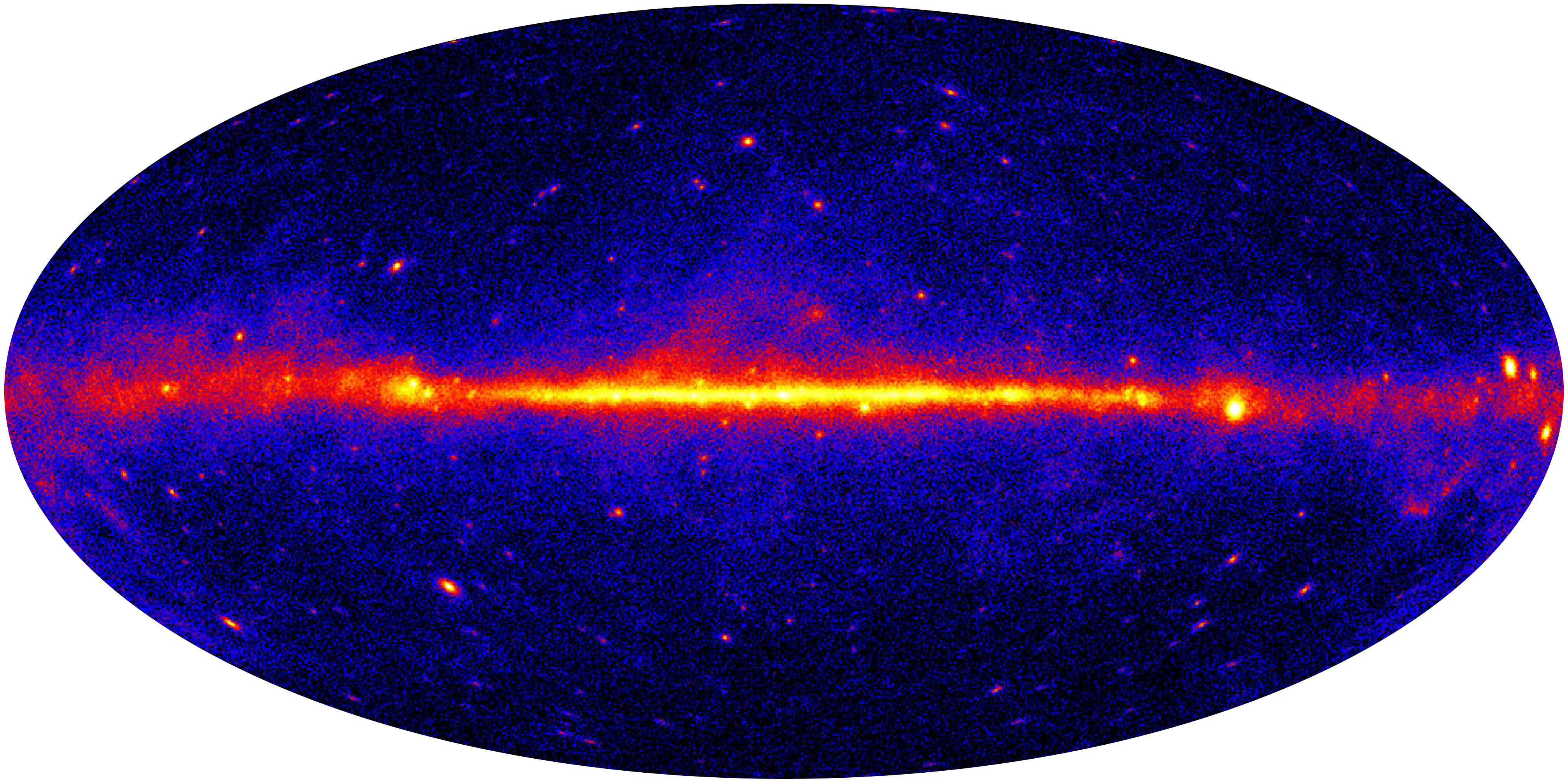
Image Credit: NASA/DOE/International LAT Team

Dark matter implications of the WMAP/Planck Haze



Jennifer Gaskins

GRAPPA, University of Amsterdam

Egorov, JG, Pierpaoli, Pietrobon
arXiv:1509.05135

Image Credit: Planck Collaboration 2013

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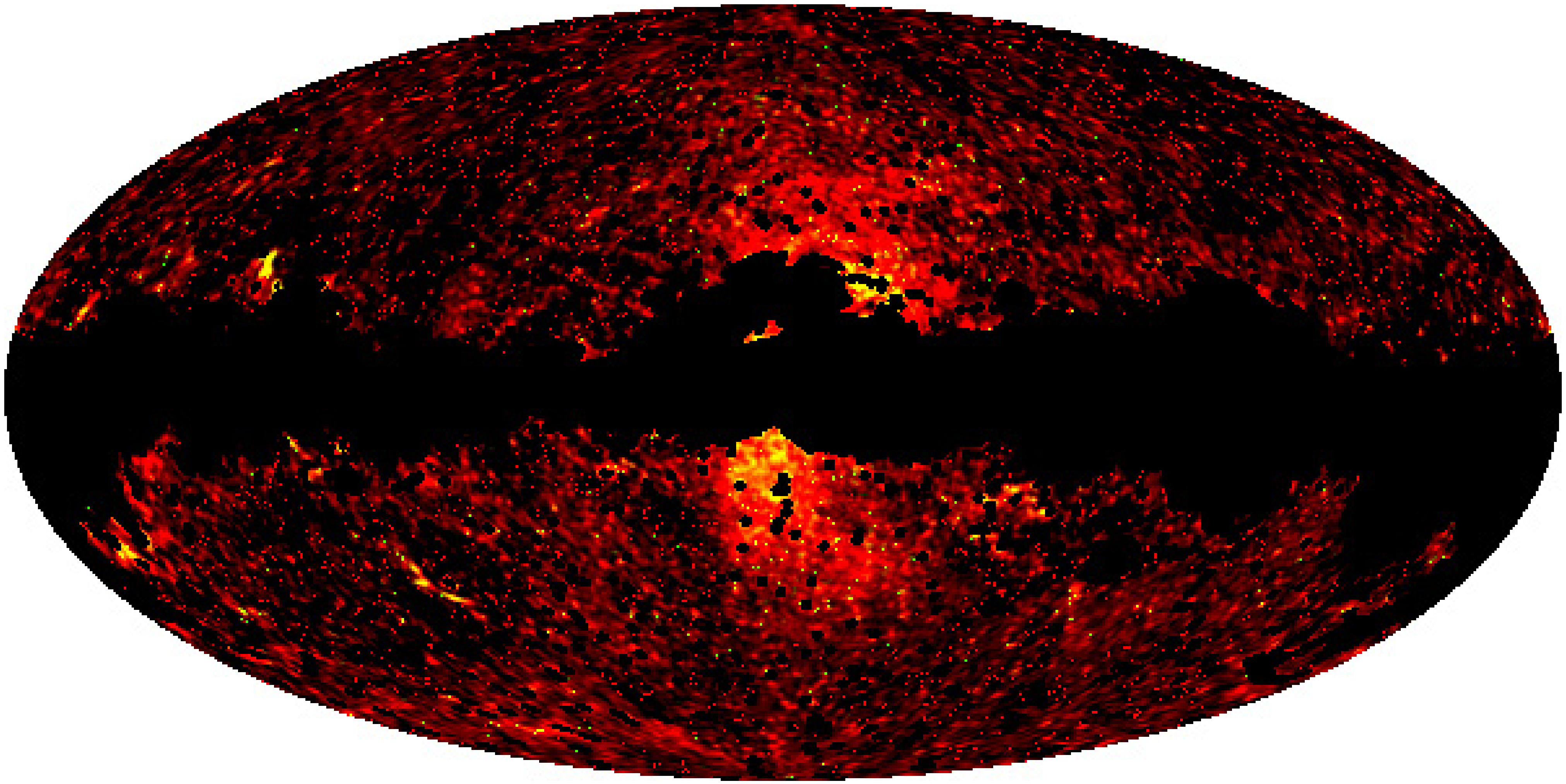

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Photons from Galactic cosmic rays

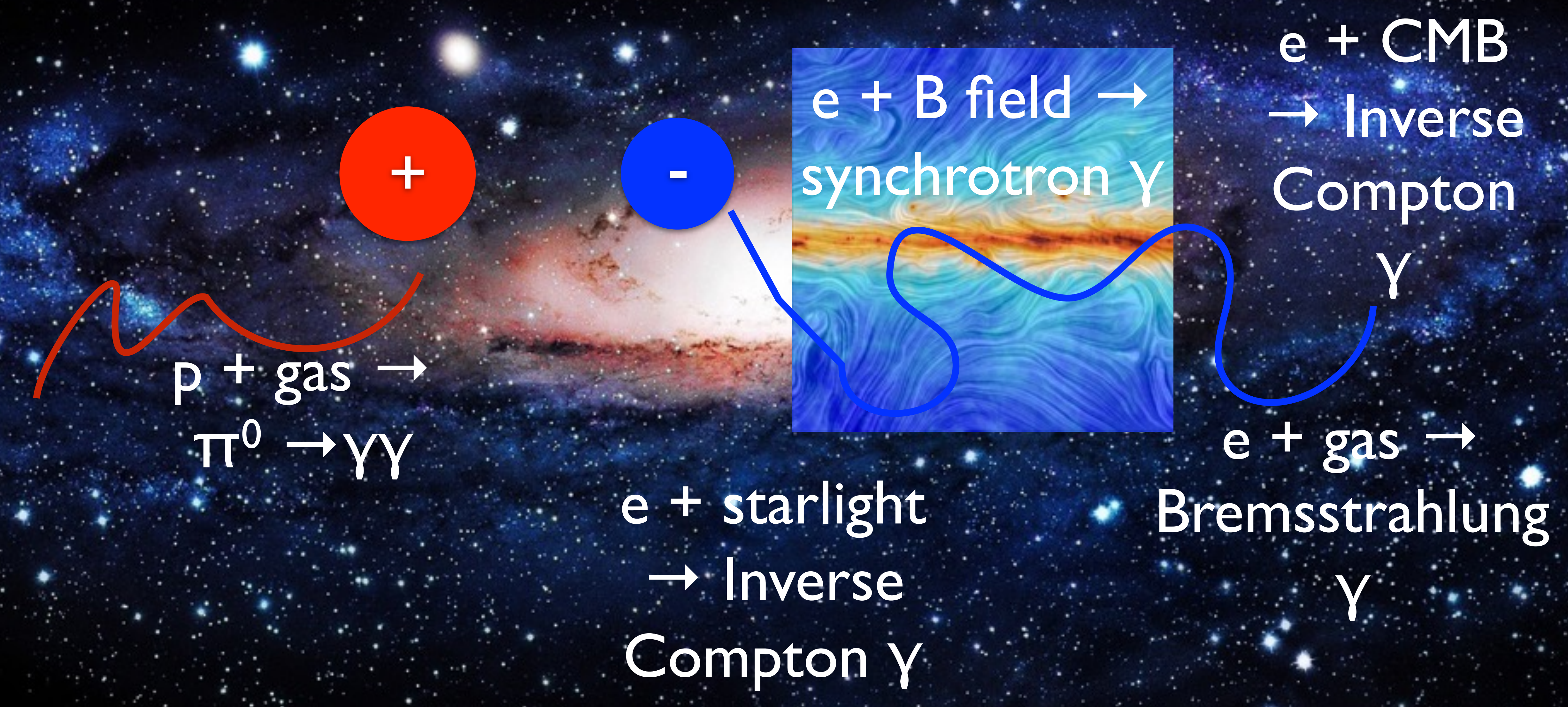
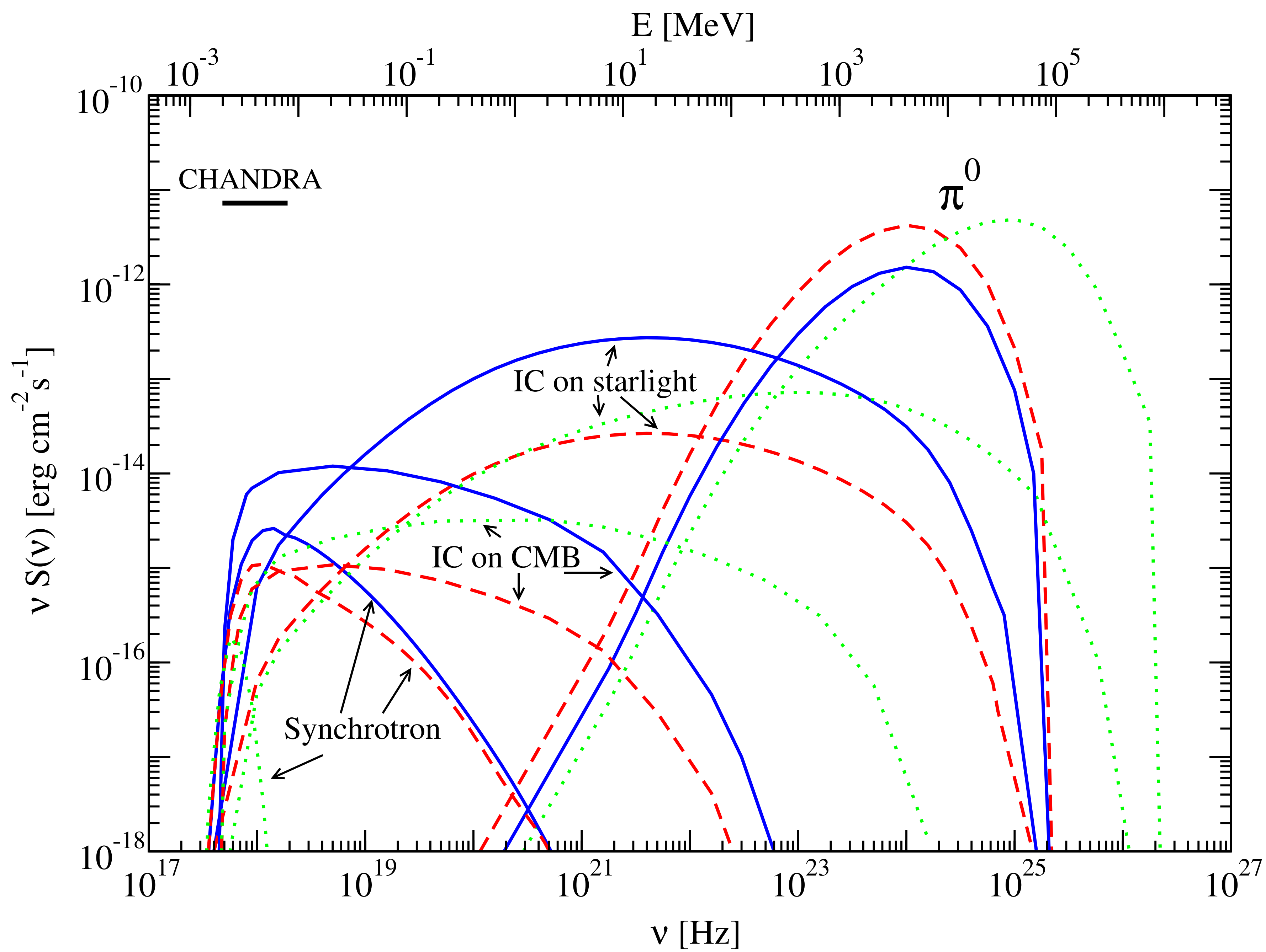


Image credits:
shonj.wordpress.com
ESA/Planck Collaboration

Multi-wavelength dark matter photon spectra

- secondary photon emission associated with charged particle final states:
    - inverse Compton scattering of starlight, CMB
    - synchrotron due to magnetic fields
    - Bremsstrahlung on gas
    - hadronic cosmic-ray interactions

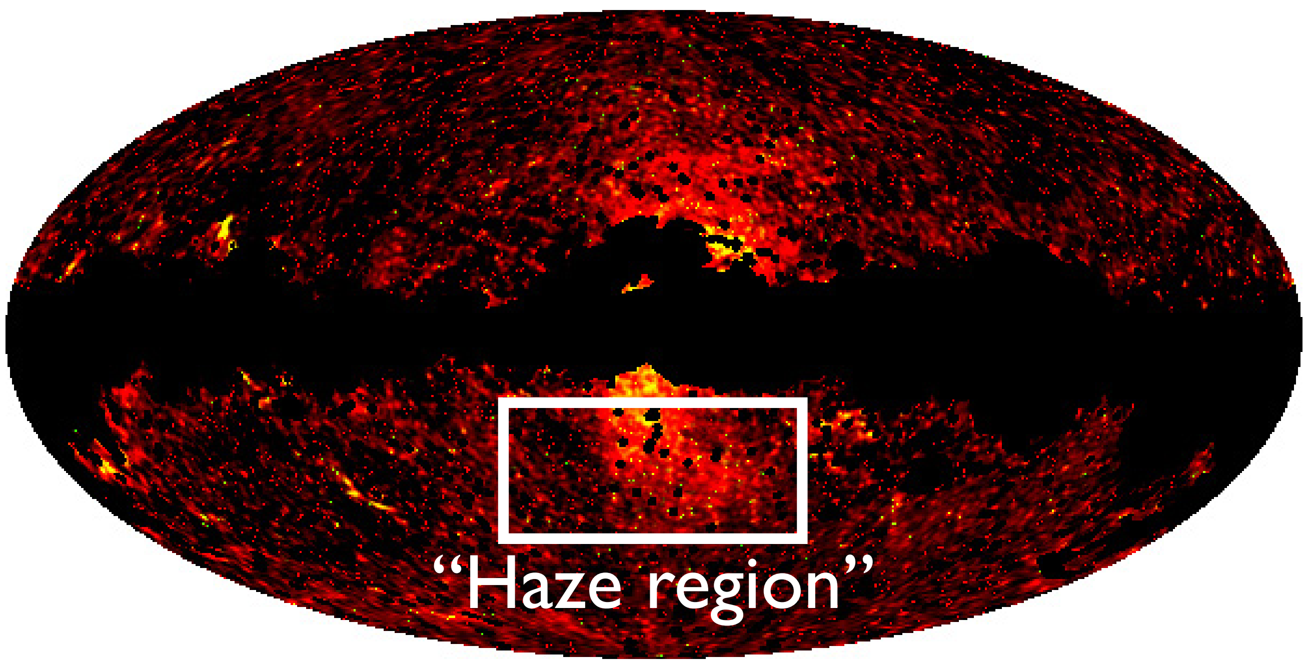
DM spectrum from the Galactic Center



Regis & Ullio 2008

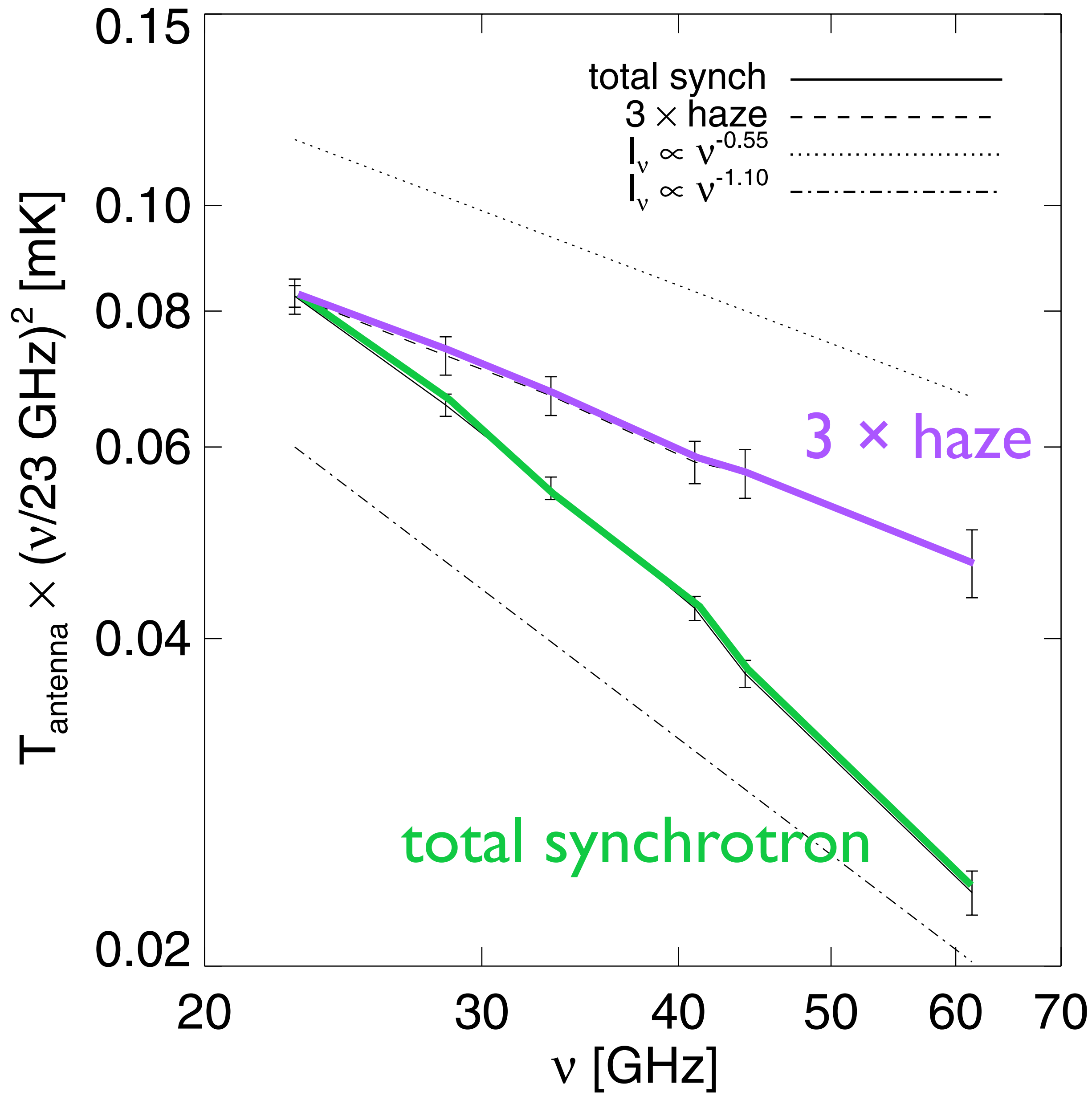
The WMAP/Planck Haze

Planck haze (30 GHz)



- WMAP "Haze" originally found by Finkbeiner 2004, confirmed by Planck Collaboration 2013
- spectrum of Haze harder than total synchrotron spectrum — suggests a distinct population of cosmic-ray electrons

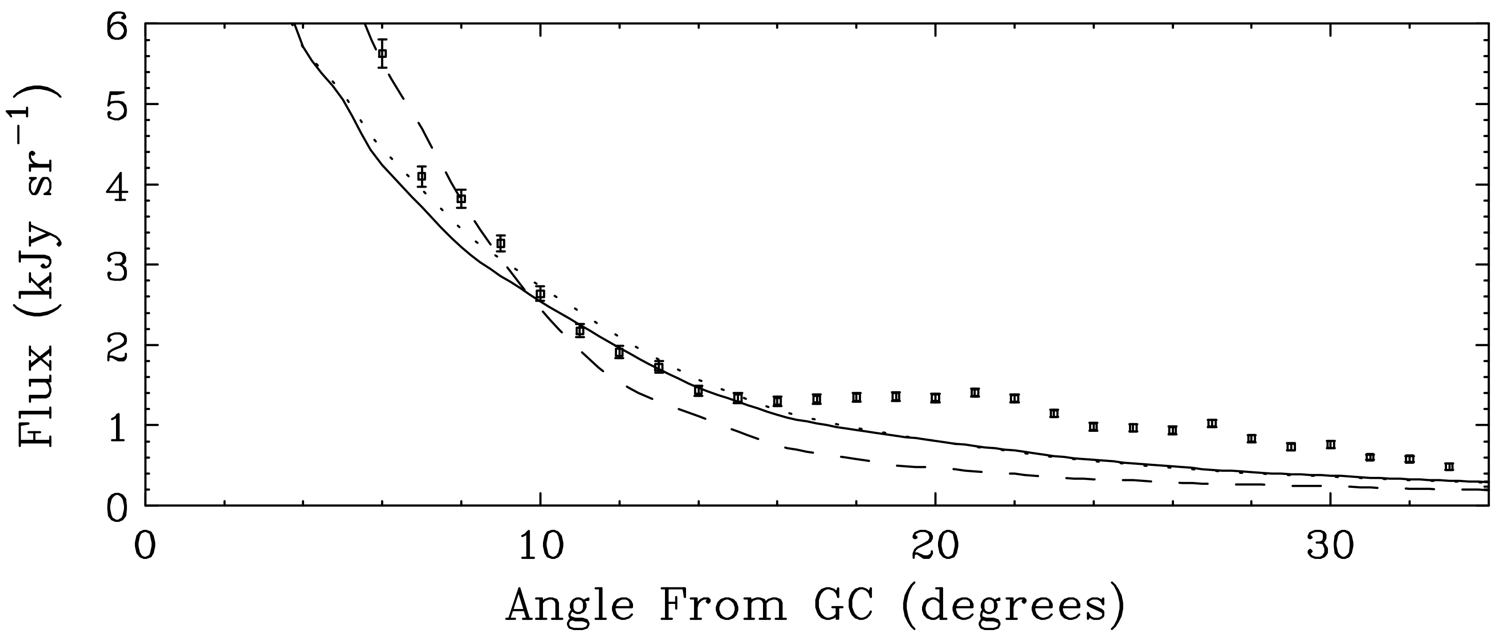
Haze region spectrum
(|ℓ|<35°, -35°<b<-10°)



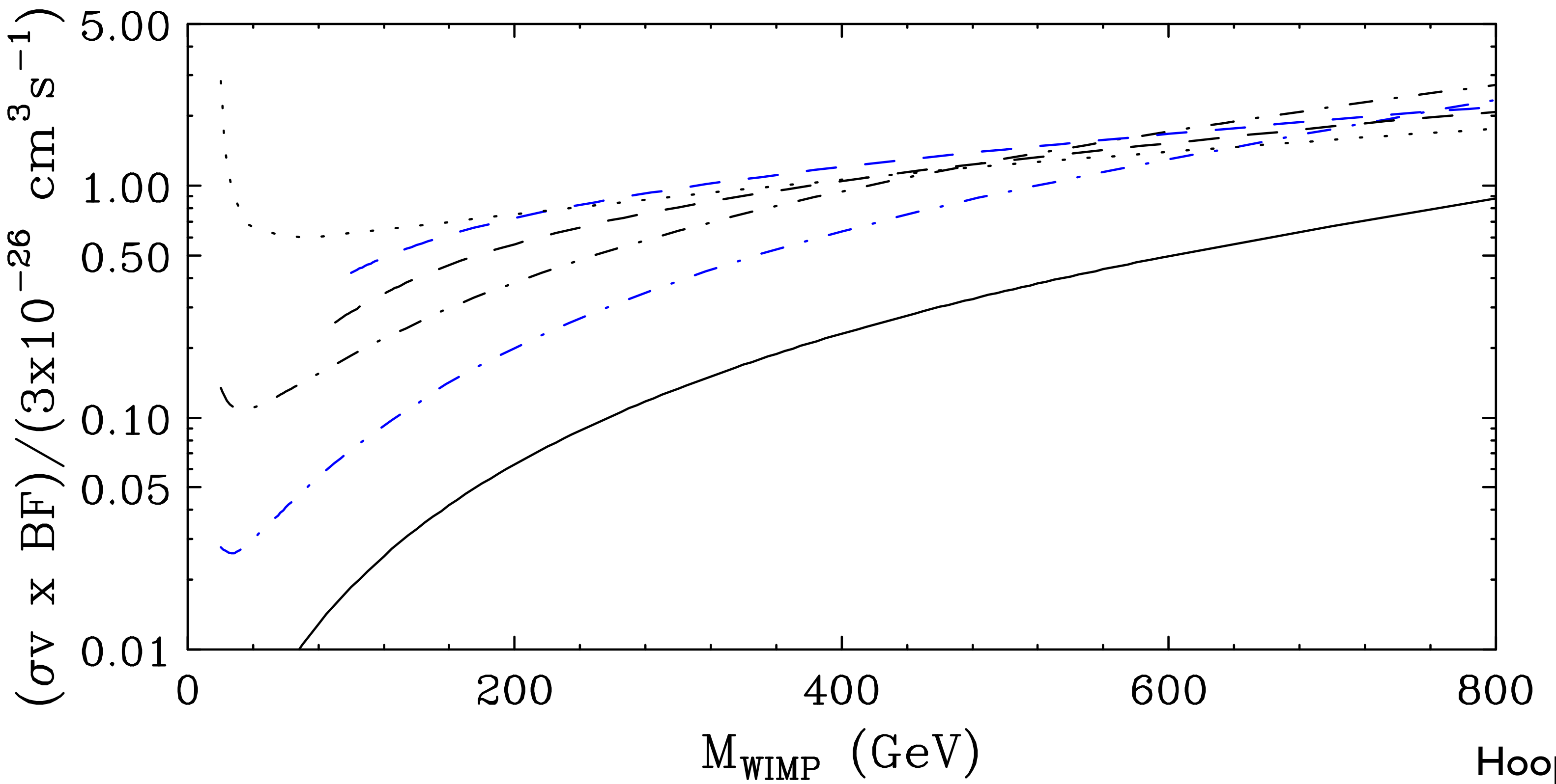
Planck Collaboration 2013

A DM origin for the WMAP Haze

Angular dependence of WMAP haze (22 GHz)



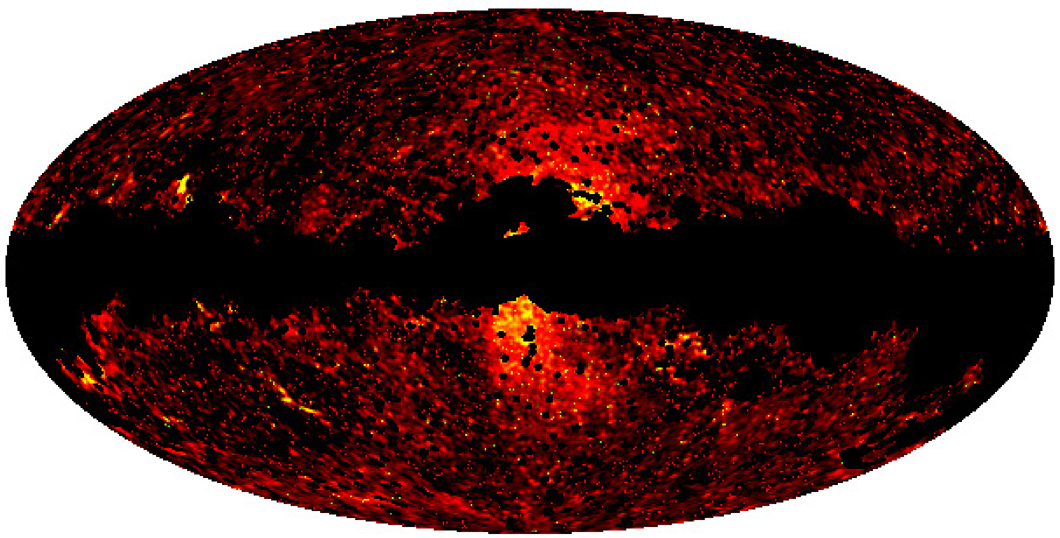
DM particle models that can fit the WMAP haze



Hooper, Finkbeiner, Dobler 2008

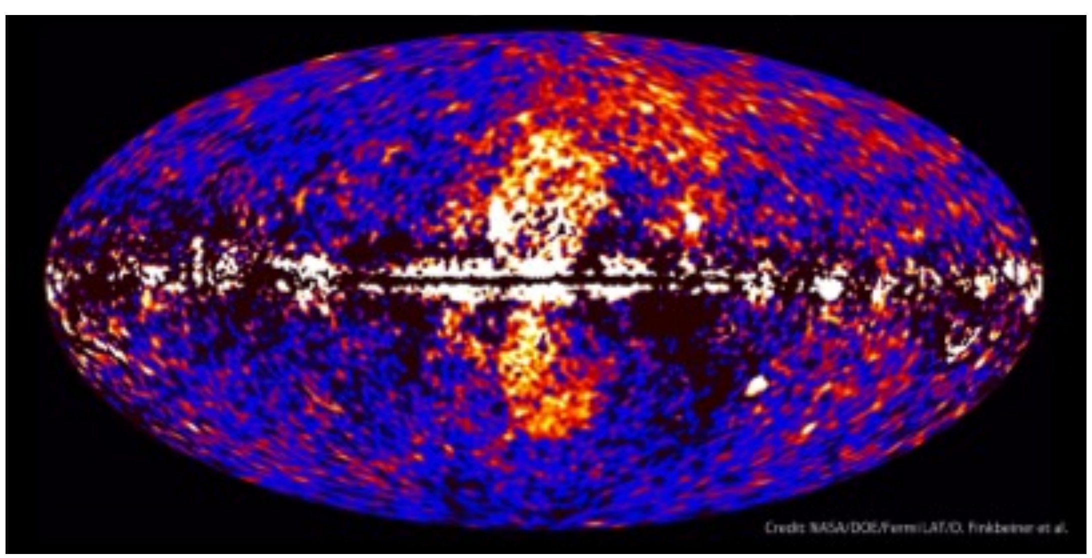
Fermi Bubbles = Planck Haze?

Planck (microwave) haze (30 GHz)



Planck Collaboration 2013

Fermi (gamma-ray) Bubbles

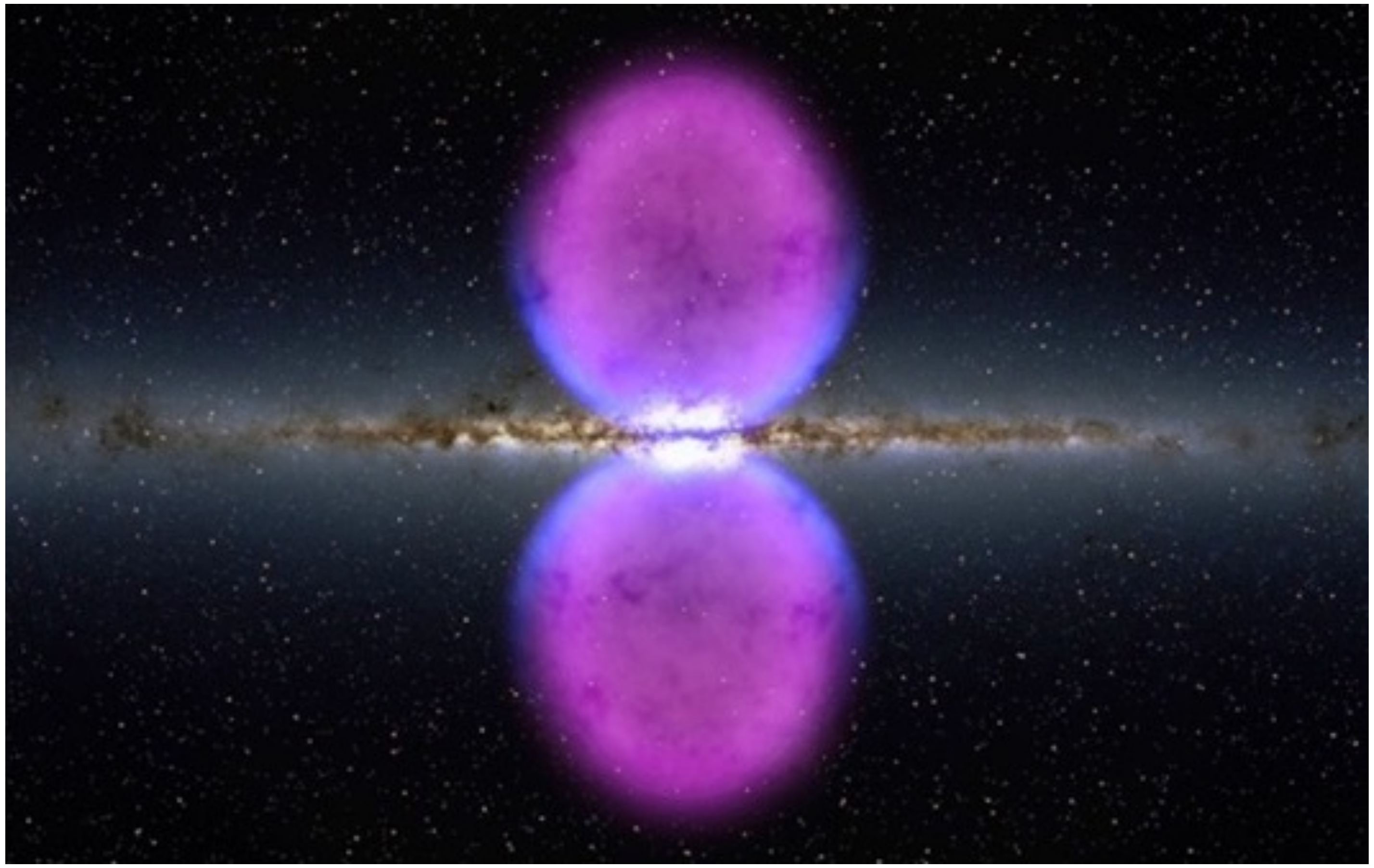


NASA/DOE/Fermi LAT/Finkbeiner et al.

The Planck haze is not symmetric about the GC — it is correlated with the Fermi bubbles…
trouble for a DM interpretation

The Fermi Bubbles

- hourglass-shaped structure centered on Galactic Center seen in Fermi gamma-ray data, extending to tens of degrees above and below Galactic plane (large — several kpc scale!)
- same phenomenon seen in multiple wavelengths — including in the Planck data
- exact mechanism of production uncertain but likely due to active past at the Galactic Center
- hard to precisely predict associated microwave emission (microwave depends on B field, gamma rays depend on ISRF)



Credit: NASA's Goddard Space Flight Center

Dark Matter and the WMAP/Planck data

Dark Matter and the WMAP/Planck data

- the Bubbles aren't from DM, but a DM origin of the GC gamma-ray excess implies a microwave component → is the microwave data still consistent with a dark matter interpretation of the GC gamma-ray excess? (Planck collaboration Haze analysis does not test for a component with a DM morphology)

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- we performed 2 analyses on WMAP + Planck data:
  - very conservative upper bounds on a DM contribution, assuming the data contain only CMB, noise, and DM
  - test for significance of DM component in a full component separation analysis: CMB + standard astrophysical foregrounds + Bubbles + DM

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- synchrotron emission associated with DM annihilation in the WMAP/Planck bands calculated using a modified version of GALPROP

Calculating the WIMP signal in microwaves

- vary B field model (50/100 μG central value, 6 μG locally, with exponential radial and z dependence) and propagation (5 setups) to explore range of possibilities (NOT claiming to bracket all possibilities)

Parameter	MED	MAX	Reacc
Half-height of the diffusion box h, kpc	4.0	15	5.4
Diffusion coefficient normalization D_0, cm^2/s	$3.4 \cdot 10^{27}$	$2.3 \cdot 10^{28}$	$5.4 \cdot 10^{28}$
Diffusion coefficient energy dependence power δ	0.70	0.46	0.31
Alfven speed in the intragalactic media v_a, km/s	0	0	38
MF vertical scale height, version 1 $z_{B1} = \delta \cdot h$, kpc	2.8	6.9	1.7
MF vertical scale height, version 2 $z_{B2} = 0.5 \cdot h$, kpc	2.0	-	2.7

Egorov, JG, Pierpaoli, Pietrobon 2015

- vary dark matter parameters within range motivated by models that provide a good fit to GC excess:
  - density profile: generalized NFW w/ inner slope 1.1-1.3
  - WIMP mass: ~ 7-50 GeV
  - bb and $\tau\tau$ channels

Variations in the dark matter signal

(ratio with respect to top left panel)

reference case

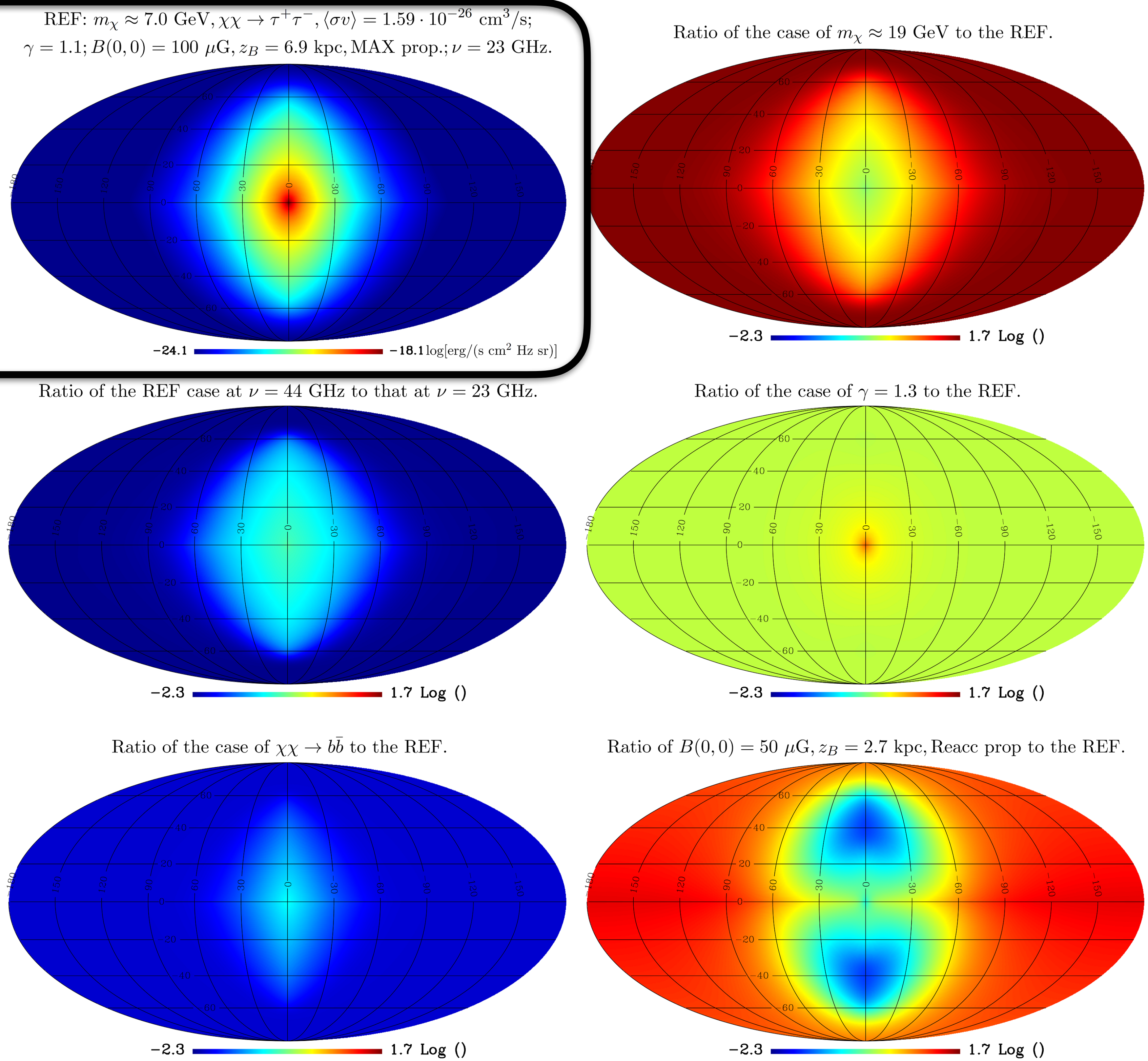
increase DM mass

increase microwave frequency

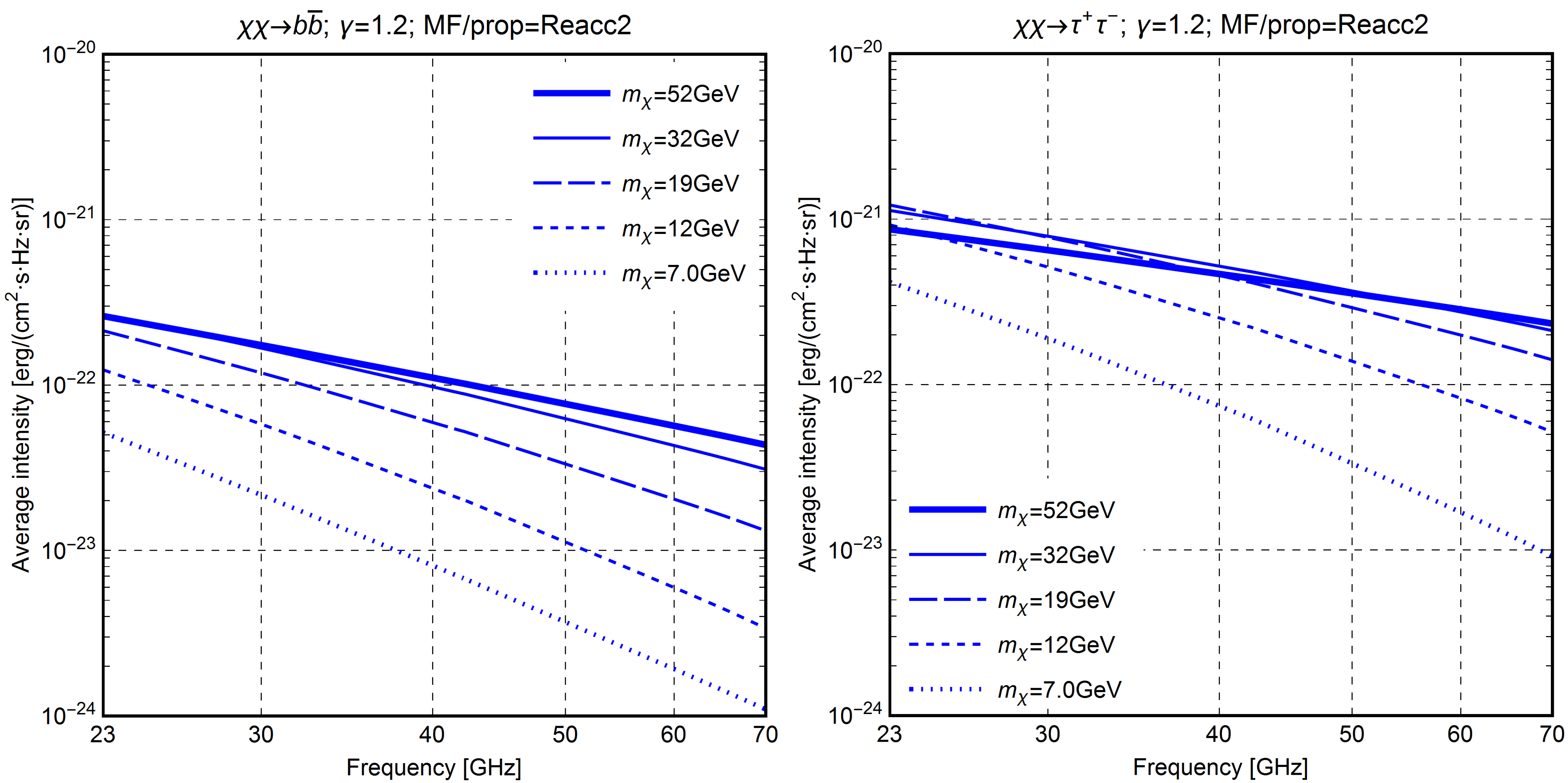
steepen inner slope

change annihilation channel

change B field / propagation model



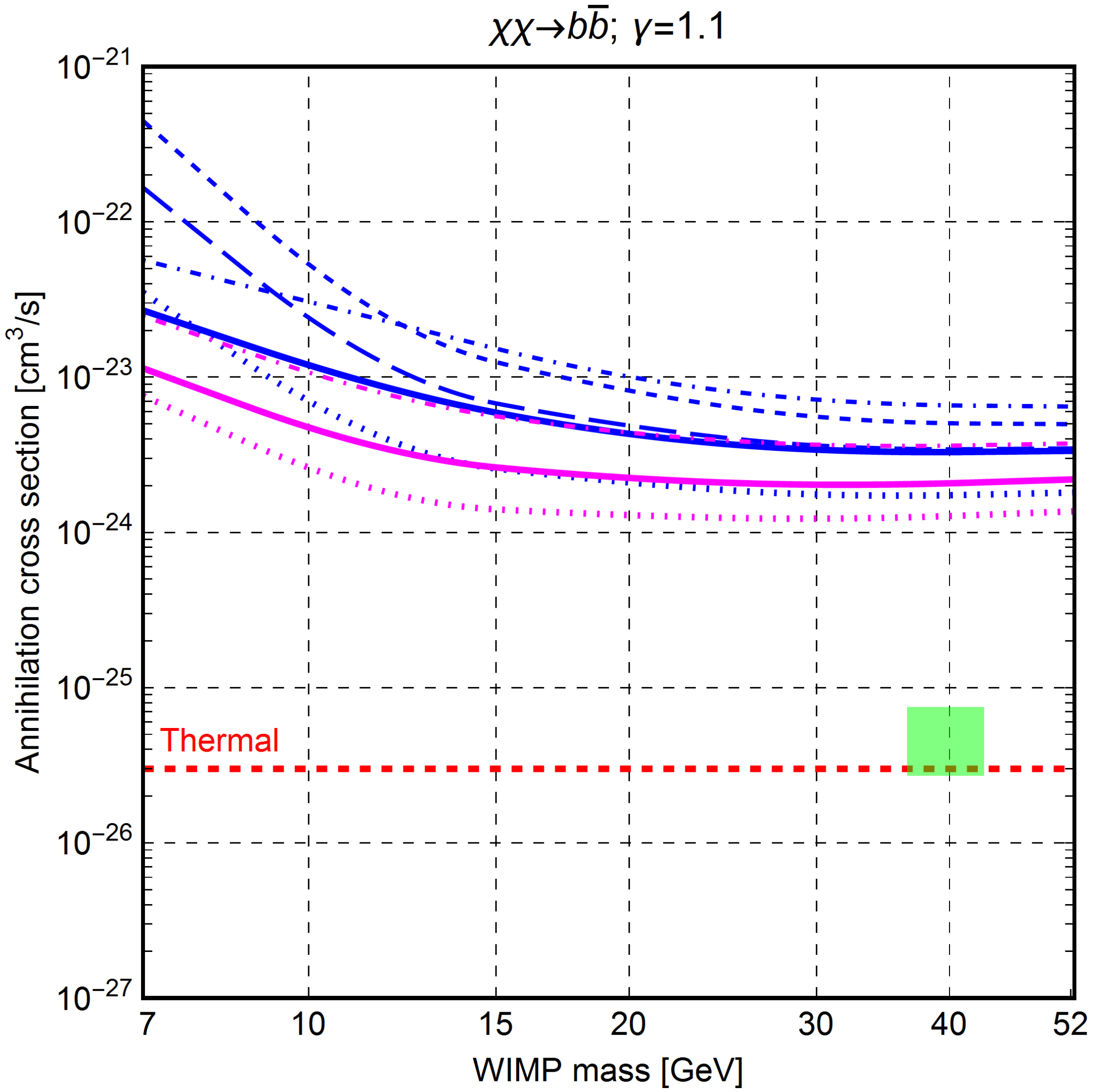
DM spectra in microwaves

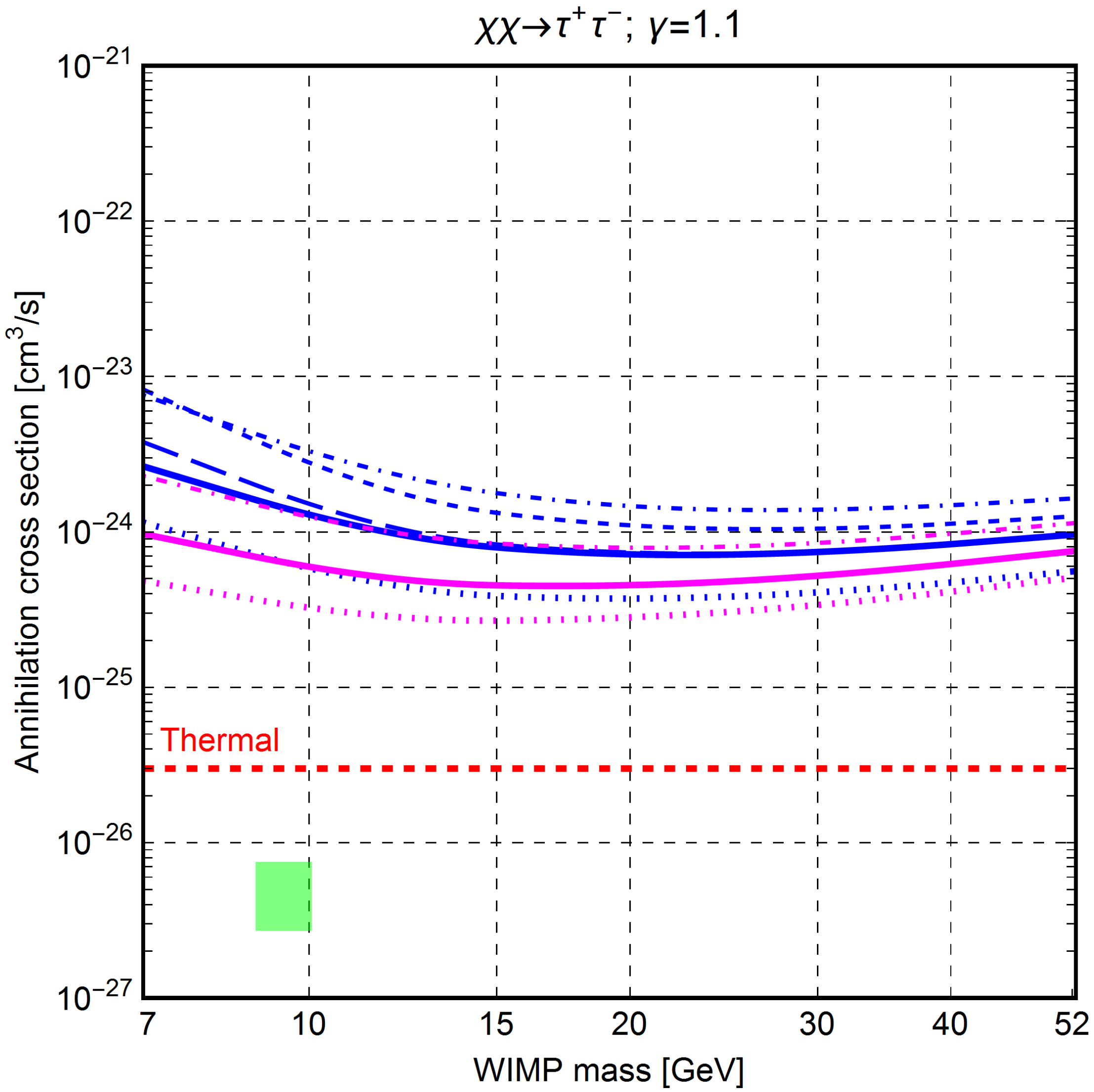


- DM spectra (for our chosen mass / annihilation channel range) have limited range of slopes
- spectra harden with increasing mass

Conservative DM constraints

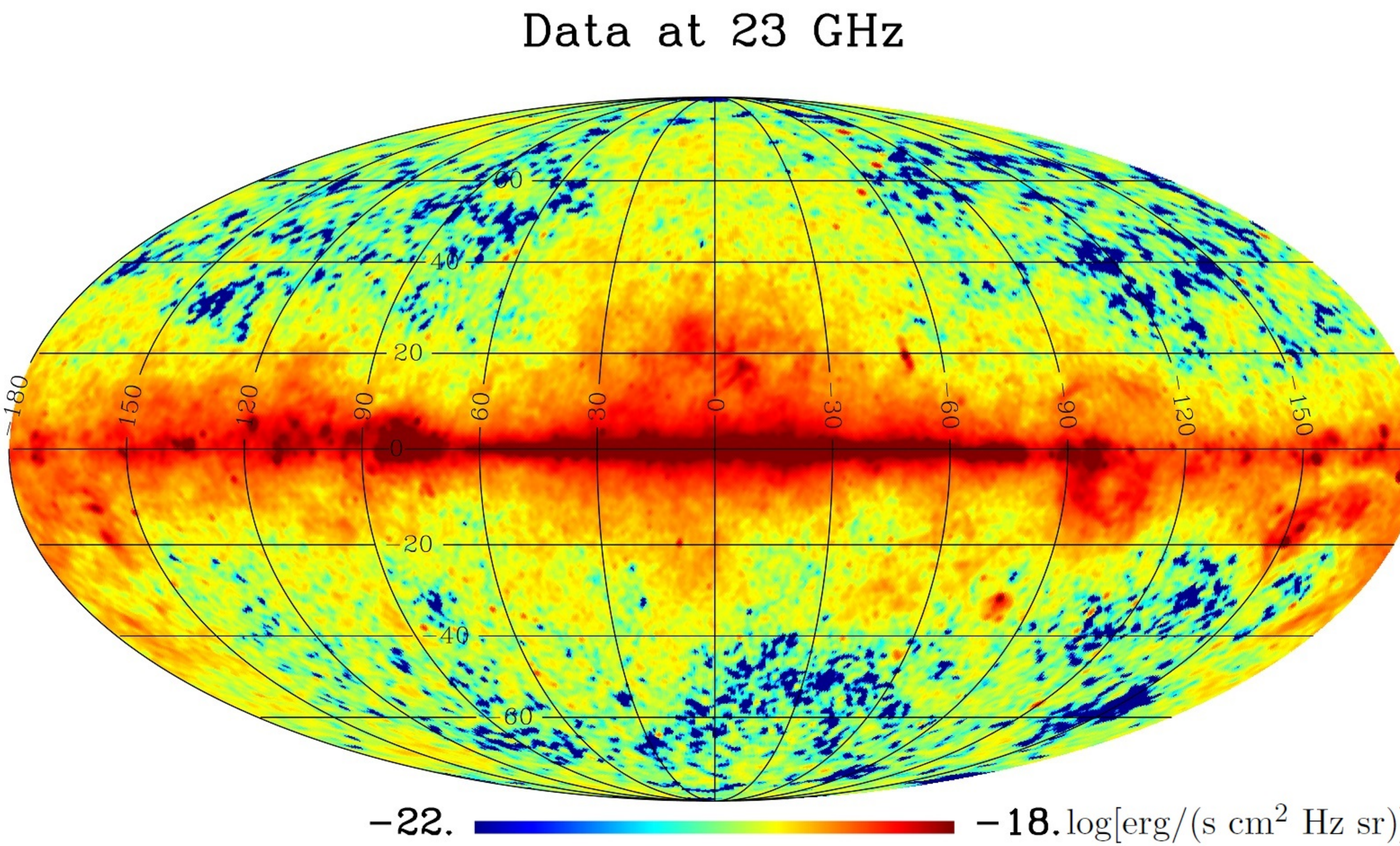
- DATA: three Planck LFI channels: 28, 44, 70 GHz
- mask same region as Planck haze analysis
- subtract CMB and noise, and require DM emission doesn't exceed the ROI intensity in any frequency





Egorov, JG, Pierpaoli, Pietrobon 2015

Component separation analysis



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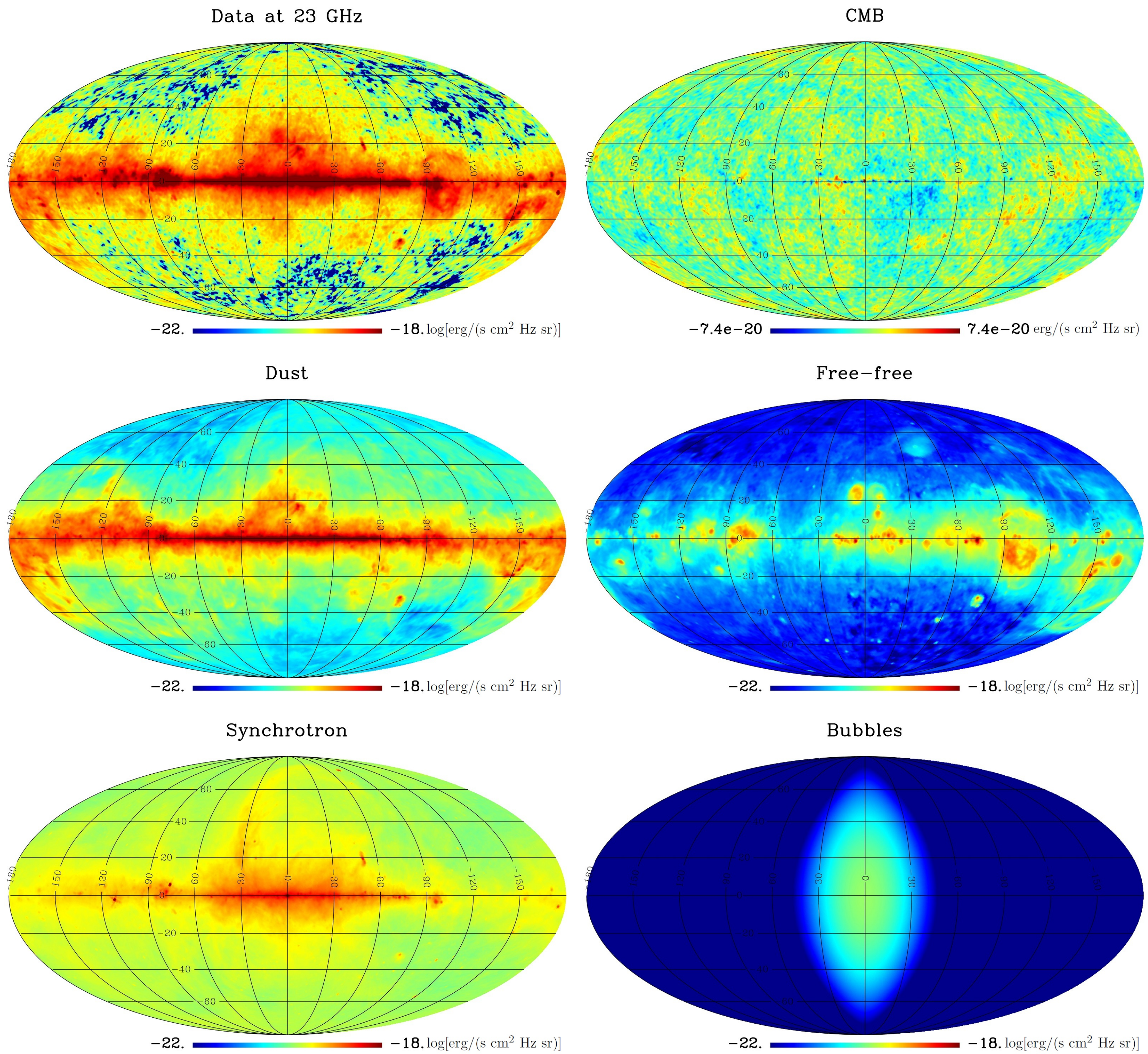
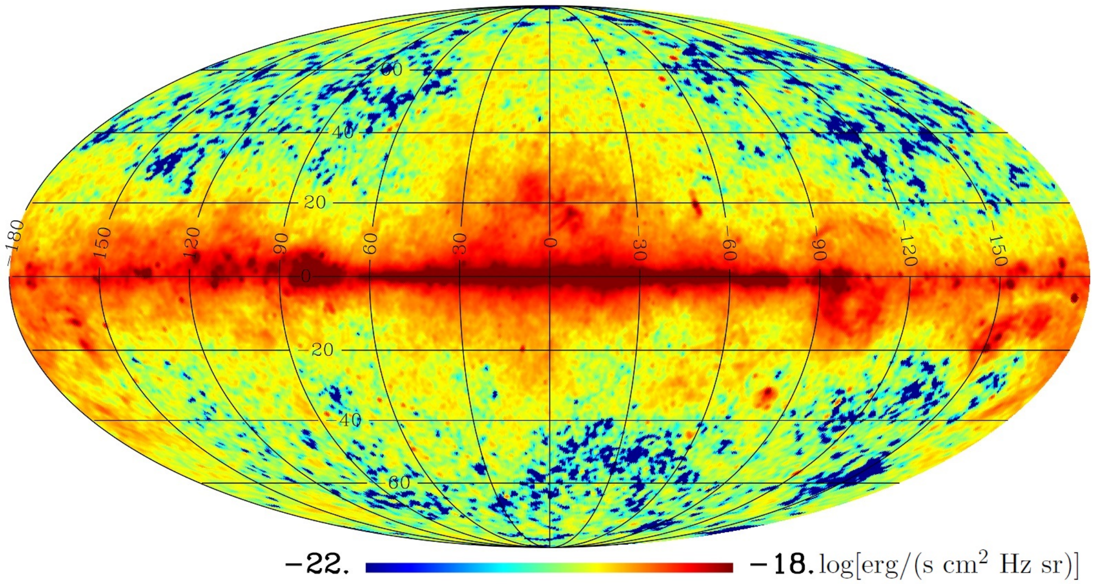
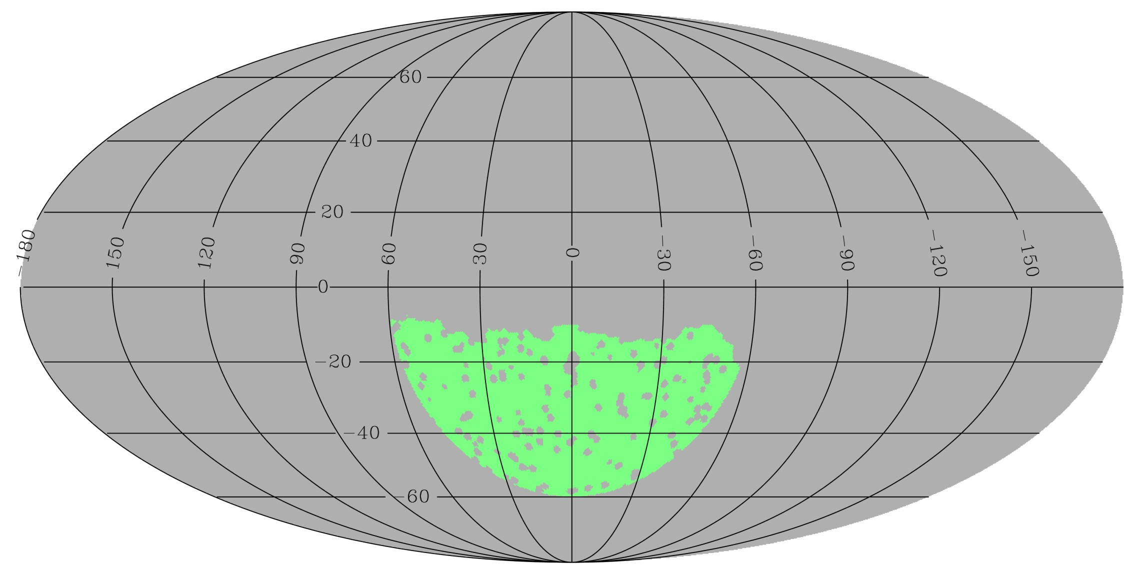


Component separation analysis

Data at 23 GHz



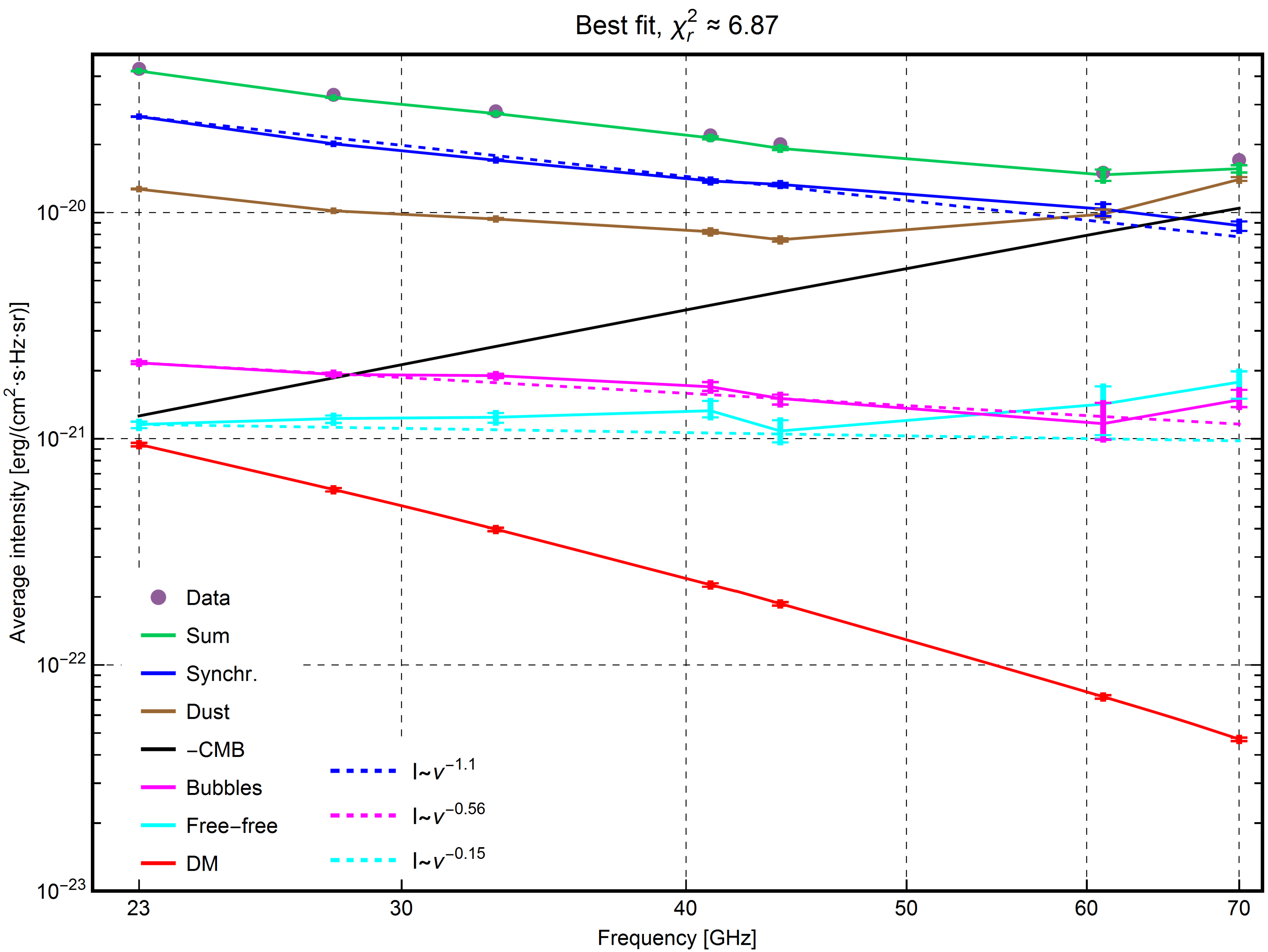
Mask for component separation analysis



Egorov, JG, Pierpaoli, Pietrobon 2015

- MASK:
  - choose region similar to that for Planck haze analysis
  - big enough to include relevant emission and avoid foreground degeneracies
  - small enough that each foreground has fairly spatially-uniform frequency dependence
- DATA:
  - four WMAP channels: 23, 33, 41, 61 GHz (K, Ka, Q, and V bands)
  - three Planck LFI channels: 28, 44, 70 GHz
- TEMPLATE ANALYSIS:
  - get DM only from GALPROP, others from standard templates
  - tie DM amplitudes across frequencies, allow foreground spectra to vary

Spectra of components (best-fit)



Egorov, JG, Pierpaoli, Pietrobon 2015

DM / Bubbles / Haze

Parameter	23 GHz	70 GHz
Range/mean of Haze contribution to the data, %	[7.2-10]/7.8	[8.7-10]/9.2
Range/mean of DM contribution to the data, %	[0.43-6.3]/1.7	[0.0043-4.7]/0.59
Range/mean of DM contribution to the Haze, %	[5.5-62]/21	[0.047-45]/6.5
Range/mean of the residuals, %	[1.7-2.1]/2.0	[7.7-9.1]/8.6

Component separation results

ν	χ^2_r with CMB, mono/dipole, f-f, synchr., dust	$\Delta\chi^2_\mathrm{r}$ after addition of the Bubbles	$\Delta\chi^2_\mathrm{r}$ after addition of the BF DM model	$\Delta\chi^2_\mathrm{r}$ after addition of the Bubbles and BF DM model
23	37.4	-15.9	-15.4	-17.8
28	21.4	-6.35	-5.42	-6.86
33	10.0	-3.13	-2.67	-3.47
41	2.23	-0.475	-0.363	-0.533
44	3.31	-0.343	-0.219	-0.379
61	0.563	-0.023	-0.013	-0.023
70	2.29	-0.078	-0.007	-0.077
Gl.	11.0	-3.75	-3.44	-4.16

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Egorov, JG, Pierpaoli, Pietrobon 2015

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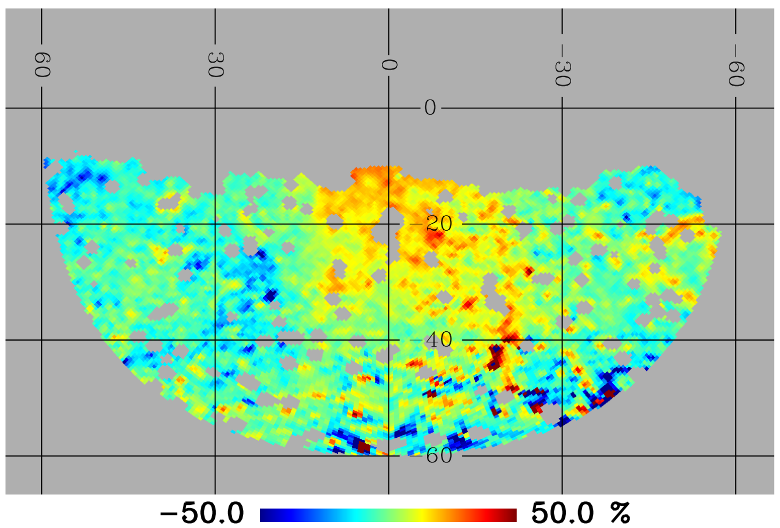
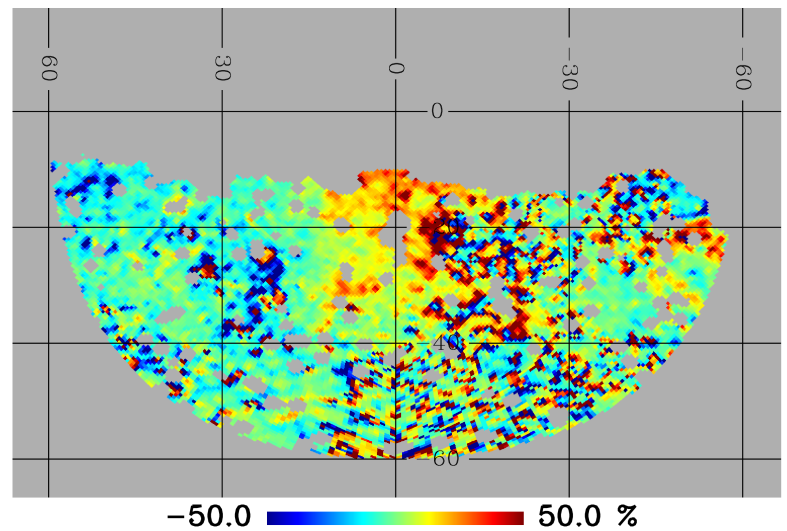
Dark matter vs the bubbles

TOP row: no bubbles or DM, at different frequencies

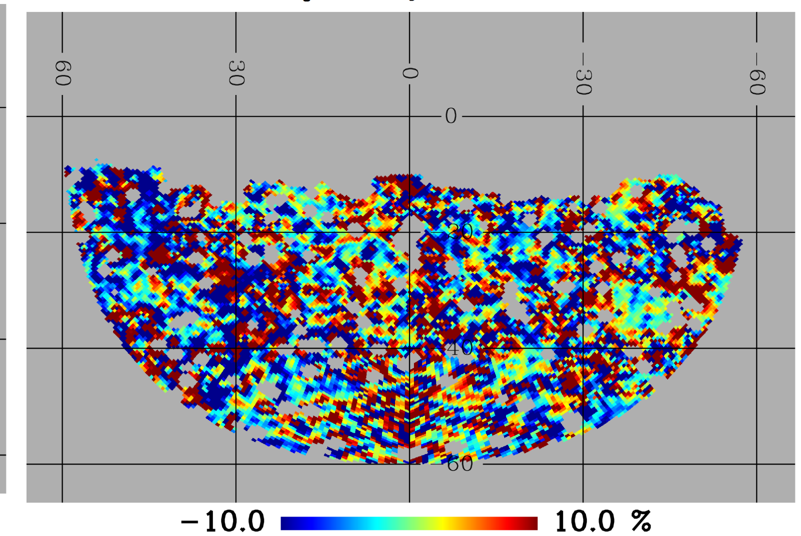
No B/DM, 23 GHz.



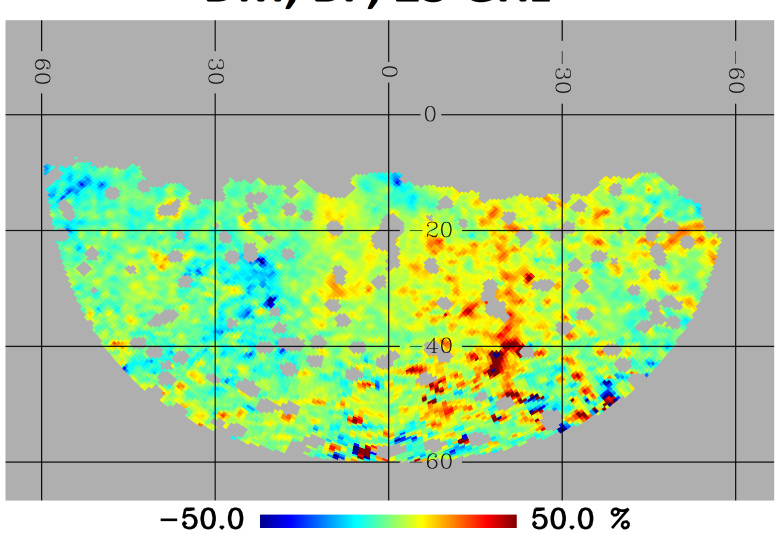
No B/DM, 33 GHz.



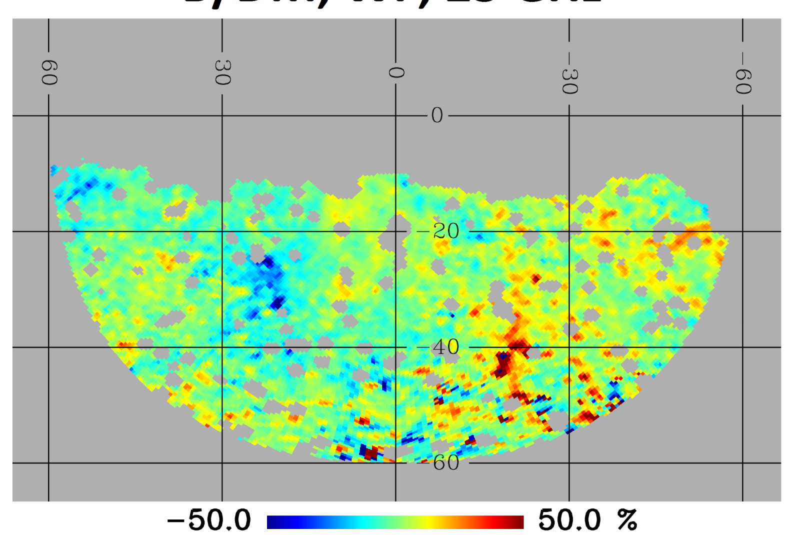
No B/DM, 70 GHz



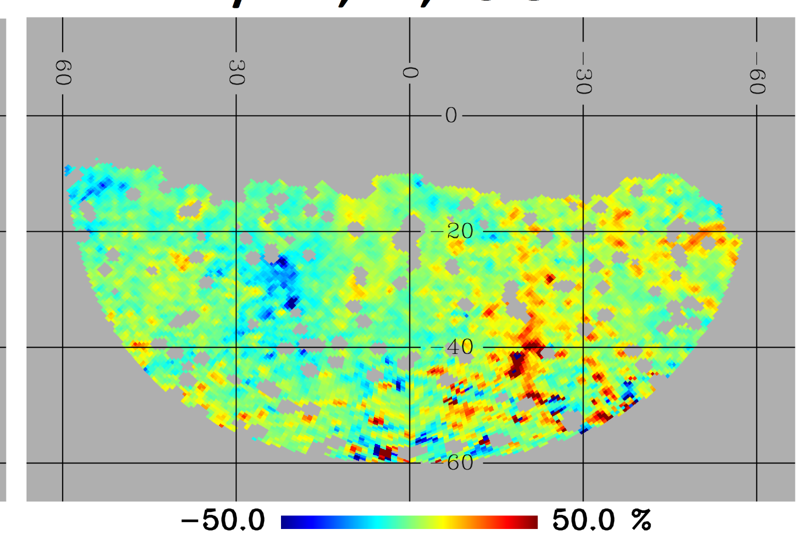
DM, BF, 23 GHz



B/DM, WF, 23 GHz



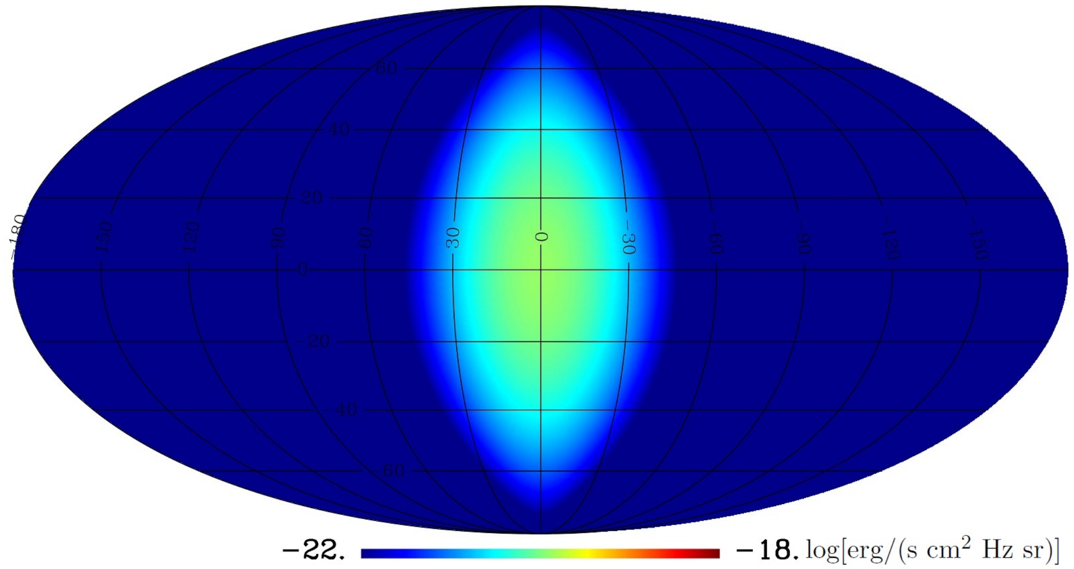
B/DM, BF, 23 GHz



BOTTOM row: DM, at 23 GHz

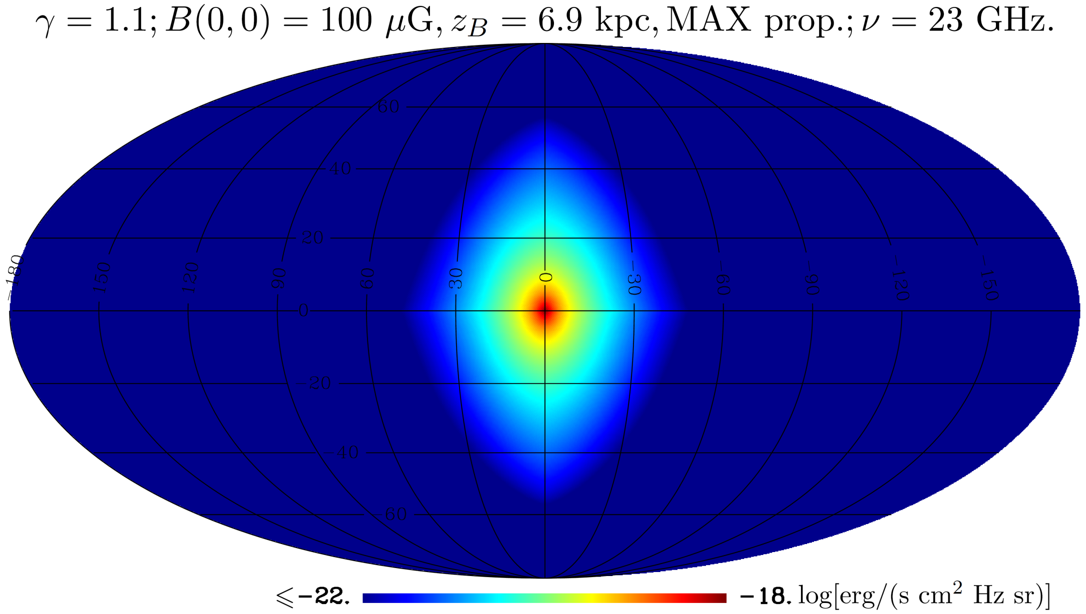
Dark matter vs the bubbles

bubbles template



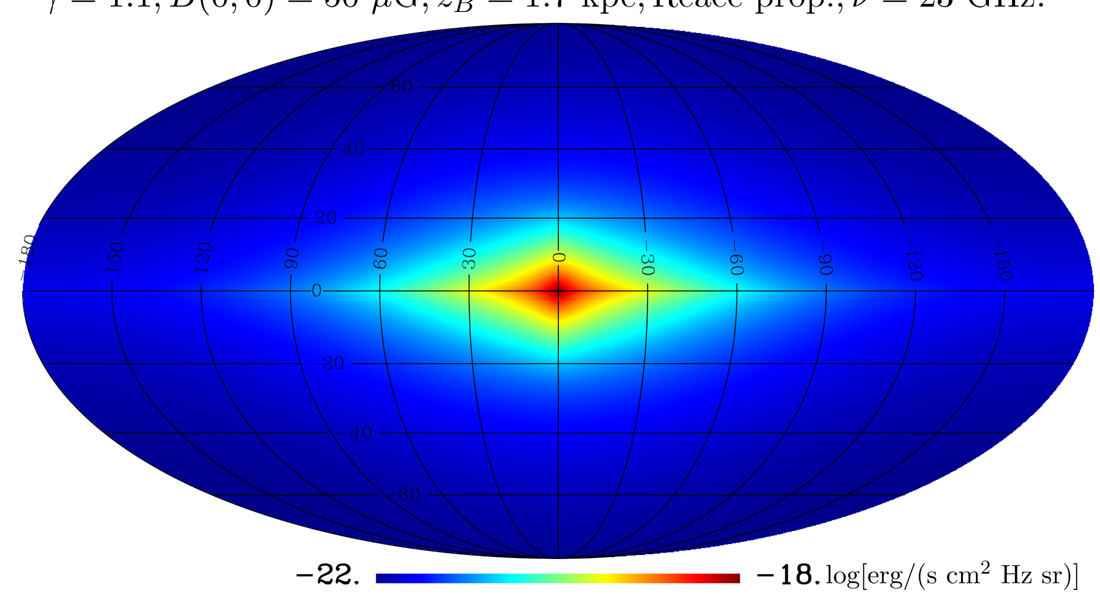
"best fit" dark matter

Best fit: $m_\chi \approx 7.0$ GeV, $\chi\chi \to \tau^+\tau^-$, $\langle \sigma v \rangle = 1.59 \cdot 10^{-26}$ cm^3/s;
$\gamma = 1.1$; $B(0,0) = 100\ \mu$G, $z_B = 6.9$ kpc, MAX prop.; $\nu = 23$ GHz.

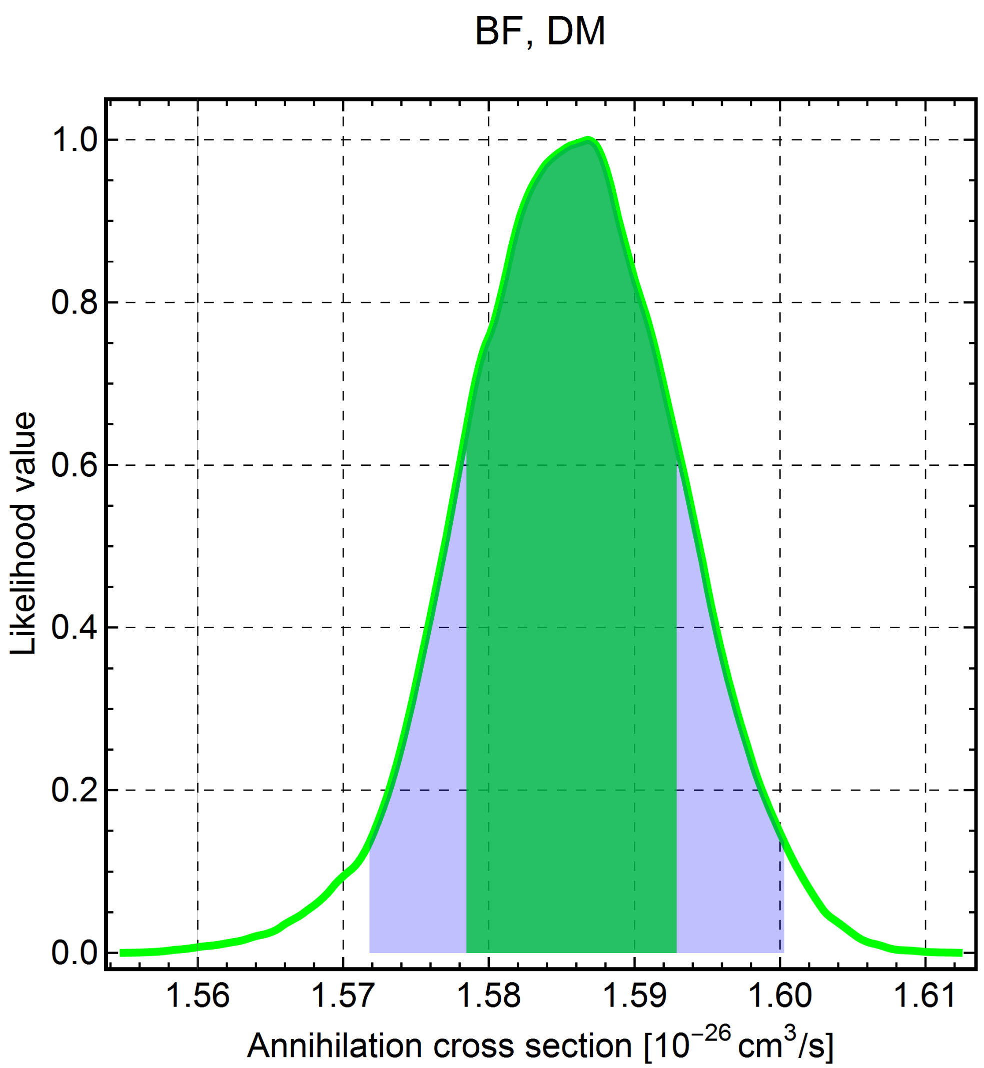


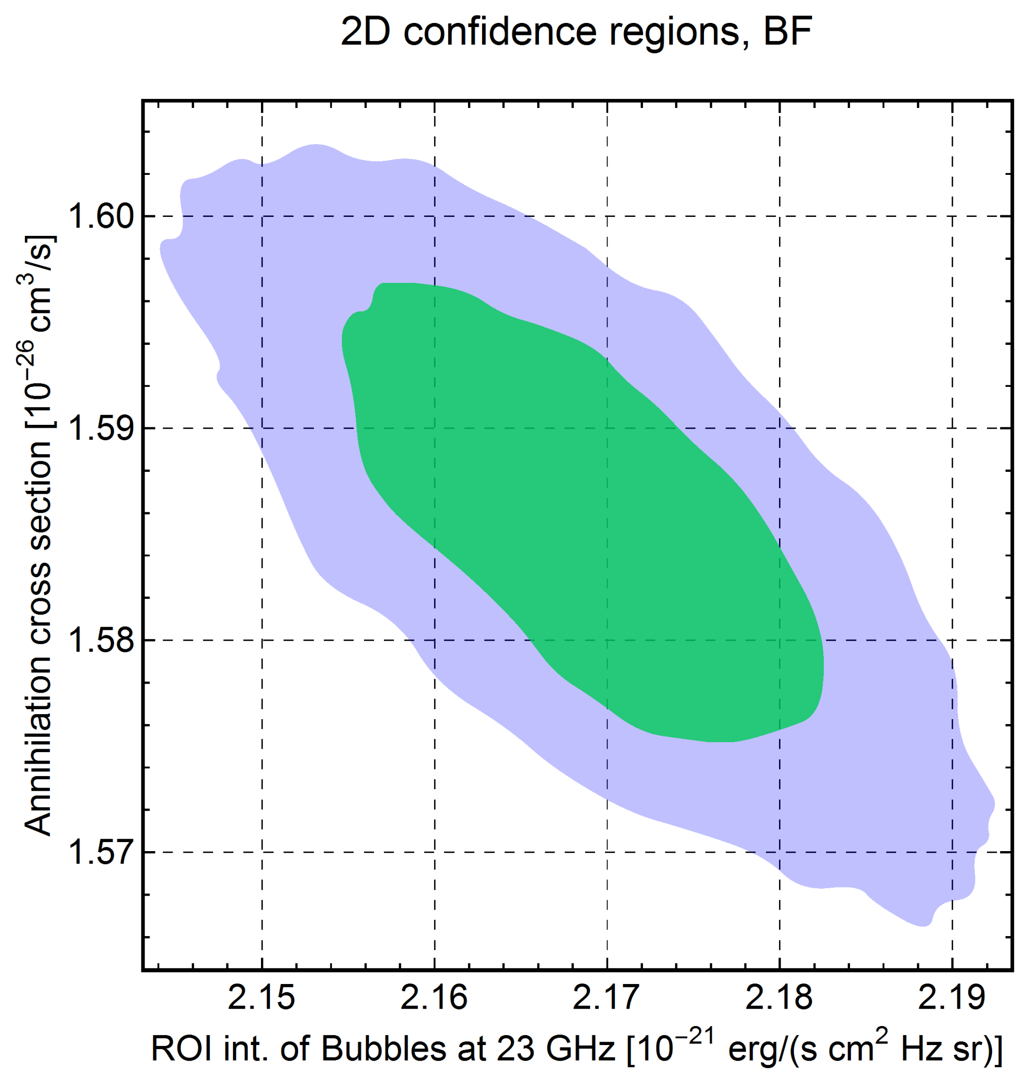
"worst fit" dark matter

Worst fit: $m_\chi \approx 7.0$ GeV, $\chi\chi \to b\bar{b}$, $\langle \sigma v \rangle = 1.06 \cdot 10^{-24}$ cm^3/s;
$\gamma = 1.1$; $B(0,0) = 50\ \mu$G, $z_B = 1.7$ kpc, Reacc prop.; $\nu = 23$ GHz.



Likelihoods and correlation

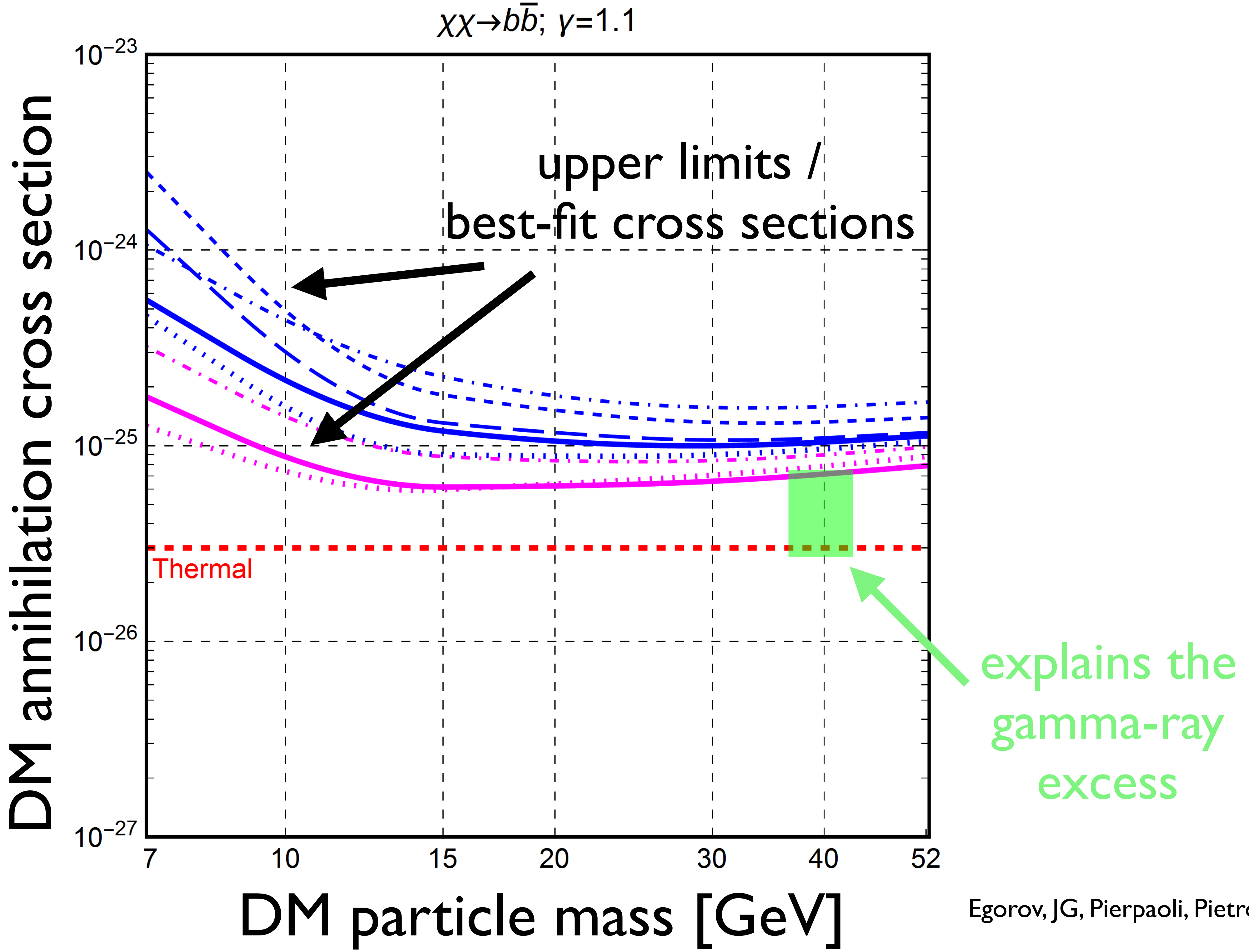




- likelihood profiles are very narrow: max likelihood and 95% CL upper limit are almost identical
- formally this looks like a detection of DM, but we are cautious due to correlations and systematic uncertainties
- as expected, DM cross section and Bubbles intensity strongly correlated

Component separation results

95% CL upper limits on dark matter annihilation
(best-fit is indistinguishable from upper limits)



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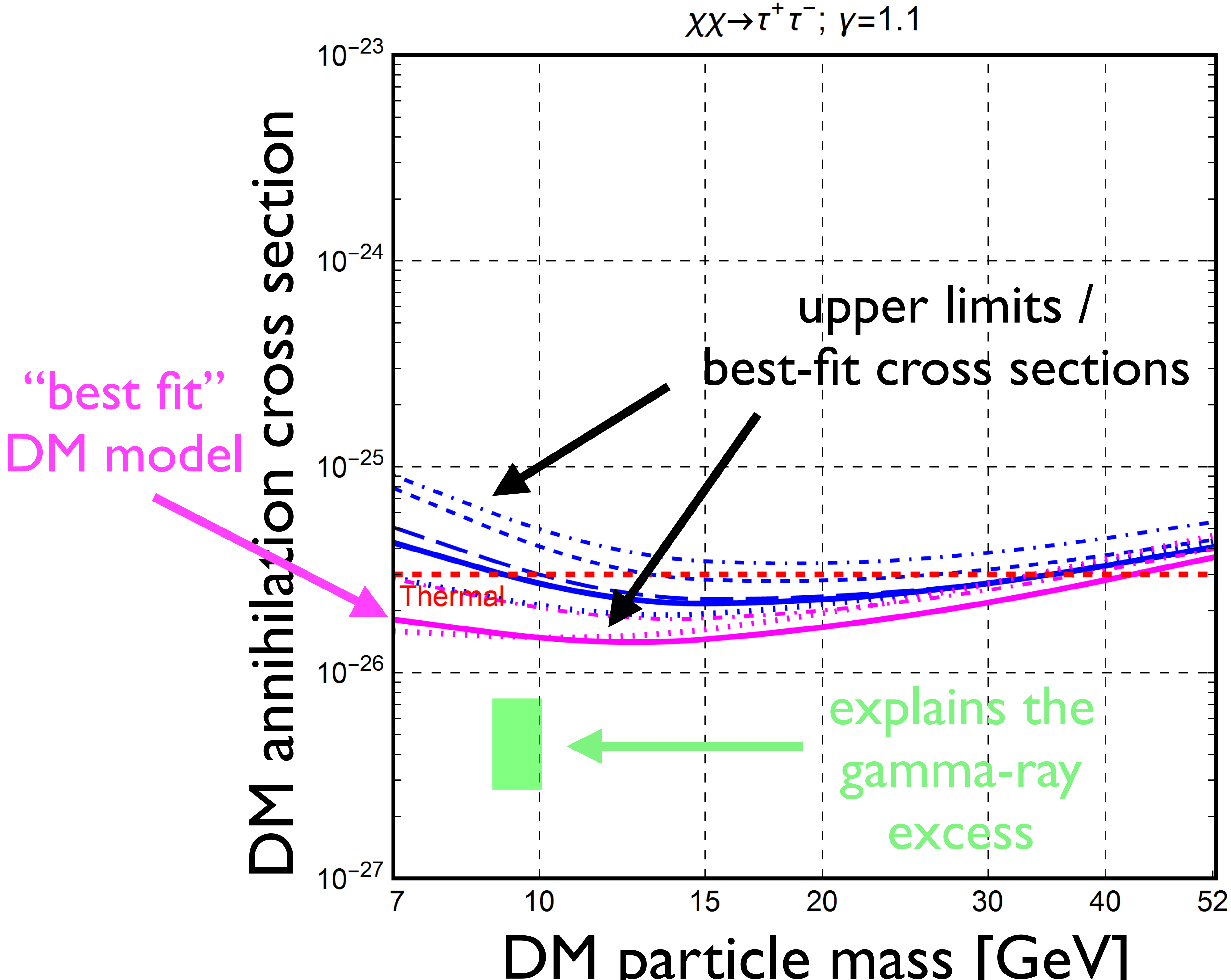

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Summary

- multiwavelength analysis has the potential to constrain interpretations of gamma-ray signals
  - microwave data consistent with a DM interpretation, but favored cross-sections are a bit higher than needed to explain the gamma-ray excess
  - challenges of separating components (esp. DM and Bubbles) currently limit the robustness of a DM detection
- could improve sensitivity by better/consistent multi-wavelength modeling of Bubbles instead of template