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

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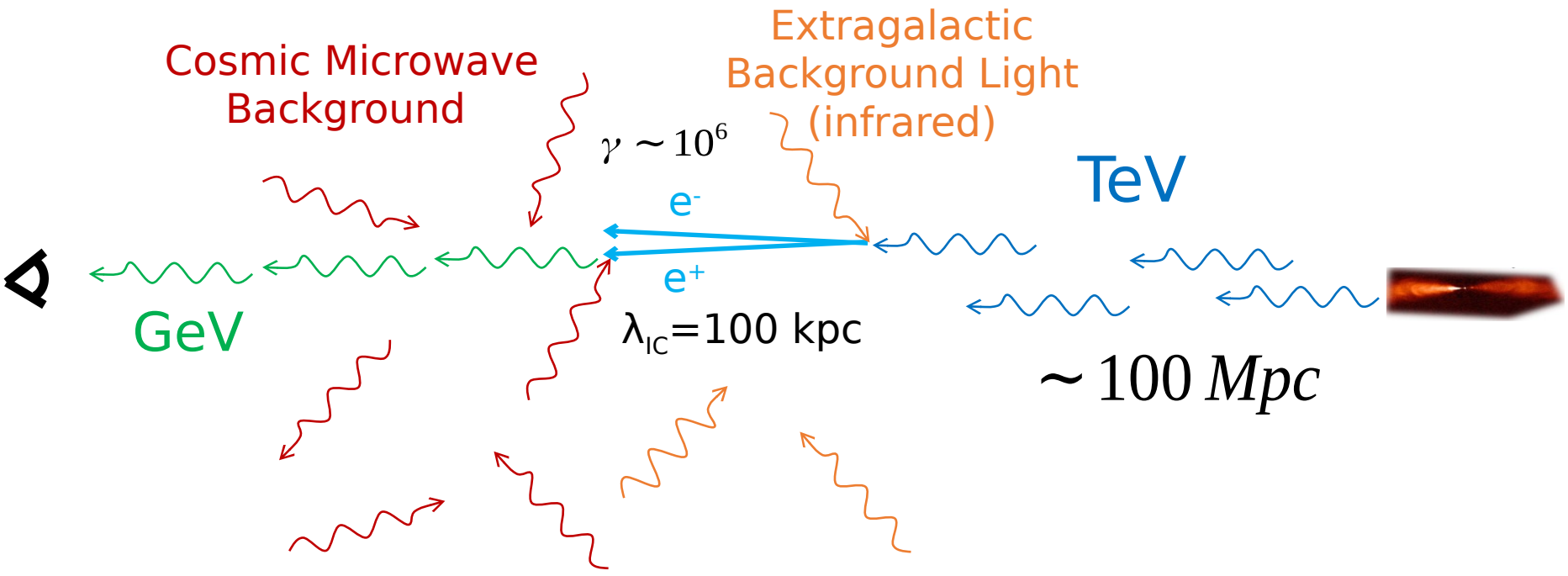
* on behalf of the Fermi-LAT Collaboration

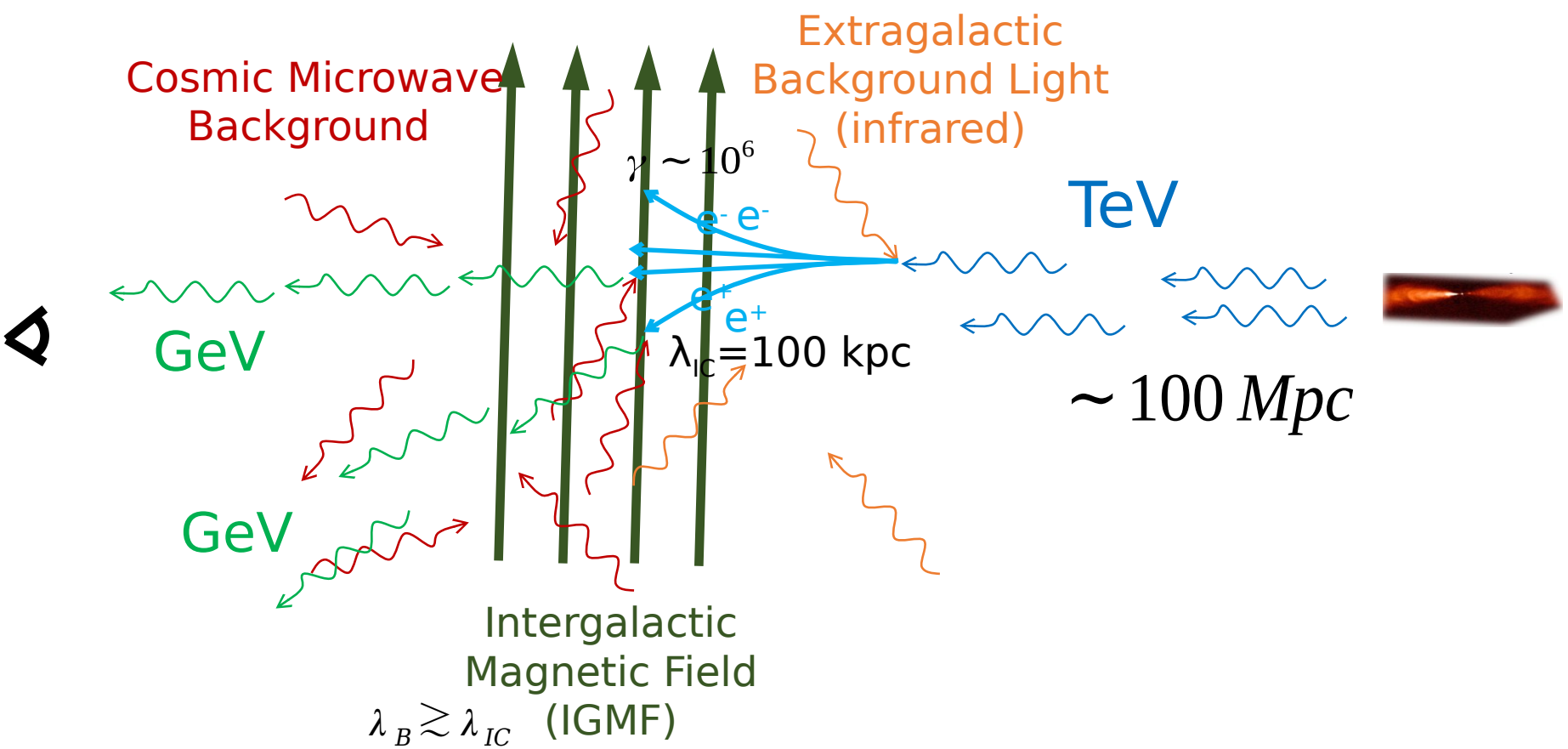
Summary

- Physical process
- Proper choice of the VHE primary spectrum
- CRPropa simulations for different IGMF settings
- Comparison between the simulated SEDs and lightcurve with the *Fermi*/LAT results

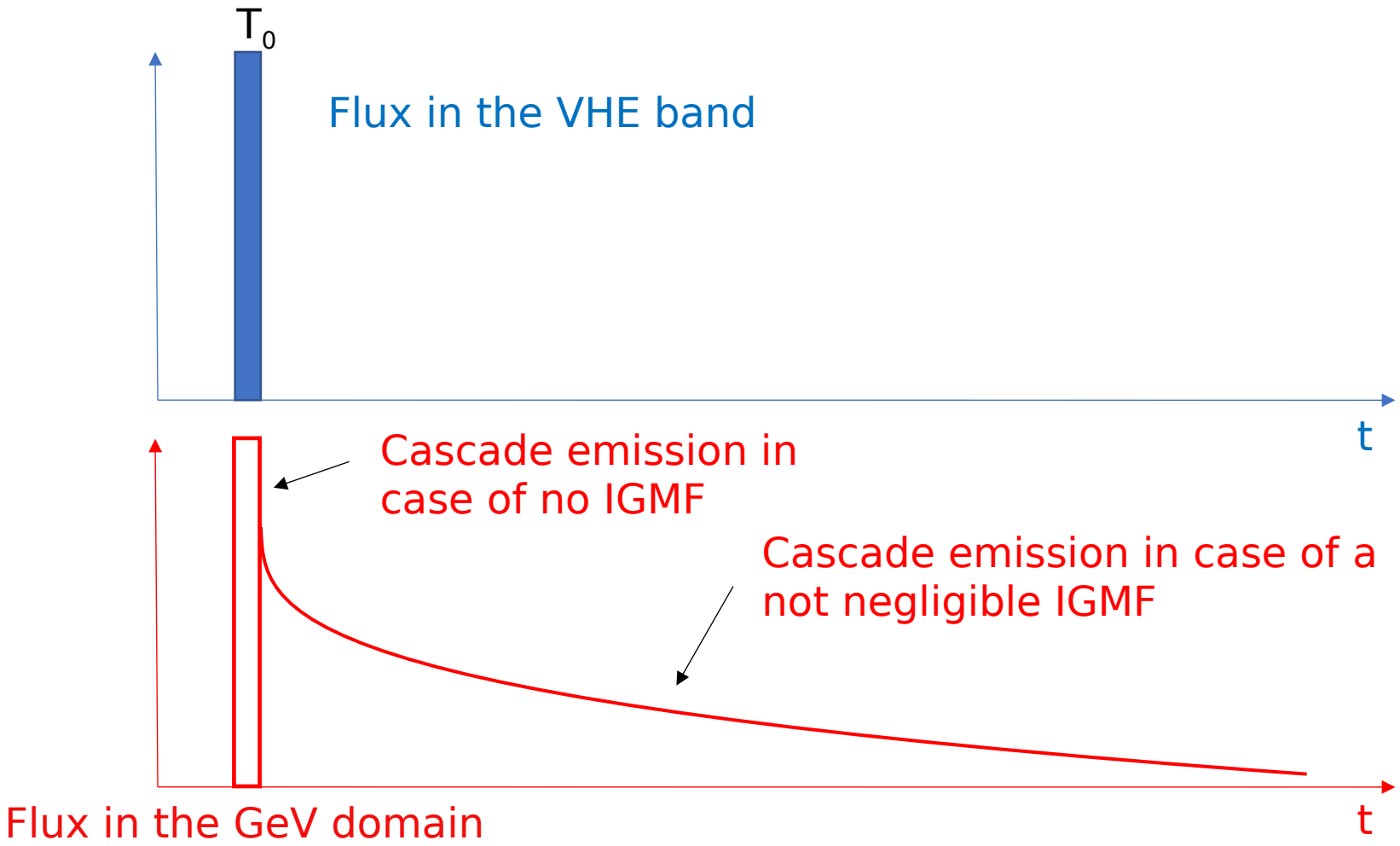
Summary of a TeV γ-ray's life absent any other process...



Summary of a TeV γ-ray's life with an IGMF

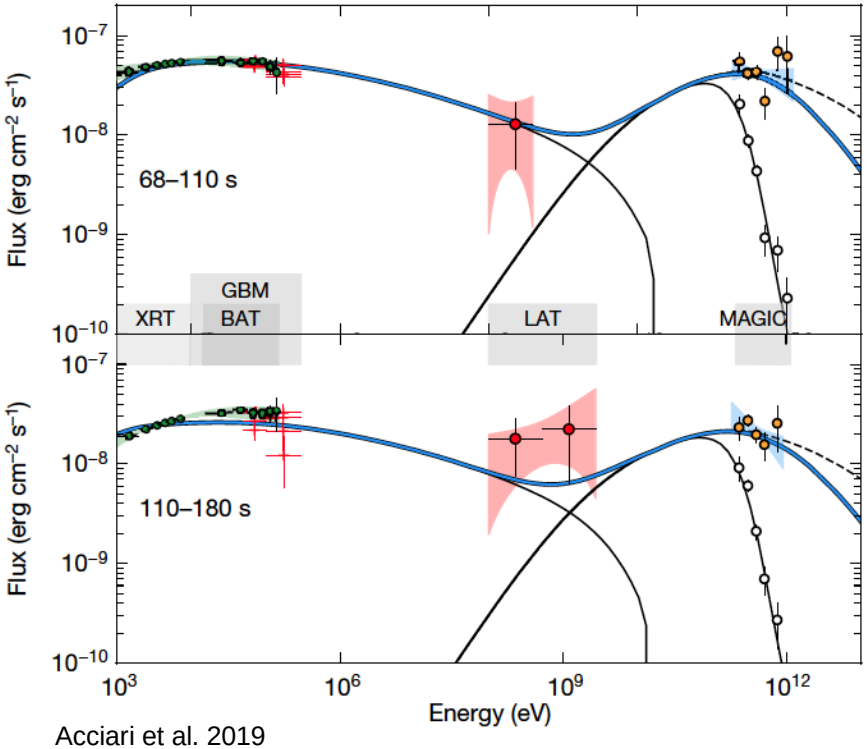


“Delayed“ cascade emission



Primary spectrum

» We used the GRB 190114C model in the MAGIC band (200 GeV<E<10 TeV) in the first temporal bin (68 – 110 s) approximated it with a log-parabola:



Acciari et al. 2019

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

» We extrapolated the flux up to the first 6 s after prompt emission

CRPROPA simulations: settings

»Source:

- Point source
- z=0.42
- Logparabola spectrum between 200 GeV and 10 TeV, 10^6 primary photons
- Minimum energy of cascade photons: 0.05 GeV

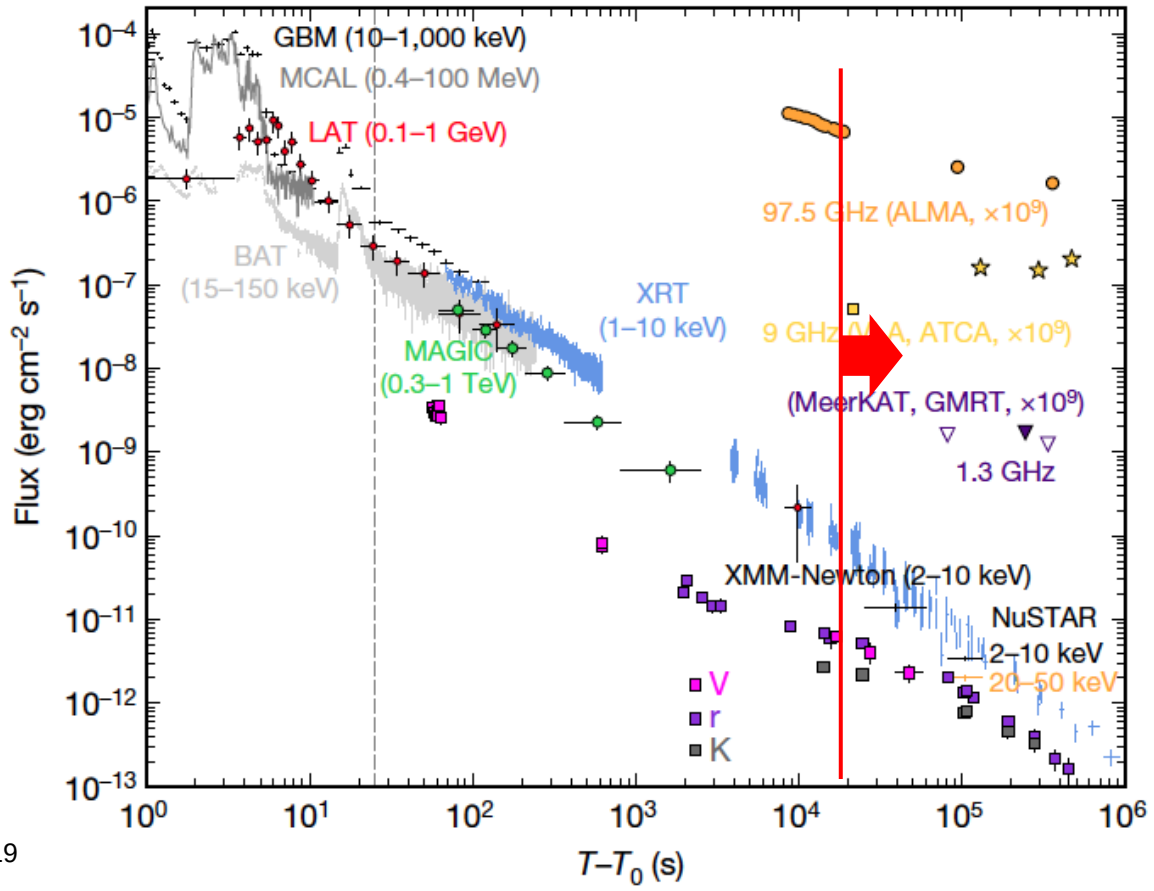
»Magnetic Field:

- Turbulent magnetic field with a Kolmogorov spectrum and different B_{rms}
- Correlation length: ≳ 1 Mpc

»Observer:

- Sphere with radius 1.6 Gpc with the source at the centre

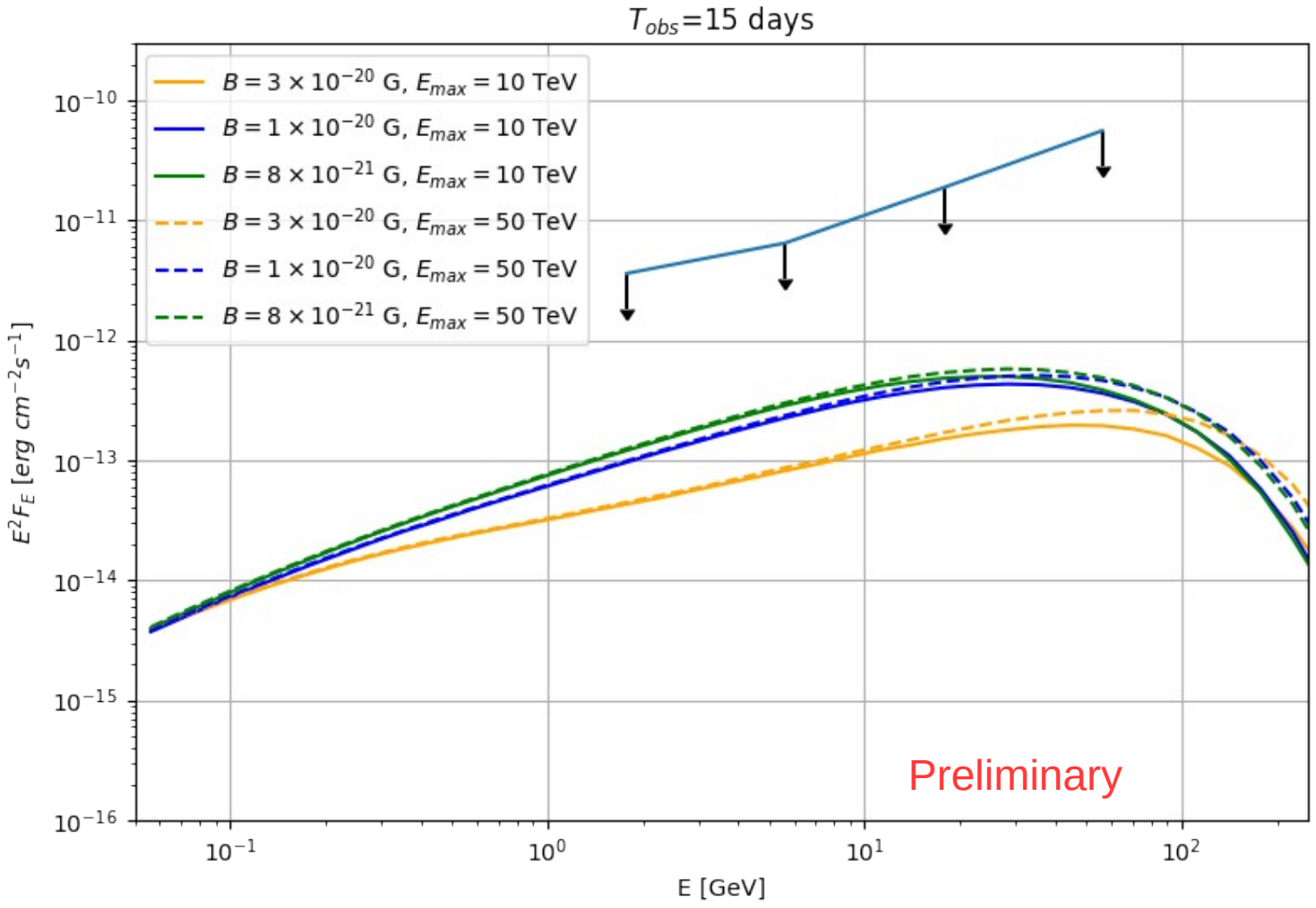
Starting time



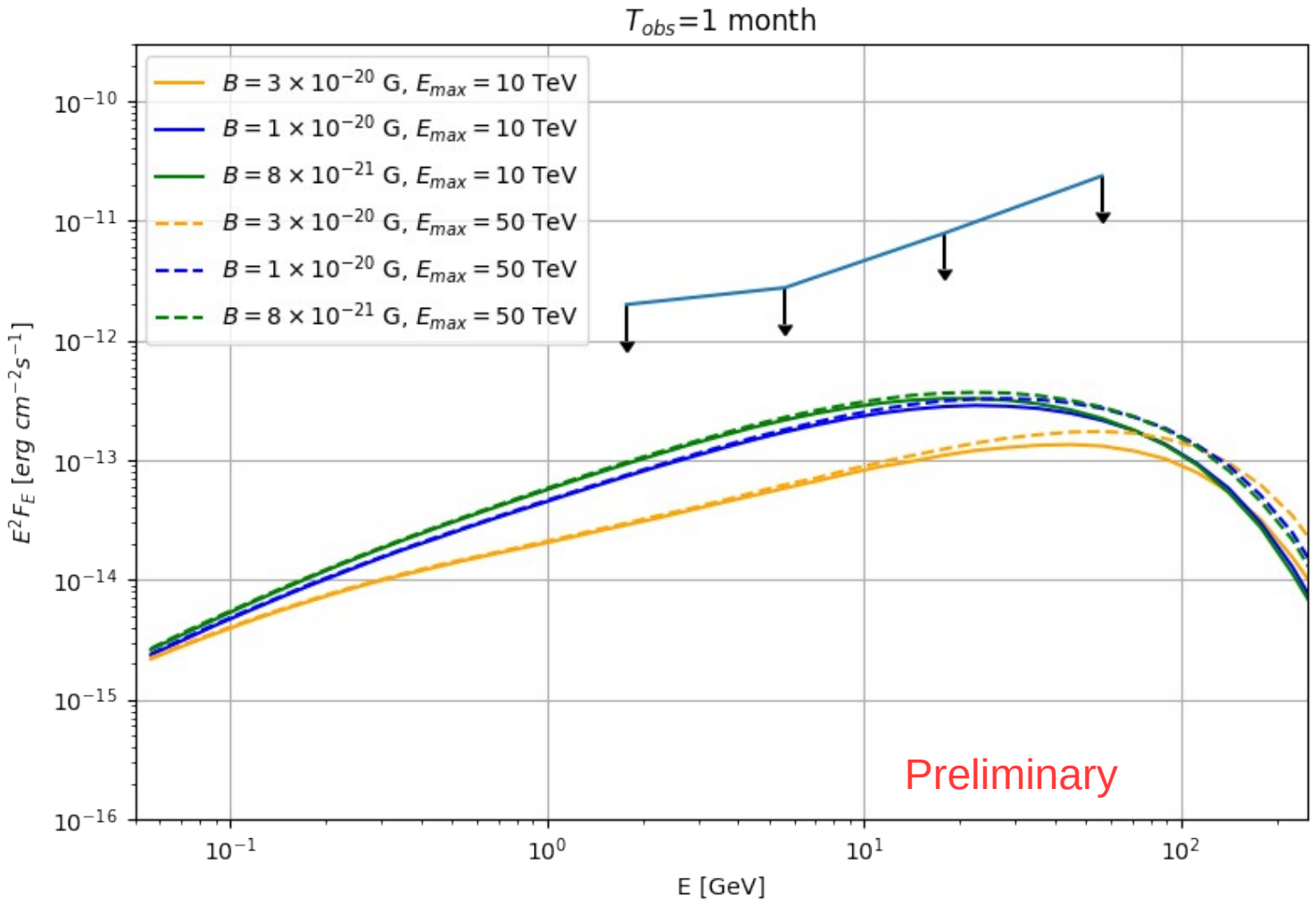
Acciari et al. 2019

» In order not to look for the echo emission in a time window where the GRB is still ongoing in the *Fermi* band we started counting the cascade photons from $T\text{-}T_0 = 2\times10^4$ s

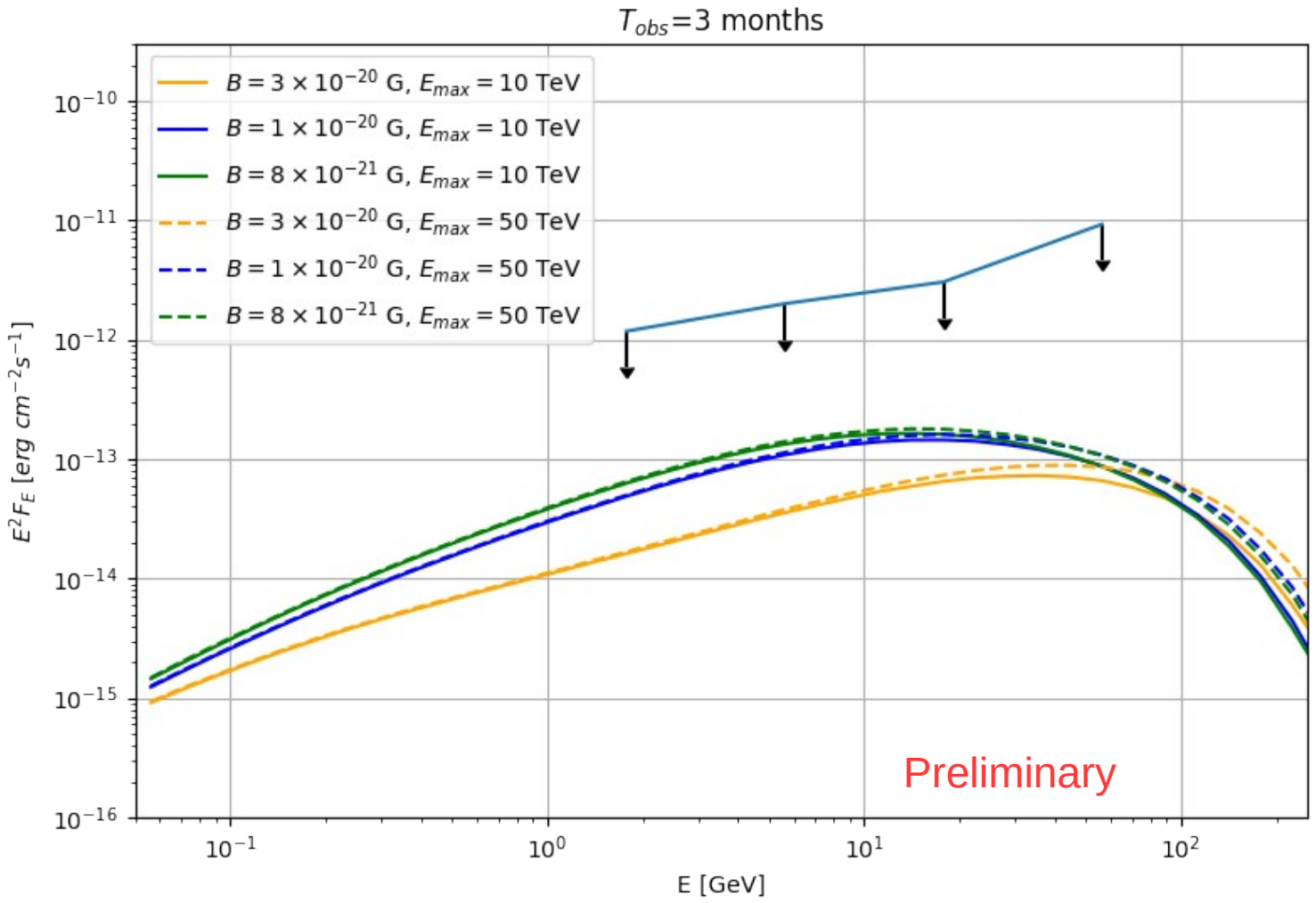
SEDs vs observation time: 15 days



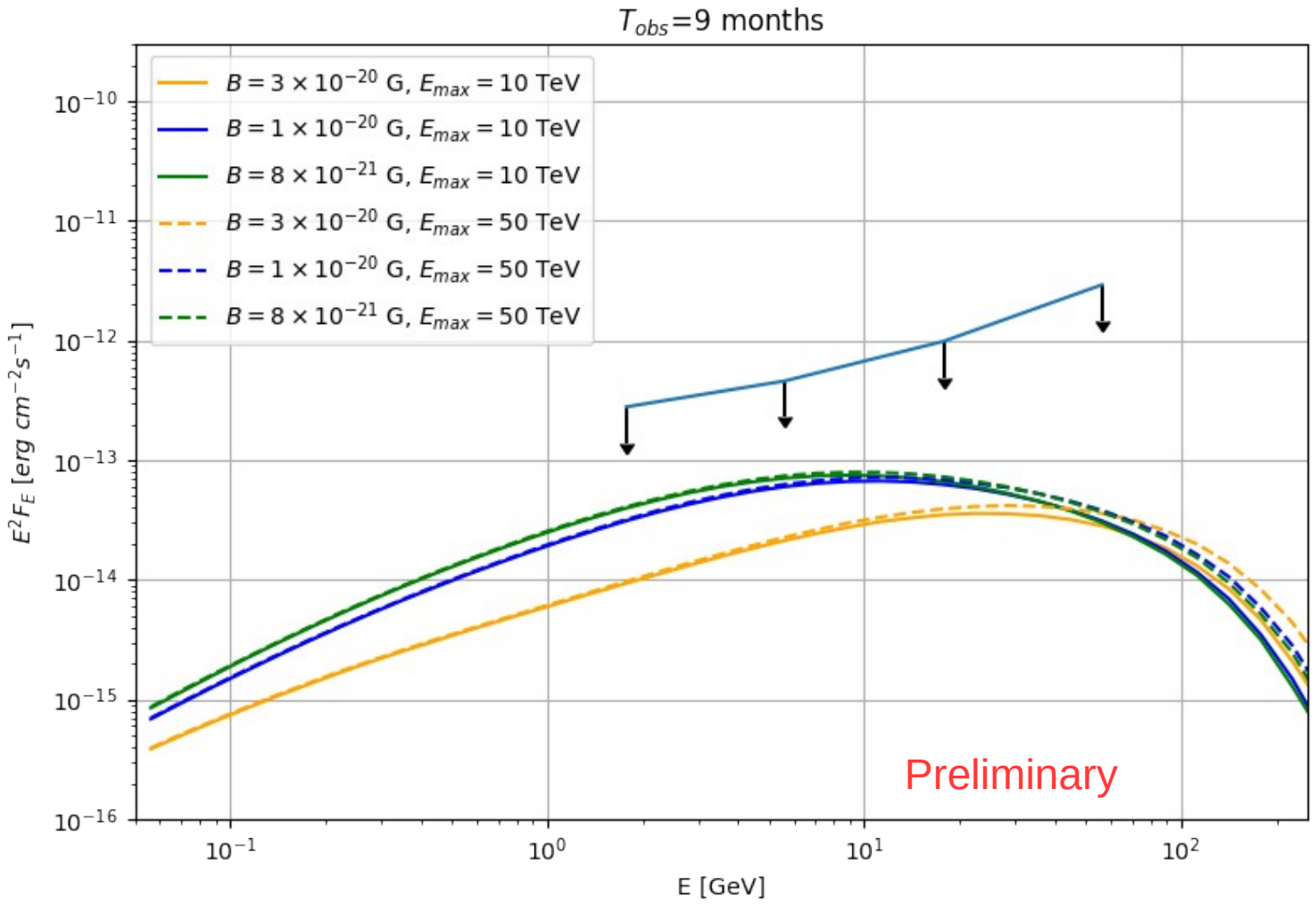
SEDs vs observation time: 1 month



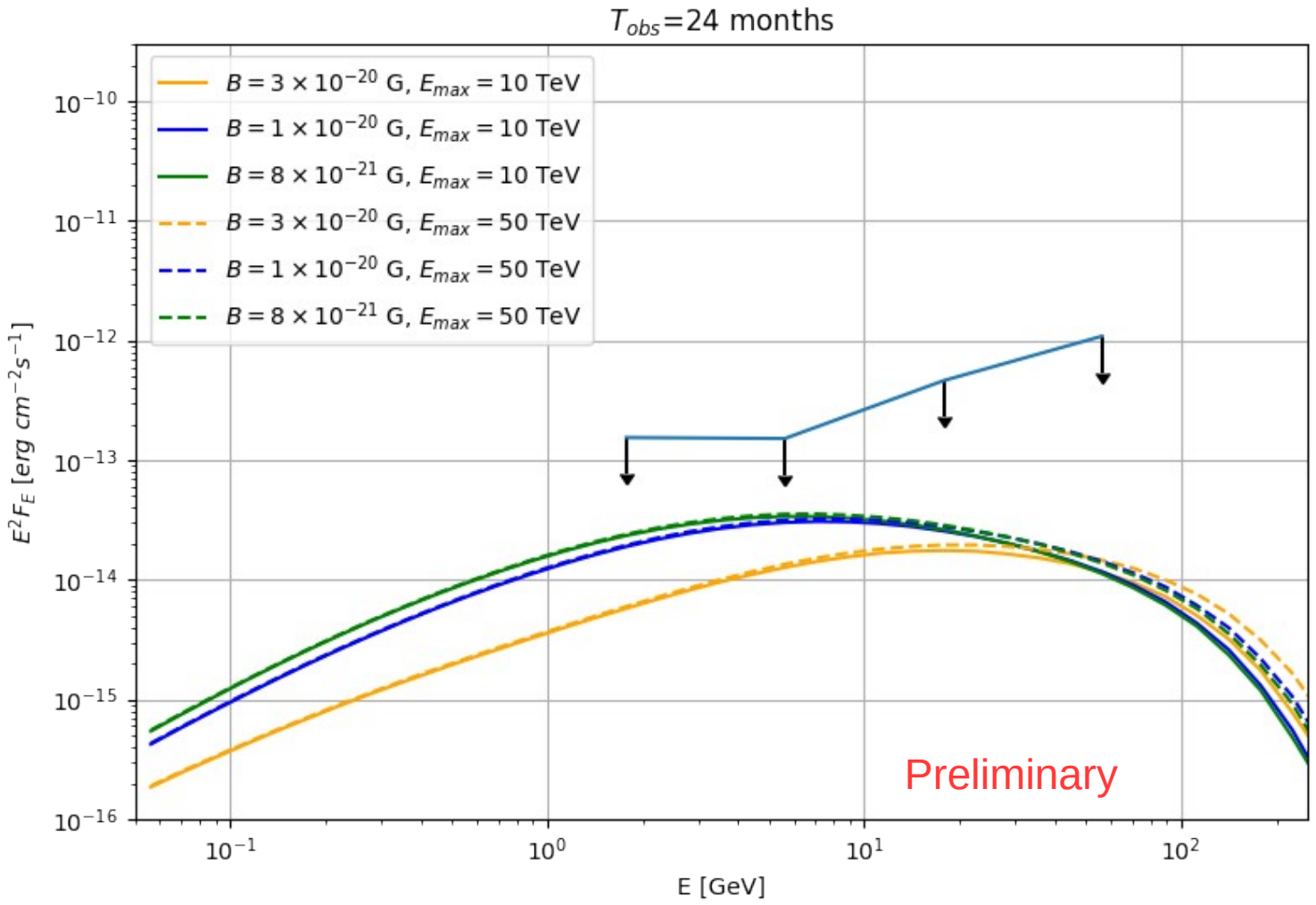
SEDs vs observation time: 3 months



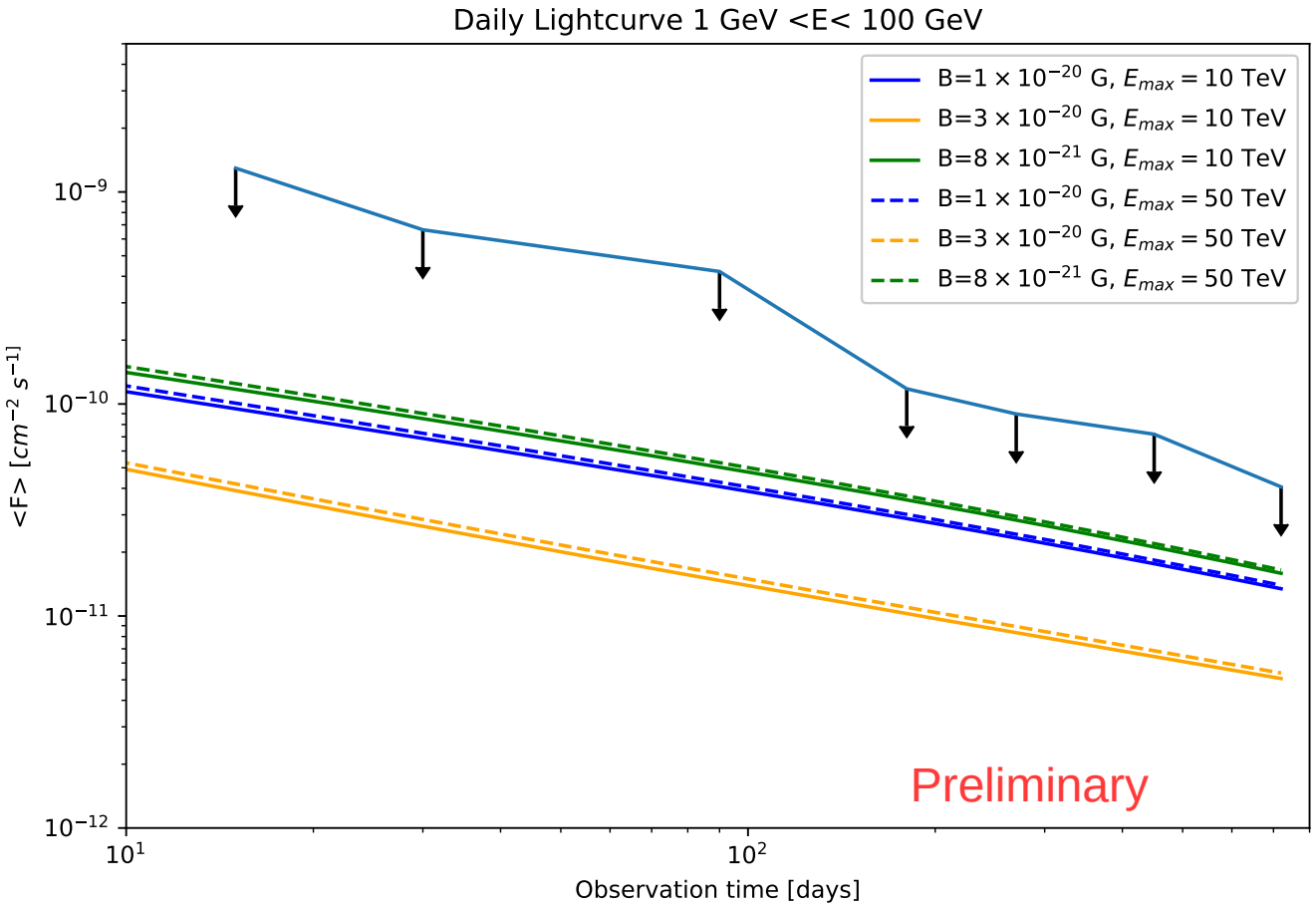
SEDs vs observation time: 9 months



SEDs vs observation time: 24 months



Lightcurves 1 GeV<E<100 GeV



Conclusions

- We simulated the cascade delayed emission from GRB 190114C for different IGMF settings and using, as VHE primary spectrum, the GRB model published by MAGIC coll.

- We performed the *Fermi*/LAT analysis from the end of the GRB up to 24 months

- Comparing the simulated SEDs and light curve with the *Fermi*/LAT no constraints can be placed on the IGMF strength

Back up

Probing the “weakest” IGMF through pair echoes from GRBs

» Since the pairs are deviated, the cascade emission is also delayed (Neronov et al. 2009):

- $\lambda_B >> D_e$ $$T_{delay} \simeq 7 \times 10^5 (1-\tau^{-1})(1+z)^{-5} \left[\frac{E}{0.1TeV}\right]^{-5/2} \left[\frac{B}{10^{-18}G}\right]^2 \; s$$
- $\lambda_B << D_e$ $$T_{delay} \simeq 10^4 (1-\tau^{-1})(1+z)^{-2} \left[\frac{E}{0.1TeV}\right]^{-2} \left[\frac{B}{10^{-18}G}\right]^2 \left[\frac{\lambda_{B0}}{1kpc}\right] \; s$$

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

» The delayed emission is strongly diluted…

From simulation to physical units

» To convert the simulations units to physical units we followed this procedure

$$F_E = \frac{F(E > 200GeV)}{\Delta N_{sim}} \frac{\Delta T_{activity}}{\Delta T} \frac{\Delta N_{cascade}}{\Delta E}(\theta < \theta_{PSF})$$

ΔN_{sim} Number of source events that survived to the EBL absorption

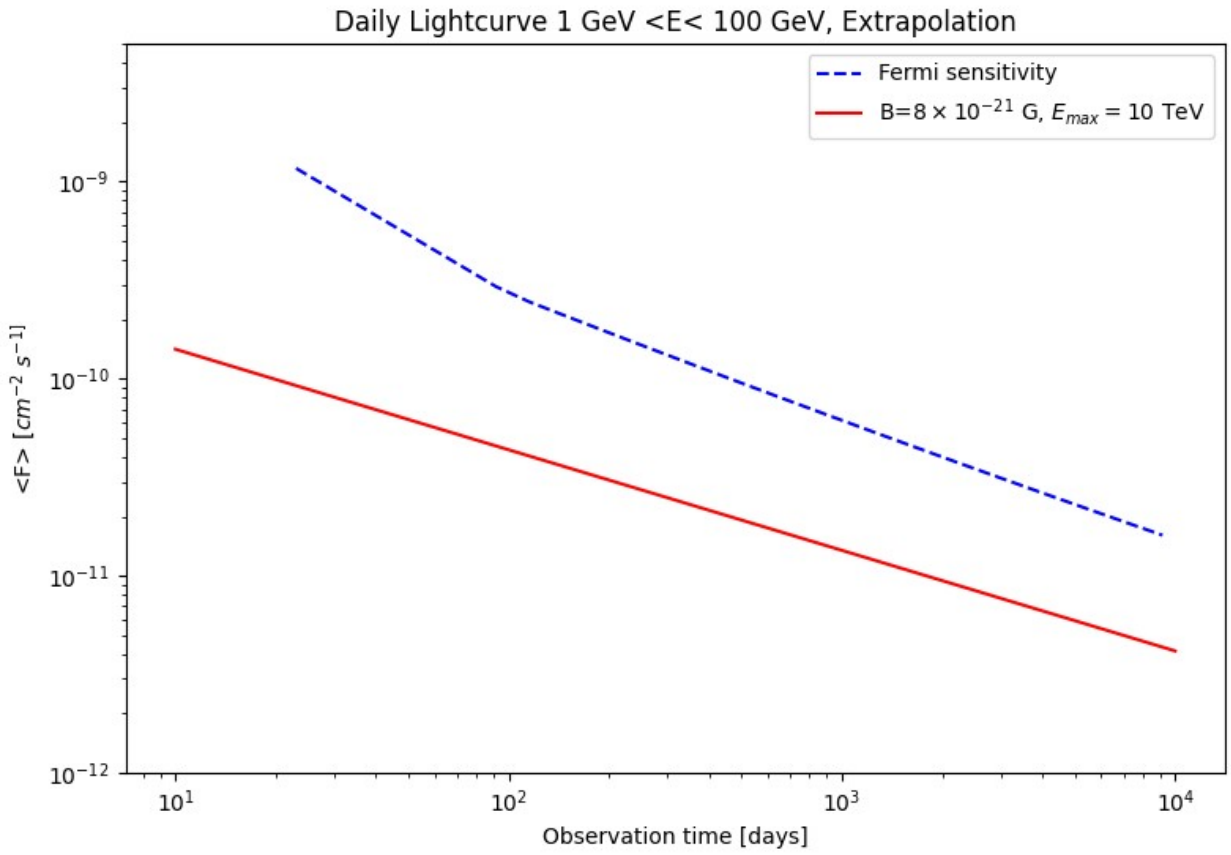
$\Delta T_{ctivity} = 40min$

ΔT Exposure time

$$F(E > 200GeV) \simeq 5 \times 2.024 \times 10^{-9} \ \ cm^{-2}s^{-1}$$

Flux measured by MAGIC and extrapolated up to the first 6 seconds after the burst (factor of 5 the measured one)

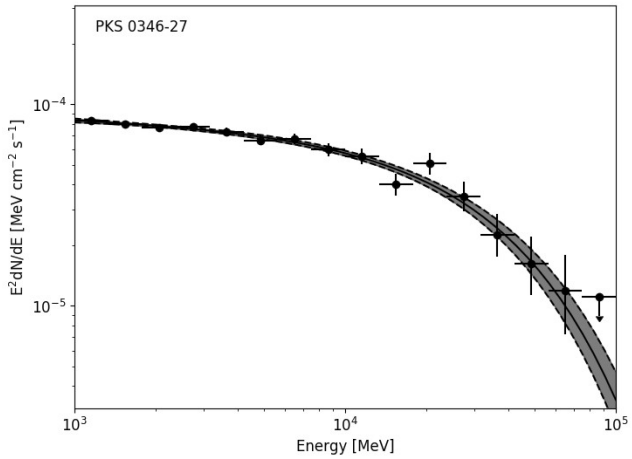
Fermi/LAT sensitivity (95% CL)

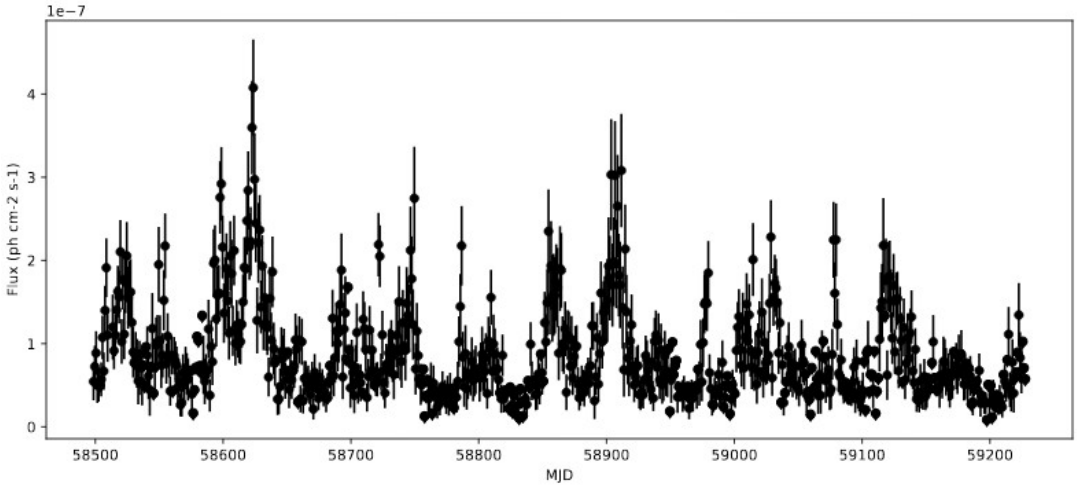


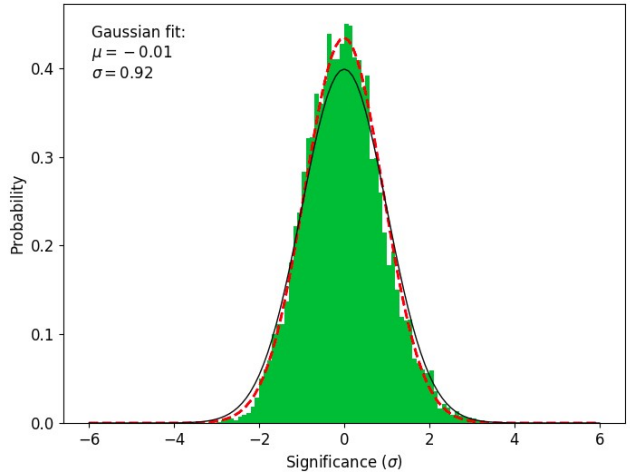
Background model optimization

The nearby blazar PKS 0346-27 is in a flaring state during the time period studied.

It is not well characterized by the 4FGL model, and requires a PLSuperExpCutOff

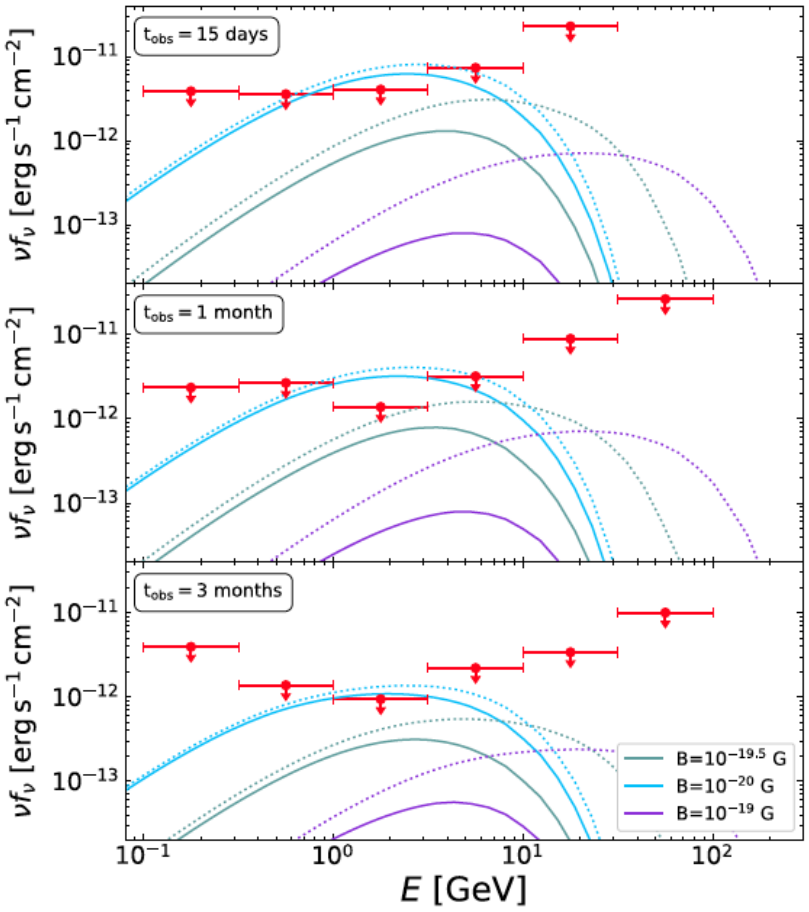






Published lower bounds on IGMF from GRB 190114C

» Wang et al. 2020



Analytic approach

Several EBL models tested

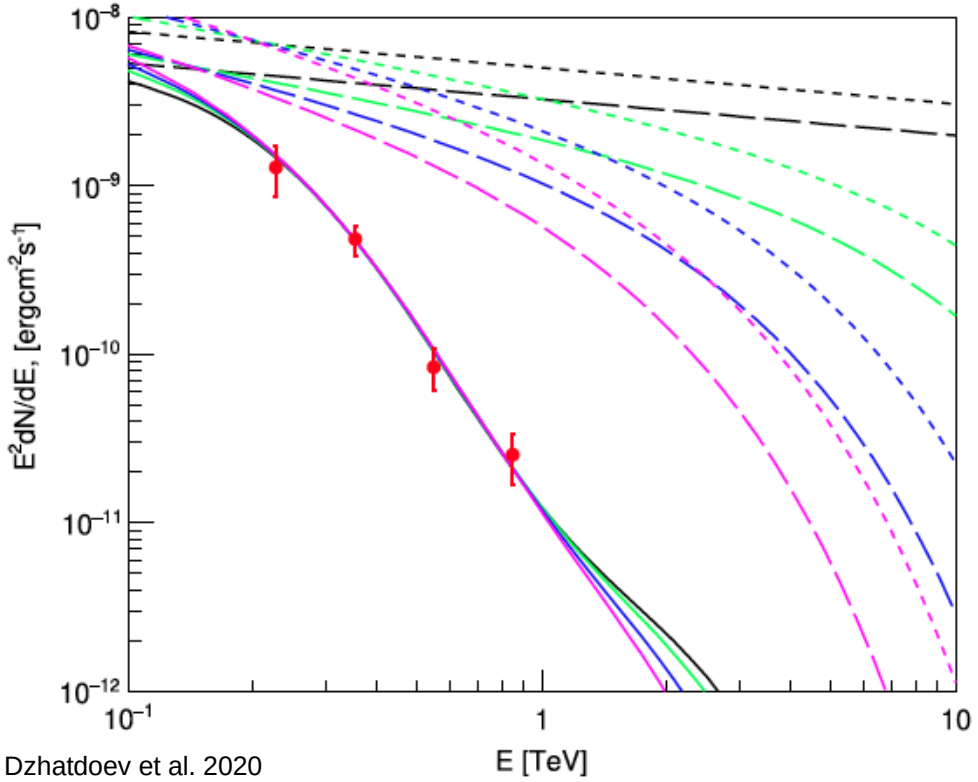
Intrinsic spectral shape in the VHE band: power law index 2 up to 1 TeV and 15 TeV

Flux above 200 GeV extrapolated up to T_0=6s (about factor of 5 the flux measured by MAGIC from T_0=64 s)

Result: **B ≳ 3×10^{-20} G for $\lambda_B \lesssim$ 1 Mpc**

Published lower bounds on IGMF from GRB 190114C

» Dzhatdoev et al. 2020: they first reconstructed the intrinsic spectrum in the VHE band using the EBL model from Gilmore et al. 2012



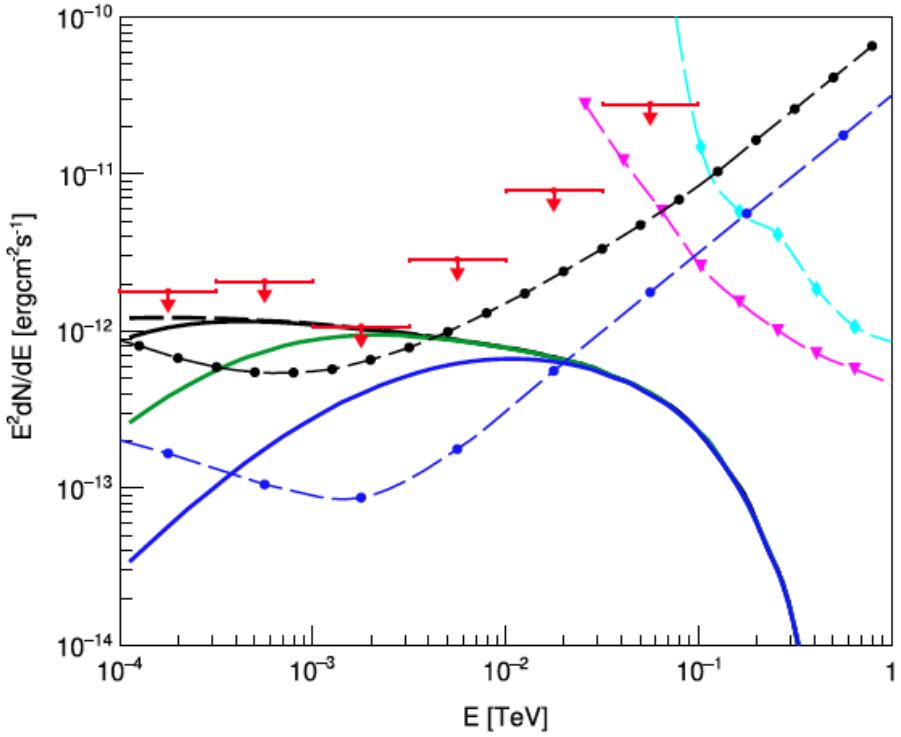
Dzhatdoev et al. 2020

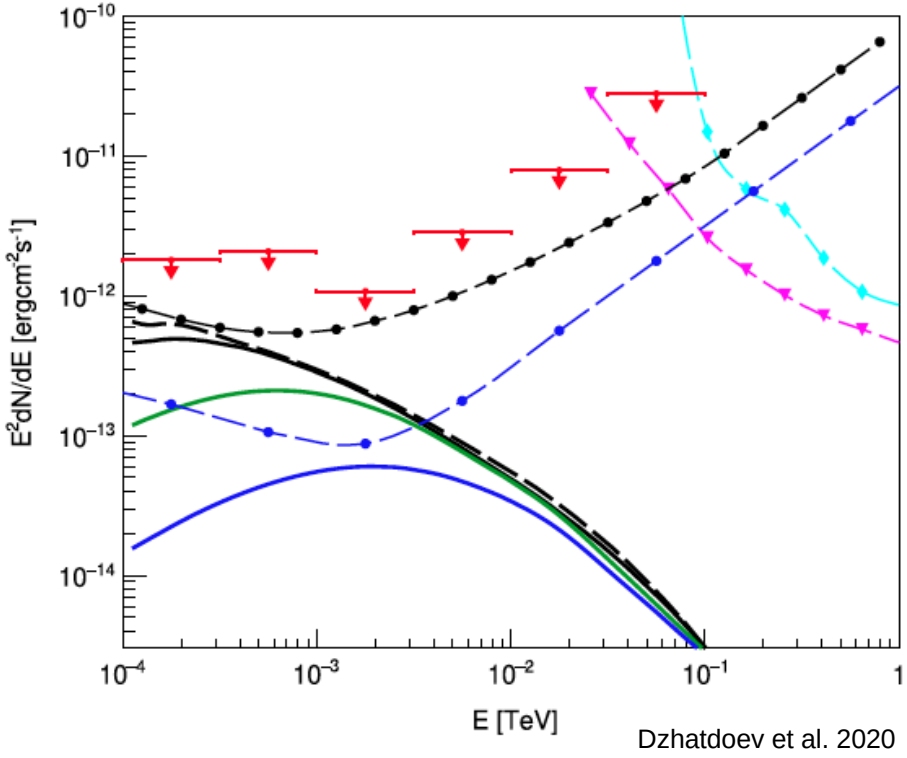
» Assuming an intrinsic spectrum $\sim E^{\gamma} * \exp(-E/E_c)$ and absorbing it using the EBL model, they scanned the (γ, E_c) space performing a χ^2 test to look for the best values

» Only considering a different normalization of the EBL intensity (90%, 80% and 70%) they were able to get a finite value of E_c

Published lower bounds on IGMF from GRB 190114C

T_{obs}= 1 month





Dzhatdoev et al. 2020

B=0 G - -
B=1×10^{-20} G
B=1×10^{-19} G
B=1×10^{-18} G

» They used Elmag3 to simulate the cascade emission with IGMF modelled as isotropic random turbulent field with a Kolmogorov spectrum and gaussian variance