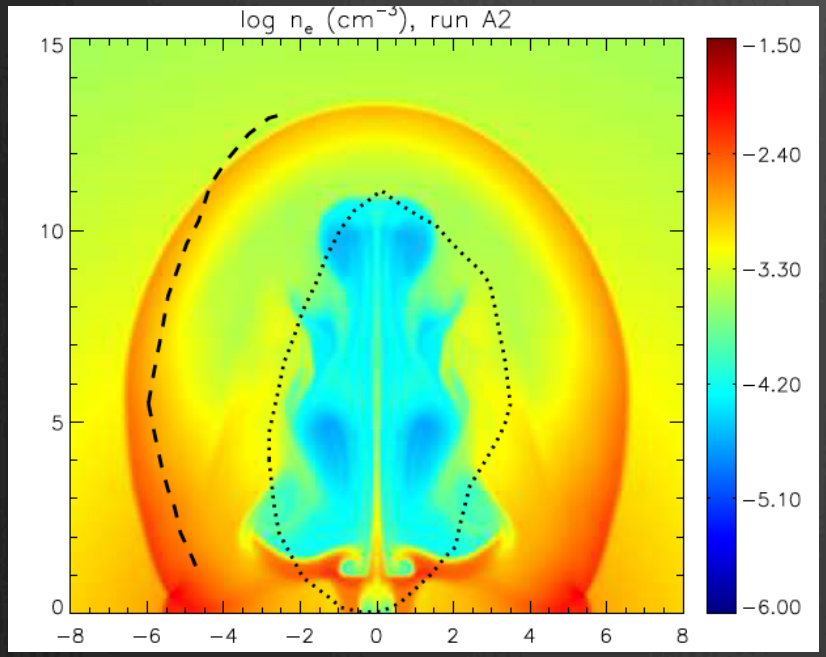
- Large starburst-produced bubble has a severe cooling time problem. The bubbles should be ~10^7 yr old, but cooling time for TeV (or even 100 GeV) electrons is much shorter

Cooling time is short!

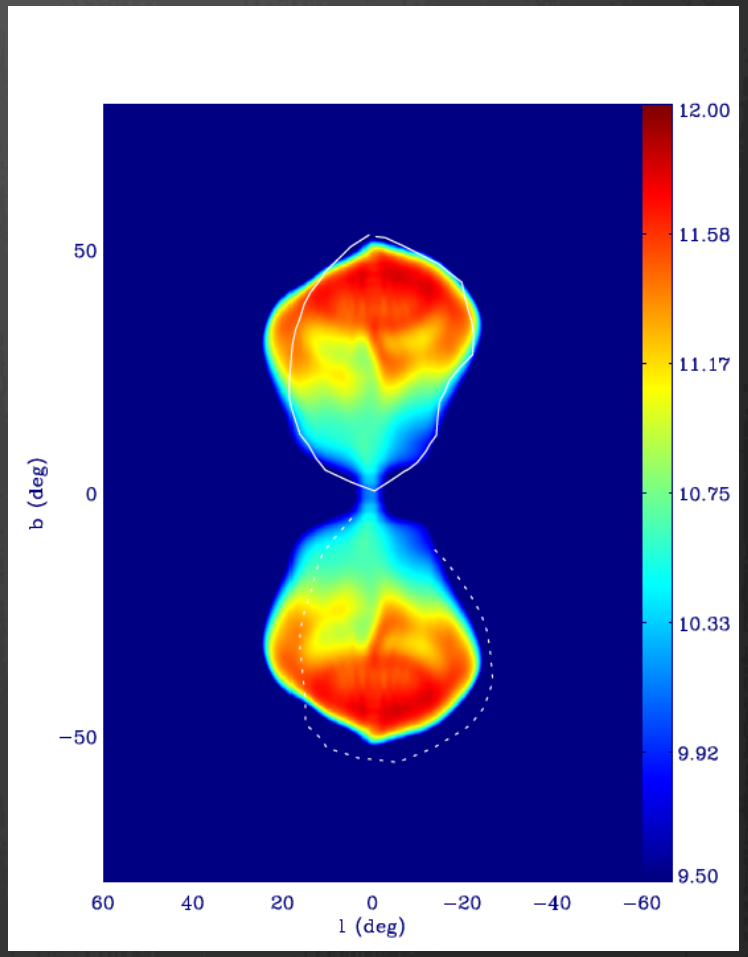


Su et al. (2010)

Past AGN jet can produce the bubbles

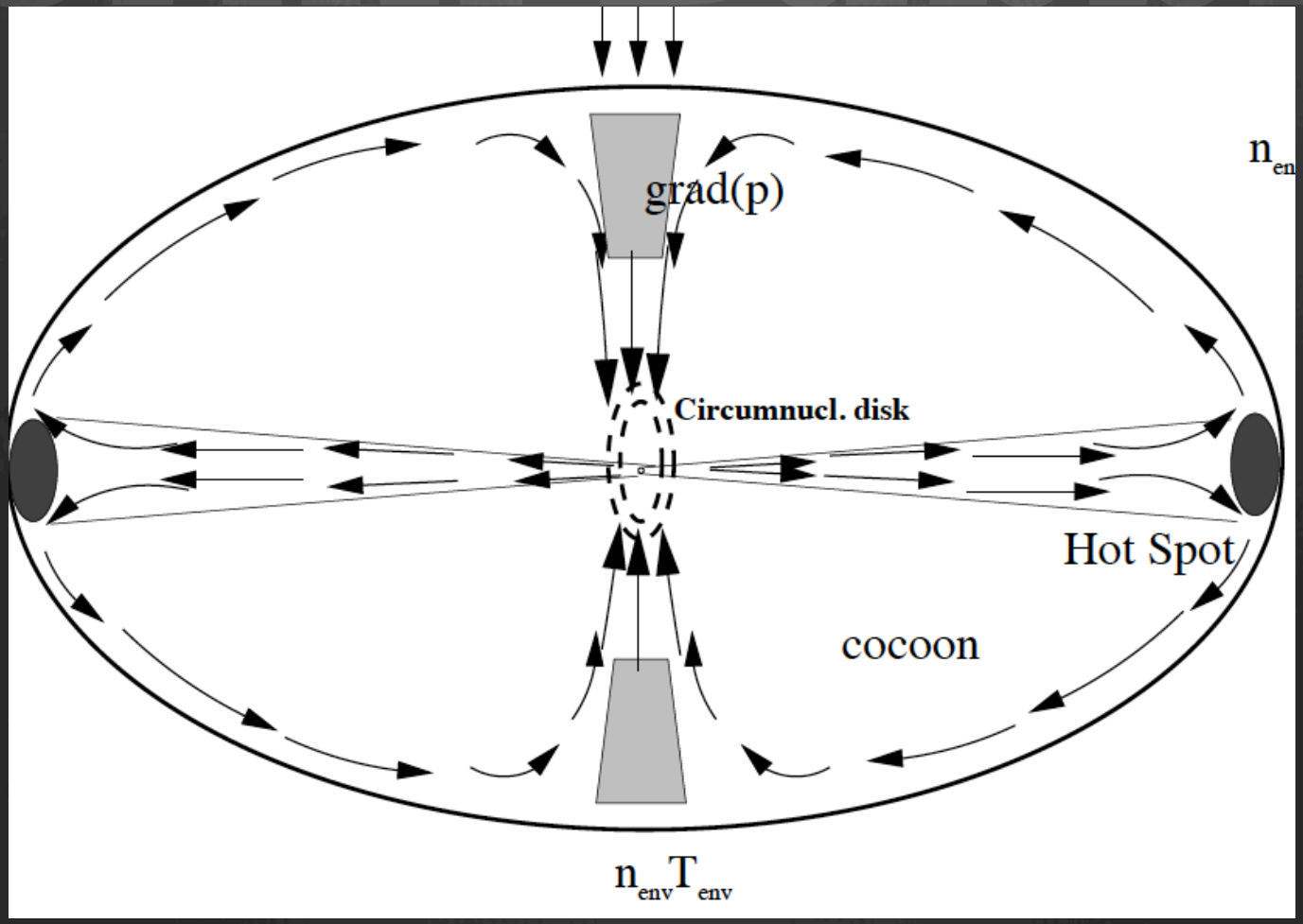


Guo & Mathews (2011)



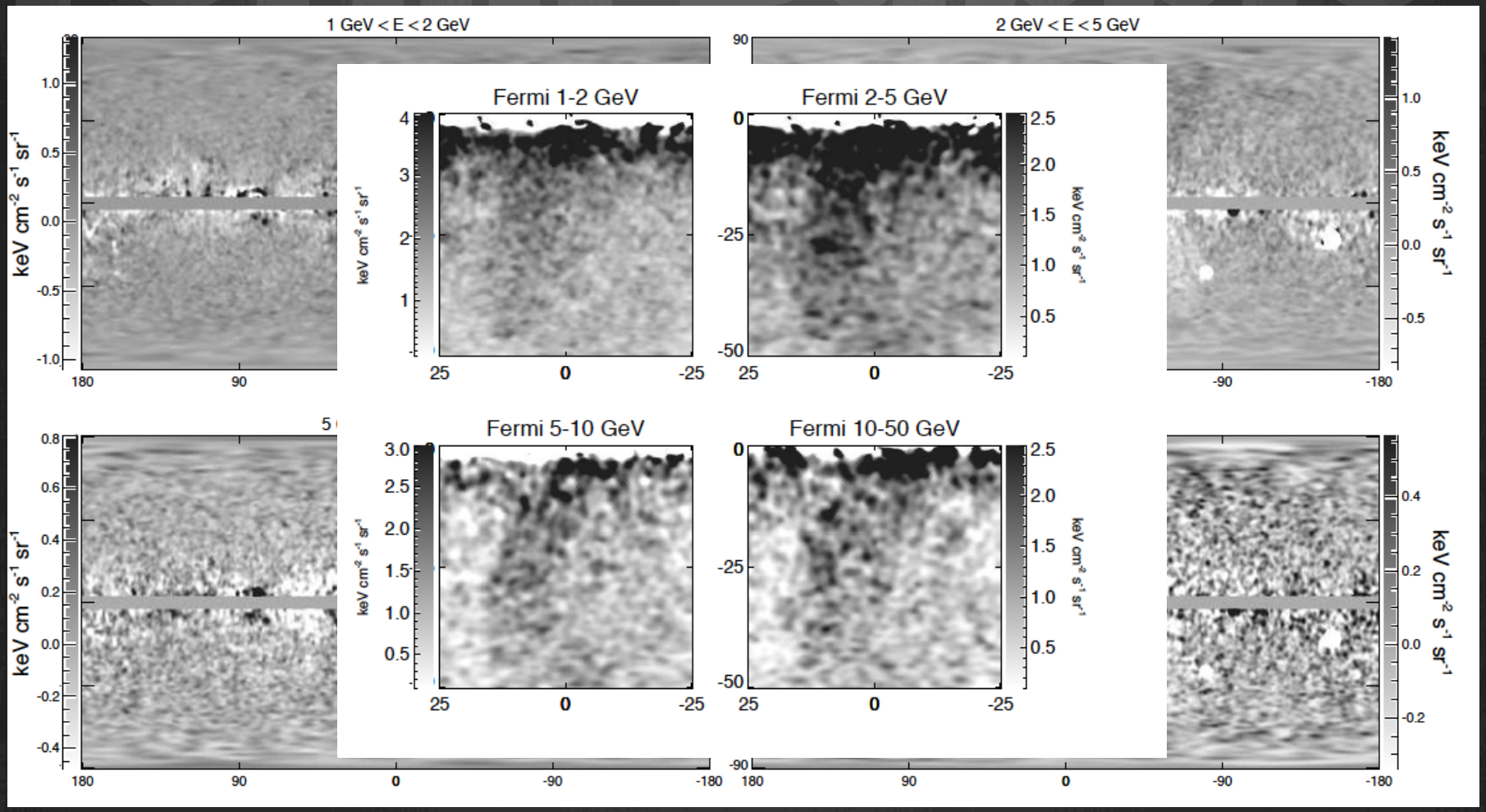
Yang et al. (2012)

Jet and Cocoon in the bubbles?

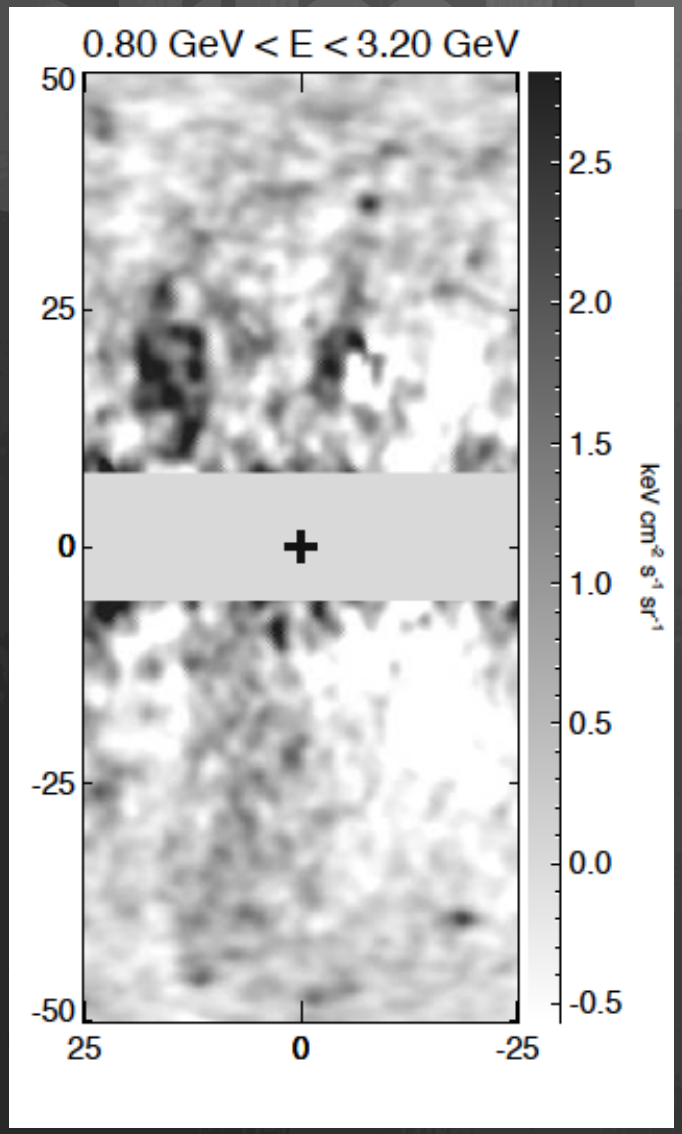


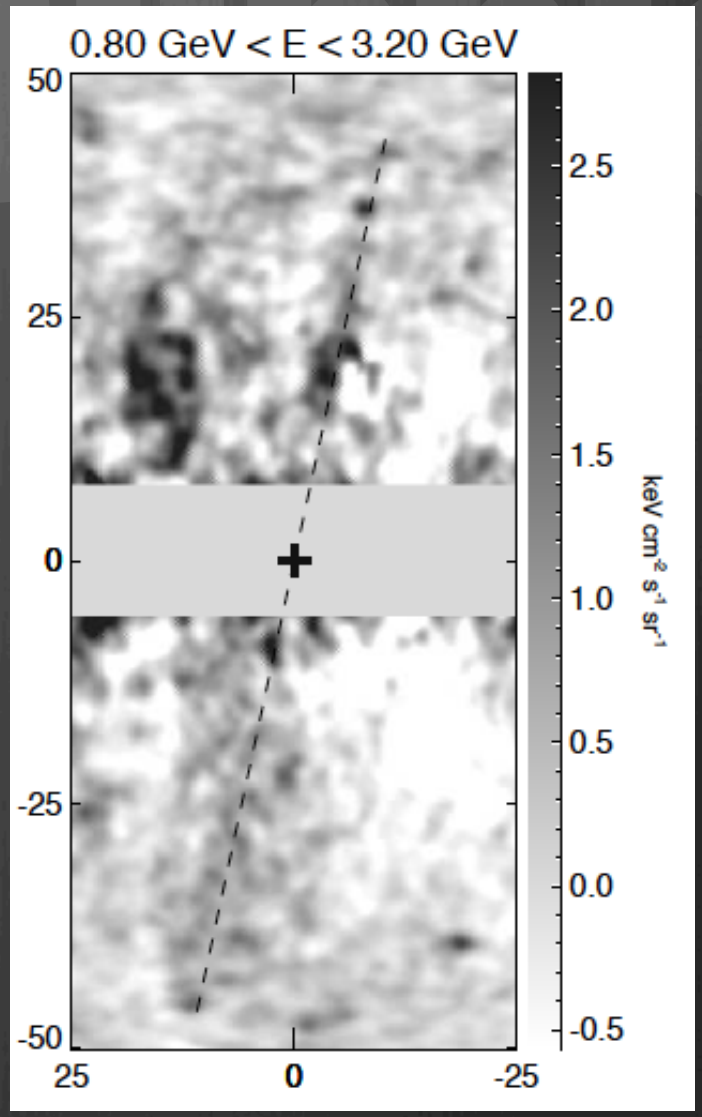
Antonuccio-Delogu & Silk (2010)

Fermi Bubble



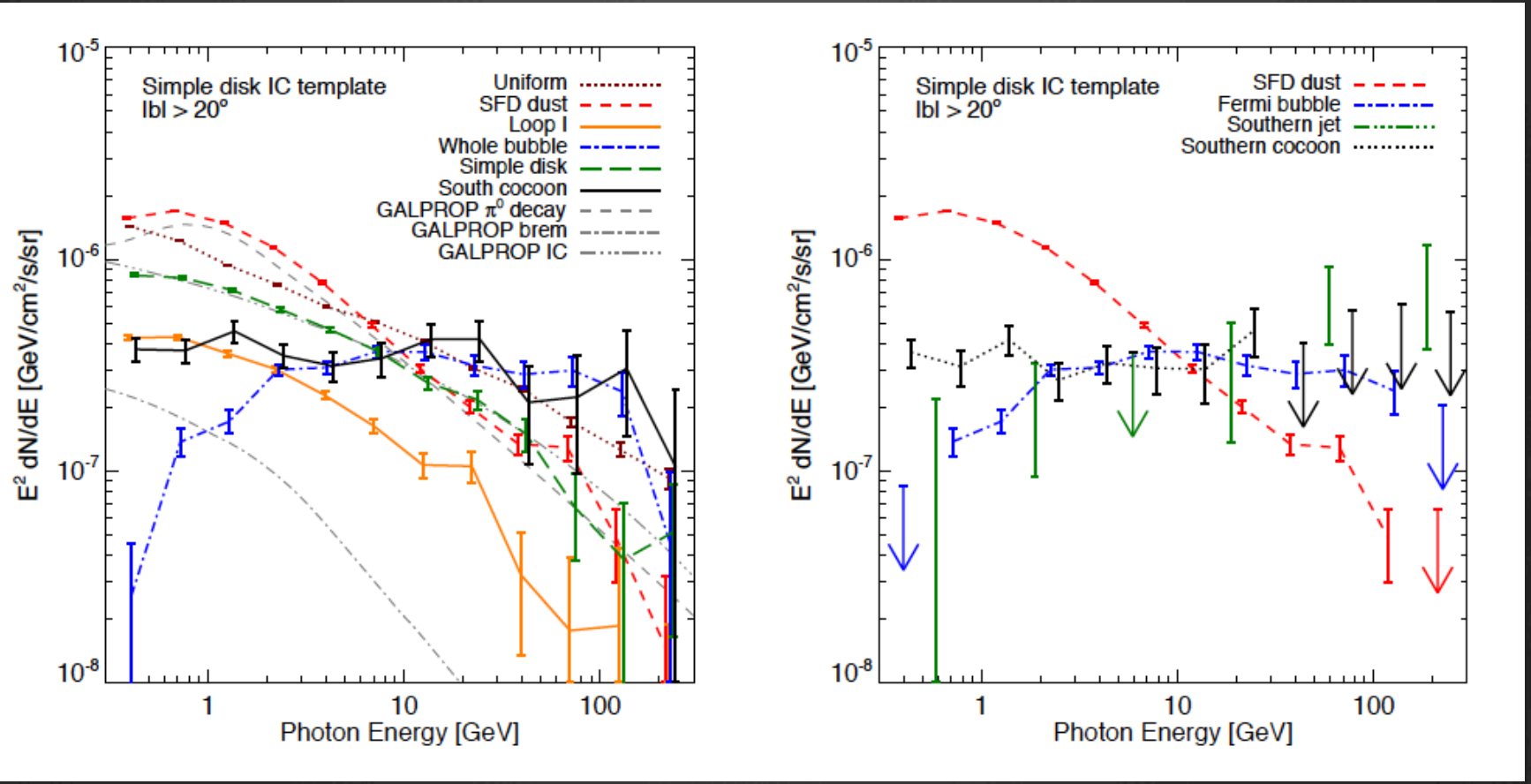
Su & Finkbeiner (2012)





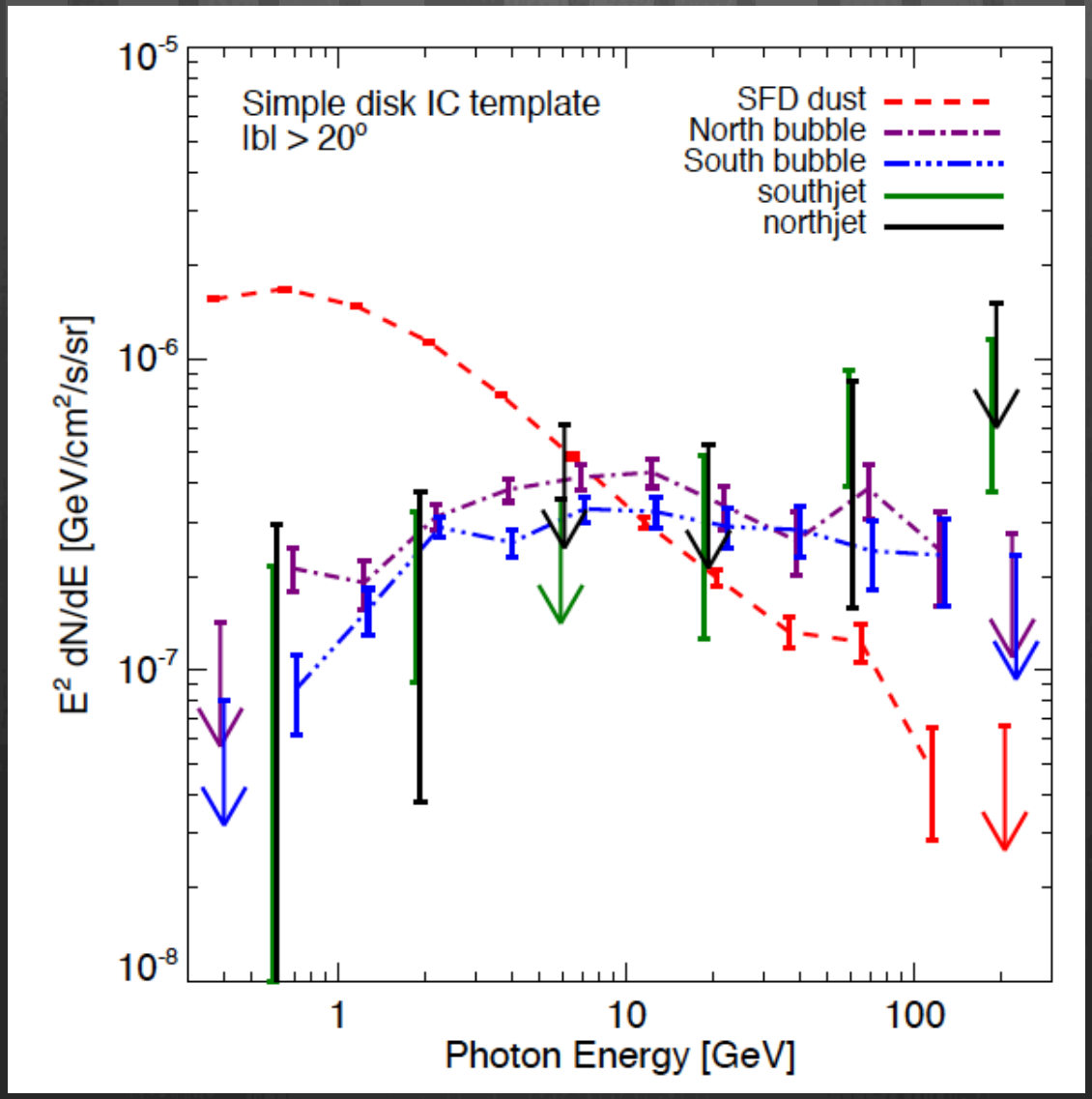
Su & Finkbeiner (2012)

Fermi Bubble

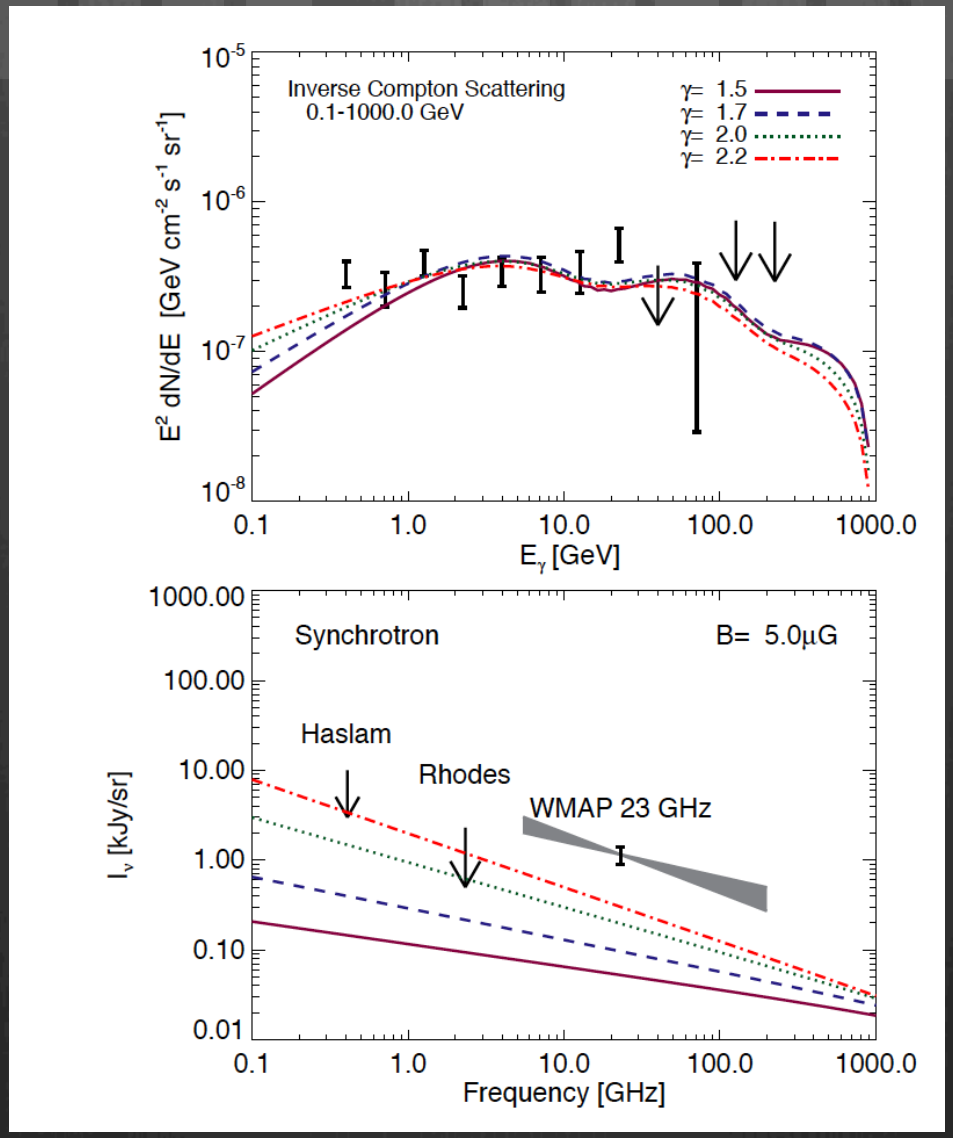


Su & Finkbeiner (2012)

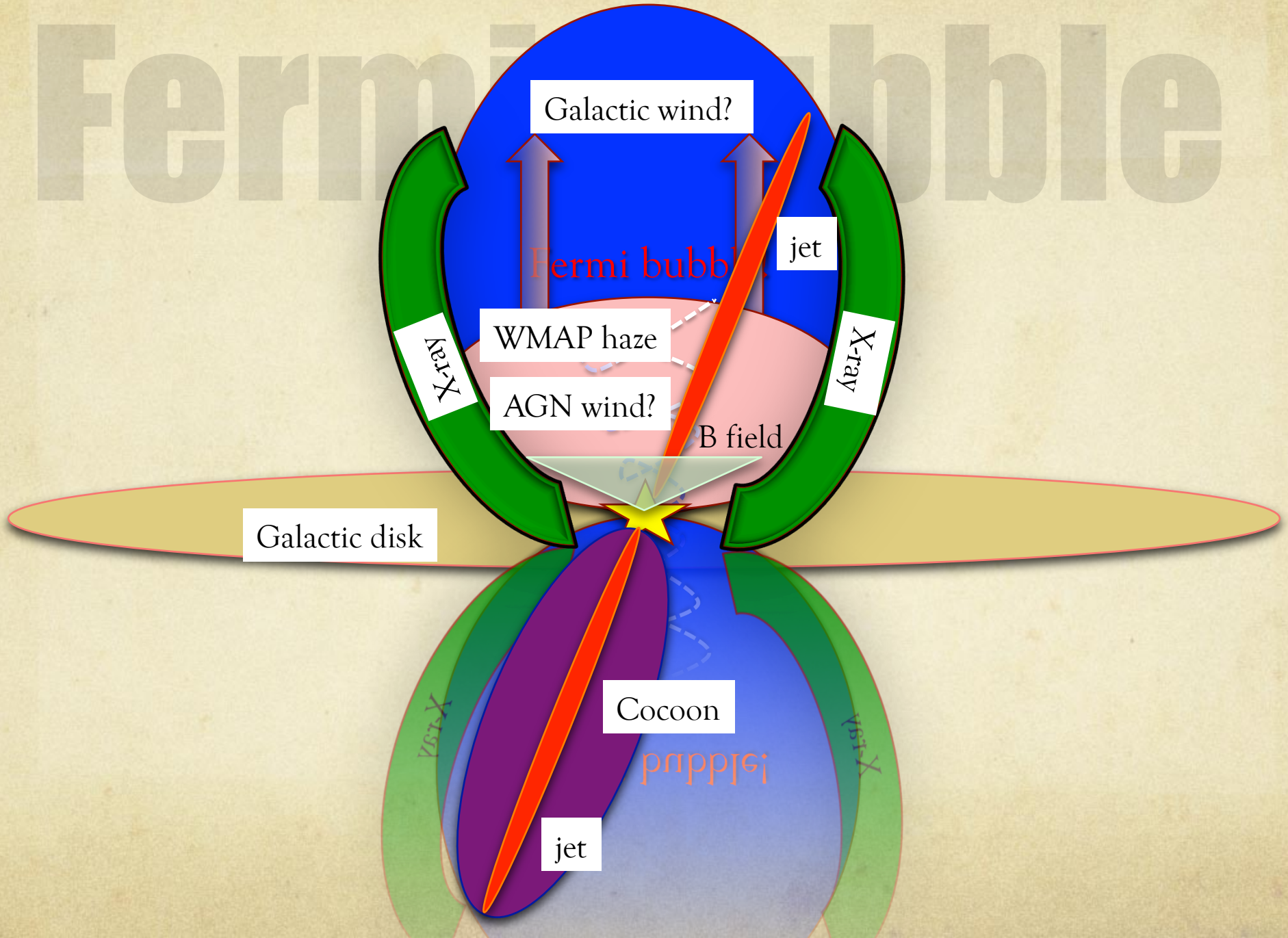
Fermi Bubble



Radio limit on the jet feature



Fermi bubble



Fermi Bubble

Thank you for your attention!

(Video credit:
NASA's Goddard
Space Flight Center)