Simulations of γ-rays propagation in magnetised astrophysical environments

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(J. Pollock, 1948-49)

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outline

- gamma-ray propagation & extragalactic magnetic field (EGMF)

- simulation framework

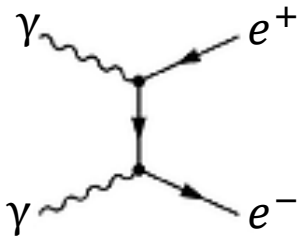
goal: characterizing the observables in dependence to the EGMF model's parameters

- perspectives for axion-like particle gamma-ray searches:

combination **CRPropa simulations/Fermi-LAT observations**

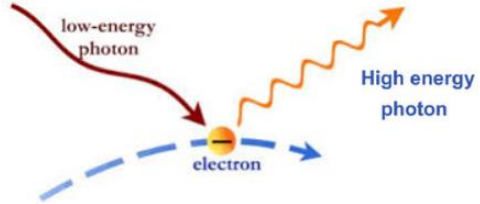
on gamma-ray propagation

- pair production: $\boldsymbol{\gamma + \gamma_{BKG} \rightarrow e^+ + e^-}$ $(E_{thr} = 2m_e c^2)$



  - double: $\boldsymbol{\gamma + \gamma_{BKG} \rightarrow e^+ + e^- + e^+ + e^-}$

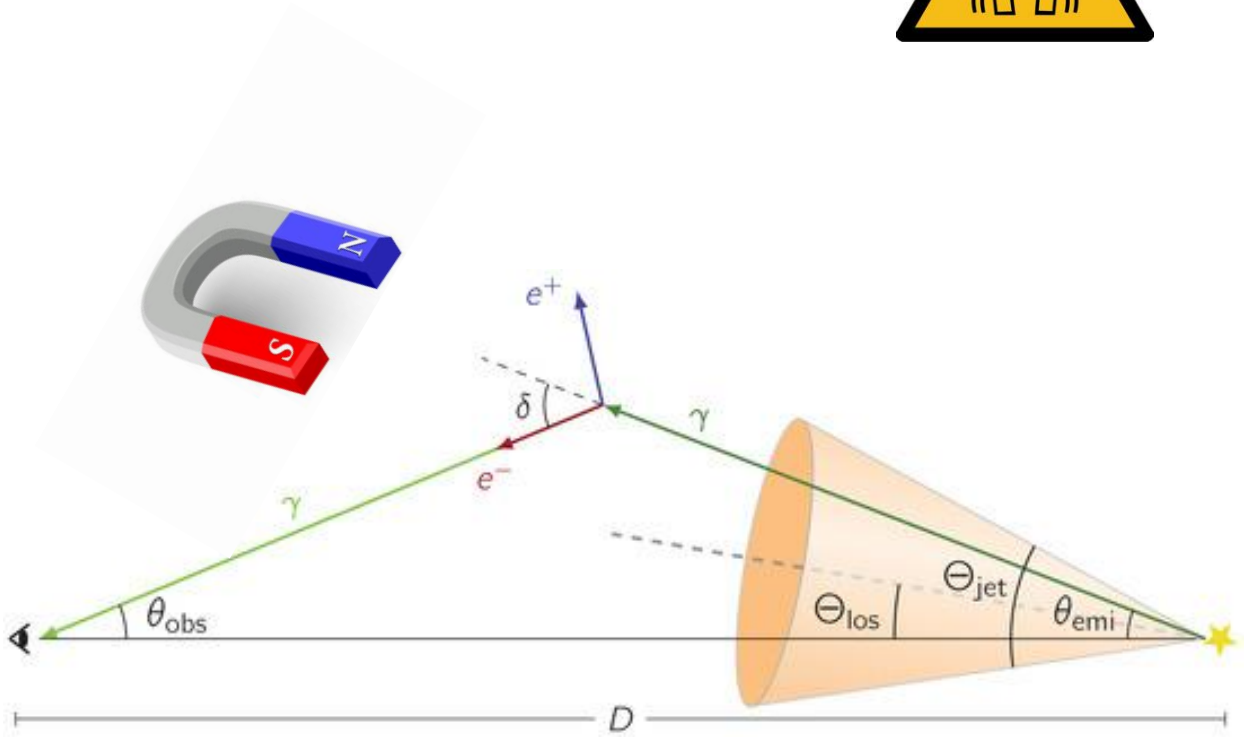
- inverse Compton scattering: $\boldsymbol{e + \gamma_{BKG} \rightarrow e + \gamma}$



  - triplet pair production: $\boldsymbol{e + \gamma_{BKG} \rightarrow e + e^- + e^+}$

$$\gamma_{BKG} \begin{cases} URB \rightarrow \text{Radio} & \textit{(Nitu+, 2021)} \\ CMB \rightarrow \text{MicroWave} & \textit{(Planck coll.+, 2018)} \\ EBL \rightarrow \text{UV, optical, IR} & \textit{(Gilmore+, 2012)} \end{cases}$$

«deflection» of gamma rays

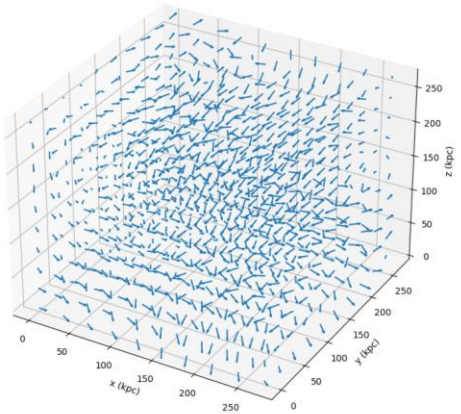


(Alves Batista & Saveliev, 2021)

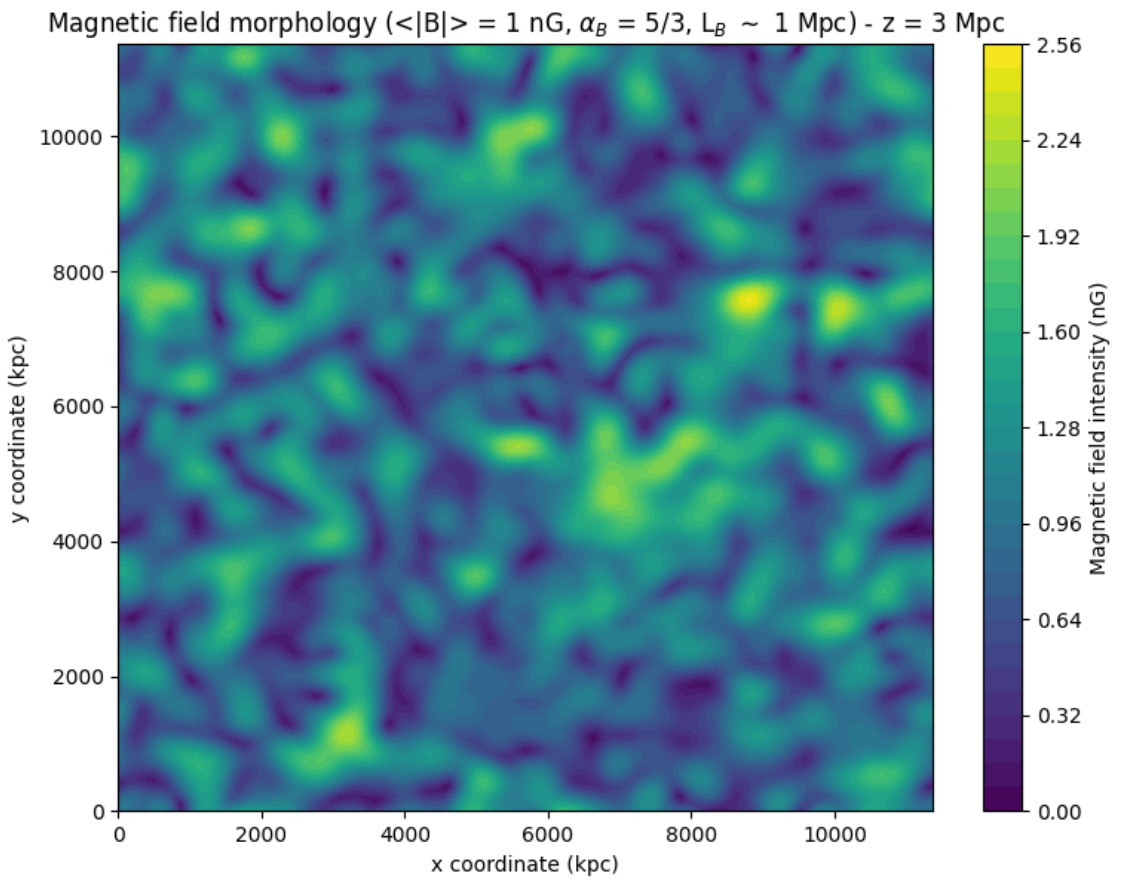
extragalactic magnetic field (EGMF)

Stochastic field's parameters:

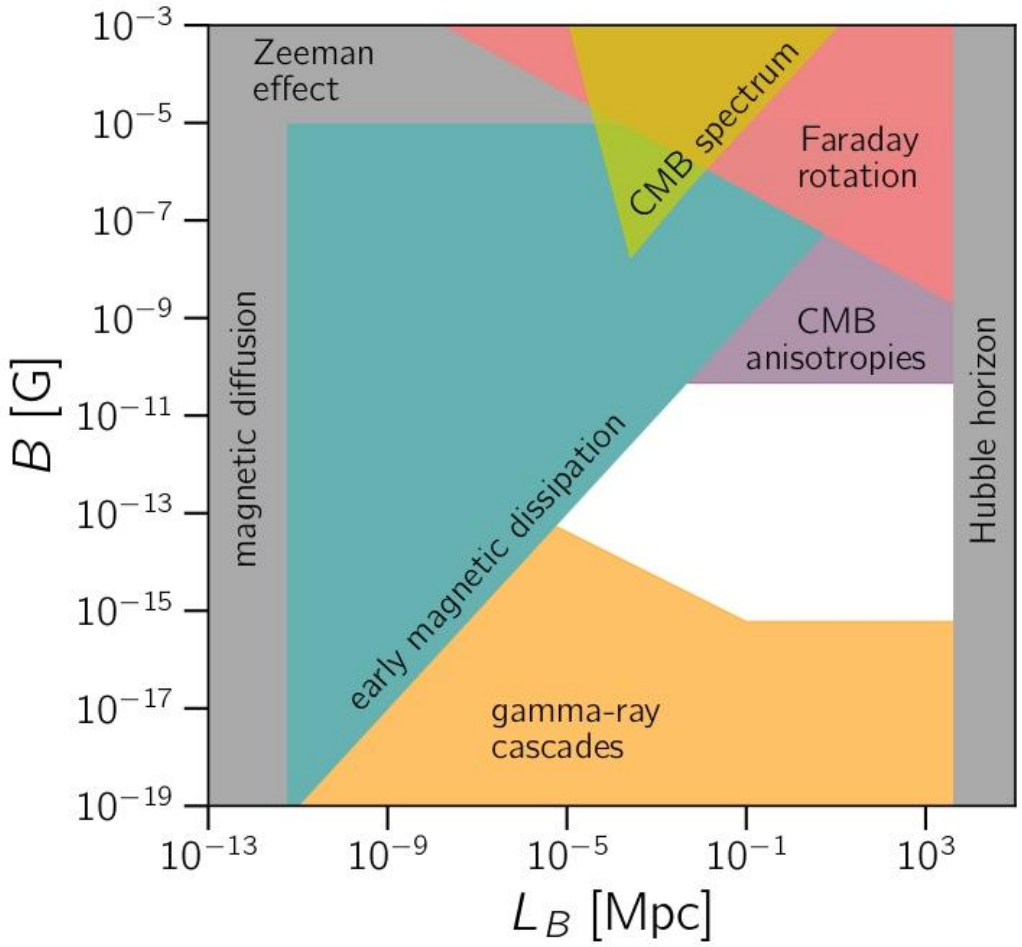
- root mean square $\boldsymbol{B_{rms}}$
- coherence length $\boldsymbol{L_B}$
- spectral energy index $\boldsymbol{\alpha_B}$
- helicity $\boldsymbol{H_B}$?



Kolmogorov spectrum



constraints on the EGMF



(Durrer & Neronov, 2013)
(Ackermann+, 2018) lower limits from Fermi-LAT

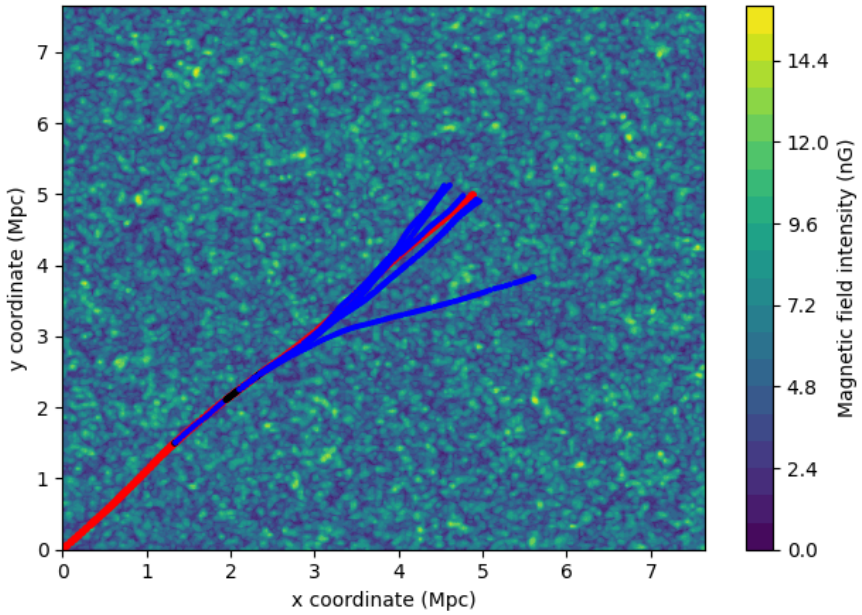
in the following:

- $\boldsymbol{L_B}$ fixed to 1 Mpc

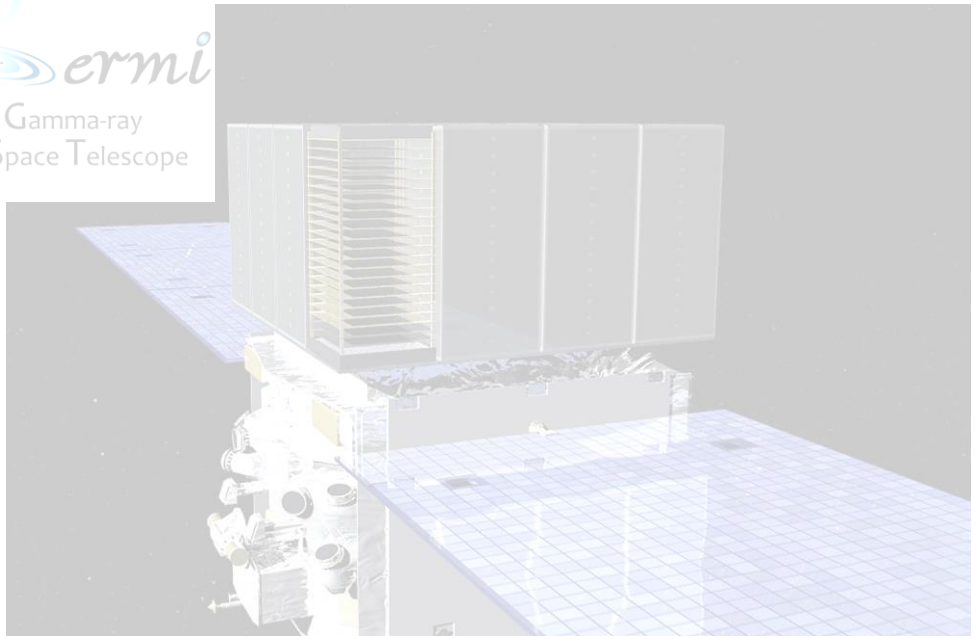
- $\boldsymbol{B_{rms}}$ alternatively 1e-16 G and 1e-17 G (and turned off)

simulation software

CRPropa *(Alves Batista +, 2022)*



Fermi Gamma-ray Space Telescope



Large Area Telescope: $20\ MeV \lesssim E_\gamma \lesssim 300\ GeV$

Constraining **ALPs properties with Gamma-ray data**: spectral distortion, spatial morphology...

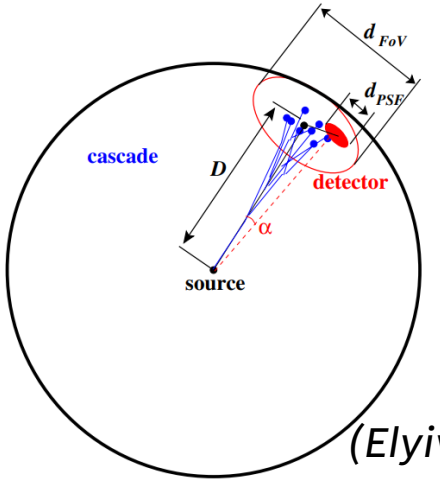
simulation setup

- magnetic field:

```
Bfield = SimpleGridTurbulence(turbSpectrum, gridprops, seed)
```

- «large sphere observer»:

```
obs = Observer()
obs.add(ObserverSurface(Sphere(Vector3d(0., 0., 0.) * Mpc, 606. * Mpc)))
sim.add(MinimumEnergy(10. * GeV))
sim.add(obs)
```



(Elyiv+, 2009)

- e.g. blazar 1ES 0229+200

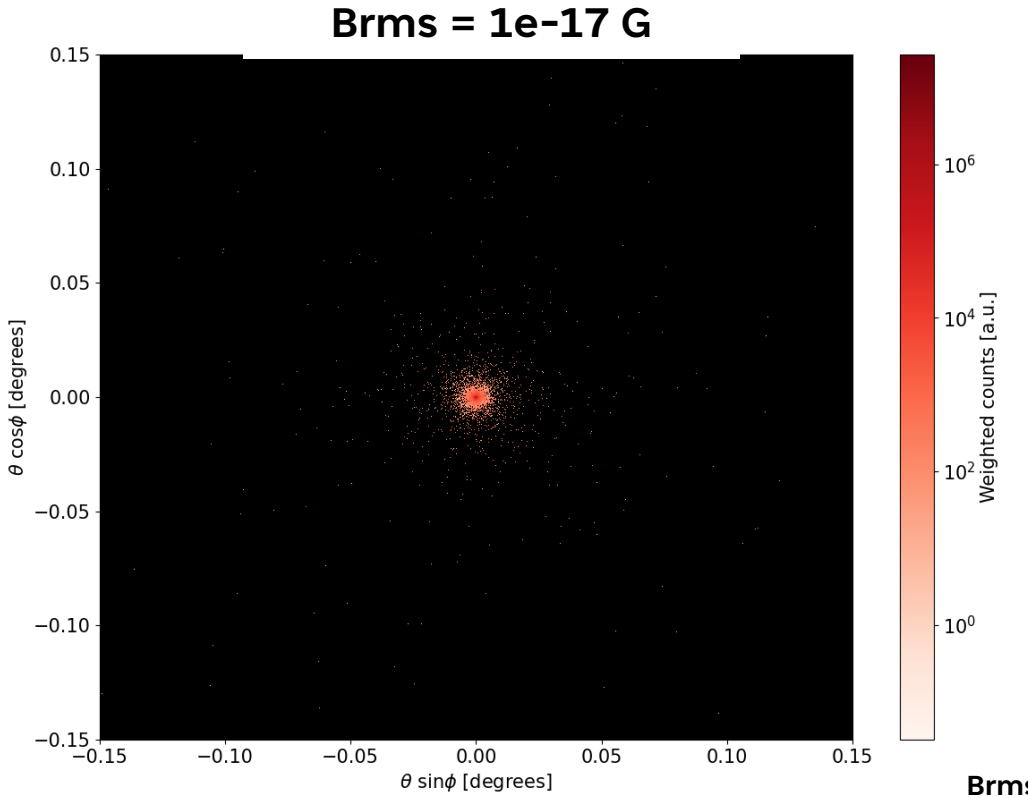
```
source = Source()
source.add(SourcePosition(Vector3d(0., 0., 0.) * Mpc))
source.add(SourceEmissionCone(Vector3d(-1., 0., 0.) * kpc, 0.1))
source.add(SourcePowerLawSpectrum(10 * GeV, 100 * PeV, specIndex))
source.add(SourceParticleType(22))
source.add(SourceRedshift(0.14))
```

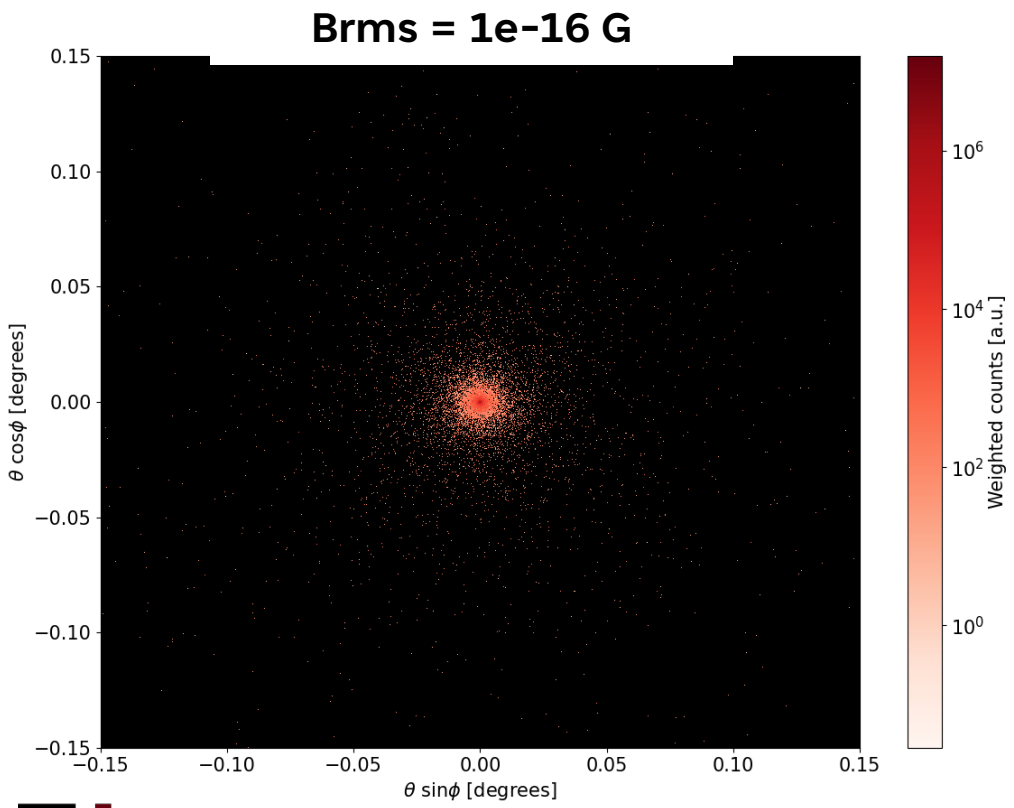
→ specIndex = -1.5, Ecutoff = 5 TeV

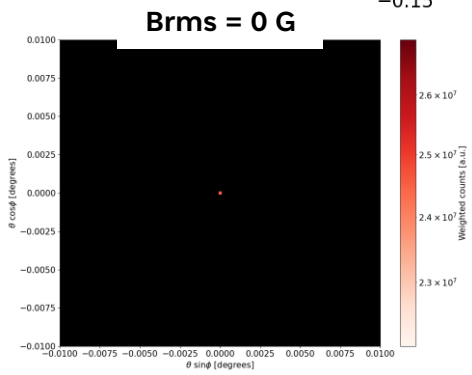
→ `sim.run(source, 1000)` x10 → total injected events: **1e4**

low statistics!

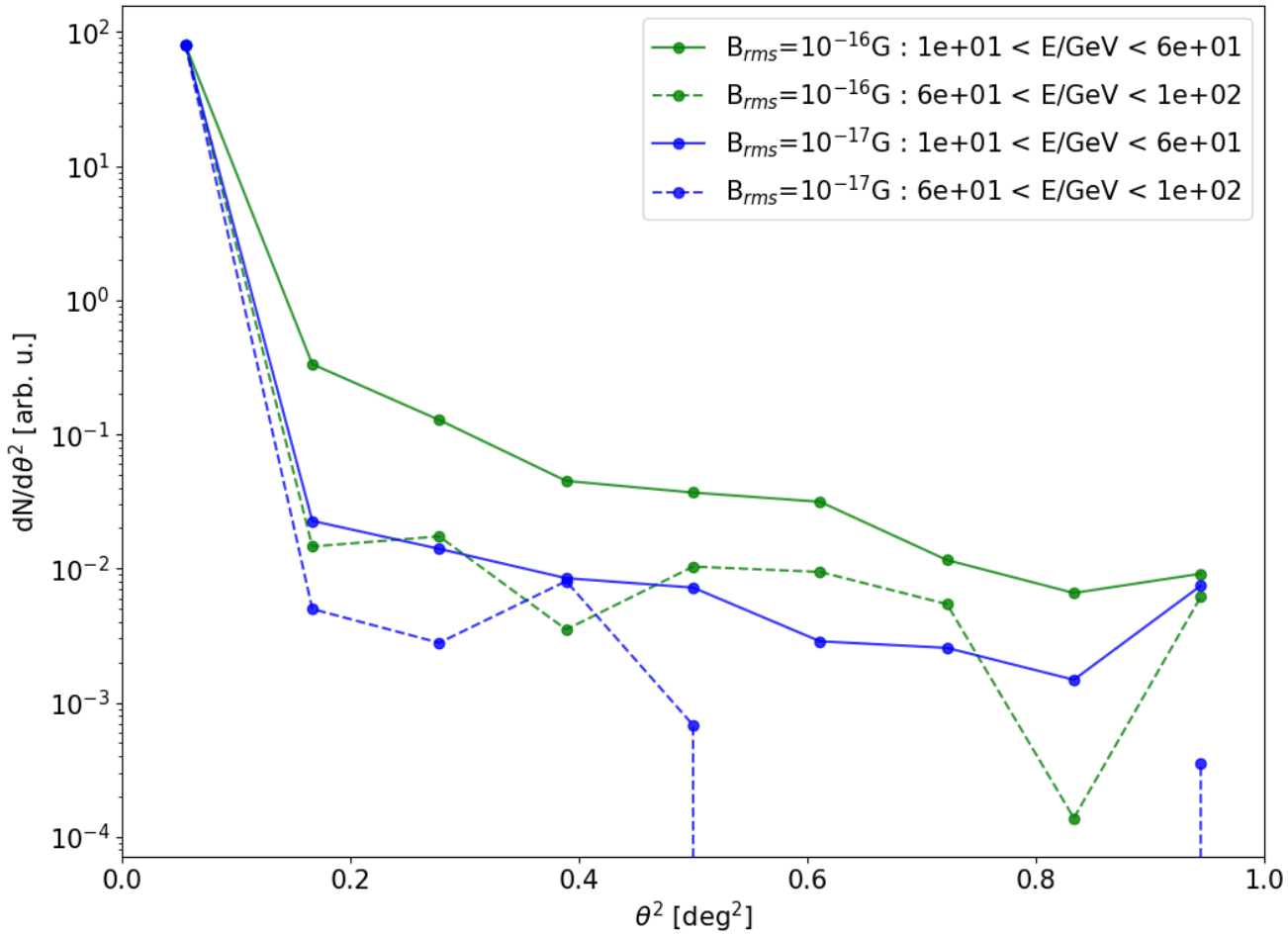
arrival directions





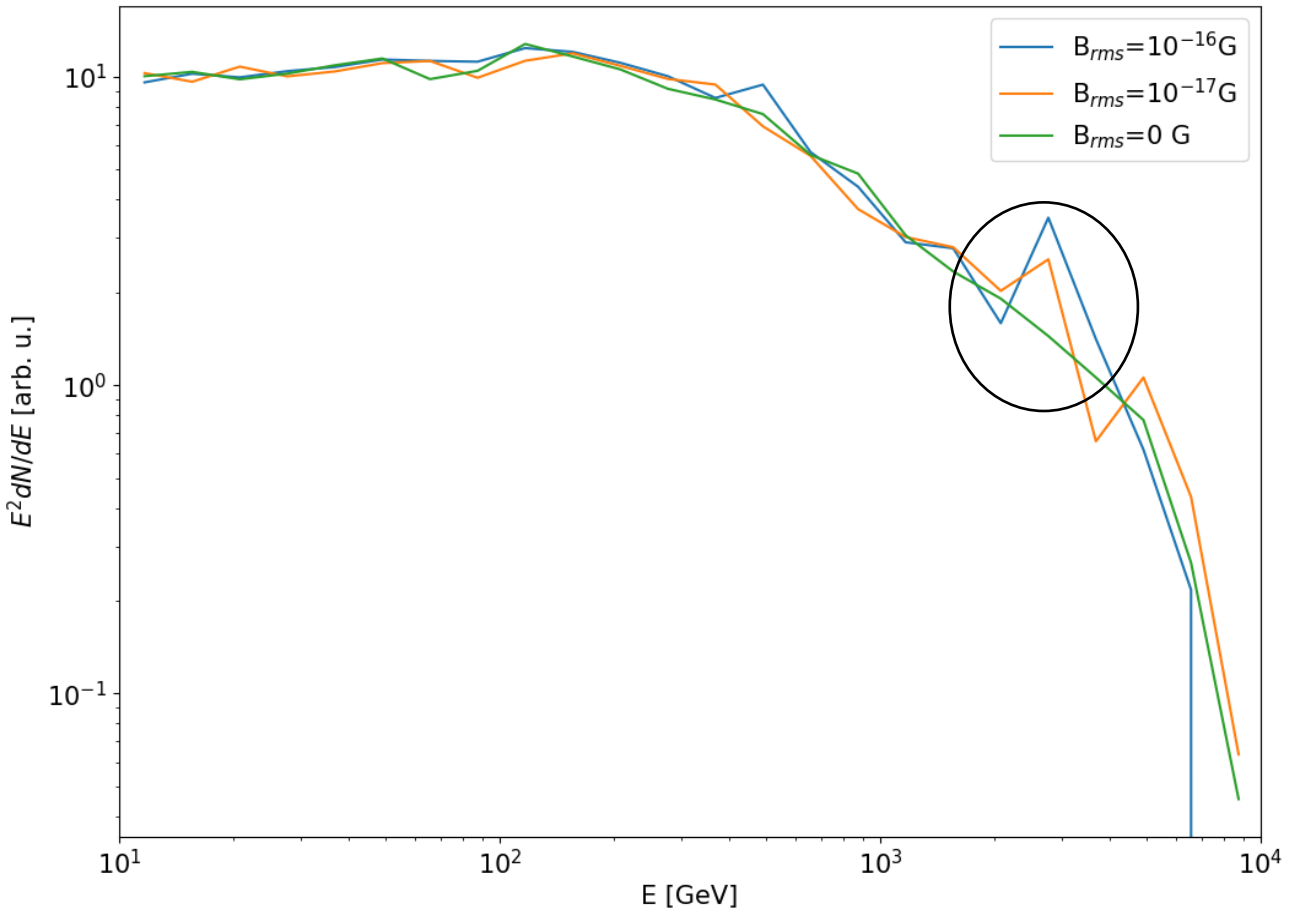


surface brightness



large contribution to the halo from the lowest energy photons

spectral energy distribution

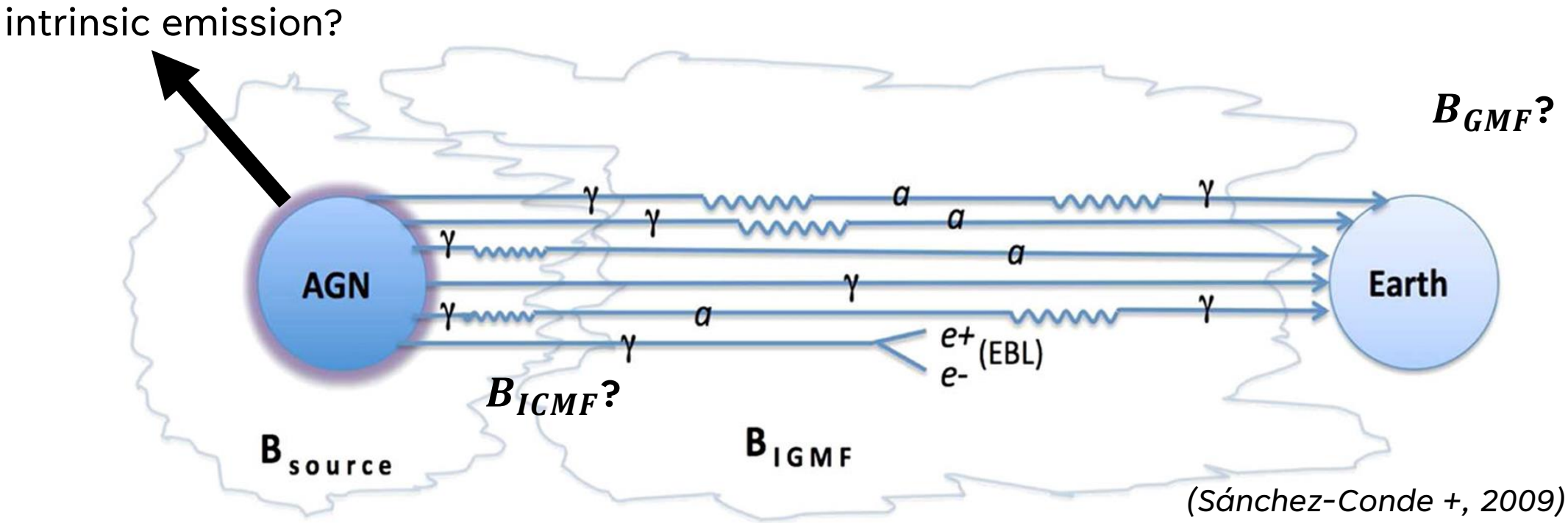


dramatic differences would have been seen at lower energies or by increasing the Brms

perspectives in searching for axion-like particles (ALPs), dark matter candidate...

gamma/ALP mixing in astrophysical environments

$$\mathcal{L}_{ALP-\gamma} = g_{a\gamma}\, \boldsymbol{E} \cdot \boldsymbol{B}_{ext}\, a$$



(Sánchez-Conde +, 2009)

constraints m_a & $g_{a\gamma}$

H.E.S.S. observing PKS 2155-304
(Abramowski +, 2013)

from Fermi-LAT
observations of NCG 1275
(Ajello +, 2018)

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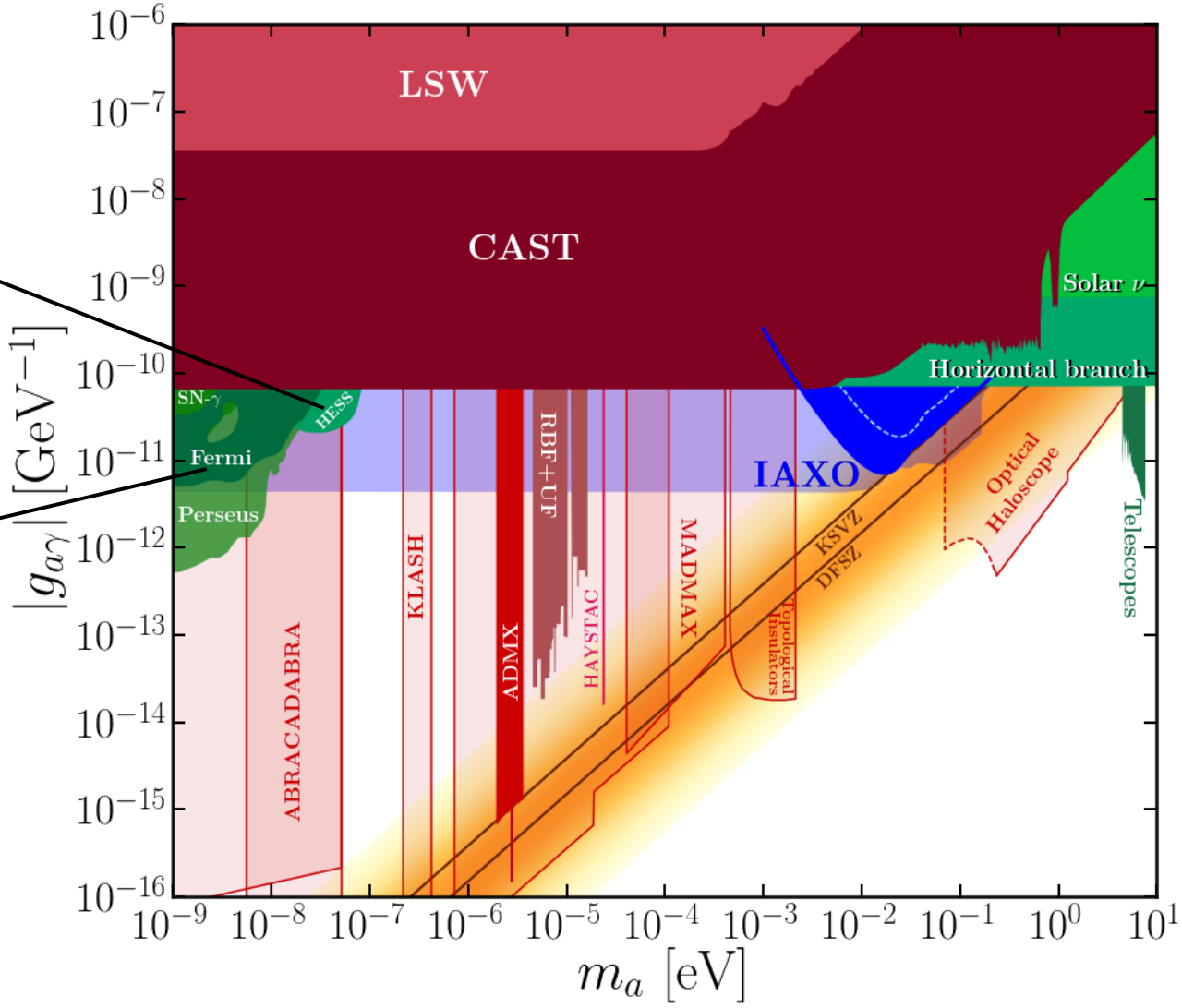
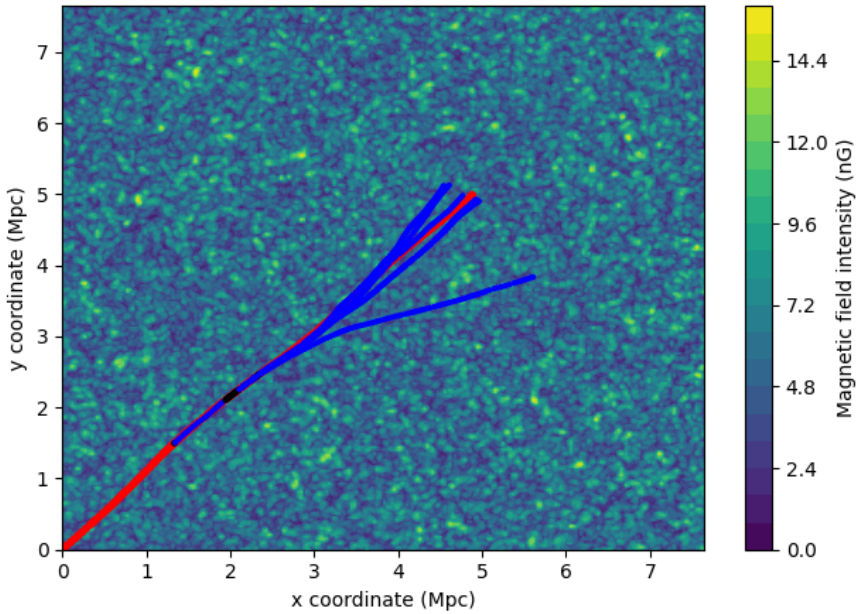
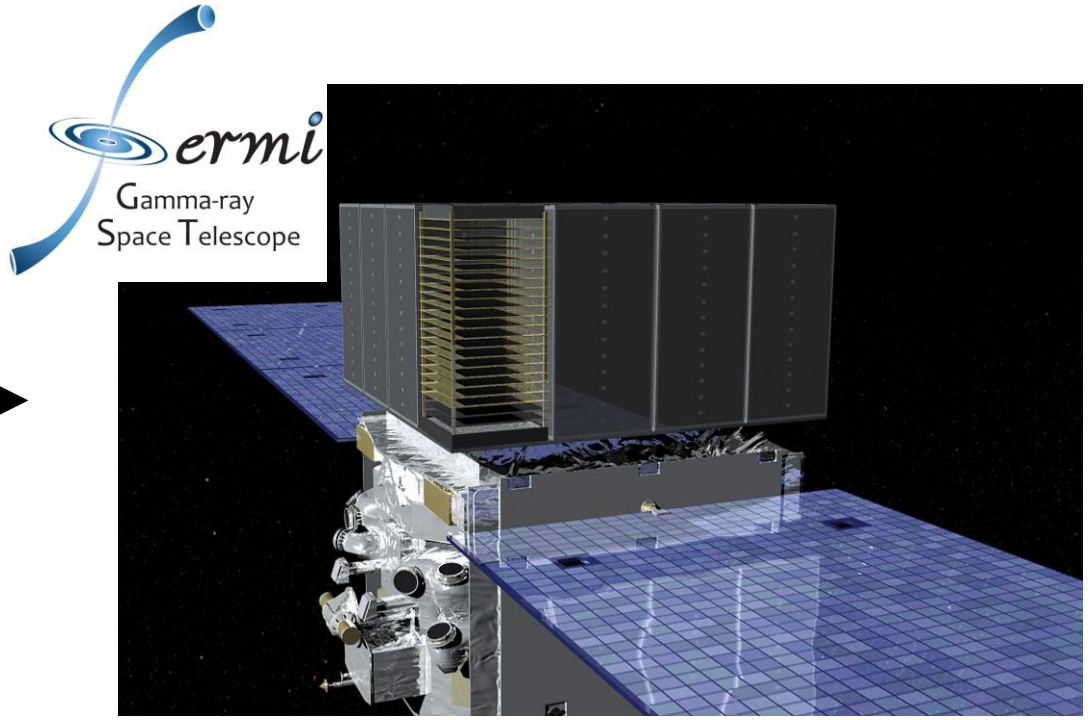


(Ciaran +, 2018)

sinergy between gamma-ray simulations & observations

CRPropa *(Alves Batista +, 2022)*





Large Area Telescope: $20\ MeV \lesssim E_\gamma \lesssim 300\ GeV$

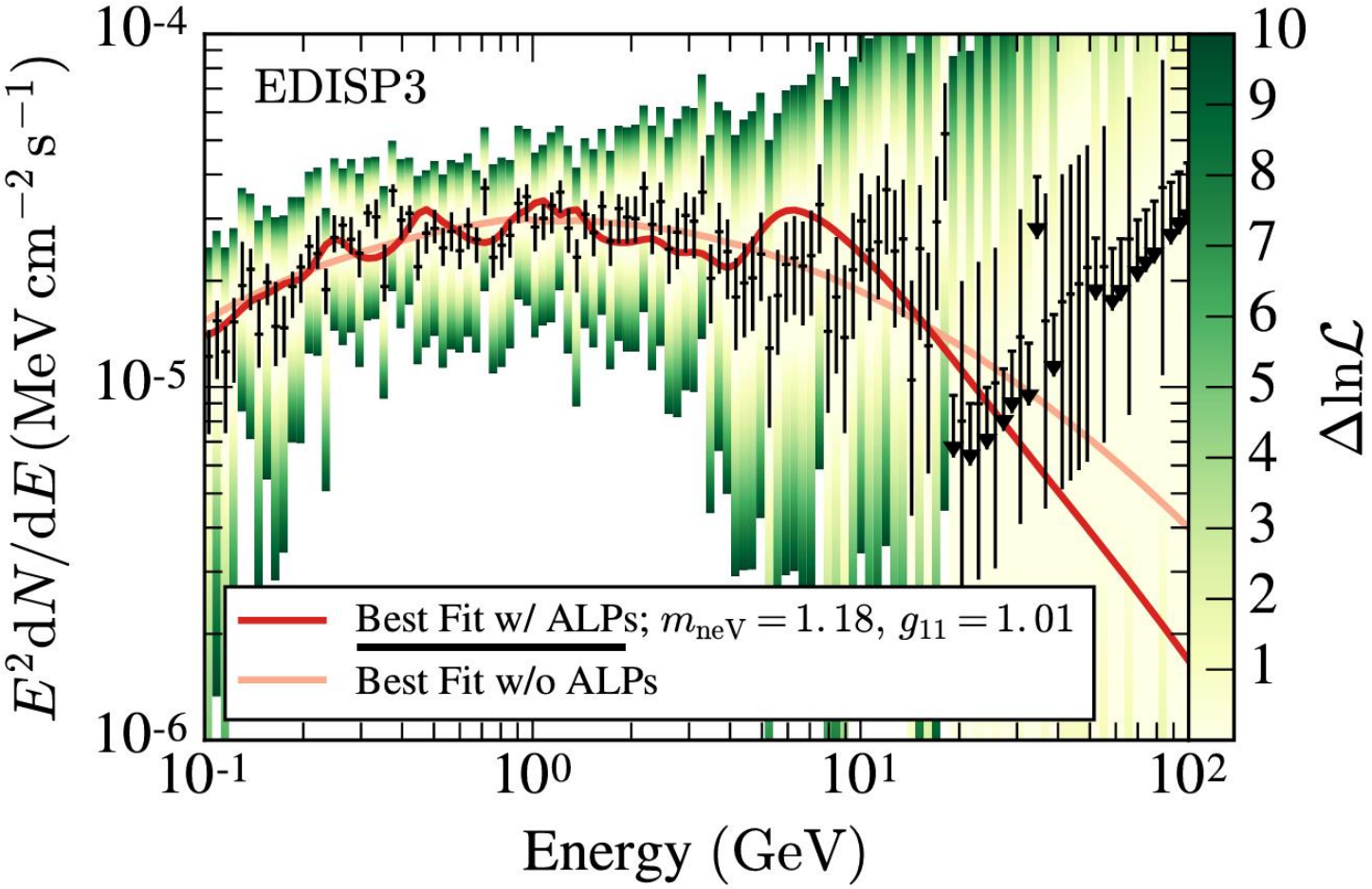
\+ to constrain **ALPs properties with gamma-ray data** (spectral distortion, spatial morphology...) taking into account the propagation effects, as before

thanks!

questions? comments?

backup...

FERMI-LAT ALPs SEARCH IN PERSEUS GALAXY CLUSTER



(Ajello +, 2018)

Considering only the **Turbulent Intra Cluster** Magnetic field