INTERGALACTIC MAGNETIC FIELD STUDIES BY MEANS OF γ-RAY EMISSION FROM GRB 190114C

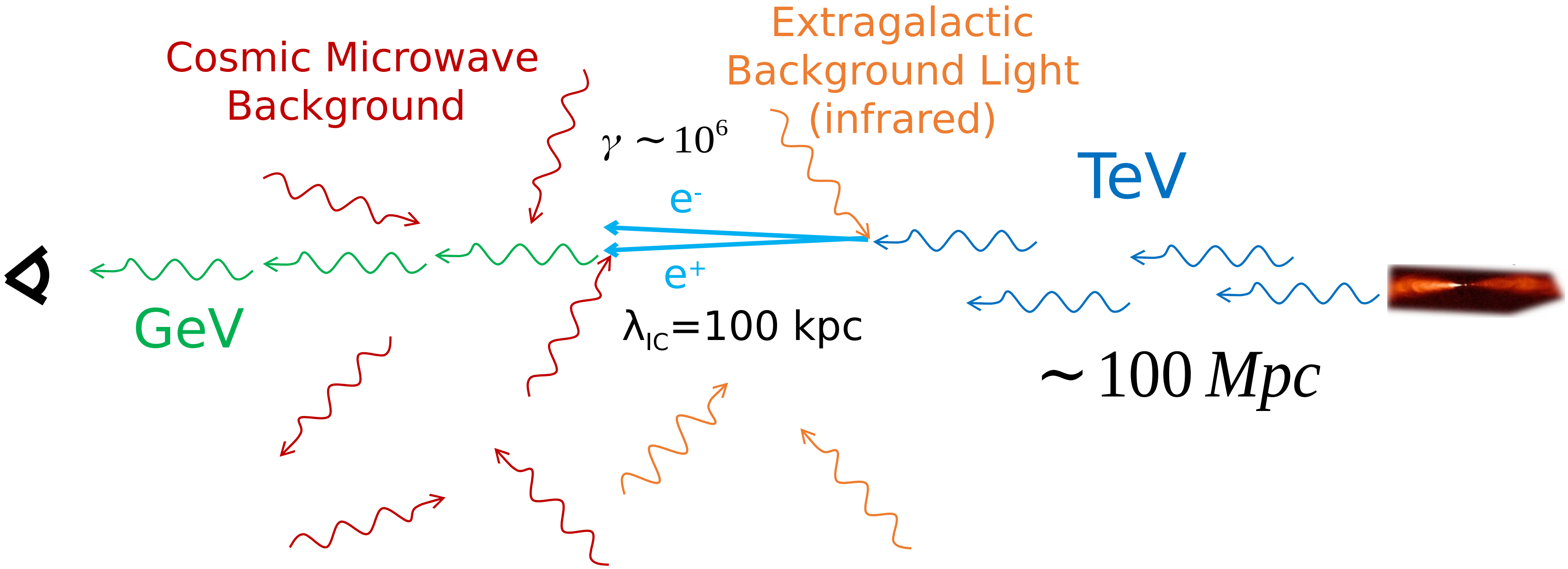
Paolo Da Vela, Guillem Martí-Devesa*, Antonio Stamerra,
Peter Veres*, Francesco G. Saturni and Francesco Longo*

* on behalf of the Fermi-LAT Collaboration

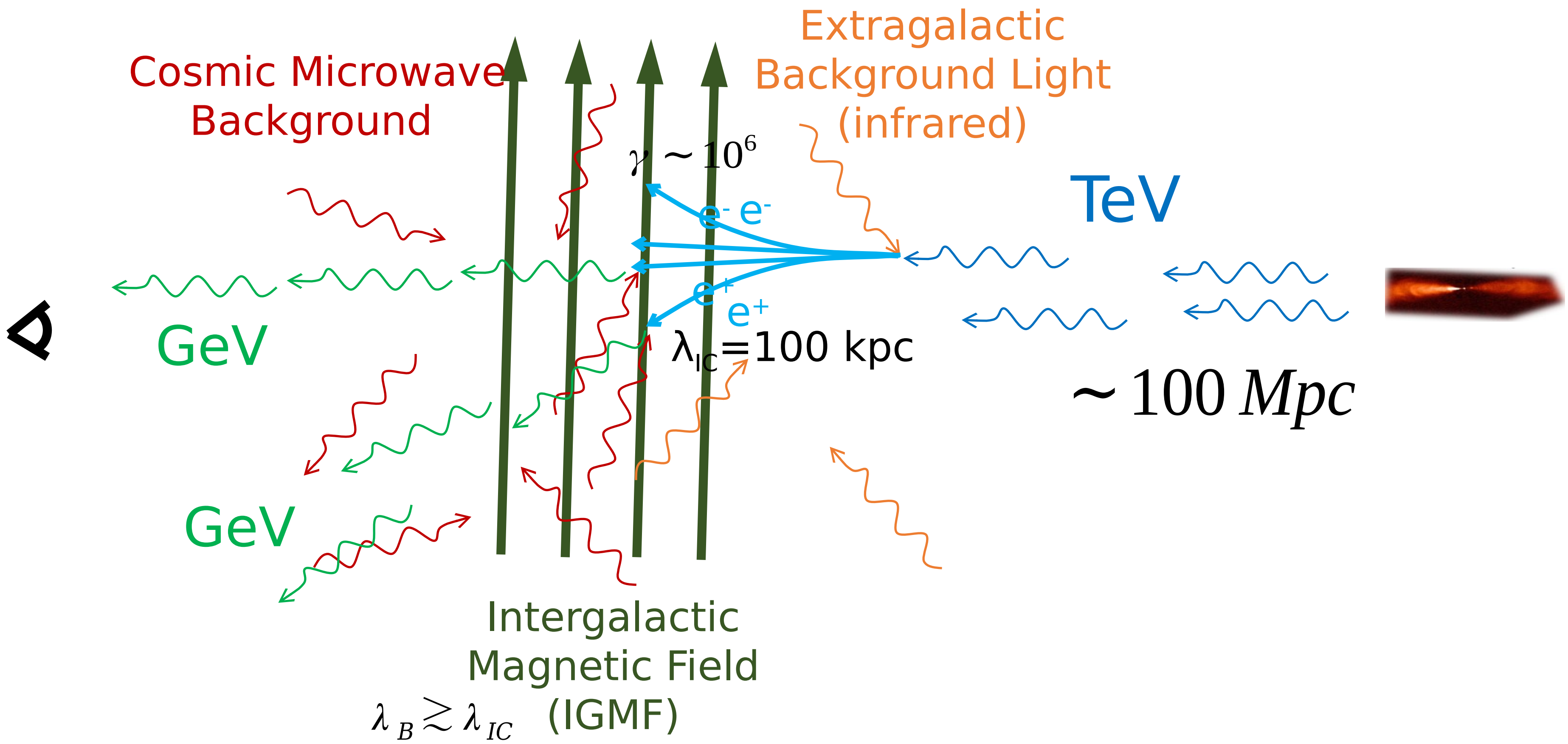
Summary

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

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



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



Probing the "weakest" IGMF through pair echoes from GRBs

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

- $\lambda_B >> D_e$

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

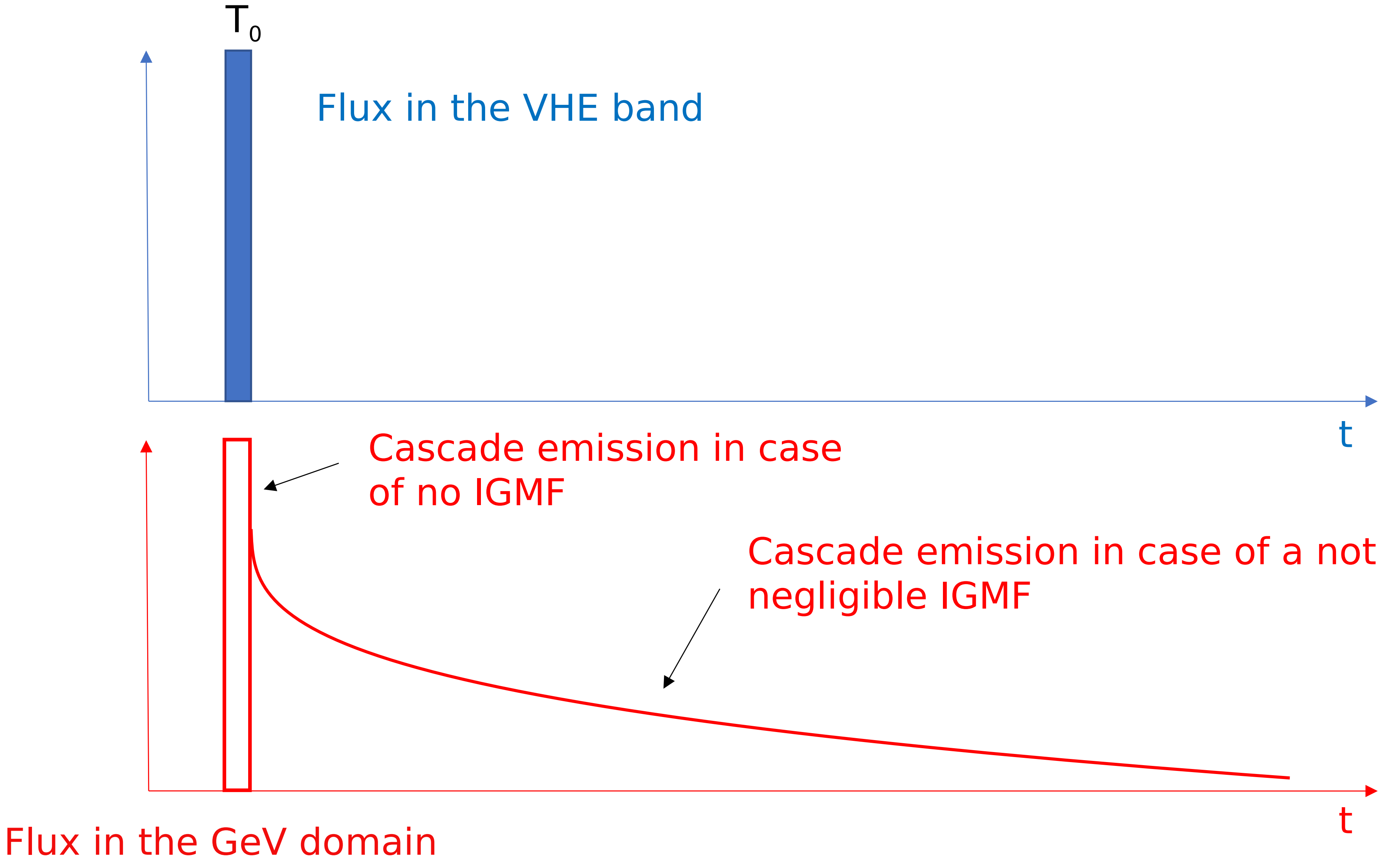
- $\lambda_B << D_e$

$$T_{delay} \simeq 10^4 (1 - \tau^{-1})(1+z)^{-2} \left[\frac{E}{0.1TeV}\right]^{-2} \left[\frac{B}{10^{-18}G}\right]^2 \left[\frac{\lambda_{B0}}{1kpc}\right] \quad s$$

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

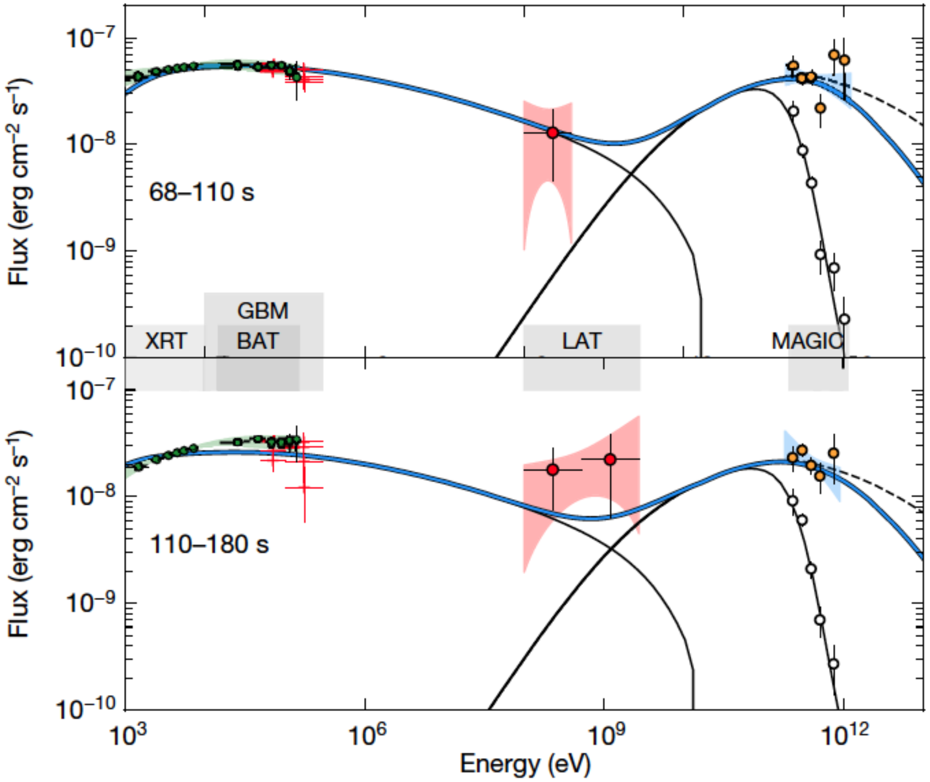
- The delayed emission is strongly diluted

“Delayed” cascade emission



Primary Spectrum

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



Acciari et al. 2019

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

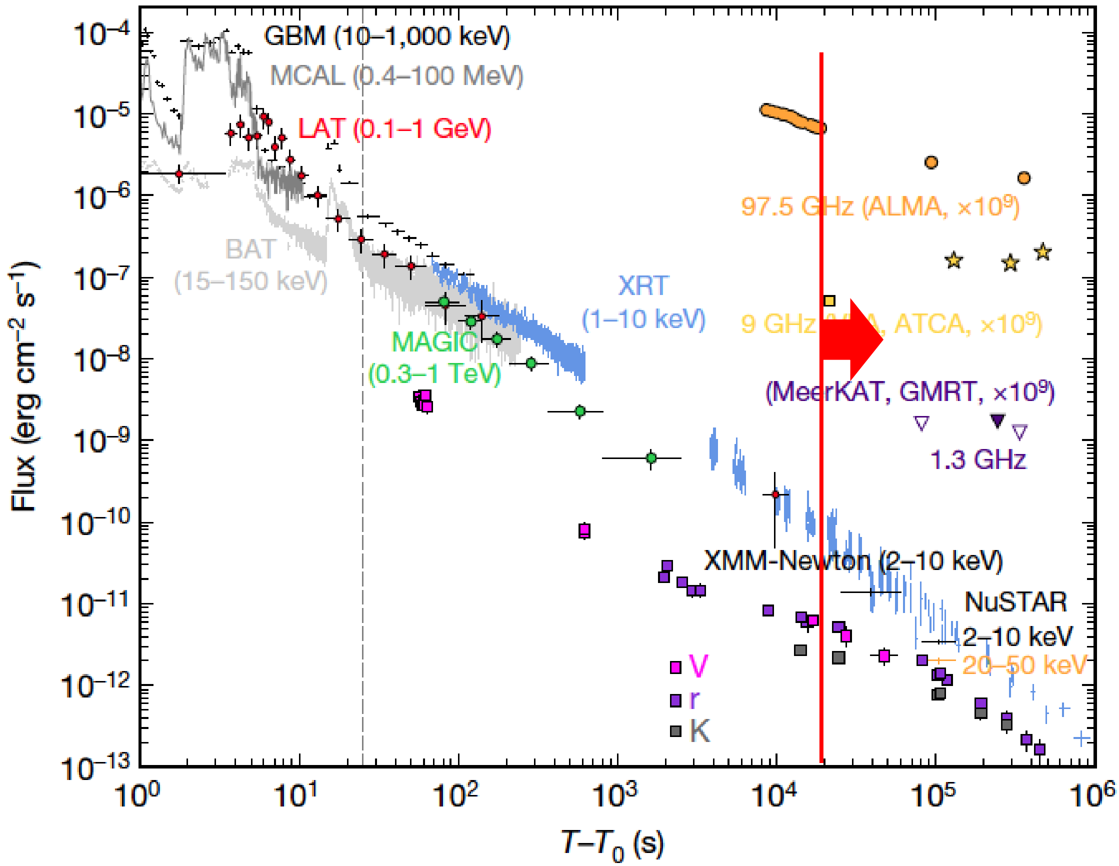
- We extrapolated the flux up to the first 6 s after the prompt emission

CRPropa simulations

- Source:
  - Point source
  - Z=0.42
  - Logparabola spectrum between 200 GeV and 10 TeV, 1e6 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: $\gtrsim$ 1 Mpc
- Observer:
  - Sphere with radius 1.6 Gpc with the source at the center

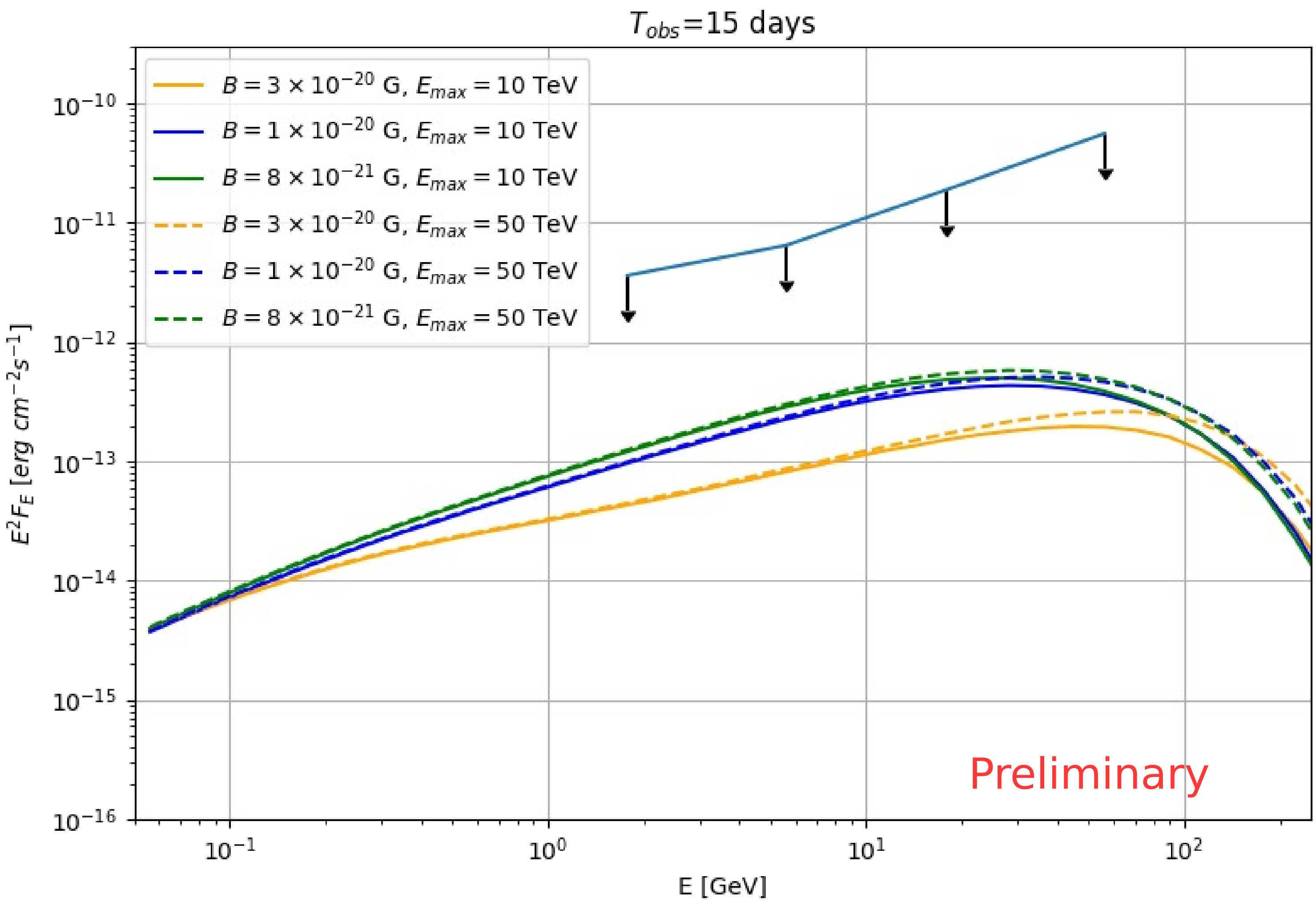
Starting time

Acciari et al. 2019

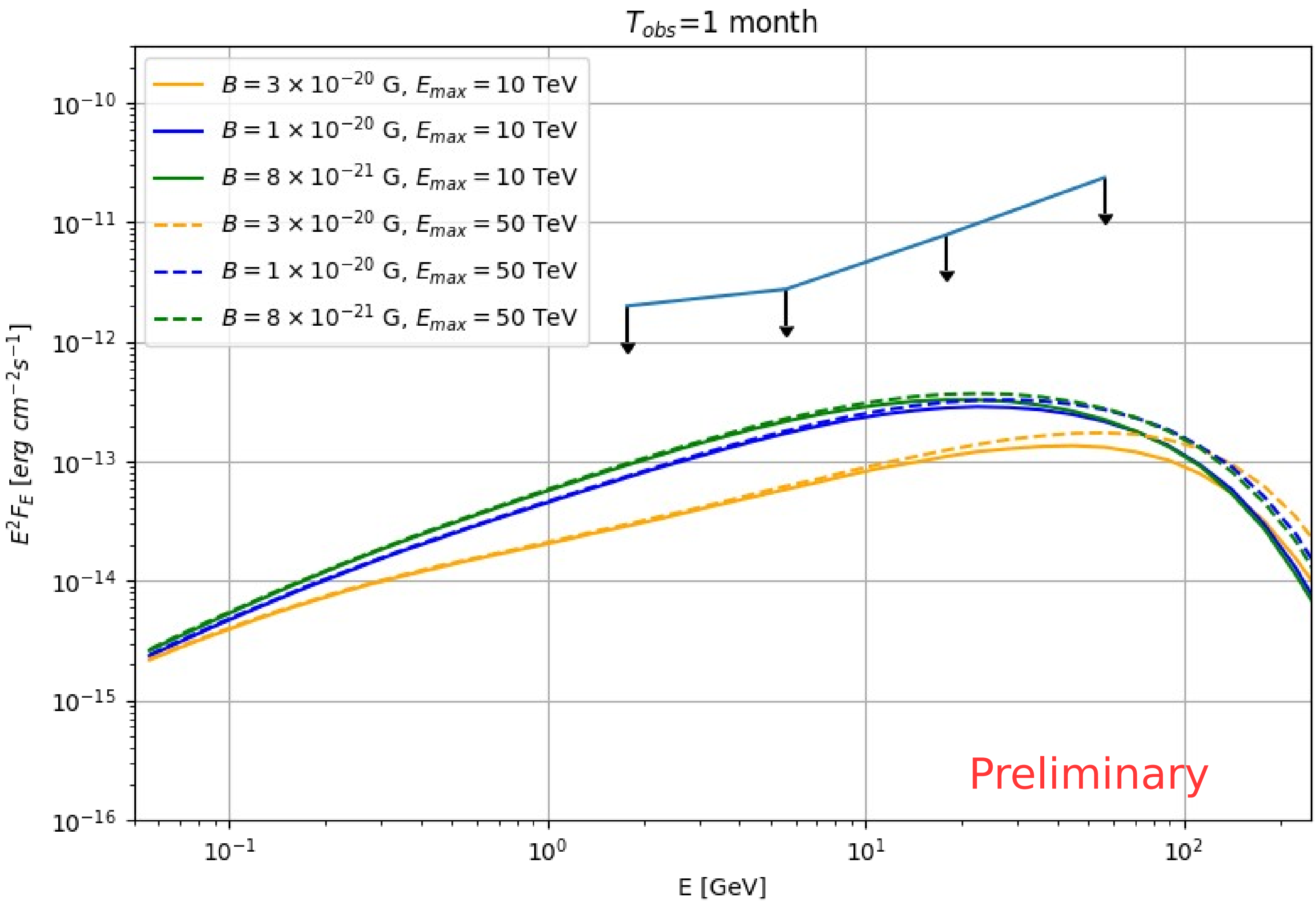


- In order not to look for the echo emission in a time window where the GRB is still ongoing in the Fermi band we started counting the cascade photons from $T\text{-}T_0 = 2\times10^4$ s

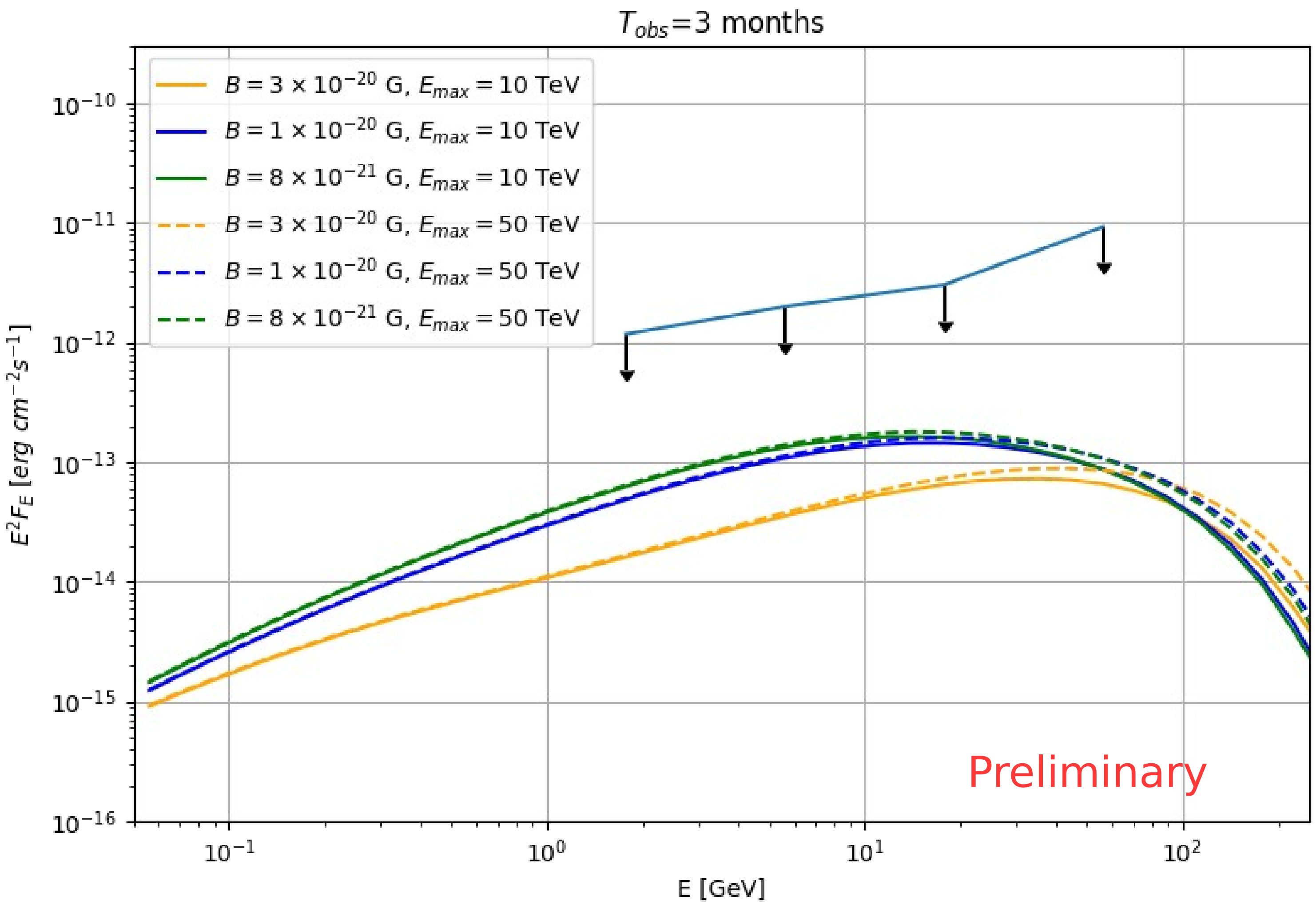
SEDs vs observation time: 15 days



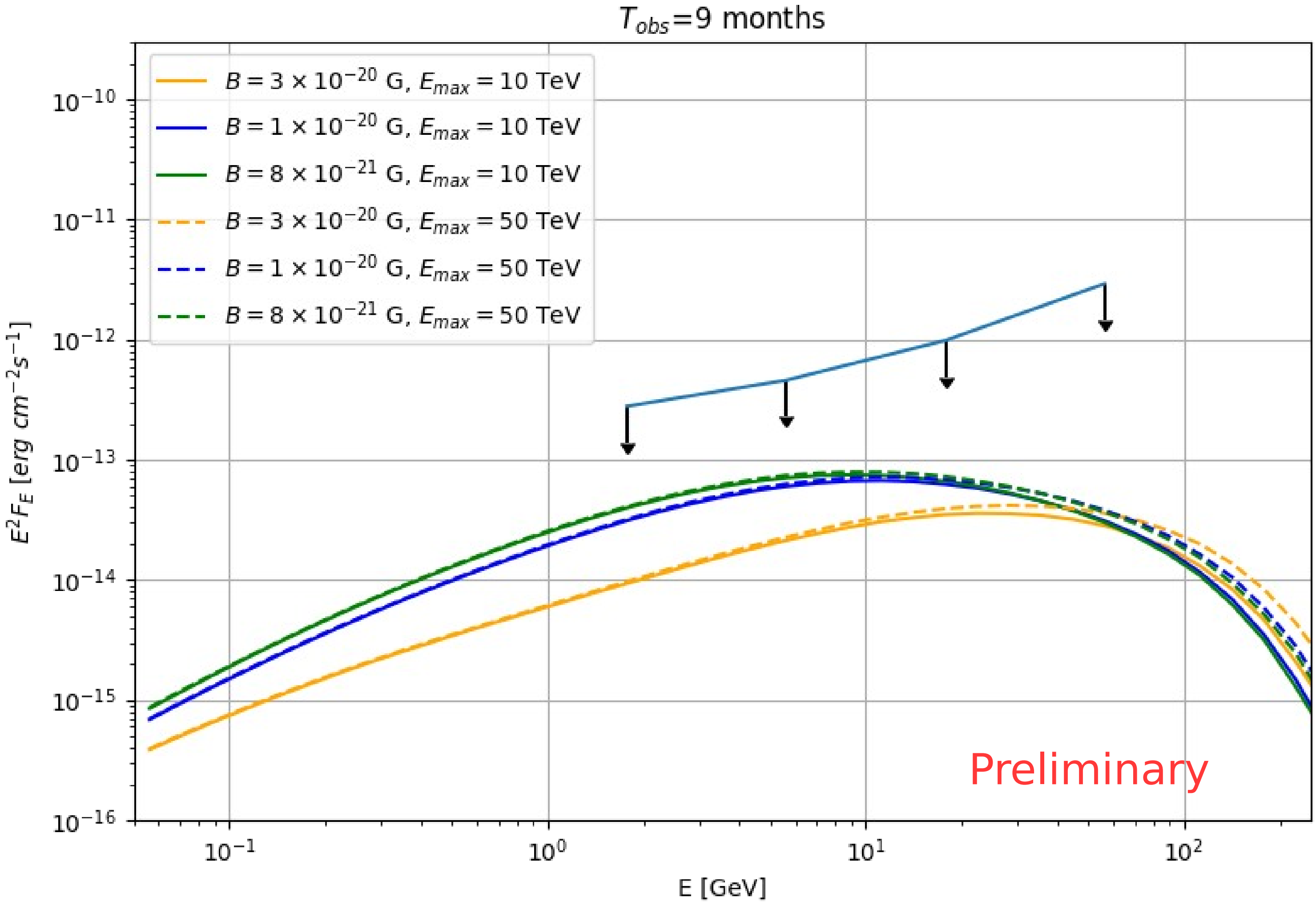
SEDs vs observation time: 1 month



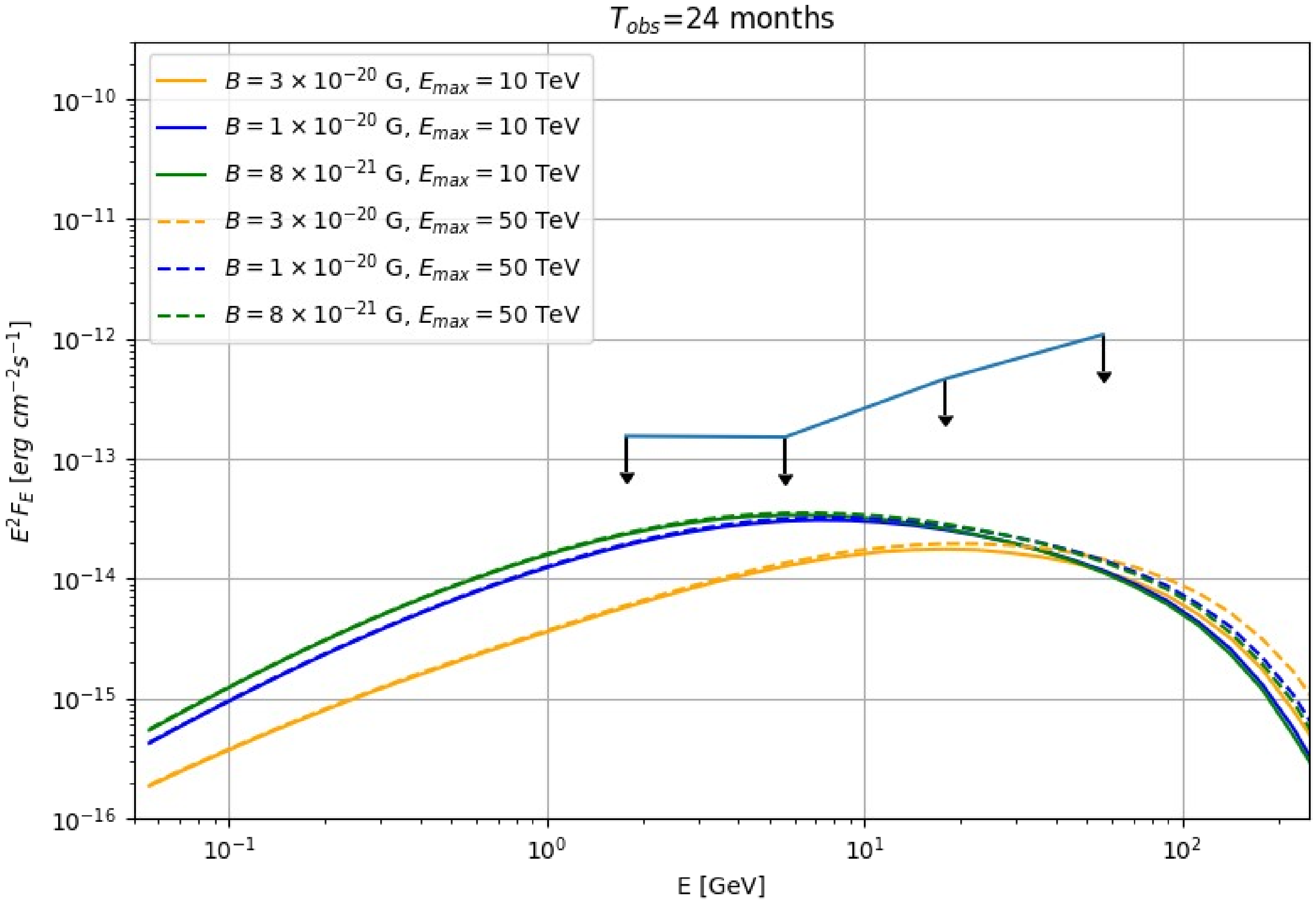
SEDs vs observation time: 3 months



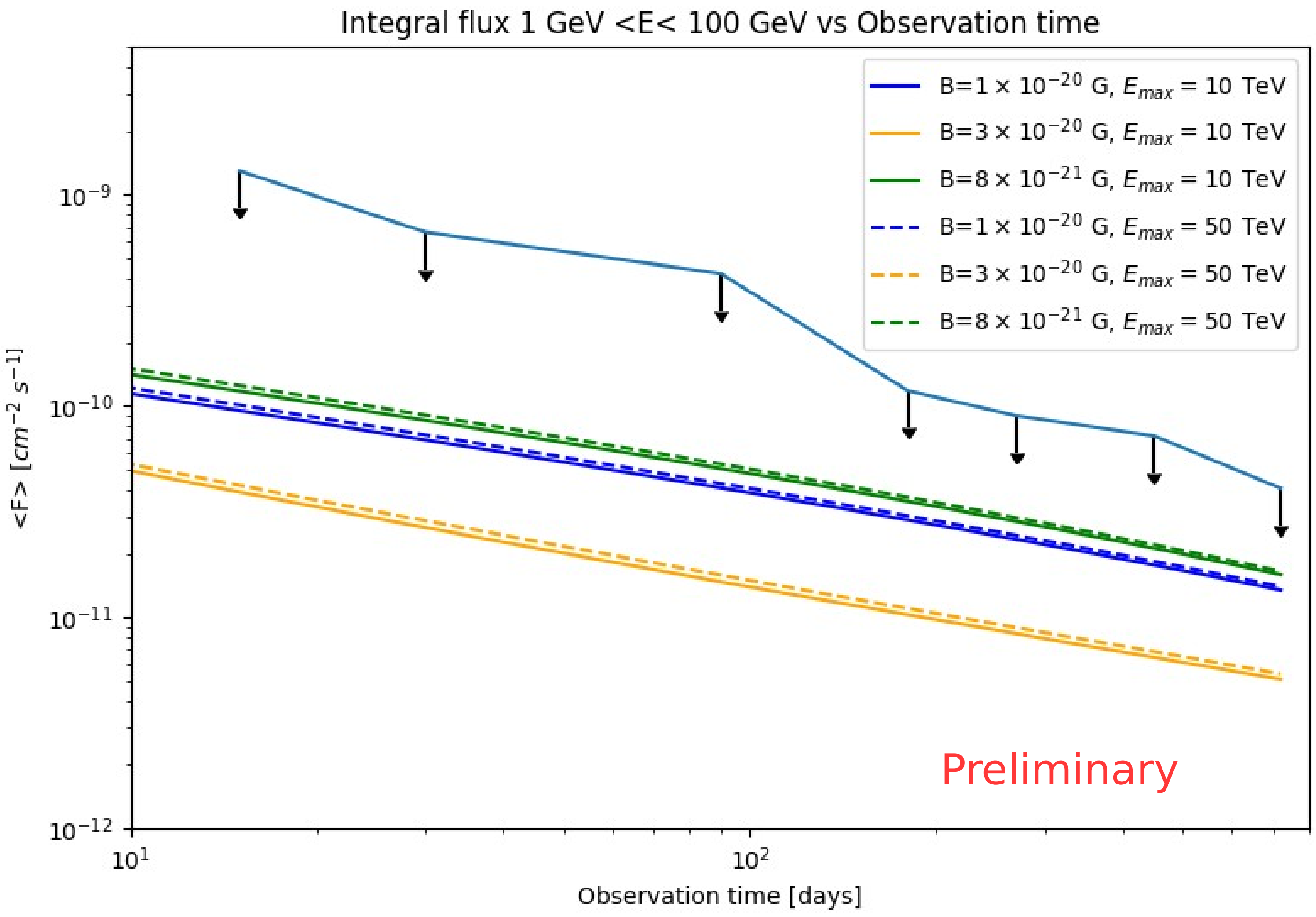
SEDs vs observation time: 9 months



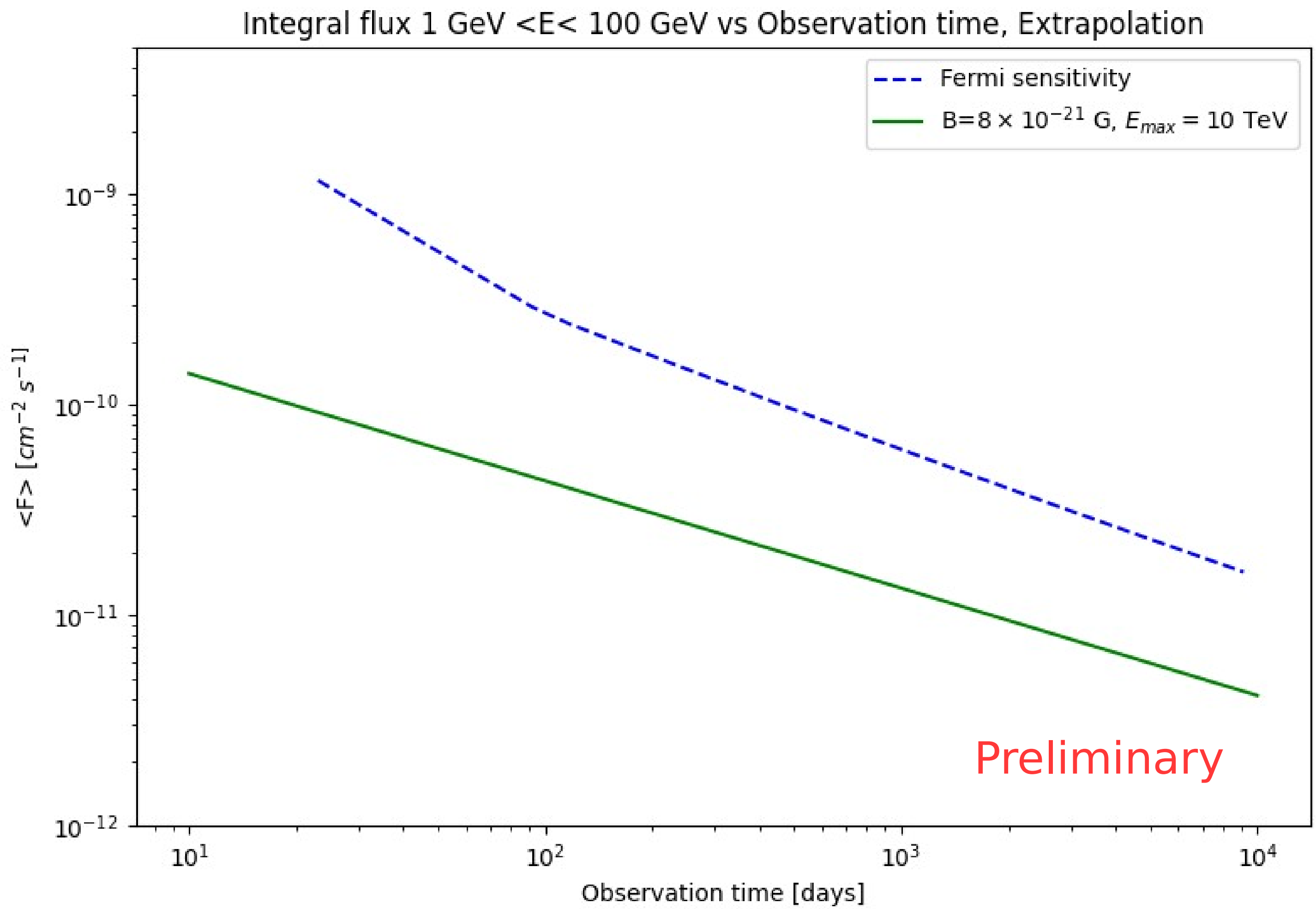
SEDs vs observation time: 24 months



Integral flux 1 GeV < E < 100 GeV



Fermi/LAT sensitivity (95% CL)



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 lightcurve with the Fermi/LAT limits no constraints can be placed on the IGMF strength

Back up

From simulation to physical units

- To convert from simulations 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

$$\Delta T_{ctivity} = 40min$$

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

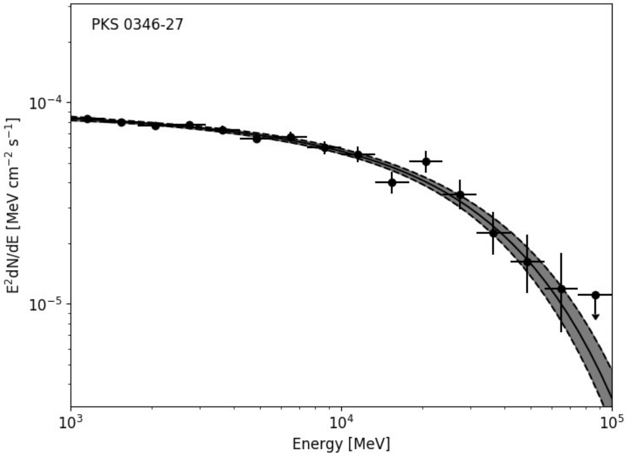
ΔT Exposure time

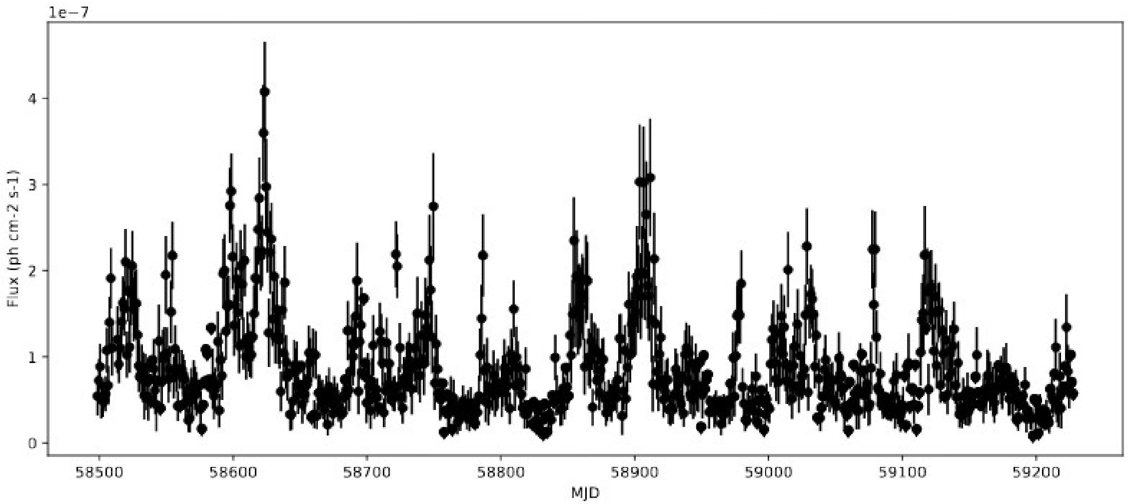
Flux measured by MAGIC and extrapolated up to the first 6 seconds after the burst (factor of 5 the measured one)

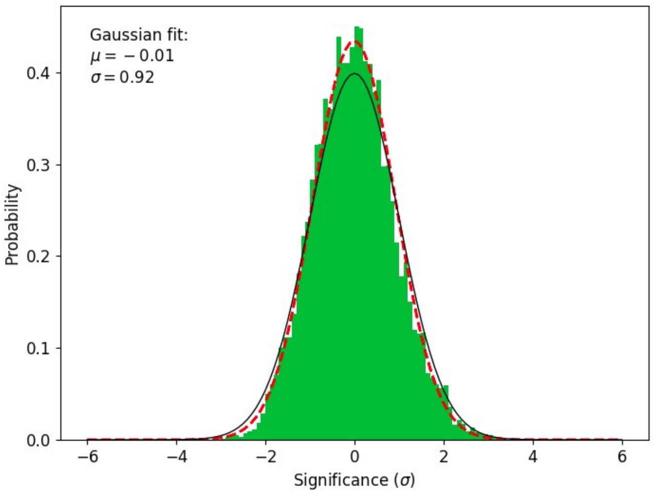
Background model optimization

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

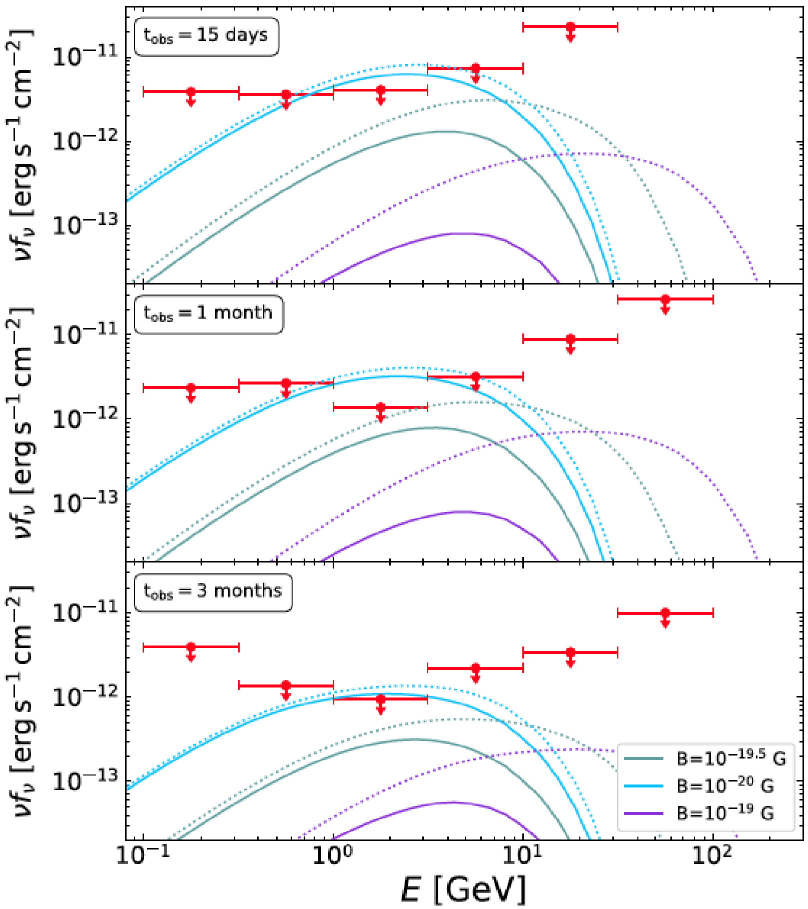






Published lower bounds on IGMF from GRB 190114C

- **Wang et al. 2020**



Analytic approach

Several EBL models tested

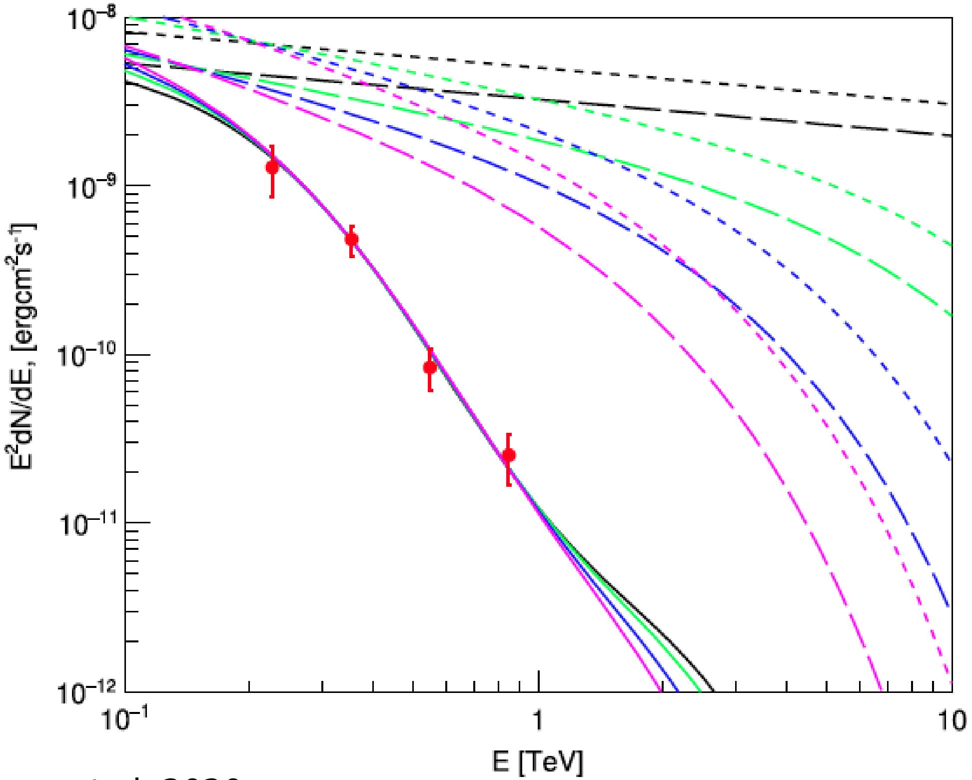
Intrinsic spectral shape in the VHE band: power law index 2 up to 1 TeV and 15 TeV

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 λ_B≲ 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

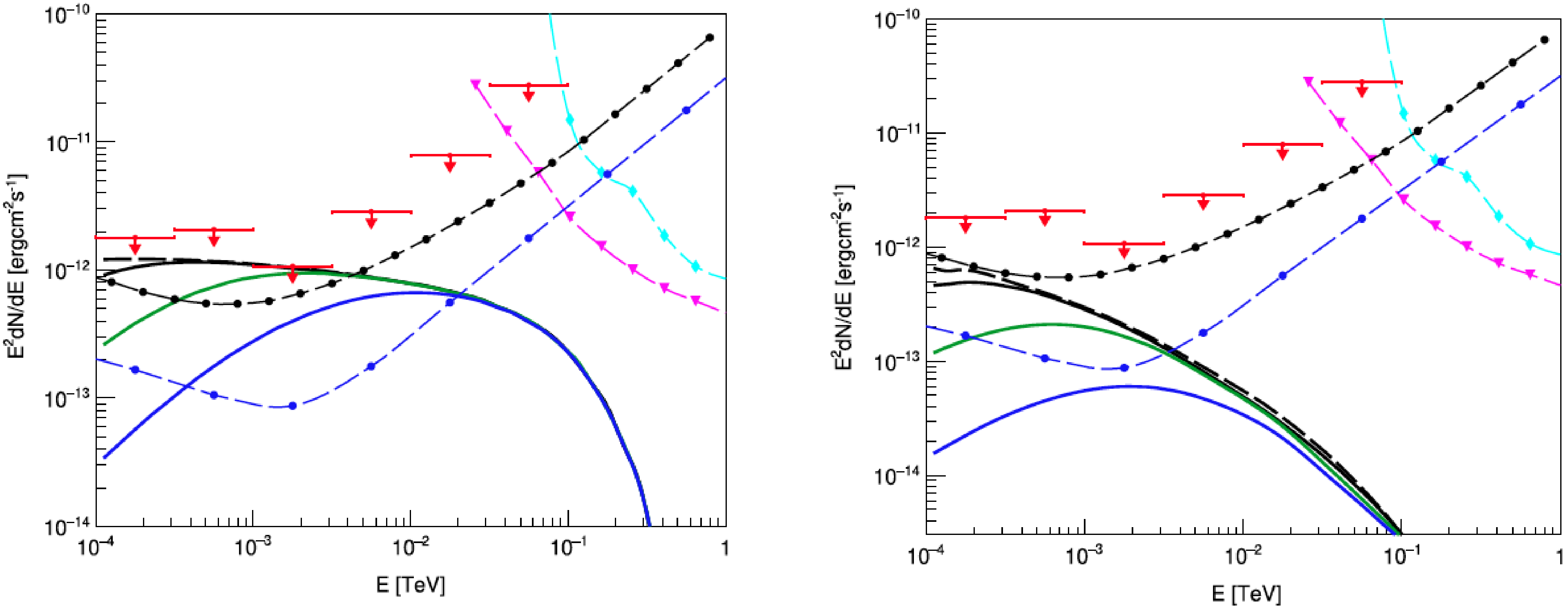


Dzhatdoev et al. 2020

- » Assuming an intrinsic spectrum ~E^{γ} * 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



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