Fermi Bubble

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

GIANT GAMMA-RAY BUBBLES FROM Fermi -LAT

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Galactic Center Workshop Heidelberg
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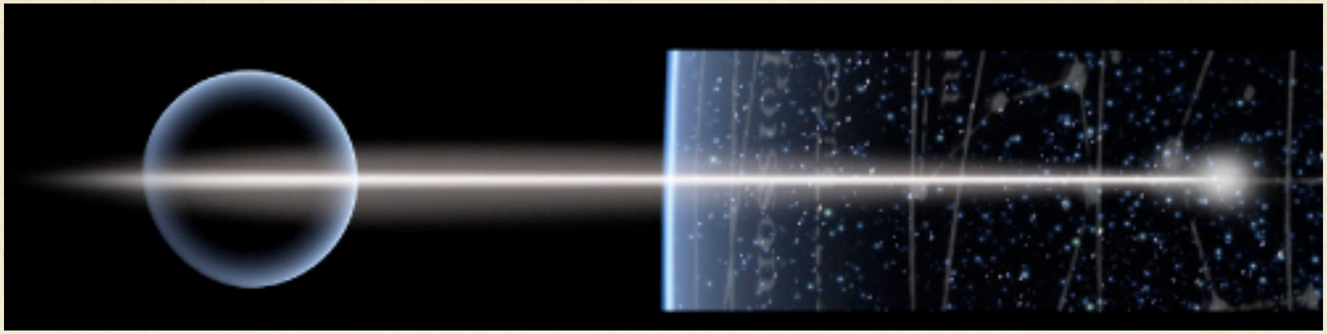
Disclaimer: no aliens found!



Suppose a civilization somewhere in the cosmos is approaching Kardashev type III status. In other words, it is already capable of using all the power resources of its star ($4*10^{26}$ W for a star like the Sun) and is on the way to exploiting the power of its galaxy ($4*10^{37}$ W). Imagine it expanding out of its galactic niche, turning stars in its stellar neighborhood into a series of Dyson spheres. If we were to observe such activity in a distant galaxy, we would presumably detect a growing void in visible light from the area of the galaxy where this activity was happening, and an upturn in the infrared. Call it a 'Fermi bubble.'

Never invent a name without google it!

Fermi Bubbles

Su, Slatyer, & Finkbeiner (2010); arXiv: 1005.5480

Giant gamma-ray structure with sharp edges
Appearing rise up & down from the Galactic center

They are:

- *50 degrees high (~8.5 kpc)*
- *Well centered on longitude zero (close to latitude zero)*
- *Imply ~TeV electron energy!*

Fermi Bubble

Two motivations for looking at the Inner Galaxy with *Fermi*: :

- *1. Investigate the WMAP haze (Finkbeiner 2004)*
  (Microwave excess with hard spectrum in the inner galaxy)

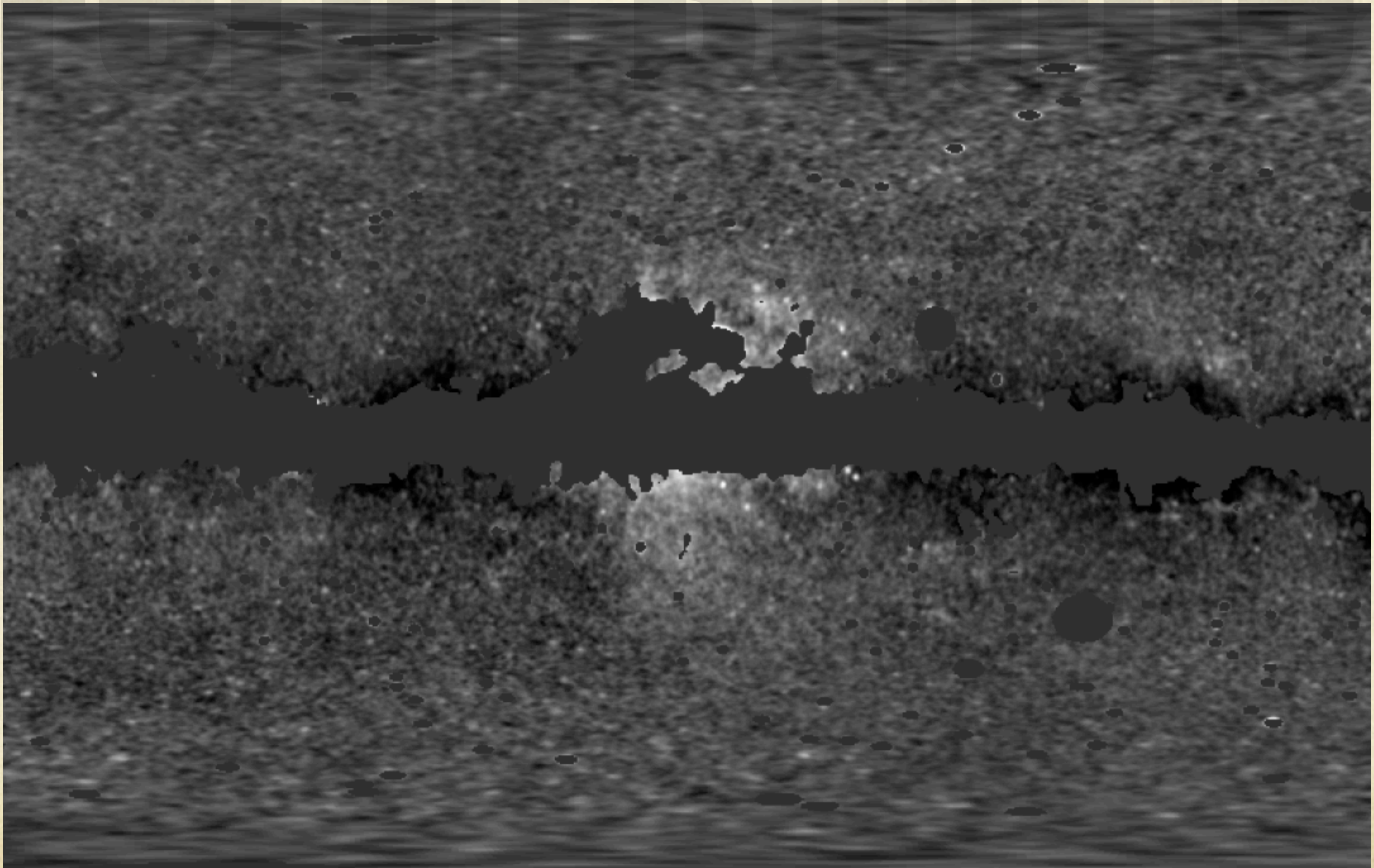
  Difficult to explain as free-free, dust, or spinning-dust

  If synchrotron, must be unusually hard electron spectrum.

- *2. Indirect detection of dark matter*

Dobler et al., arXiv:0910:4583
Su et al., arXiv:1005.5480

WMAP haze



(Finkbeiner 2004)

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3 views of the haze:

-Null 1: There is no excess synchrotron, merely free-free or spinning dust

Fermi Bubble

3 views of the haze:

-Null 1: There is no excess synchrotron, merely free-free or spinning dust

-Null 2: The haze is synchrotron, but is normal spectral variation - nothing special.

Fermi Bubble

3 views of the haze:

-Null 1: There is no excess synchrotron, merely free-free or spinning dust

-Null 2: The haze is synchrotron, but is normal spectral variation - nothing special.

- Haze hypothesis: Synchrotron from electrons produced by a distinct physical mechanism.

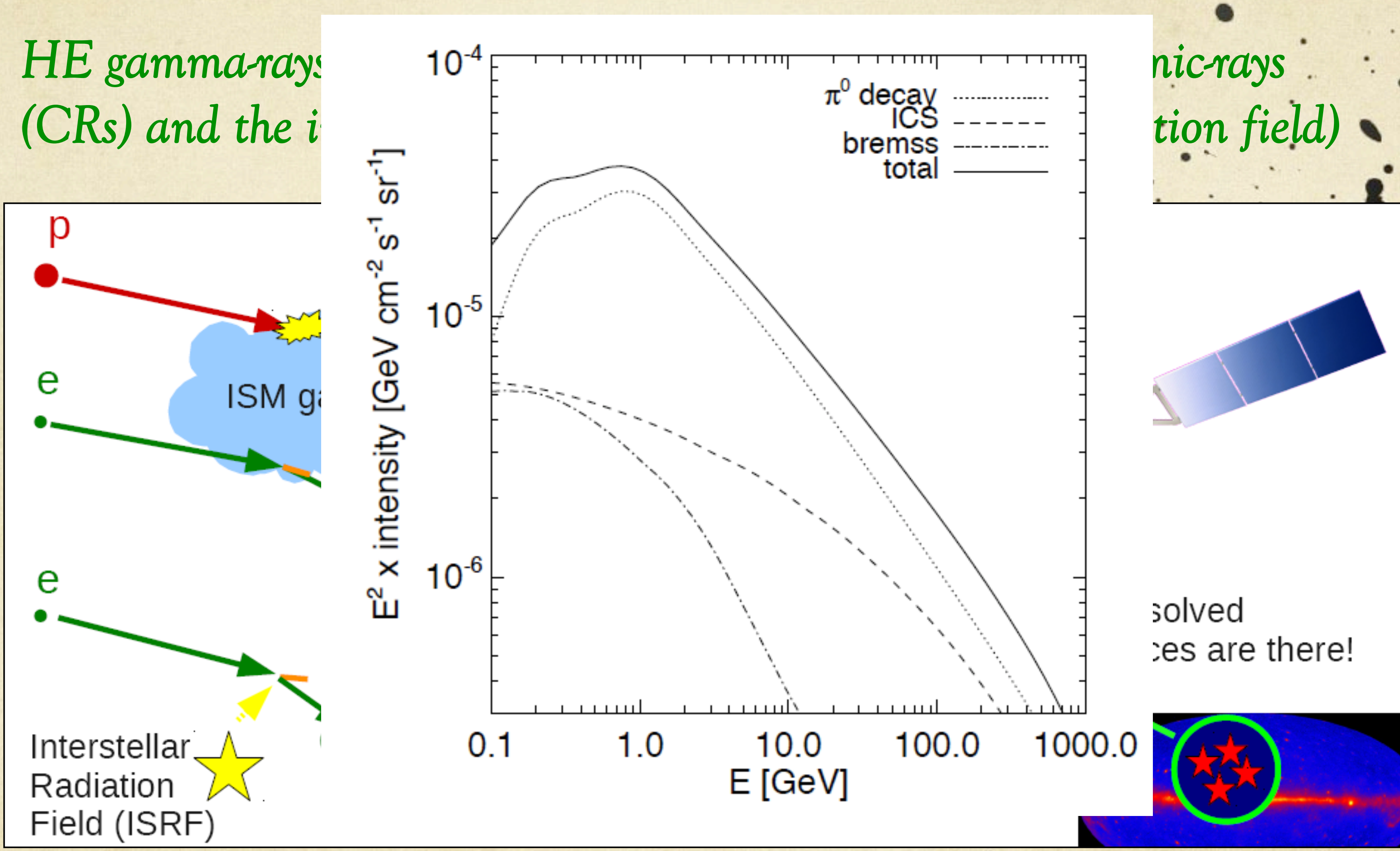
Fermi Bubble

How to test the WMAP haze idea?

1) Can we see the IC gammas expected if the WMAP haze is synchrotron? (this would rule out null hypothesis 1)

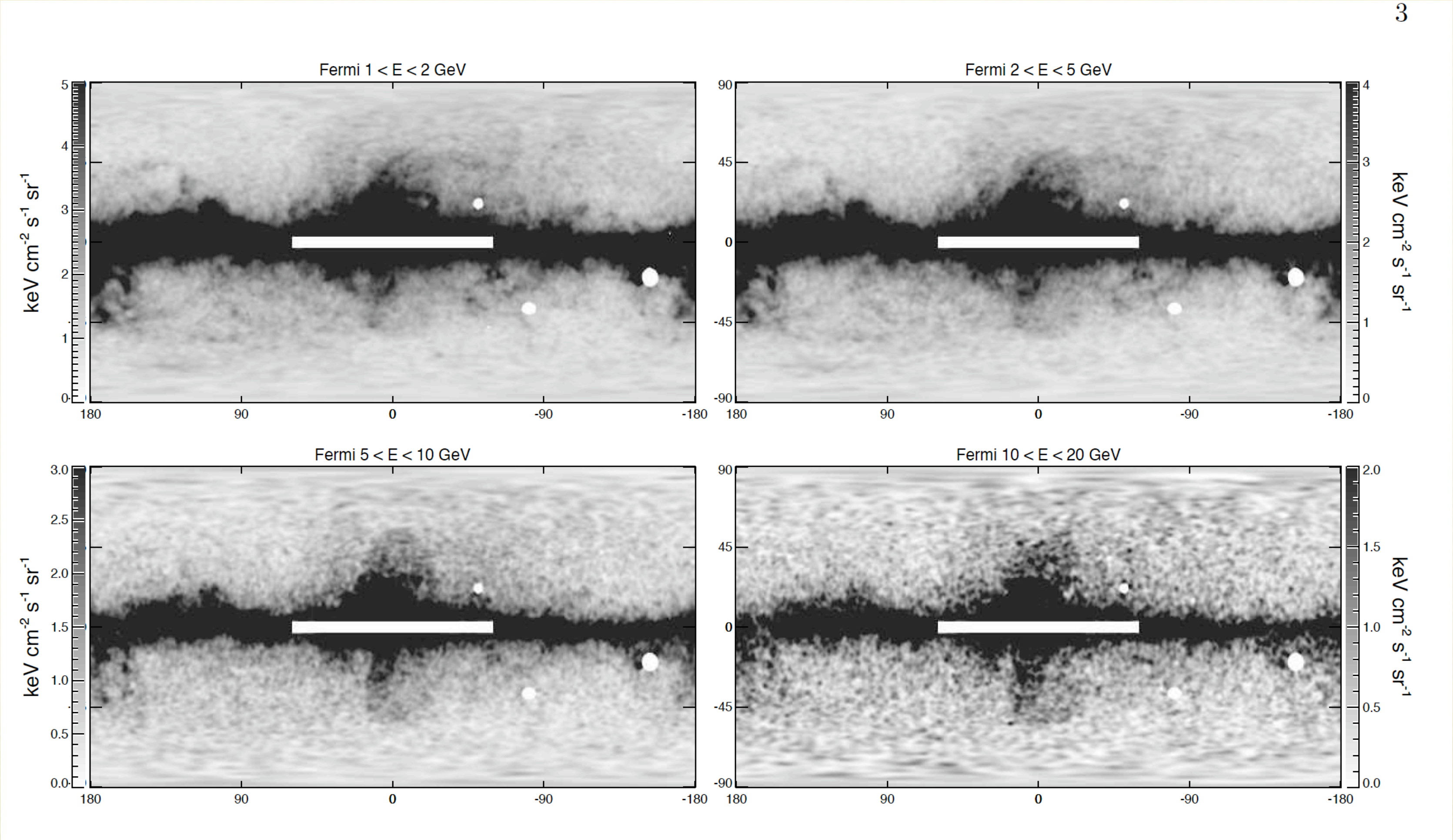
2) Does the structure look like a transient (have sharp edges), or steady state (look hazy)?

HE gamma-rays … *nic-rays*
(CRs) and the i … *tion field)*



(from Tsunefumi Mizuno)

The Fermi-LAT three year maps



To understand the data...

- *Full physical model:*

  Pro: uses everything we know to fit data.

  Con: only used what we put in the model

  Provides the most secure interpretation of the data

- *Template analysis*

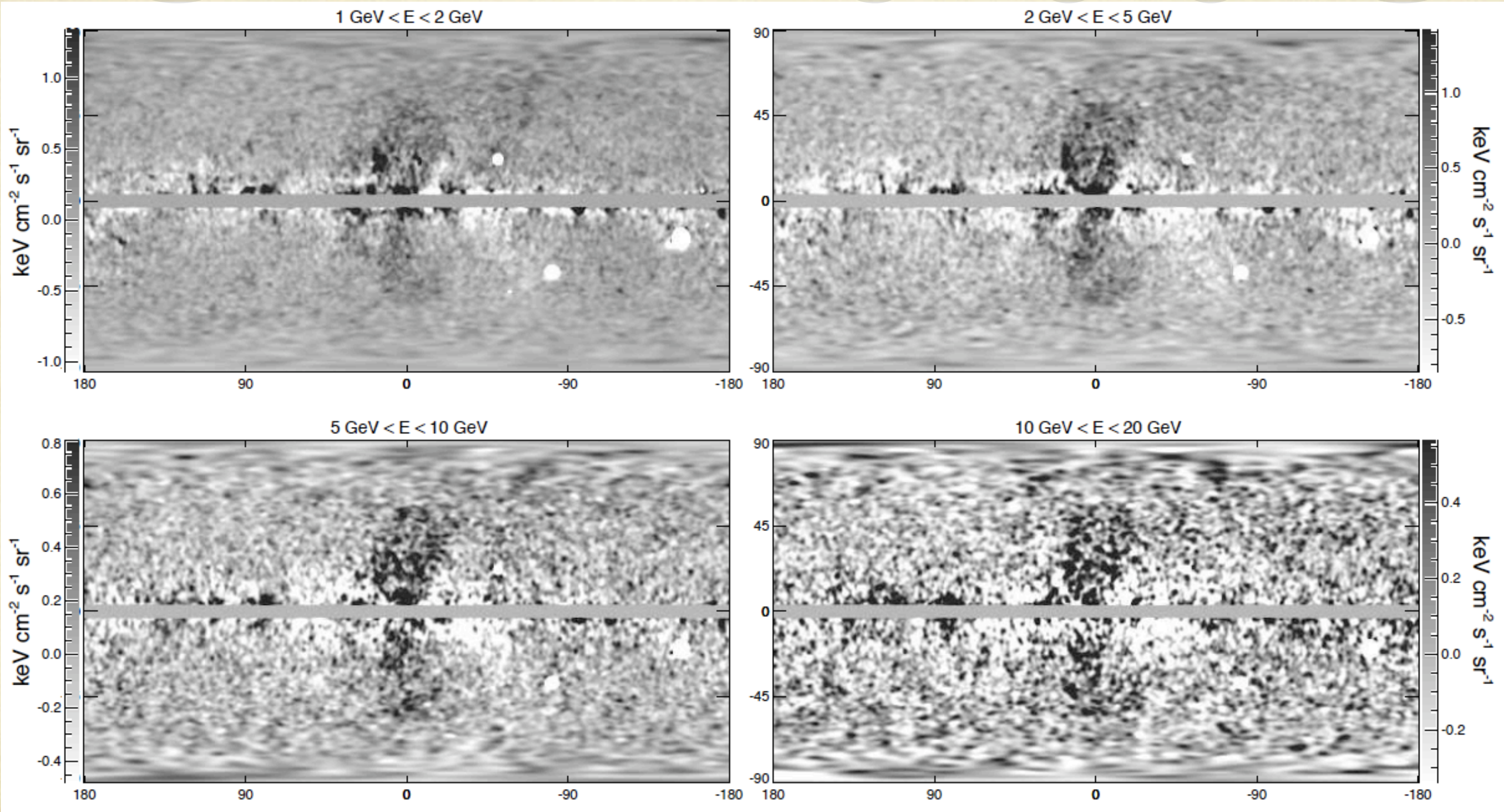
  Pro: the templates work pretty well; may reveal new emission mechanisms. Simple.

  Con: must assess fit residuals carefully, because fit is never perfect

  Good for finding the unexpected!

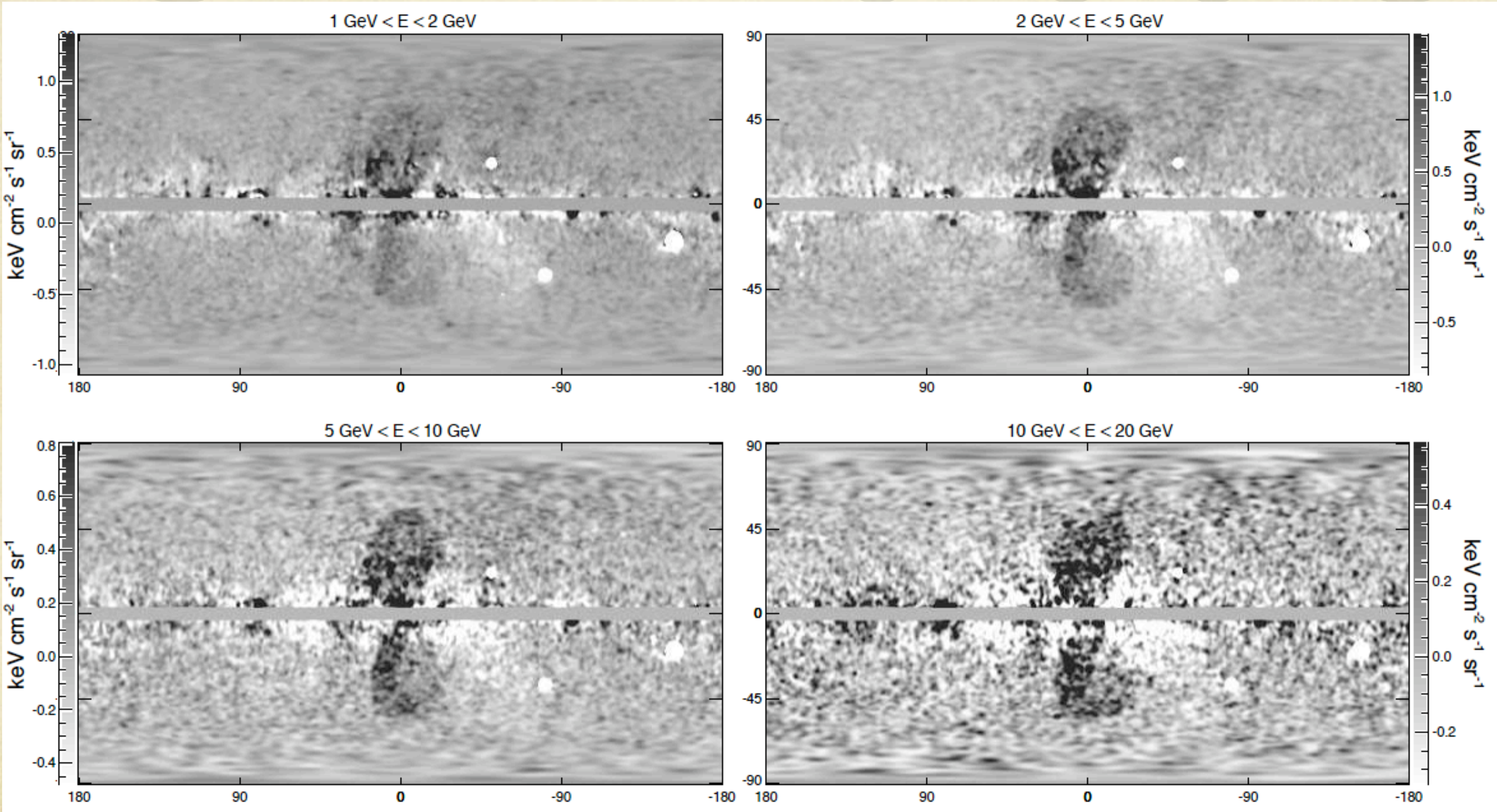
Fermi Bubble

Data minus Fermi diffuse emission model:



Fermi Bubble

Three year maps



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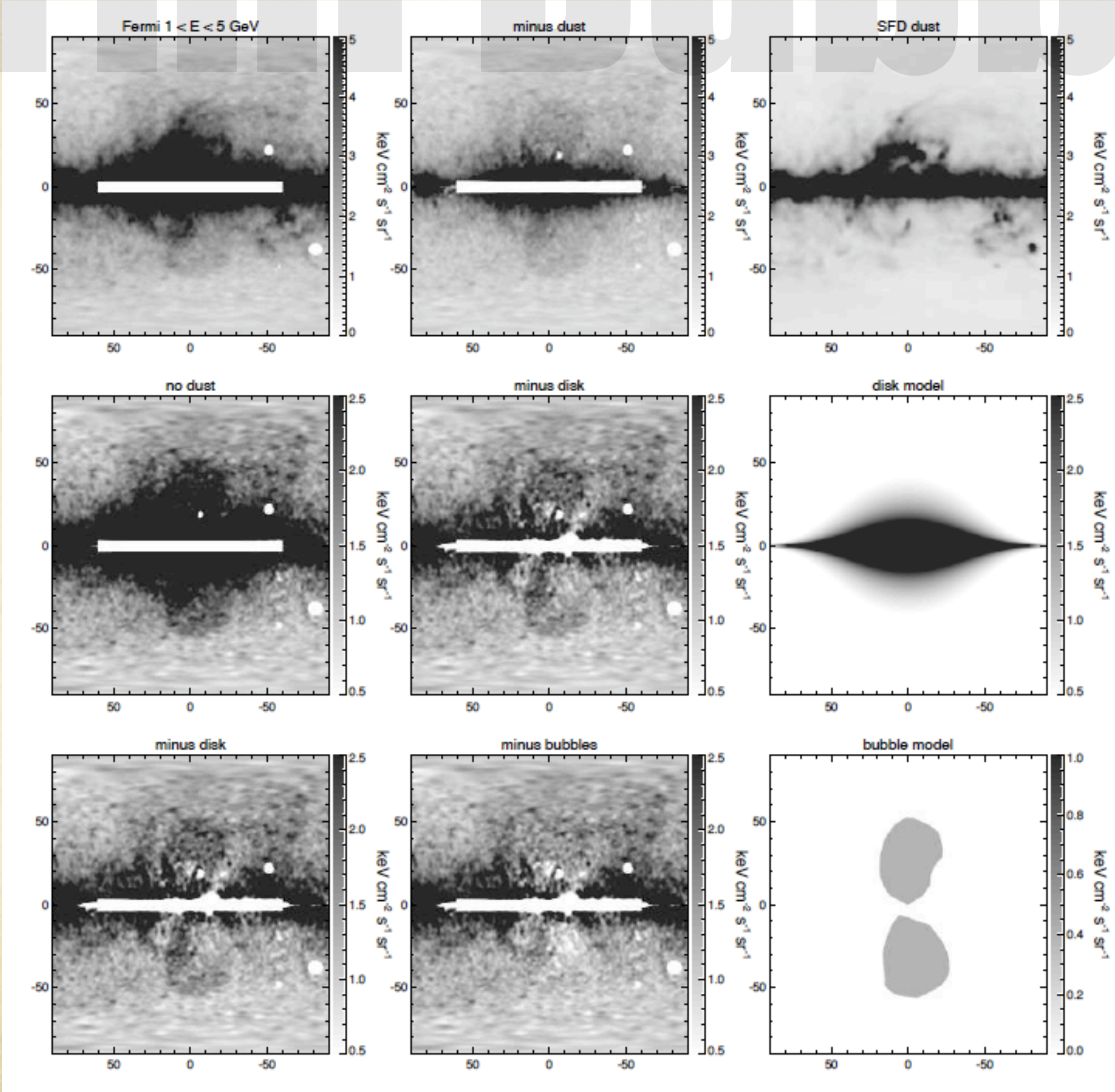
Subtracting the Fermi diffuse emission model reveals a faint bilobular structure in the inner Galaxy.

This is a complicated model - could the residual structure be an artifact?

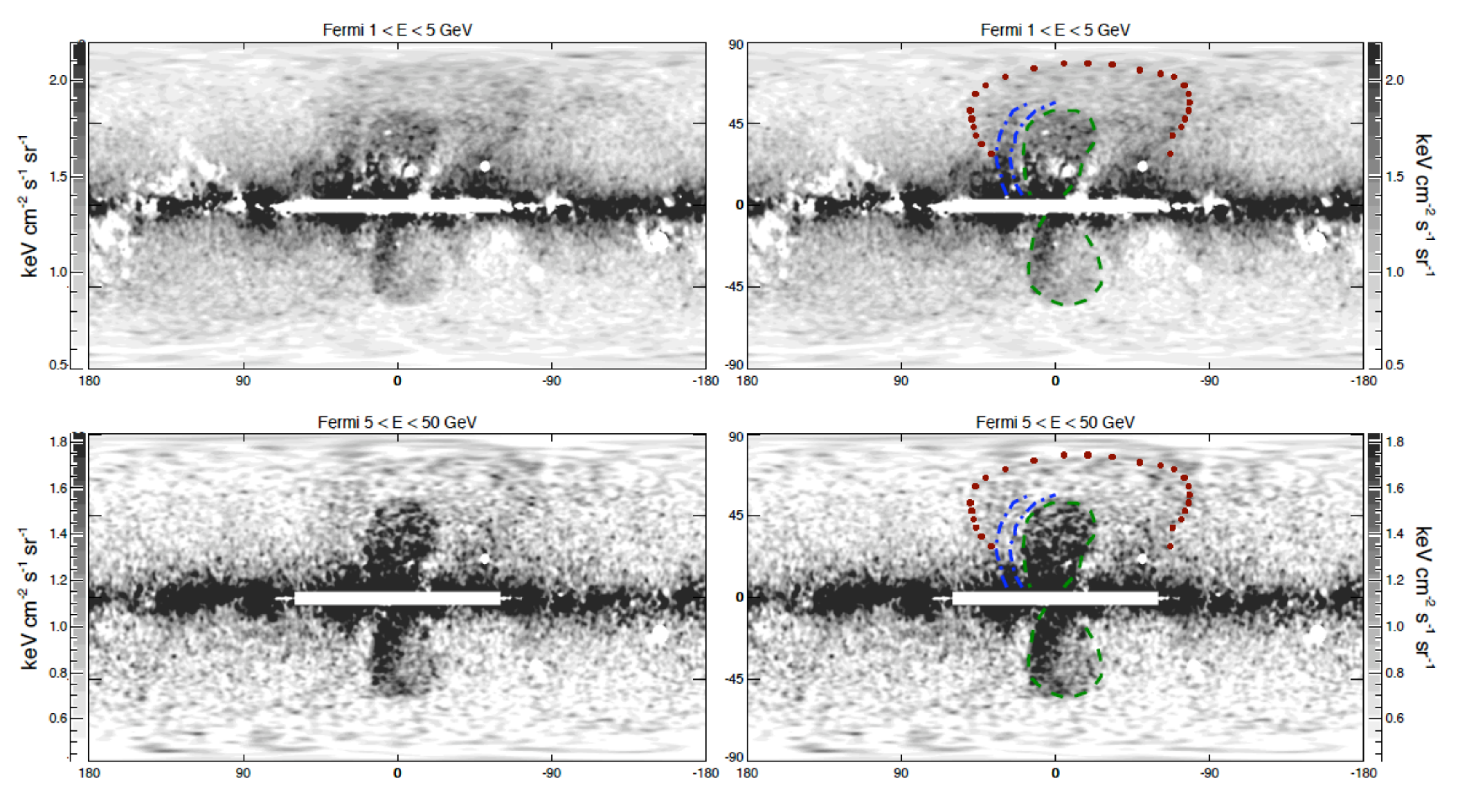
Model contains π^0 and bremsstrahlung from gas maps; IC from GALPROP; North Polar Spur feature from Haslam map.

Let's try something very simple and see how robust this is.

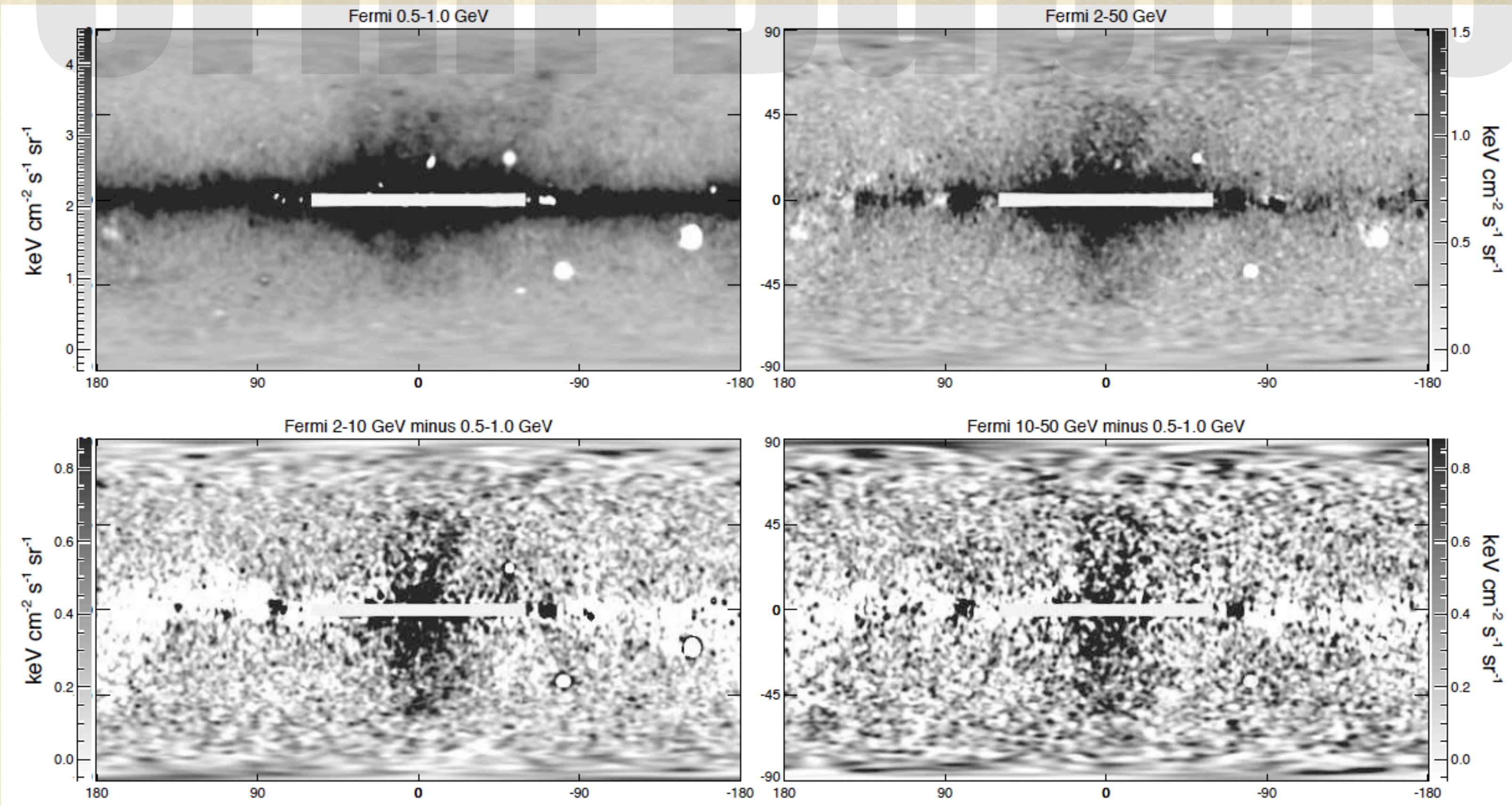
Simple disk model



Fermi Bubble from three year maps

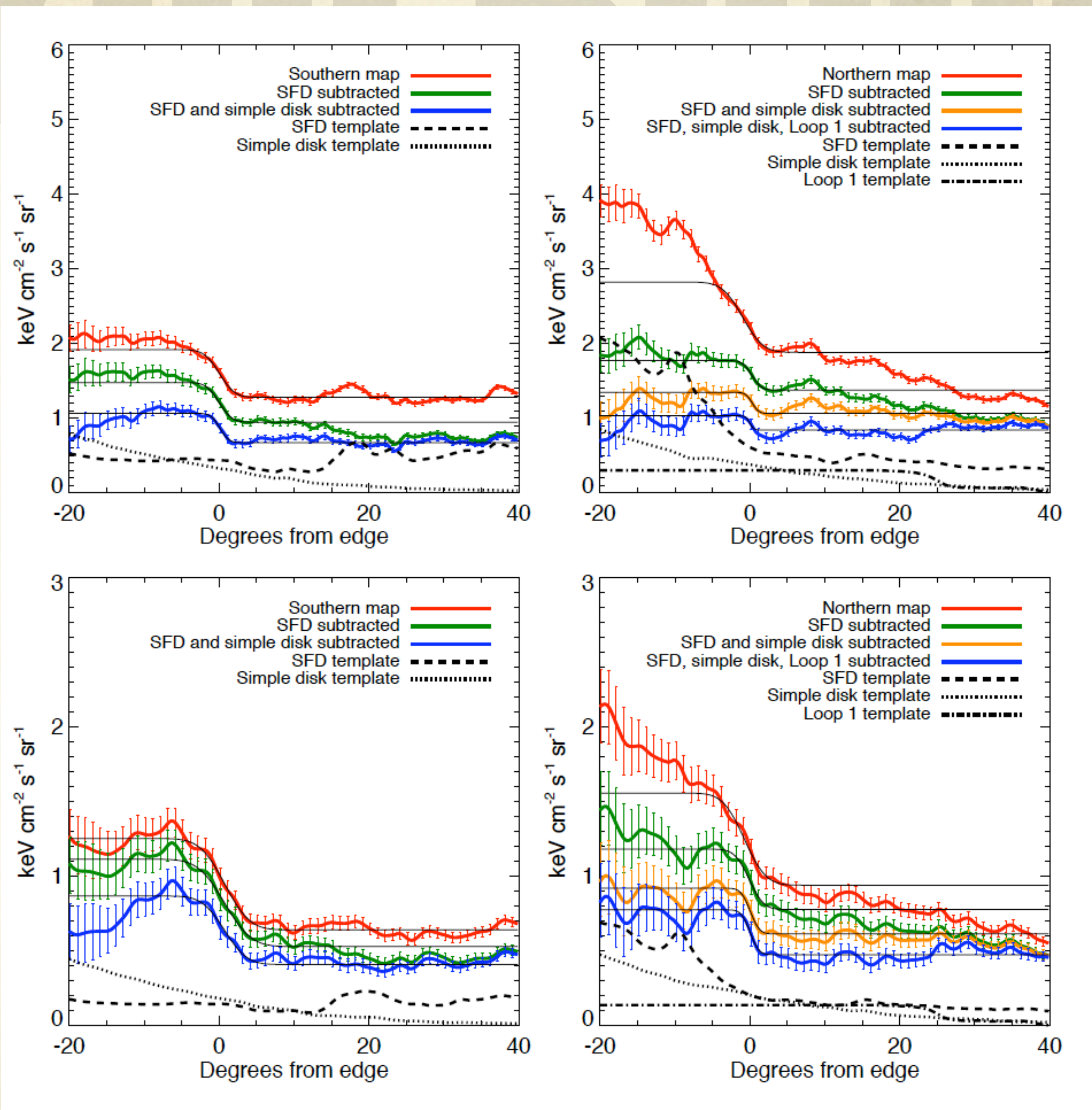


Fermi Bubble

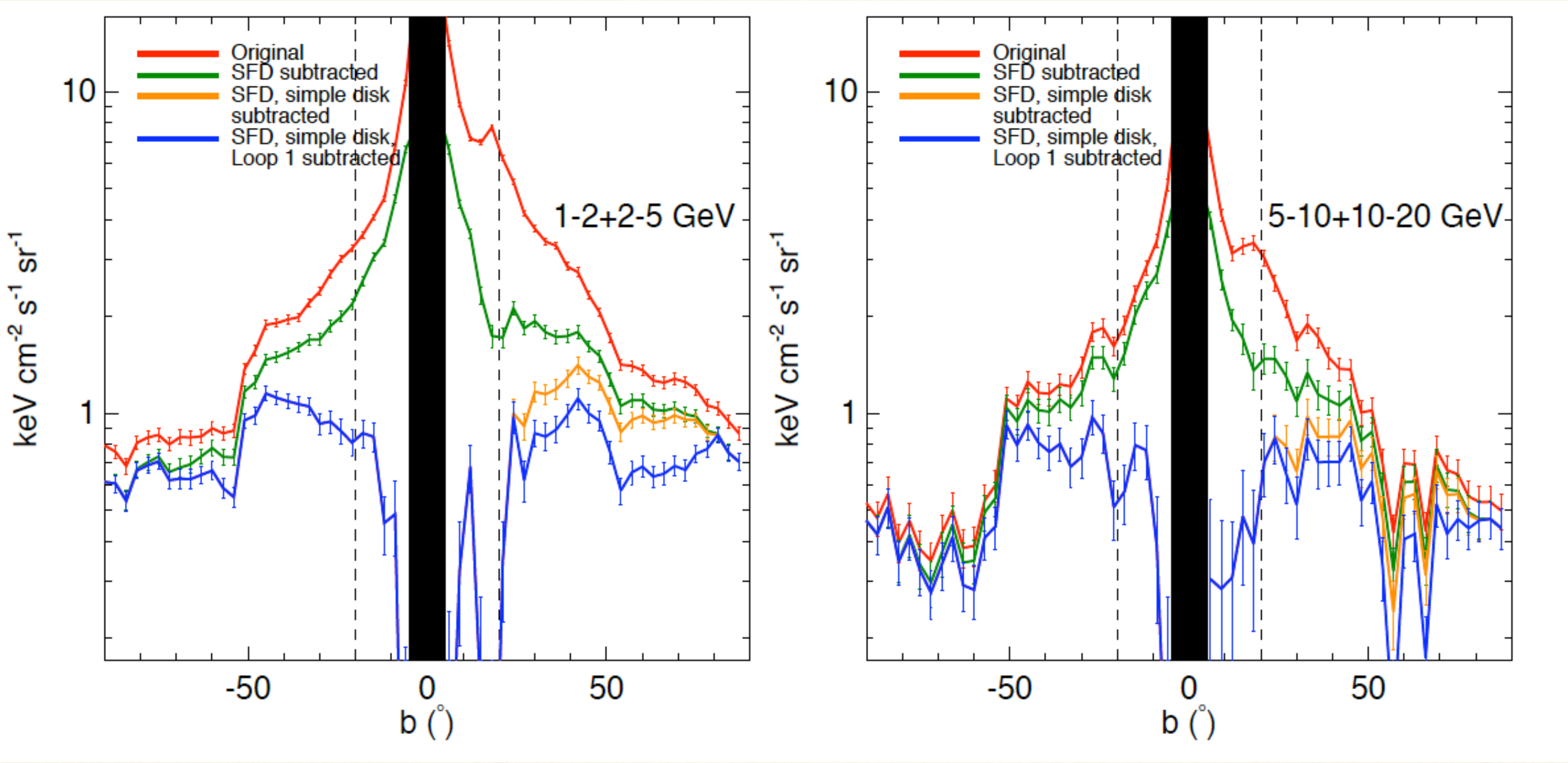


We use a low energy gamma-ray template (dust-subtracted) as the IC component.

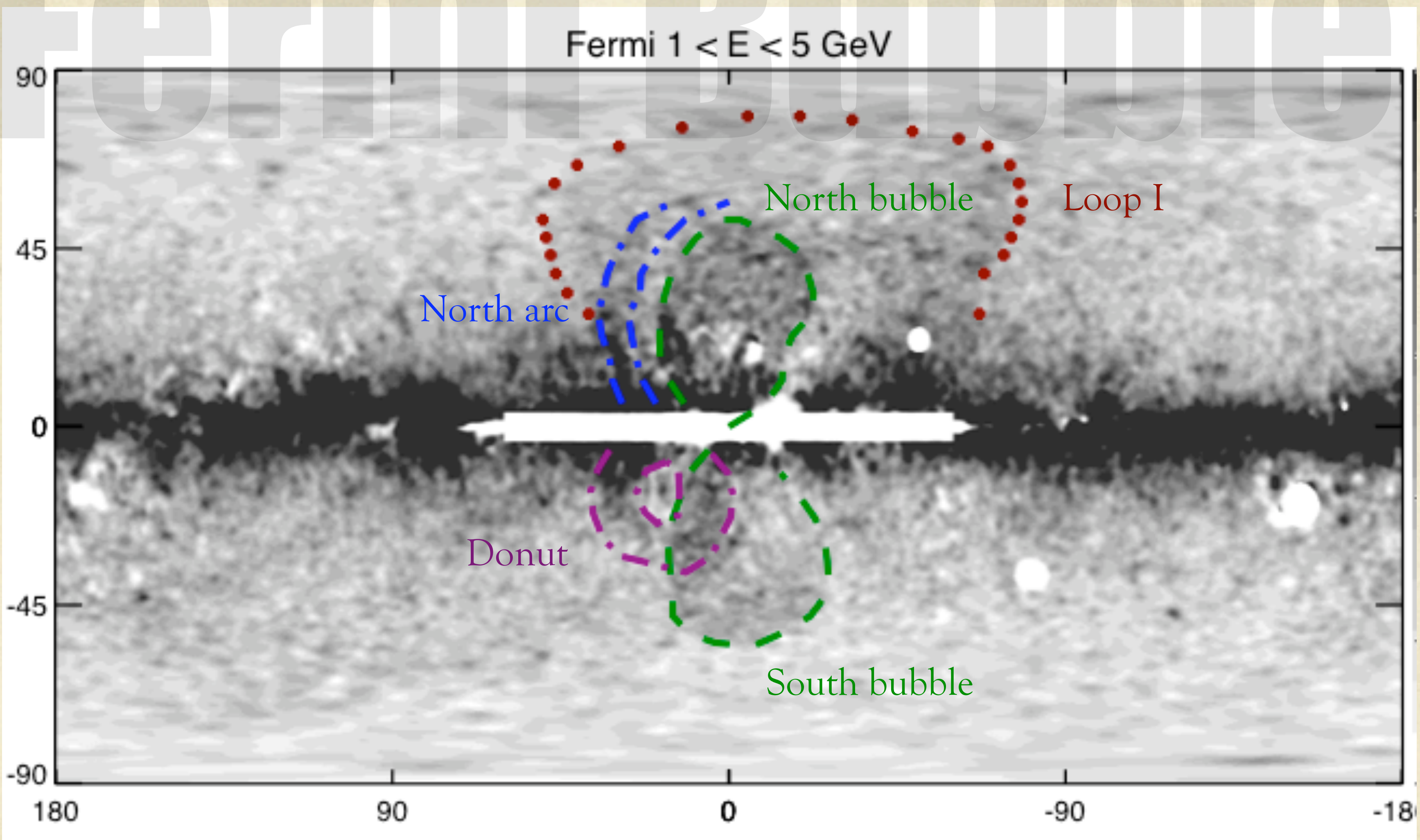
The bubbles have Sharp edges!



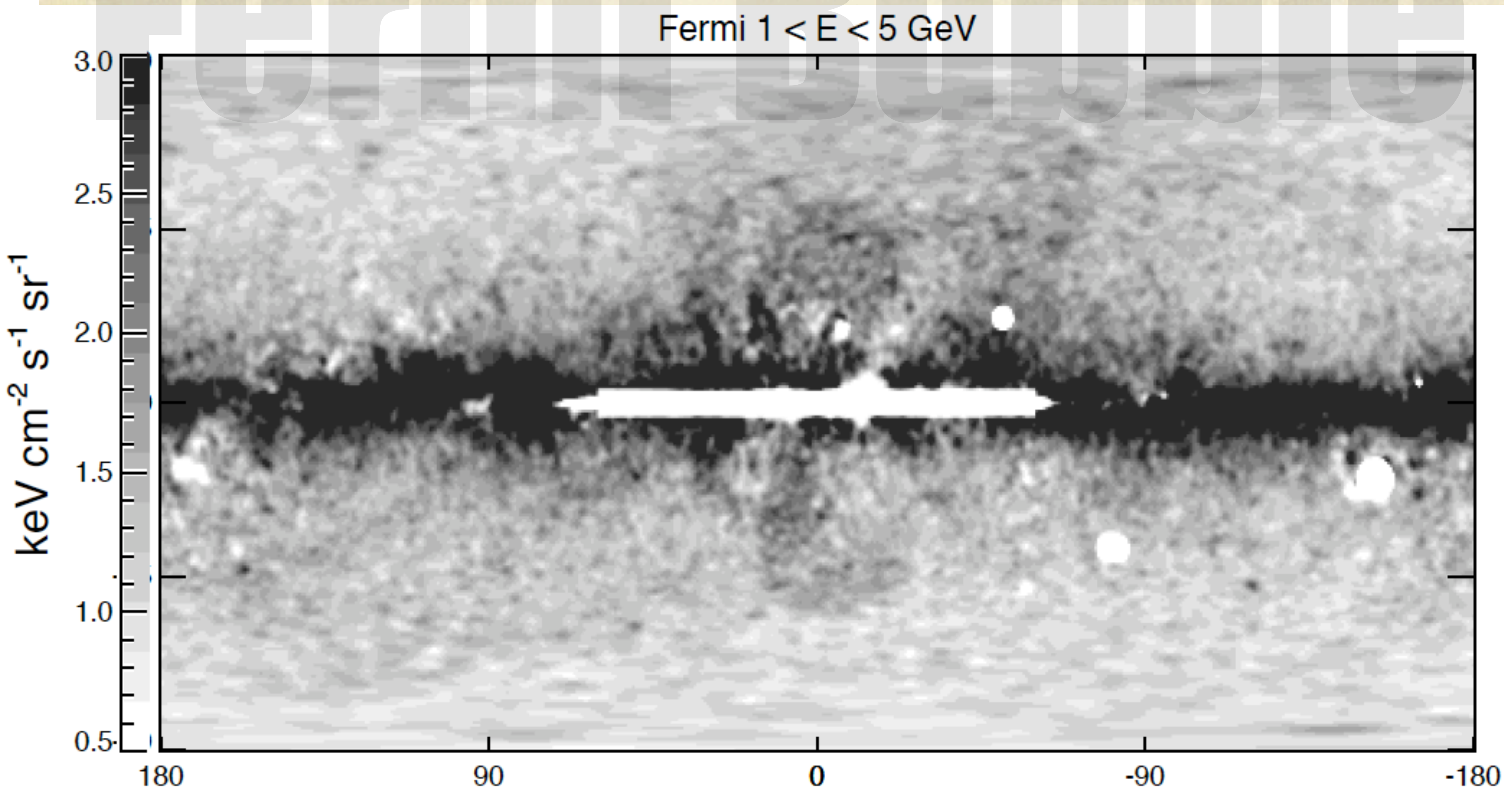
Fermi Bubble



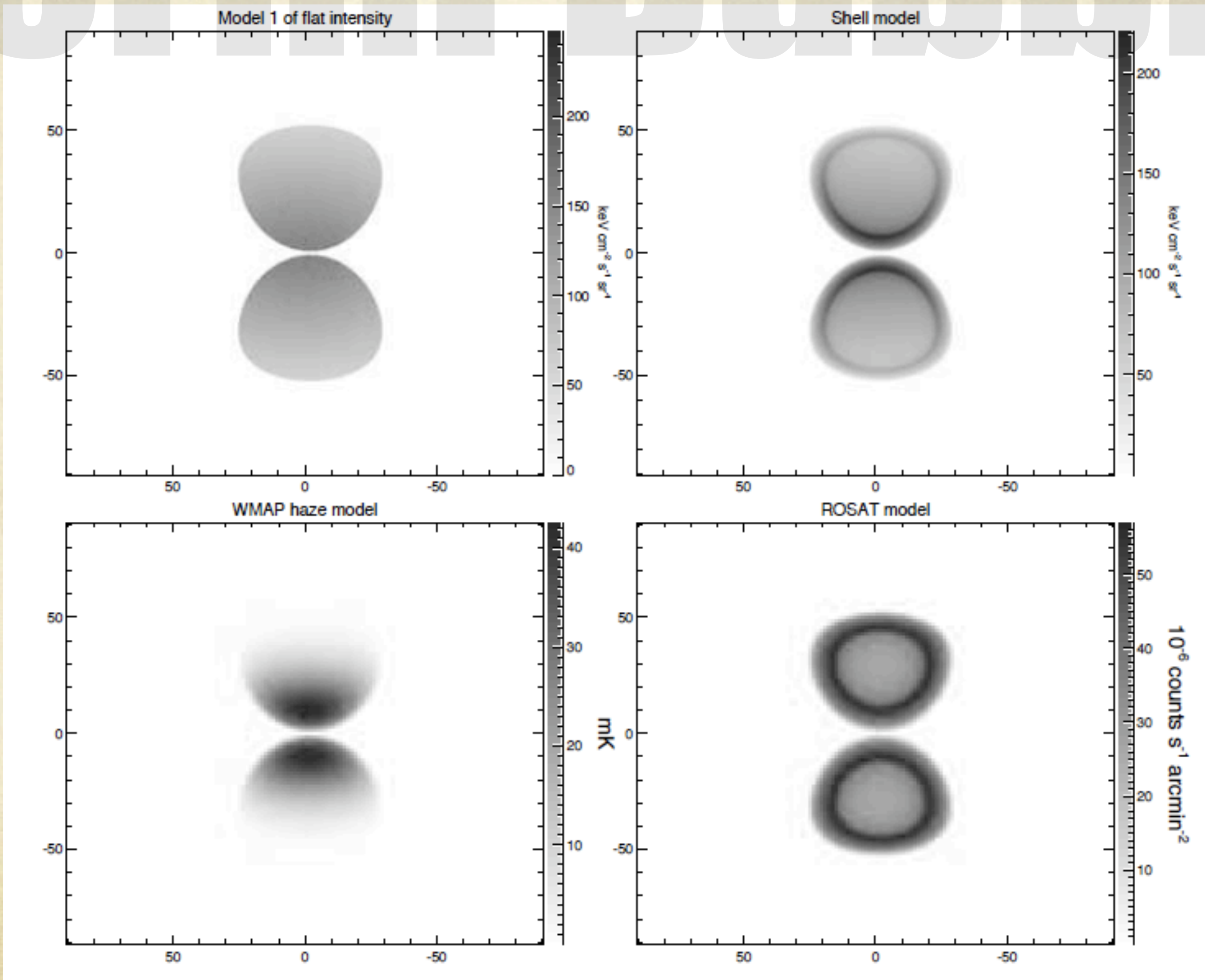
Fermi Bubble



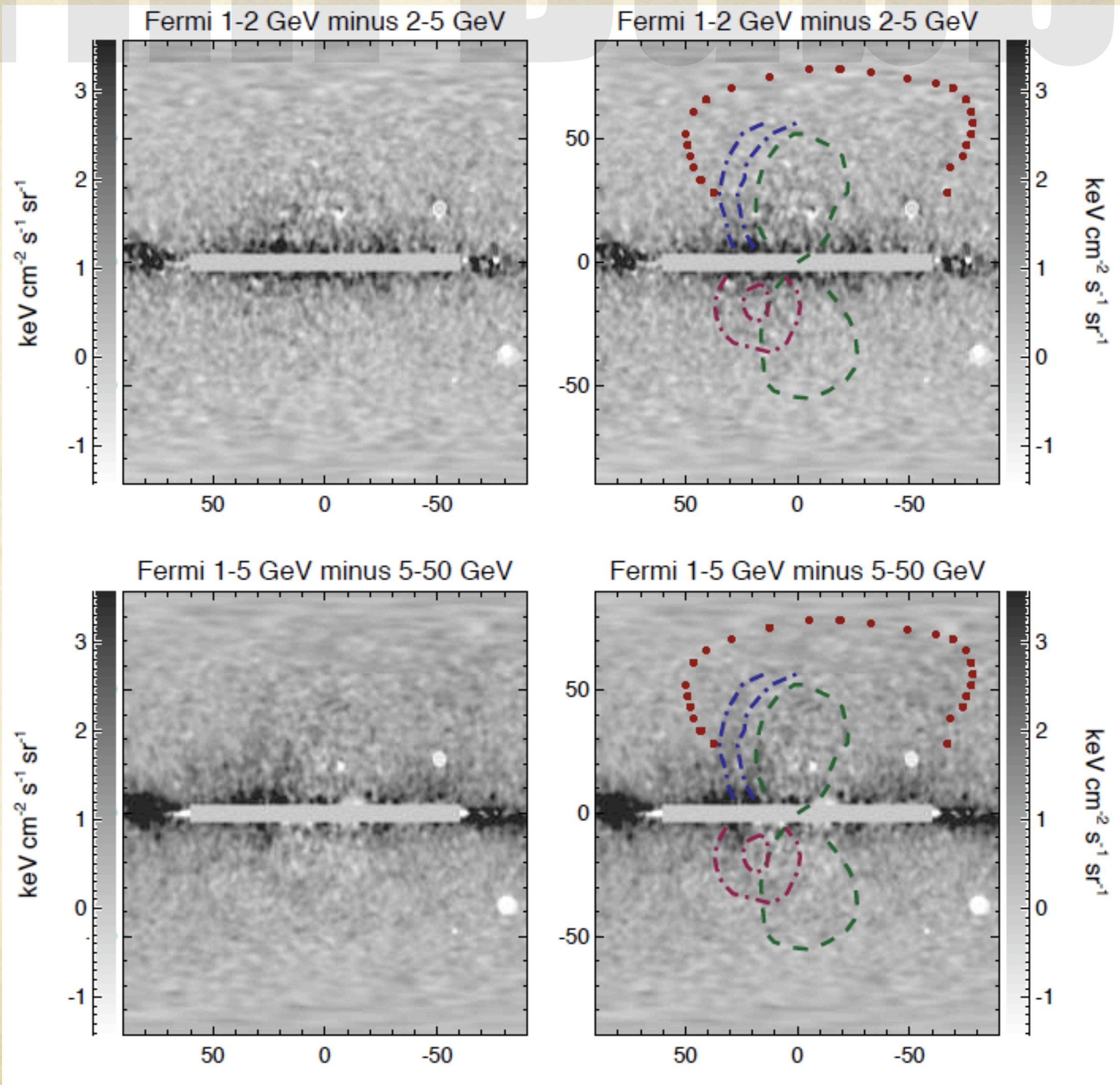
Fermi Bubble



Fermi Bubble



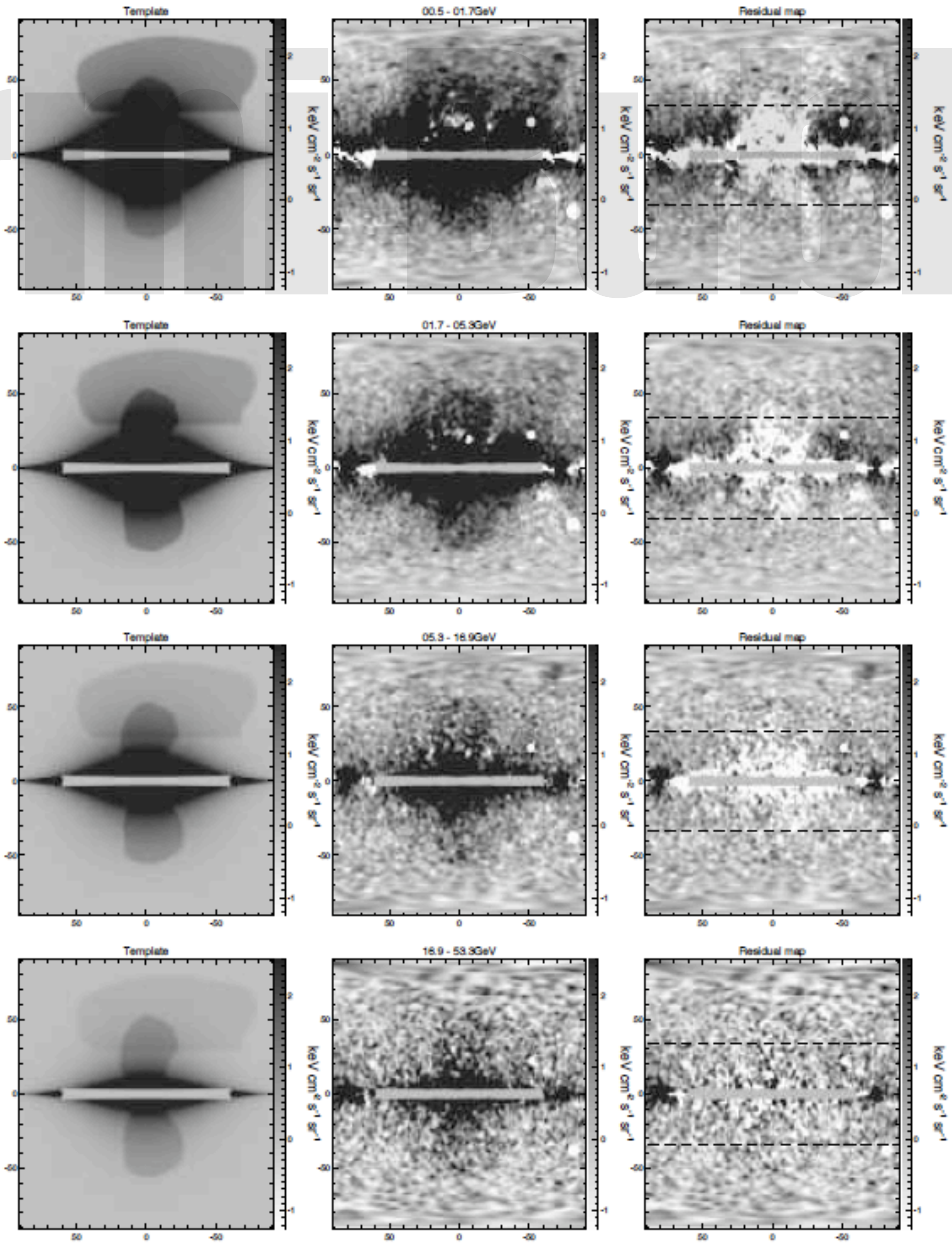
Fermi bubbles are uniform



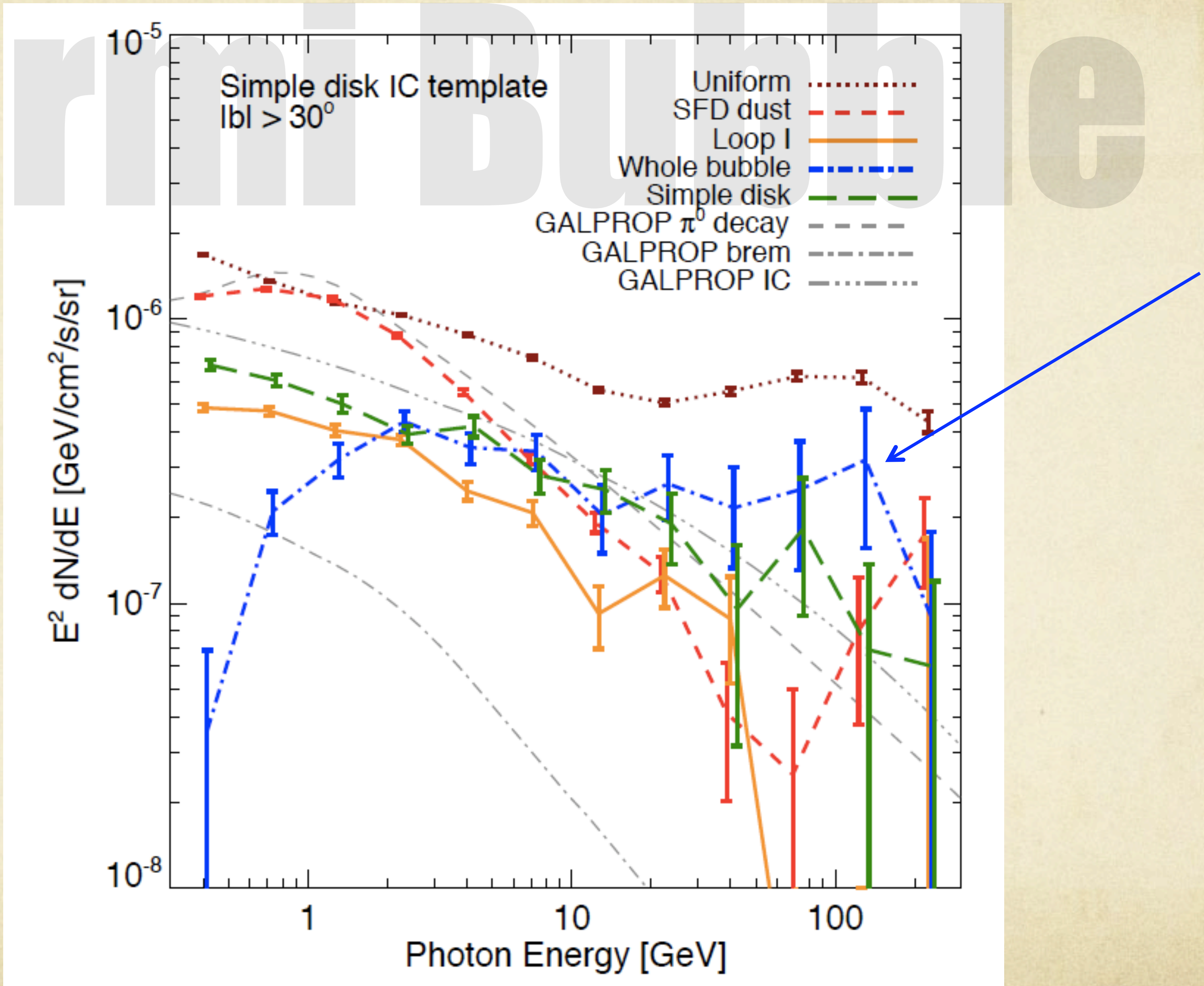
Fermi Bubble

Now we can do a multilinear regression at each energy, including dust and simple templates for disk, Loop I, and the bubbles

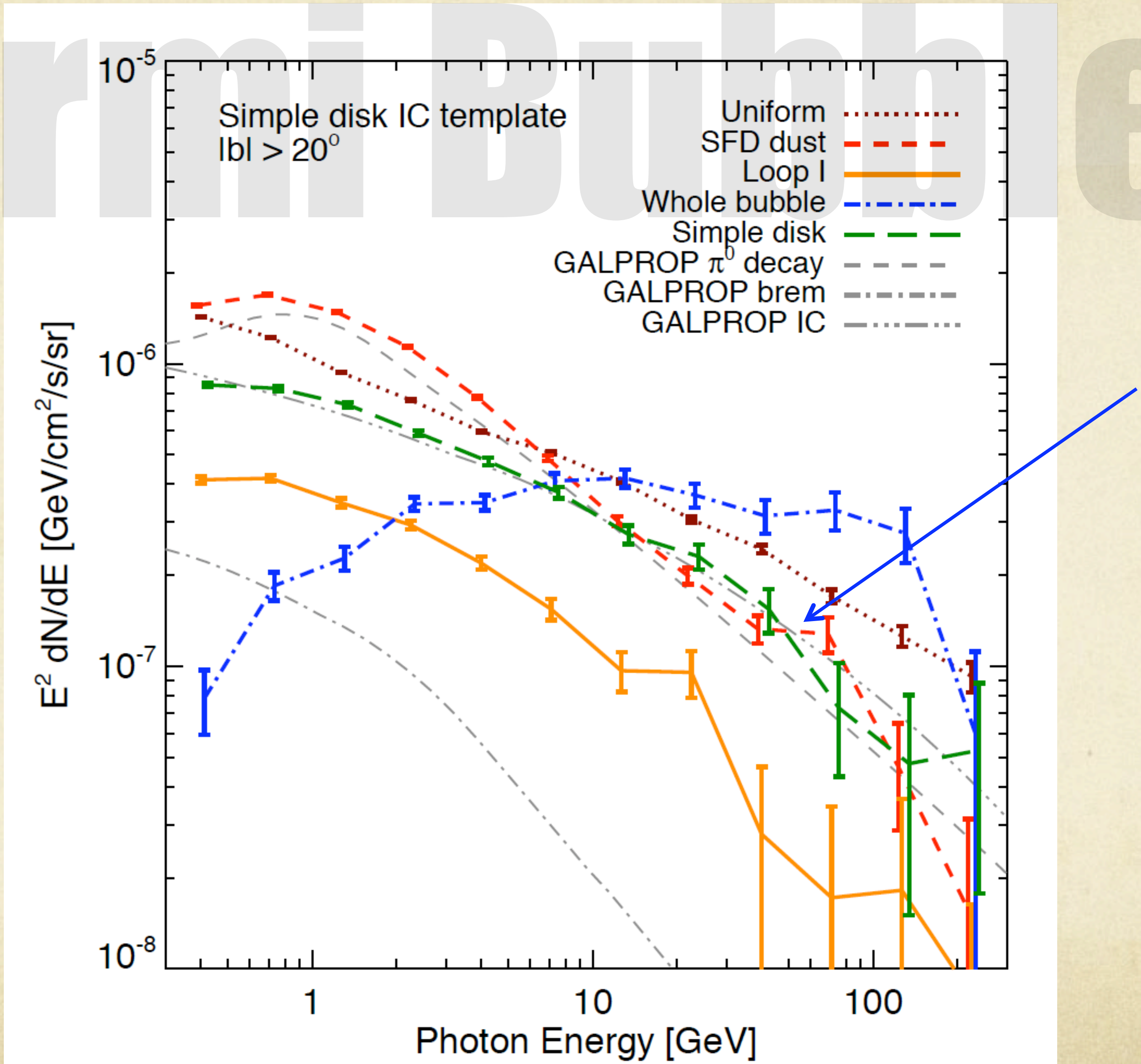
Fermi Bubble



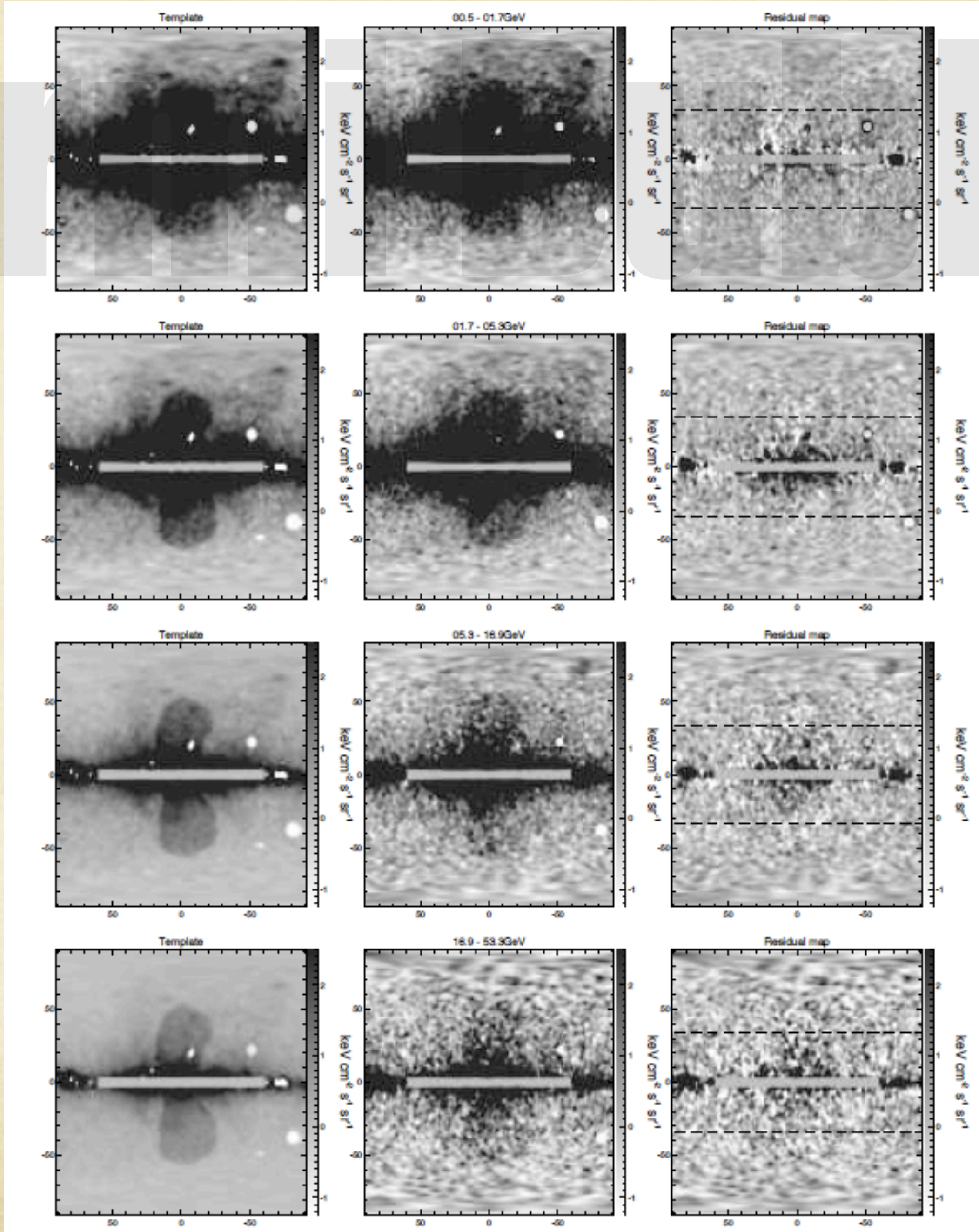
Fermi Bubble



Fermi Bubble



Fermi Bubble



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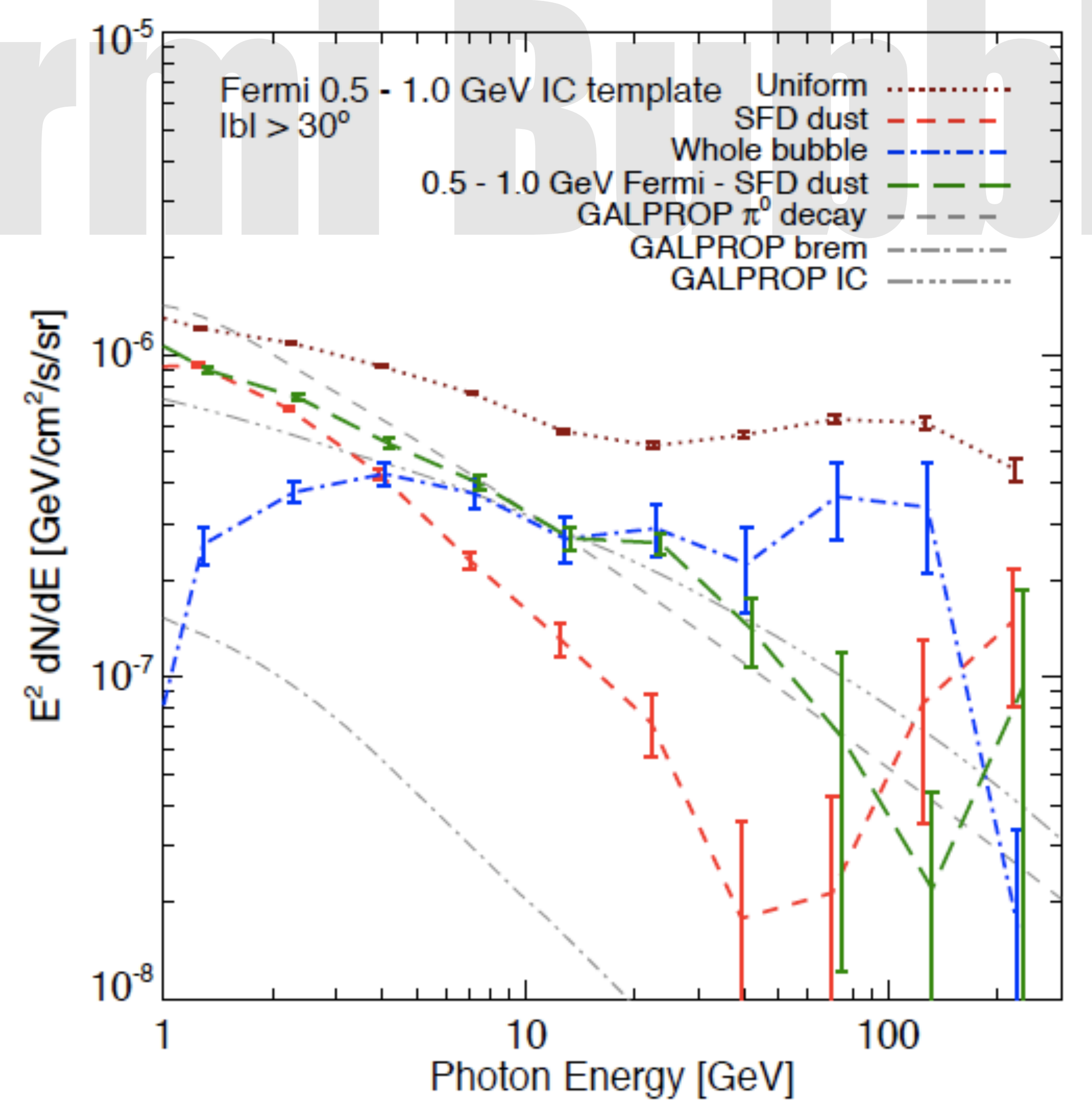
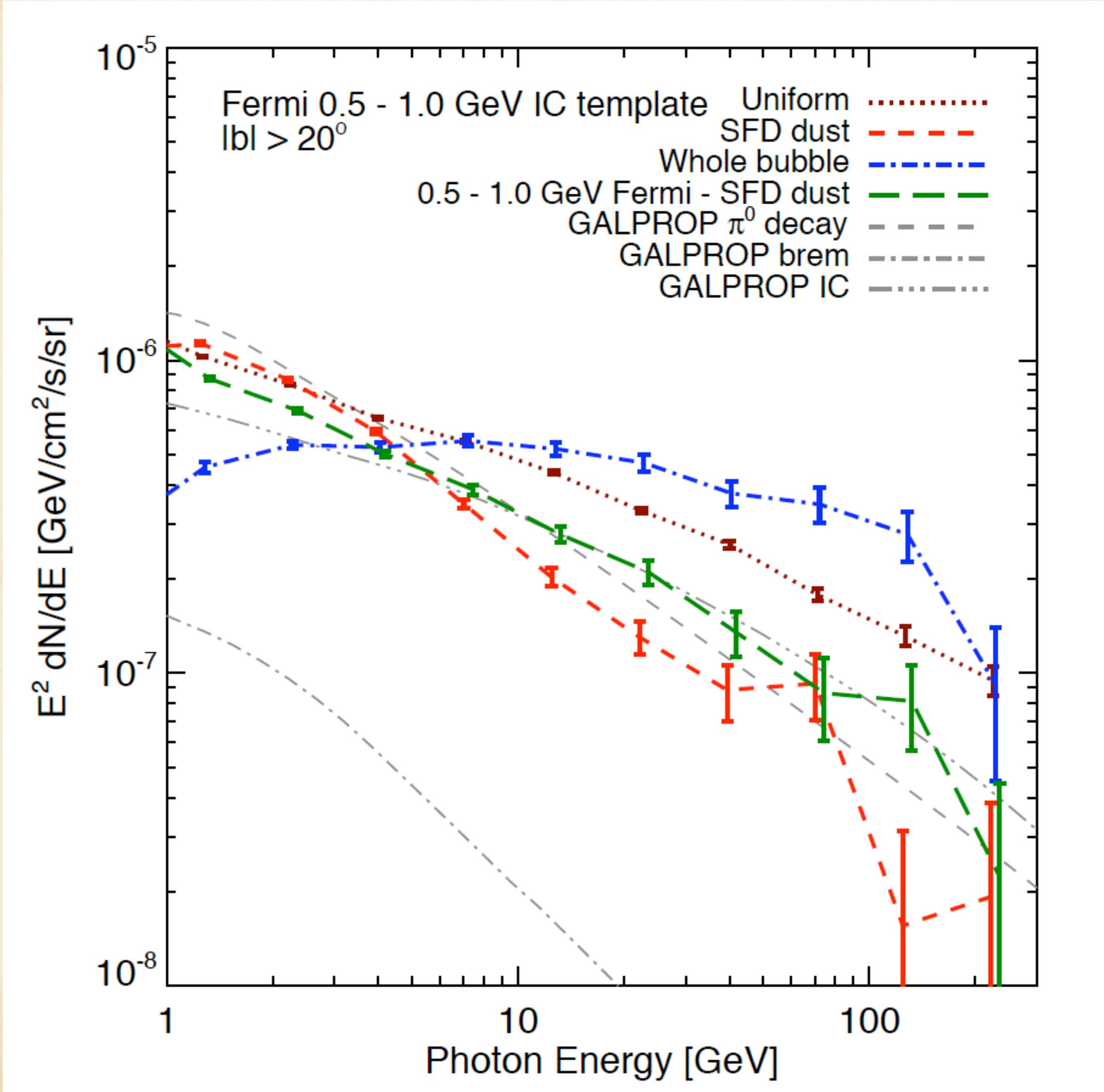
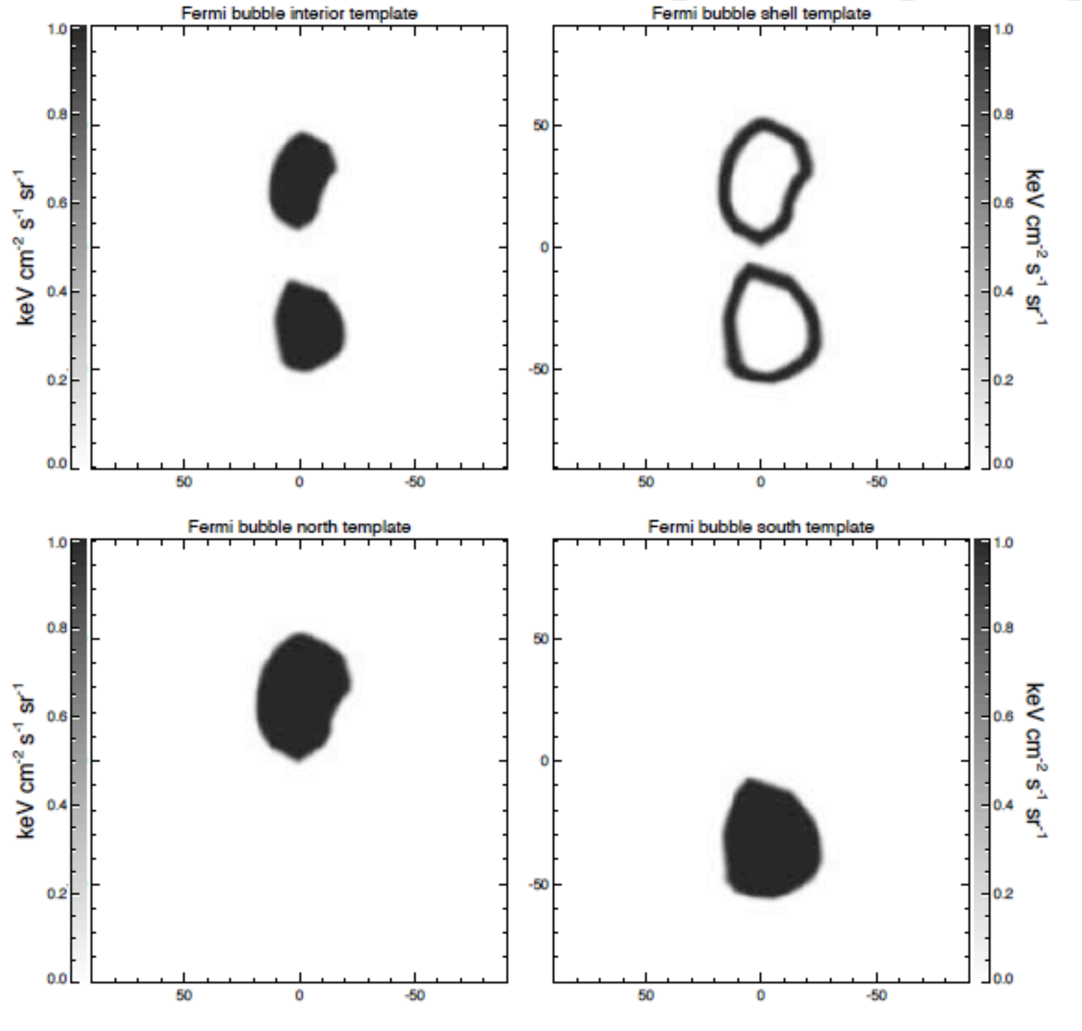


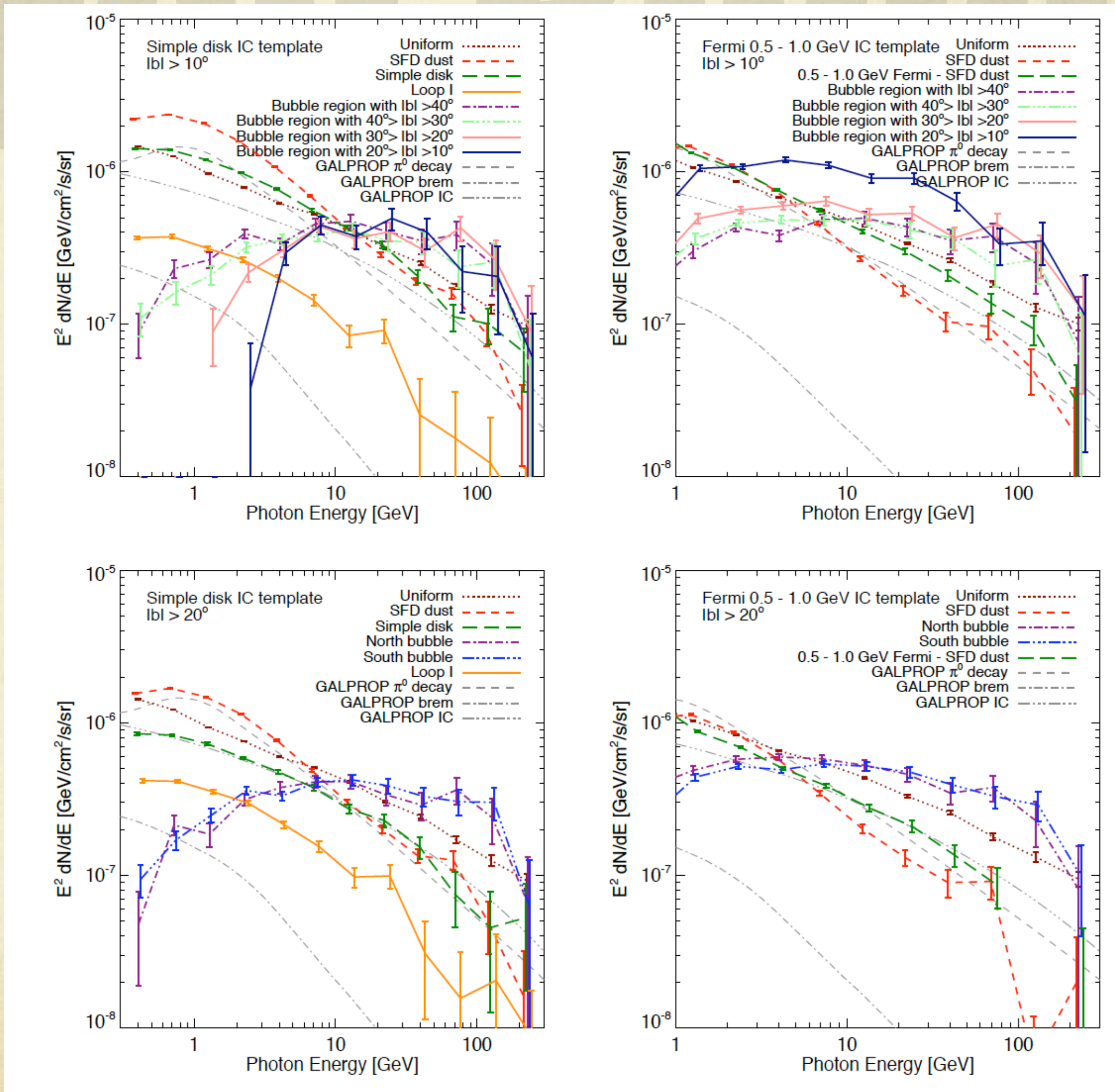


Fermi 0.5 - 1.0 GeV IC template
|b| > 20°
Uniform
SFD dust
Whole bubble
0.5 - 1.0 GeV Fermi - SFD dust
GALPROP π⁰ decay
GALPROP brem
GALPROP IC
E² dN/dE [GeV/cm²/s/sr]
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
1
10
100
Photon Energy [GeV]

Any Substructure of the bubbles?



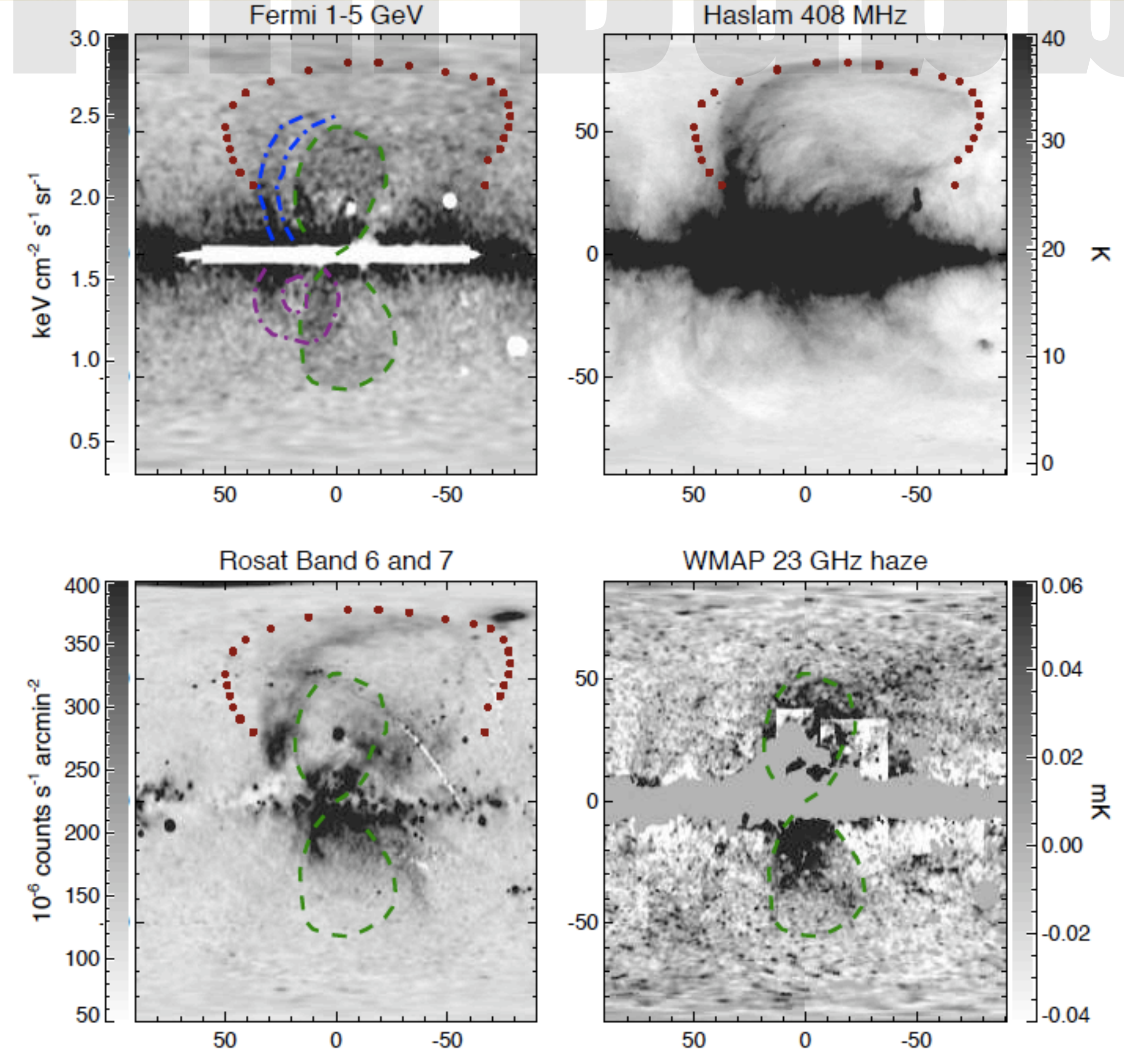
Fermi Bubble



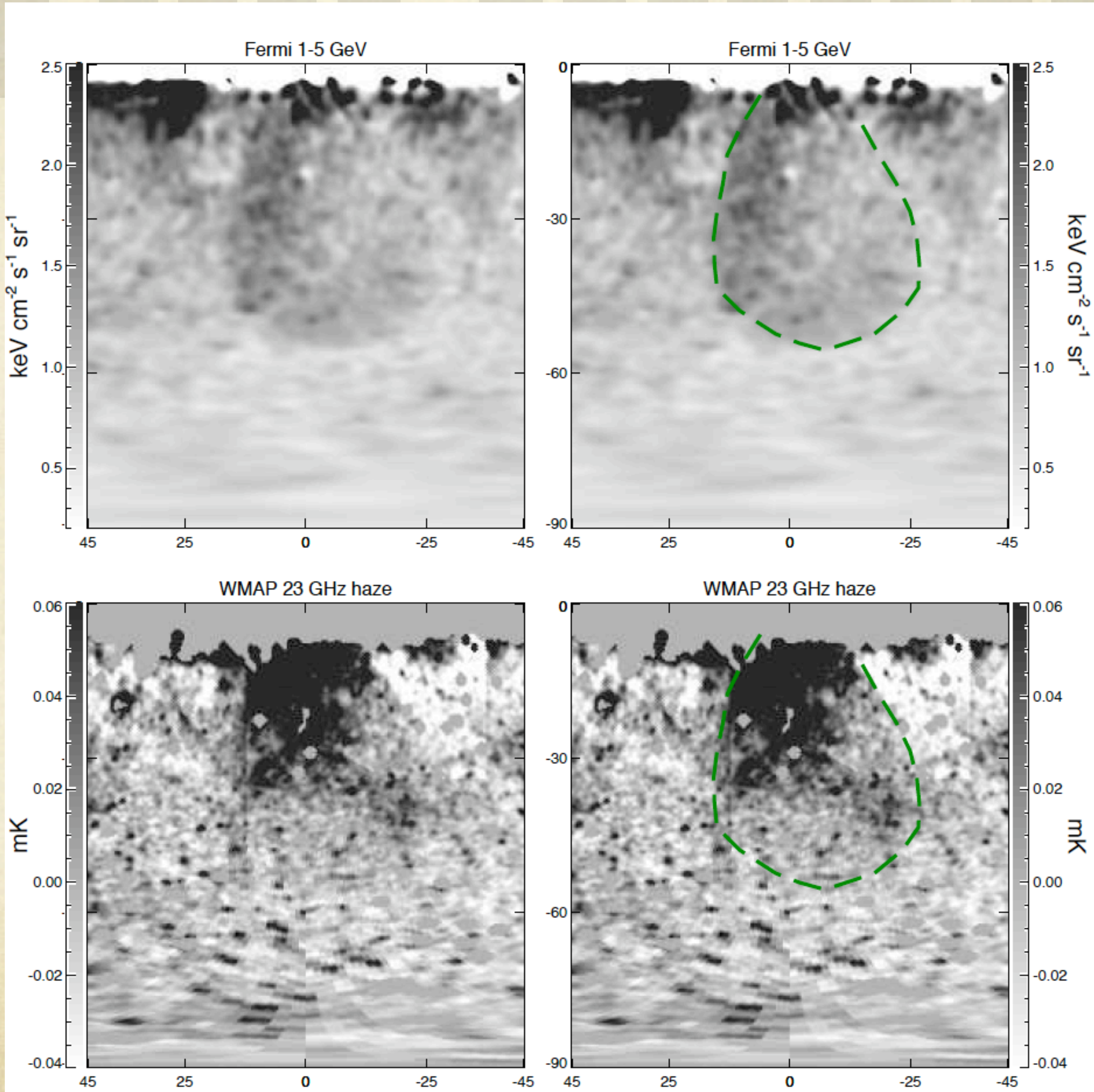
Fermi Bubble

- *Does the edge have a harder spectrum than the interior?* NO.
- *Is the north harder than the south?* NO.
- *Bottom line: No matter how we do the fit,*
  the bubbles have a harder spectrum (index ~ -2)
  than the other IC emission (index ~ -2.5).
- *The gamma-ray spectrum extends up to ~ 50 GeV or more, implying >~ 100 GeV electrons.*
- *If it is CMB scattering, we have ~ 1 TeV electrons!*

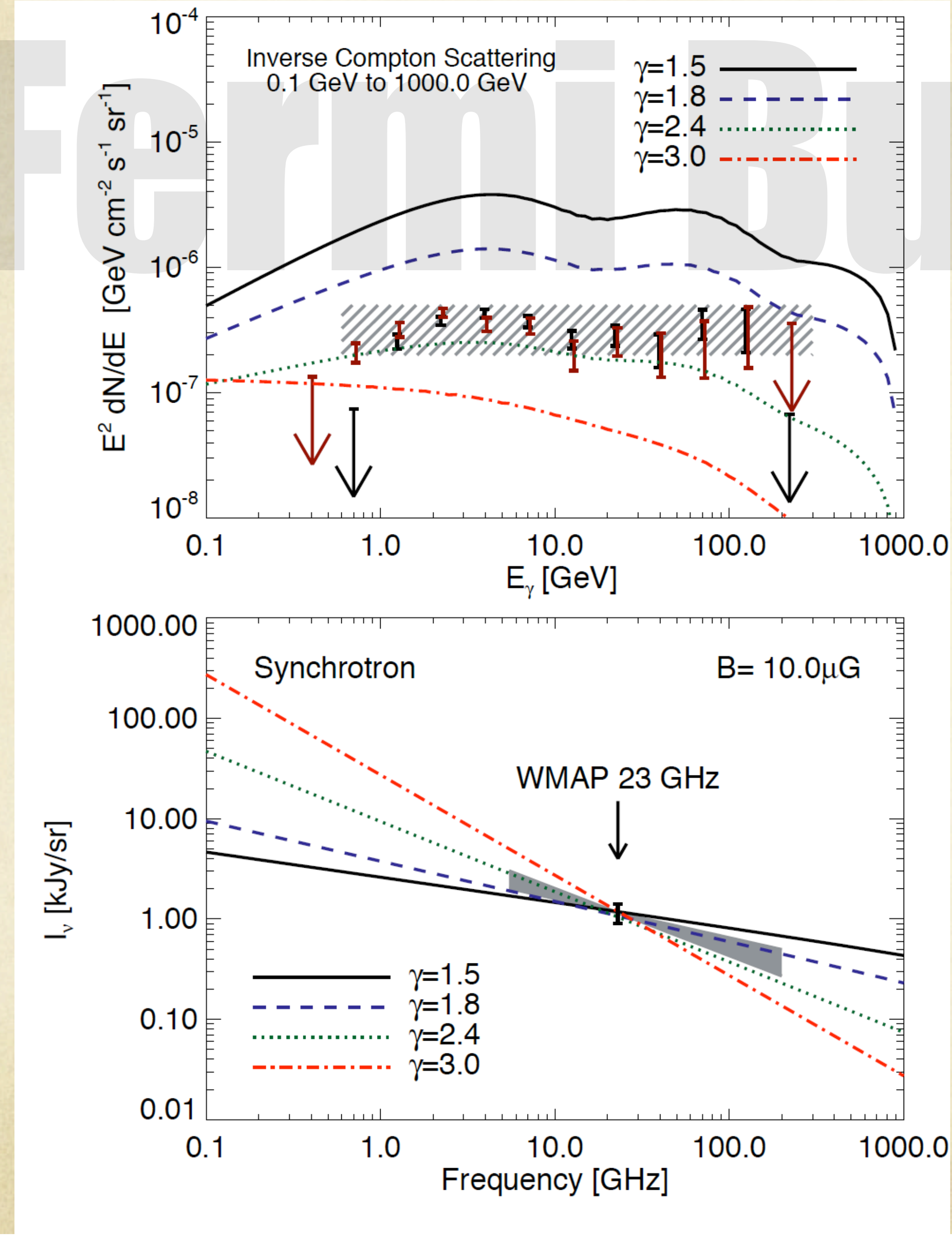
Fermi Bubble



Compare with WMAP haze



Fermi Bubble

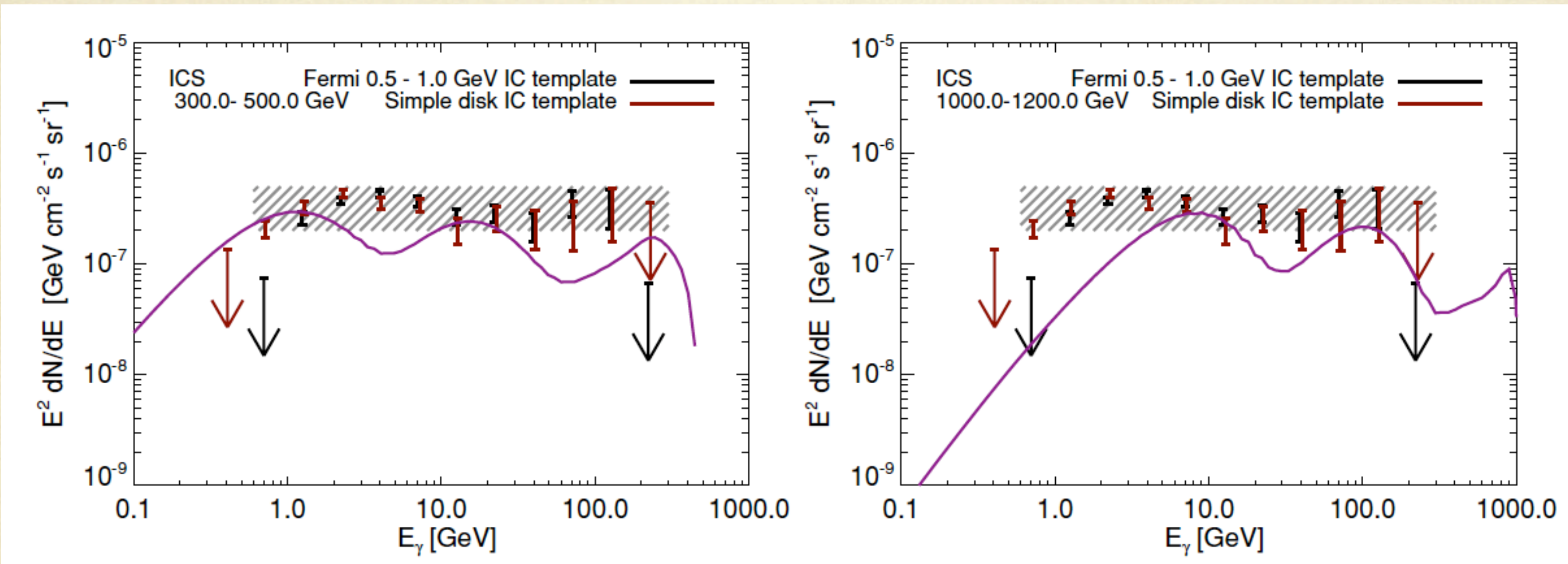


The Fermi bubbles are clearly associated with WMAP haze

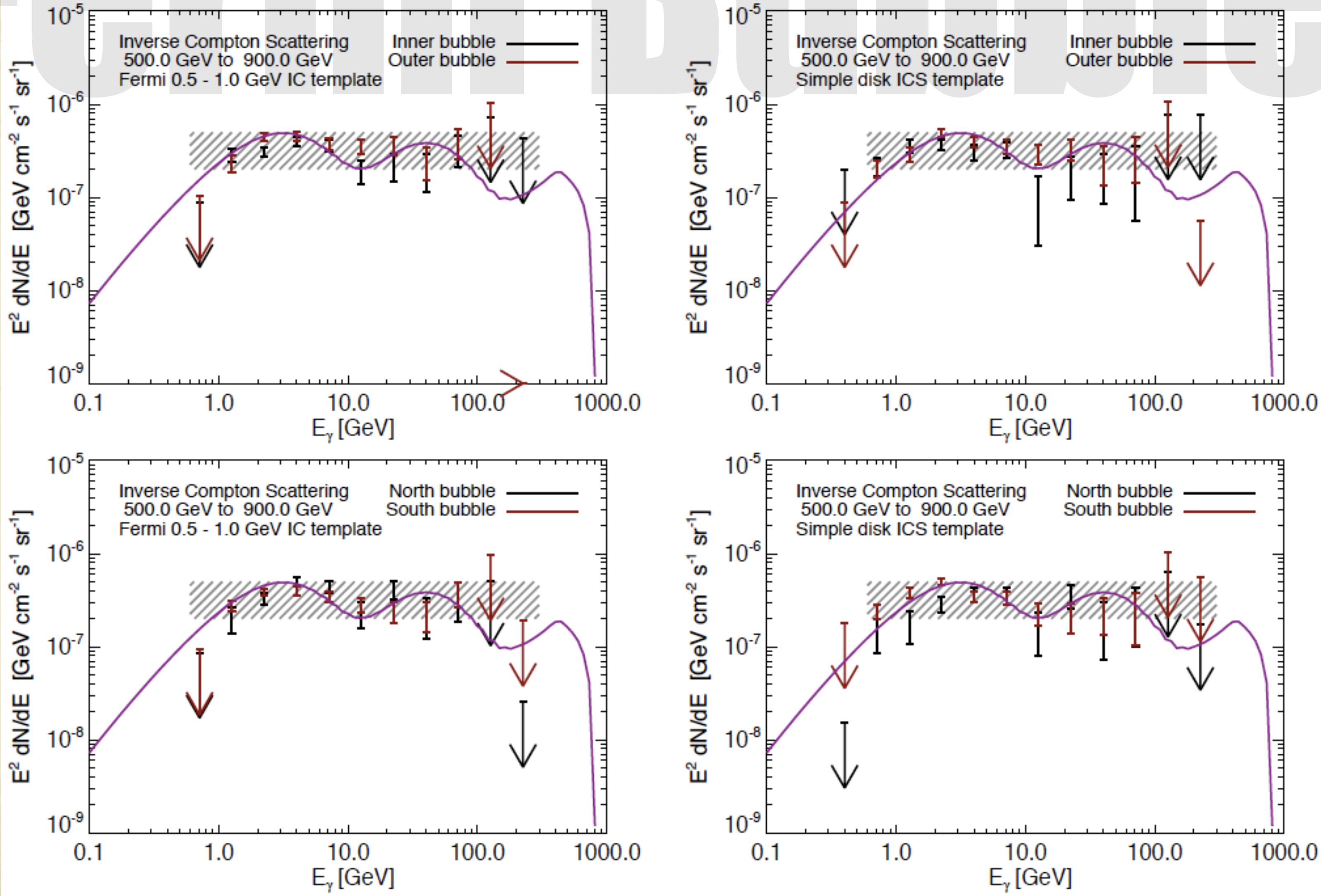
The same electron spectrum can easily make both!

Fermi Bubble

It is easy to get bumps and wiggles in the wrong places…



500-900 GeV electrons scattering CMB roll off at the right (low) energy.



Fermi Bubble

Two arguments for CMB scattering:

- *1. The bubble intensity is ~flat with latitude, while starlight density is falling.*

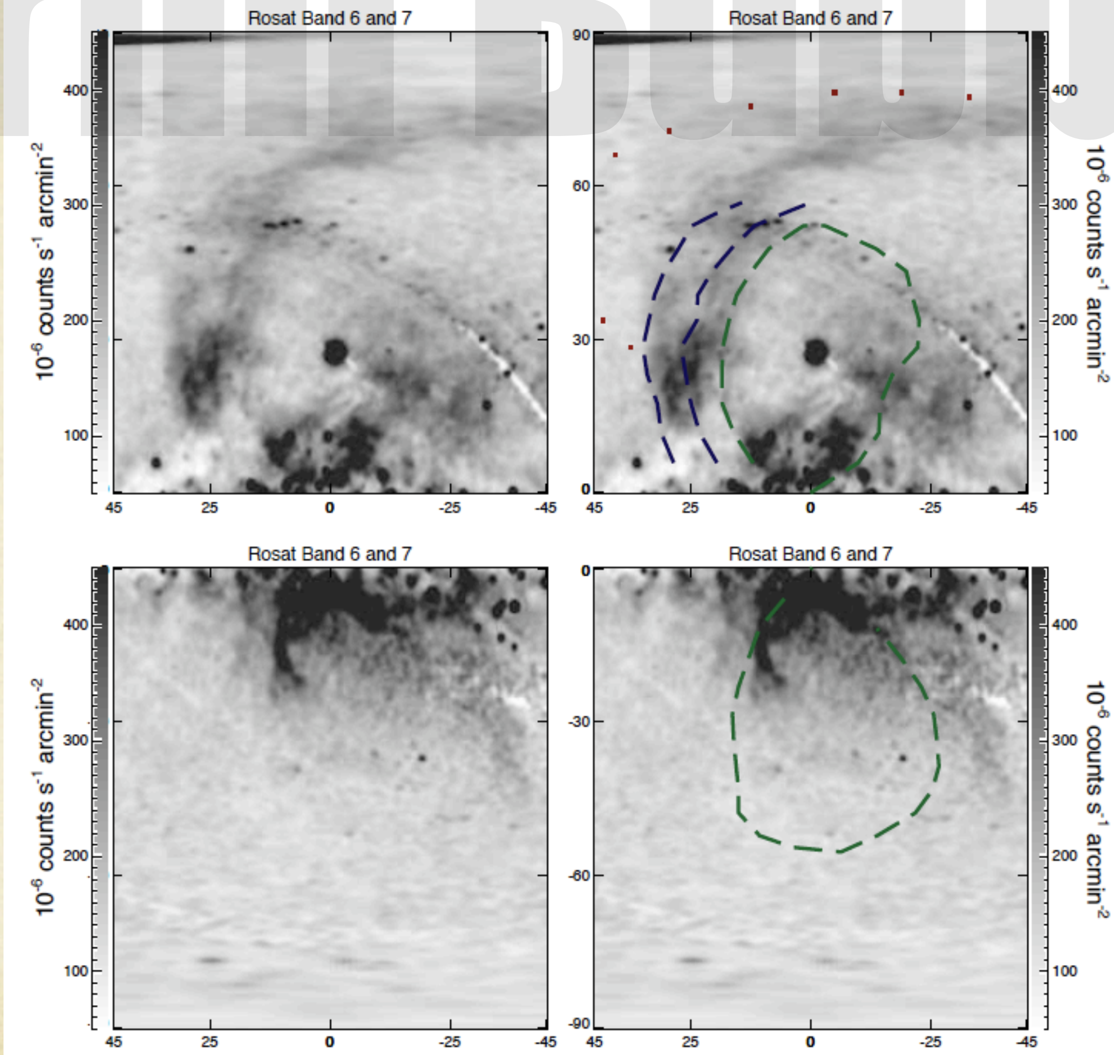
- *2. The shape of the IC spectrum.*

500-900 GeV electrons scattering CMB roll off at the right (low) energy.
(But see Crocker & Aharonian 2010)

Together these imply that the Fermi bubbles are Mainly ~TeV electrons scattering the CMB. (Note that the WMAP haze is produced by ~10 GeV electrons.)

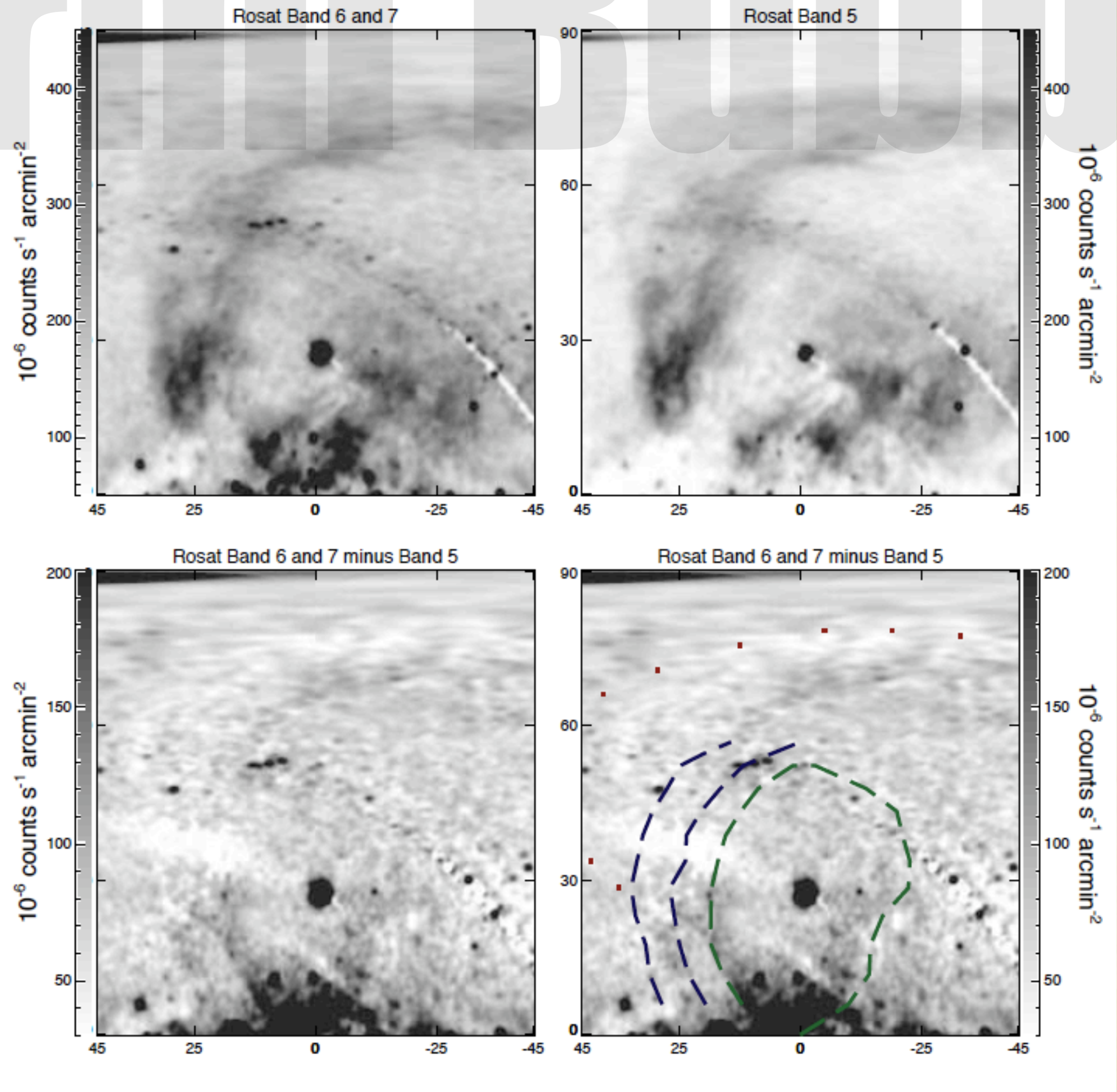
Now, how about X-rays?

ROSAT 1.5 keV



(See discussion in e.g. Sofue 2000a; Bland-Hawthorn and Cohen 2003a).

Fermi Bubble



Fermi Bubble

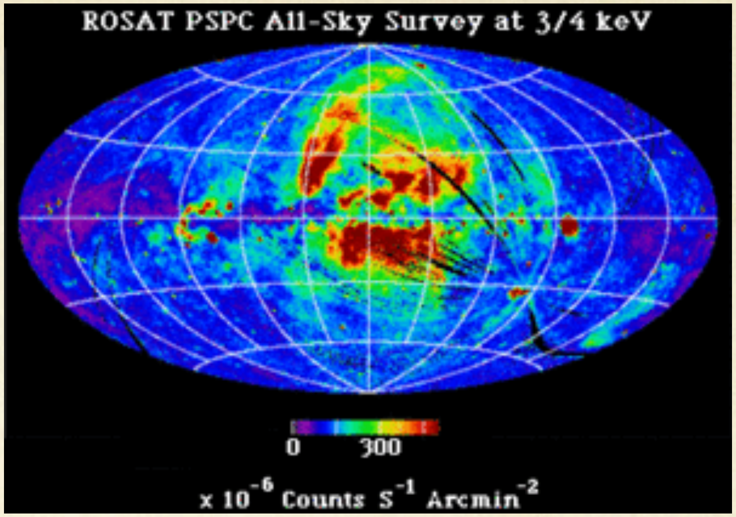
So far: there appear to be a pair of giant (50 degree high) gamma-ray bubbles at 1-5 GeV, and probably up to at least 50 GeV.

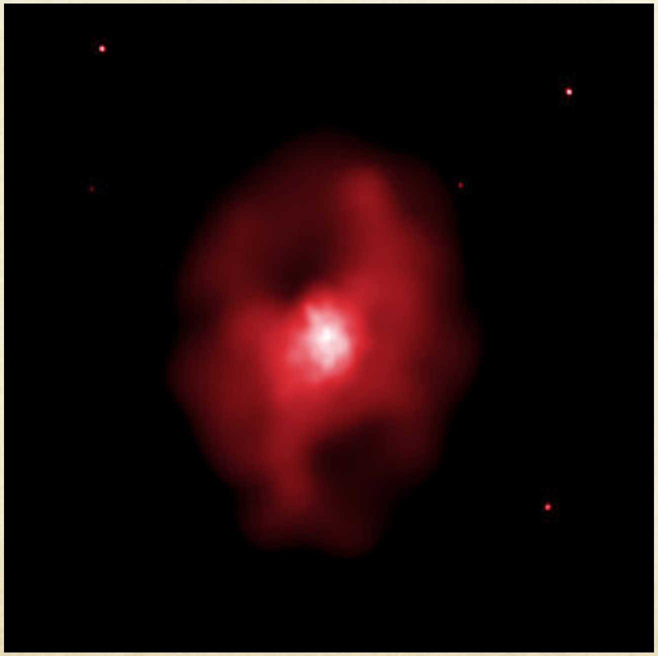
What are they?

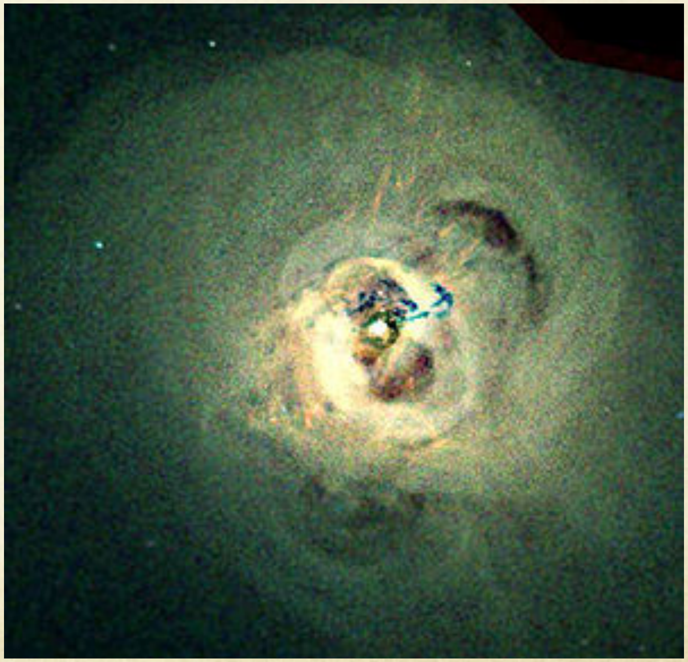
Black hole "burp"

Superwind bubble?

Dark matter? *(Dobler et al arXiv:1102.5095)*





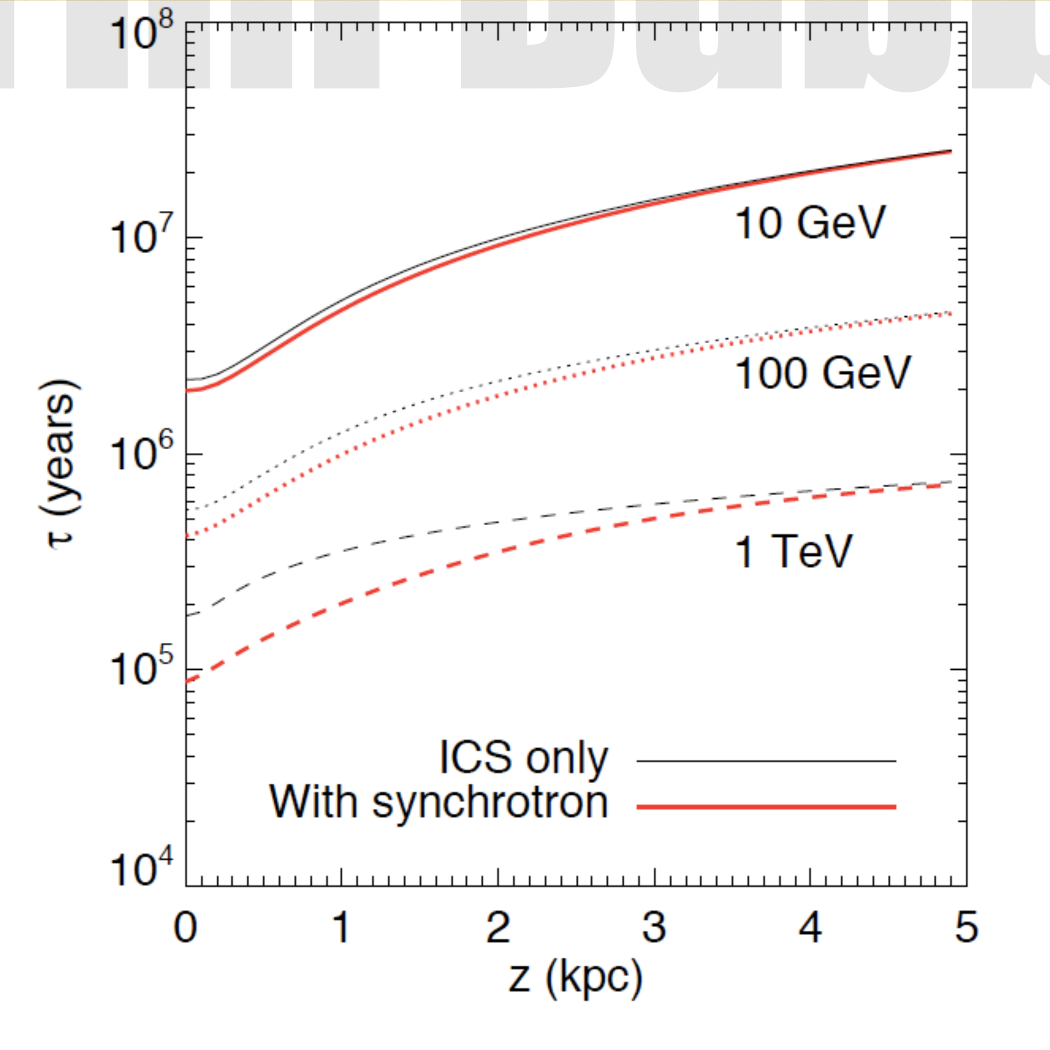


galaxy cluster MS 0735.6+7421 in Camelopardus

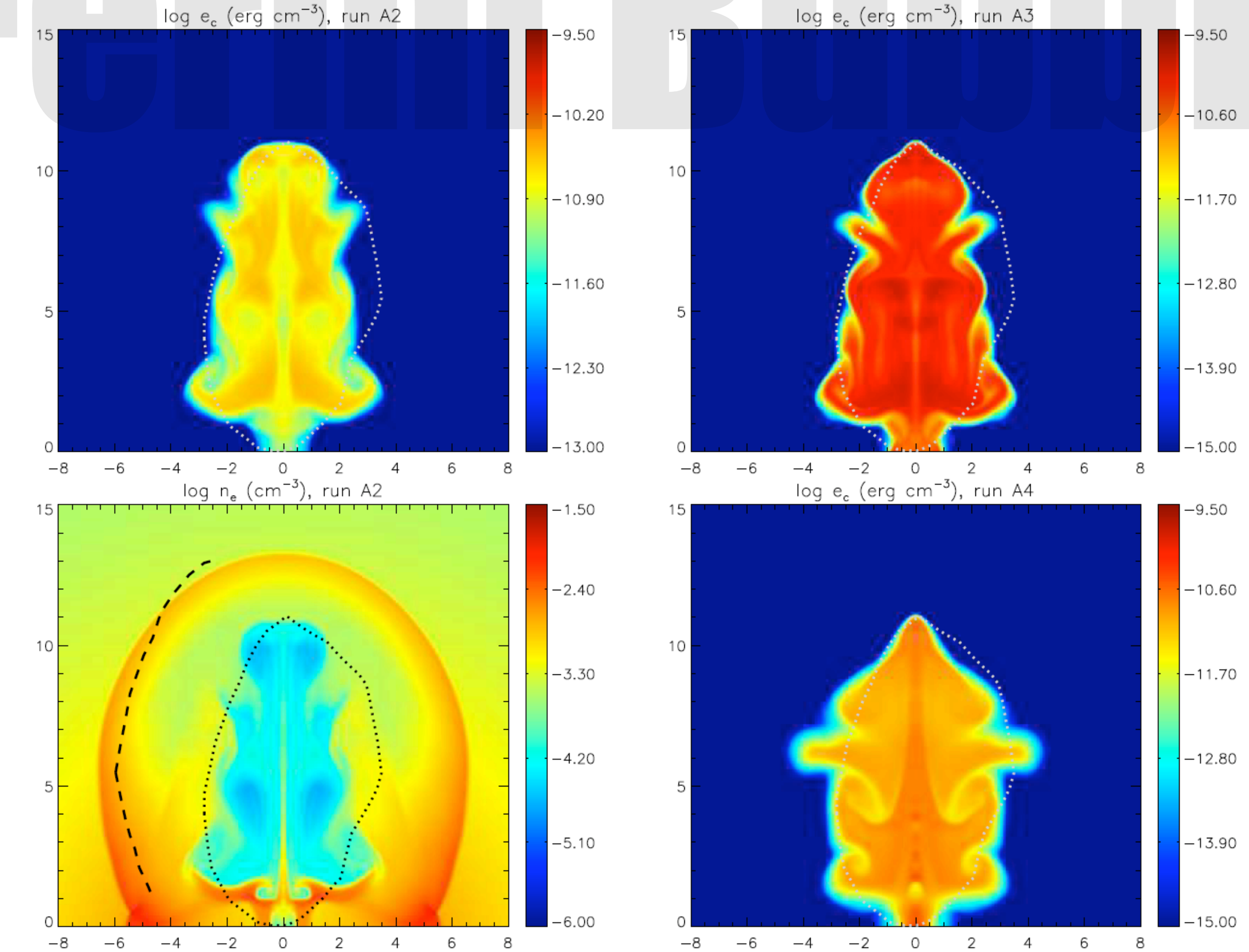
Perseus galaxy cluster

Fermi Bubble

Cooling time is short!



Fermi Bubble



Guo & Mathews (arXiv:1103.0055)

Fermi Bubble

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

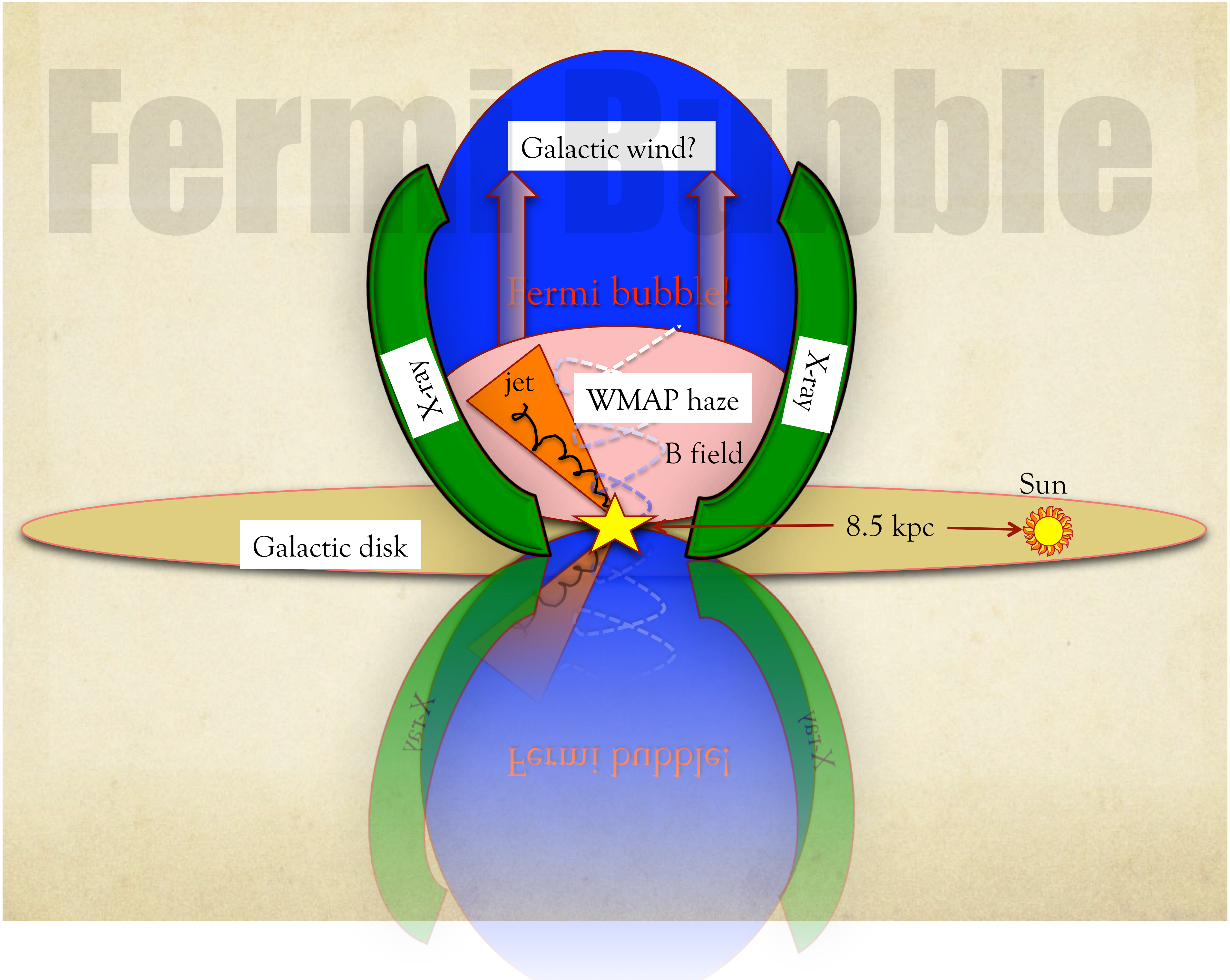
In situ acceleration. Shocks? Reconnection?

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 BH.

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

Fermi Bubble

Take home message


Fermi Bubble
Galactic wind?
Fermi bubble!
X-ray
X-ray
jet
WMAP haze
B field
Sun
Galactic disk
8.5 kpc

Fermi Bubble

- *Fermi -LAT reveal two large gamma-ray huge bubbles*
- *The gamma-ray emission associated with these bubbles has a significantly harder spectrum (dN/dE ~ E^{-2})*
- *There is no significant spatial variation in the spectrum or gamma-ray intensity within the bubbles, or between the north and south bubbles.*
- *The bubbles are spatially correlated with the hard-spectrum microwave excess known as the WMAP haze; the edges of the bubbles also line up with features in the ROSAT X-ray maps at 1.5 - 2 keV.*

Fermi Bubble

- *The Galactic gamma-ray bubbles which were most likely created by some large episode of energy injection in the Galactic center, such as past accretion events onto the central massive black hole, or a nuclear starburst in the last ~ 10 Myr*
- *Dark matter annihilation/decay seems unlikely to generate all the features of the bubbles*
- *Study of the origin and evolution of the bubbles also has the potential to improve our understanding of recent energetic events in the inner Galaxy and the high-latitude cosmic ray population.*

Fermi Bubble

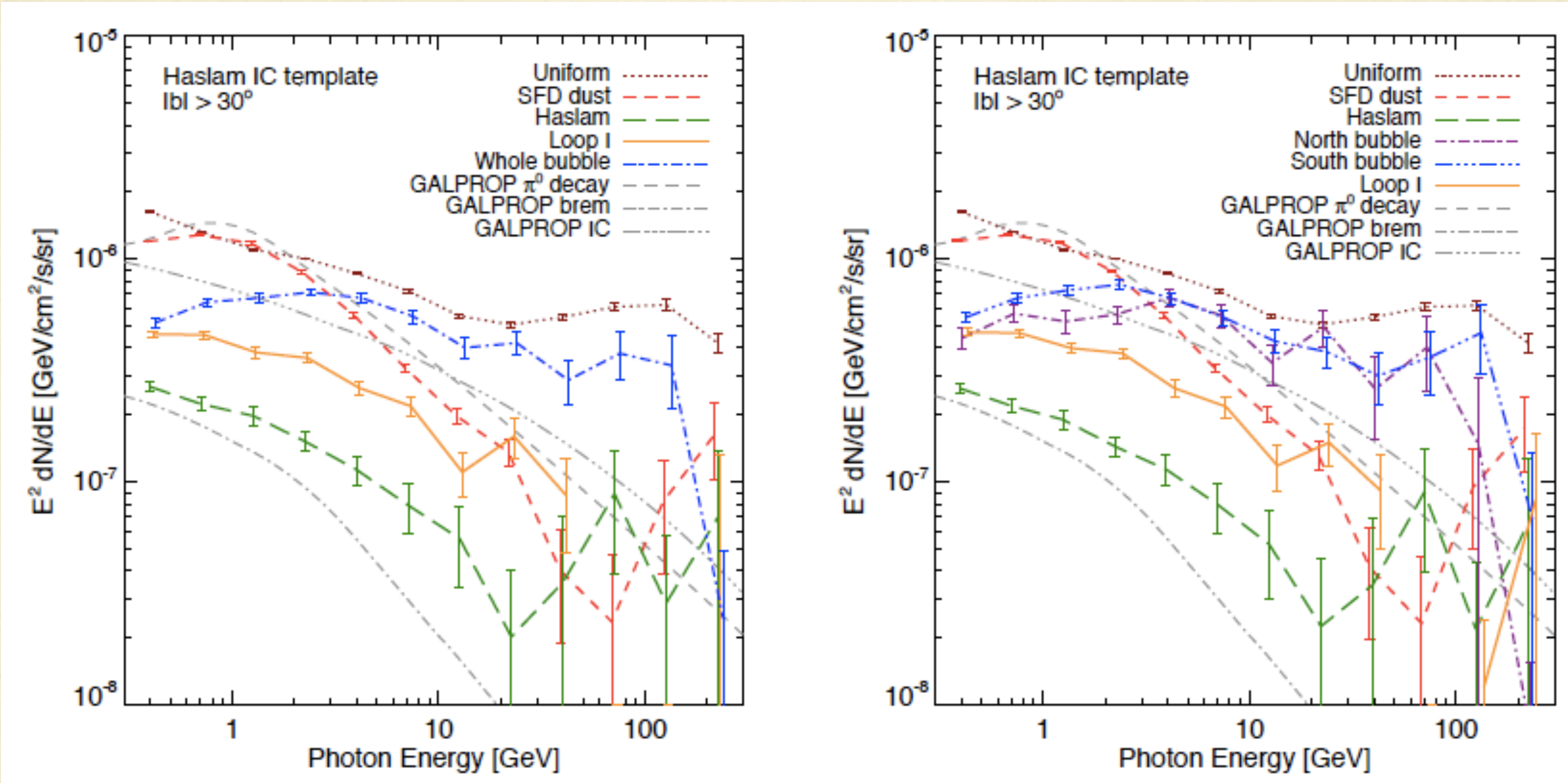
- *Continue observation of Fermi*
- *XMM-Newton data coming soon*
- *The eROSITA and Planck experiments will provide improved measurements of the X-rays and microwaves, respectively, associated with the Fermi bubbles*
- *Magnetic field structure of the bubbles*
- *Study of the origin and evolution of the bubbles also has the potential to improve our understanding of recent energetic events in the inner Galaxy and the high-latitude cosmic ray population.*

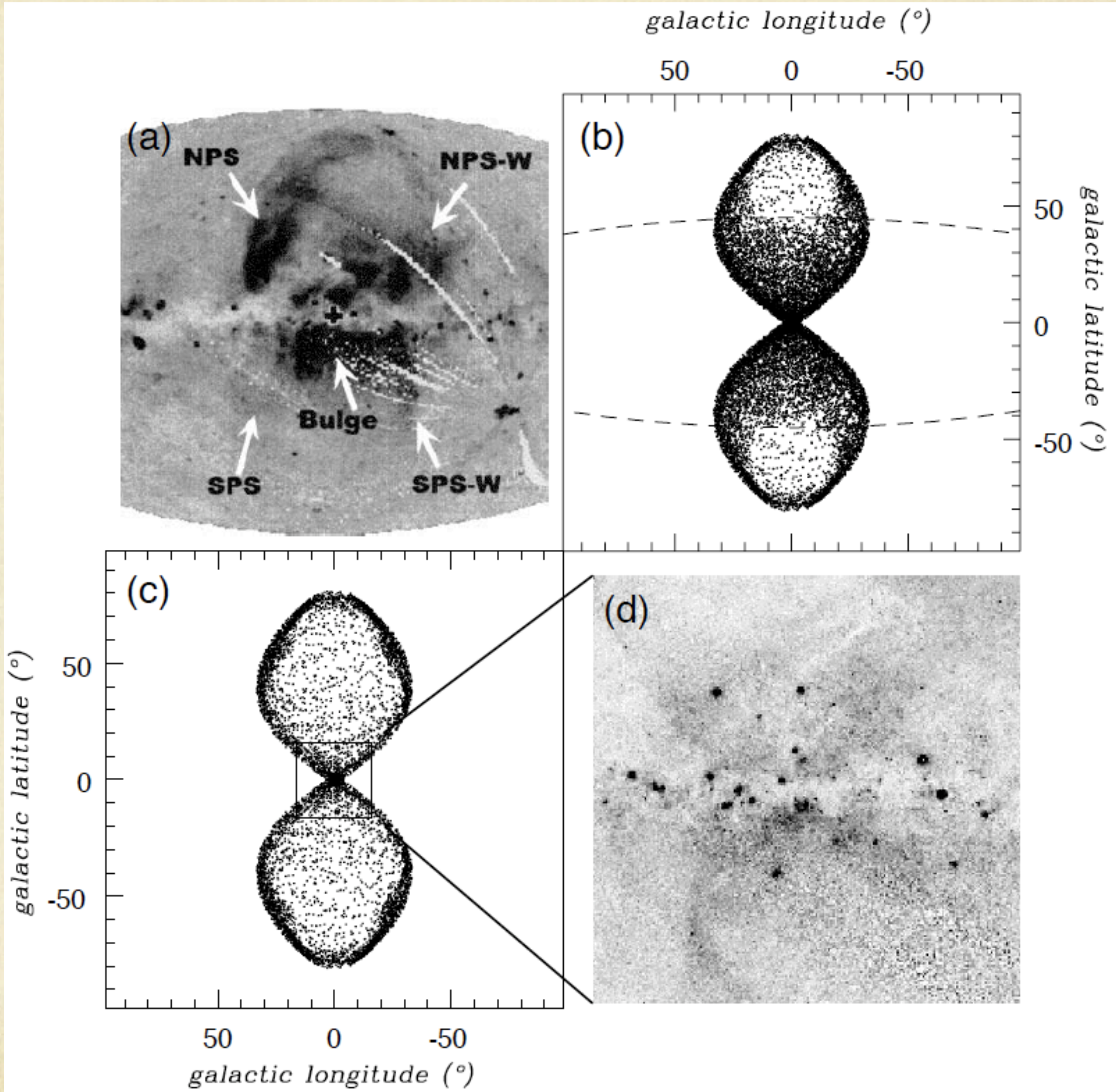
Fermi Bubble

Thank You for Your Attention!

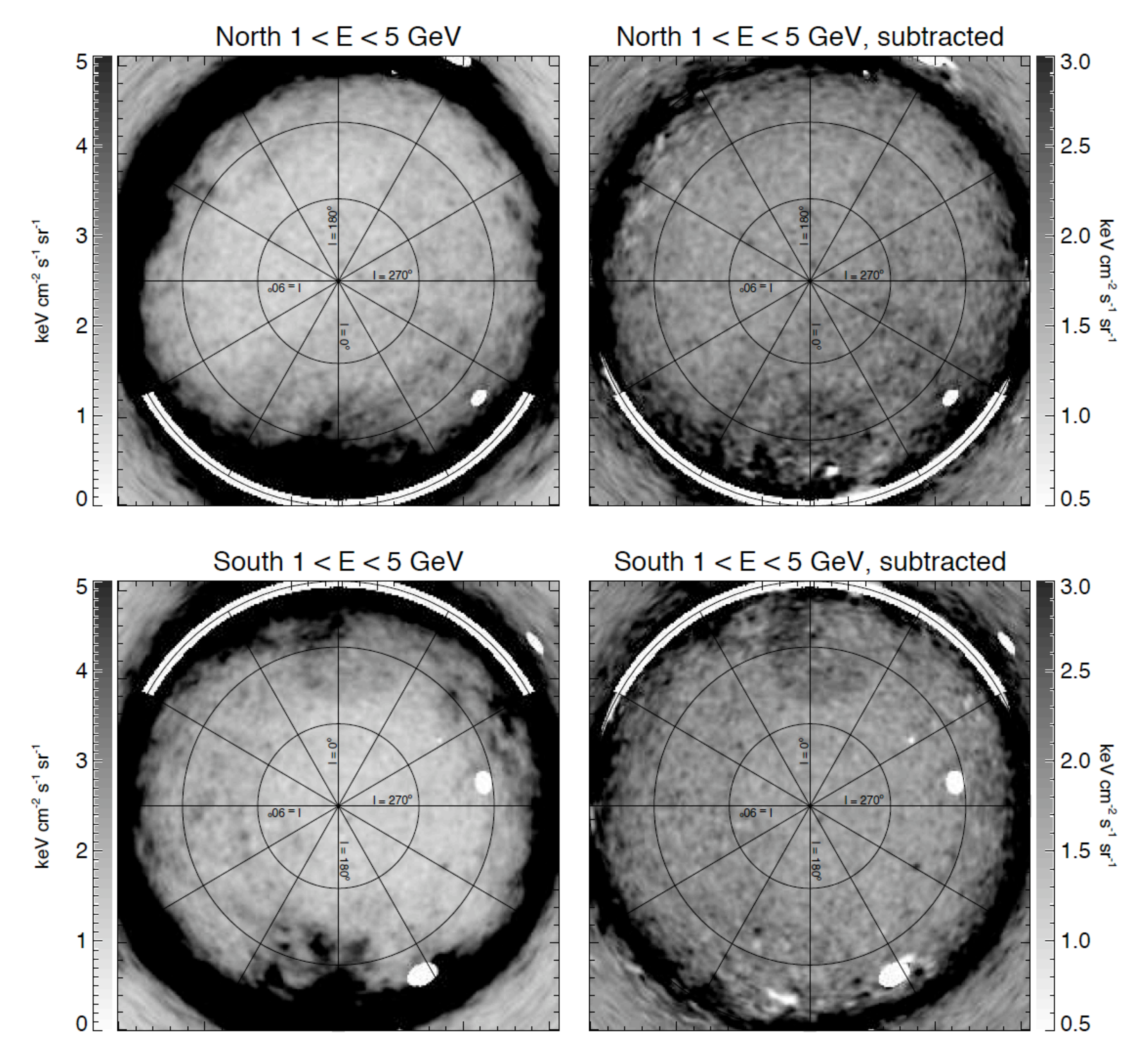
(Video credit: NASA's Goddard Space Flight Center)

Fermi Bubble



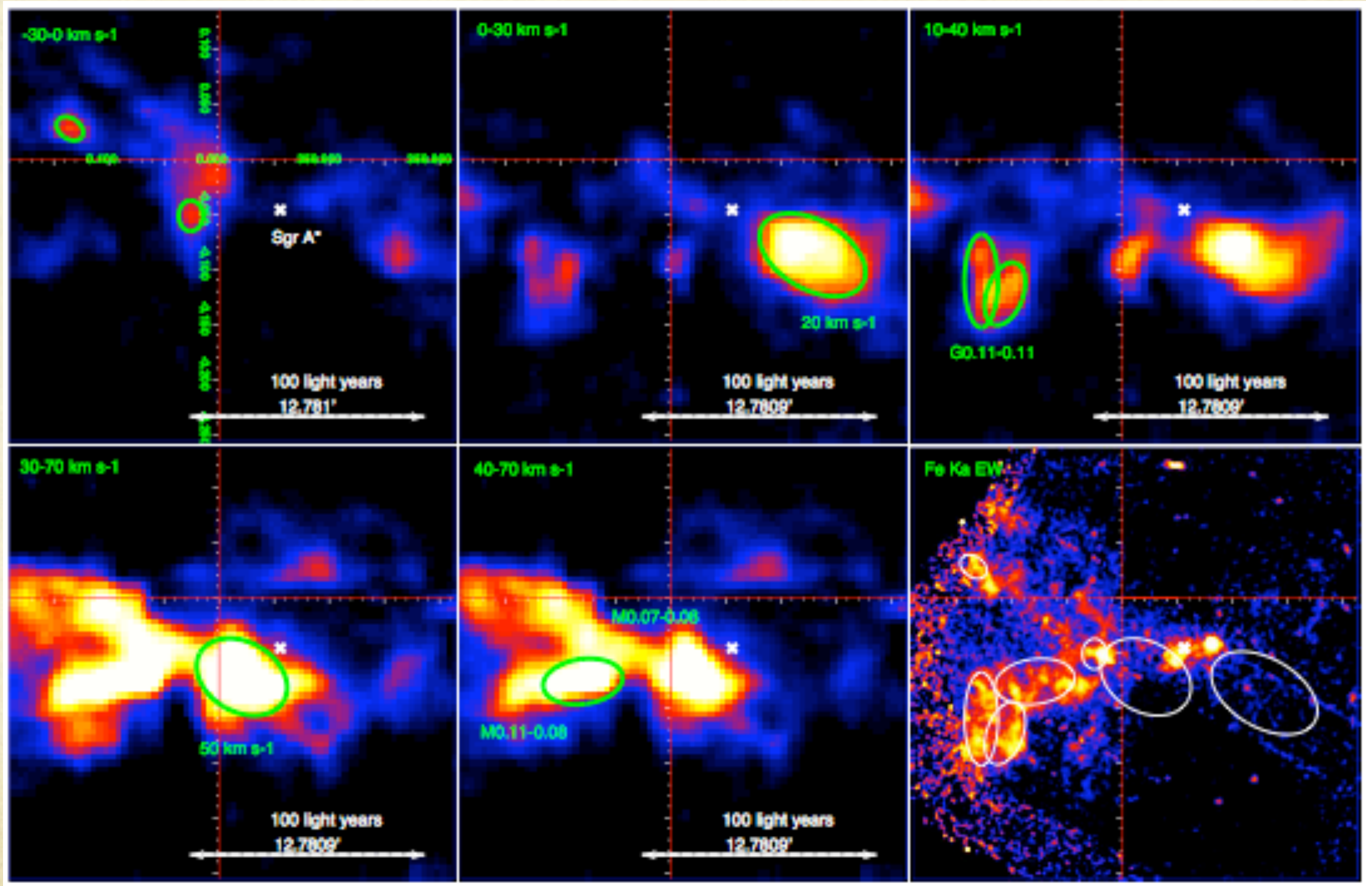


(Bland-Hawthorn and Cohen 2003)


North 1 < E < 5 GeV
North 1 < E < 5 GeV, subtracted
South 1 < E < 5 GeV
South 1 < E < 5 GeV, subtracted
keV cm-2 s-1 sr-1
l = 180°
l = 270°
l = 90°
l = 0°
0
1
2
3
4
5
0.5
1.0
1.5
2.0
2.5
3.0

X-ray reflection nebulae in the GC.

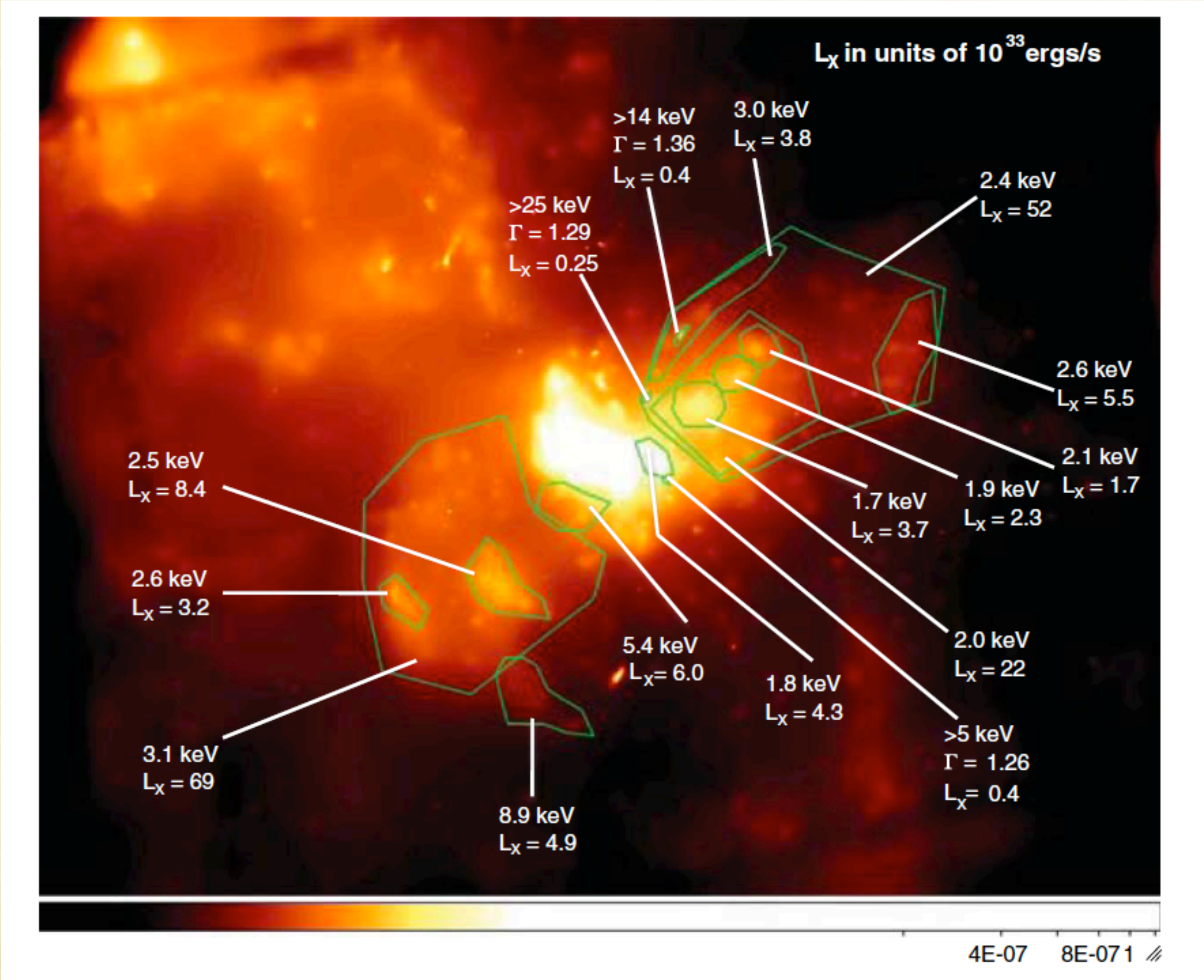
There are indications of previous GC activity from X-ray echoes and time variability of reflected X-ray lines (Sgr B1 and B2, Sgr C, and M0.11-0.11) They are likely due to reflected X-rays from previous activity of Sgr A* with high luminosity ~300 yr ago.



1, Thermal wind from the central cluster of massive young stars

2, Steady outflows from Sgr A*

3, Repeated episodic outbursts (jets) from Sgr A* **(Markoff 2010)**



(Markoff 2010)

- GR production and propagation
- Feedback to Galactic halo
- Dynamitics towards the GC (gas, star)
- BH accretion/AGN
- Starburst/SN

Fermi Bubble