Probing Galactic Magnetic Field

through Cosmic Ray Leptons, Diffuse γ-Rays and Radio Waves

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Workshop on Cosmology with Next Generation Radio Surveys

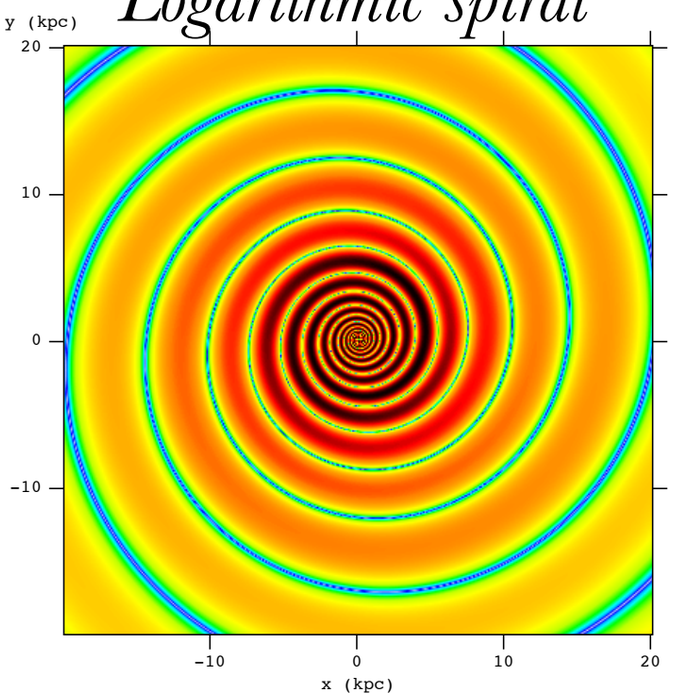
June 21, 2016

Galactic Magnetic Field

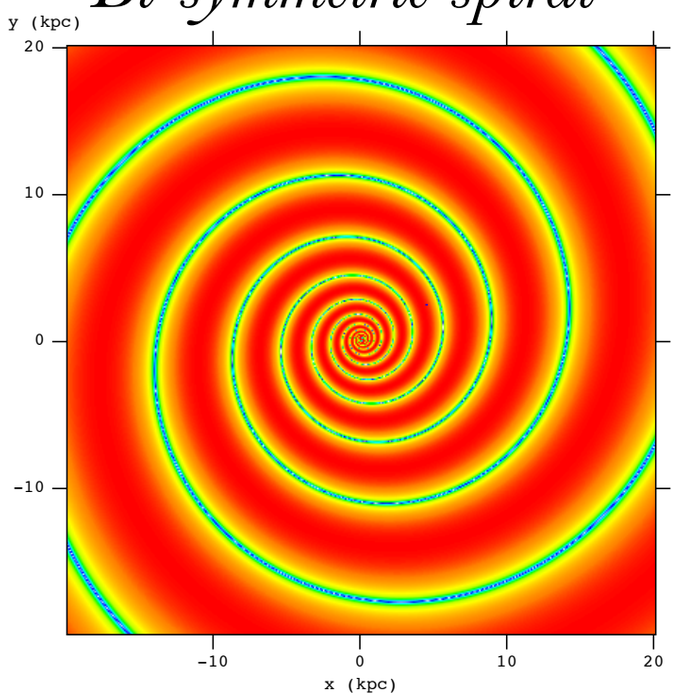
$$B = B_{reg} + B_{turb}$$

Regular component

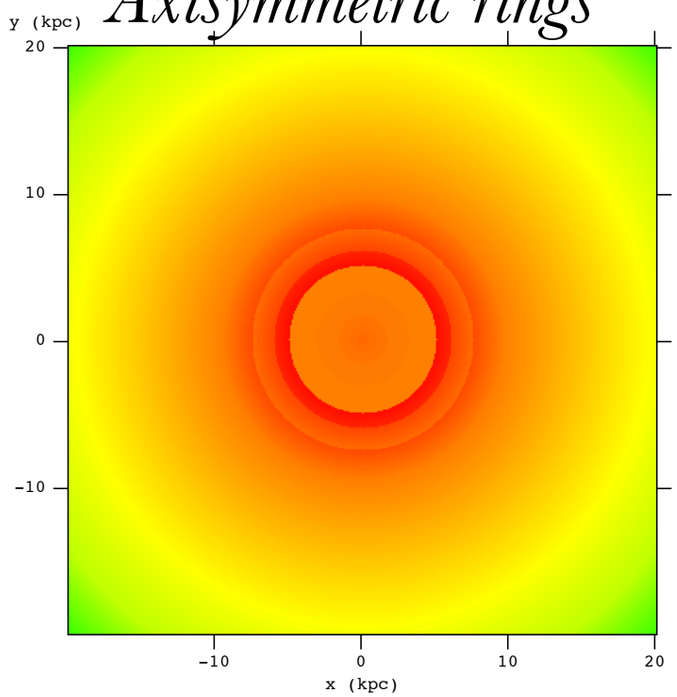
Logarithmic spiral

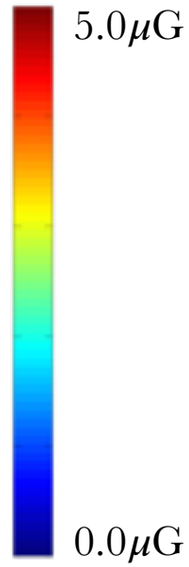


Bi-symmetric spiral



Axisymmetric rings





- Faraday rotation measure $\theta_{pol}=RM\times\lambda^2$
- total and polarized intensity of synchrotron emission

Galactic Magnetic Field

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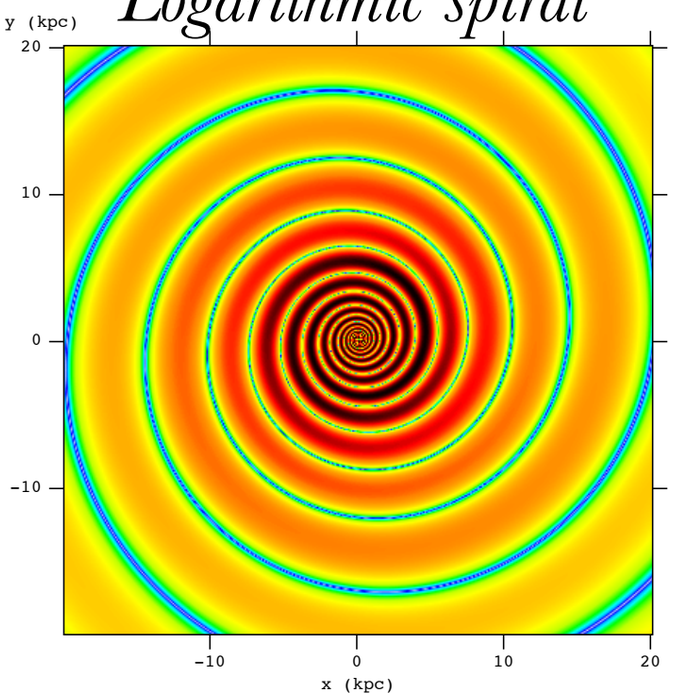
Regular component

Logarithmic spiral



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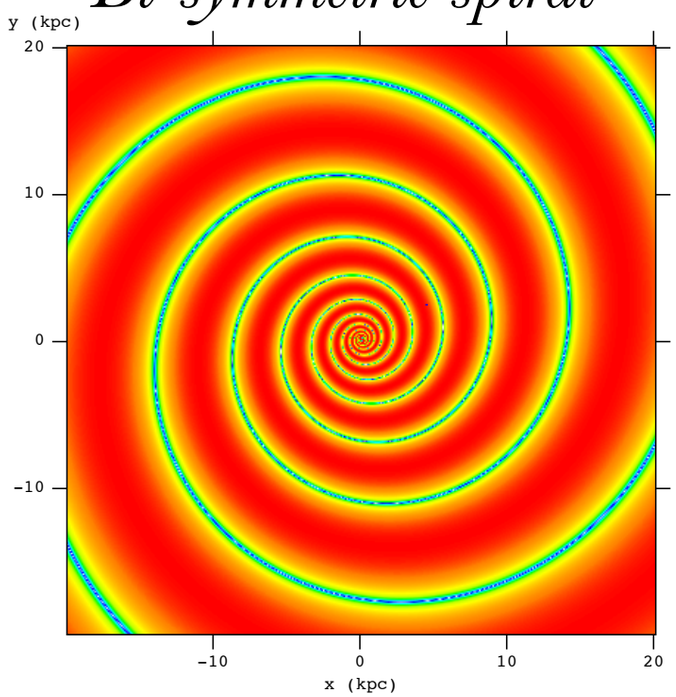

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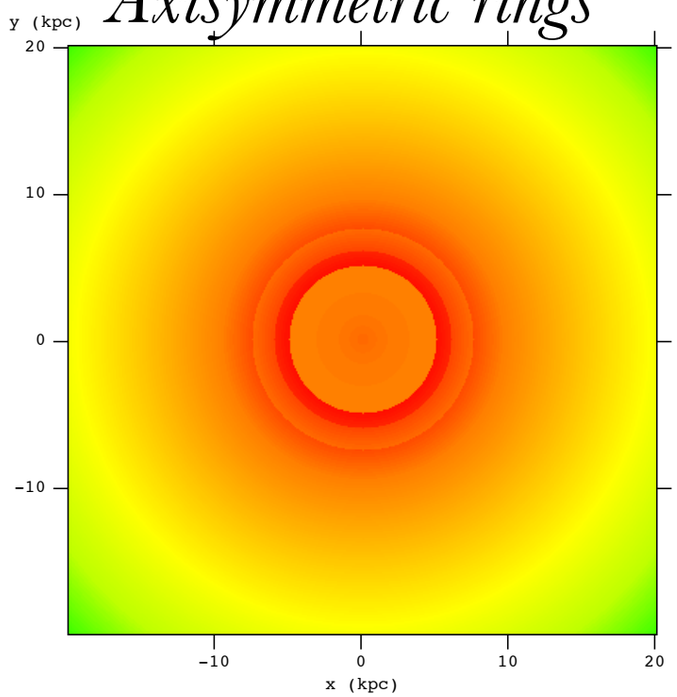
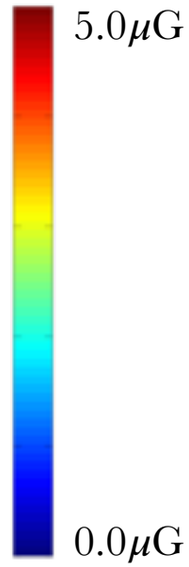




Turbulent component

$$B_{turb} = B_{0,turb} \exp\left(-\frac{R - R_{\odot}}{R_{0,turb}}\right) \exp\left(-\frac{|z|}{z_{0,turb}}\right)$$

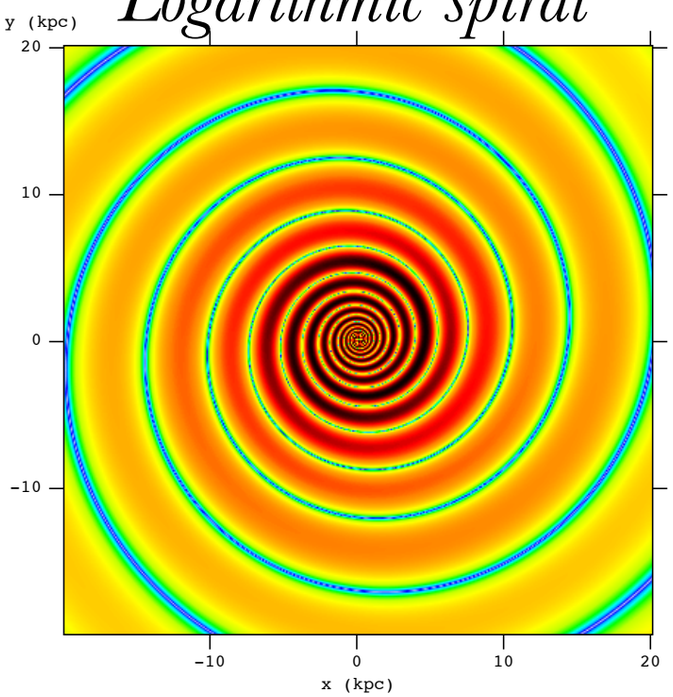
- total intensity of synchrotron emission

Galactic Magnetic Field

$$B = B_{reg} + B_{turb}$$

Regular component

Logarithmic spiral



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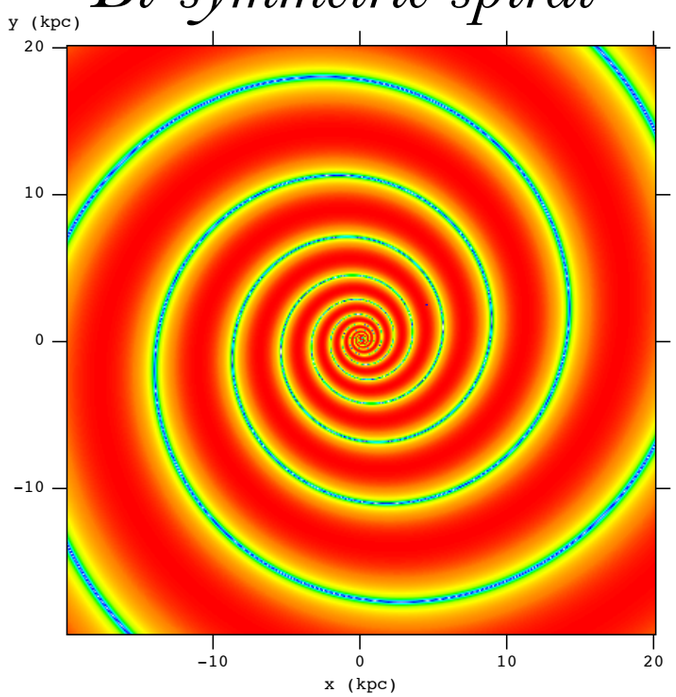

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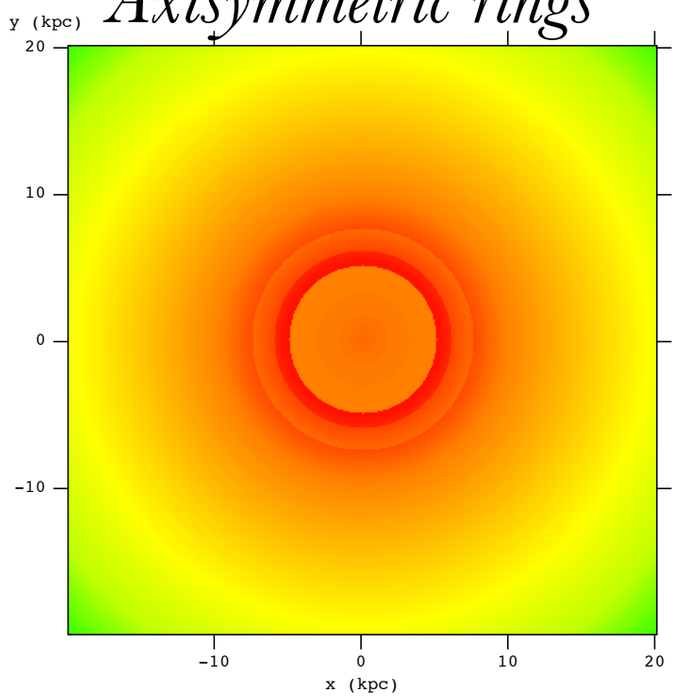

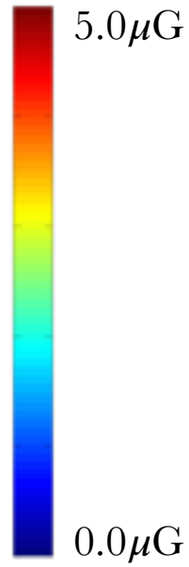

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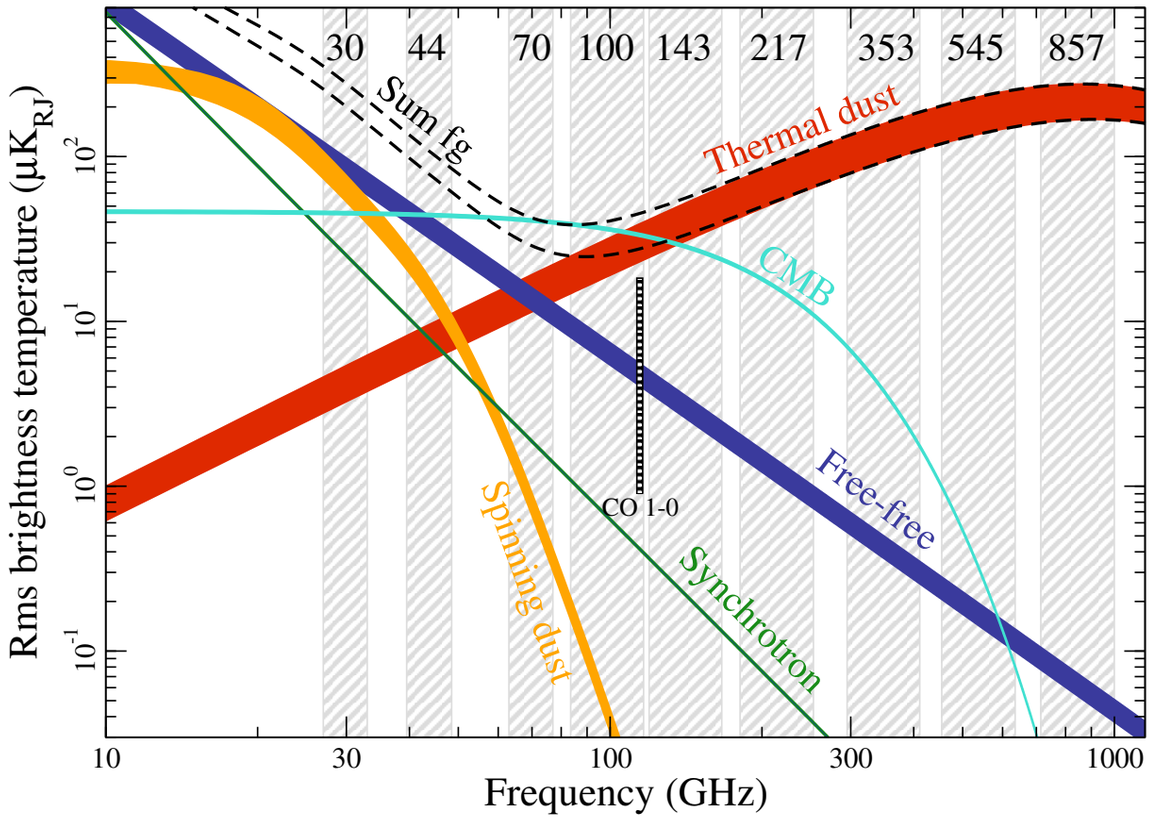
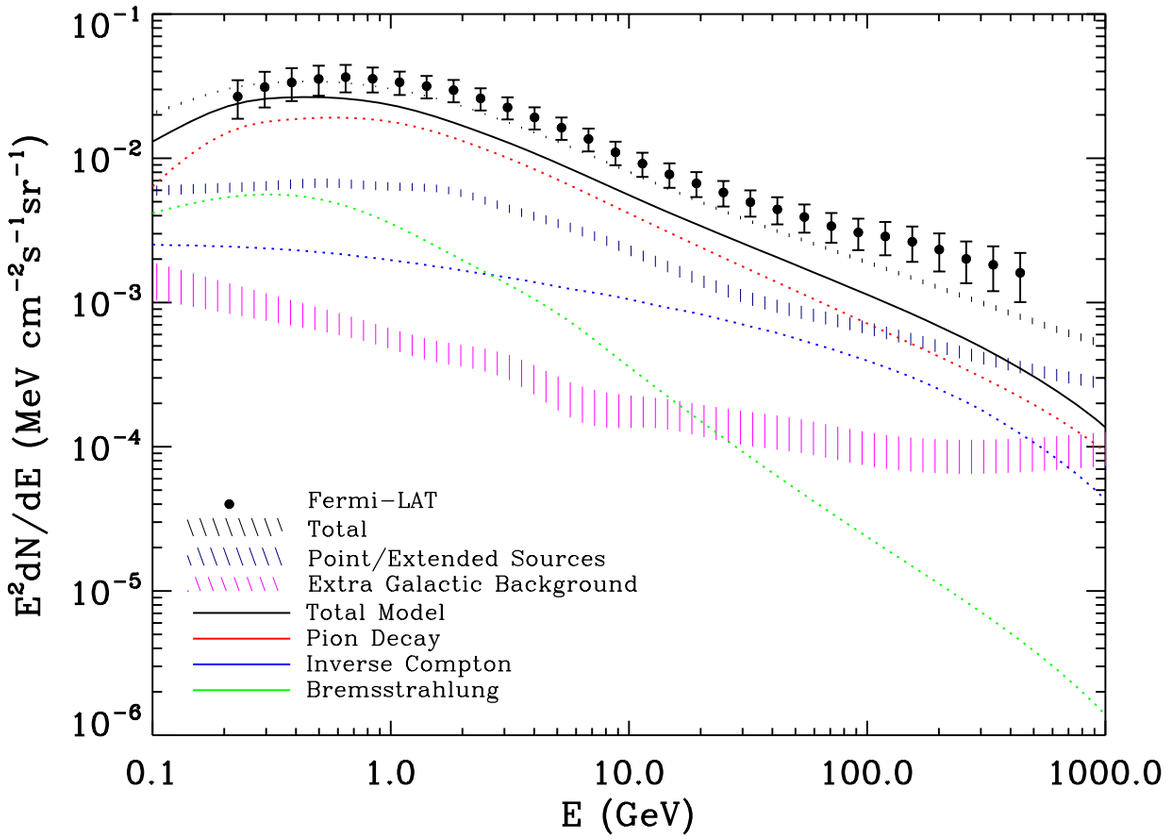
$$A_{turb} = \left(B_{turb}/B_{reg}\right)_{\odot} = 1\text{-}1.5 \quad , \quad B_{total}\,(GC) \sim 50\text{-}200\mu G$$

Is there an alternative approach to probe the Galactic magnetic field?

Noting that …

Comic ray electron (positron) energy losses at high energies





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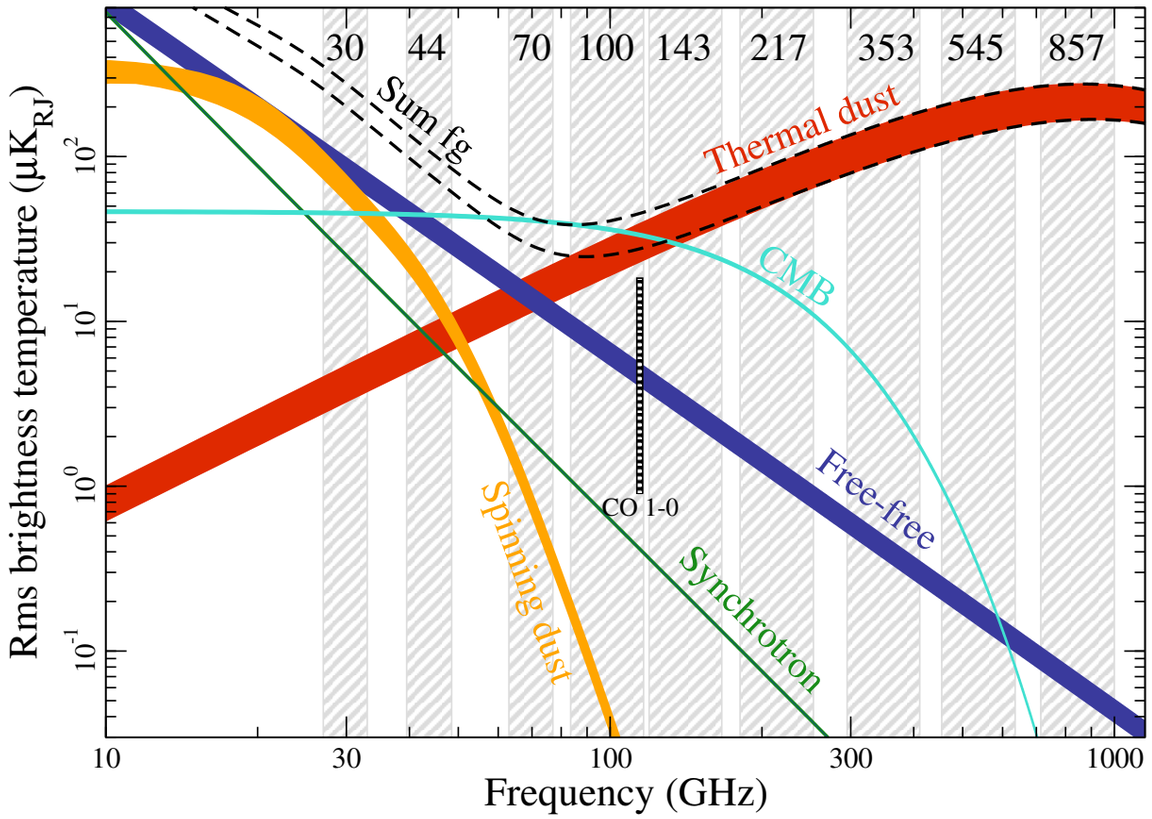

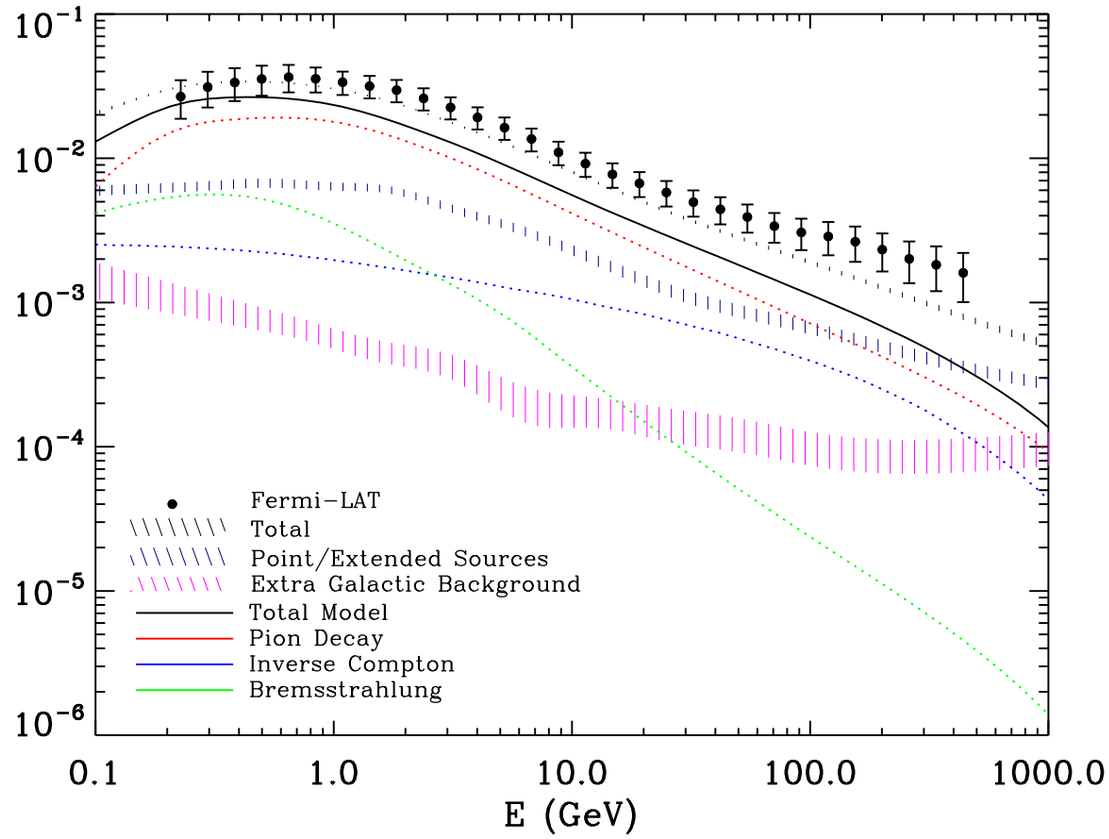

$$\left(\frac{dE}{dt}\right)_{sync} = \frac{4}{3}\sigma_T c u_{mag}\left(\frac{v}{c}\right)^2\gamma^2$$

$$\left(\frac{dE}{dt}\right)_{ICS} = \frac{4}{3}\sigma_T c u_{rad}\left(\frac{v}{c}\right)^2\gamma^2$$

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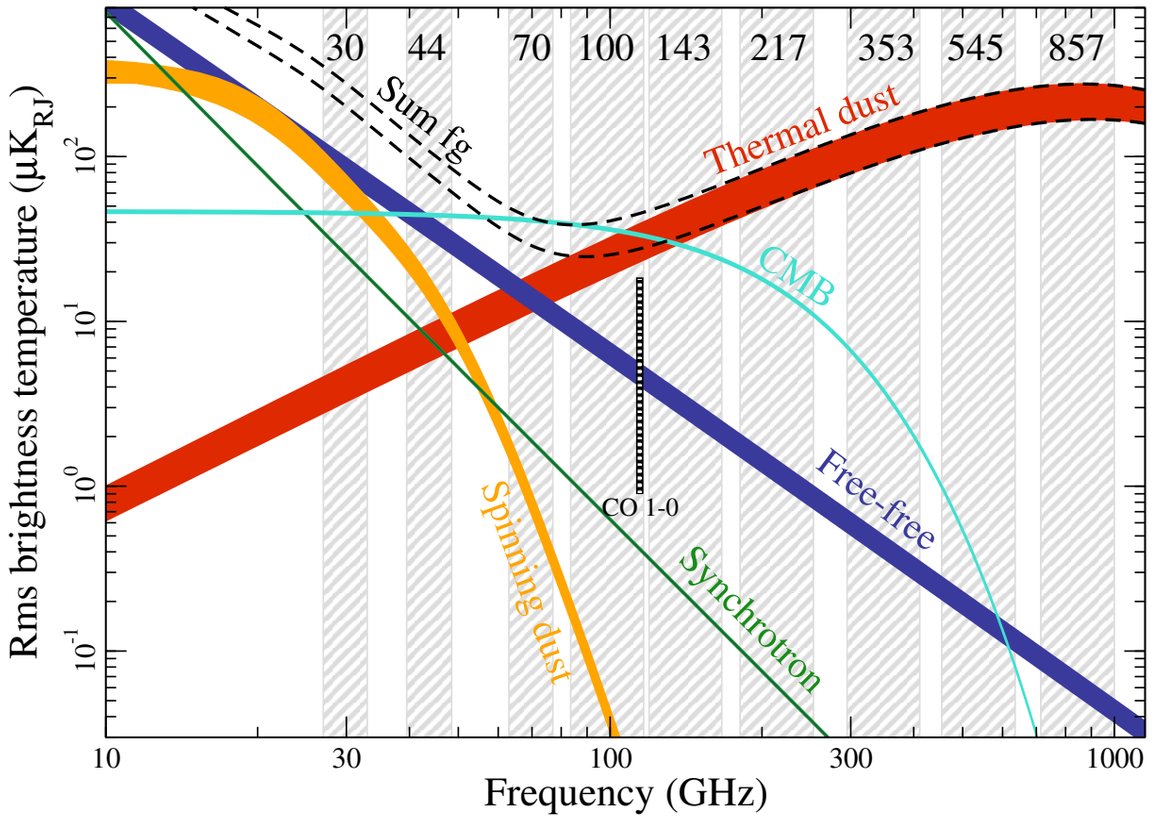

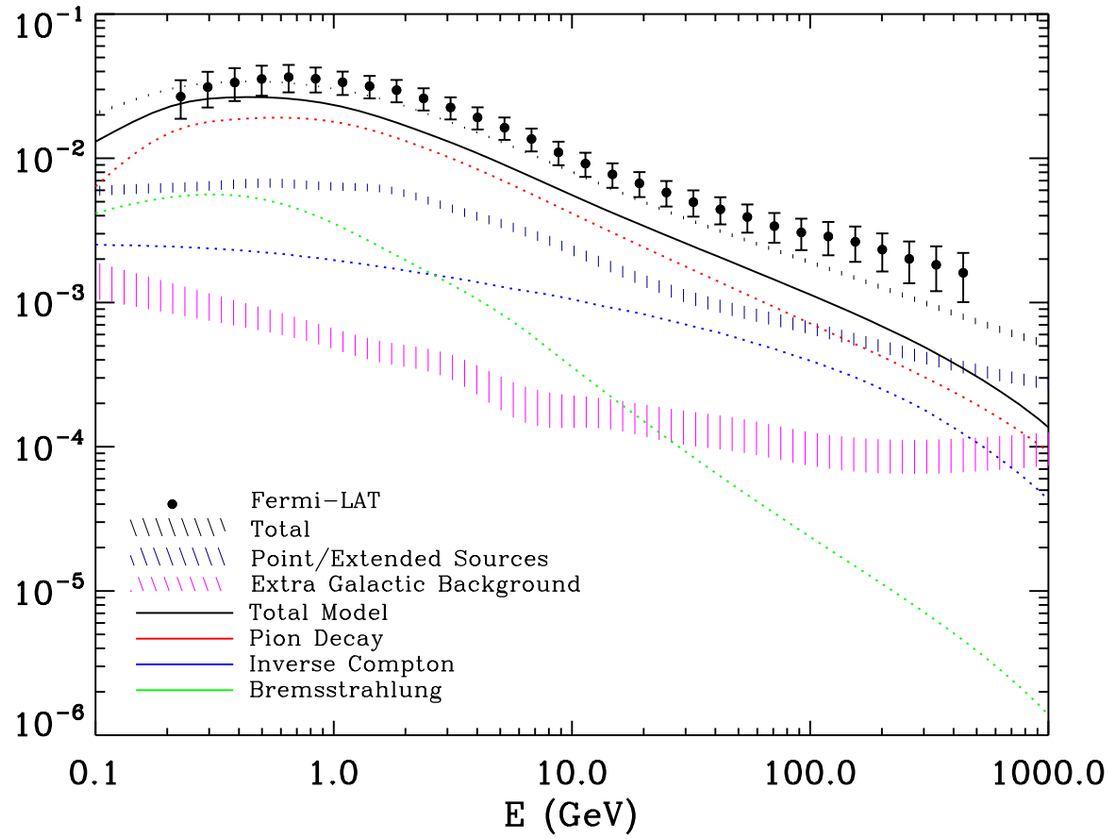

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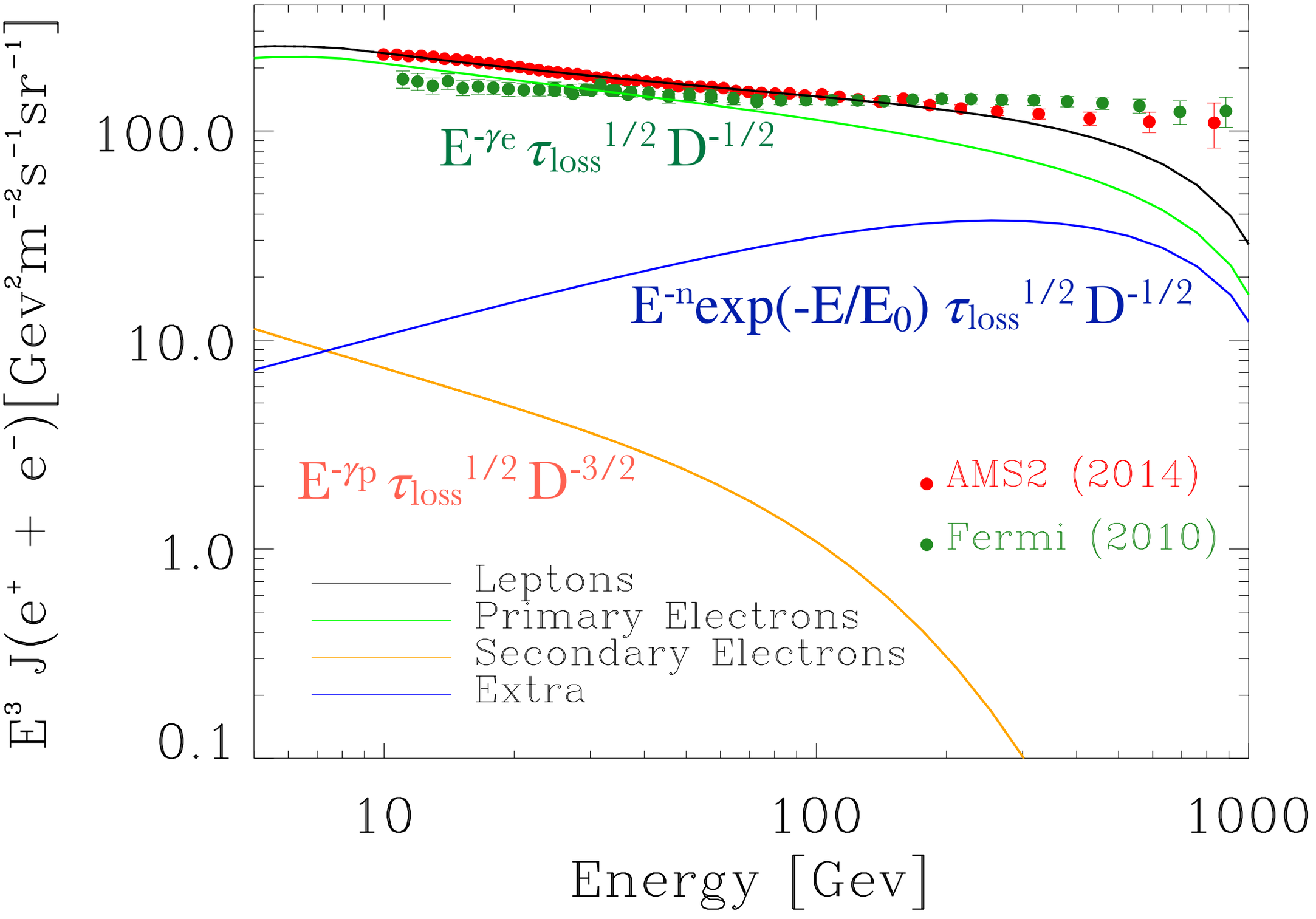
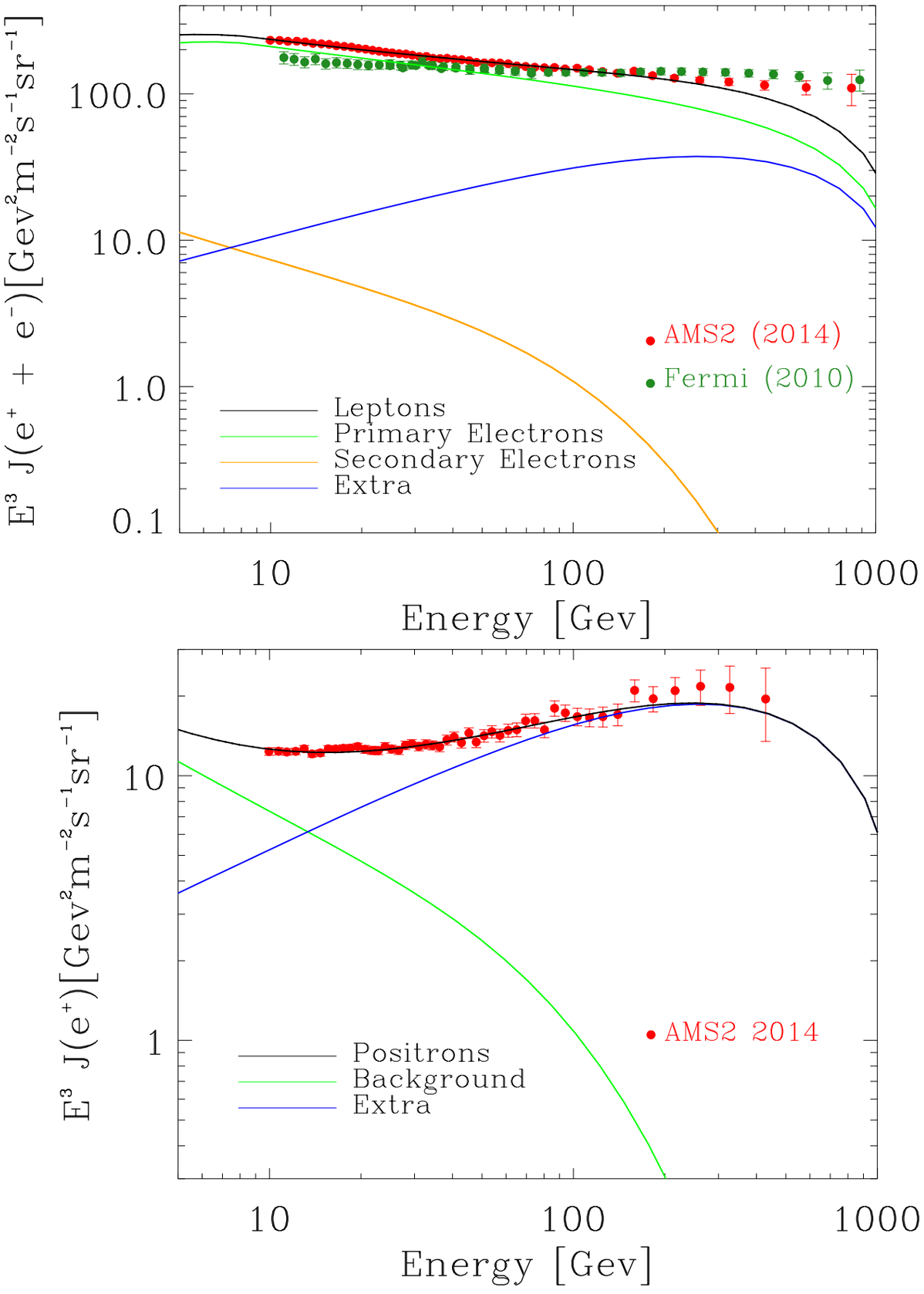
Galactic magnetic field properties impact

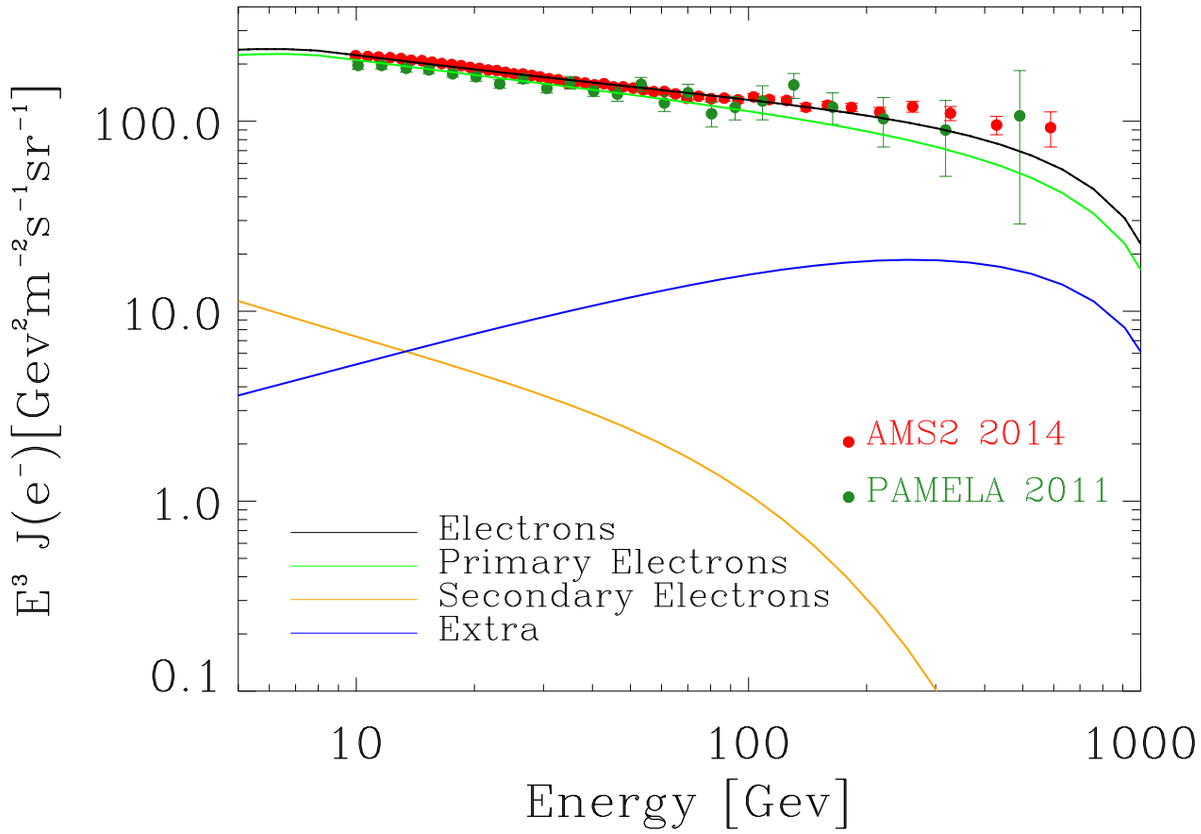
- distribution of cosmic ray leptons
- spectra and morphology of diffuse γ-rays and radio waves

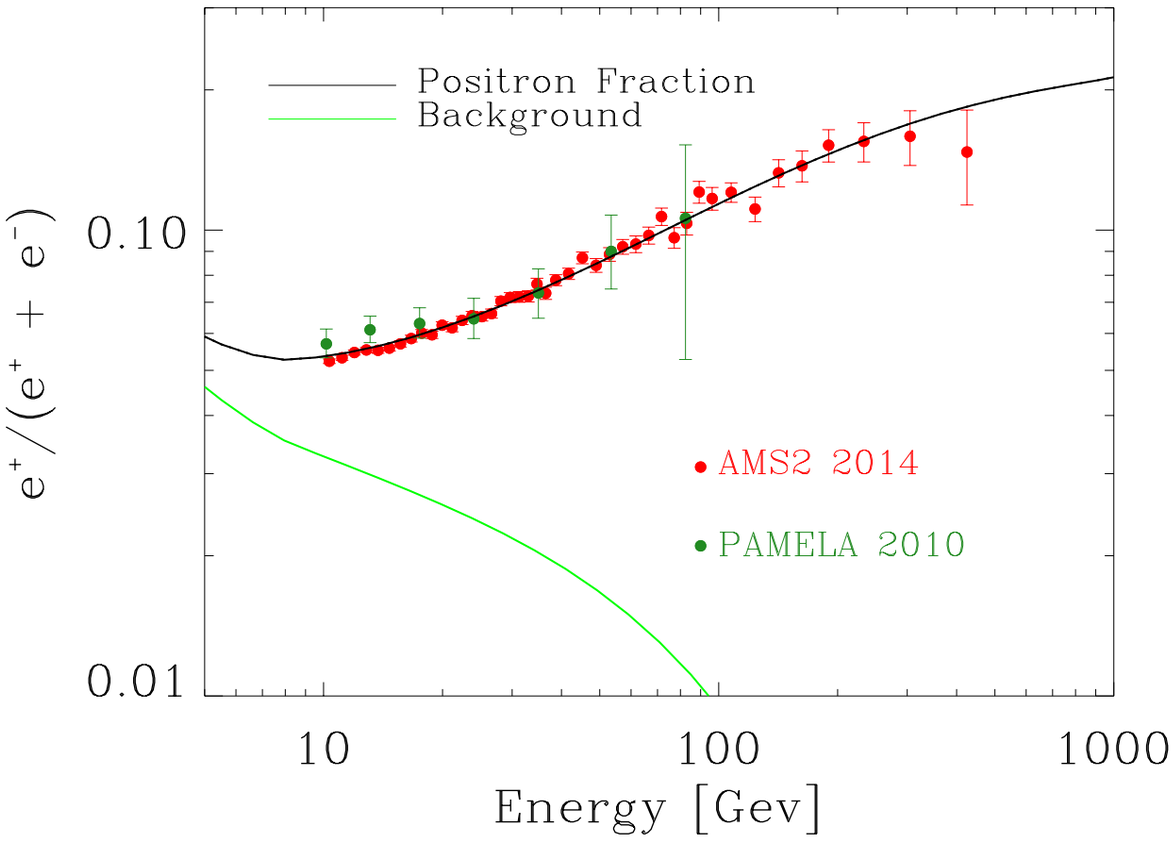
Cosmic Ray Leptons



Cosmic Ray Leptons







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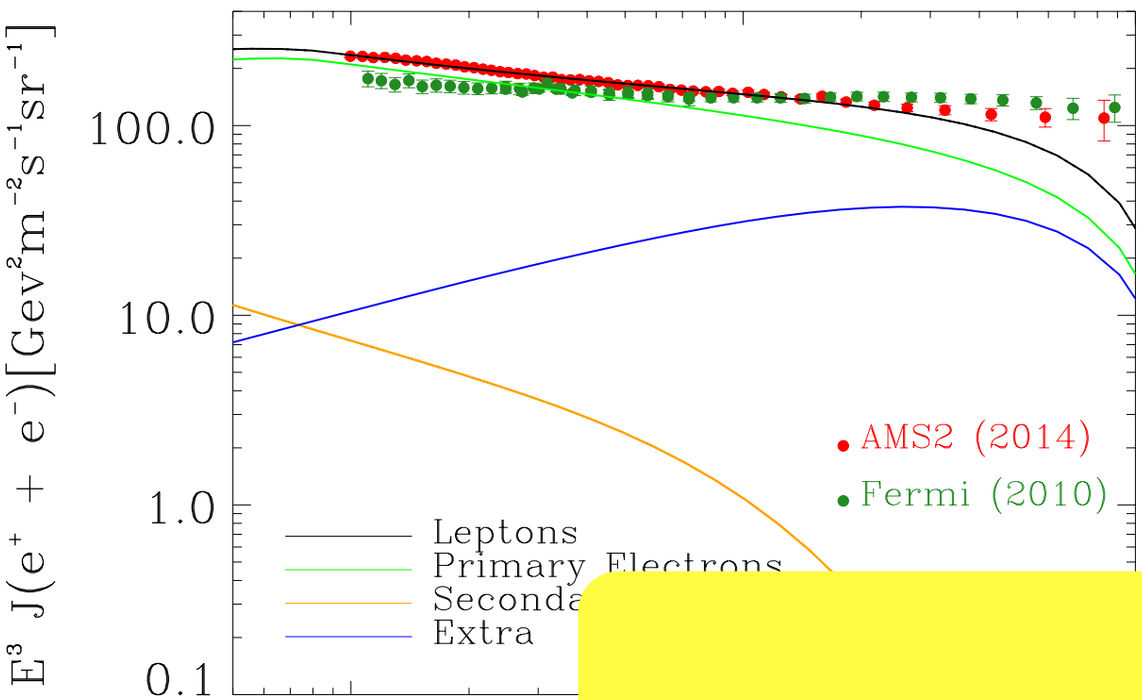
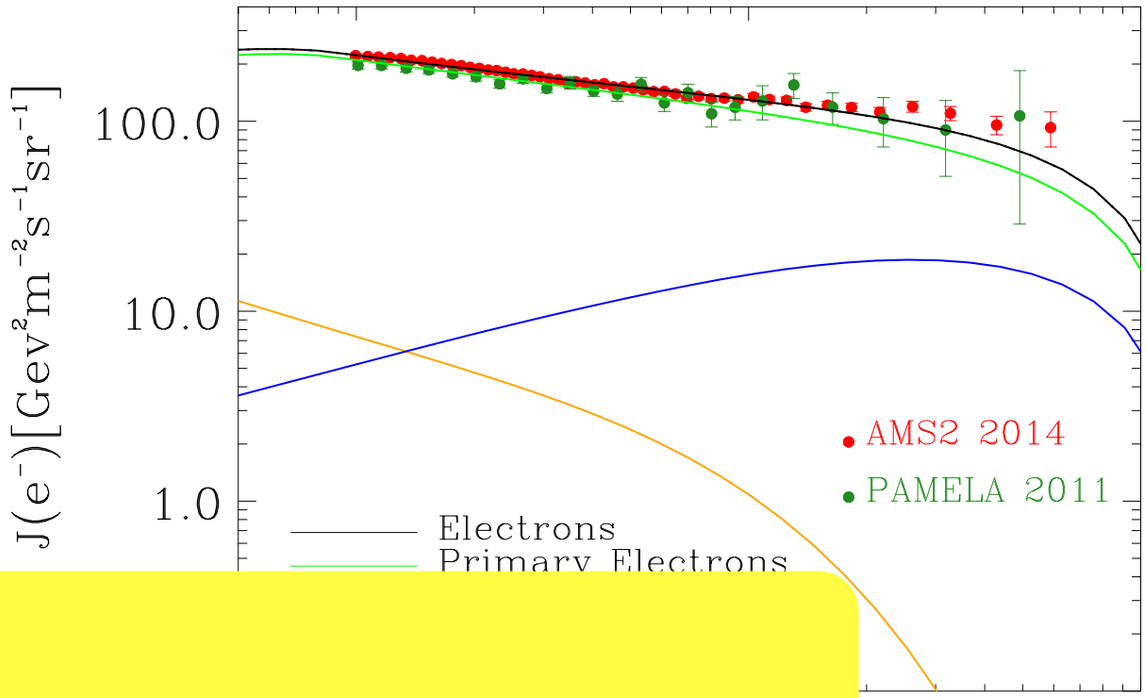
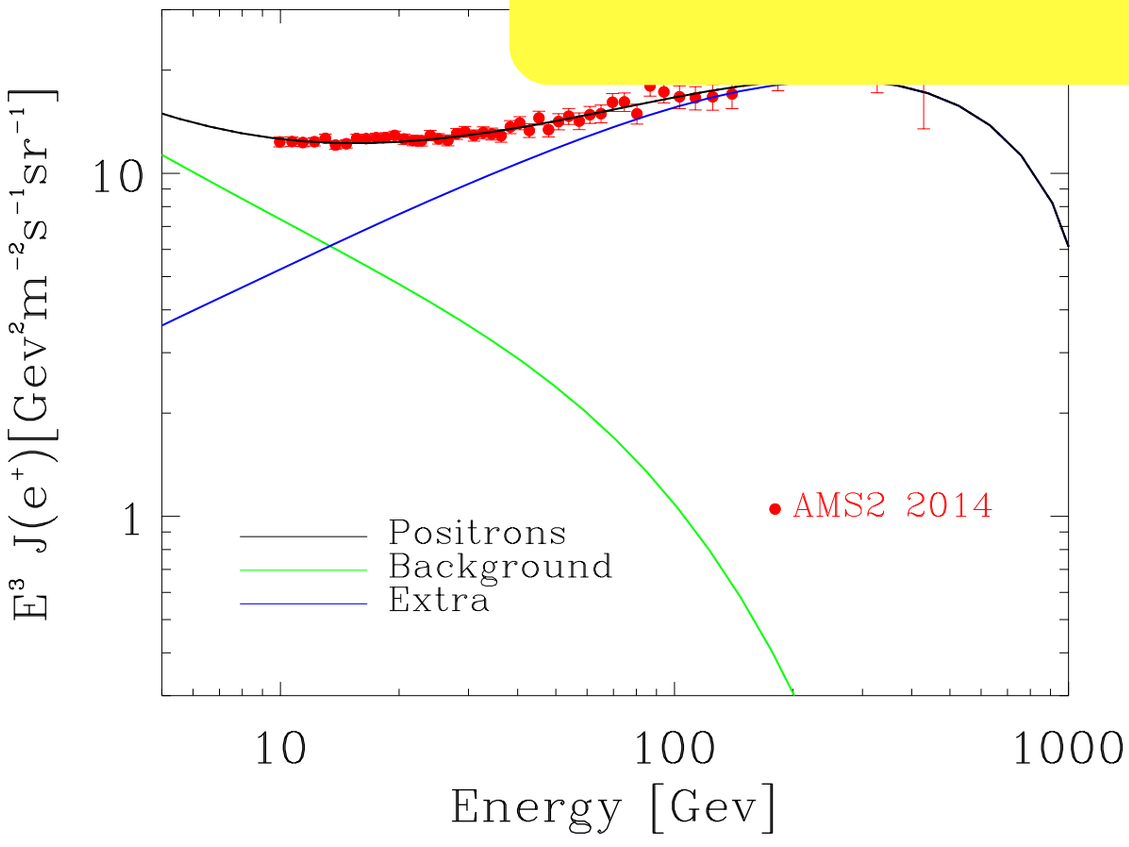
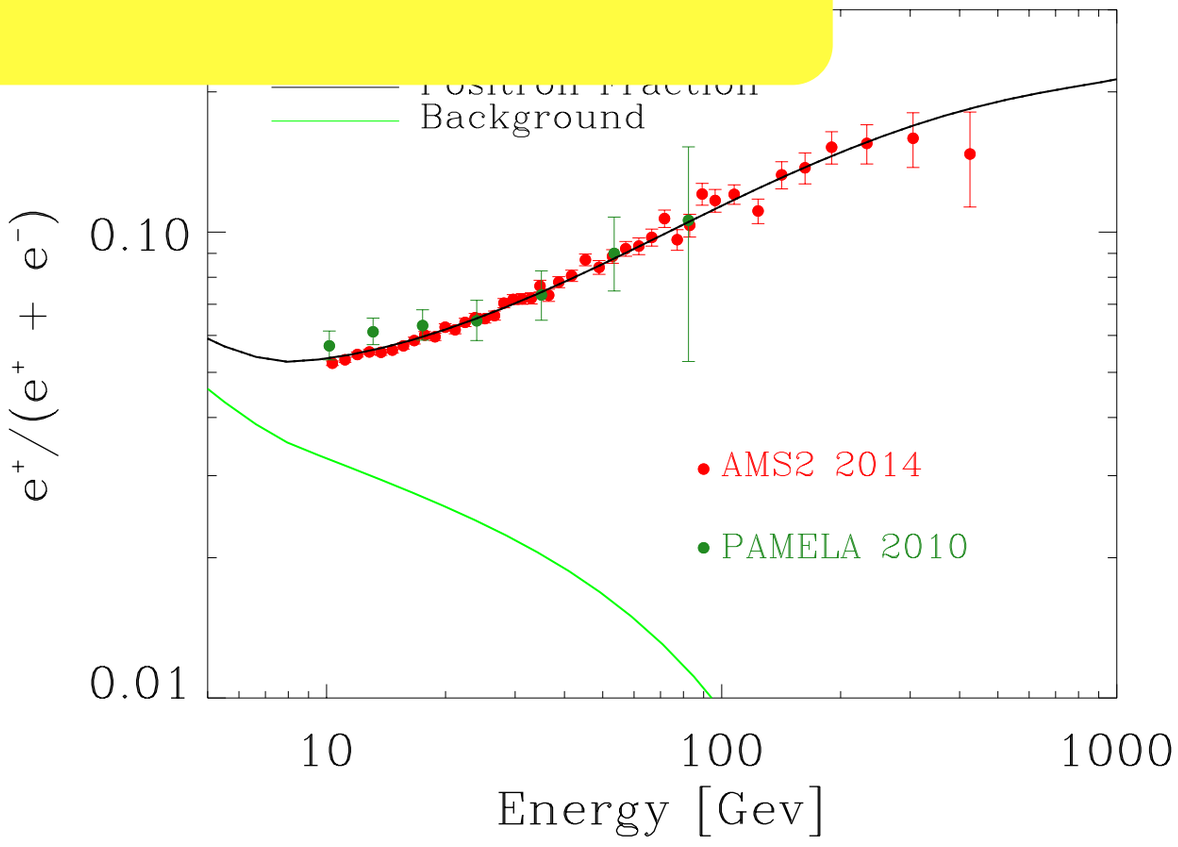




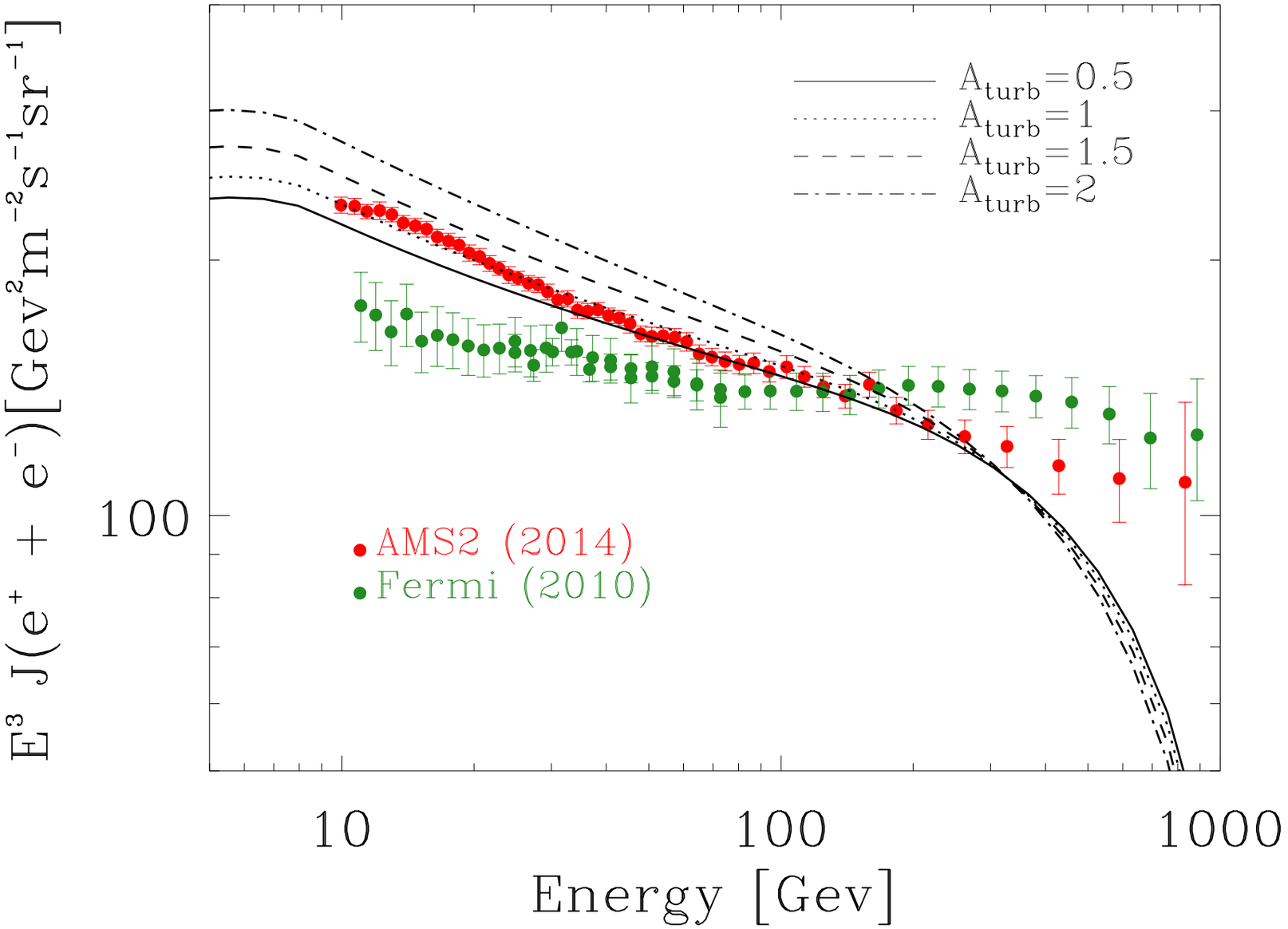
$$n\,(x,y,z,E) \propto q\,(x,y,z,E) \times \tau_{loss}^{1/2}\, D^{-1/2}$$





Cosmic Ray Leptons

The local flux of cosmic ray leptons is most sensitive to the local turbulence.



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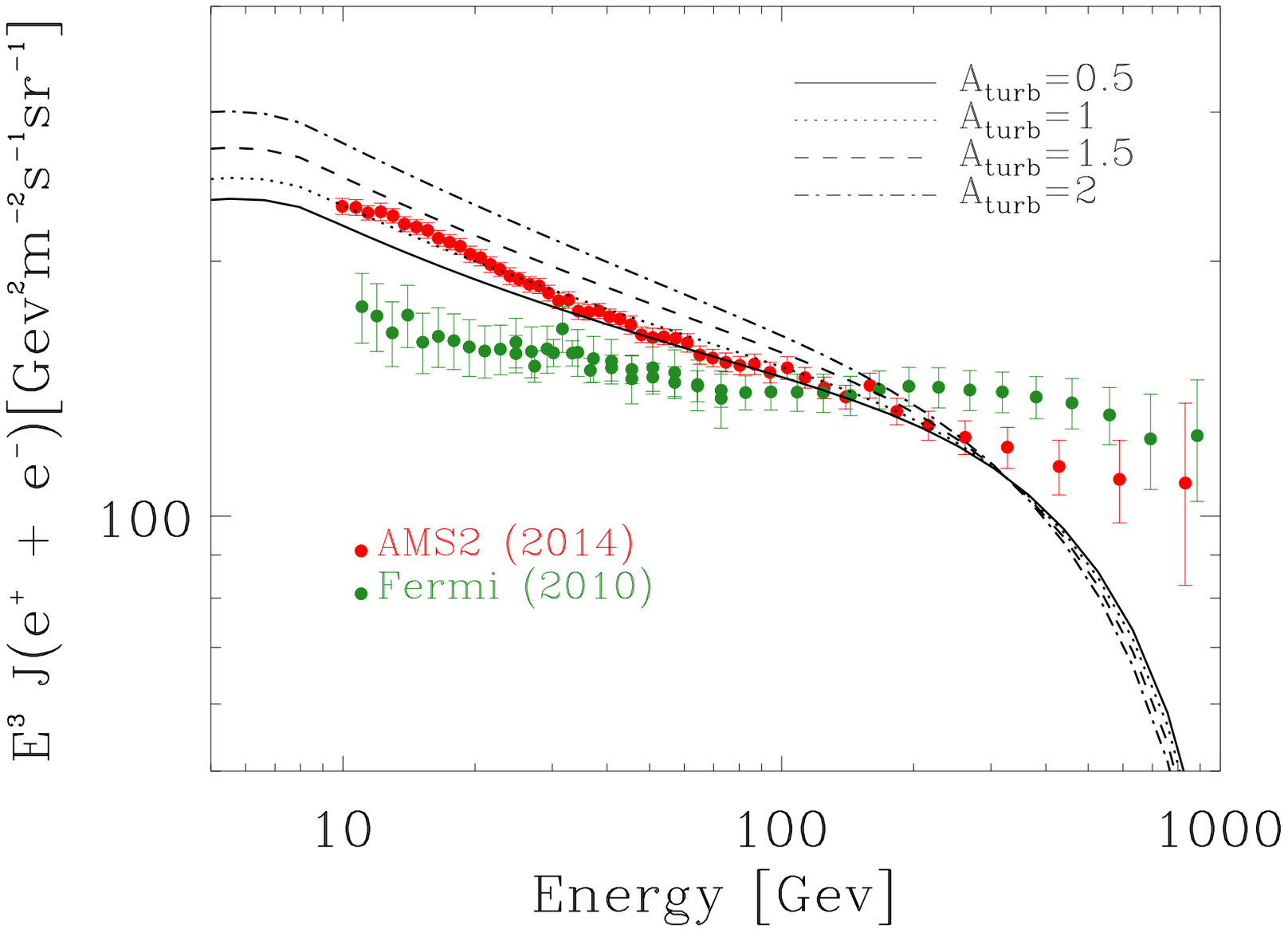


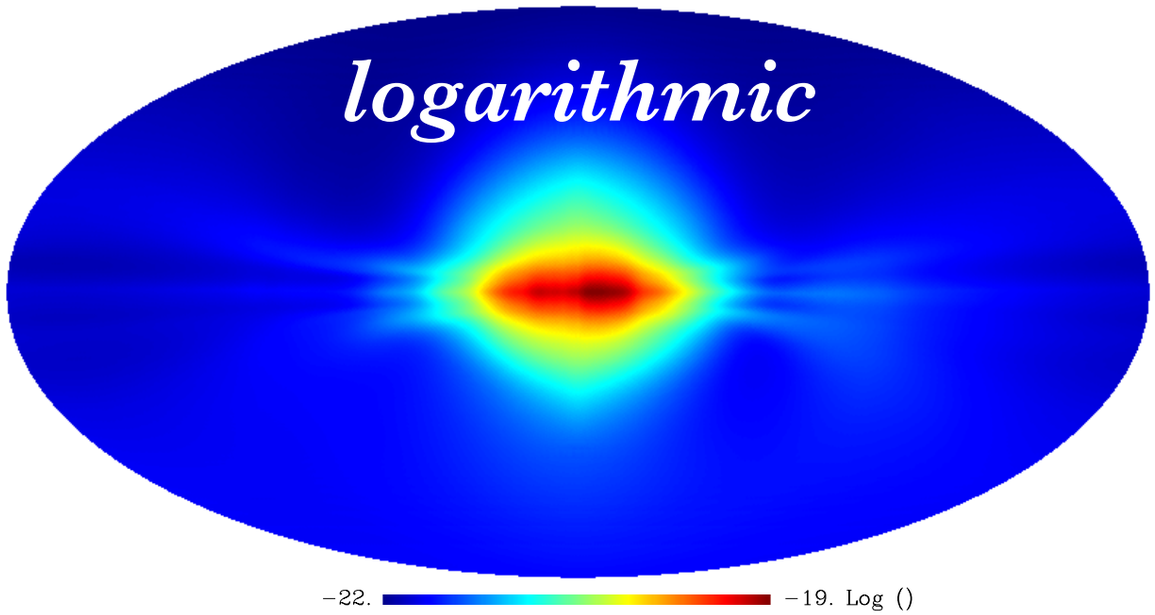
✓ The stronger local turbulence, the more depletion of high energy leptons.

$A_{turb}^{best} = 0.3\ (\gamma_e = 2.54)$

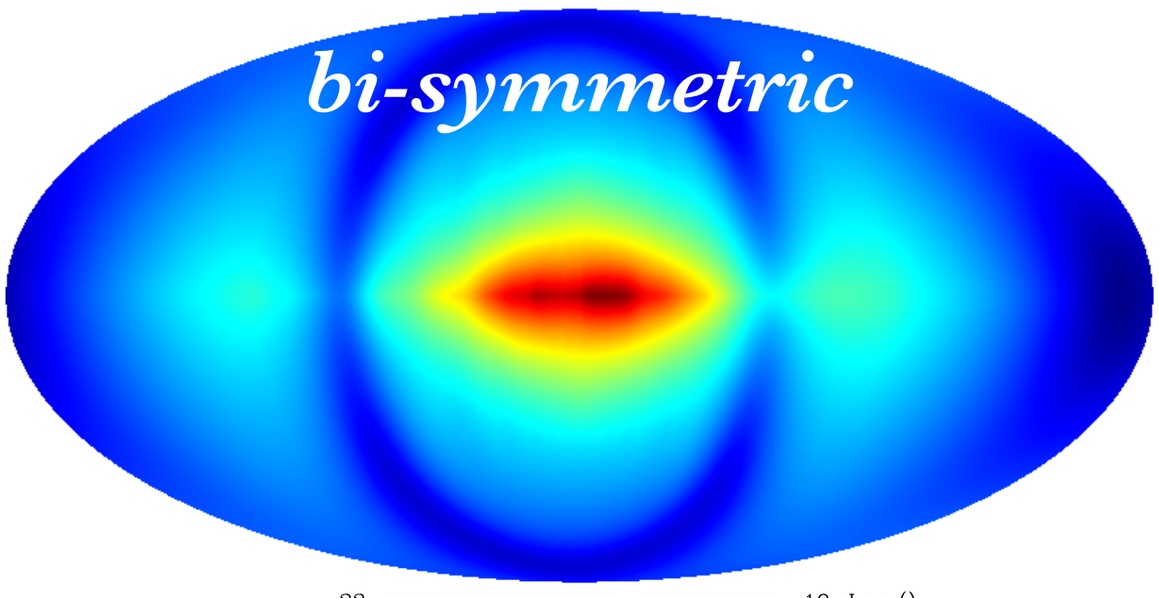
$A_{turb}^{3\sigma} = 1.2\ (\gamma_e = 2.51)$

Synchrotron Emission

Morphology of synchrotron emission strongly depends on the magnetic field structure.



$\mathrm{erg/cm^2/s/sr/Hz}$



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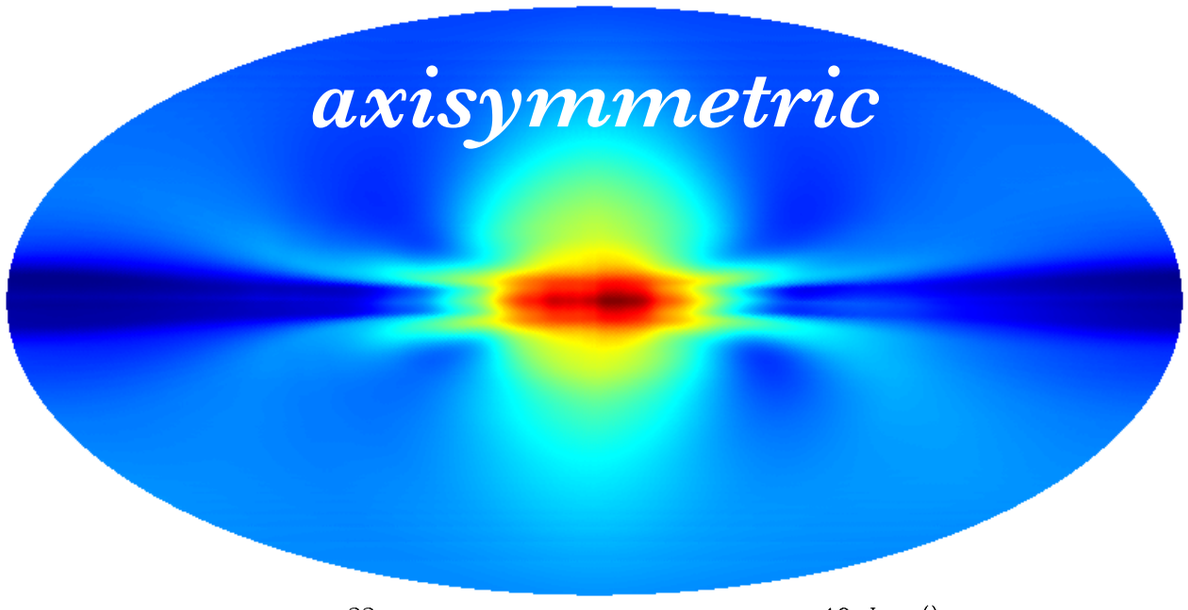

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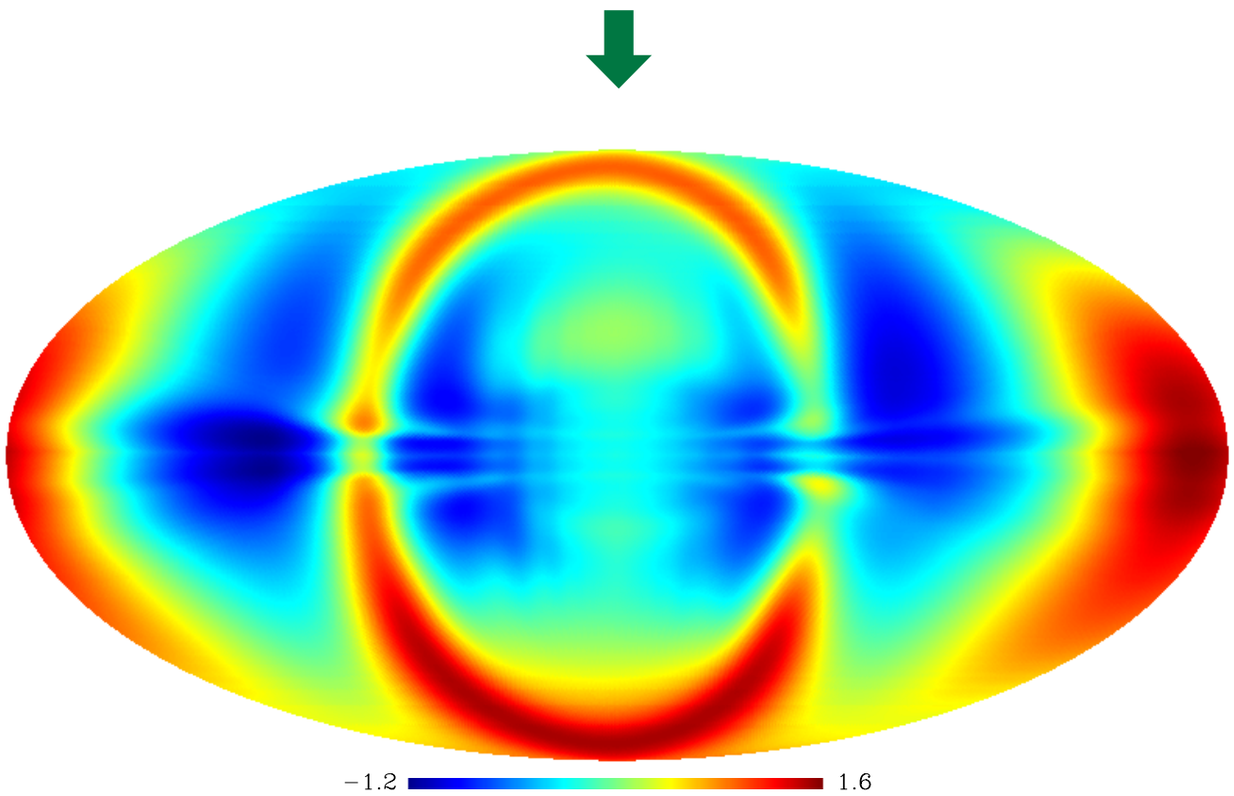
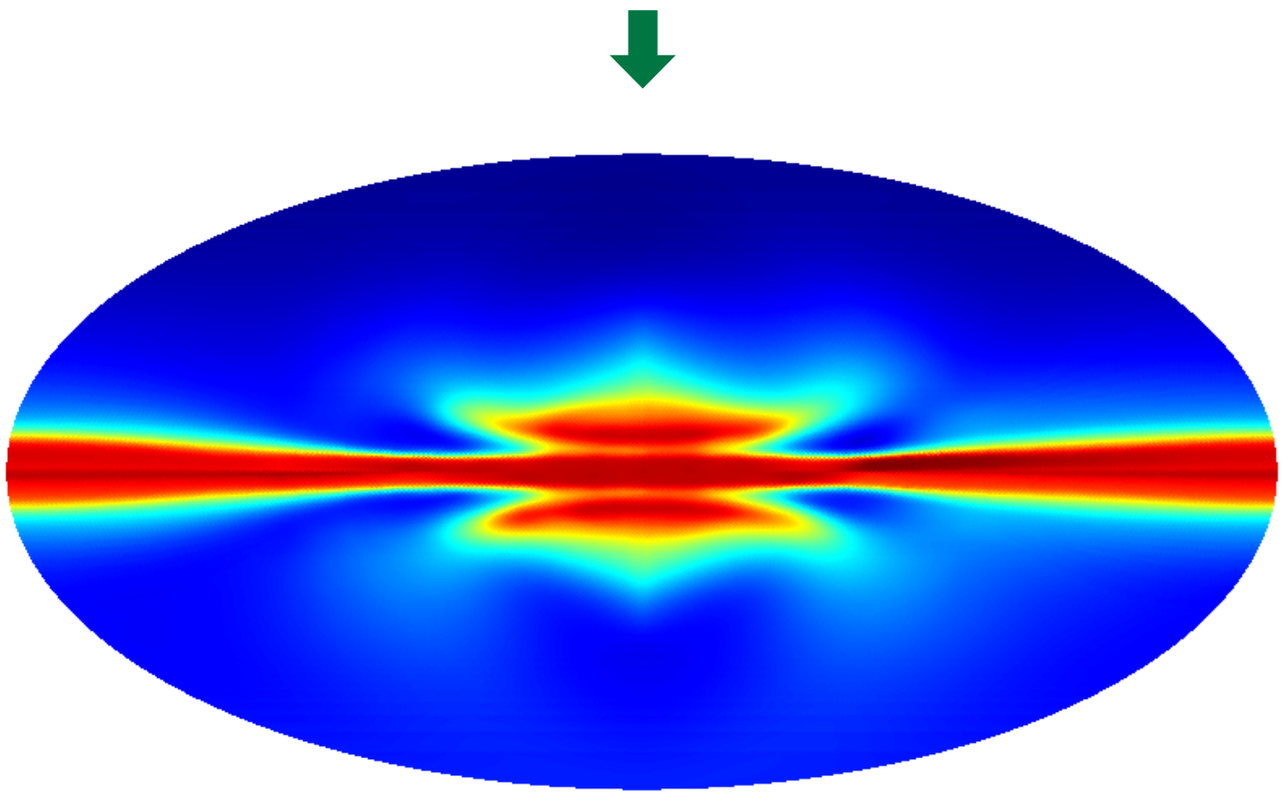
Synchrotron Emission

Morphology of synchrotron emission strongly depends on the magnetic field structure.

logarithmic spiral vs
bi-symmetric spiral



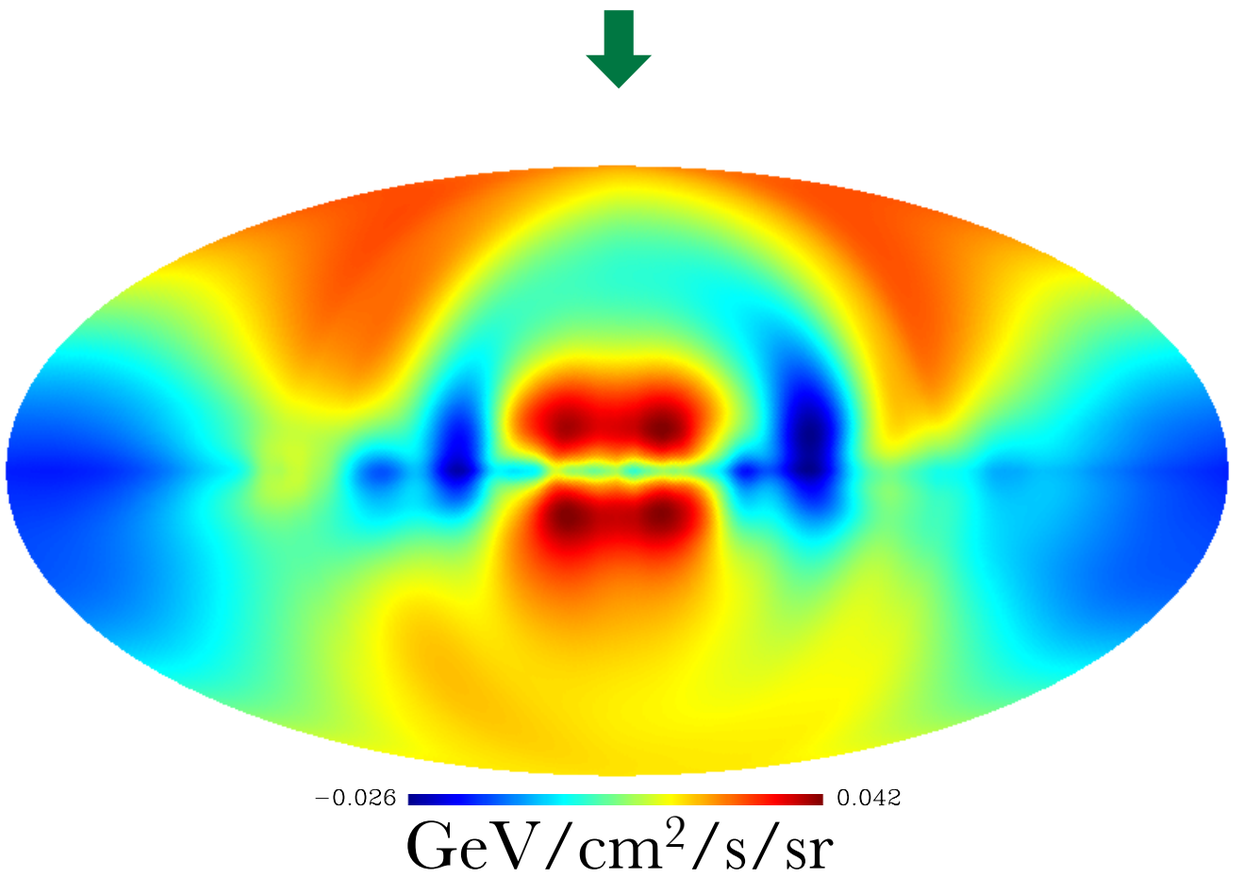
logarithmic spiral vs
axisymmetric rings



Inverse Compton Scattering

Different magnetic field structures can not be discriminated by diffuse γ-rays.

logarithmic spiral vs
bi-symmetric spiral



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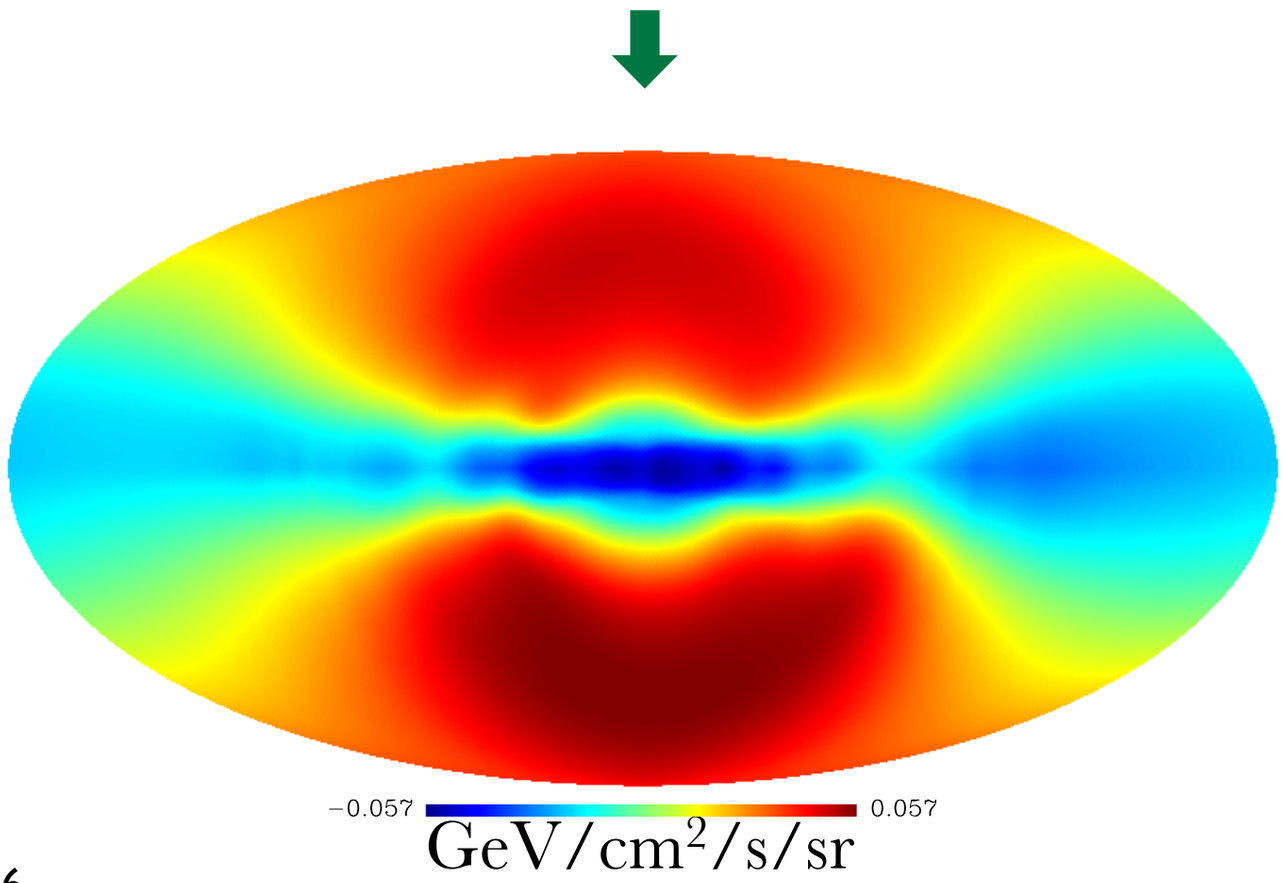

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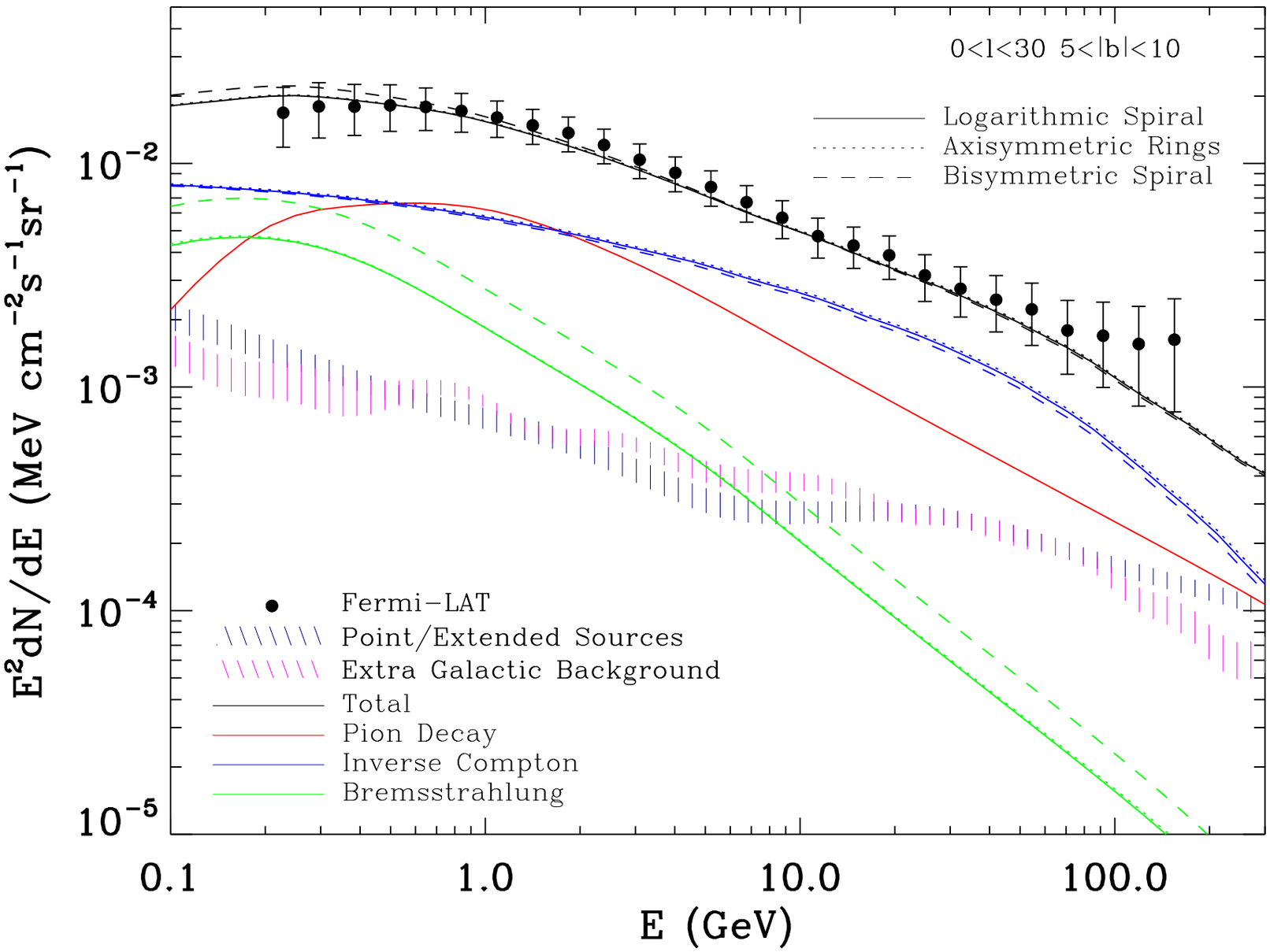
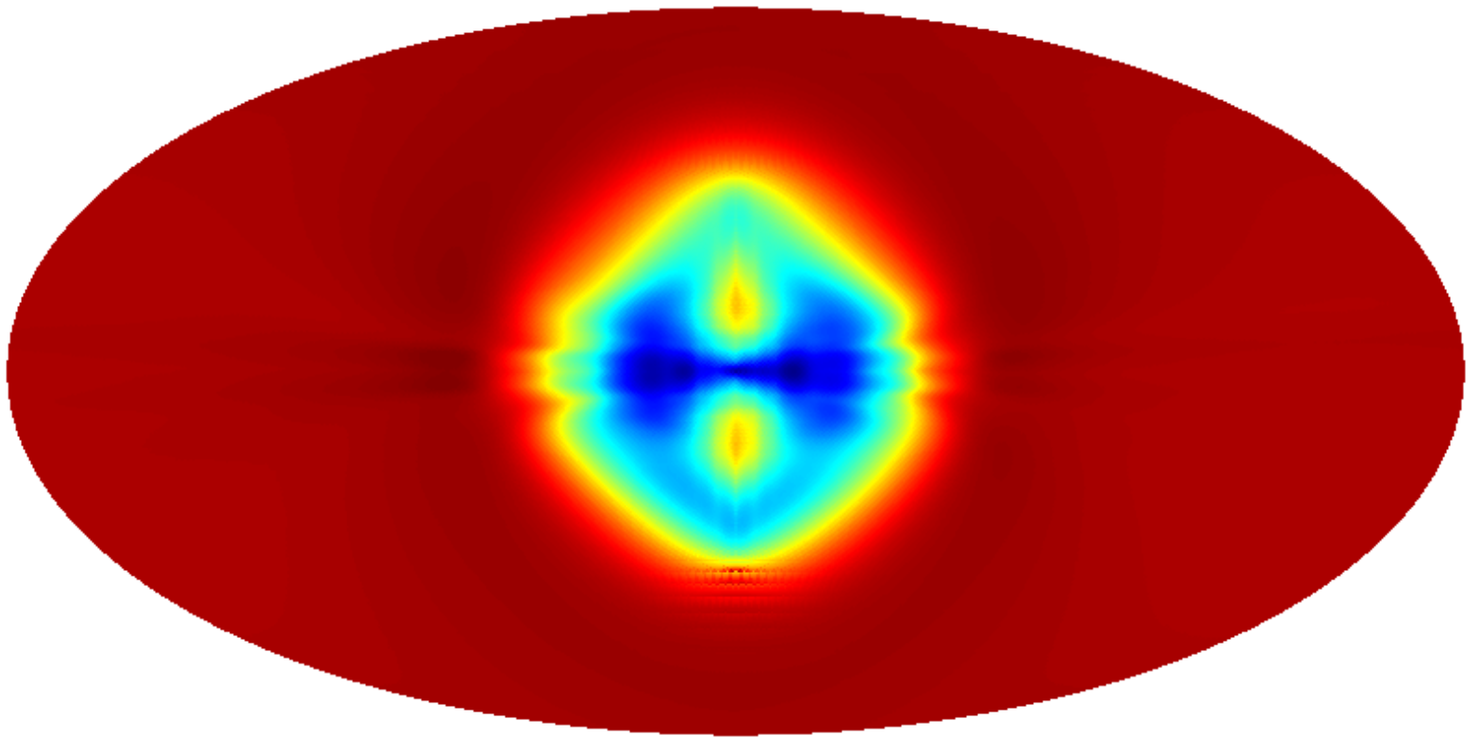


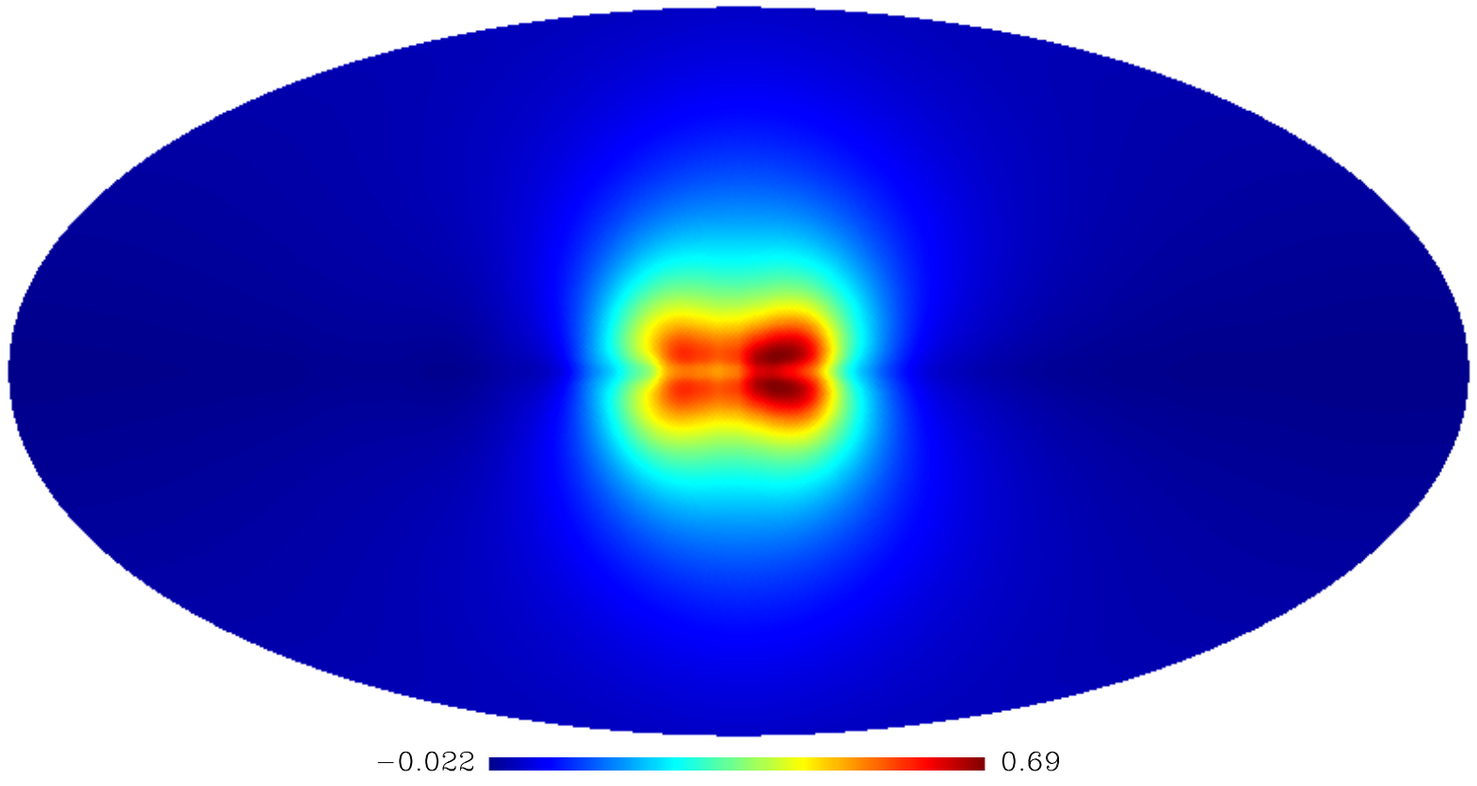
Low vs High B_{GC}



synchrotron relative difference

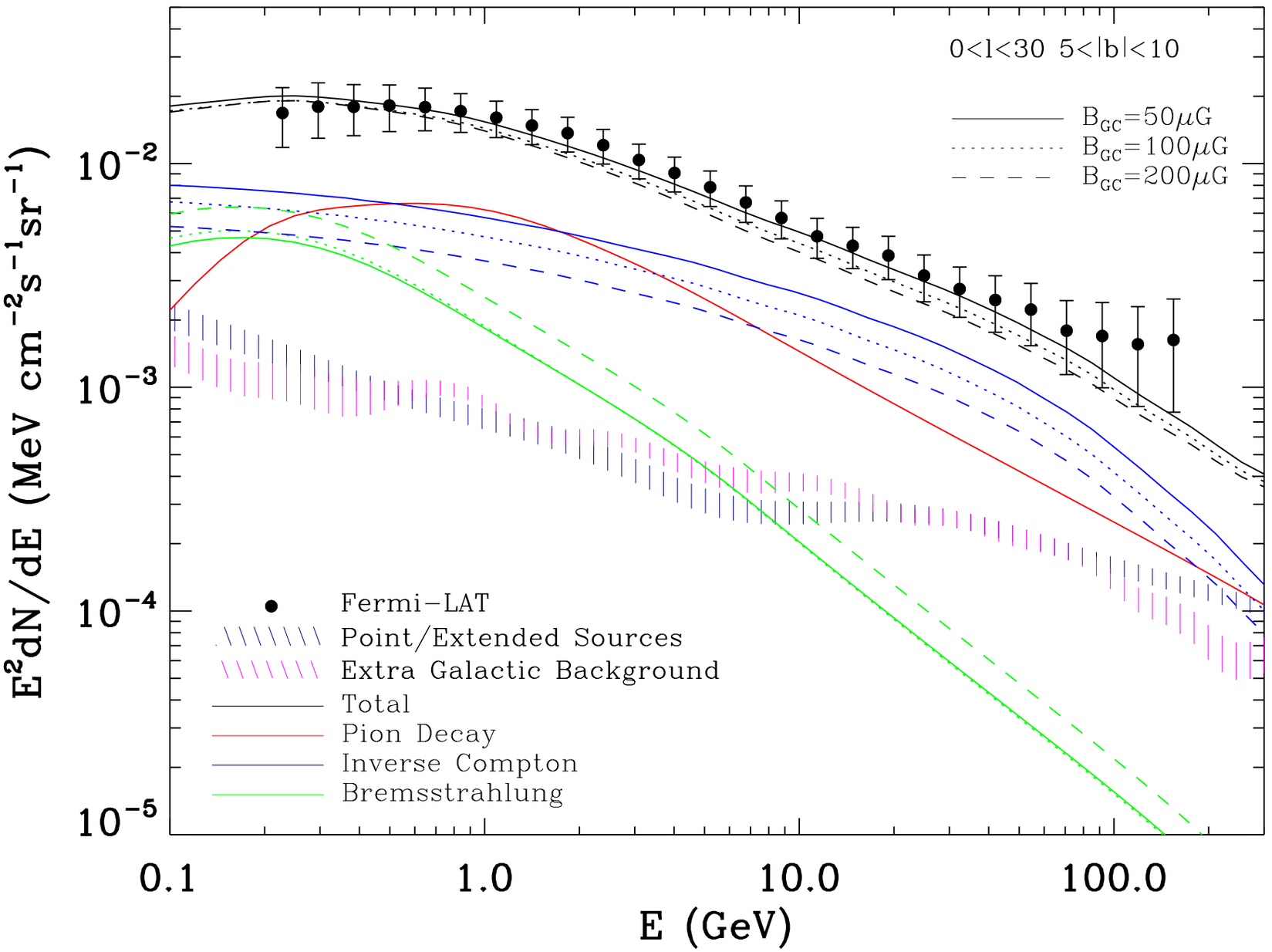
$\mathrm{erg/cm^2/s/sr/Hz}$

ICS relative difference



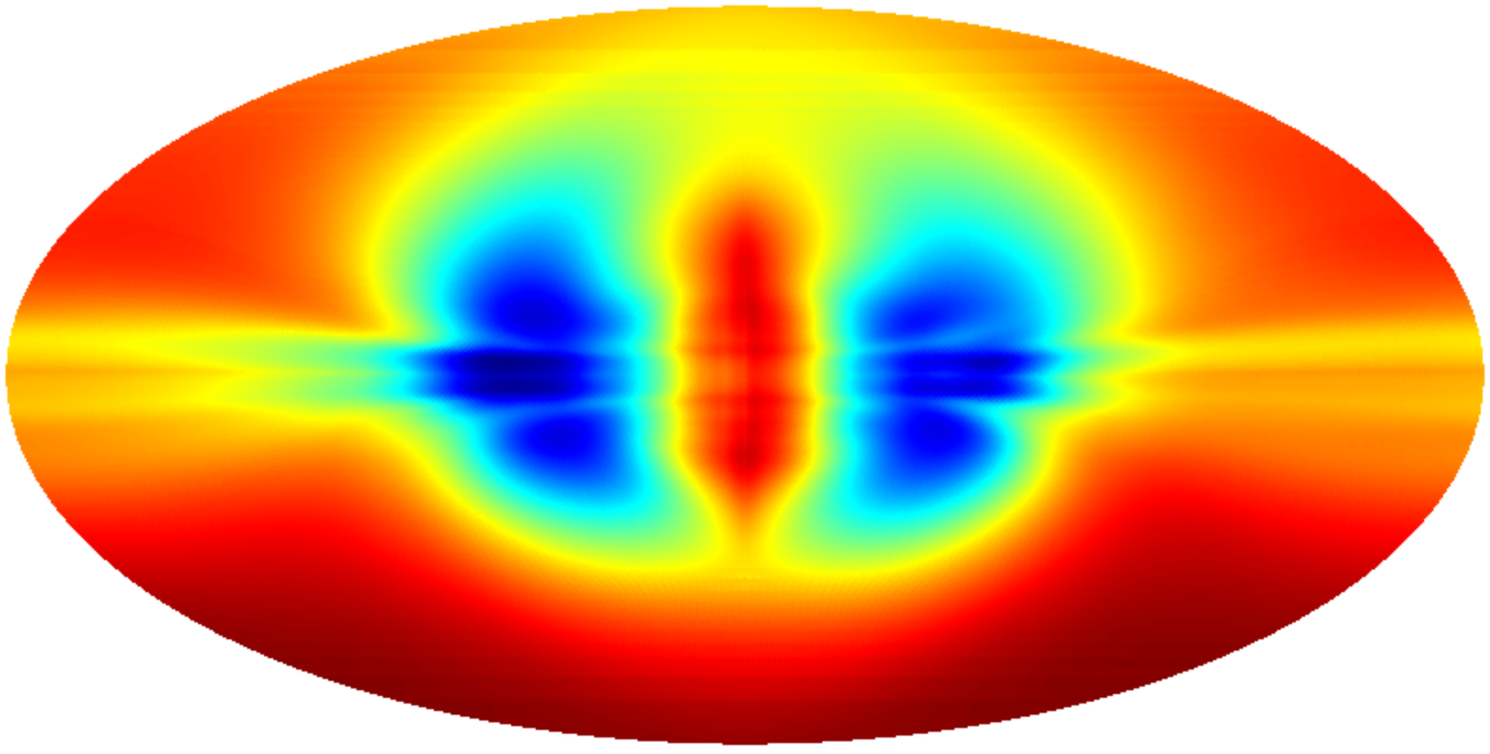
$\mathrm{GeV/cm^2/s/sr}$

Effect of B_{GC} on ICS



✓ Stronger B_{GC} makes cosmic ray electrons at the Galactic center lose energy via synchrotron more effectively than via ICS.

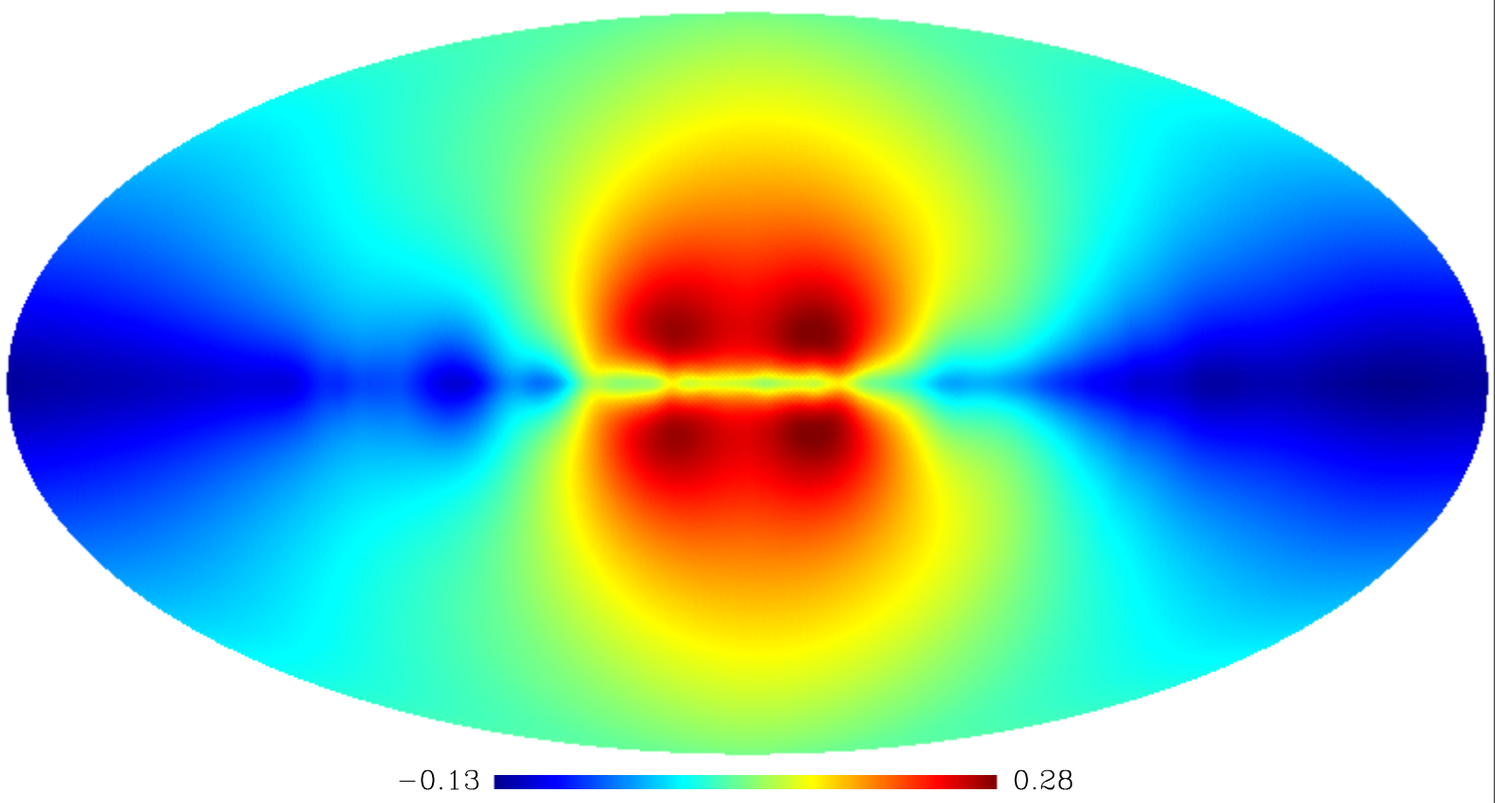
Low vs High Local Turbulence



$\mathrm{erg/cm^2/s/sr/Hz}$

← synchrotron relative difference

ICS relative difference →



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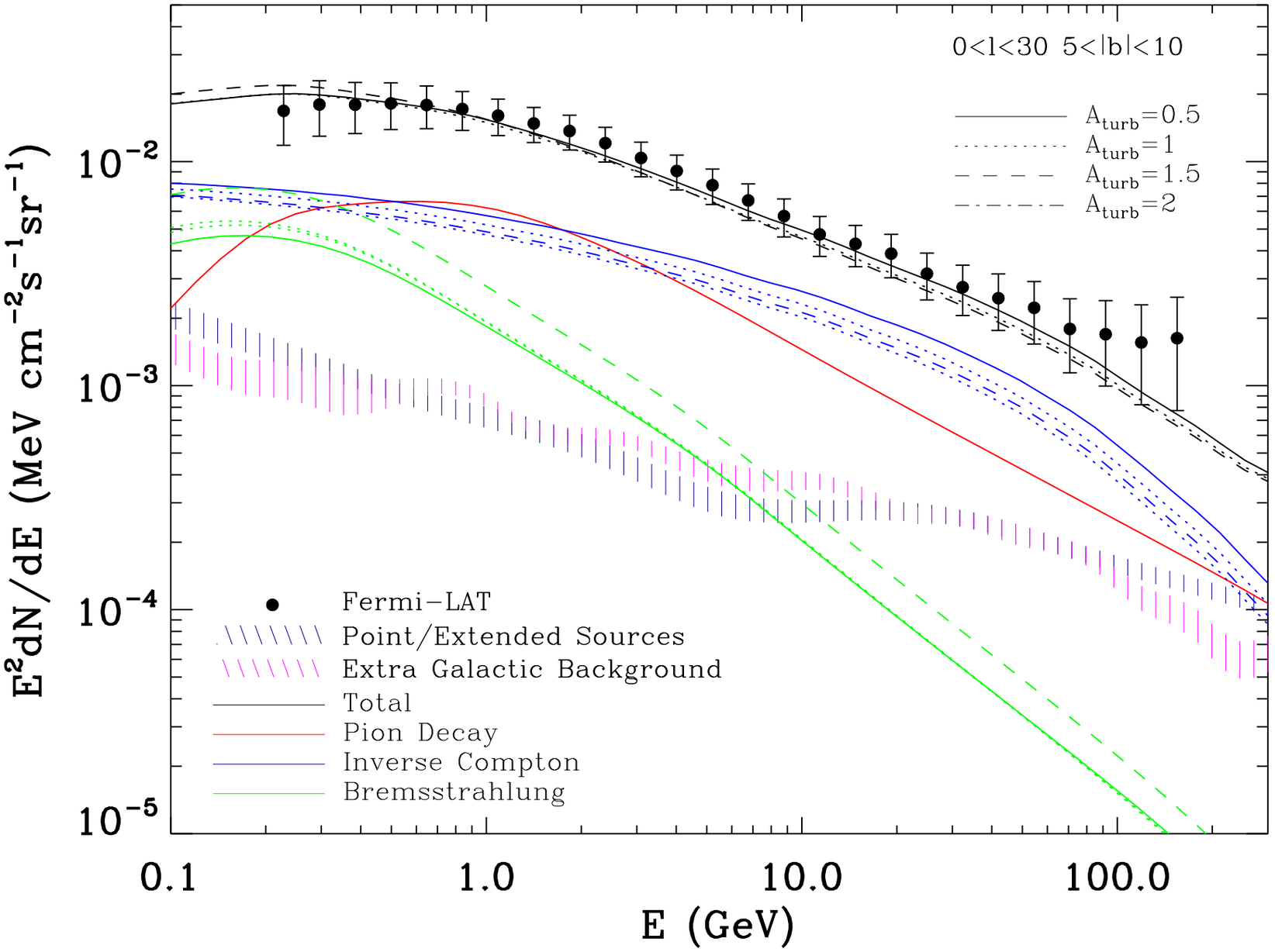

✓ Stronger local turbulence slightly weakens ICS emission over a large region of the sky.

Summary

✓ Local turbulence of the magnetic field can be constrained by local flux of leptons.

✓ Magnetic field structure can be probed and constrained by the morphology of the synchrotron emission.

✓ Strength of the magnetic field at the Galactic centre can be constrained by the spectrum of diffuse γ-rays in that region.

Thanks