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Spectrum of cosmic rays in the galactic disk

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See:1505.07601

Sources of Galactic cosmic rays ; APC, Paris - December 7-9, 2016

Cosmic rays spectrum

In a perfect world we would know 3D distribution of CRs in our galaxy.

<u>Why this is important?</u>

- nature of CR accelerators and accelerating mechnisms (SNRs ; acceleration on shocks?)
- Distribution of CR accelerators in space
- Allow diffusion studies (energy-dependent diffusion; magnetic fields)
- A way to validate CR propagation codes/strongly motivated input parameters for these codes/better gamma-ray diffuse background models
- ...

<u>Why it is not so trivial to measure it?..</u>

On Earth measurements of CRs – a direct way to get 0D (measurements in 1 point) information.
To get 2D information we need to study linearly-propagating products of CR/medium interaction products – photons.

<u>Number of caveats are on these ways:</u>

- All results strongly depend on the template for ISM/photon field density template
- Possibility to separate the contribution of unresolved gamma-ray sources
- Blur of limited sensitivity does not allow to measure CRs distribution around potential accelerators (see however HESS collaboration, Nature'2016)
- On larger scales picture is blured by energy-dependent CR propagation
- Are we living in a peculiar location? Possible bias from nearby source(s) of CRs...

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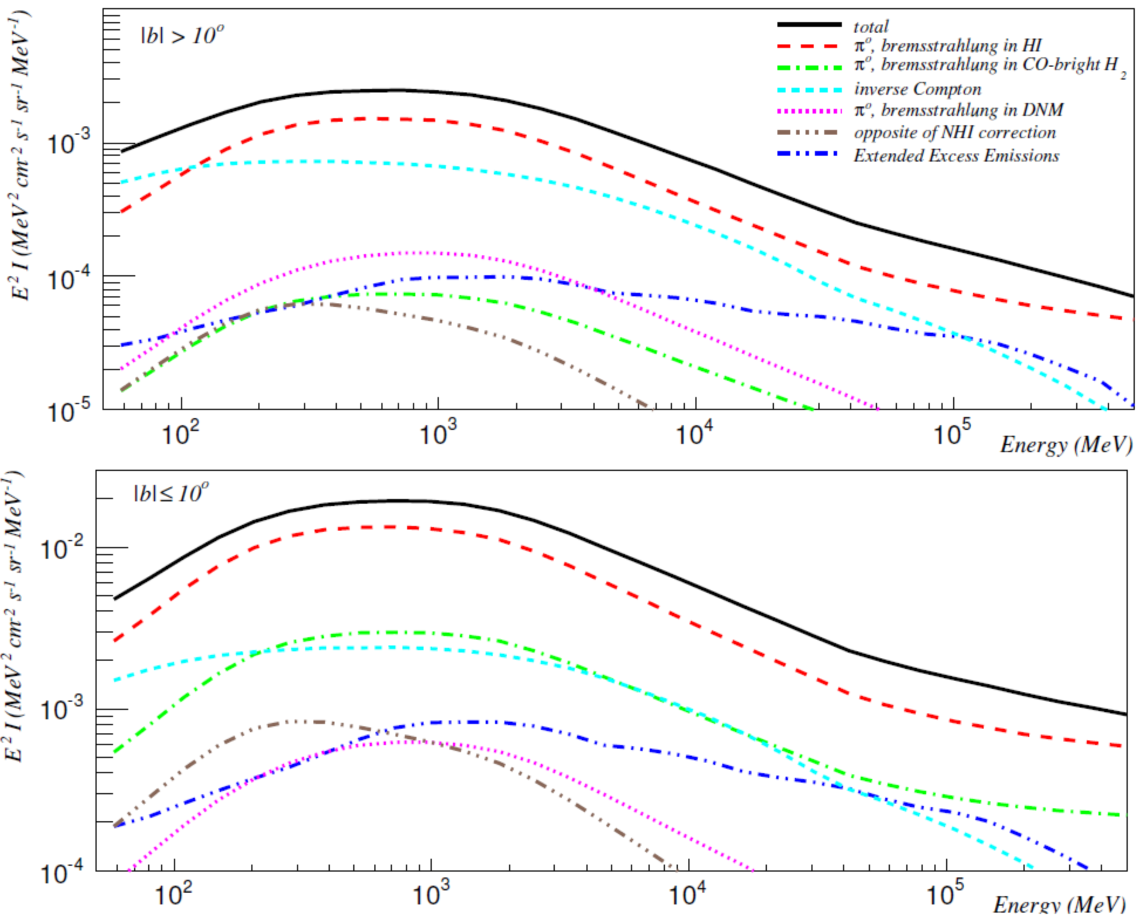
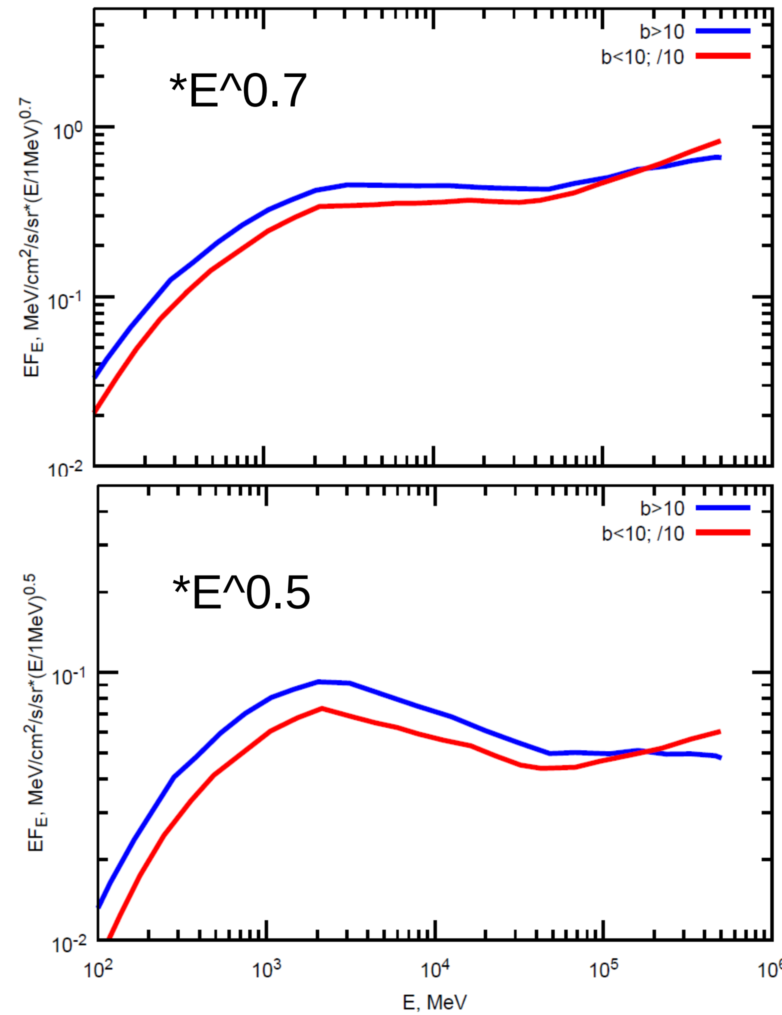
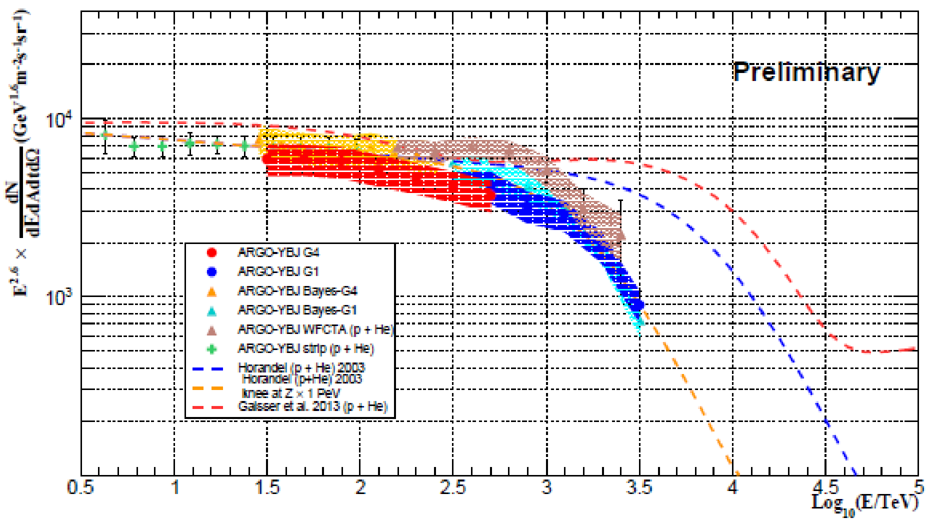
Our galaxy: TWO broad regions



FERMI/LAT collaboration: 1602.07246

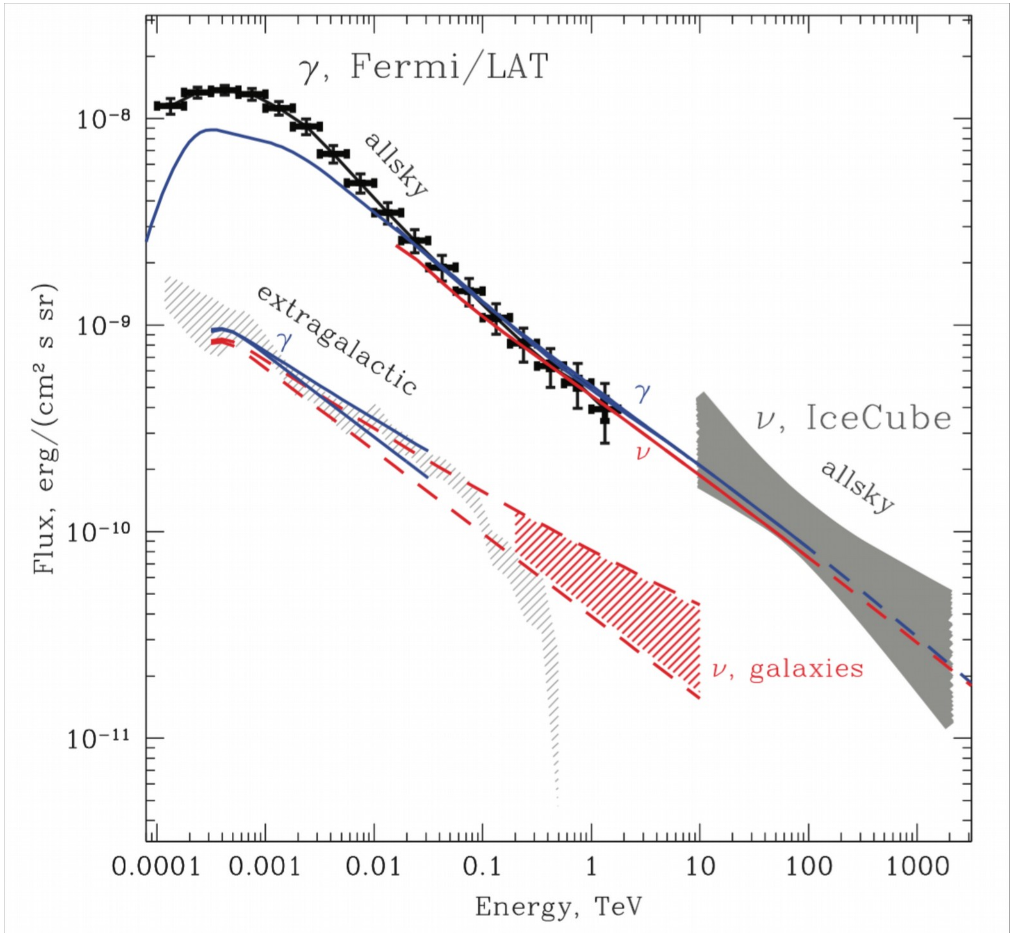


<u>Non-trivial:</u> The index reported by the FERMI/LAT collaboration is ~2.5 – 2.4 @>10 GeV energies, significantly harder, than measured localy spectrum of CRs (2.7).



ARGO-YBJ collaboration: 1503.09102

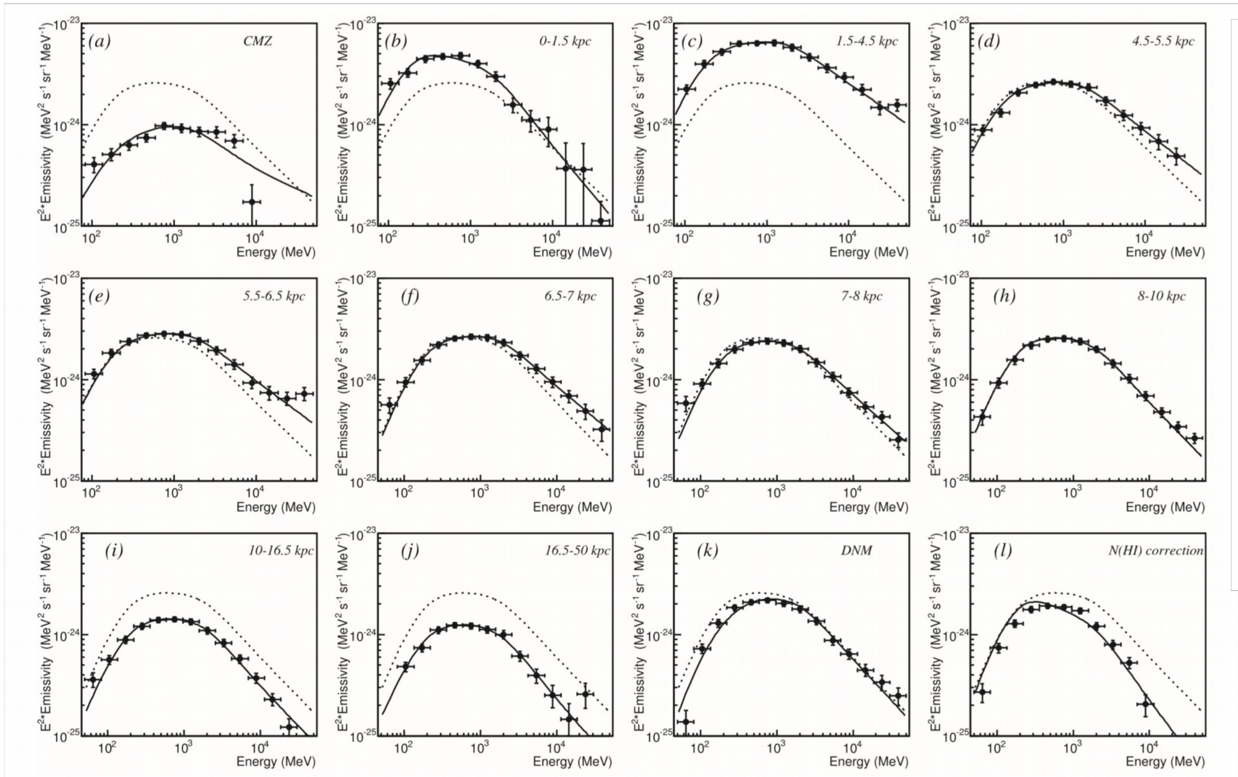
Best-fit Γ = 2.63 +/- 0.06 is consistent with FERMI



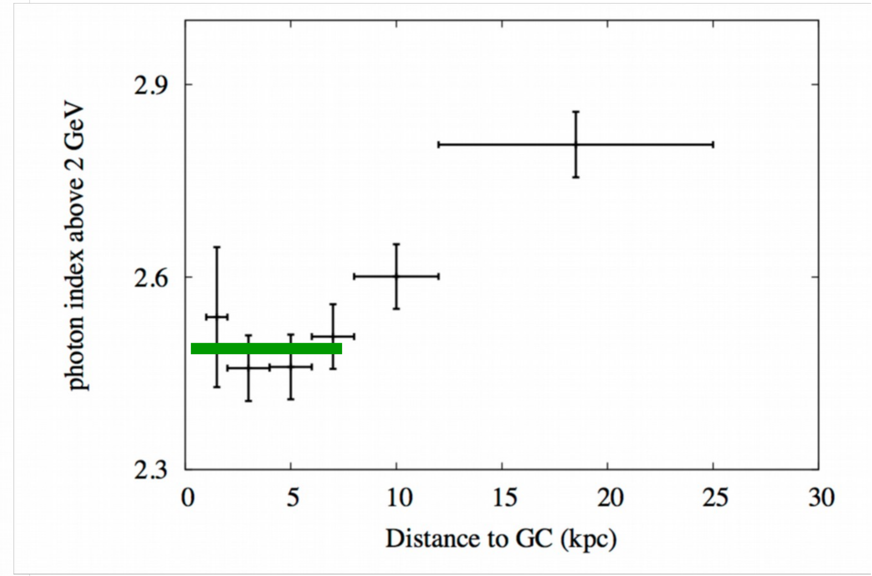
Neronov et al: 1307.2158

<u>Non-trivial:</u> The results of ARGO-YBJ and IceCube are consitent with the spectrum 2.5 seen by FERMI.

Our galaxy: more regions



FERMI/LAT collaboration: 1602.07246



Yang,Aharonian,Evoli:1602.04710

<u>Non-trivial:</u> Spectrum of the outer galaxy is significantly softer than the inner one. Inner galaxy's spectrum is consistent with 2.5.

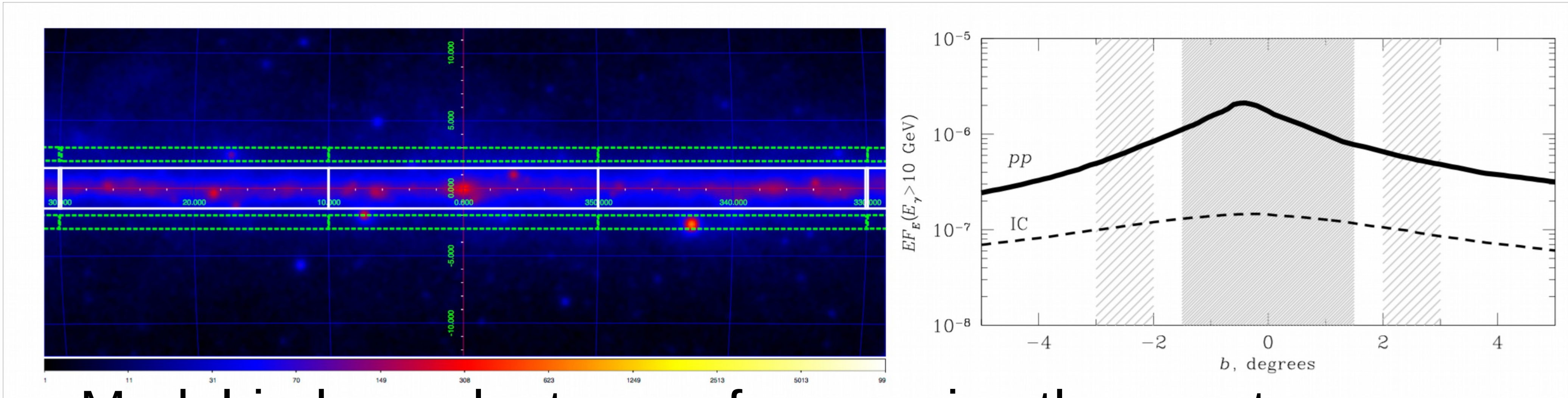
Universal slope 2.7 for CRs in our Galaxy is no more the case!

Hard CR spectrum measurements support a model proposed in Neronov&Malyshev:1505.07601 for a set of objects:

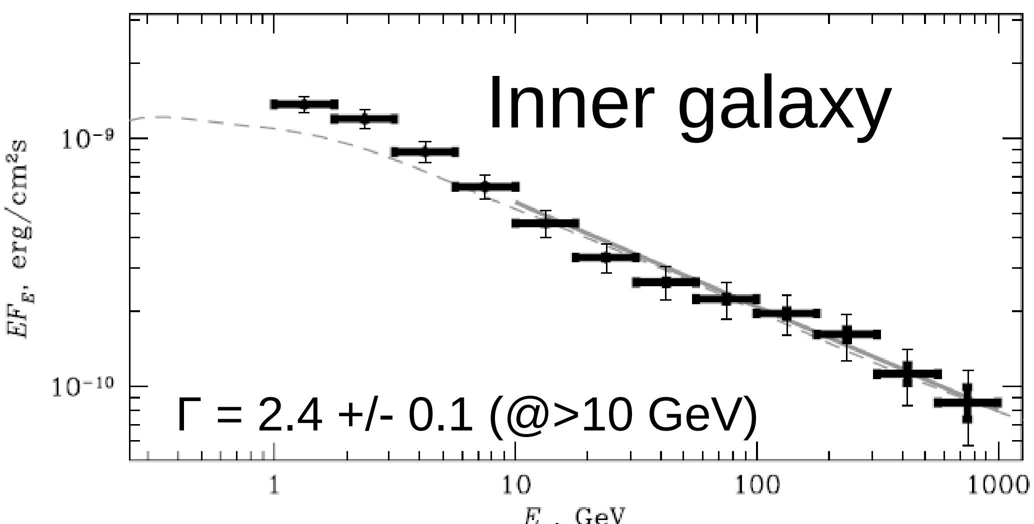
- The hard slope (Γ_{CR} = 2.4 – 2.5) observed in CR-accelerating objects is "universal" for our Galaxy, independent on the position of the observer.
- This slope originates from a standard injection CR spectrum Γ_{inj} = 2 – 2.1 as CRs are propagating through the galactic magnetic field, $\Gamma_{CR} = \Gamma_{inj} + \delta$, with δ related to the slope of turbulence power spectrum, δ =1/2 for Iroshnikov-Kraichnan and δ=1/3 for Kolmogorov turbulences.
- The difference with the observed locally CR spectrum slope (2.7) is explained by a presence of nearby CR-accelerating source(s). Single source, injected 10^{50} erg can significantly alter the CR density in $(0.1\text{pc})^3$ for 10^6yrs timescale.

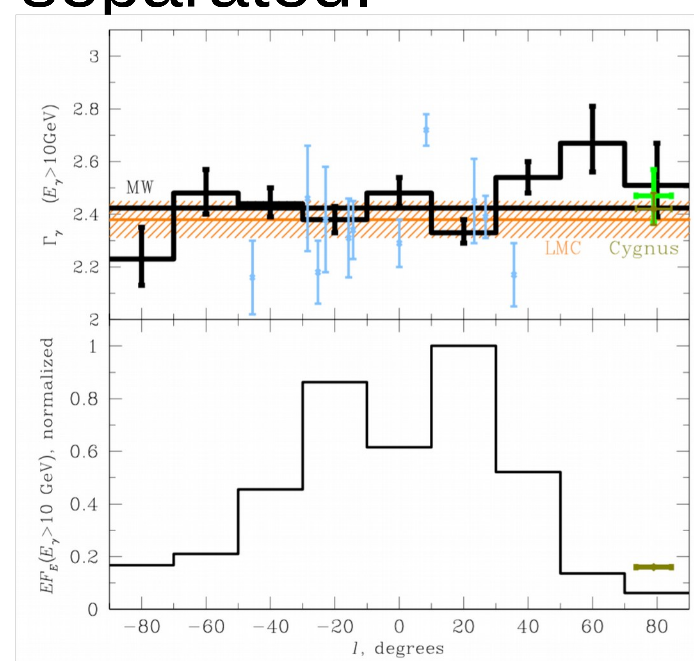
Our galaxy: individual regions

Inner galaxy (|l|<90 ; |b|<1.5)



Model-independent way of measuring the spectrum.
Contributions from pp and IC could be separated.





Neronov&Malyshev:1505.07601

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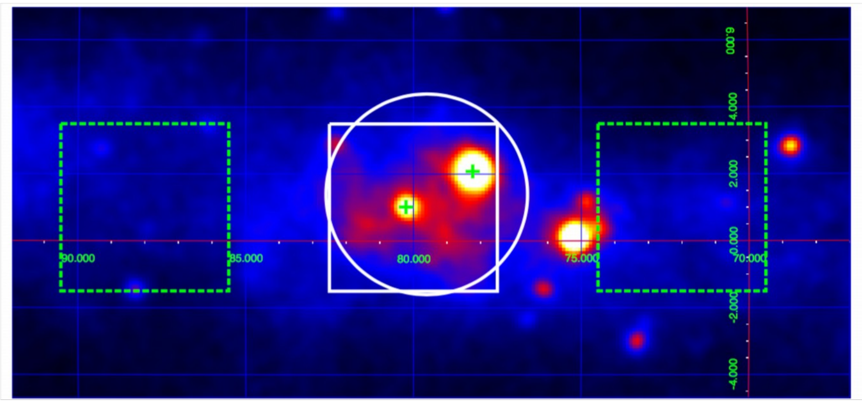
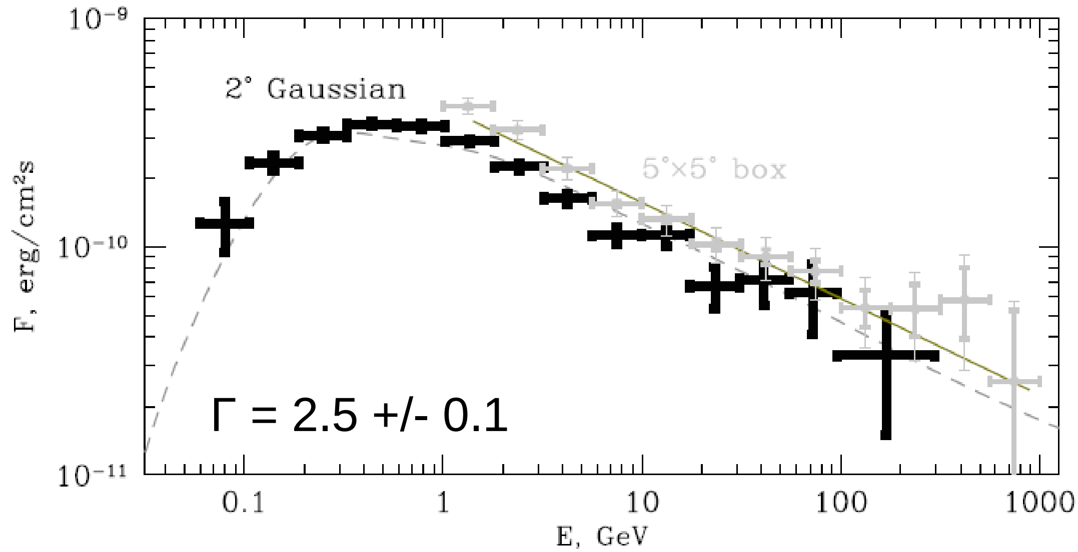
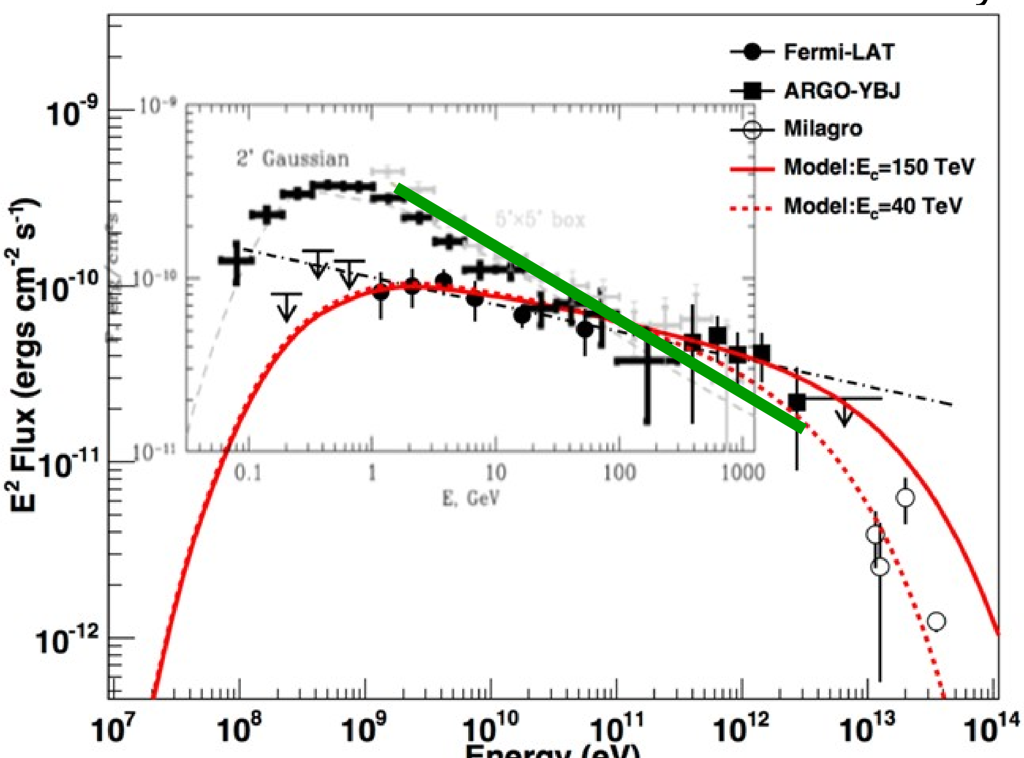
Our galaxy: individual regions

Cygnus cocoon.





Neronov&Malyshev:1505.07601



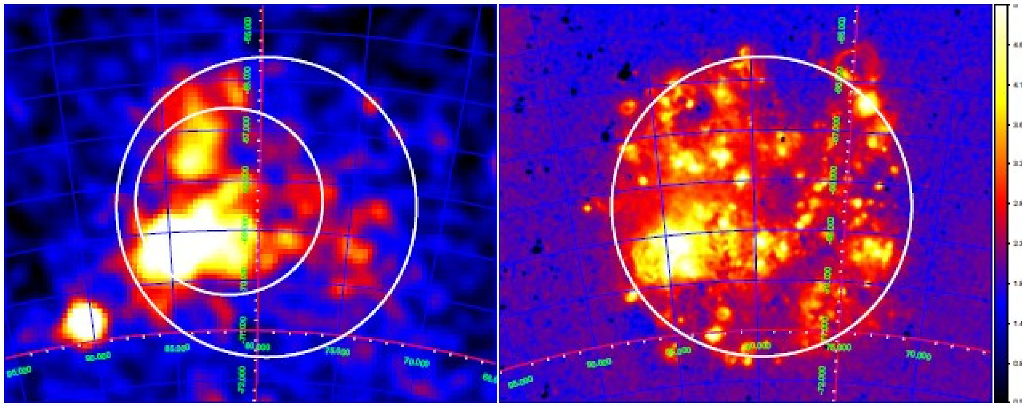
Fermi-LAT:2011; ARGO-YBJ:2014

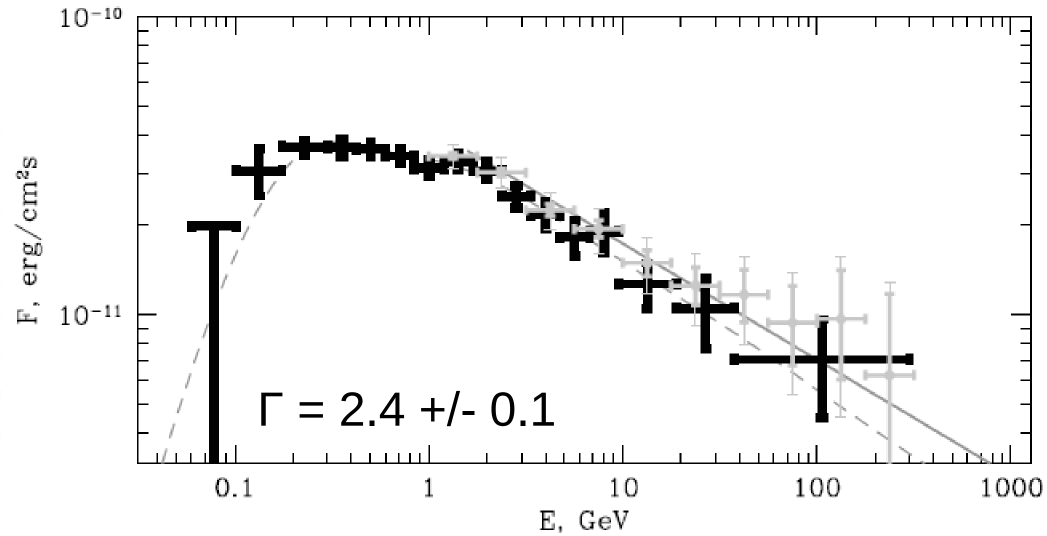
Bright, although complex region with recent star-formation activity. Previous results of FERMI/LAT and ARGO-YBJ collaborations.

Good agreement between aperture and fitting approaches.

Not Our galaxy: individual regions

LMC.





Bright, off galactic-plane region. A number of sub-structures.
Several templates for LMC brightness profiles tested.

Good agreement between aperture and fitting approaches.

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Summary:

- Spectrum of CRs deduced from FERMI/LAT observations of large MW regions and certain CR-accelerating regions is significantly harder than one observed on the Earth (2.4 – 2.5 @>10GeV vs. 2.7)

- This can be explained by a standard acceleration of CR on shocks with the spectral slope of 2 – 2.1 with further softening (by 0.5 – 0.3) due to propagation in the magnetic field

- Observed locally softer spectrum can originate from the activity of one or several nearby CR-accelerating sources.

- Detection of hard spectrum in Cygnus Cocoon and certain others regions makes these regions to be good CR-accelerators candidates.