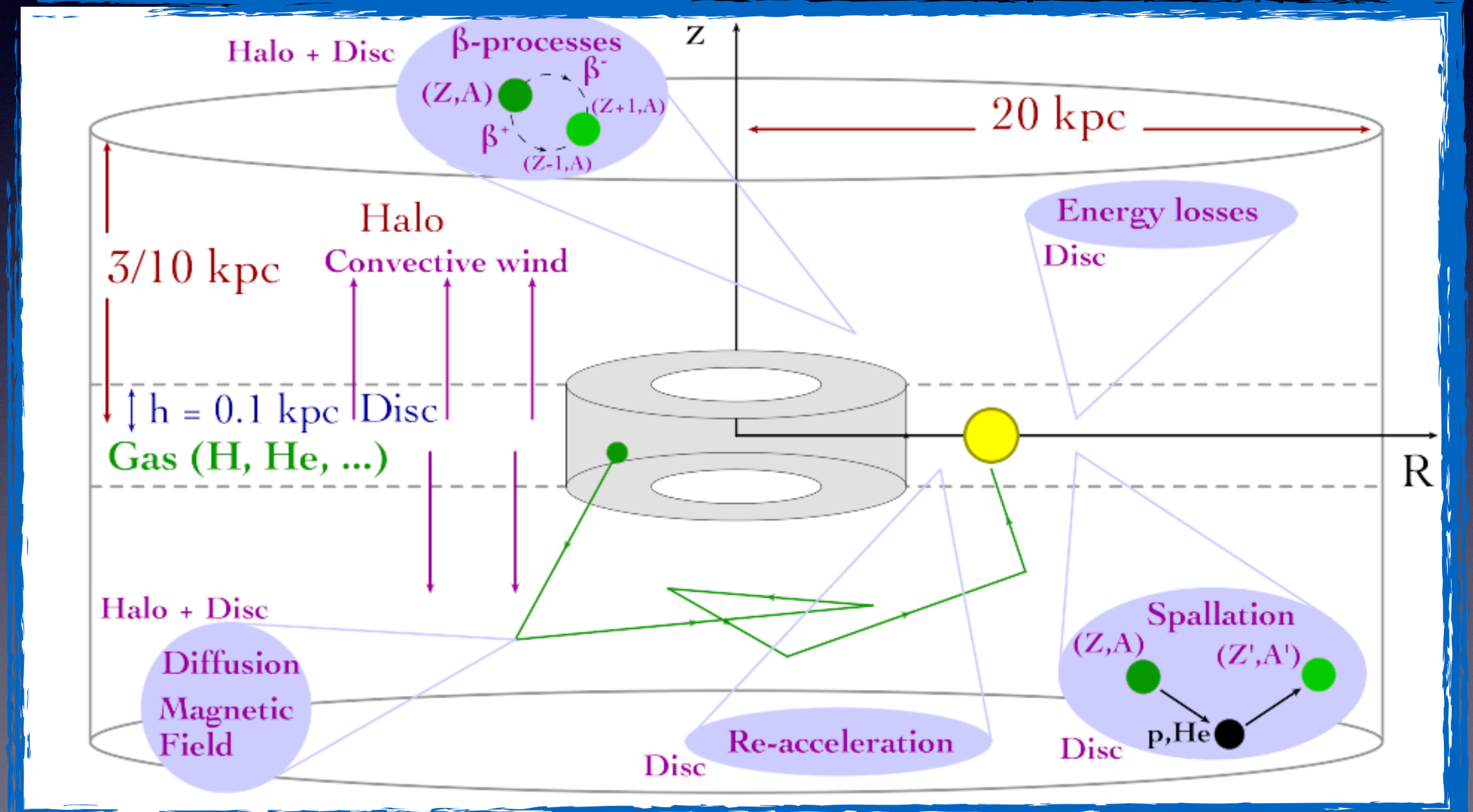
Gamma rays as a probe for non-standard diffusion properties

Alfredo Urbano
CERN, Theory division

with D. Gaggero, M. Valli, P. Ullio
Phys.Rev. D91 (2015) 8, 083012 (arXiv:1411.7623)

Cosmic-ray propagation



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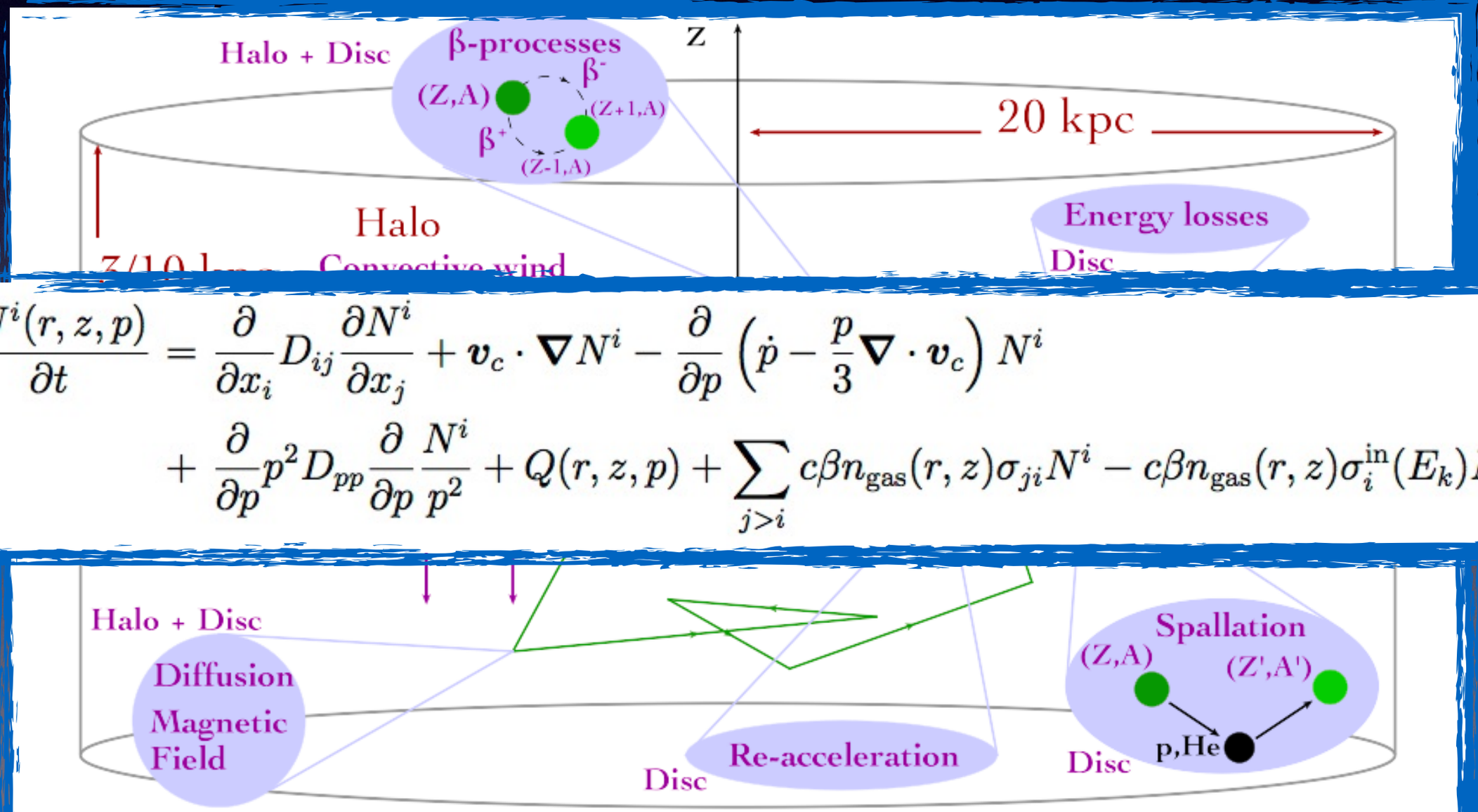

$$\frac{\partial N^i(r,z,p)}{\partial t} = \frac{\partial}{\partial x_i} D_{ij} \frac{\partial N^i}{\partial x_j} + \boldsymbol{v}_c \cdot \boldsymbol{\nabla} N^i - \frac{\partial}{\partial p}\left(\dot{p} - \frac{p}{3}\boldsymbol{\nabla}\cdot\boldsymbol{v}_c\right) N^i$$
$$+ \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{N^i}{p^2} + Q(r,z,p) + \sum_{j>i} c\beta n_{\rm gas}(r,z)\sigma_{ji} N^i - c\beta n_{\rm gas}(r,z)\sigma_i^{\rm in}(E_k) N^i$$

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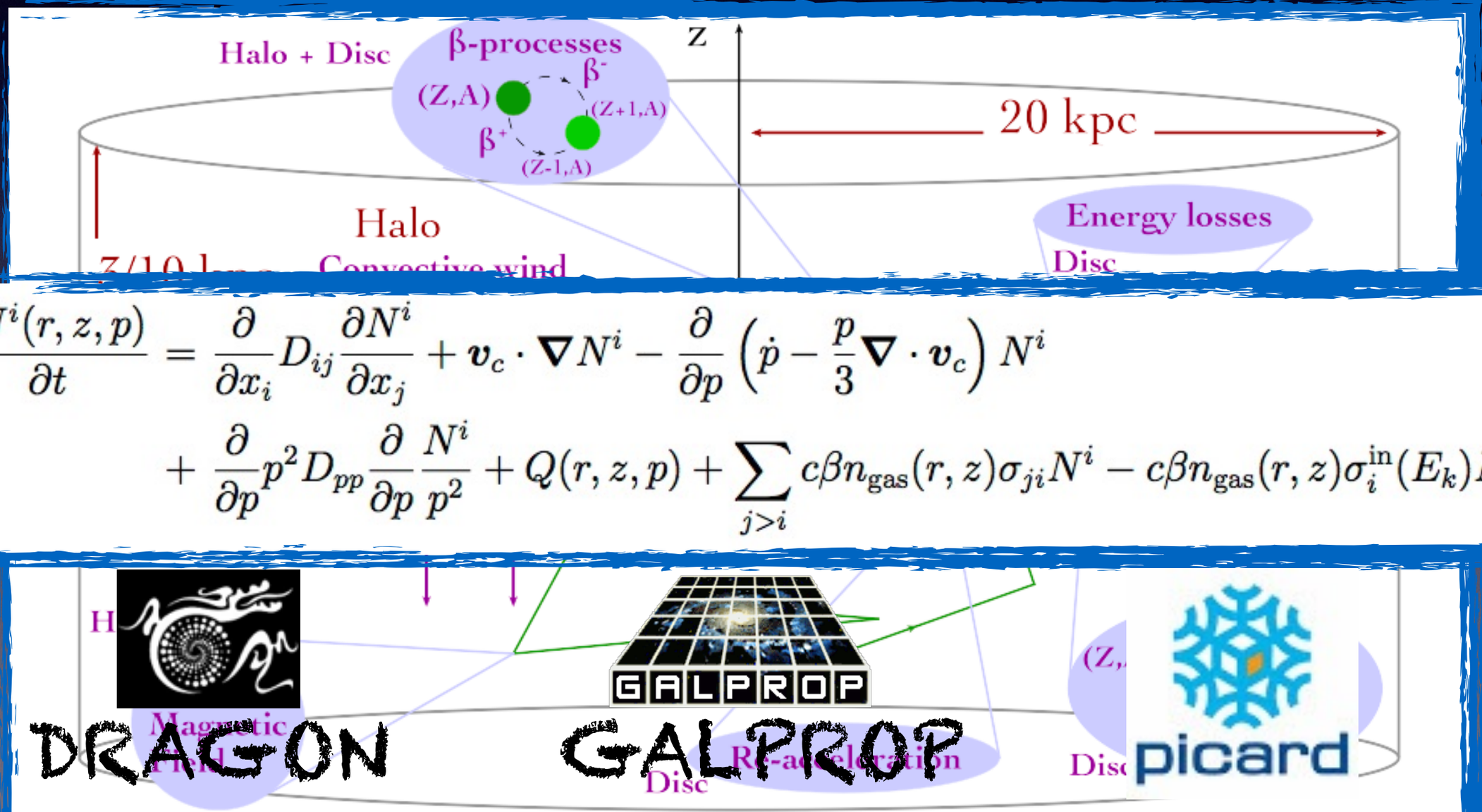

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DRAGON GALPROP picard

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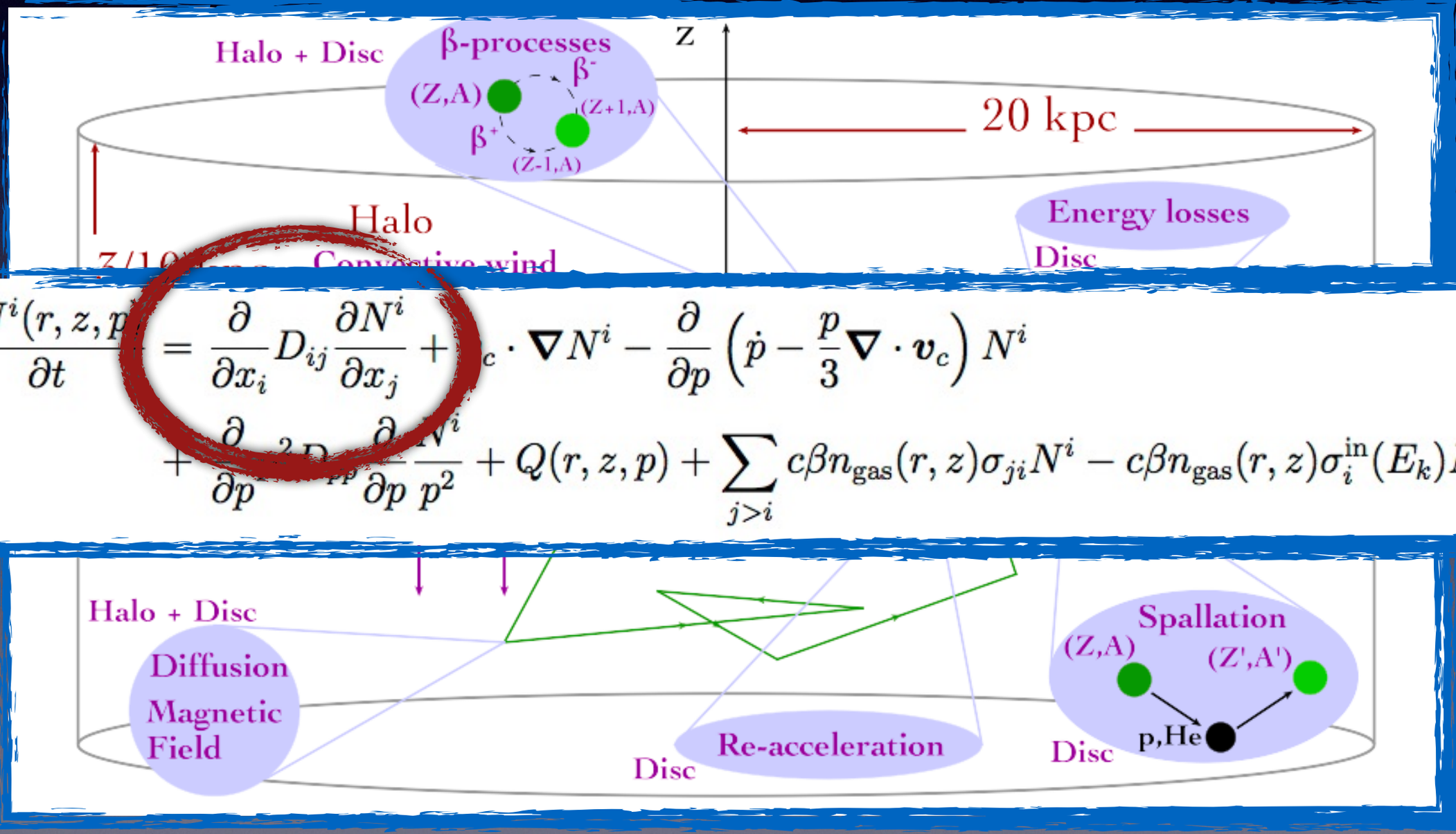

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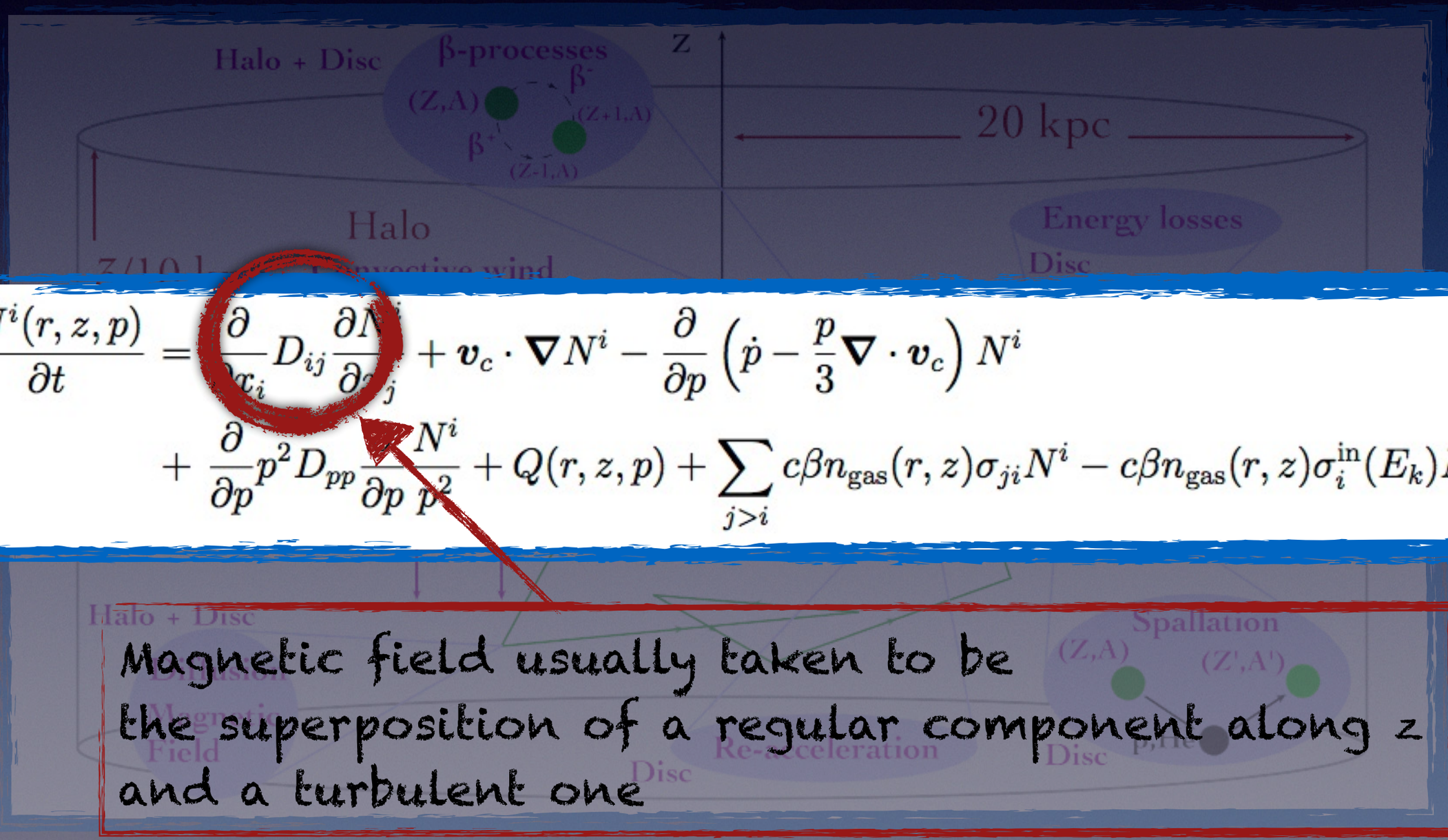

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Magnetic field usually taken to be the superposition of a regular component along z and a turbulent one

Diffusion

Injection spectrum

$$\frac{dN}{dE} \sim E^{-\gamma}$$

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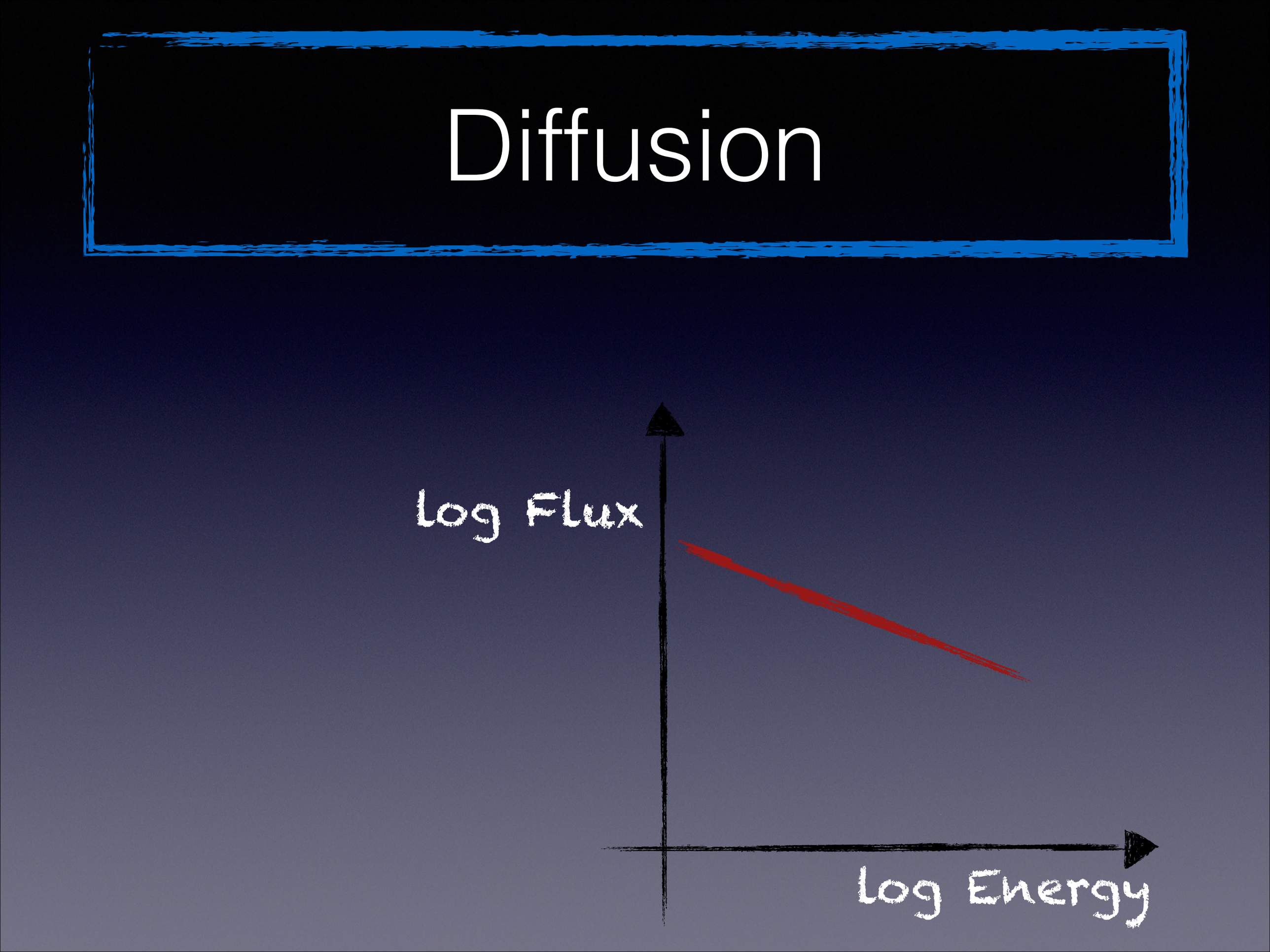
$$D_0 \sim 10^{28}\ \mathrm{cm}^3/\mathrm{s}$$

$$E_0 \sim \mathrm{GeV}$$

Related to the turbulence of the magnetic field

Diffusion



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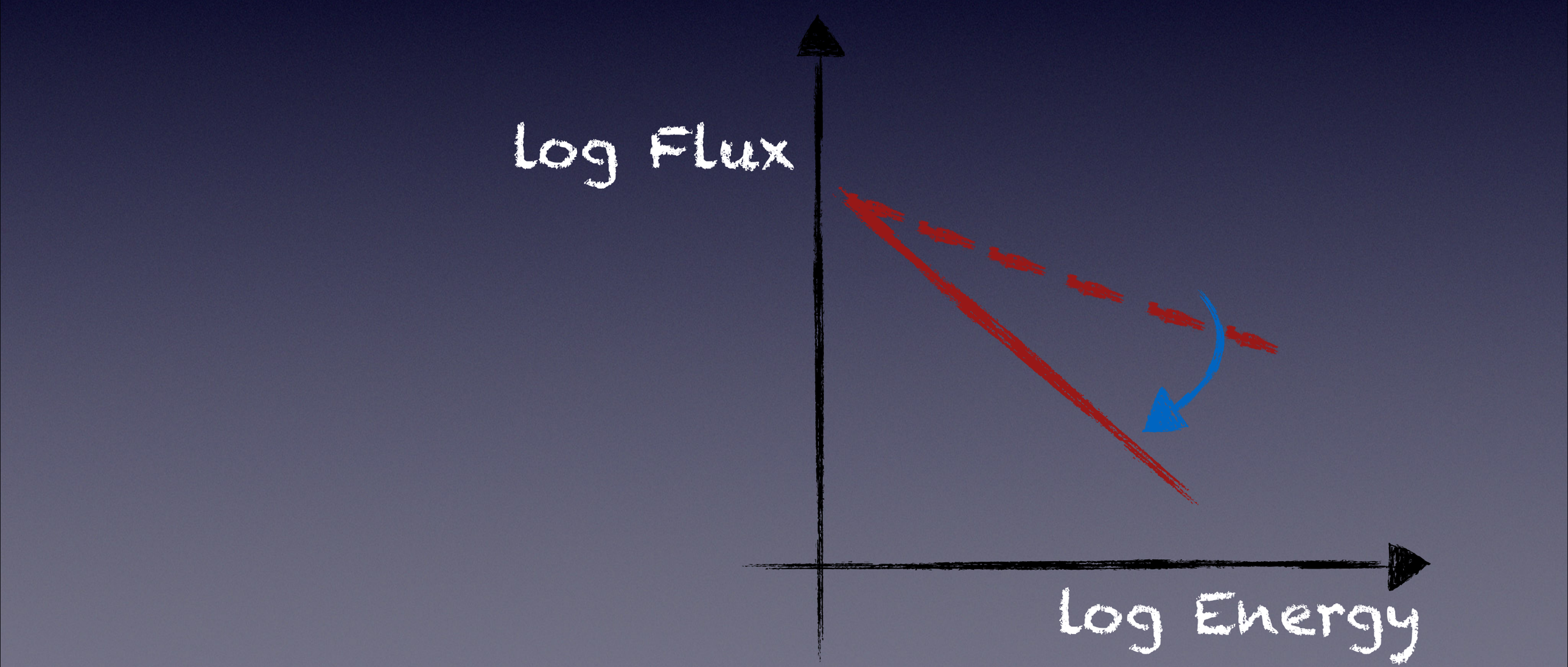

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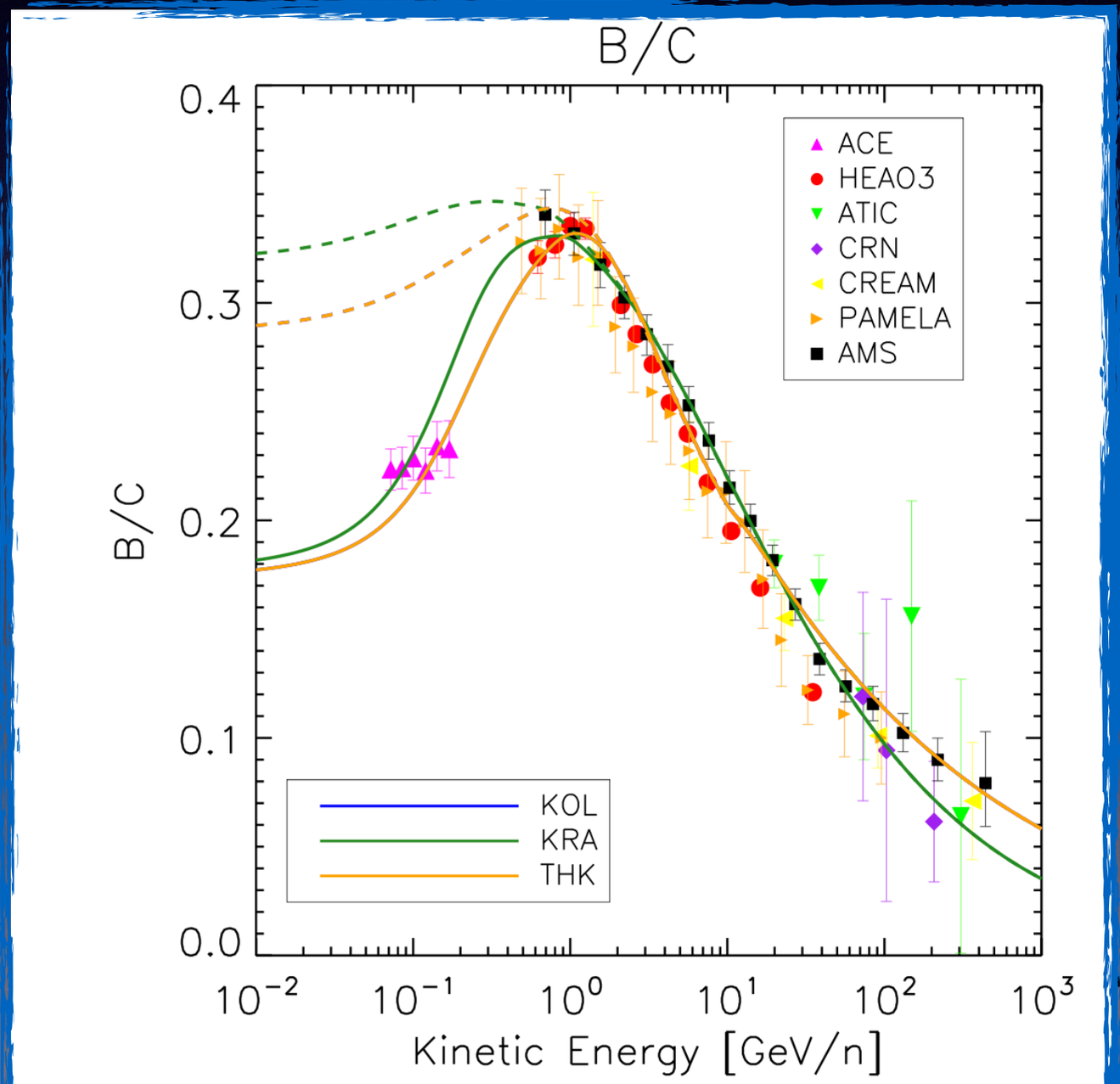
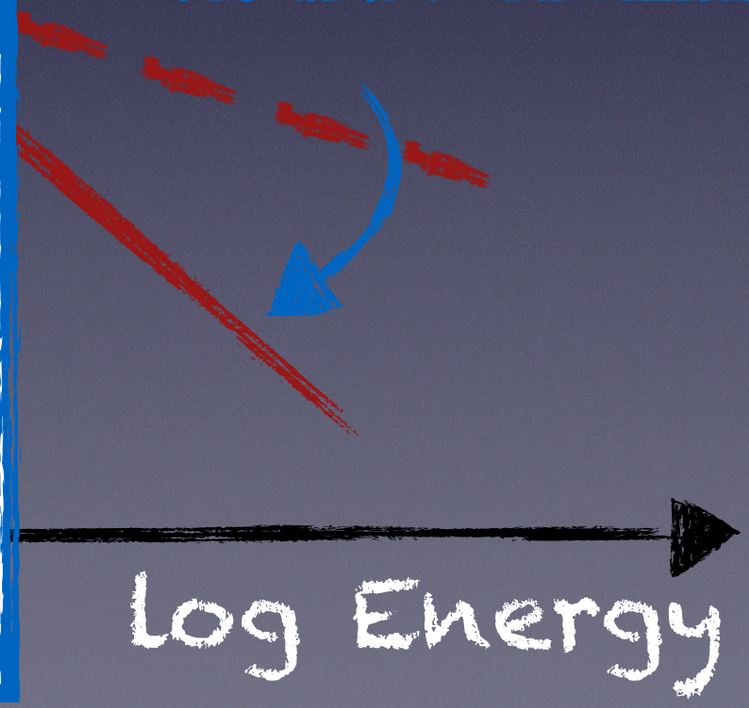


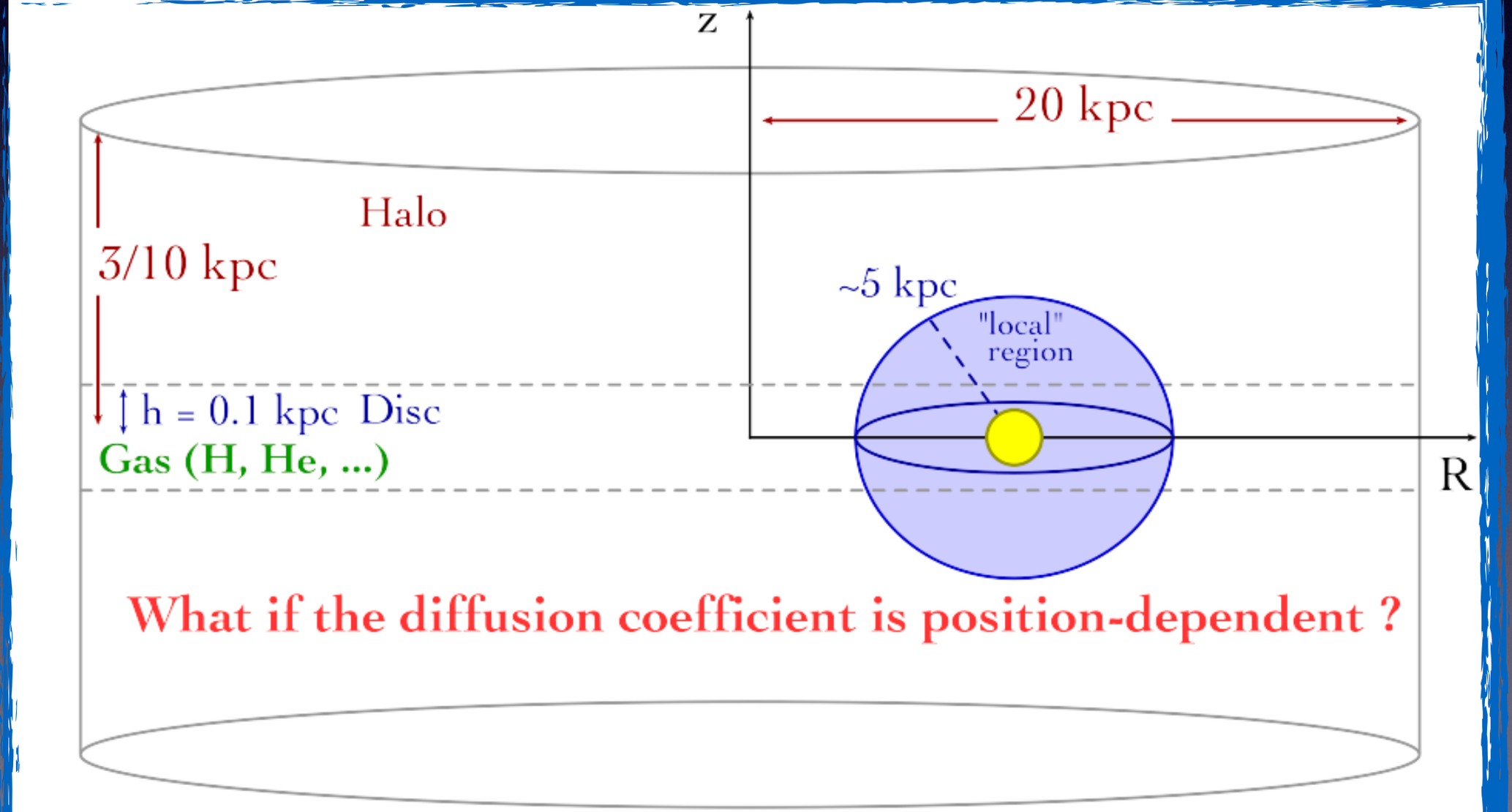
At high energies B/C ratio mostly shaped by the slope of the diffusion coefficient



What if the diffusion coefficient is position-dependent ?

Why is this effective description so good ?

What if the diffusion coefficient is position-dependent ?



What is we use gamma rays ?

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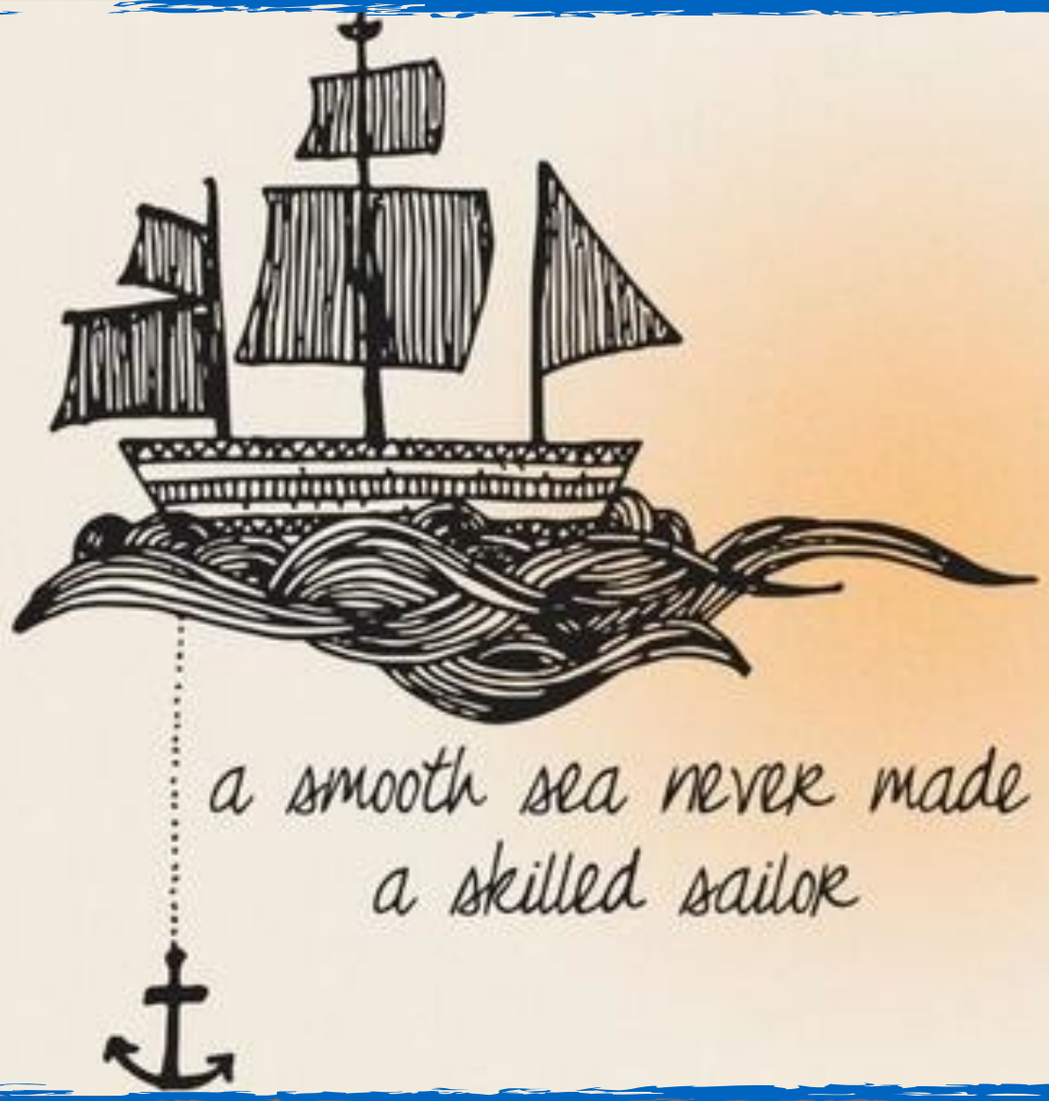


a smooth sea never made
a skilled sailor

Diffuse emission

Incident particles: cosmic-ray propagation

Cosmic-ray proton

Proton at rest in the IM

Cosmic-ray proton/electron

Proton at rest in the IM

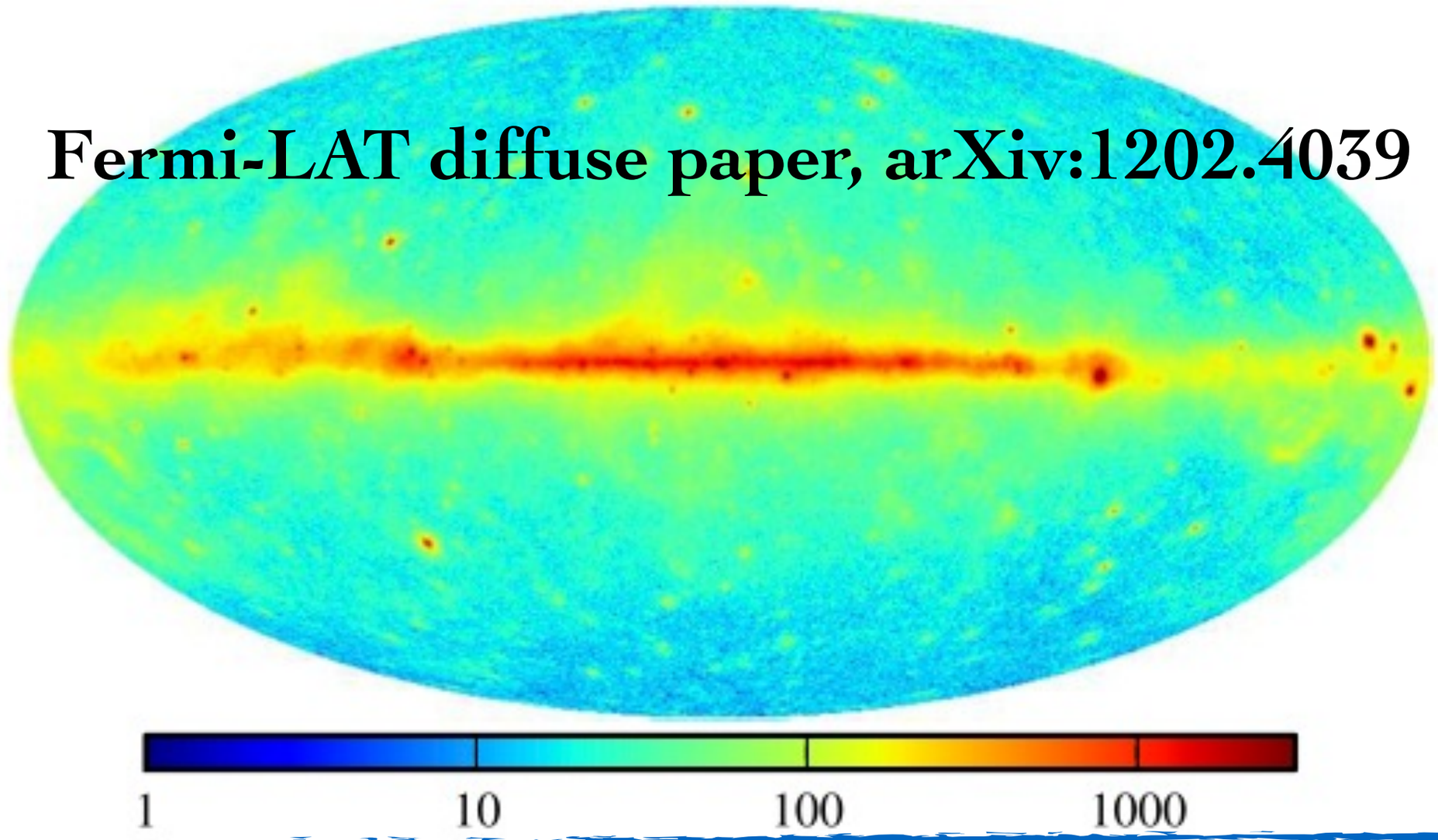
Cosmic-ray electron

Low-energy photon from the ISRF

Emitting targets: gas column density and ISRF

Diffuse emission

Fermi-LAT diffuse paper, arXiv:1202.4039



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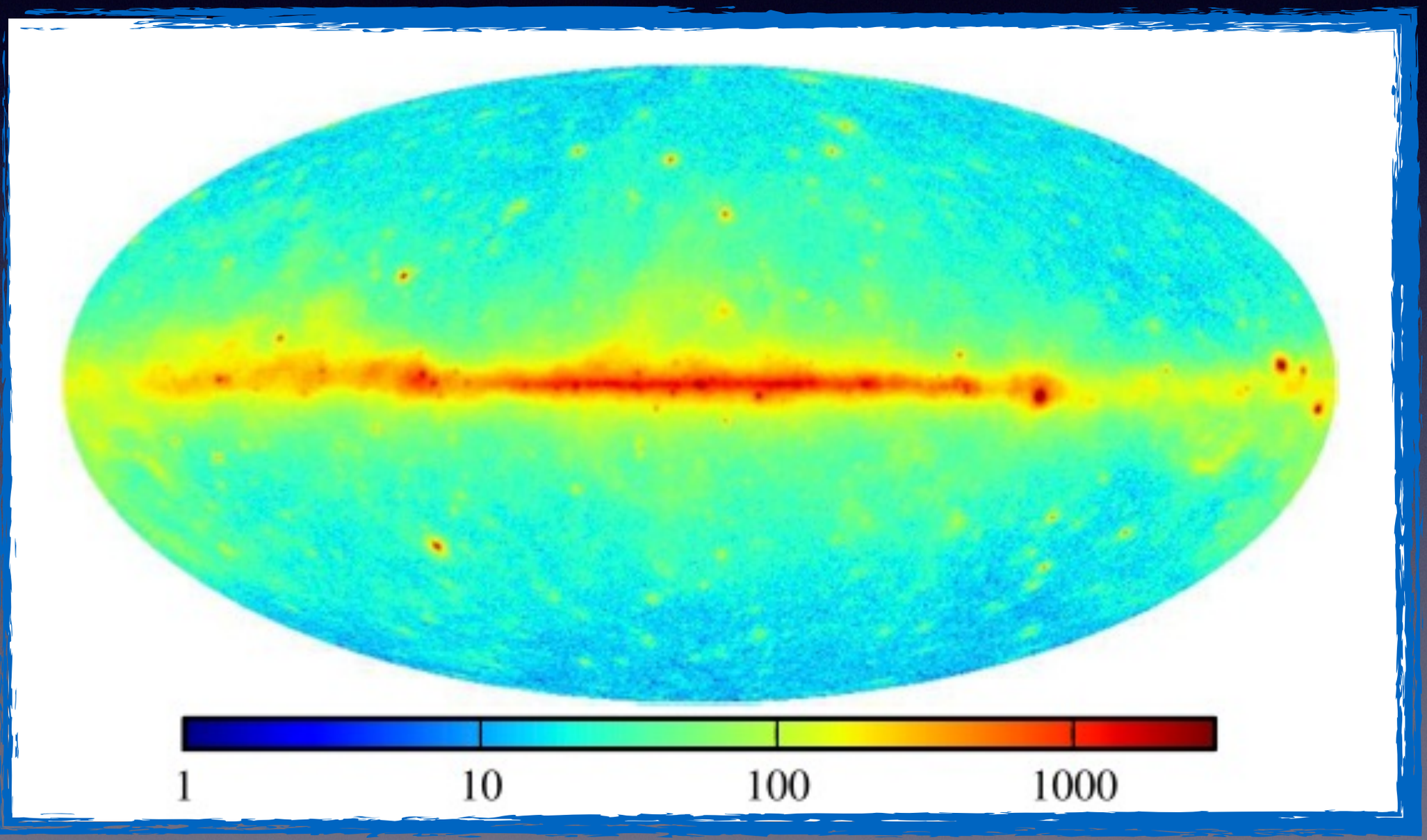

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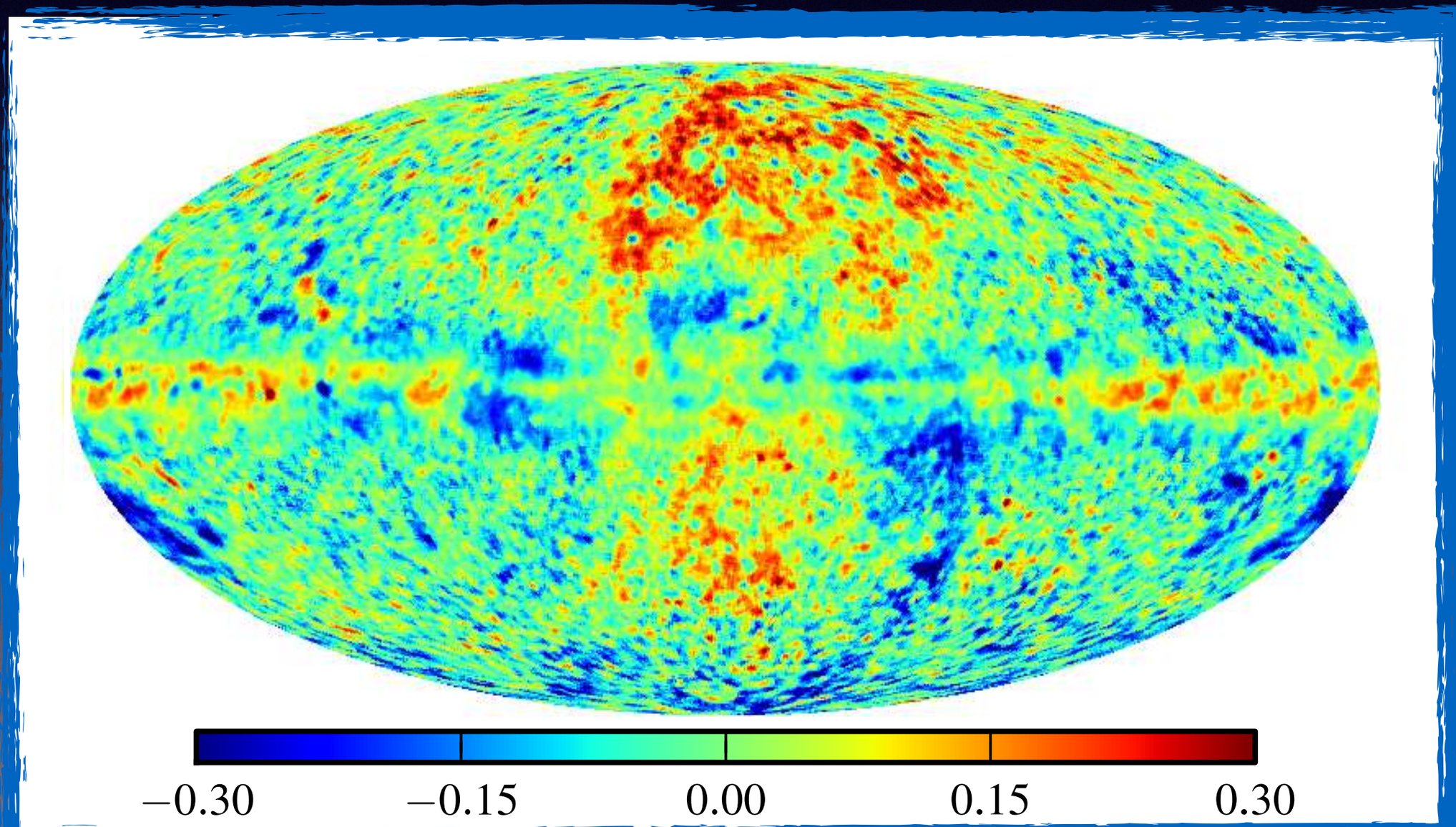

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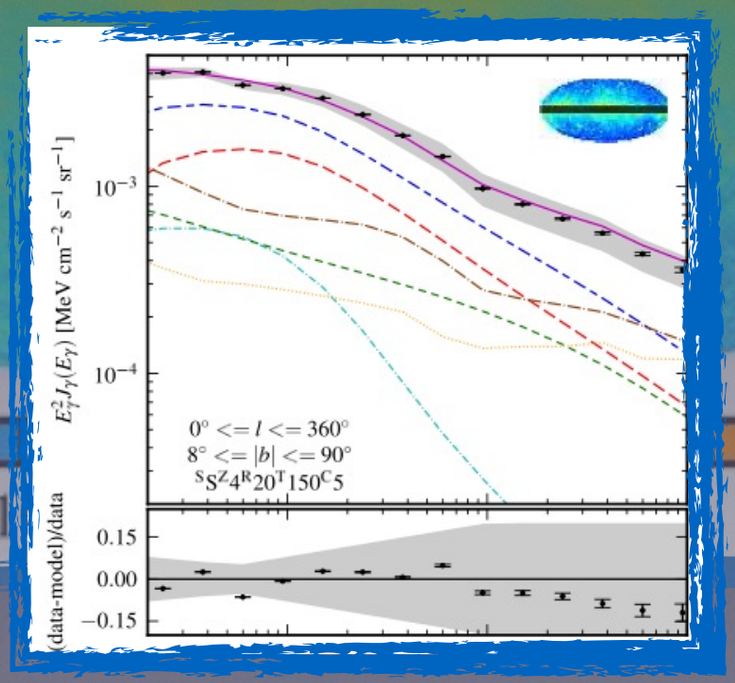

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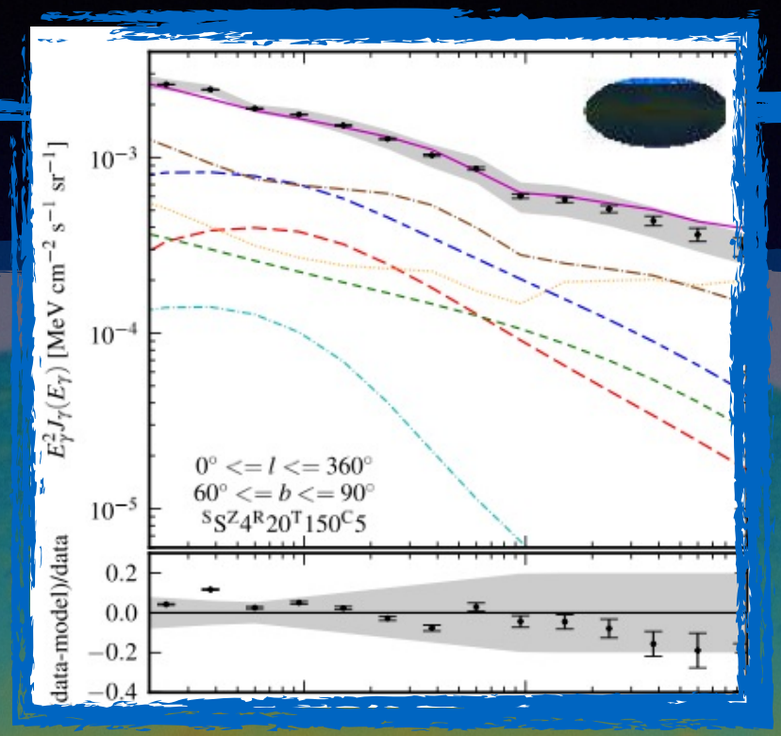

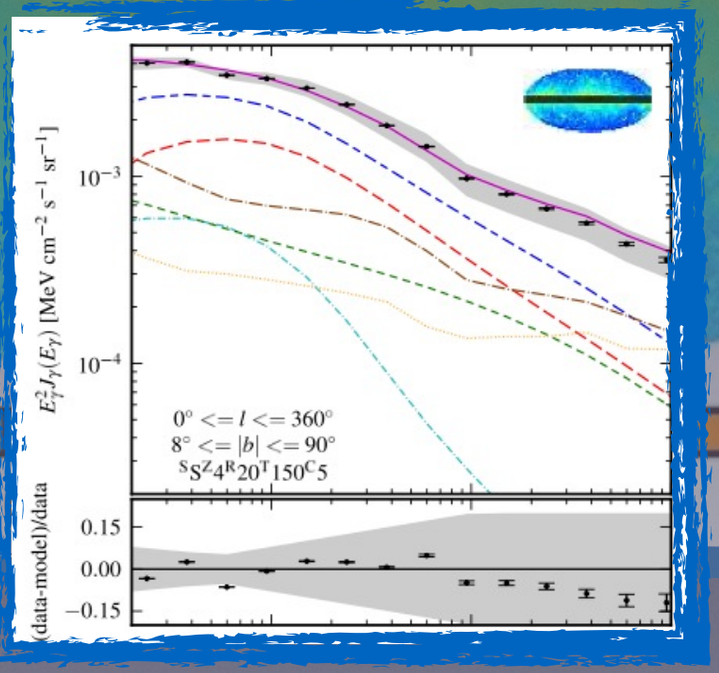

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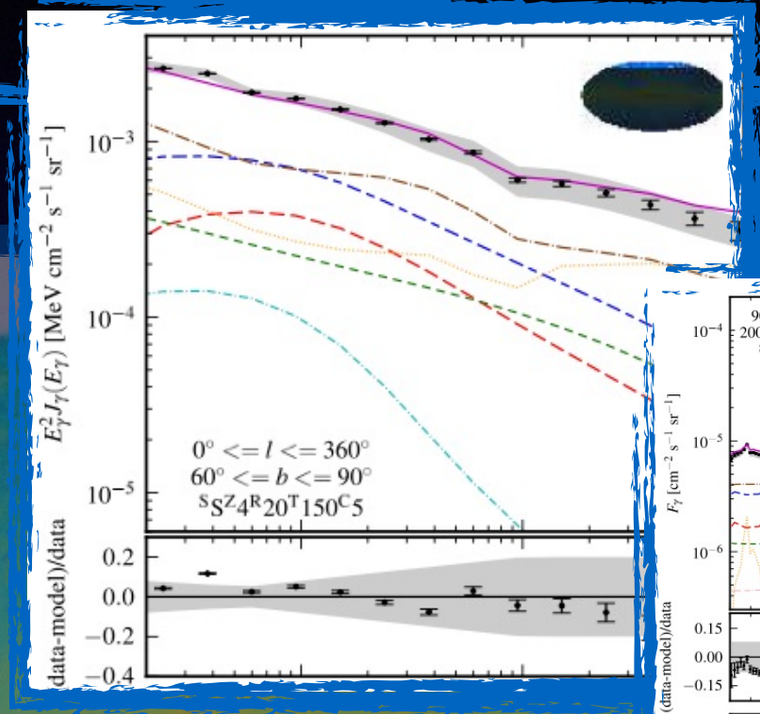

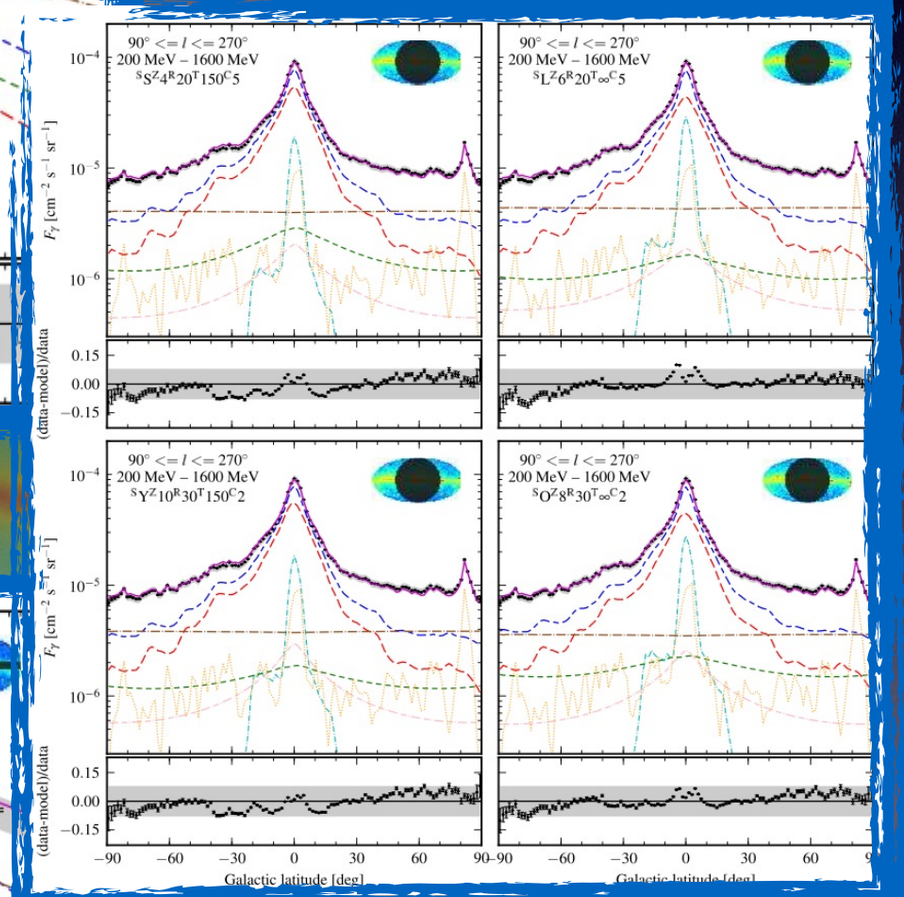

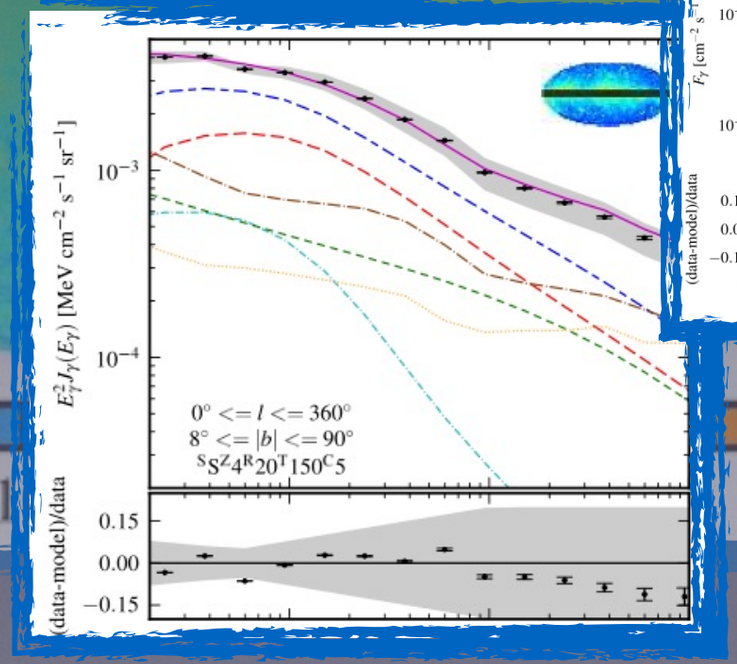

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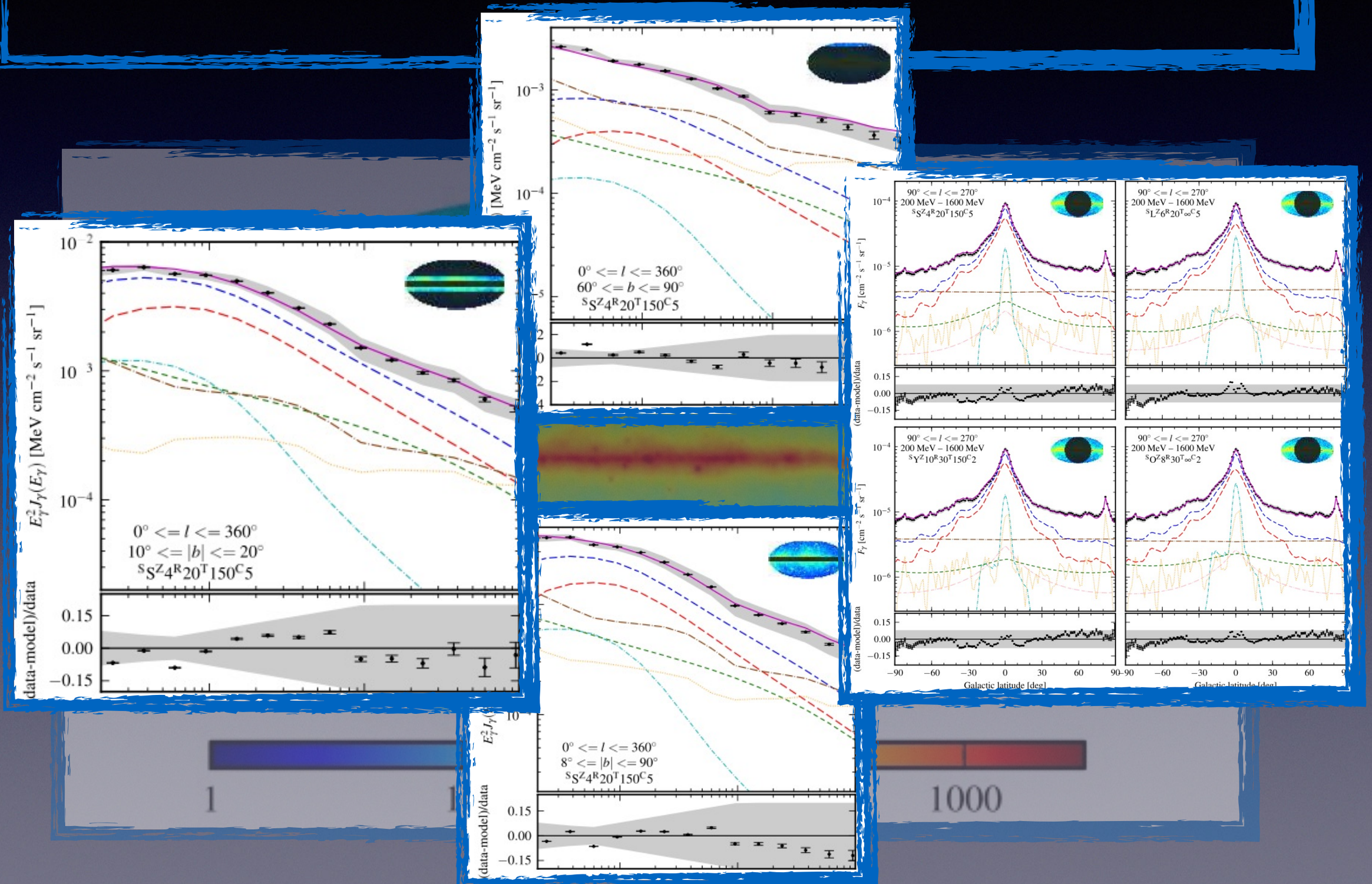

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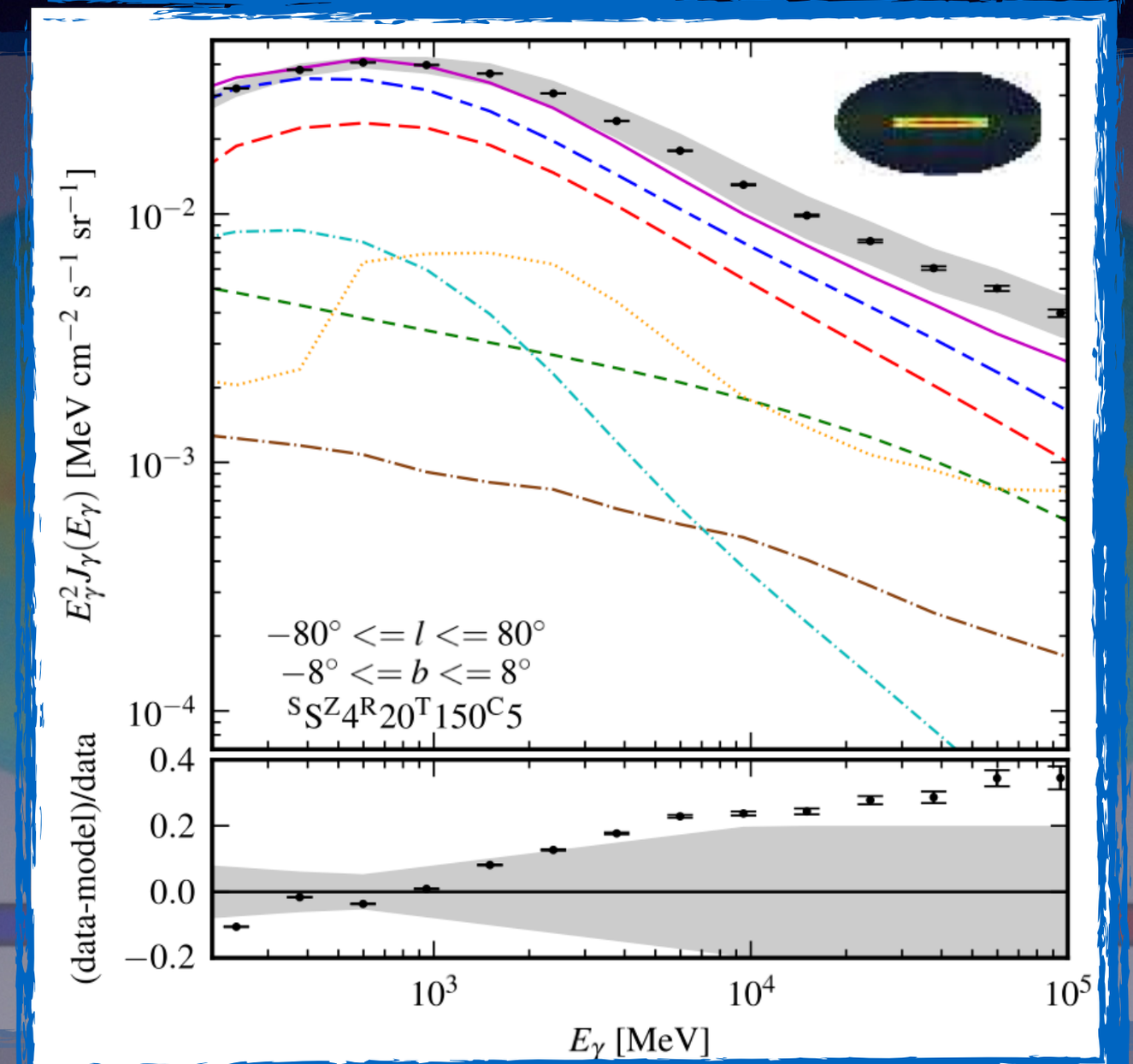

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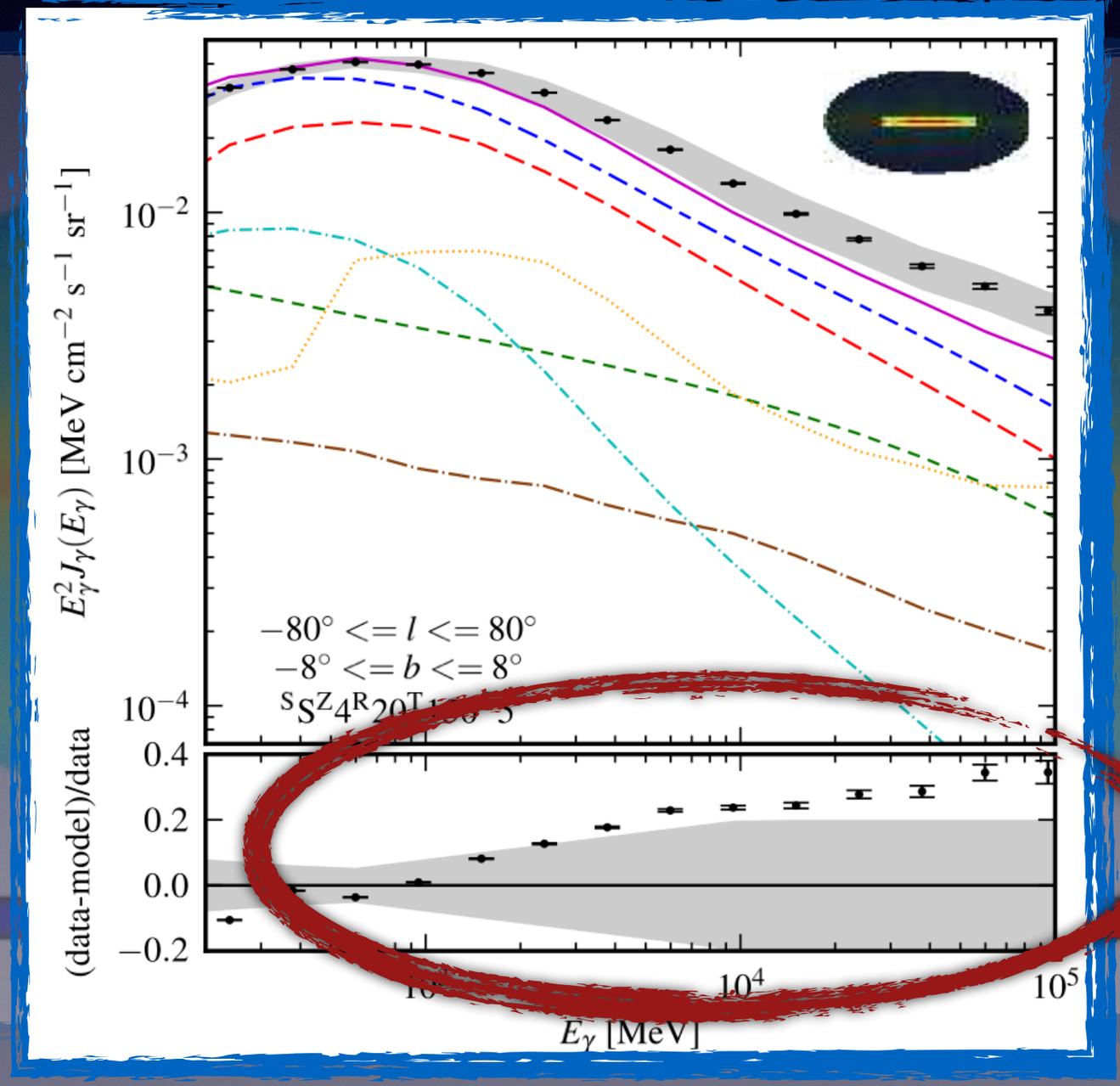

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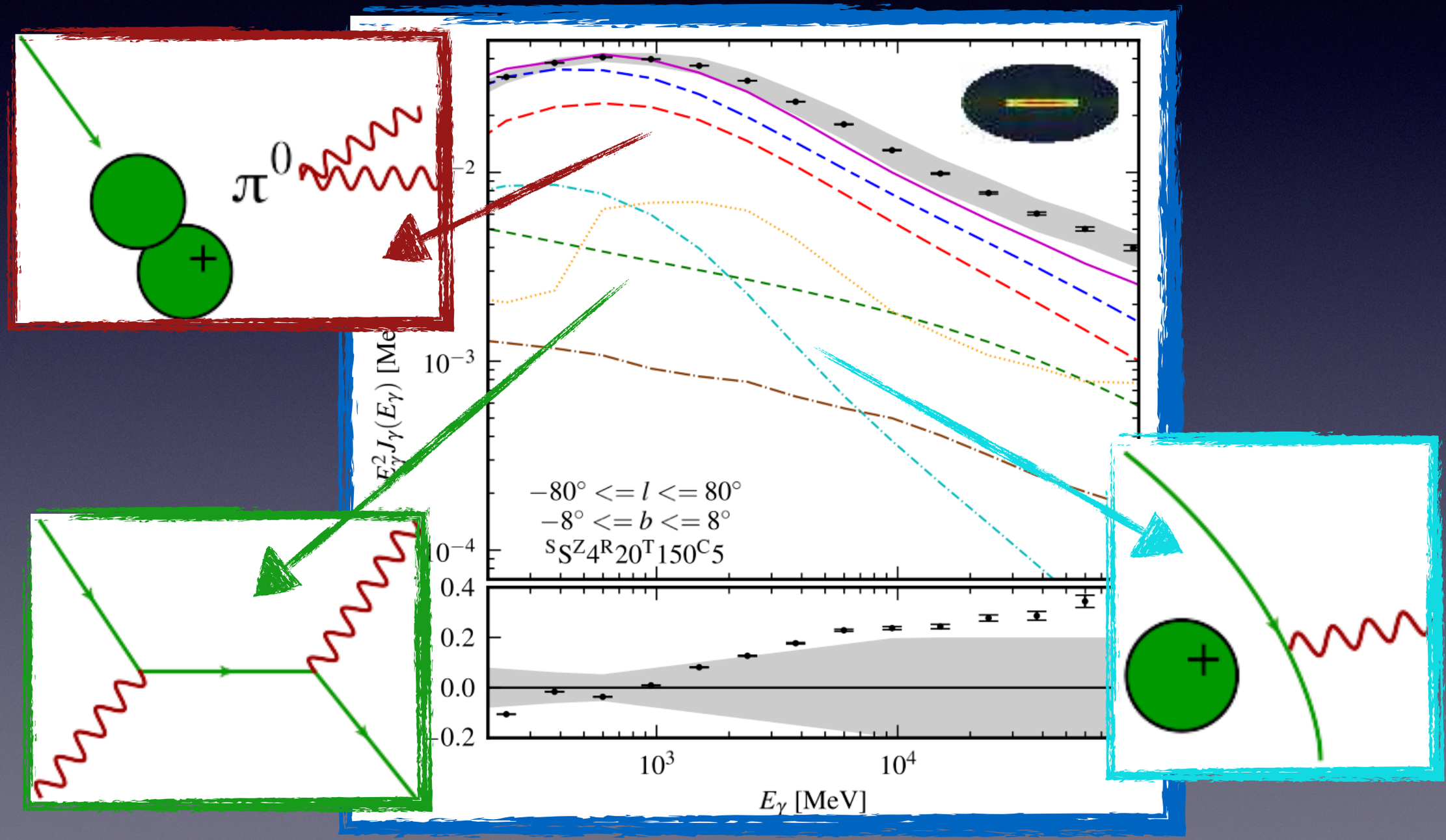
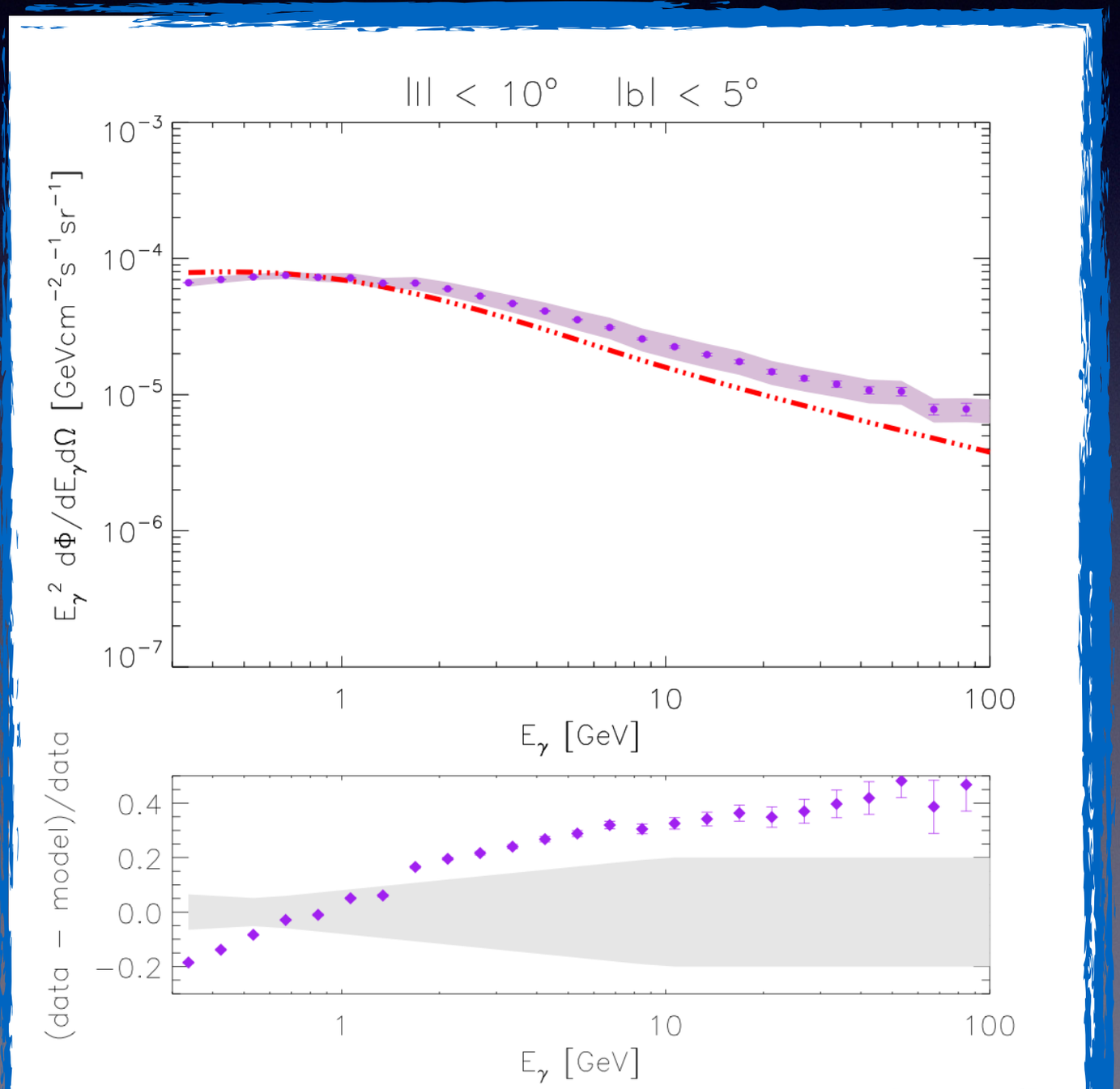


Radial gradients in diffusion



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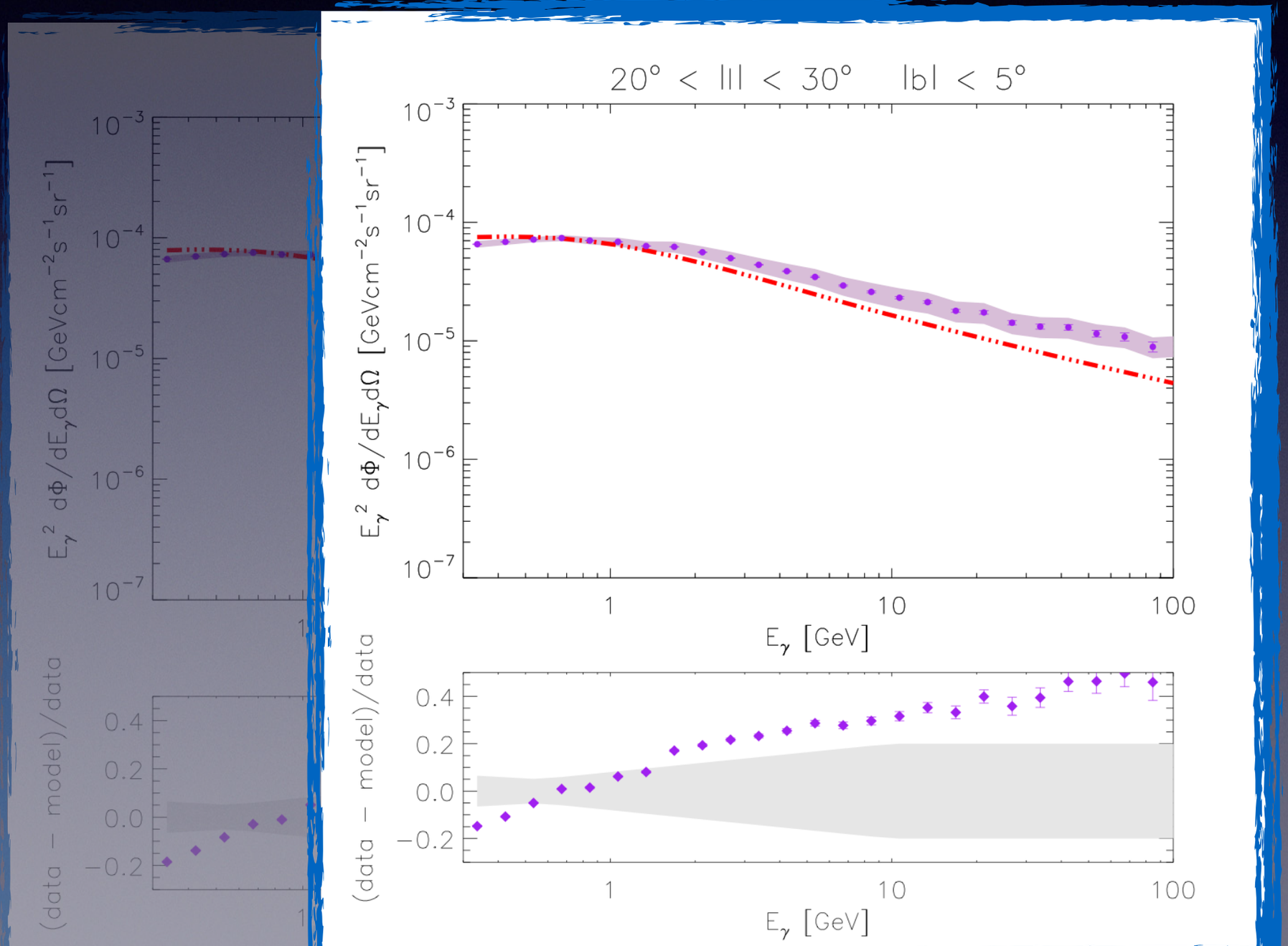

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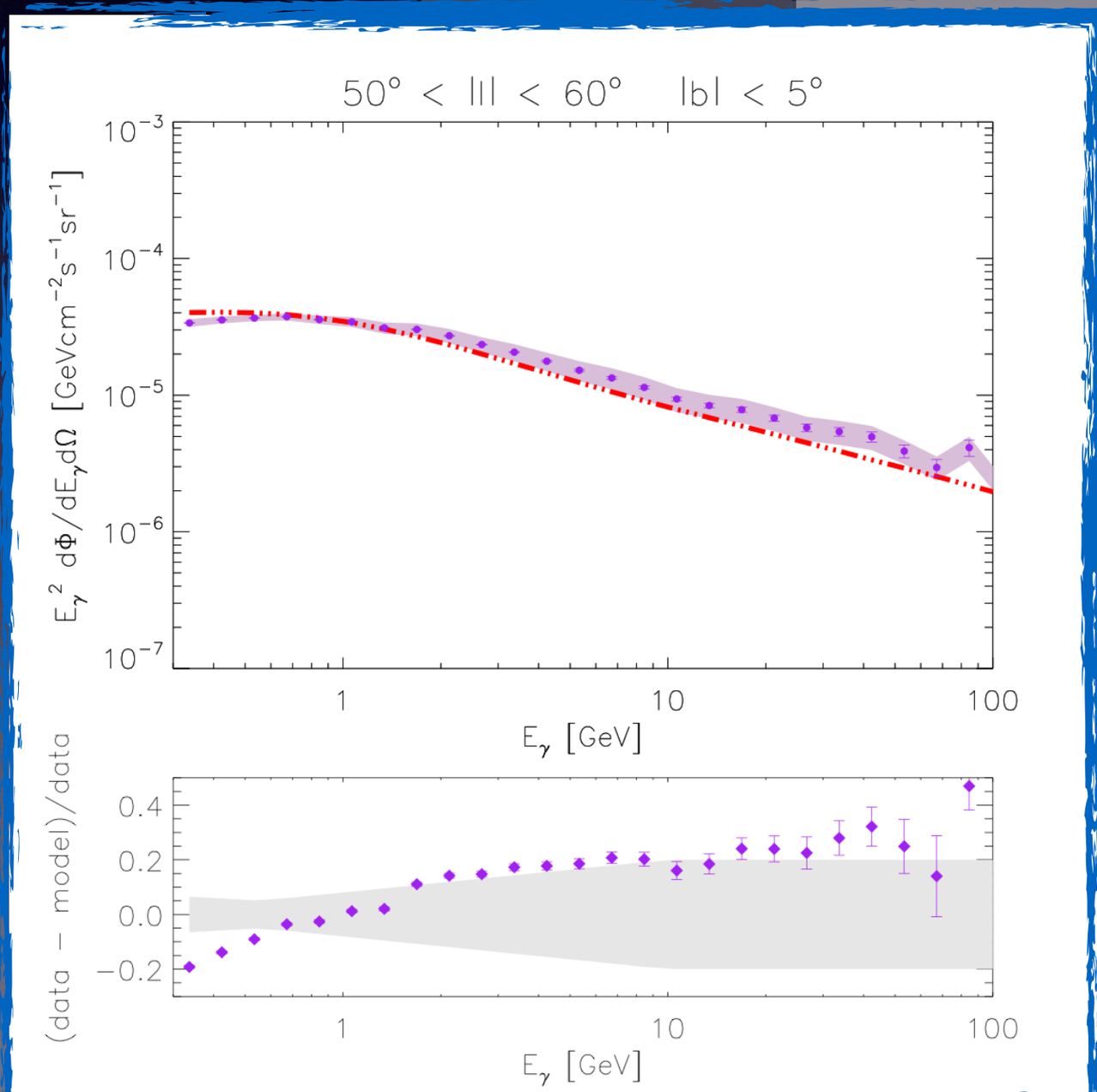

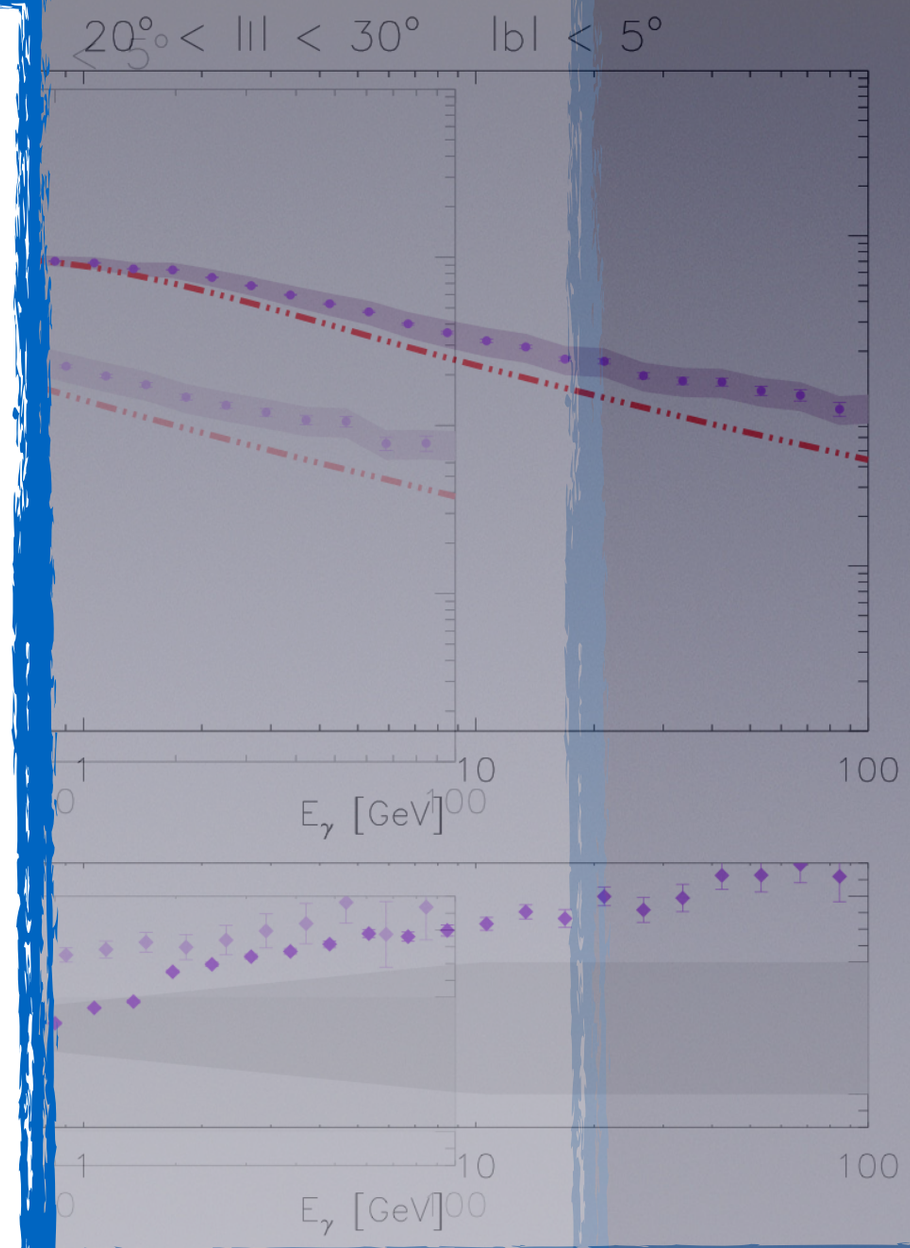

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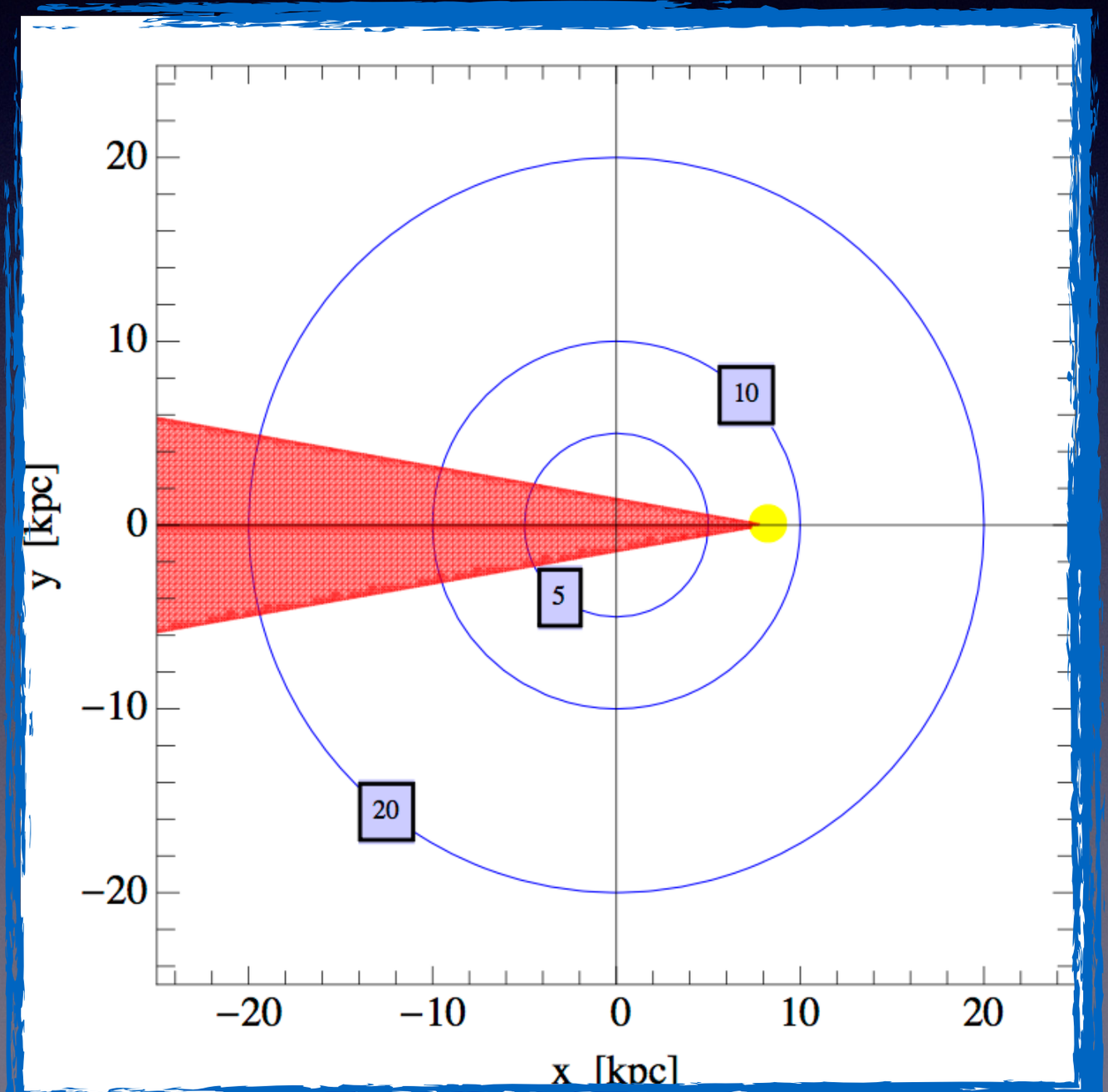

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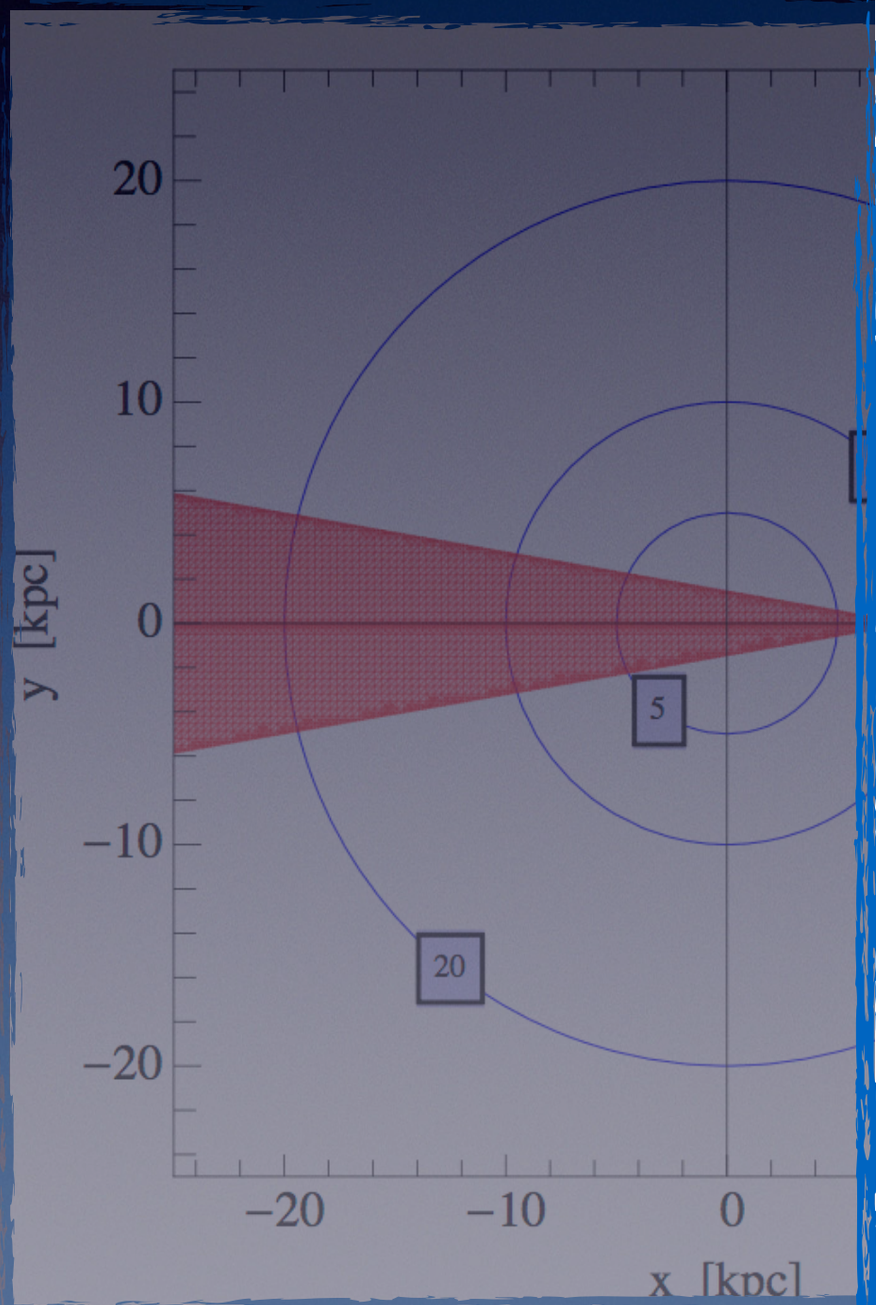

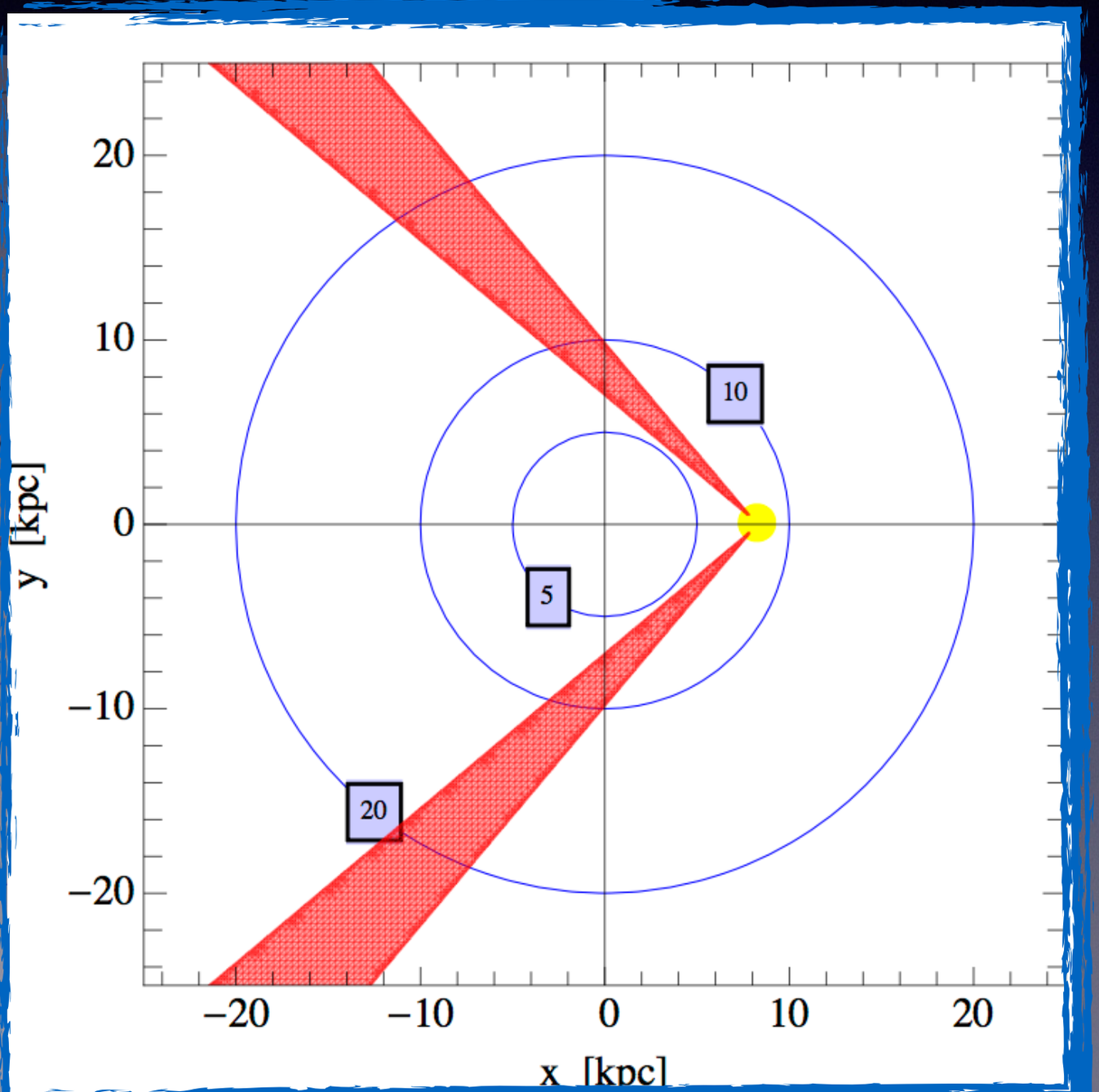

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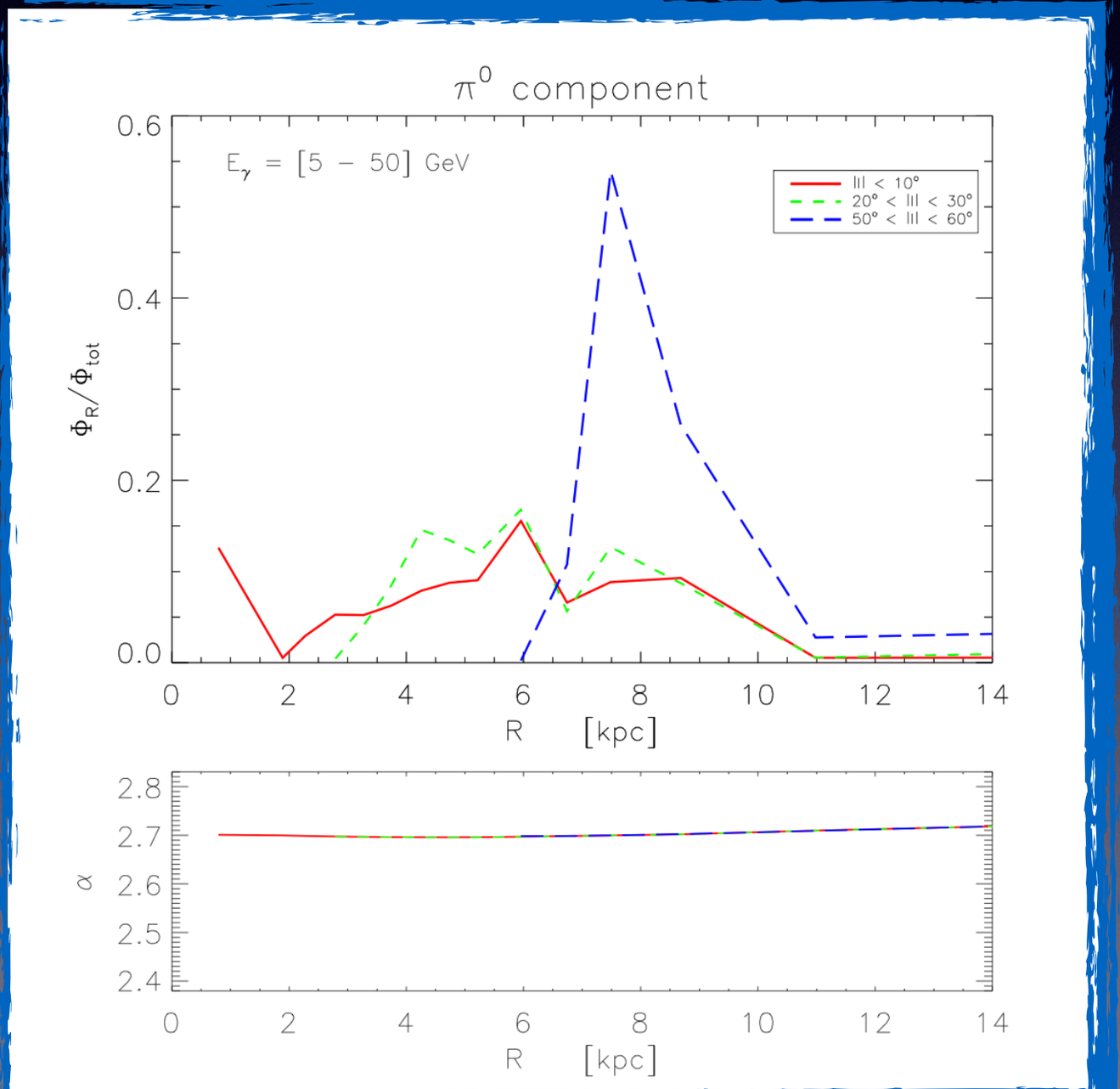

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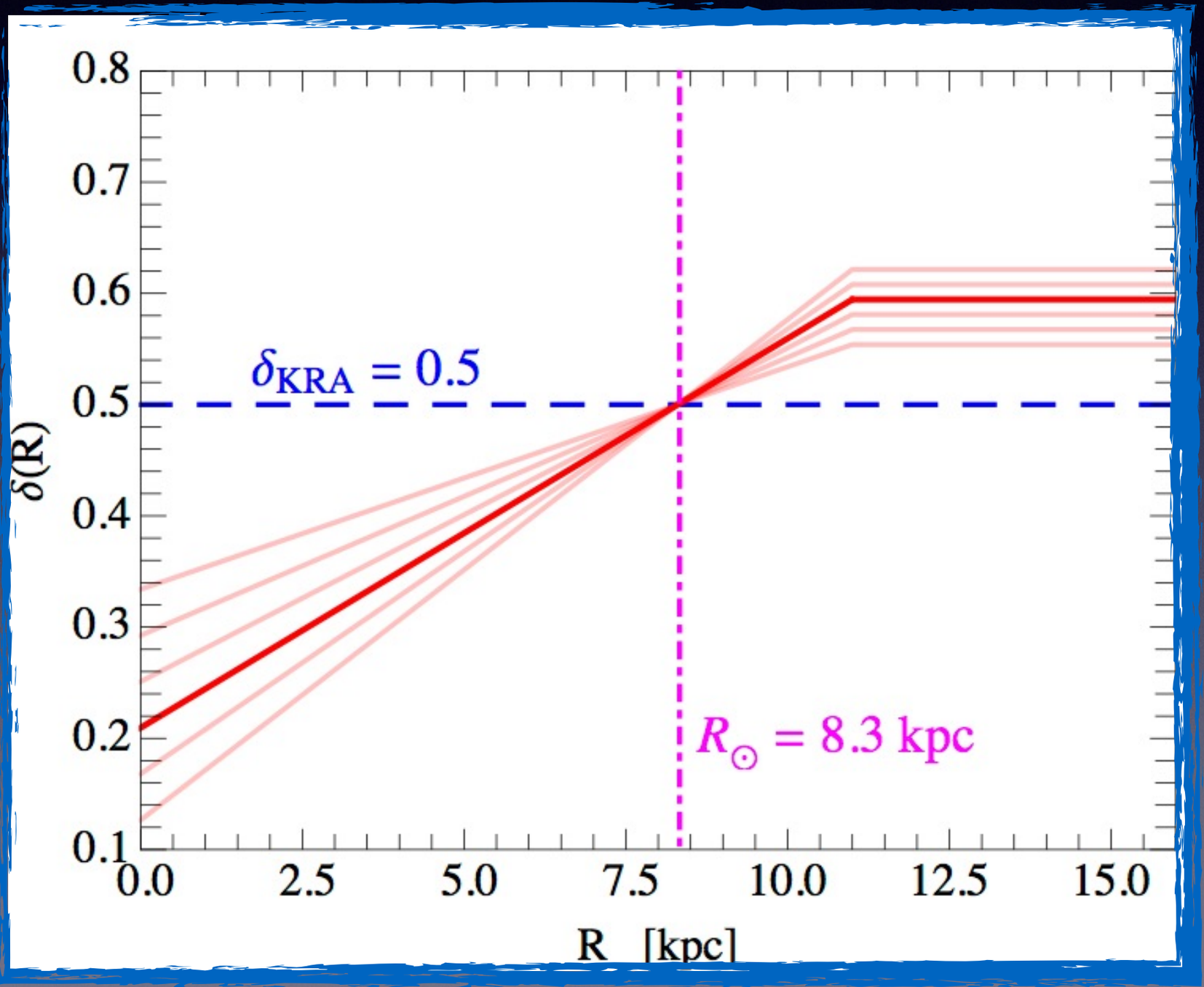

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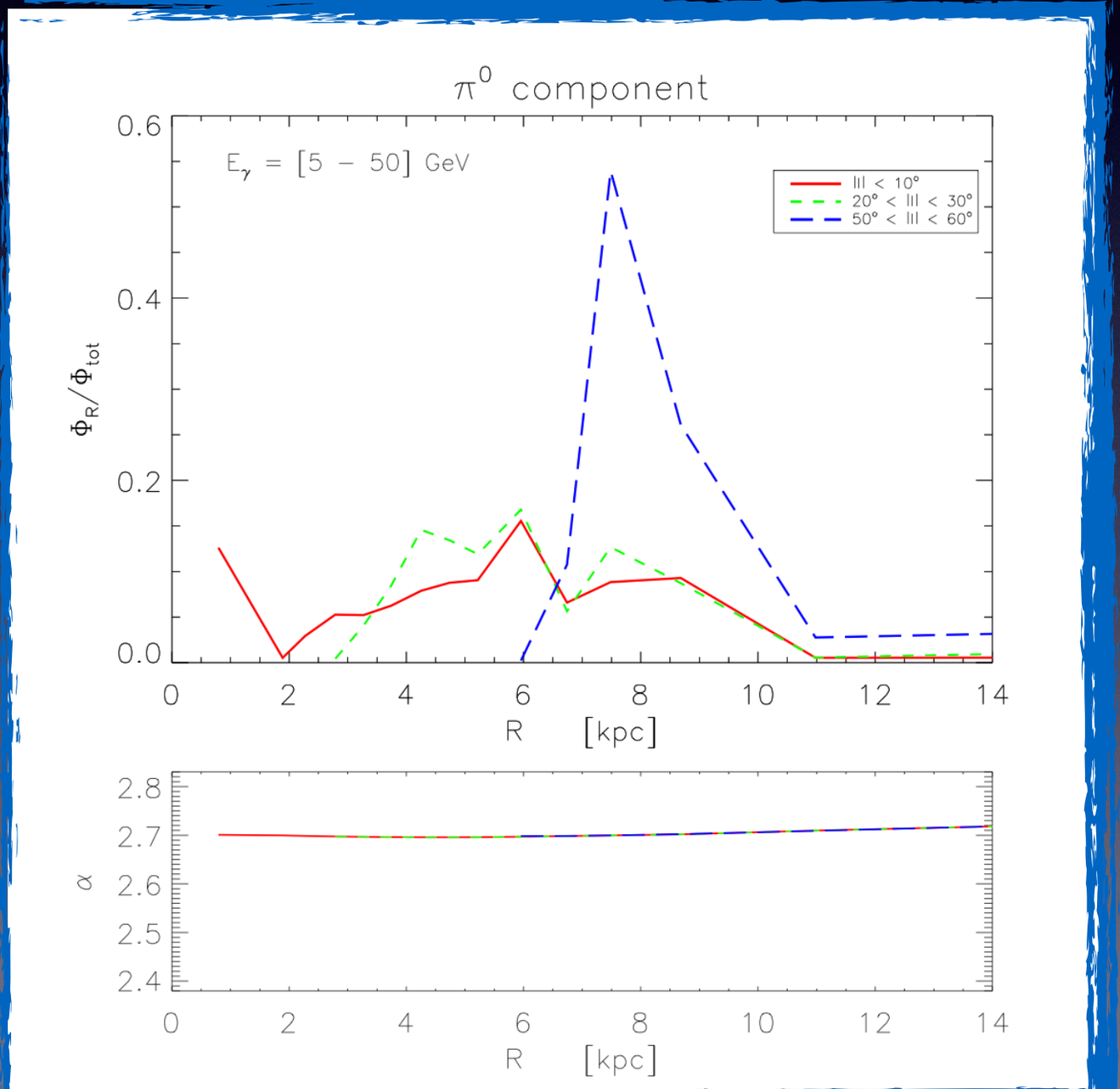

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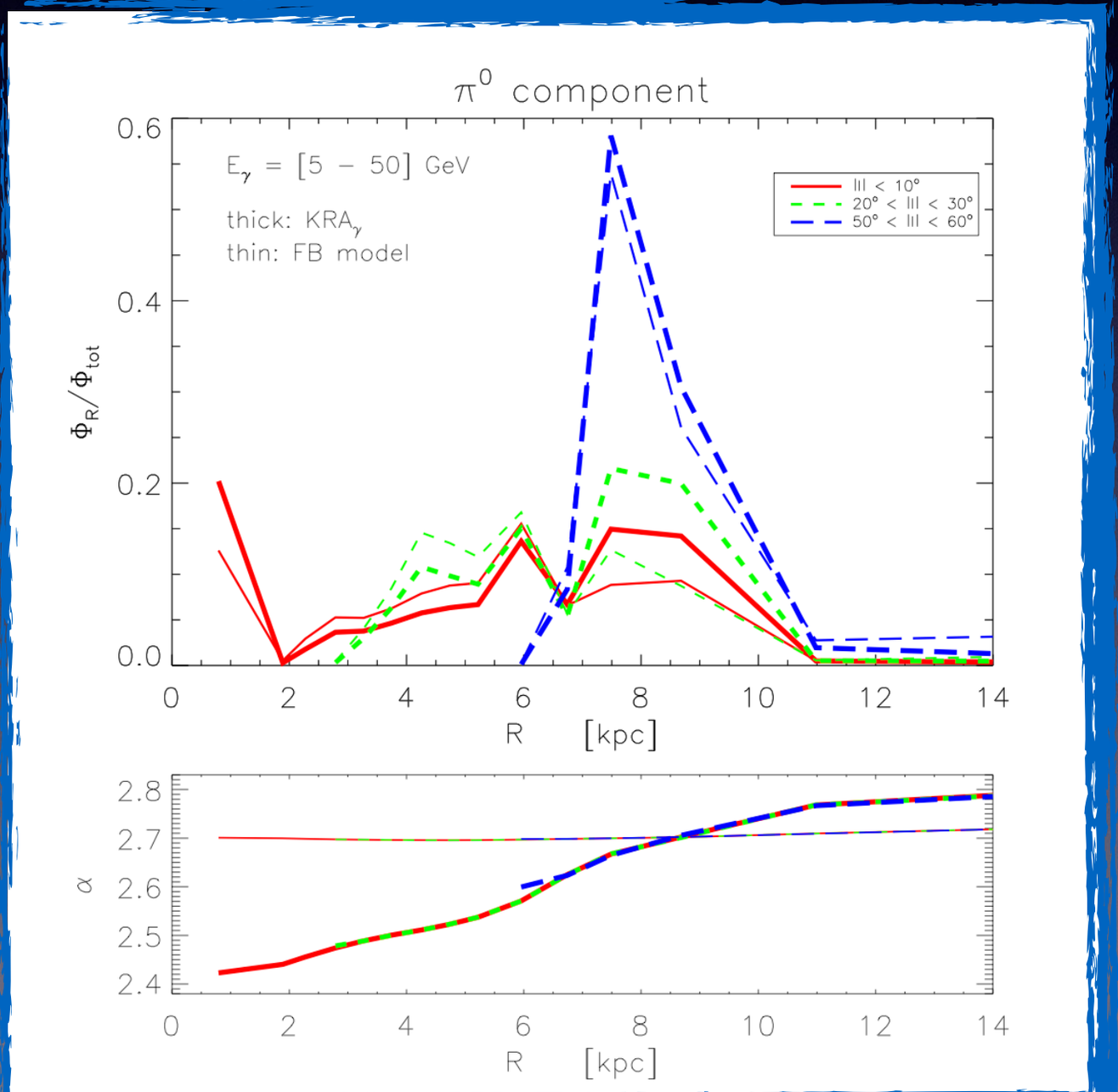
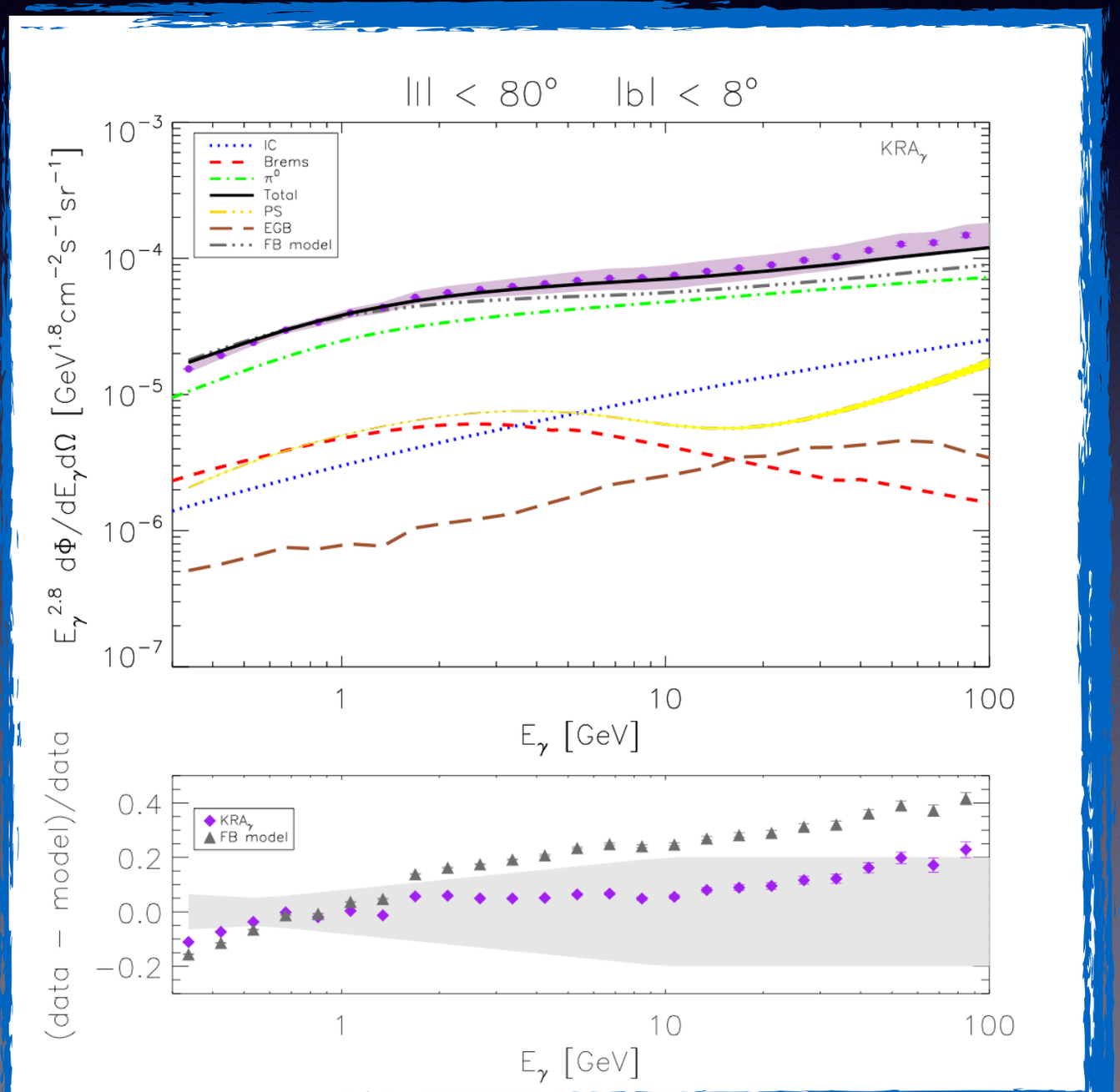
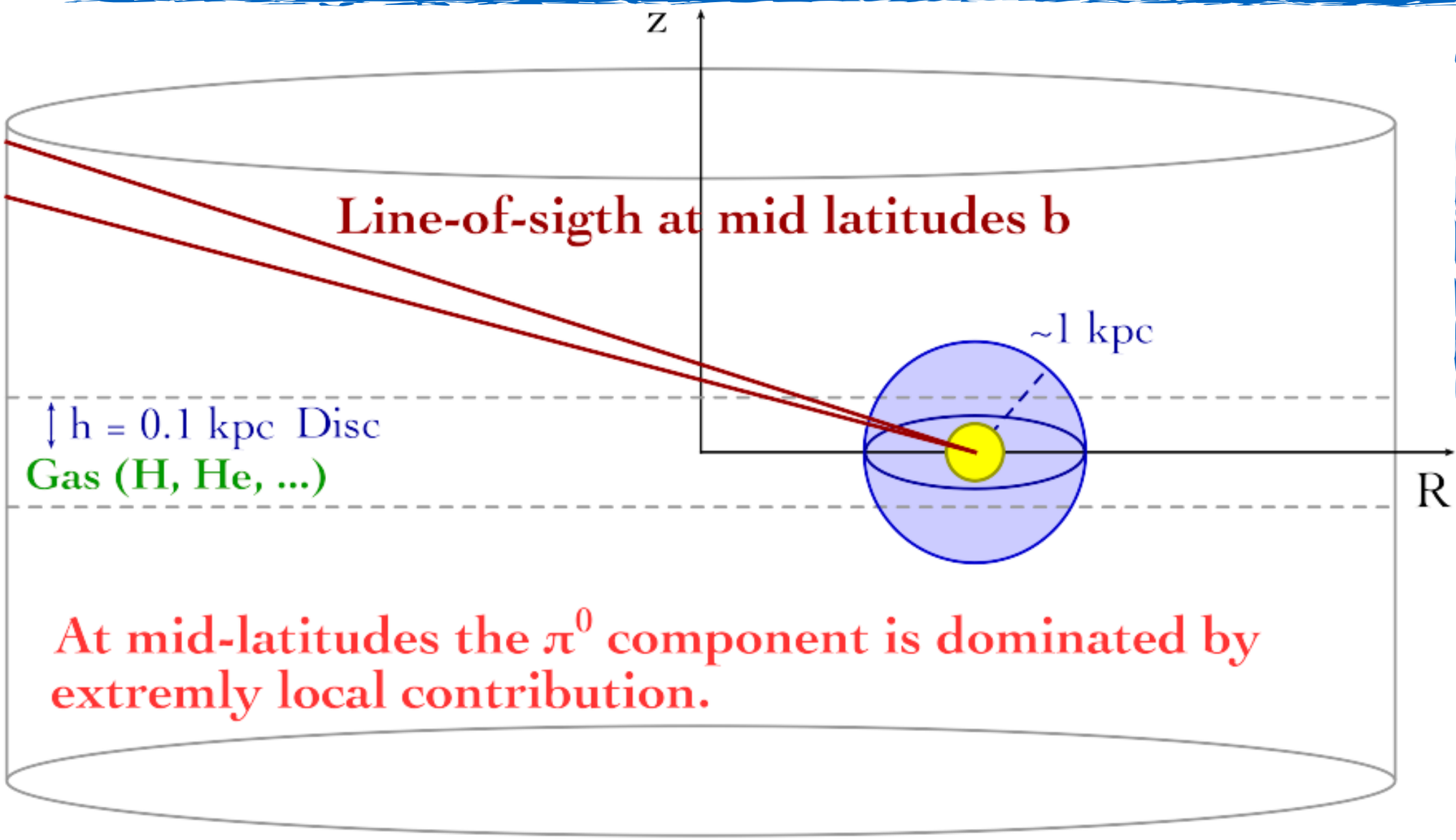


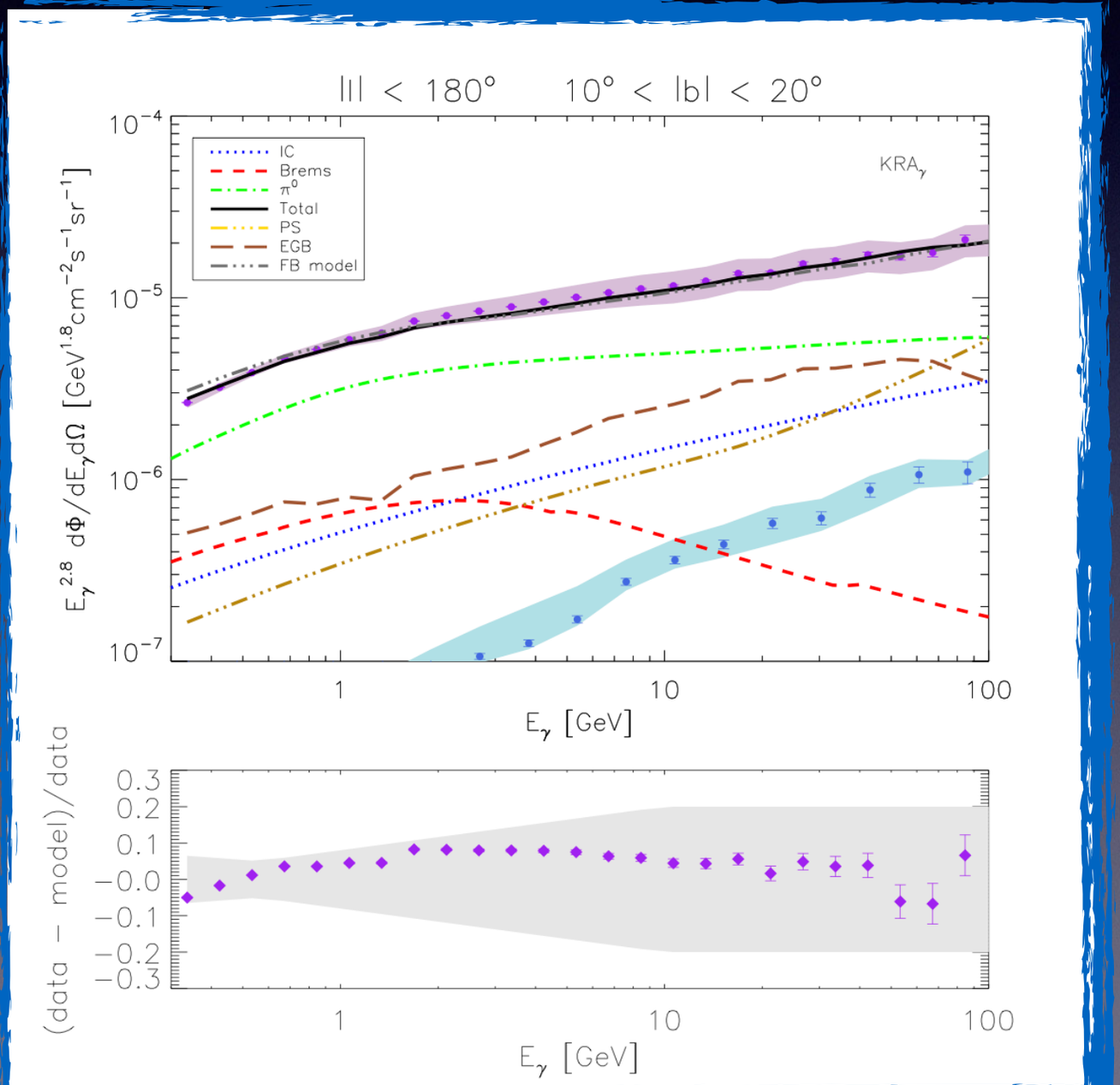
Results


|l| < 80° |b| < 8°
IC
Brems
π⁰
Total
PS
EGB
FB model
KRA_γ
E_γ^2.8 dΦ/dE_γdΩ [GeV^1.8 cm^-2 s^-1 sr^-1]
E_γ [GeV]
(data − model)/data
KRA_γ
FB model
E_γ [GeV]

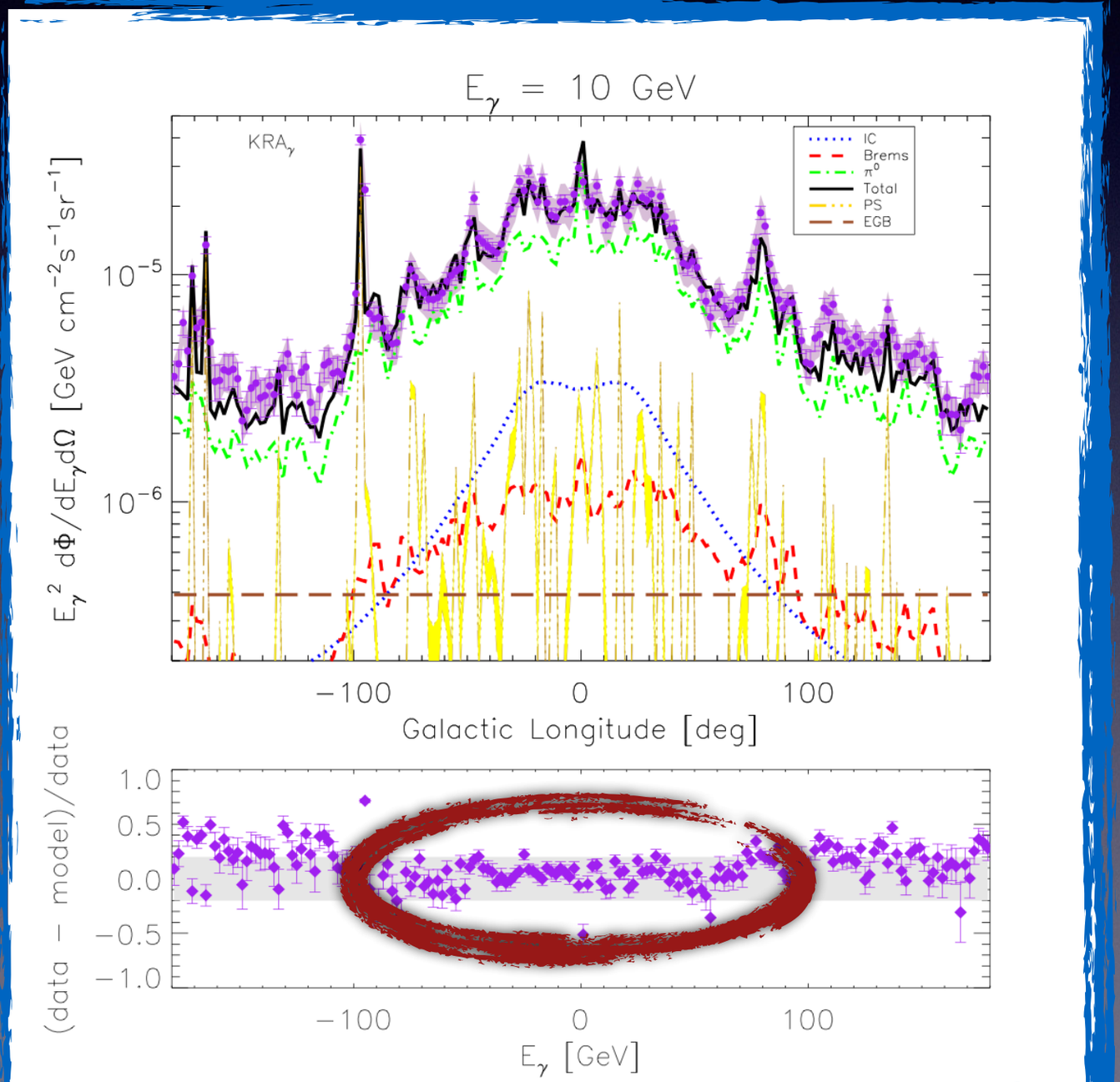
Results


z
Line-of-sigth at mid latitudes b
~1 kpc
h = 0.1 kpc Disc
Gas (H, He, ...)
R
At mid-latitudes the π^0 component is dominated by extremly local contribution.

Results

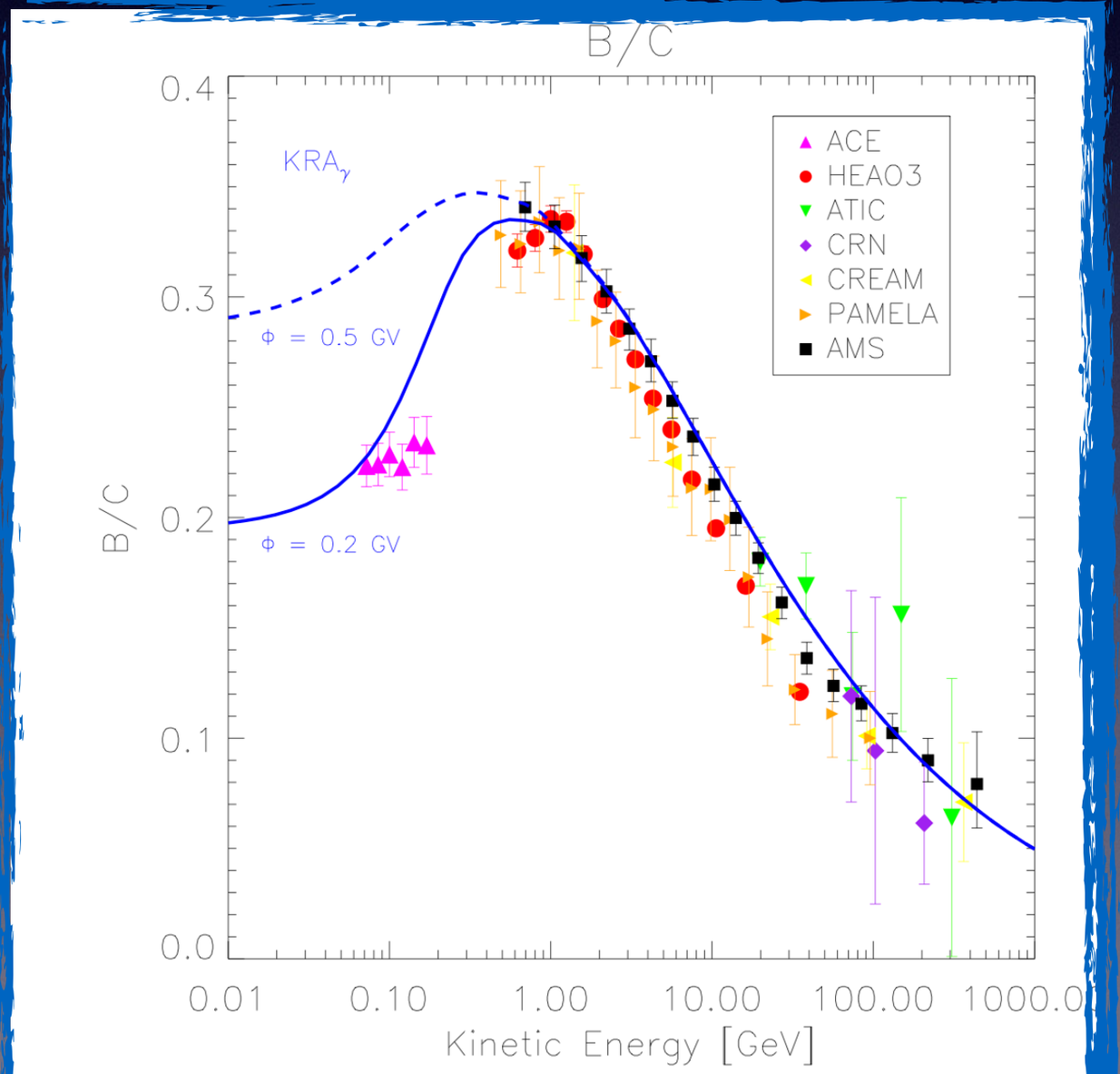

|l| < 180° 10° < |b| < 20°
IC
Brems
π⁰
Total
PS
EGB
FB model
KRA_γ
E_γ^2.8 dΦ/dE_γdΩ [GeV^1.8cm^-2s^-1sr^-1]
10^-4
10^-5
10^-6
10^-7
1
10
100
E_γ [GeV]
(data − model)/data
0.3
0.2
0.1
−0.0
−0.1
−0.2
−0.3
1
10
100
E_γ [GeV]

Results


E_γ = 10 GeV
KRA$_\gamma$
IC
Brems
π^0
Total
PS
EGB
10^{-5}
10^{-6}
E_γ^2 dΦ/dE_γdΩ [GeV cm^{-2}s^{-1}sr^{-1}]
−100
0
100
Galactic Longitude [deg]
1.0
0.5
0.0
−0.5
−1.0
(data − model)/data
−100
0
100
E_γ [GeV]

Results

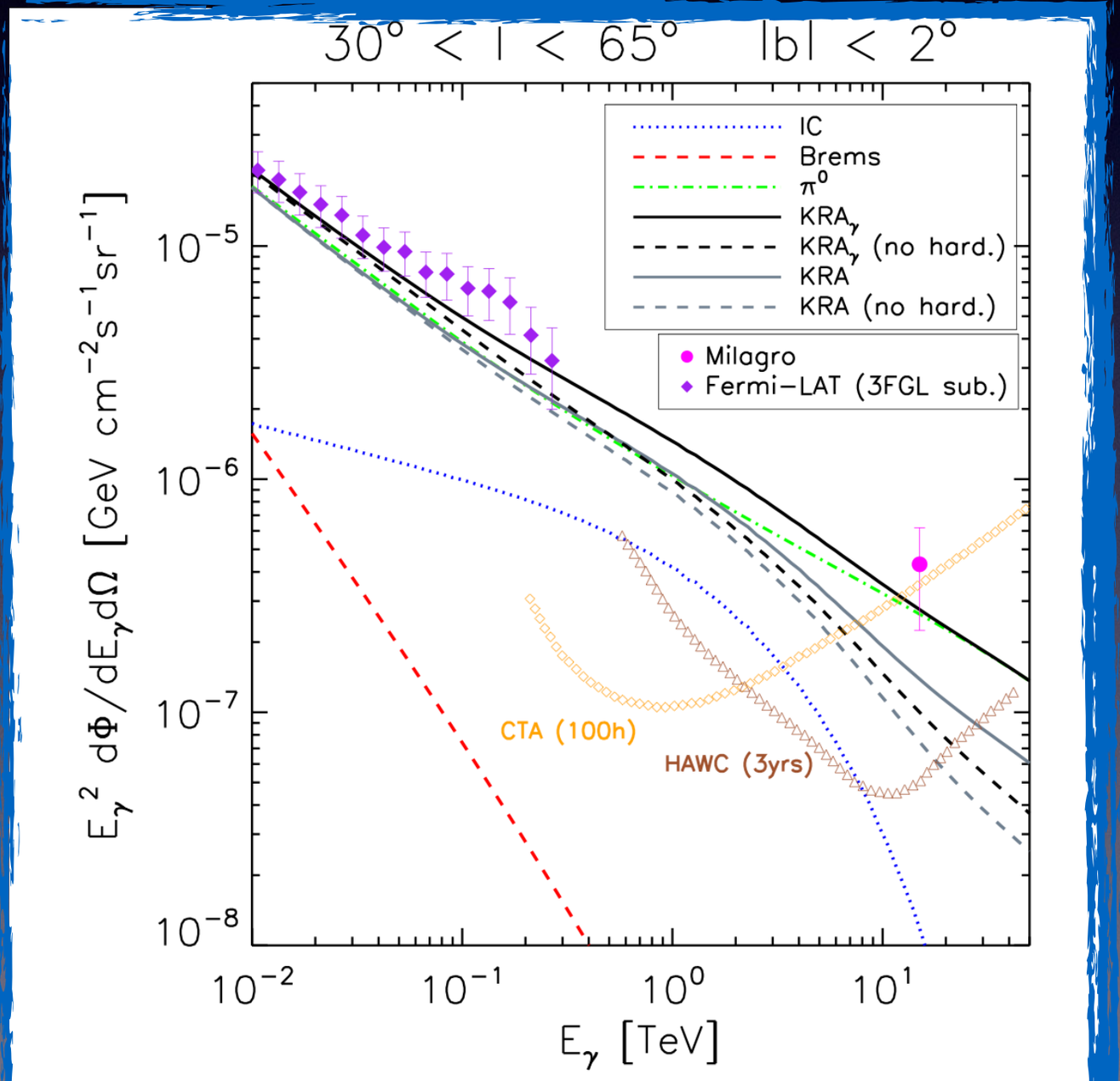
Very good agreement with local observables!



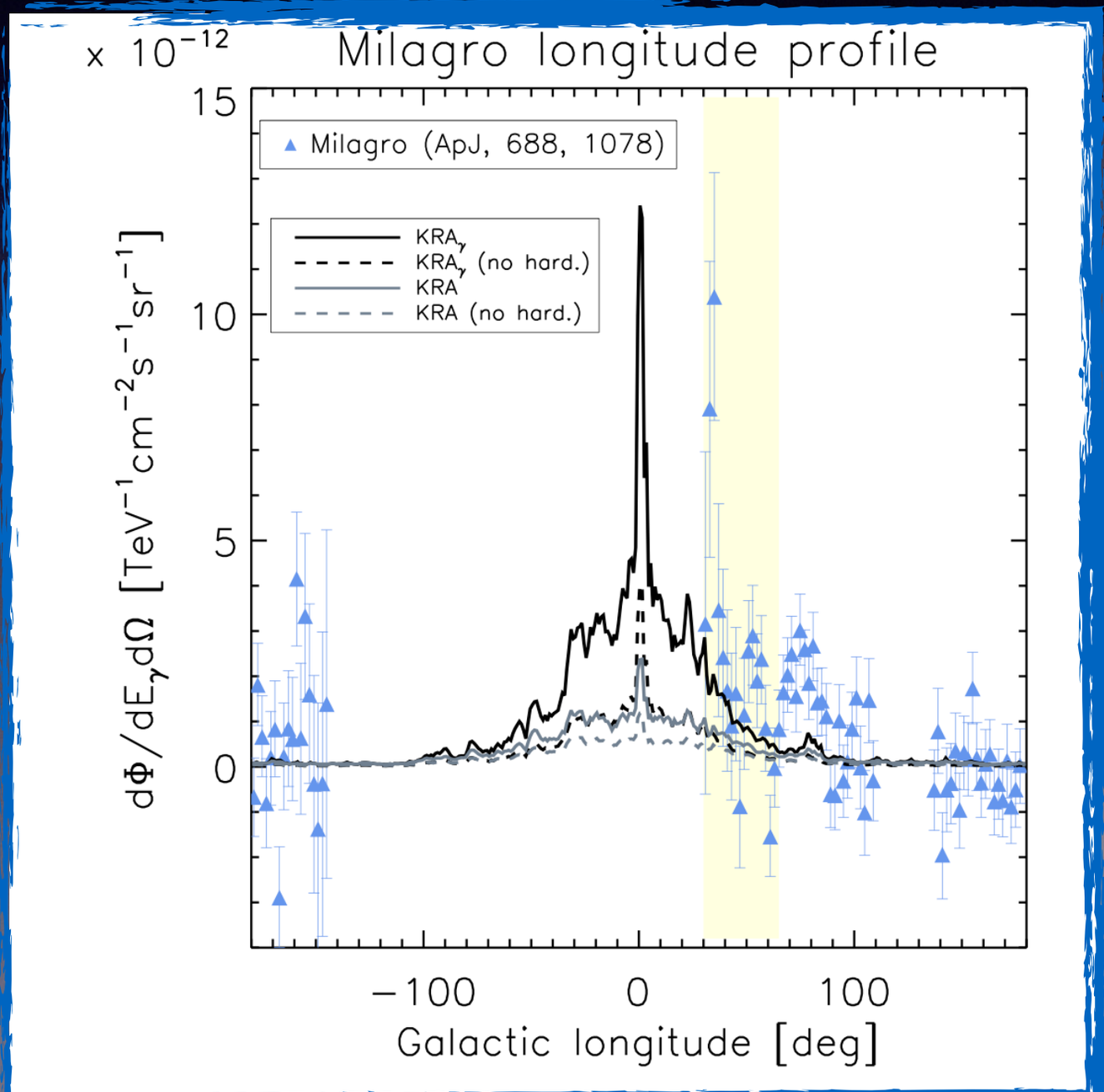
IceCube neutrinos

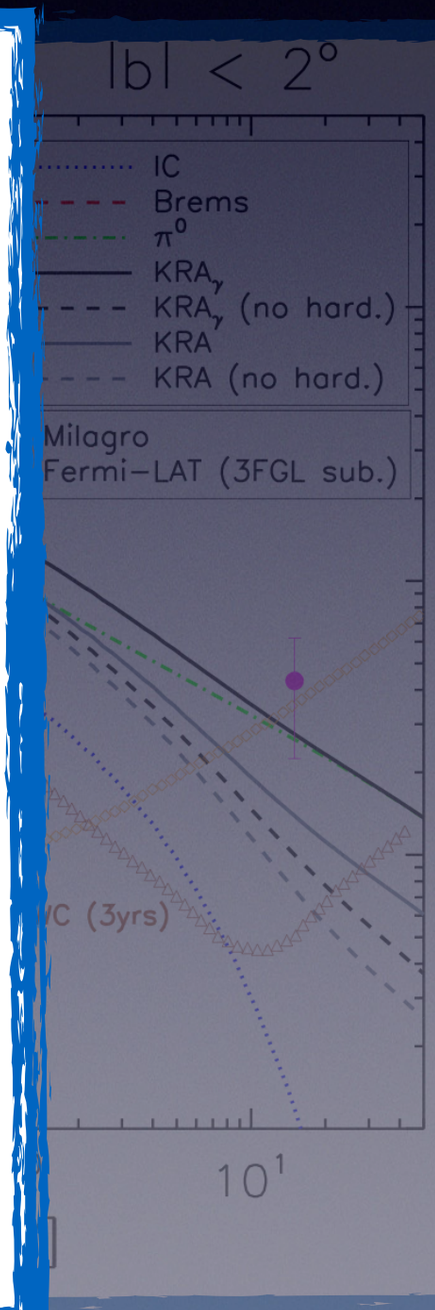
with D. Gaggero, D. Grasso, A. Marinelli, M. Valli
arXiv:1504.00227, to appear in APJ Letters

IceCube neutrinos



IceCube neutrinos





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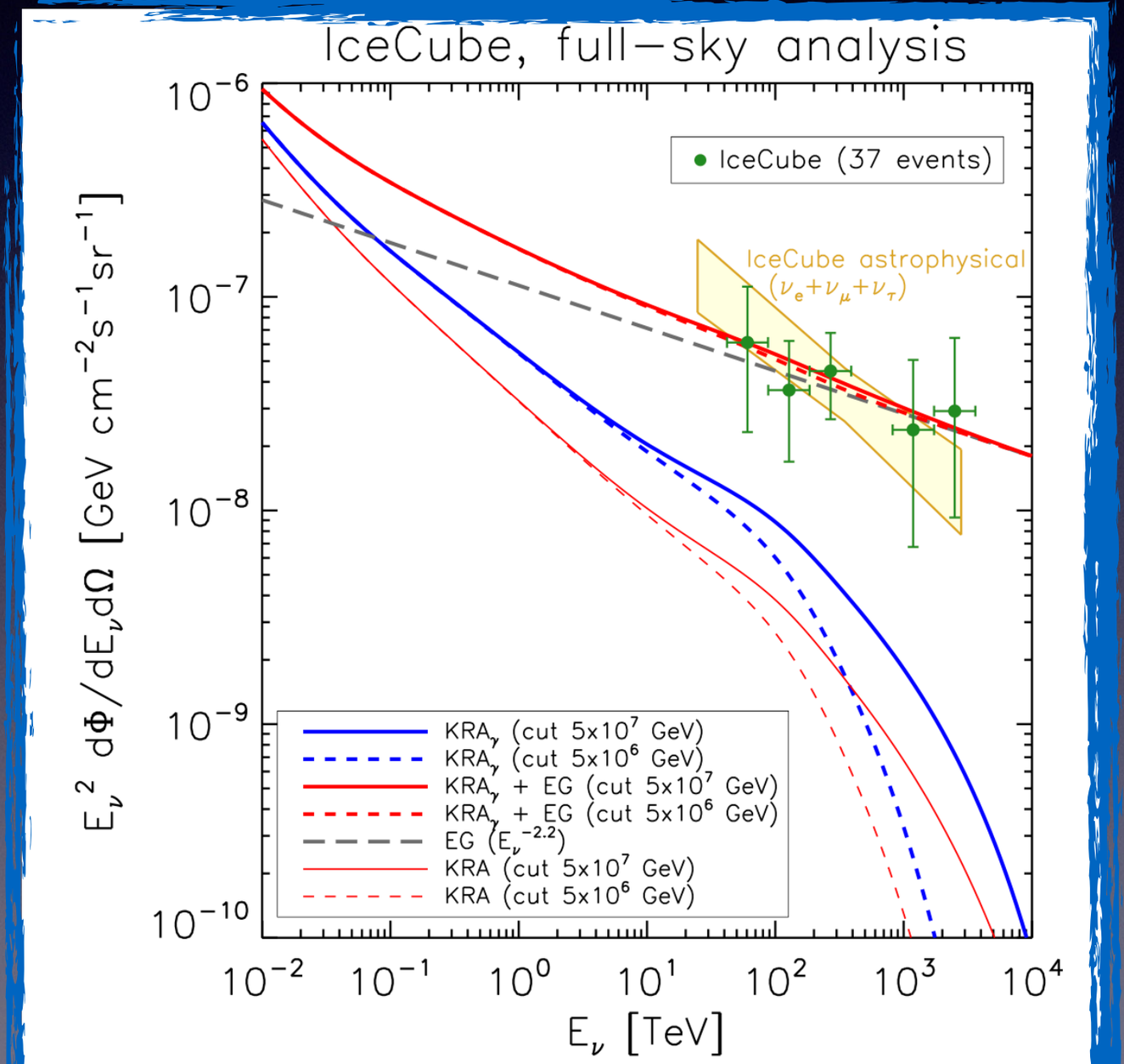

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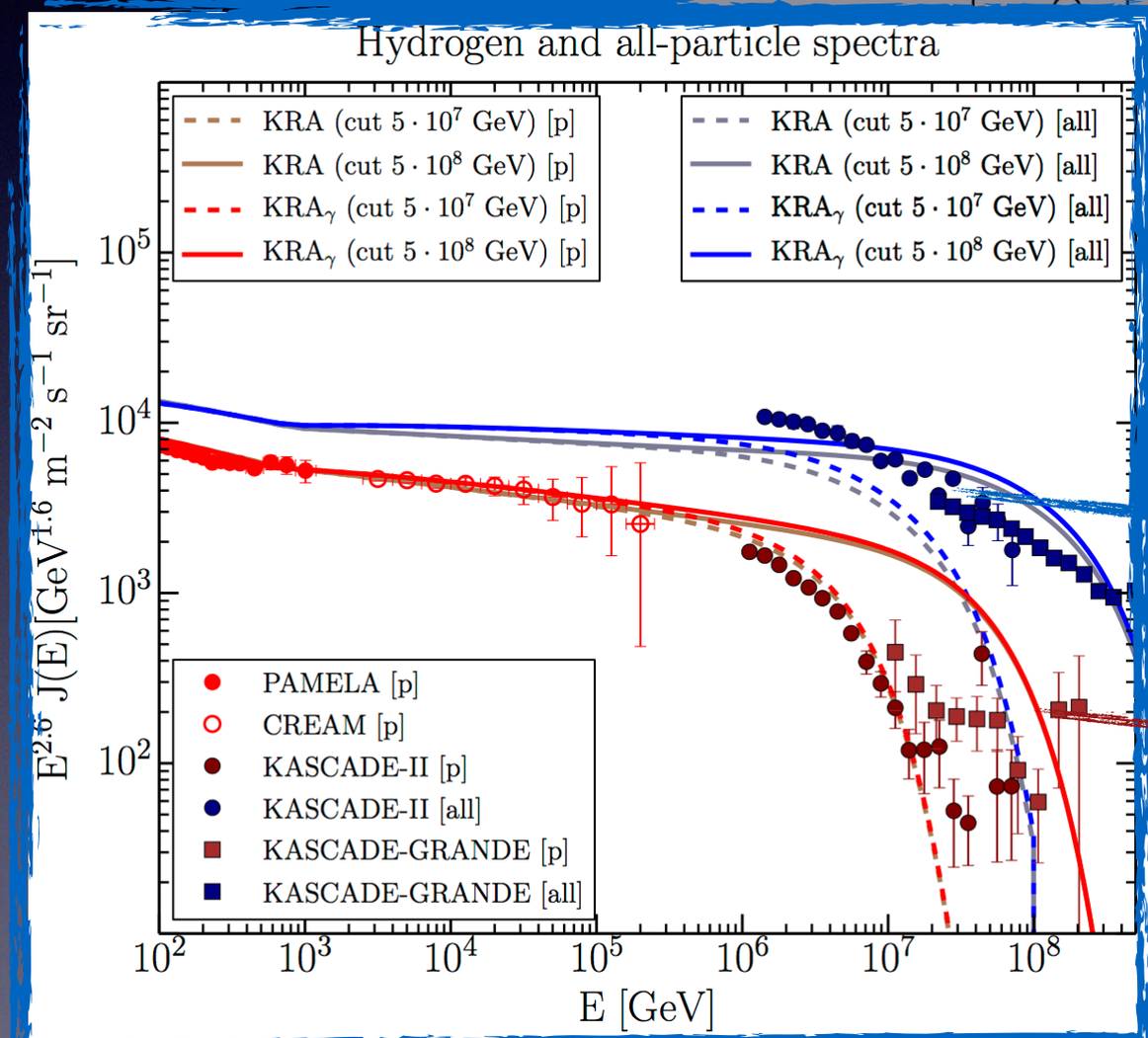
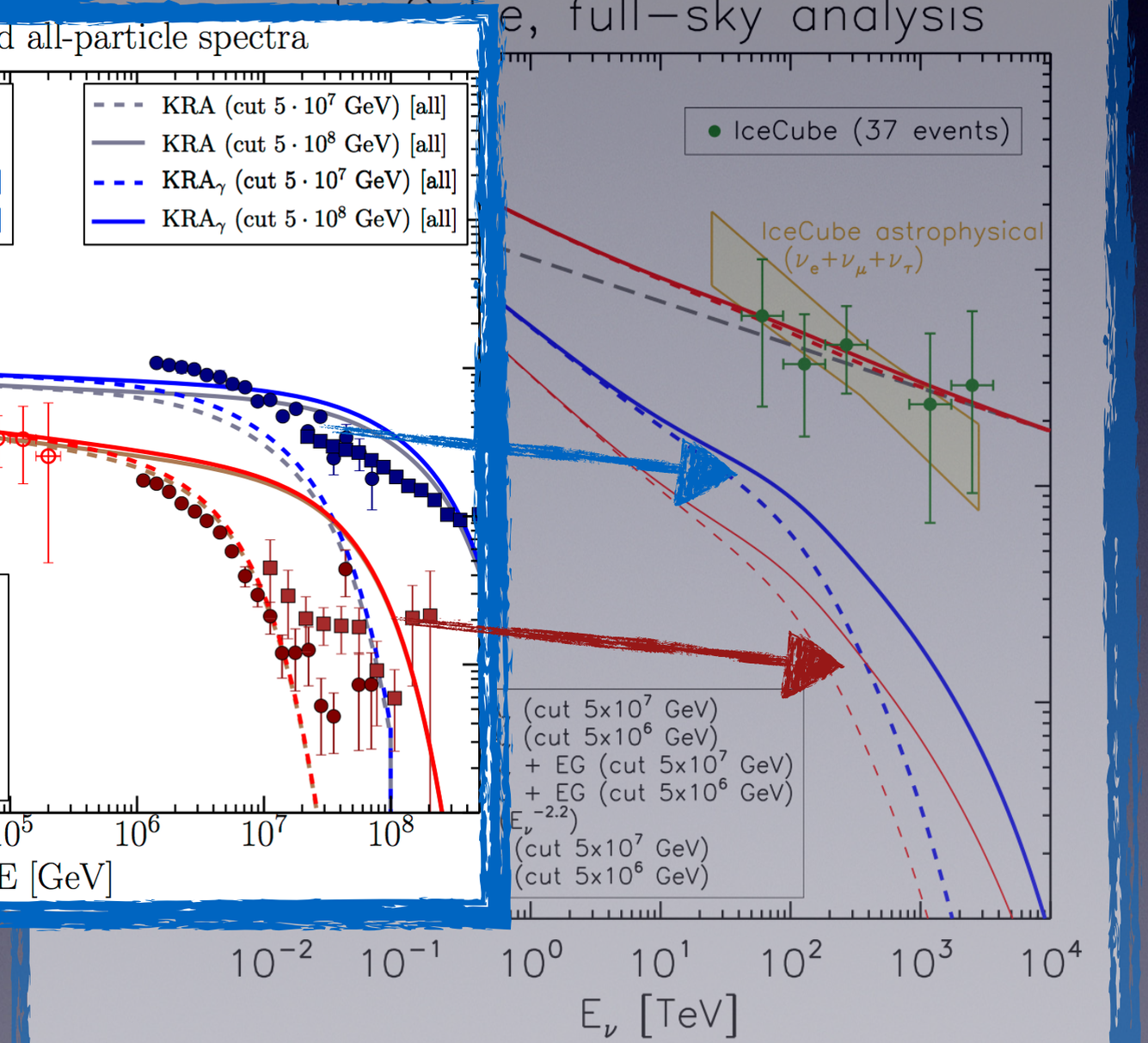
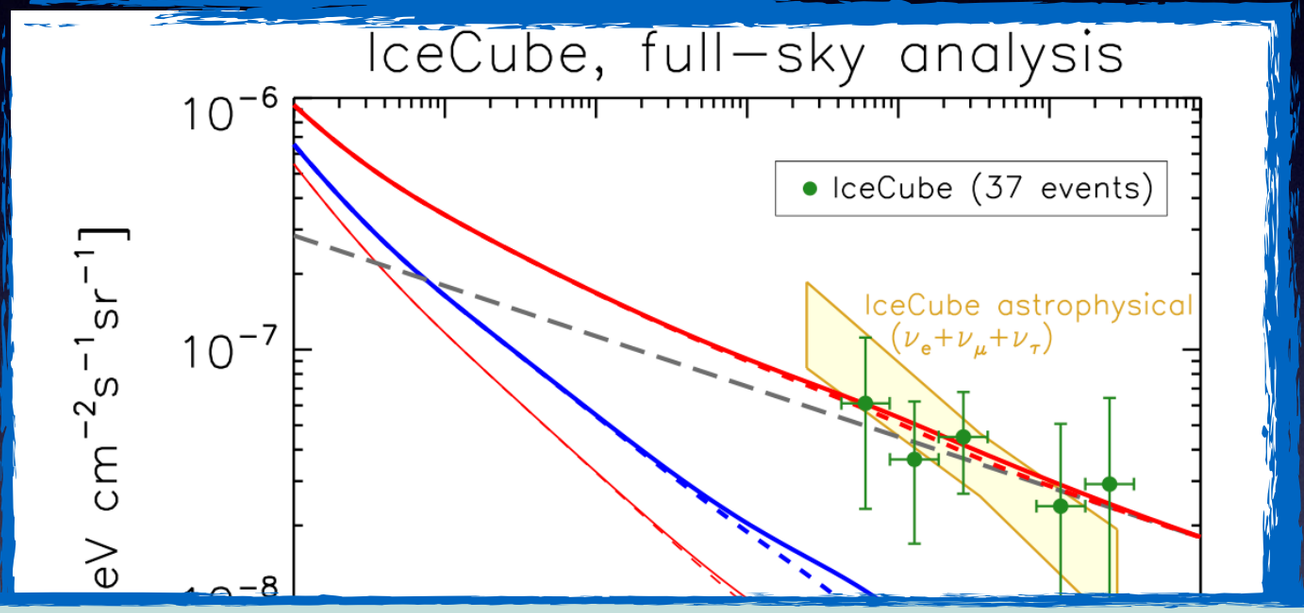


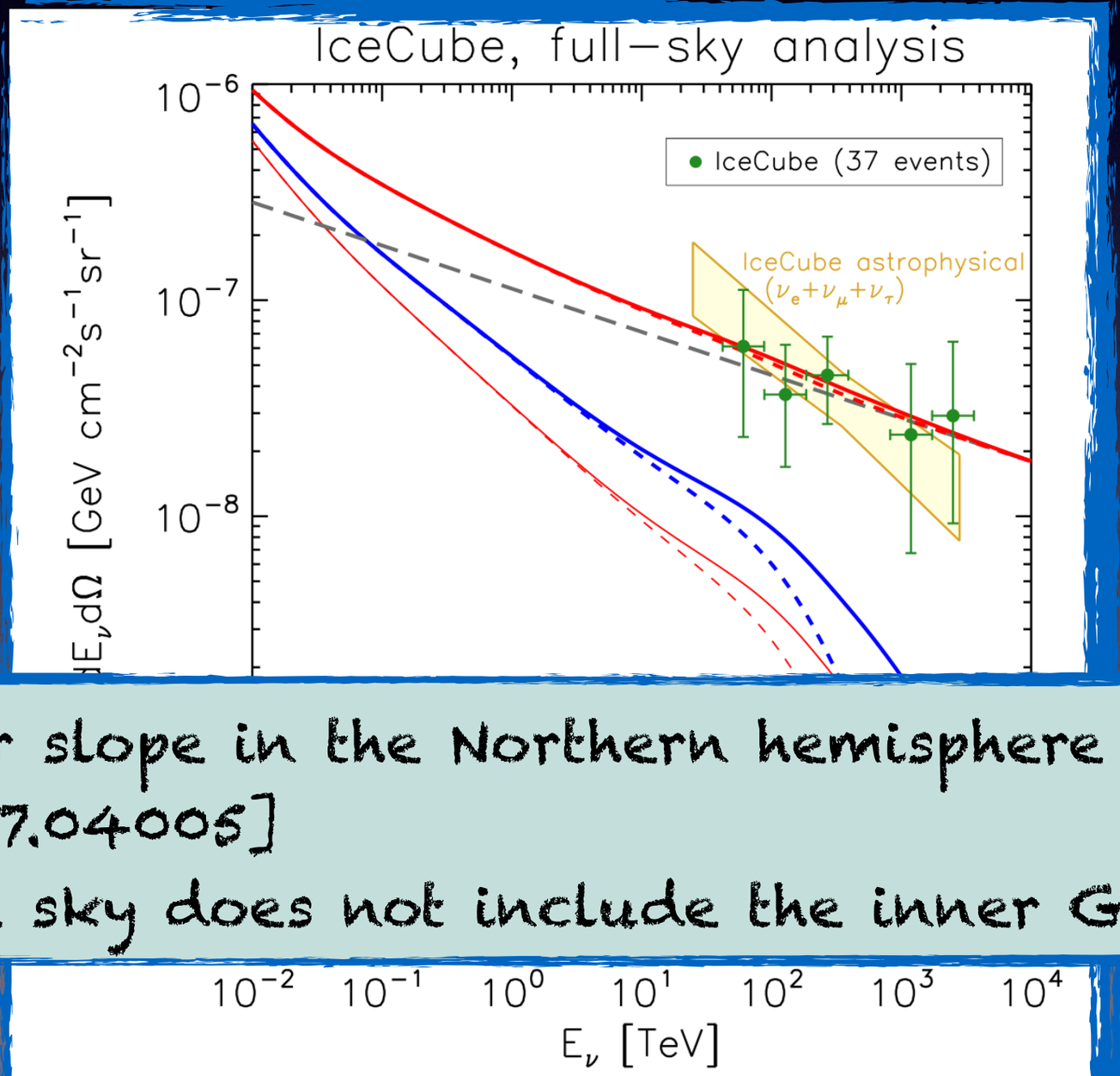


IceCube neutrinos



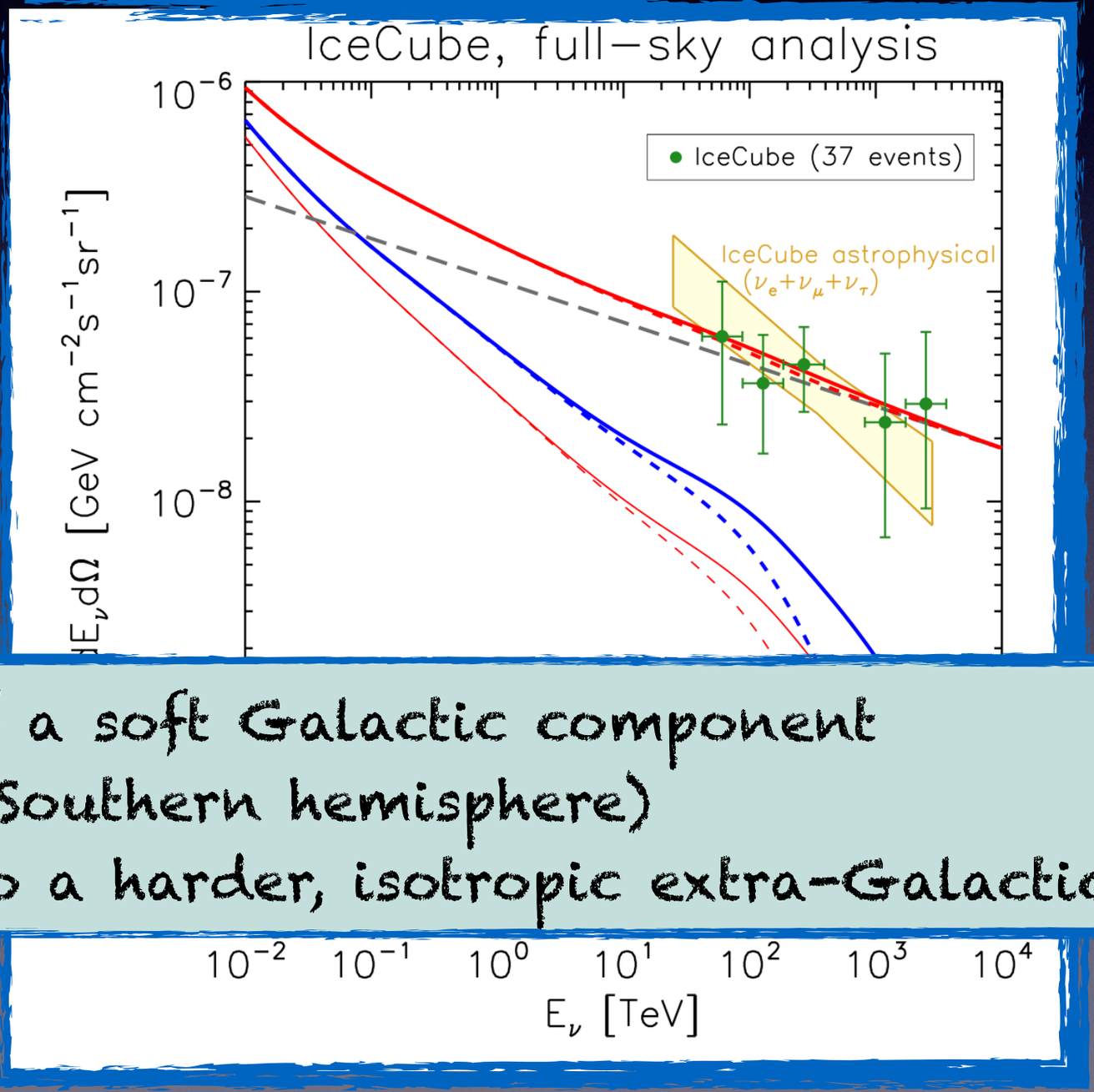
IceCube reported the detection of
37 high-energy starting neutrino events (HESE) of
extraterrestrial origin [PRL 2014, 1405.5303]
above 30 TeV in 3 years of data taking,
and, more recently,
a preliminary analysis
of 54 HESE events [ICRC 2015] in 4 years of data

IceCube neutrinos



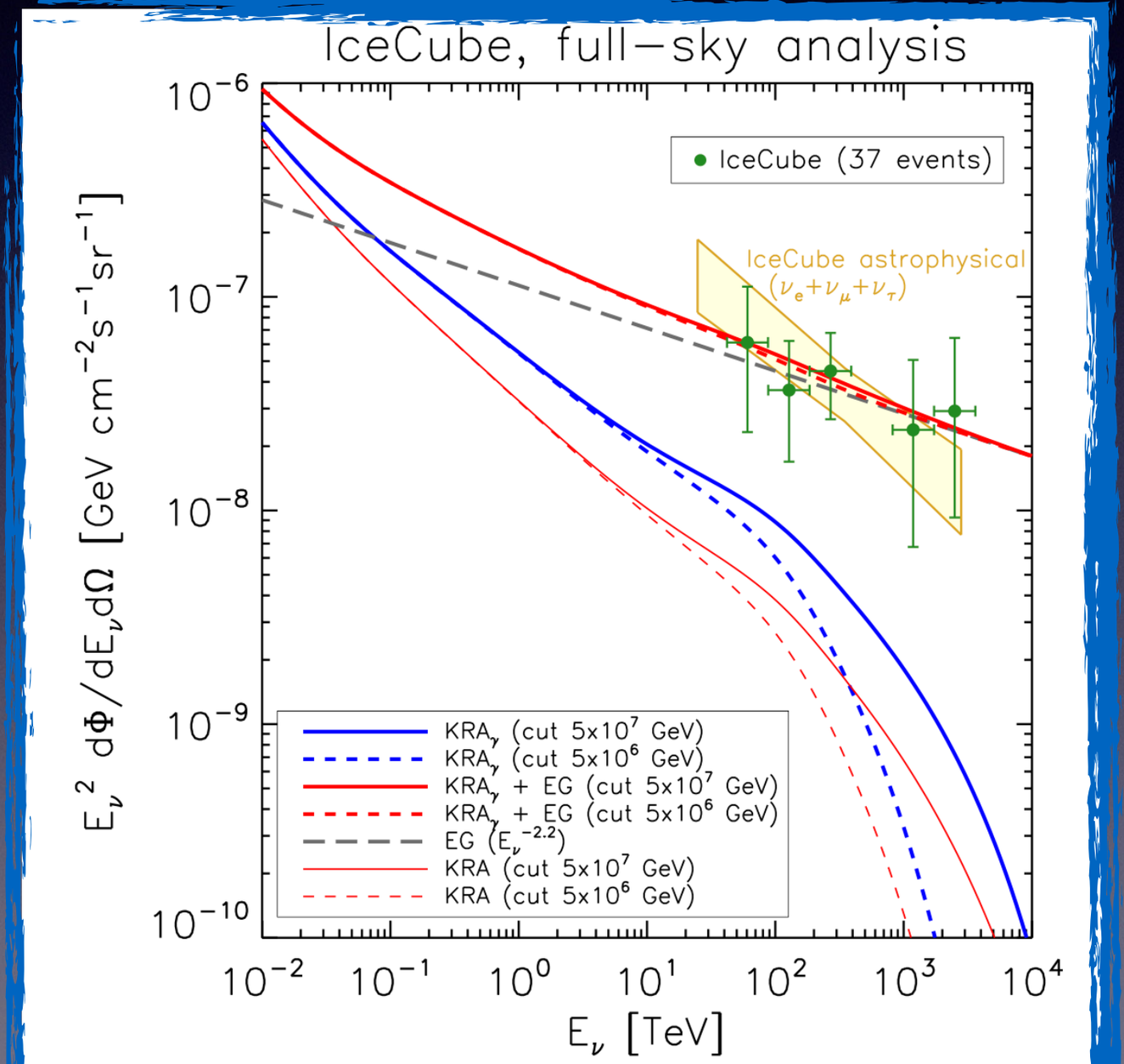
Hint of a flatter slope in the Northern hemisphere
[PRL 2015, 1507.04005]
This part of the sky does not include the inner Galaxy

IceCube neutrinos

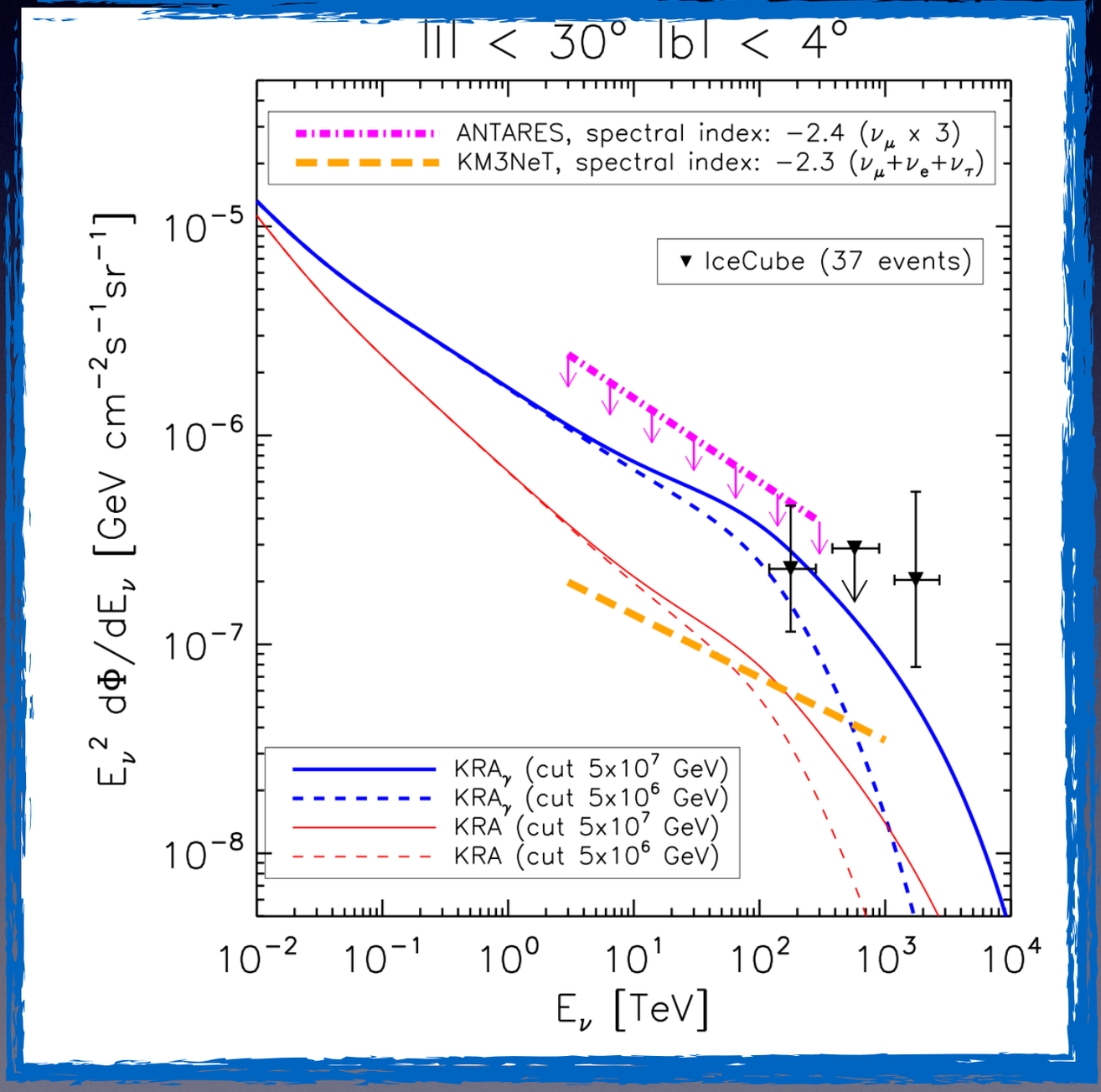


Maybe a hint of a soft Galactic component
(peaked in the Southern hemisphere)
superimposed to a harder, isotropic extra-Galactic one?

IceCube neutrinos



IceCube neutrinos



Conclusions

Gamma rays carry informations about cosmic-ray propagation

Fermi-LAT data point towards a radial gradient in cosmic-ray diffusion

Important consequences for high-energy neutrinos