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Intergalactic magnetic field studies by means of γ-ray emission from GRB 190114C

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Cosmic Magnetism in Voids & Filaments – 25.01.2023

Fermi Gamma-ray Space Telescope

Probing the "weakest" IGMF through pair echoes from GRBs

Since the pairs are deviated, the cascade emission is also delayed:

$\cdot \lambda_B >> D_E$

$$T_{\rm delay} \approx 7 \times 10^5 \left(1 - \tau^{-1}\right) (1+z)^{-5} \left[\frac{E}{0.1\ \rm TeV}\right]^{-5/2} \left[\frac{B}{10^{-18}\ \rm G}\right]^2 \rm s$$

$\cdot \lambda_B << D_E$

$$T_{\rm delay} \approx 10^4 \left(1 - \tau^{-1}\right) (1+z)^{-2} \left[\frac{E}{0.1\ \rm TeV}\right]^{-2} \left[\frac{B}{10^{-18}\ \rm G}\right]^2 \left[\frac{\lambda_{B_0}}{1\ \rm kpc}\right] \rm s$$

Hence the cascade flux is strongly diluted:

$$F_{\rm delay} \sim \frac{T}{T + T_{\rm delay}} F_0$$

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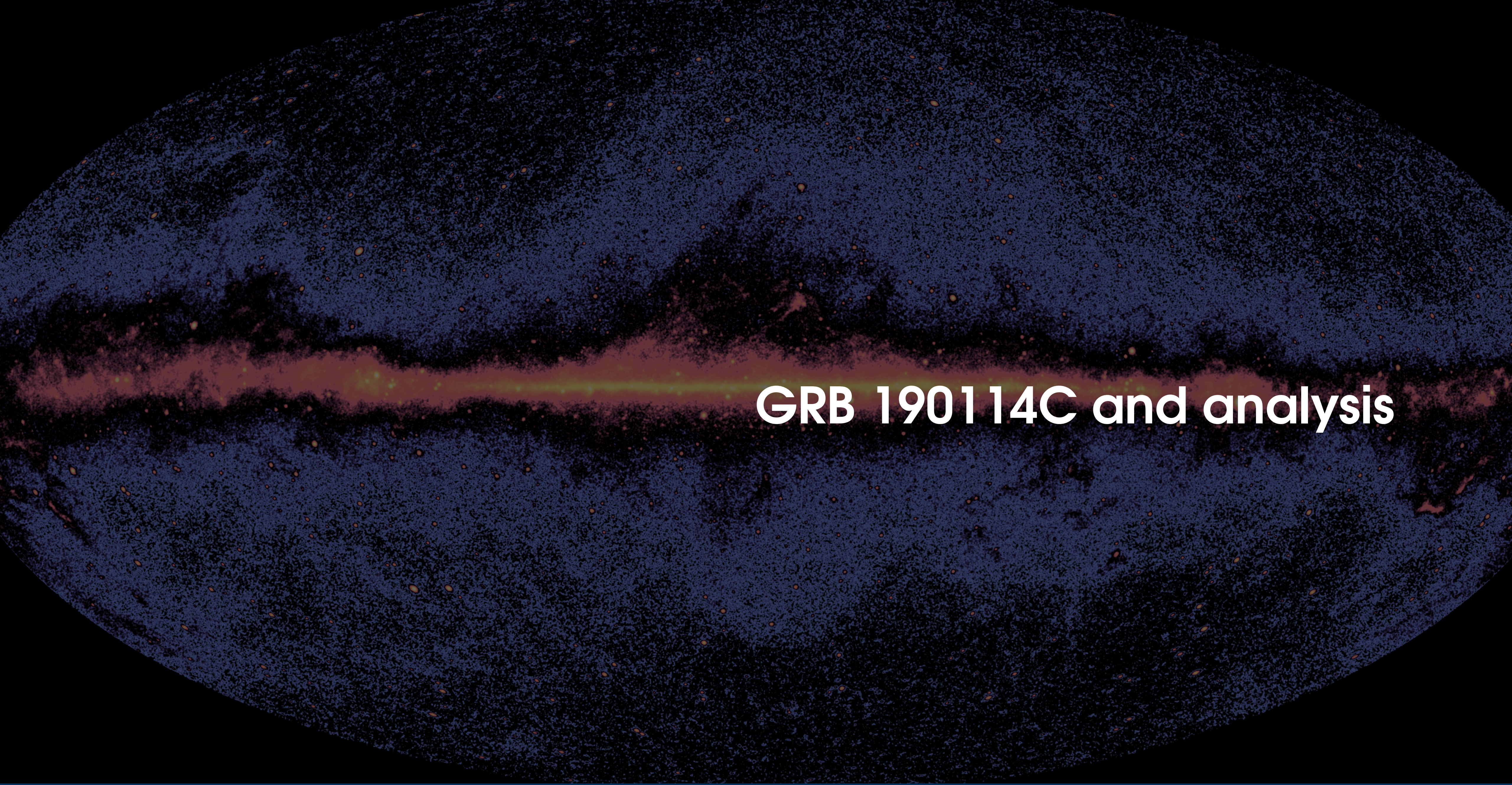
Motivation

We want to constrain the IGMF with no steady GeV emission to handle

Previous works on GRB 190114C are in disagreement: different, but not physically motivated SEDs assumed

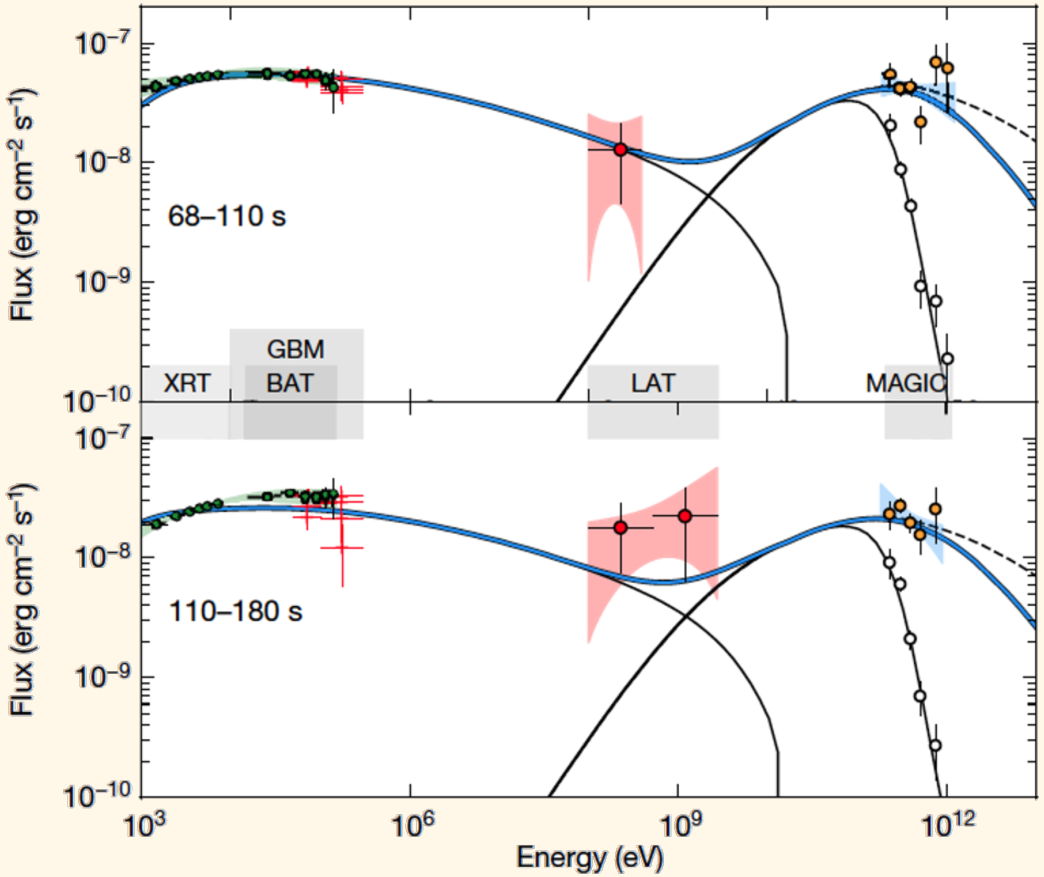


GRB 190114C and analysis

VHE SED: Synchrotron Self-Compton model

We use the SSC VHE model of the emission seen by MAGIC above 200 GeV

$$\frac{dN}{dE} \propto \left(\frac{E}{0.4\ \mathrm{TeV}}\right)^{-2.5-0.2\cdot\log(E/0.4\ \mathrm{TeV})}$$

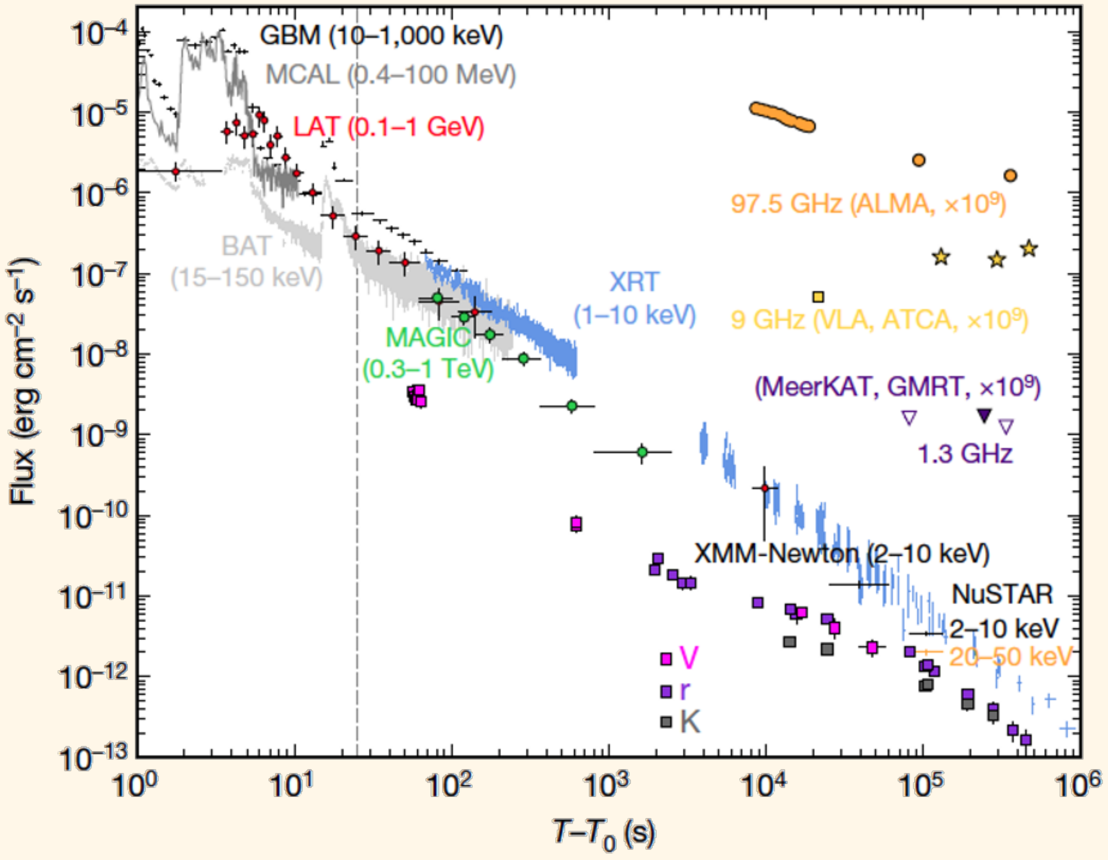


MAGIC Collaboration et al. 2019

VHE light curve: the afterglow

The flux is extrapolated to $T_0 + 6$ s, seemingly the beginning of the afterglow

The analysis is started at $T_0 + 2 \cdot 10^4$ s, when the last photon associated with the GRB itself in the GeV band is detected



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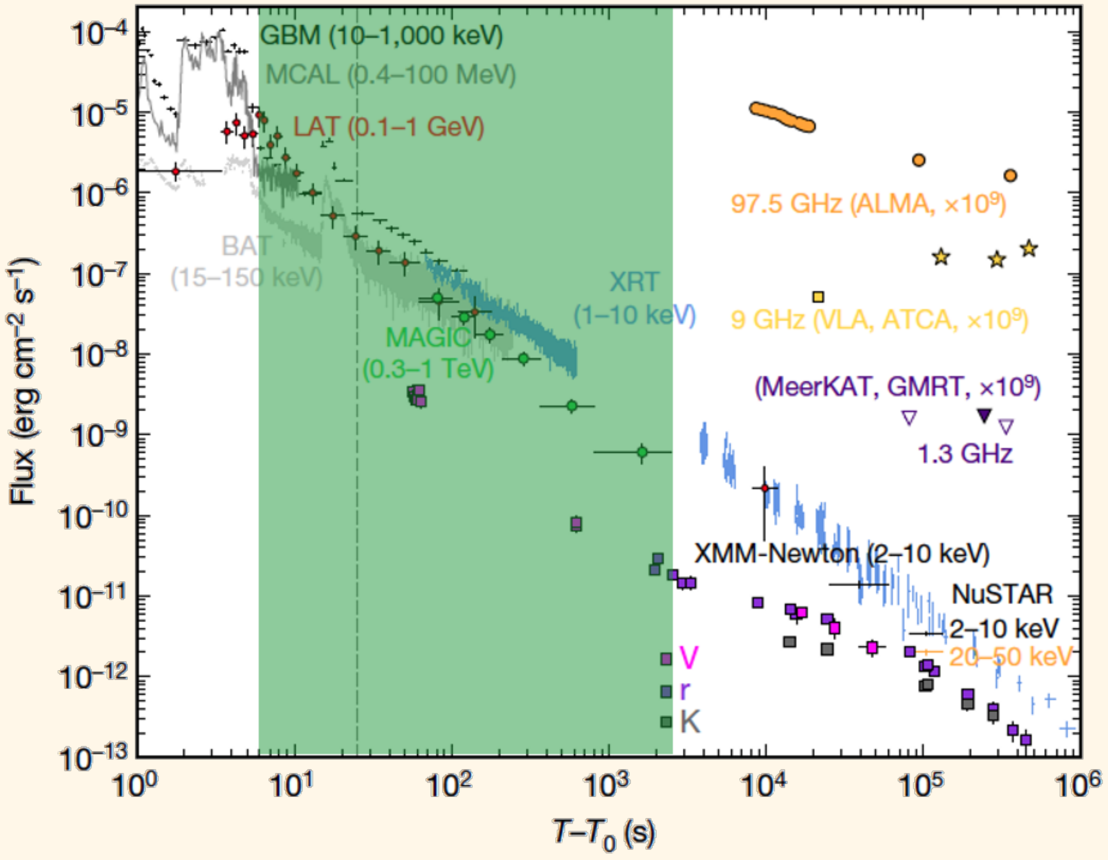

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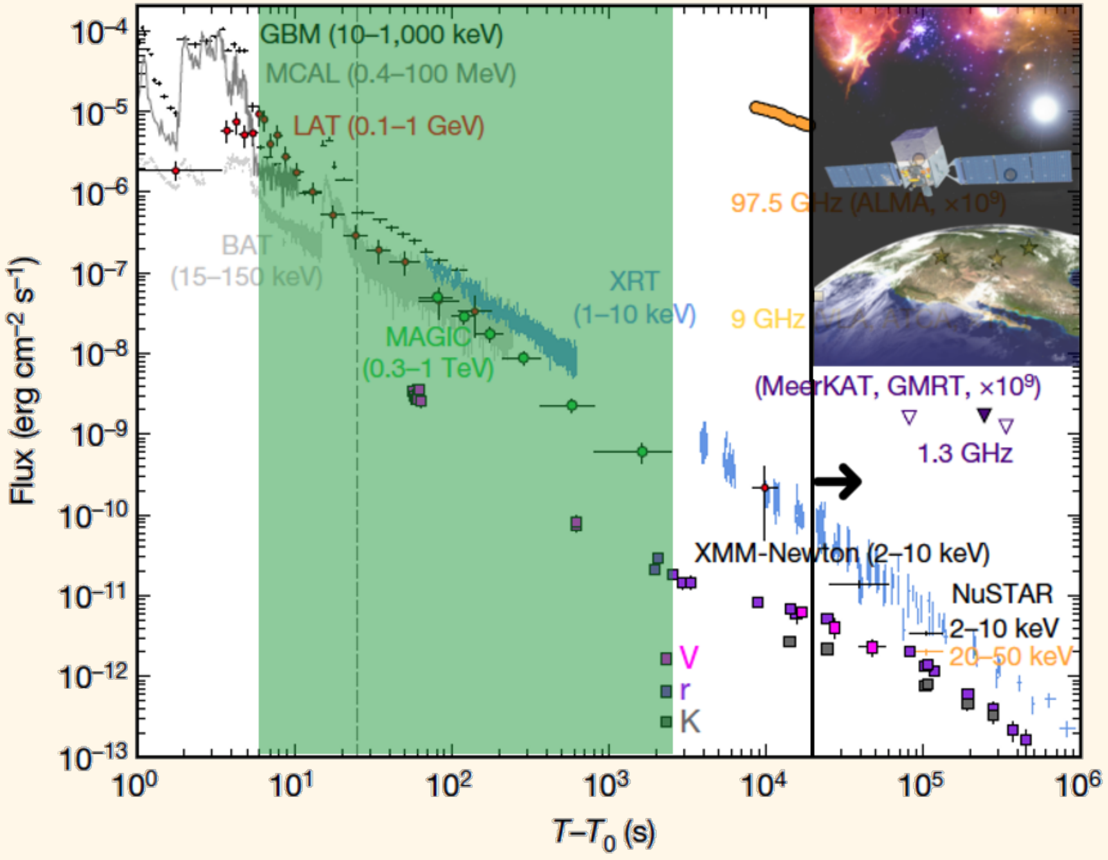

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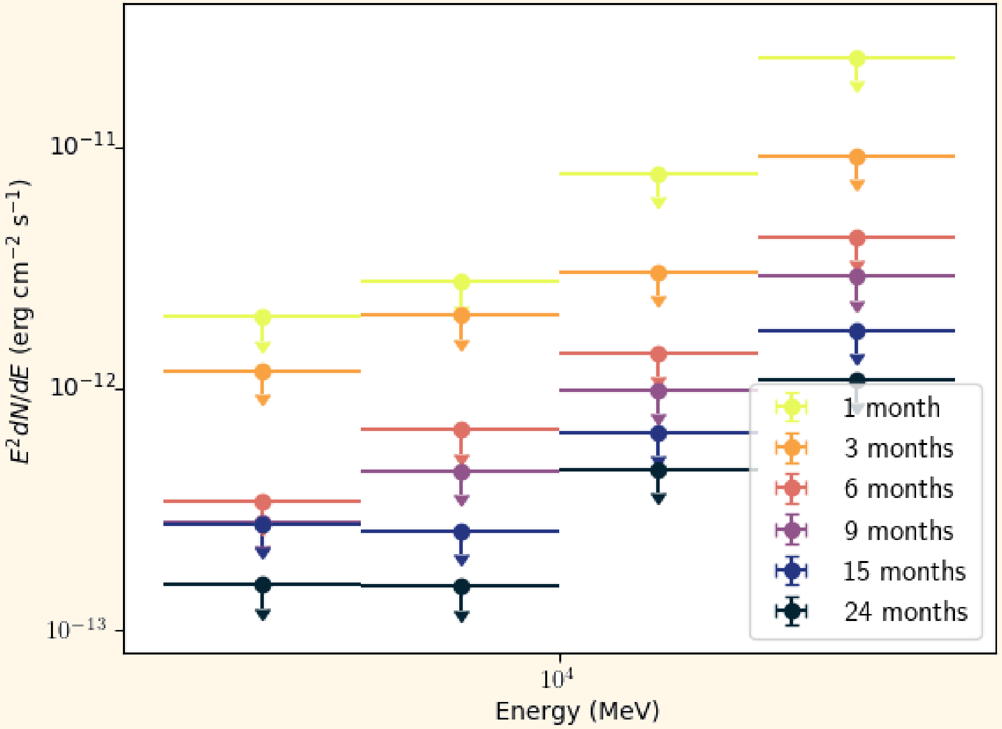
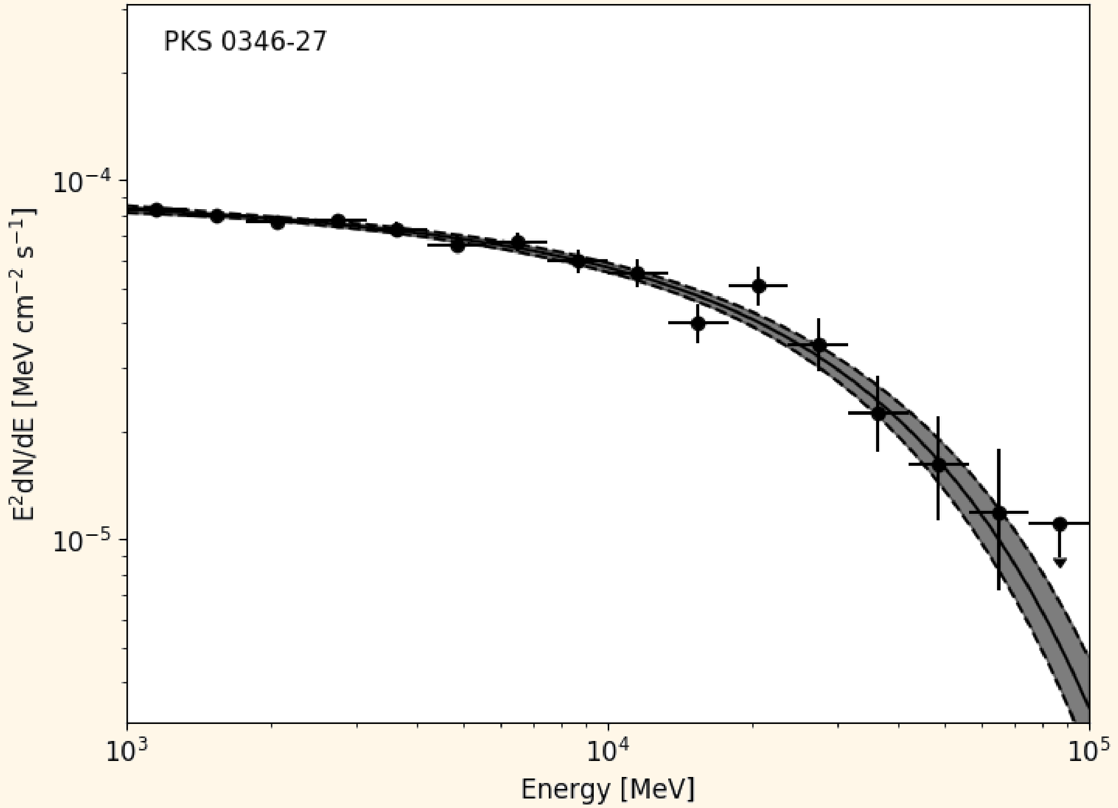
LAT analysis



Above 1 GeV: optimized to reduce Earth-limb contamination, maximize exposure

We tested different integration times: 0.5, 1, 3, 6, 9, 15, 24 months. $TS \sim 0$ in all cases. No cascade detection

PKS 0346-27 flaring: additional background source



The blazar PKS 0346-27 has been flaring intermittently during the whole observation window

Spectral shape not properly accounted in the 4FGL model: need for power law with exponential cut-off

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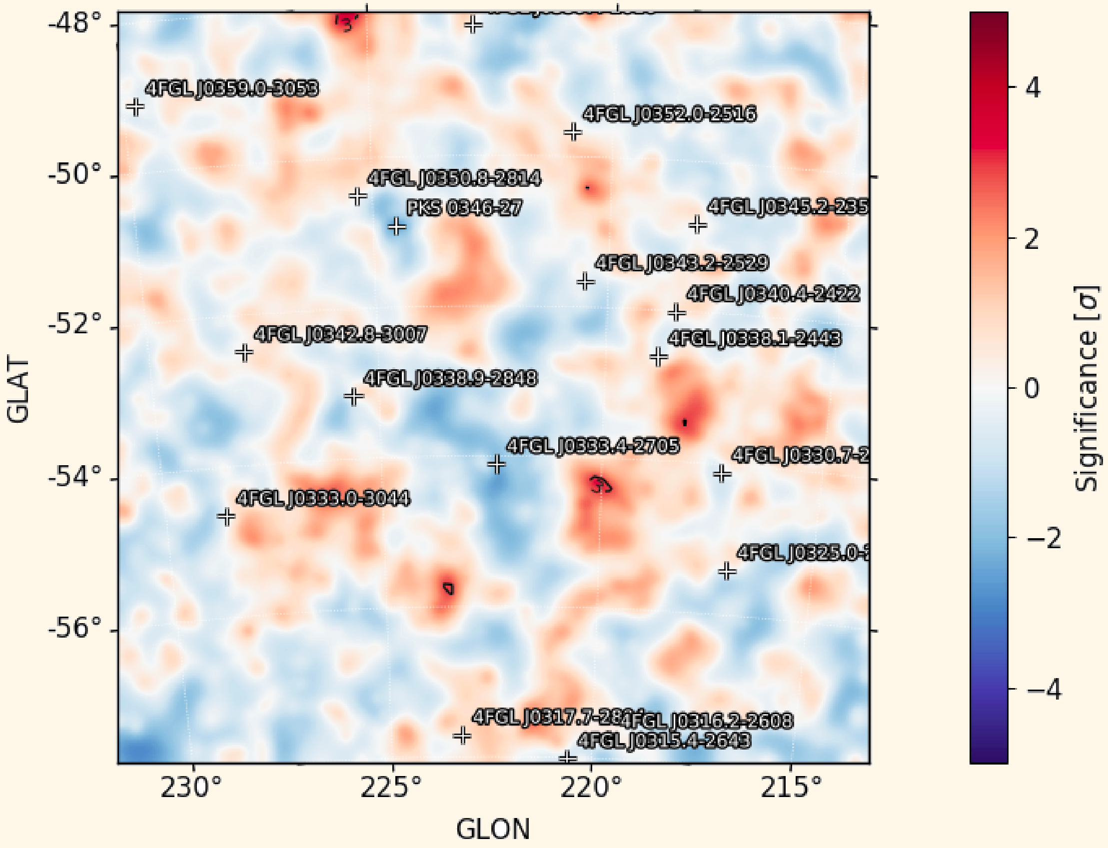

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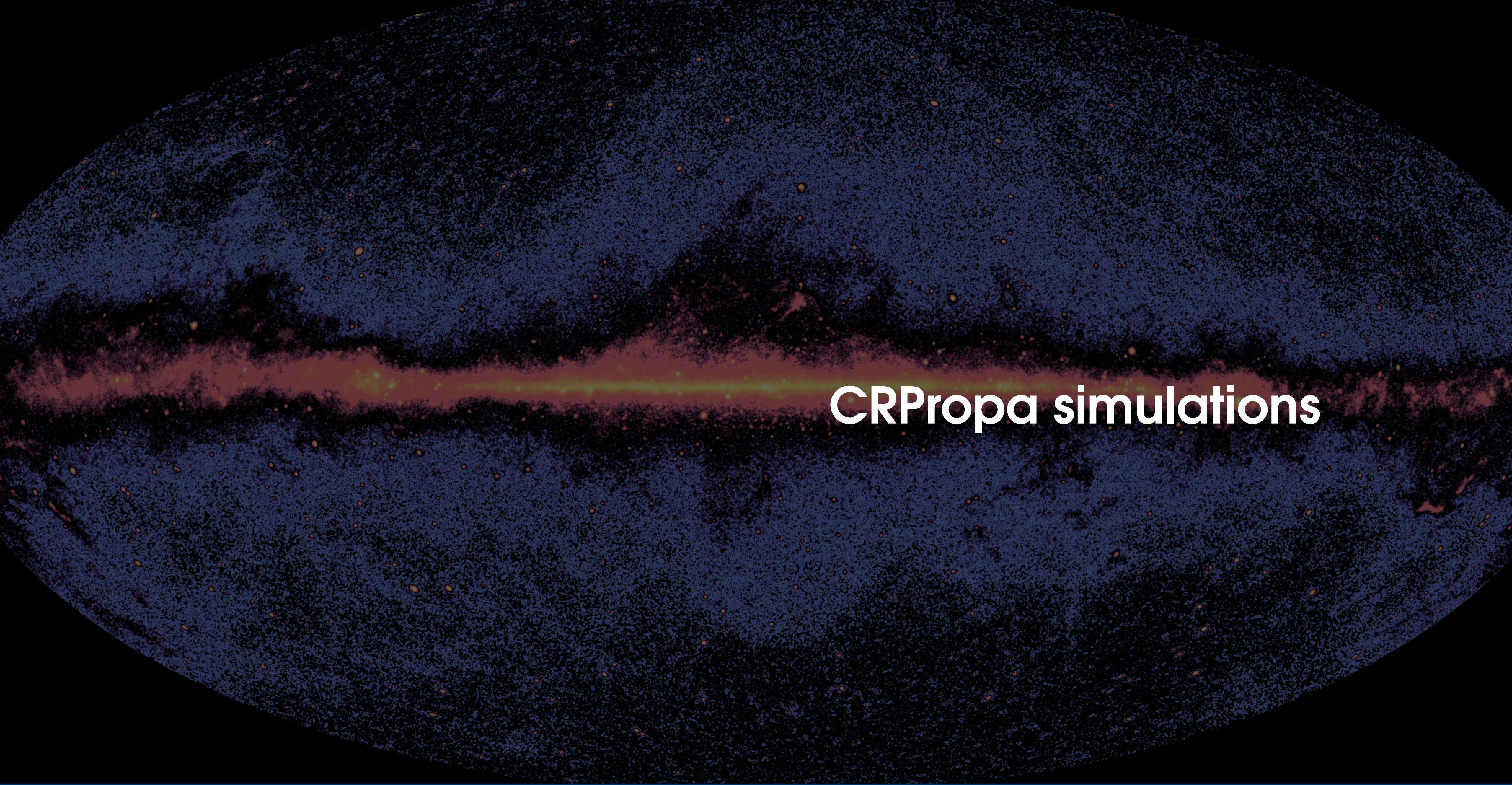


CRPropa simulations

CRPropa settings

Source:

- Point-like
- Redshift: $z = 0.42$
- Spectrum: Logparabola up to different maximum energies
- Minimum energy injected: 0.05 GeV

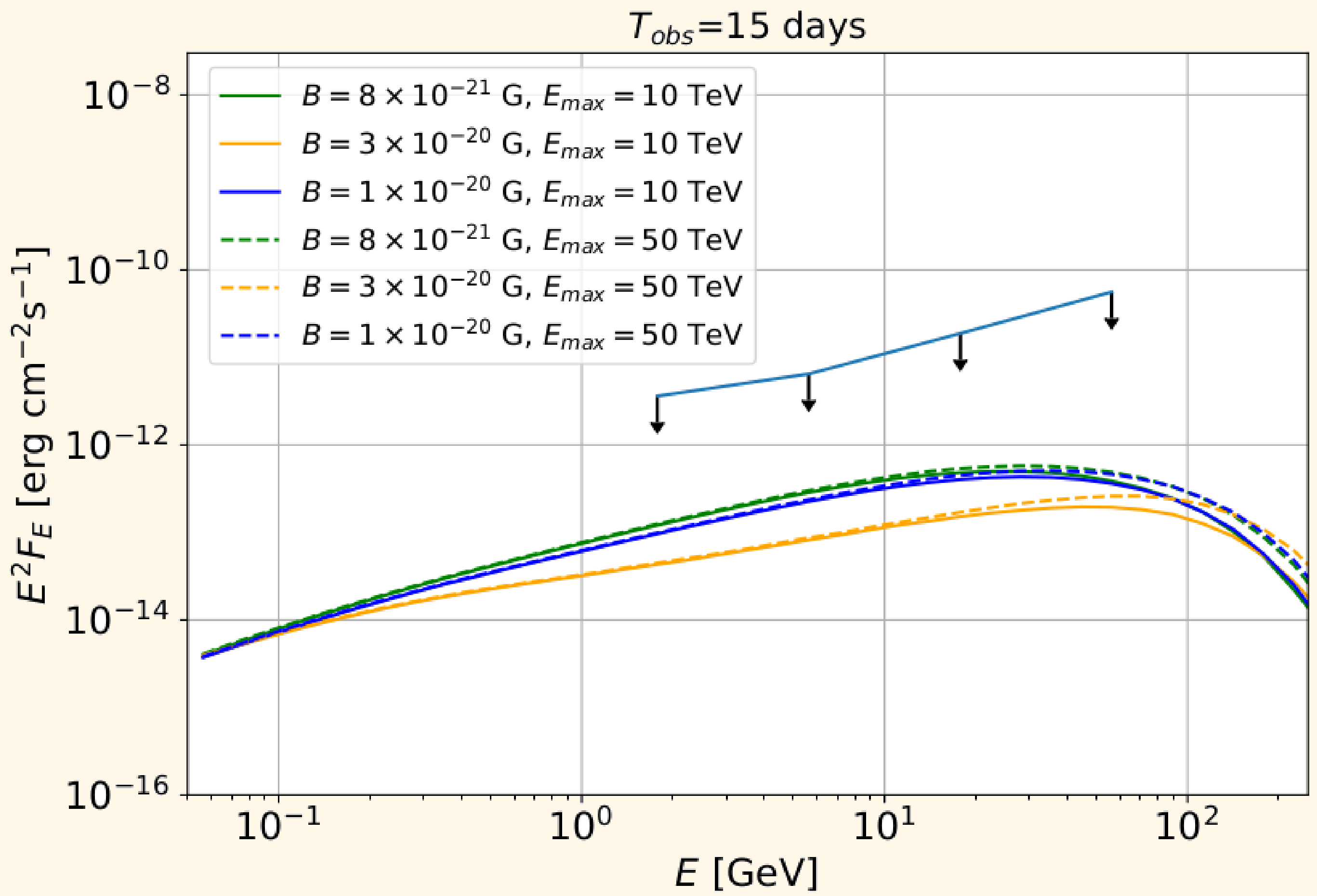
Magnetic field:

- Turbulent magnetic field with a Kolmogorov spectrum and different B_{rms}
- Correlation length $\lambda_B \gtrsim 1$ Mpc

Framework:

- Sphere of radius 1.6 Gpc with the source at the centre
- Temporal resolution: tracing particles with accuracy of ~ 3 hours

SEDs: Simulation vs LAT upper limits



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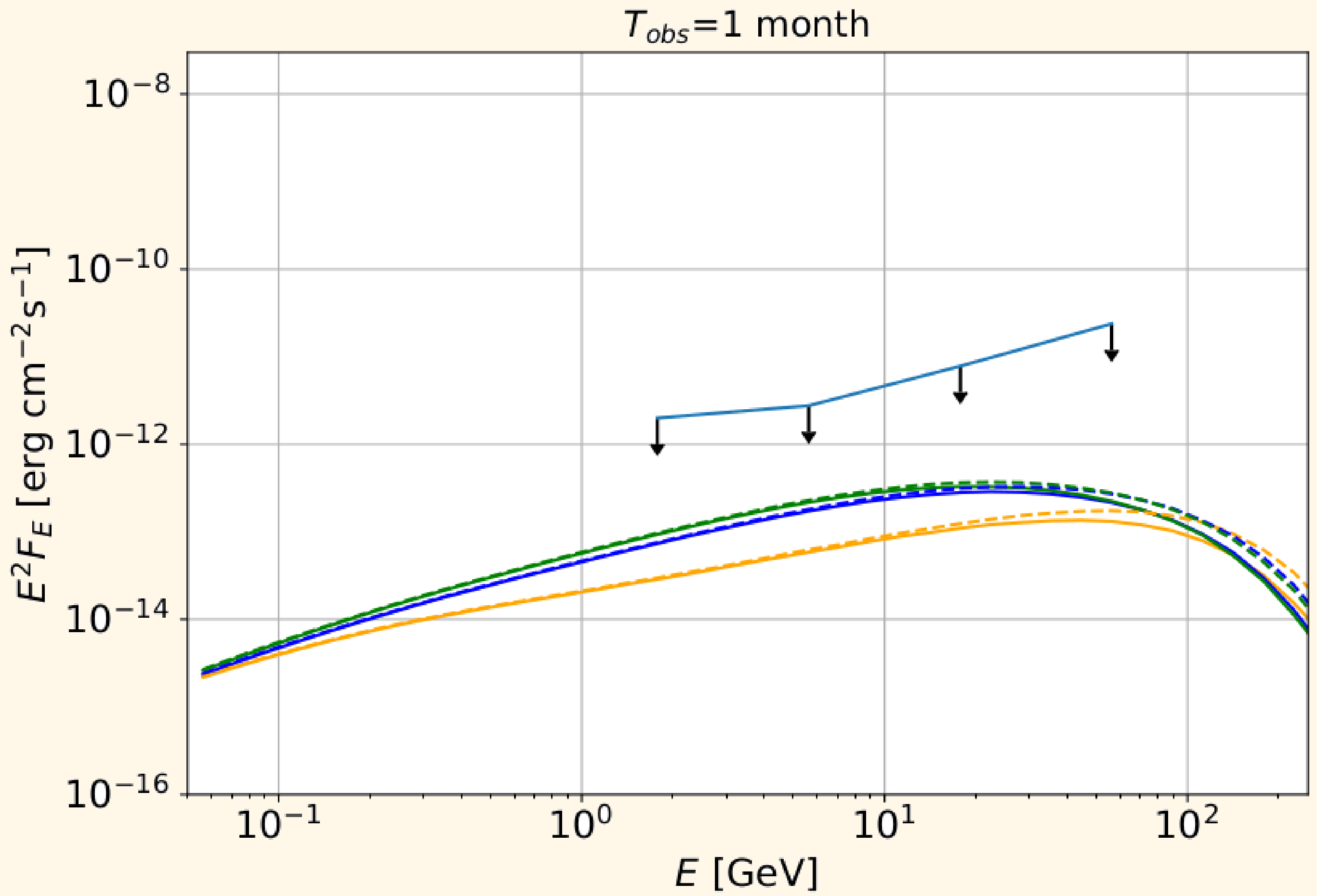

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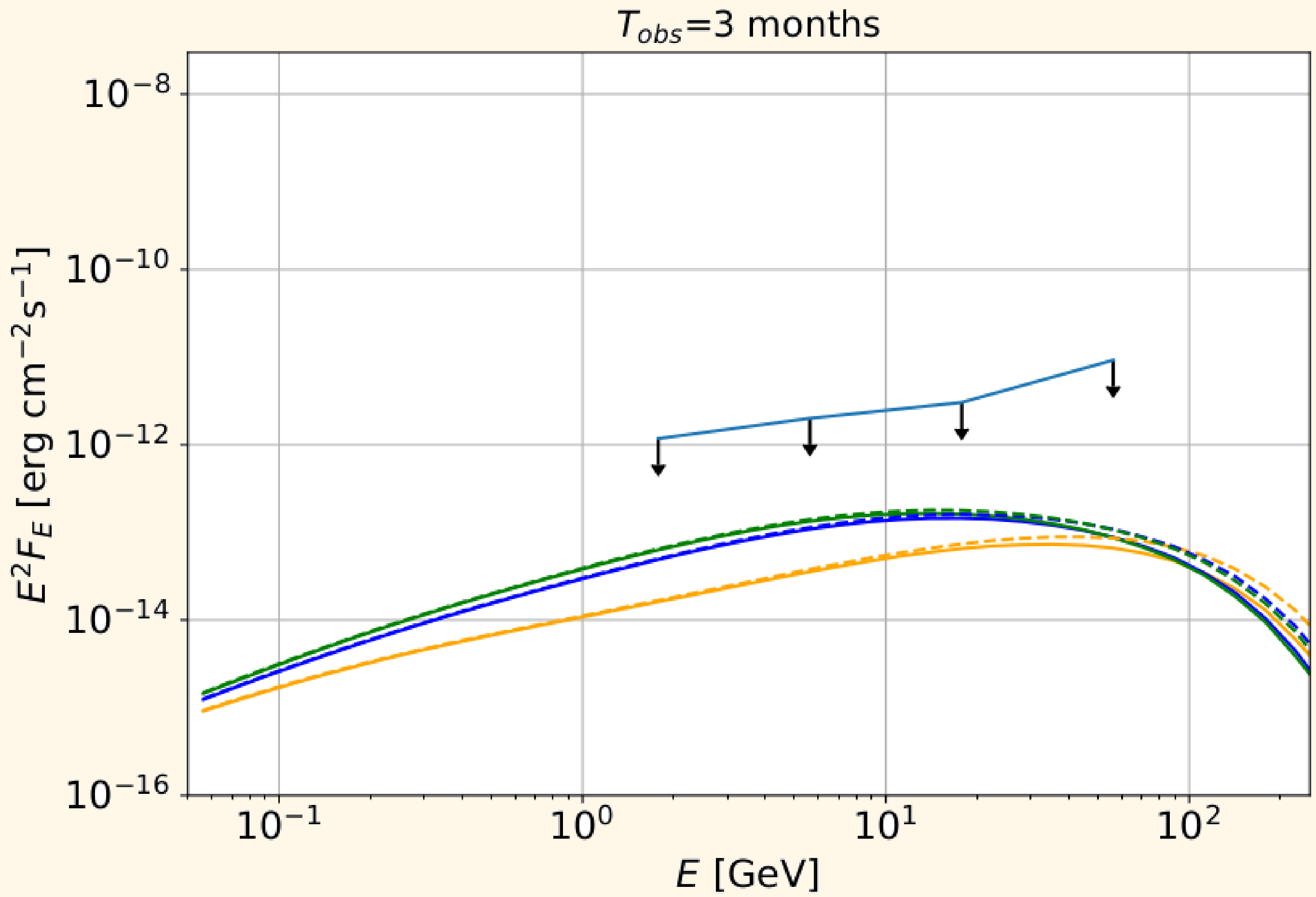

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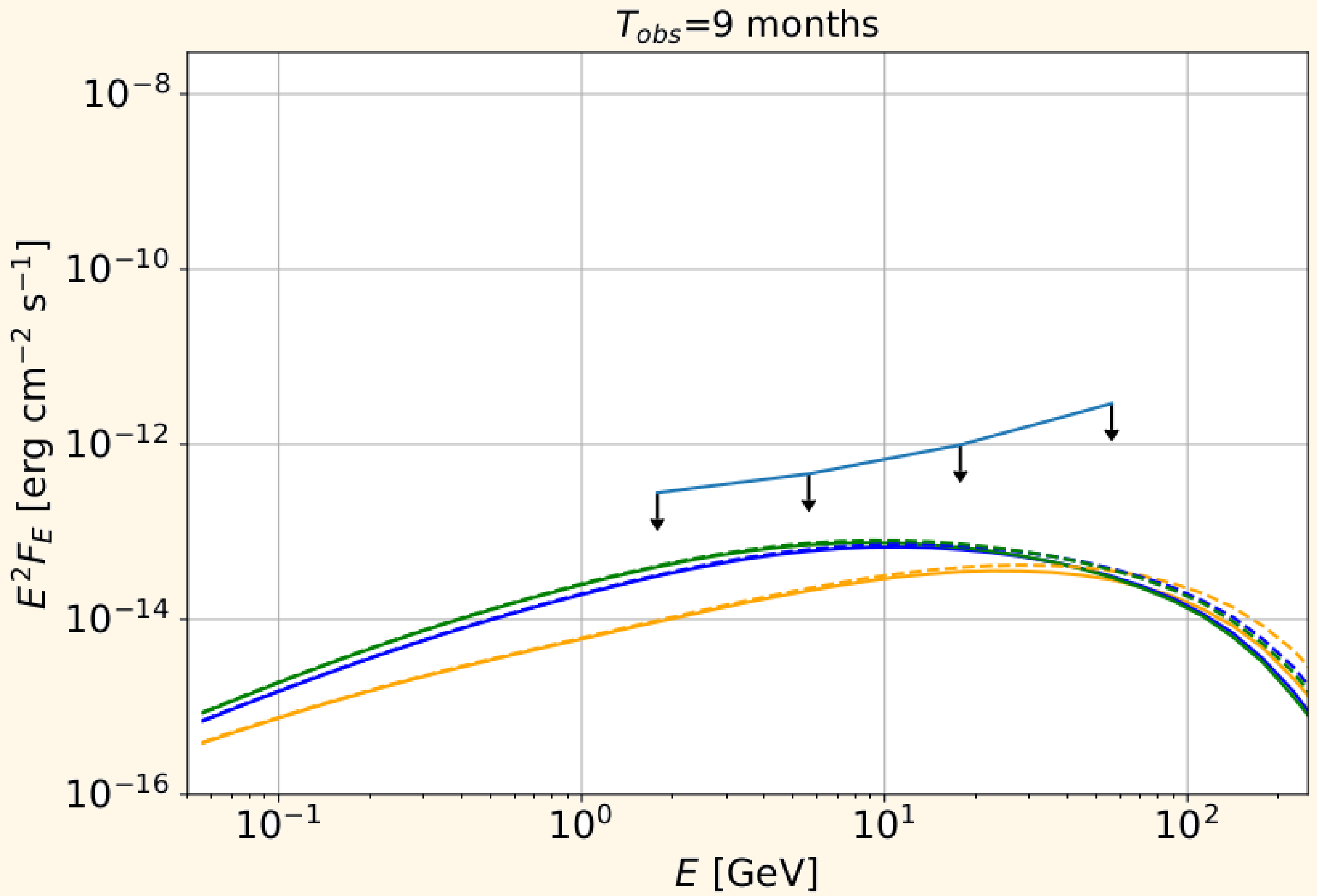

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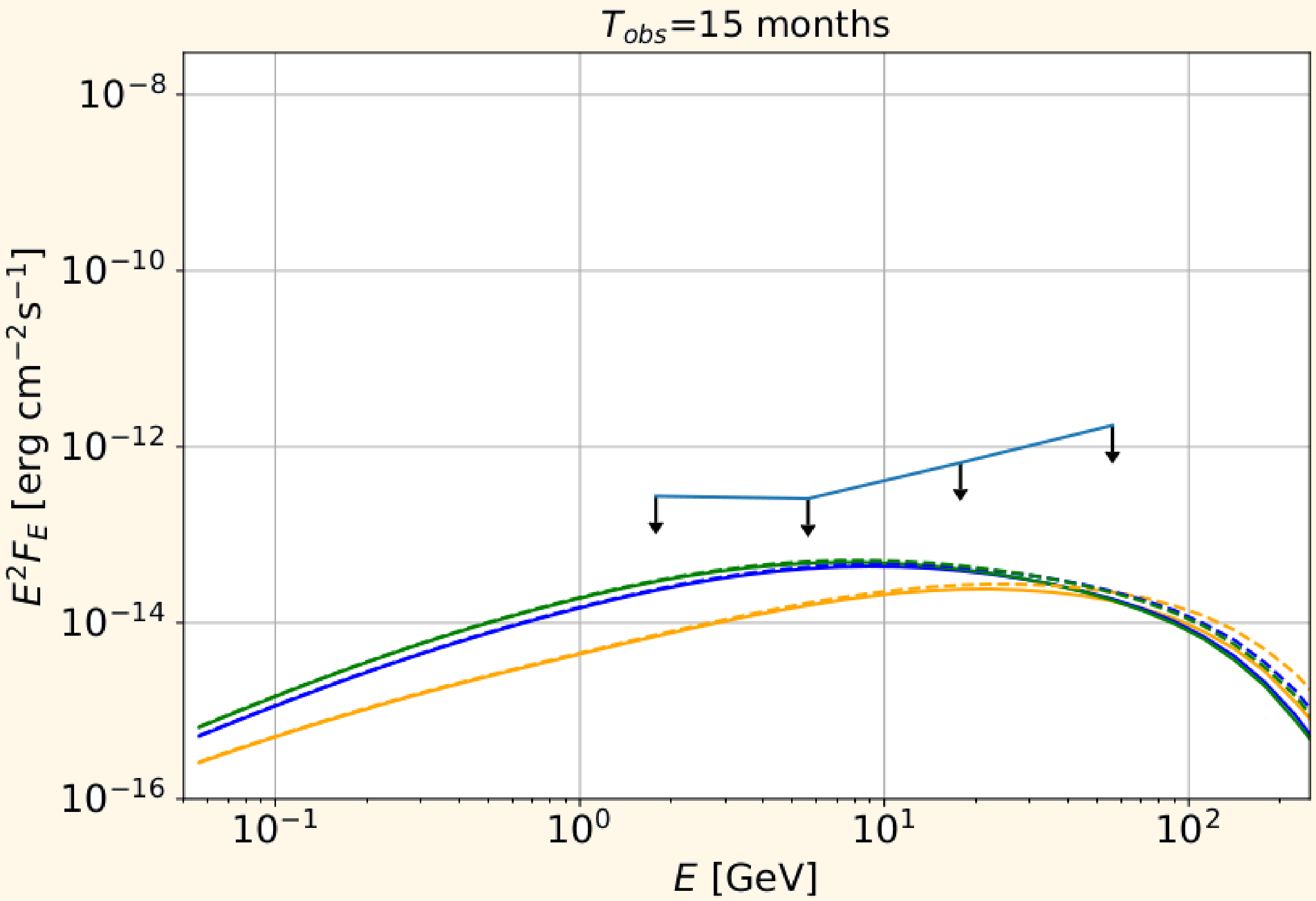

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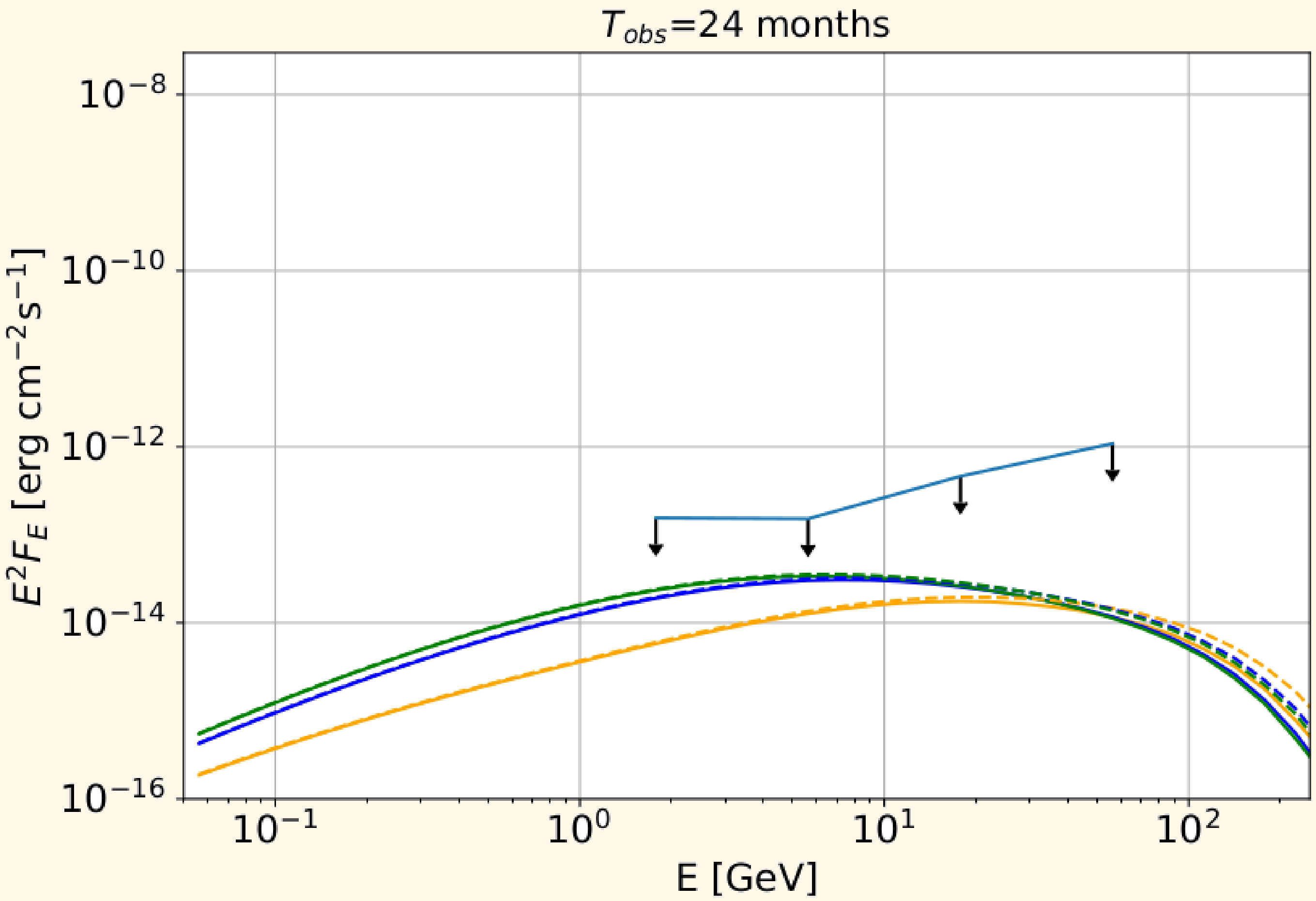

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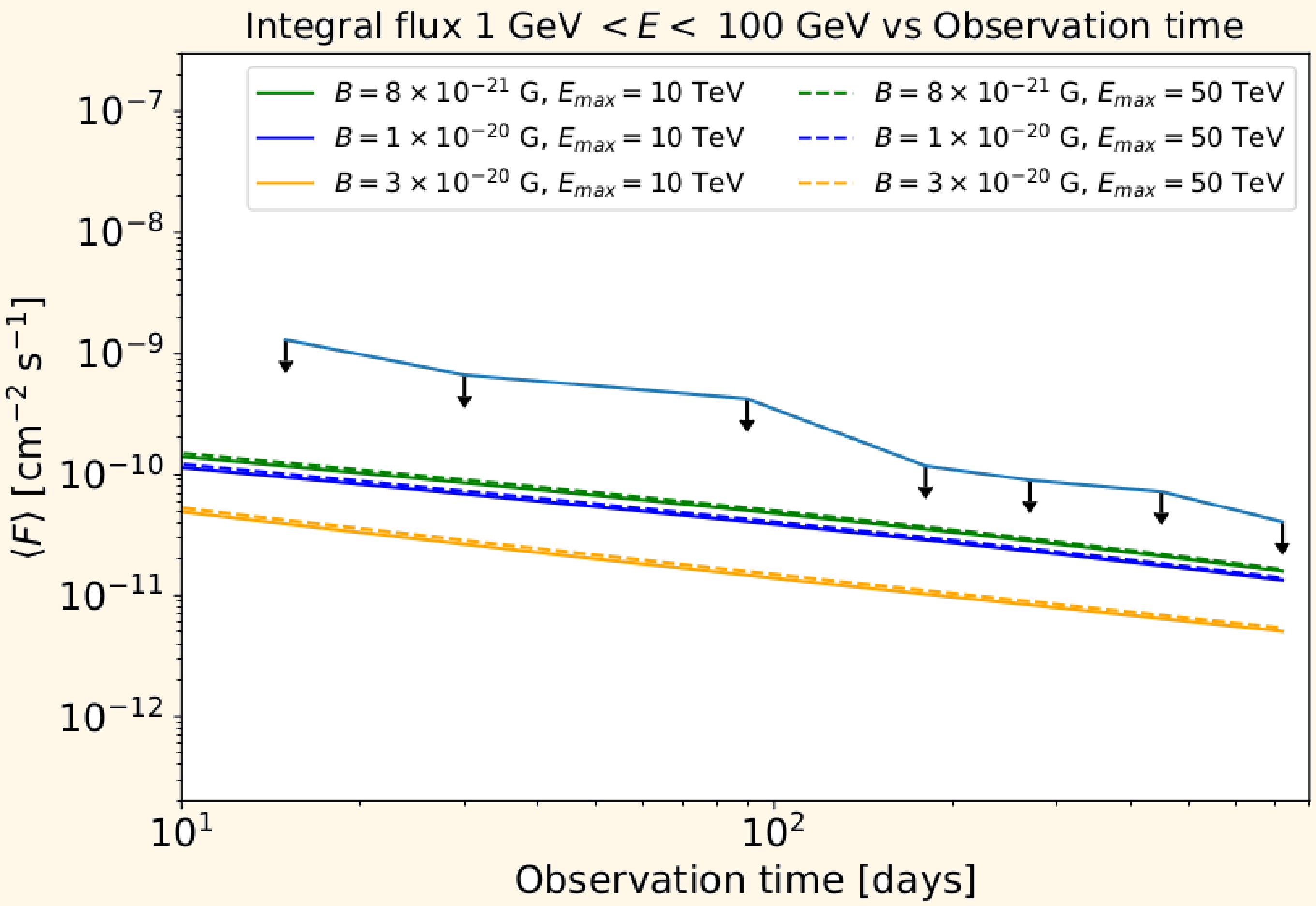
Light curve: Simulation vs *Fermi* observing strategy



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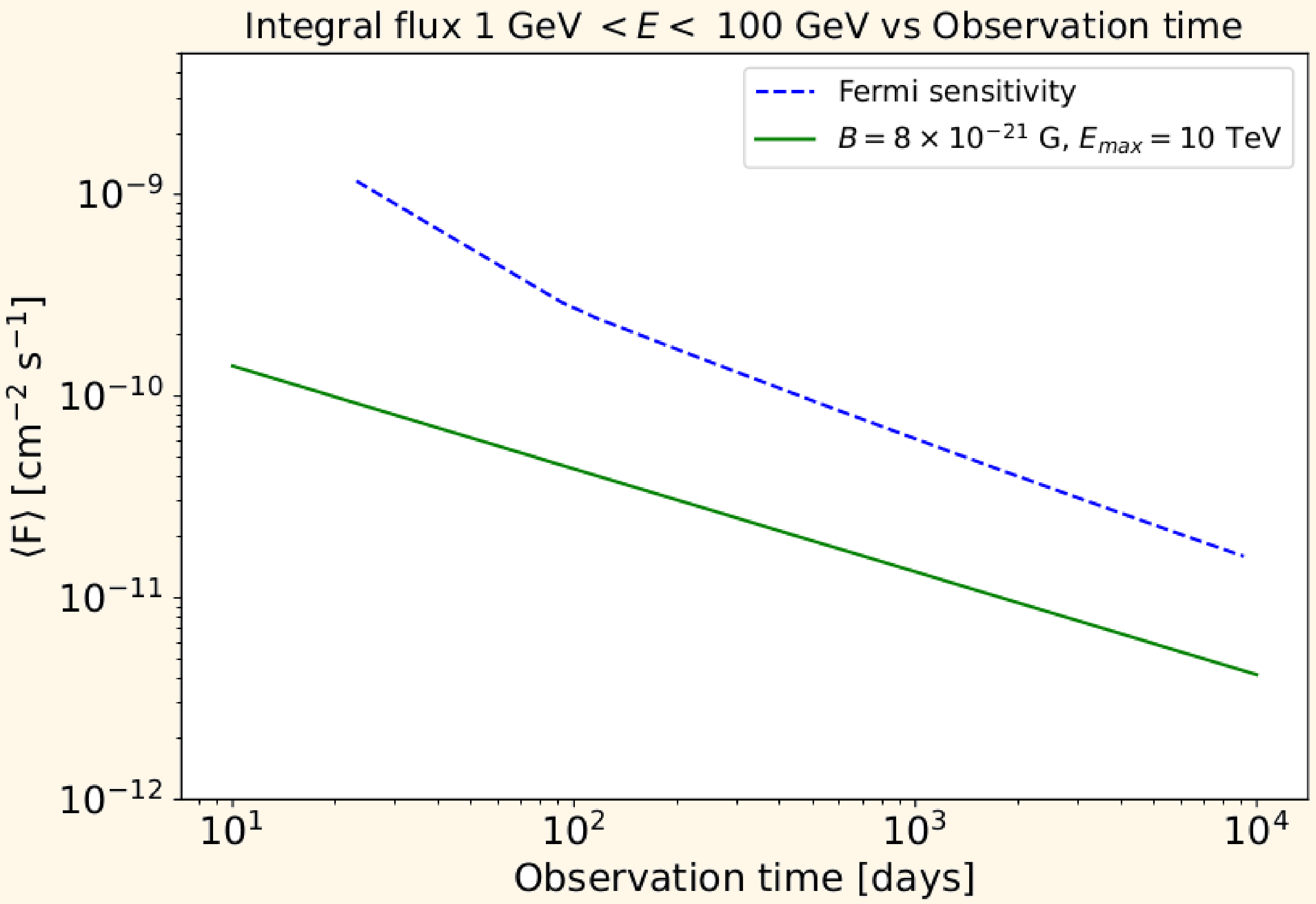

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What about other GRBs?

- GRB 190829A: $T_{\mathrm{activity}} = 51$ hours, $z = 0.0785$, VHE intrinsic spectrum power law $\Gamma = -2$. Assuming an exponential cut-off at 4 TeV (the maximum measured energy by H.E.S.S.), $B = 10 - 20$ G and 1 month of observation time the cascade SED is more than 4 orders of magnitude lower than the *Fermi*-LAT upper limit
- GRB 221009A: Promising, but missing information to reconstruct an SSC spectrum. VHE T_{activity} unknown, as well as the multi-wavelength SED.

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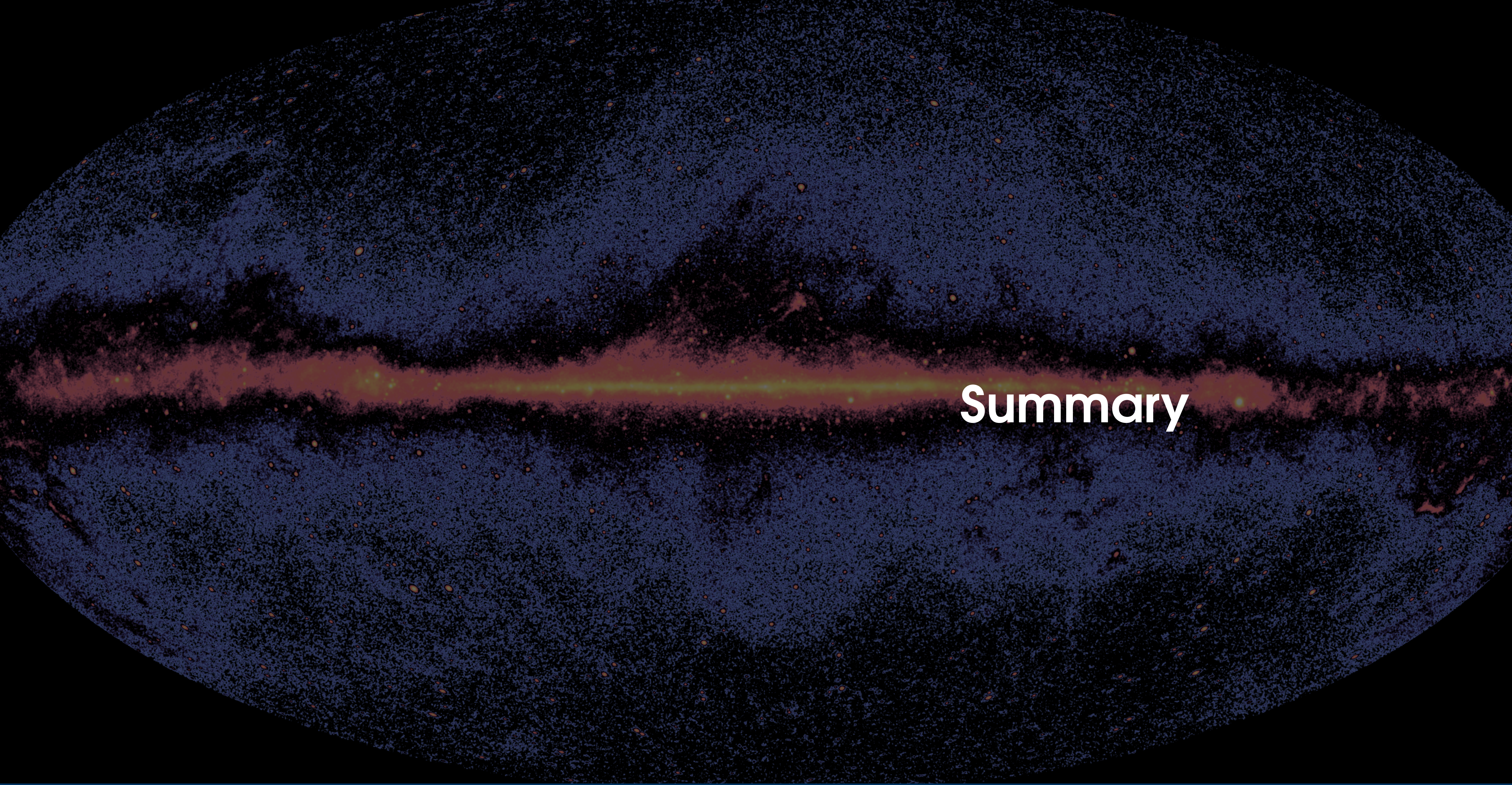

Summary

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- The presence of delayed GeV emission after a strong transient should be the signature of a non-zero magnetic field in the IGM
- We simulate the cascade produced by GRB 190114C with CRPropa3 assuming a physically motivated spectral model
- We search for the delayed emission using *Fermi*-LAT between 15 days and 24 months
- Despite its detection at TeV energies with MAGIC, GRB 190114C cannot be used to constrain the IGMF under reasonable assumptions