Some remarks on blazar emission models and multimessenger connections in active galactic nuclei

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This talk is based on:

1) Dzhatdoev et al., A&A, **603**, A59 (2017)
2) Khalikov & Dzhatdoev, MNRAS, **505**, 1940 (2021)
3) Dzhatdoev et al., Phys. Rev. D, **102**, 123017 (2020)
4) Podlesnyi & Dzhatdoev, Results in Physics, **19**, 103579 (2020)
5) Dzhatdoev et al., Universe, **7**, 494 (2021)
6) Dzhatdoev et al., astro-ph/2111.07389 (2021)
(submitted to MNRAS)
work(s) in preparation

I) Intergalactic γ-ray propagation and constraints on the extragalactic magnetic field (EGMF)
II) γ-ray – ultra high cosmic ray (UHECR) connection
III) A new model for extreme blazars?
IV) Low-state γ-ray emission of flat spectrum radio quasars – a new diagnostic tool -> γ-ray – neutrino connection

Any room for intergalactic cascade models left after Ackermann et al., ApJ Suppl., **237**, 32 (2018)?

Their results on the EGMF:

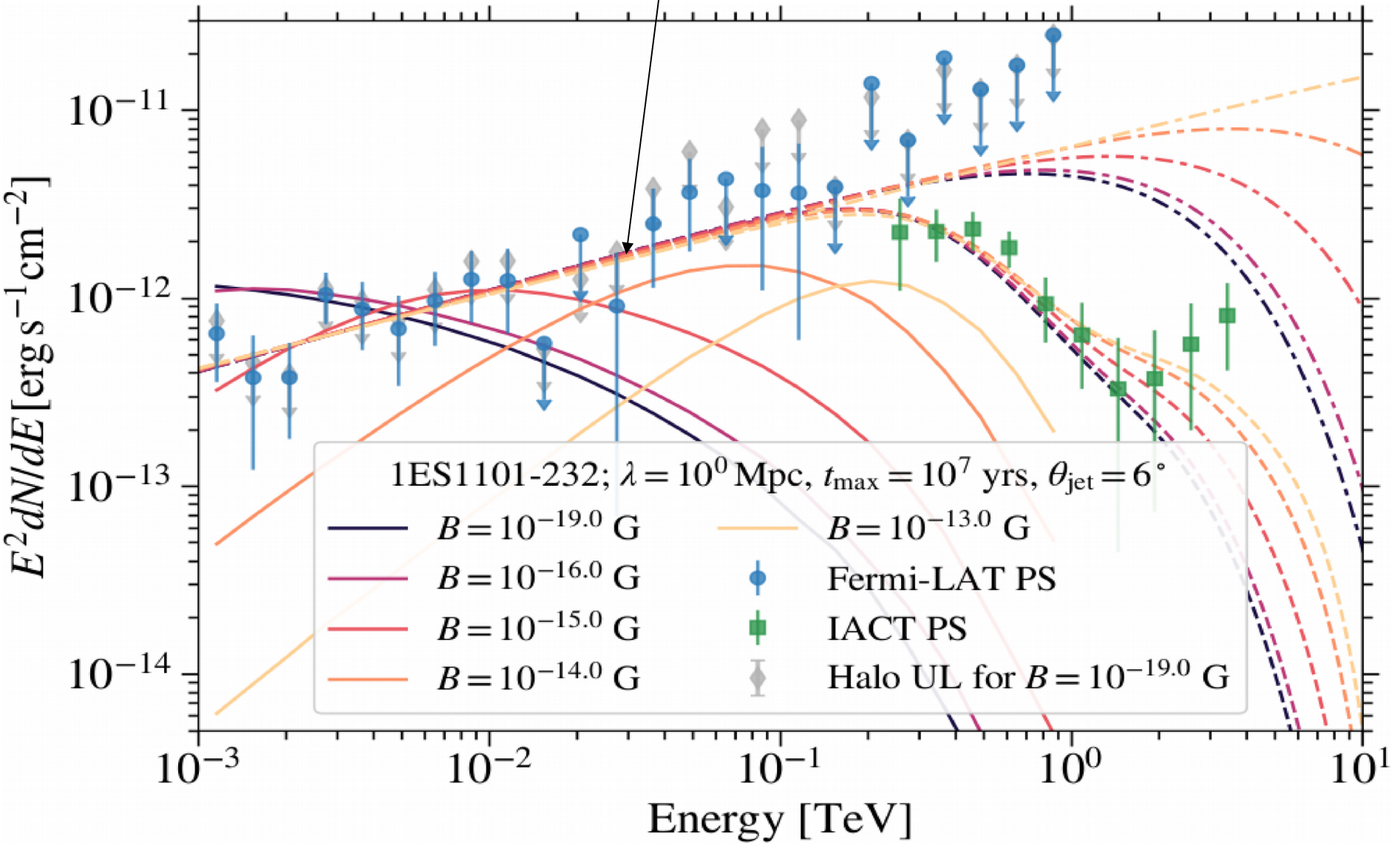
1. $B>3\times10^{-16}$ G for $\lambda>10$ kpc even for highly variable sources,
2. $B>3\times10^{-13}$ G for $\lambda>10$ kpc and stable sources

Their conclusion: "This improves previous limits by several orders of magnitude."

But they assume that "Accounting for the cascade contribution does not change the best-fit spectrum of the central point source in the entire Fermi-LAT energy band by more than 5σ";
a "simplified 1D Monte-Carlo calculation" was used

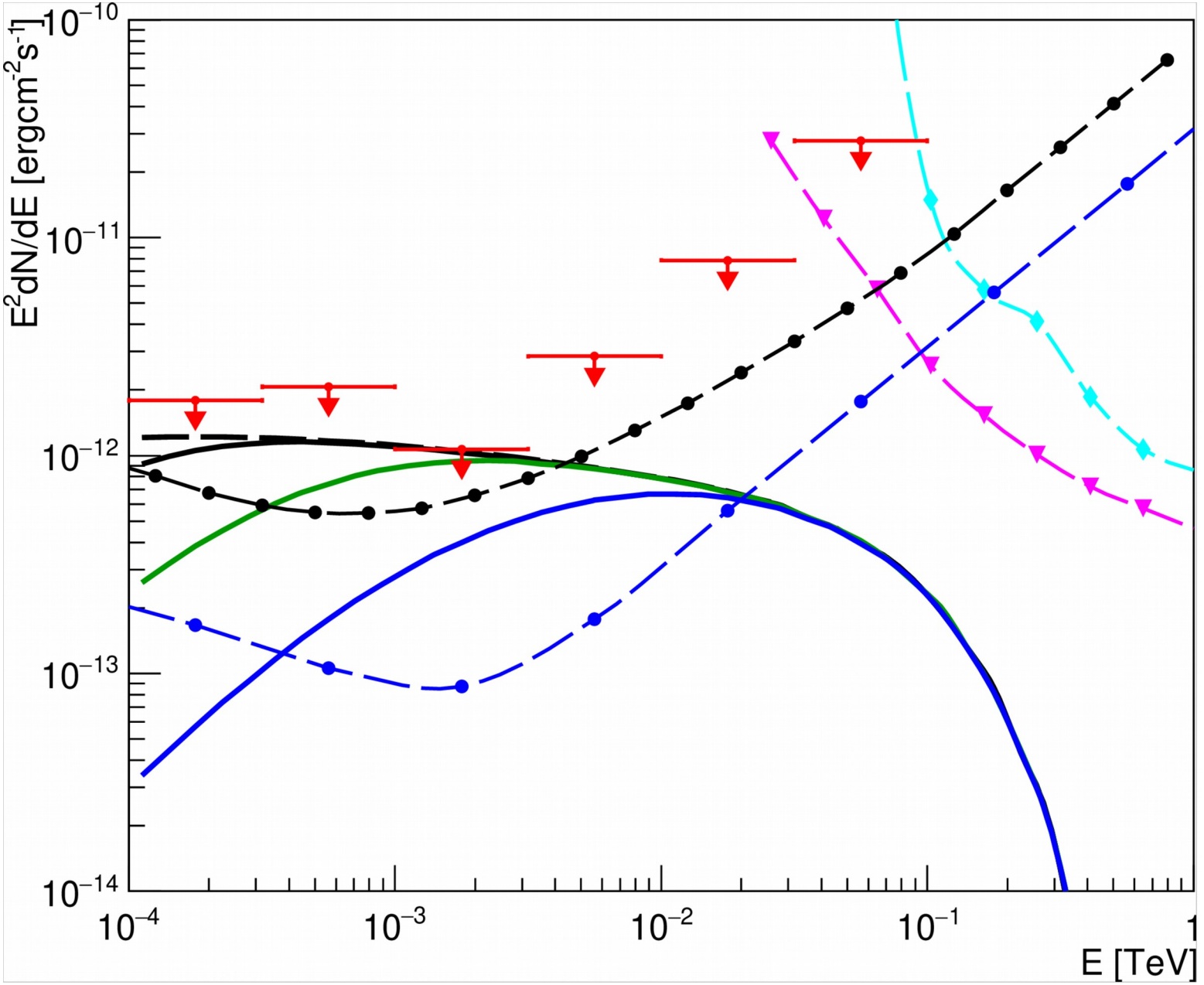
There is no room for the cascade component in their fit!

Conclusion: their results are mainly driven by their assumptions!!

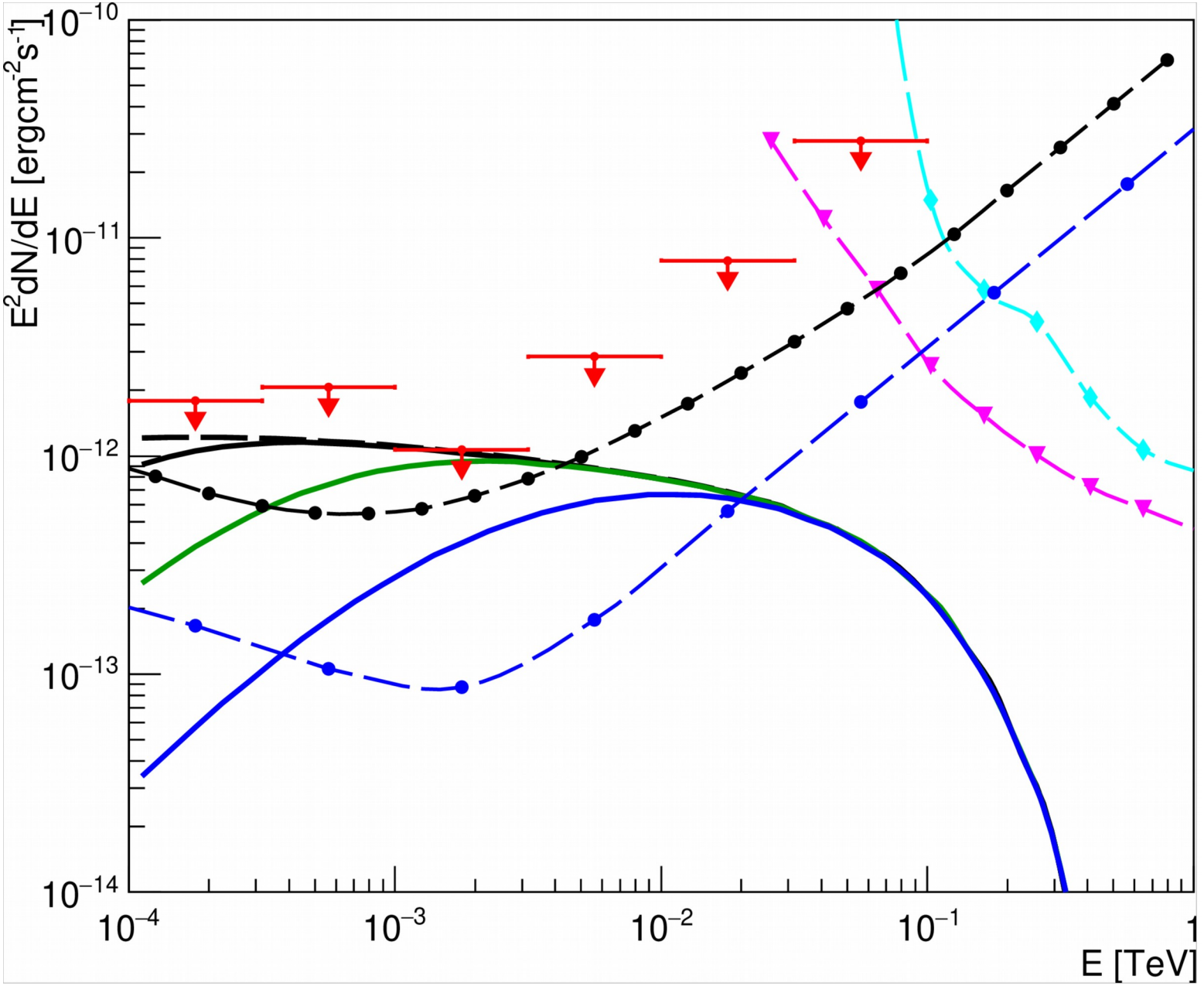


Our own results do not allow to exclude even 10 aG EGMF with the statistical significance of >2σ!

Fermi-LAT upper limits on the SED of GRB 190114C (20 000 s – 1 month); observable cascade SEDs (B= 0 – dashed black, B= 10^{-20} G – solid black, B= 10^{-19} G, B= 10^{-18} G).



CTA: 5 hours (20 deg, 60 deg)
MAST project ("Massive Argon Space Telescope",
Dzhatdoev & Podlesnyi, APh, 112, 1 (2019)): circles; 2σ, 5σ



EGMF in extragalactic filaments is already detected (Govoni et al., Science, **364**, 981 (2019)); T. Vernstrom et al., MNRAS 505, 4178–4196 (2021); astro-ph/2202.04607 (but see astro-ph/2112.01754 !)

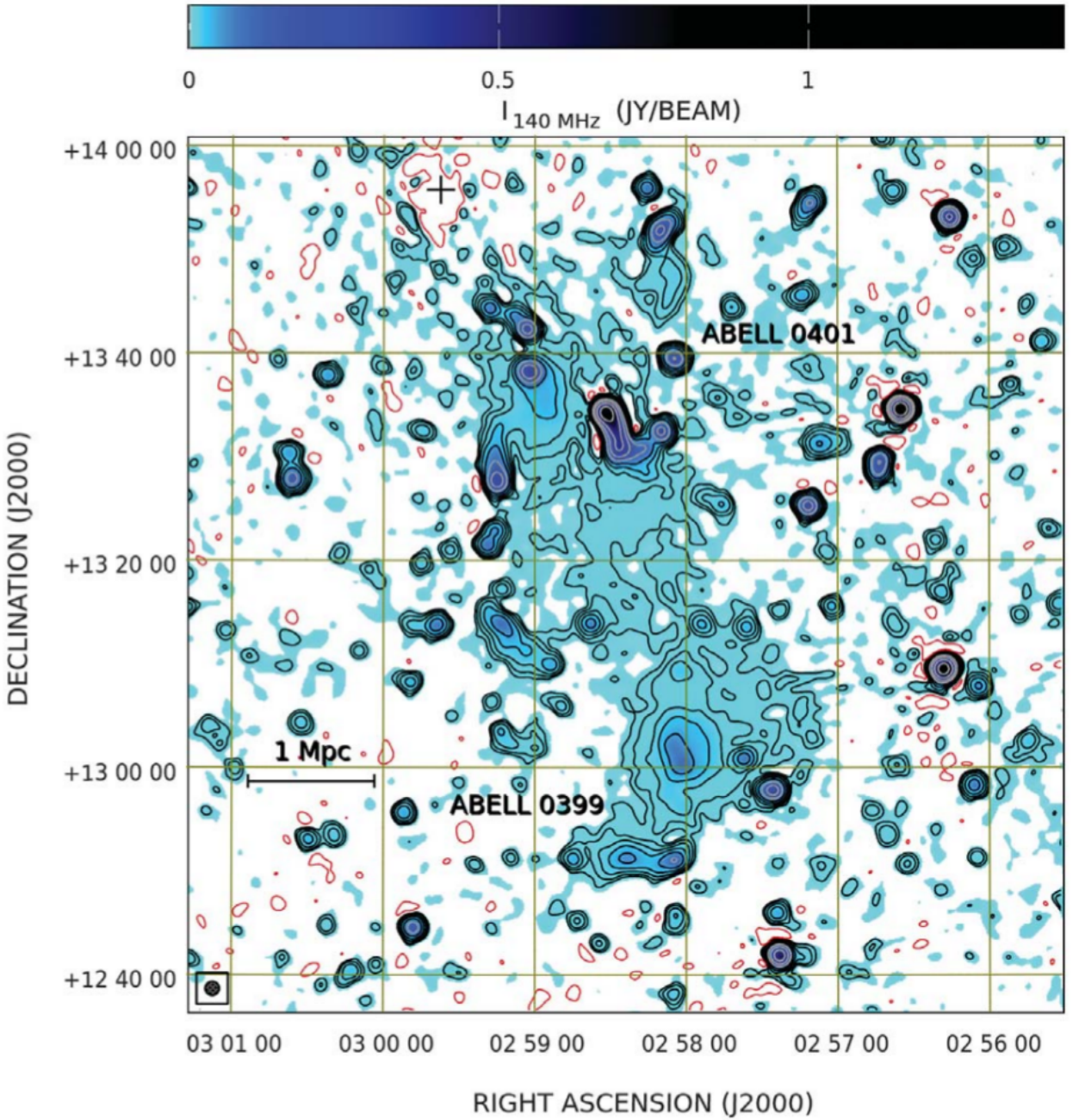
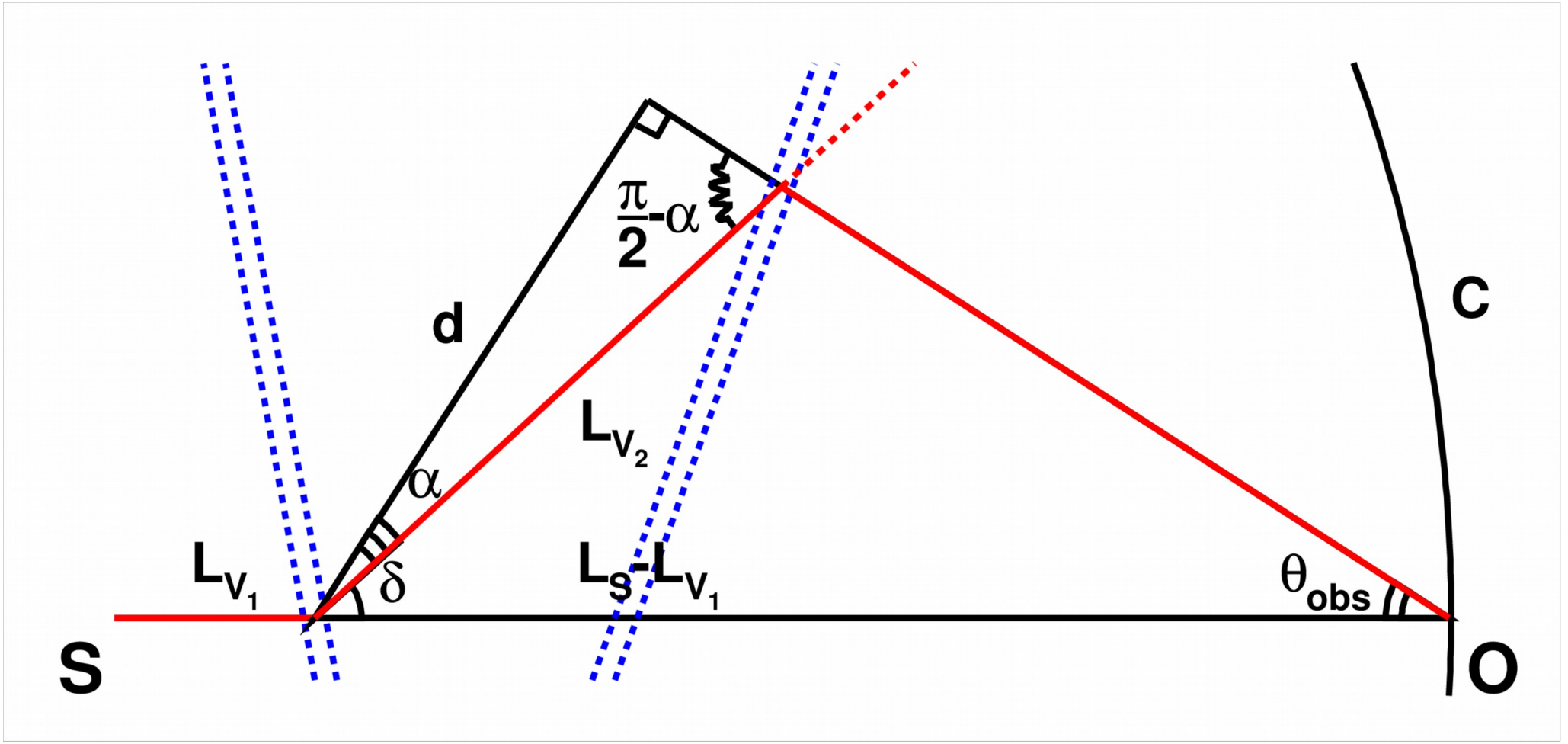


Fig. 1. LOFAR image of the 1.4° × 1.4° region centered on the Abell 0399–Abell 0401 system. Color and contours show the radio emission at 140 MHz with a resolution of 80 arc sec and RMS sensitivity of 1 mJy beam^{-1}. The beam size and shape are indicated by the inset at the bottom left. Contour levels start at 3 mJy beam^{-1} and increase by factors of 2. One negative contour (red) is drawn at −3 mJy beam^{-1}. The black cross (right ascension 02h 59m 38s, declination +13° 54′ 55″, J2000 equinox) indicates the location of a strong radio source that was removed from the image.

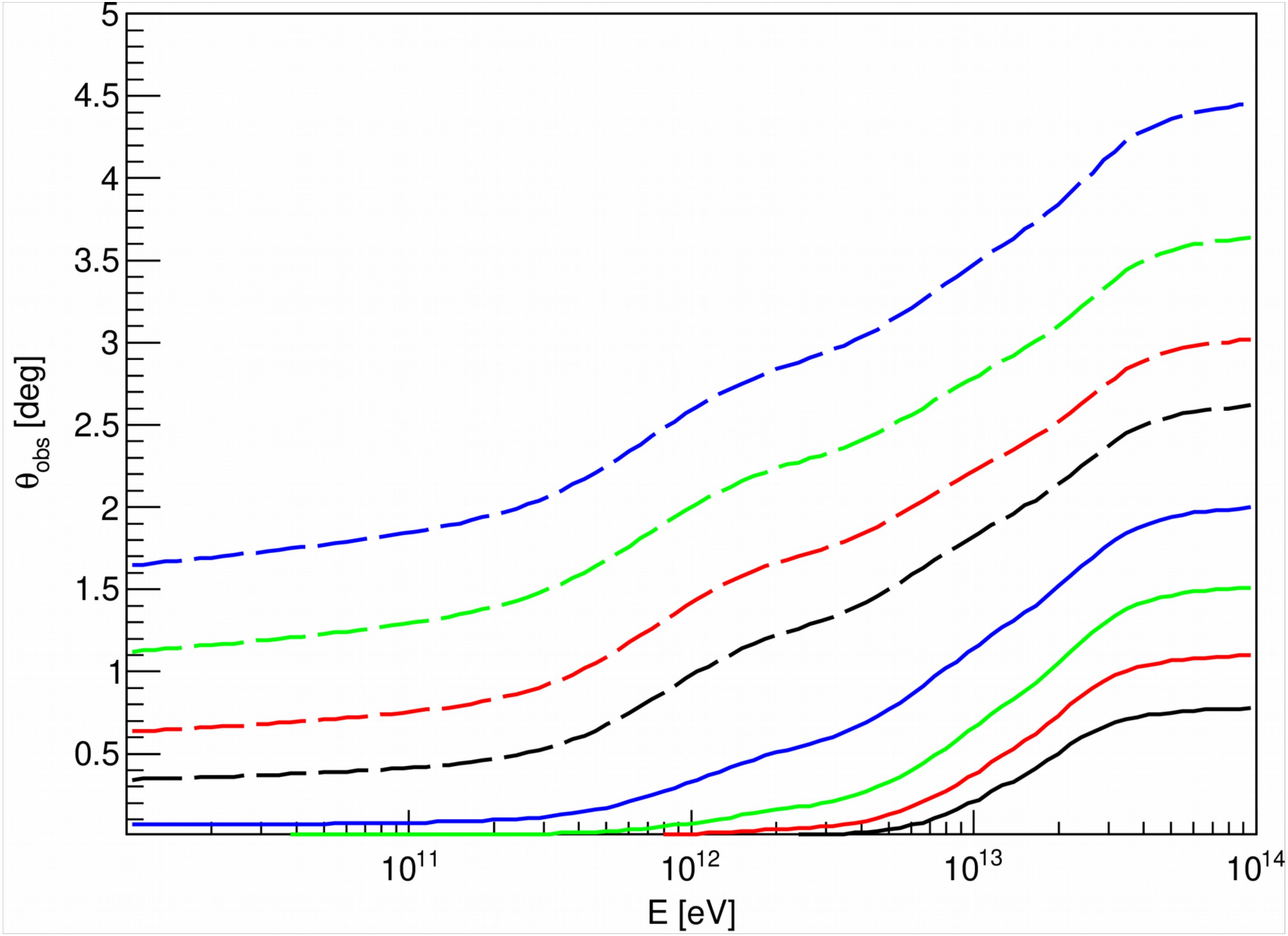
Filaments; primary proton path; observer (O)



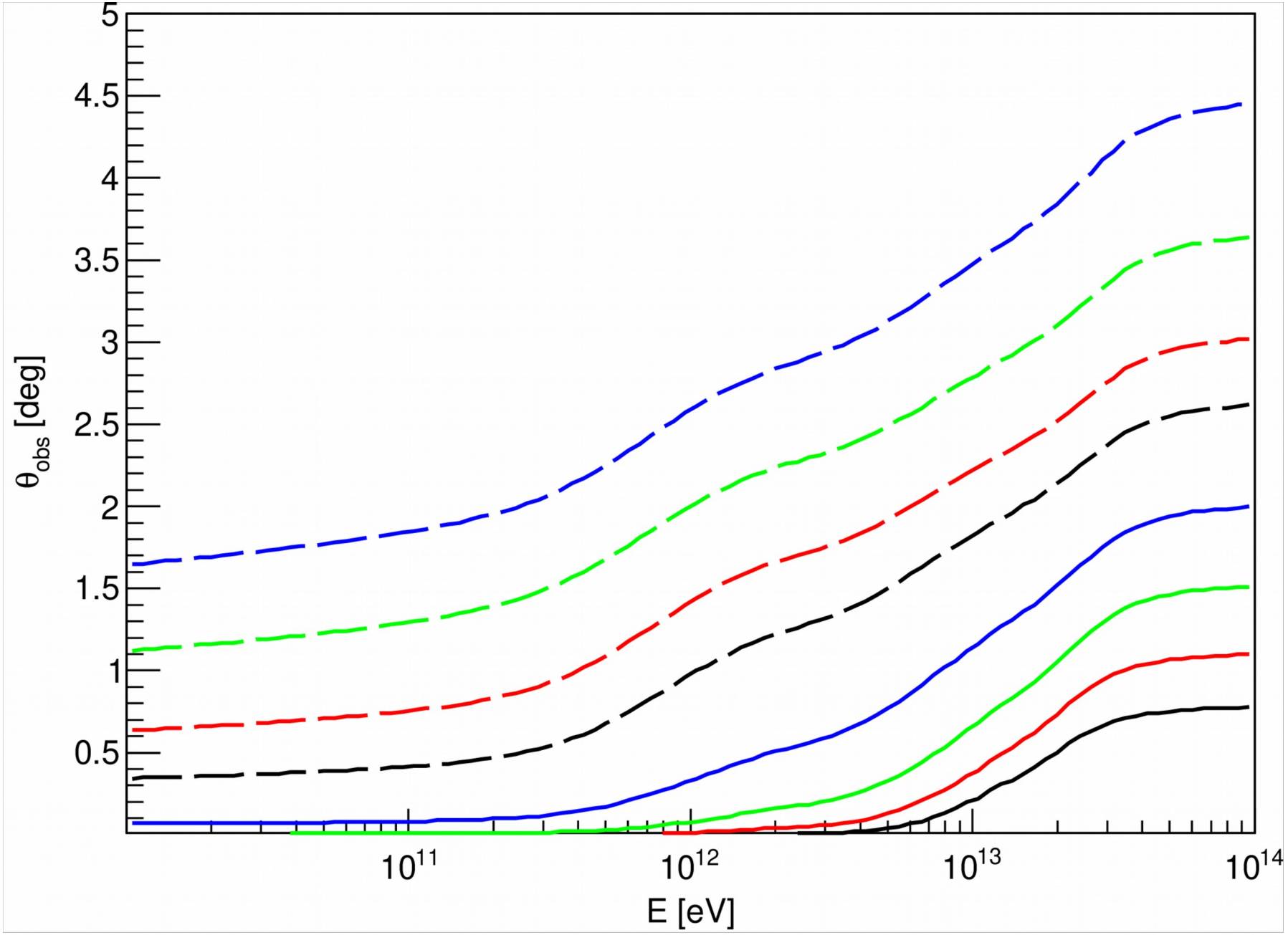
The source is extended!

Let us assume the EGMF model of Dolag et al. (2005) (in filaments and voids)

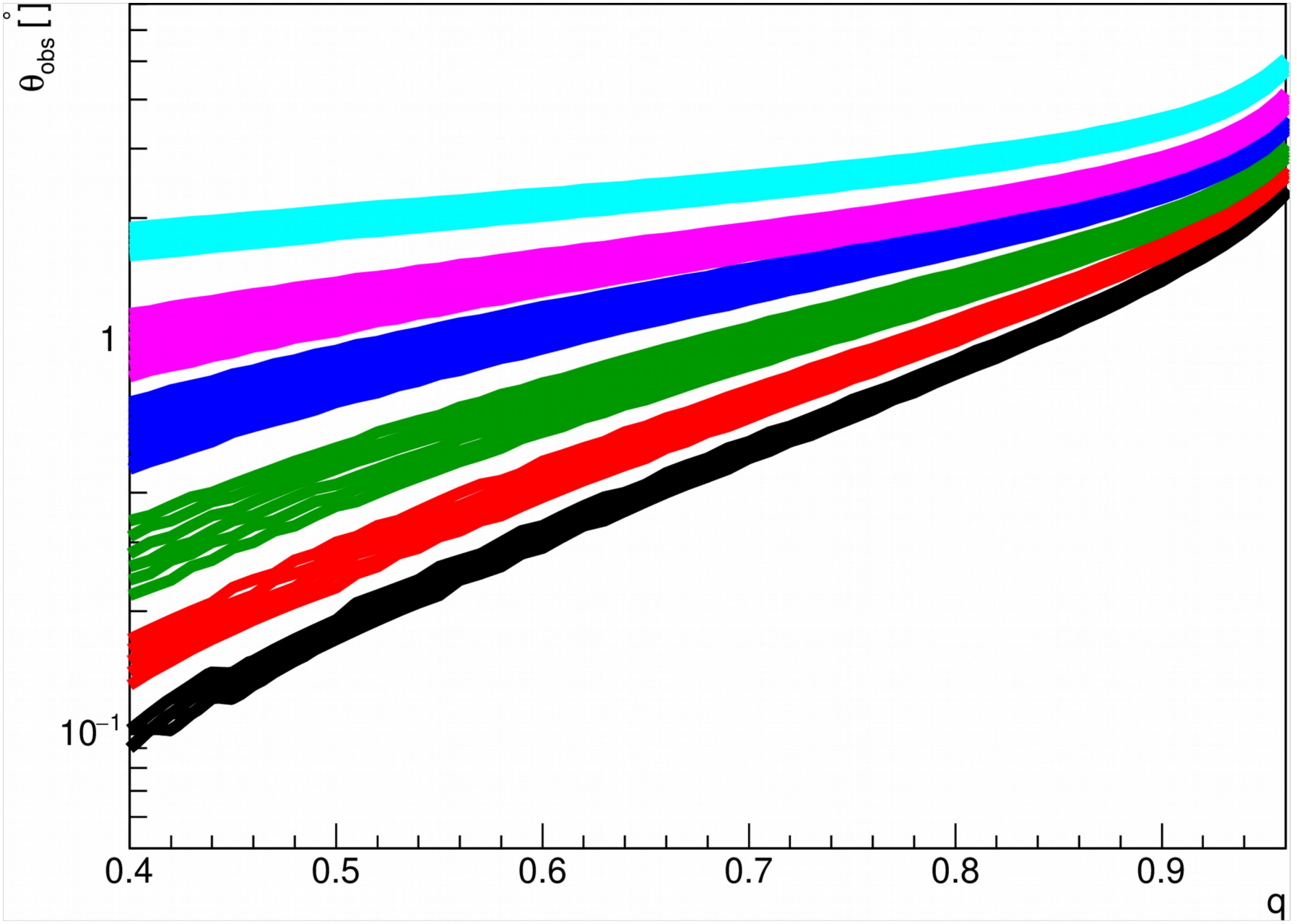
Observable angular distribution



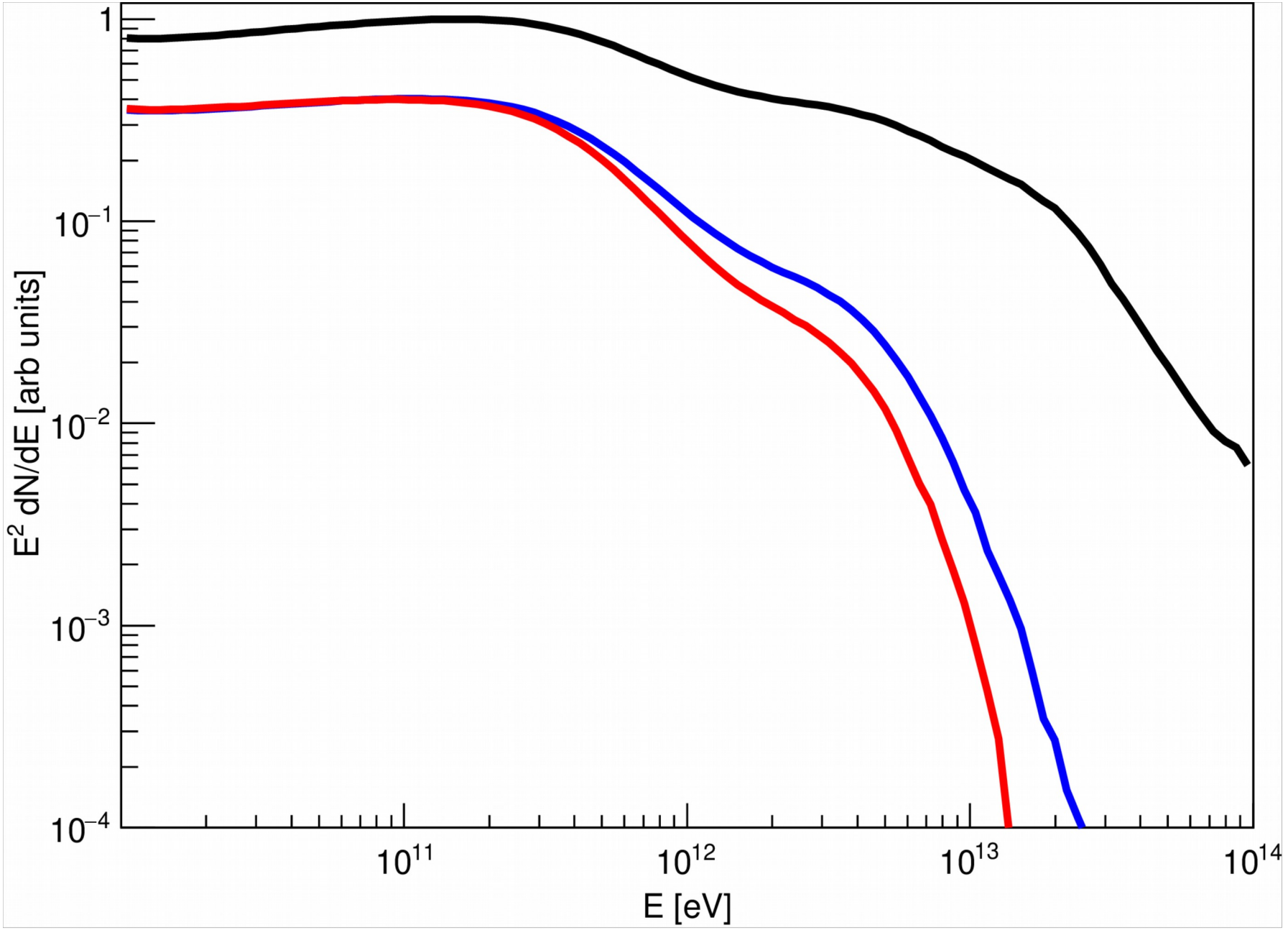
Solid curves: 5 %, 10 %, 20 %, 40 %;
dashed curves: 68 %, 80 %, 90 %, 95 %



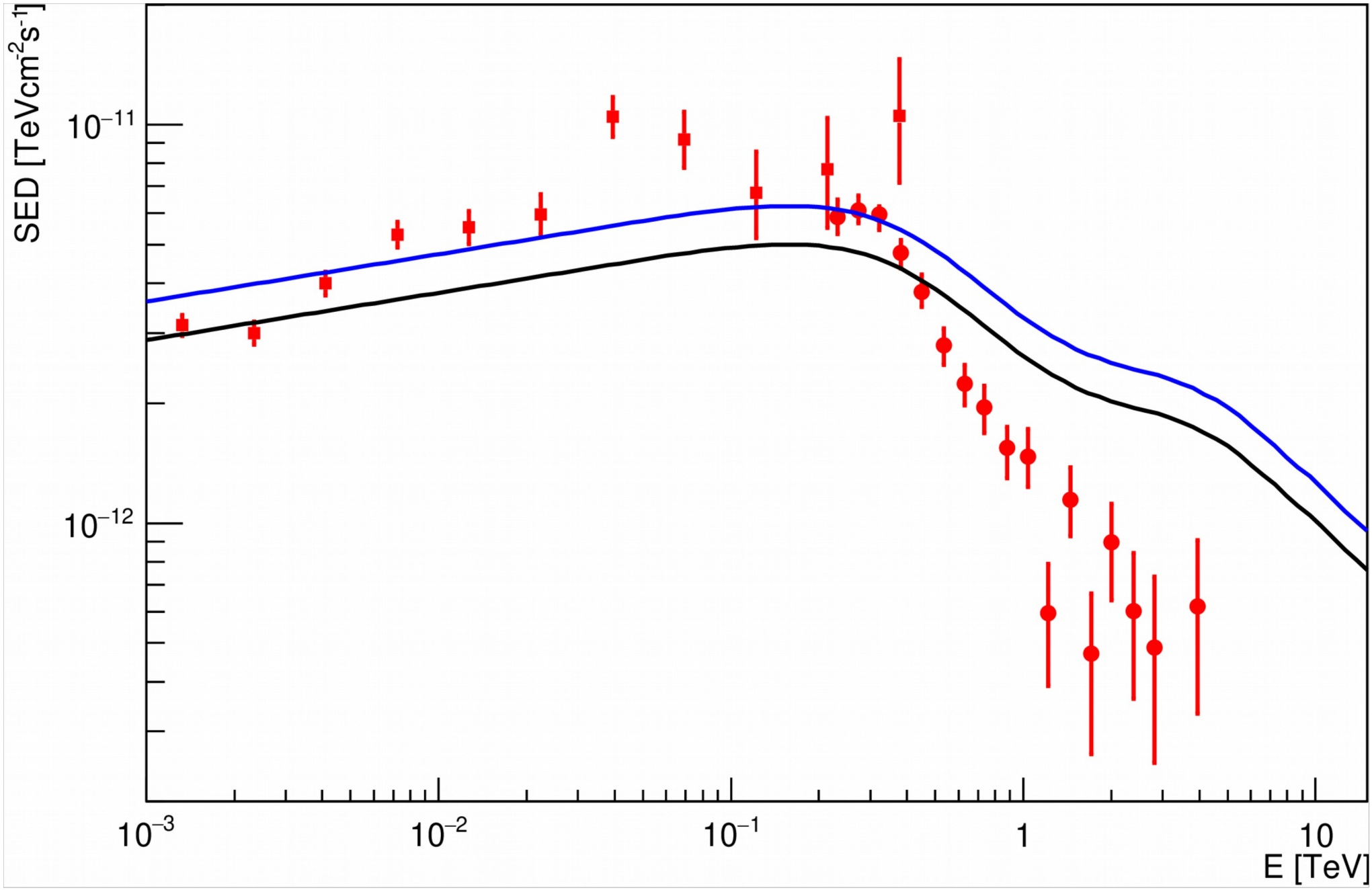
Observable energy range: 100–200 GeV, 300–500 GeV, 0.6–1 TeV, 1.5–4 TeV, 5–10 TeV, 20–40 TeV



"Basic model" (B=0); purely electromagnetic cascade;
"modified" model (the EGMF according to Dolag et al.)



Blazar 1ES 1218+304 (z= 0.182)



Blazar 1ES 0229+200 (z= 0.14): towards internal electromagnetic cascade model

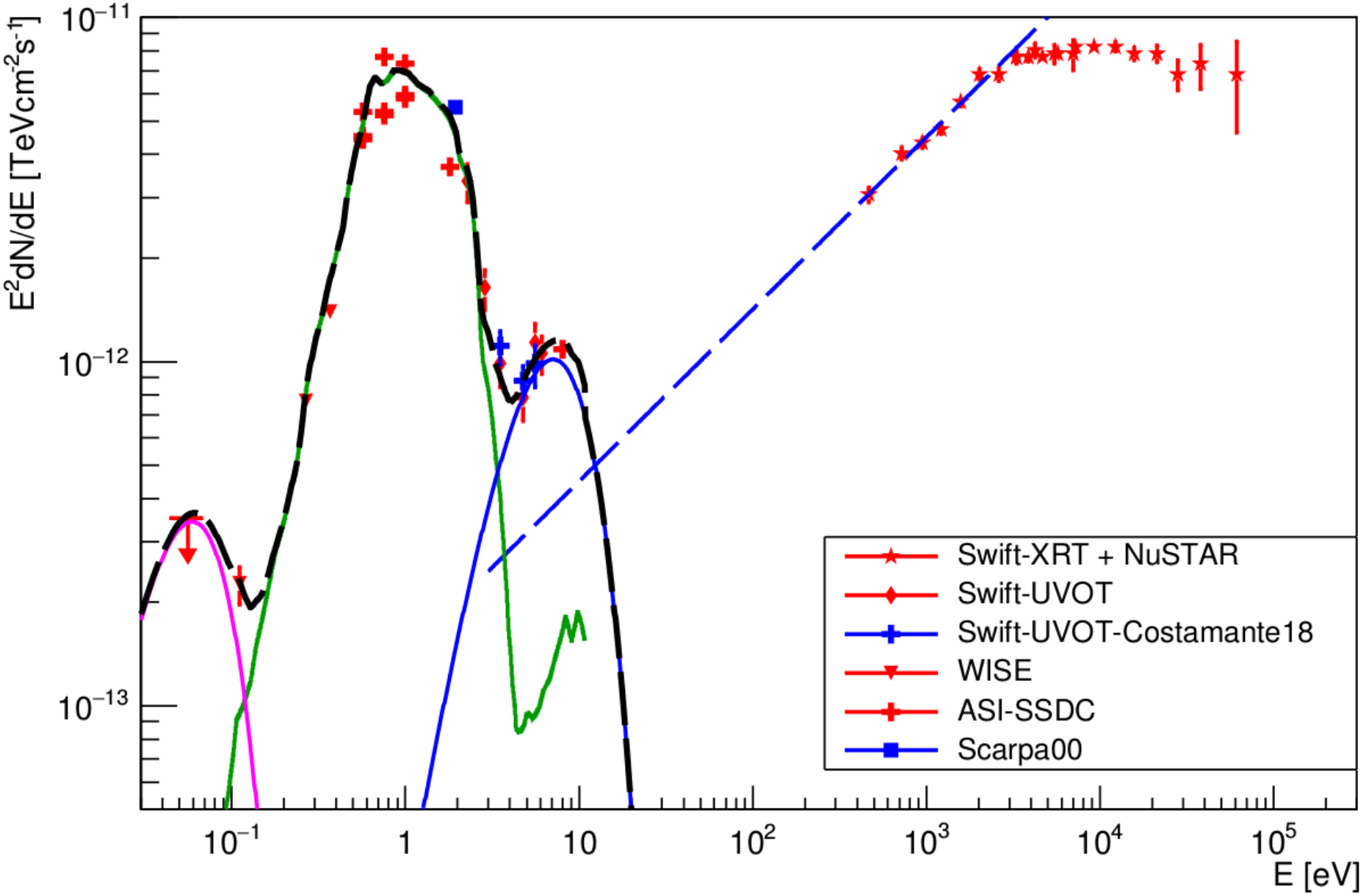


Figure 1. The low-energy part of the SED for 1ES 0229+200 observed with various telescopes.

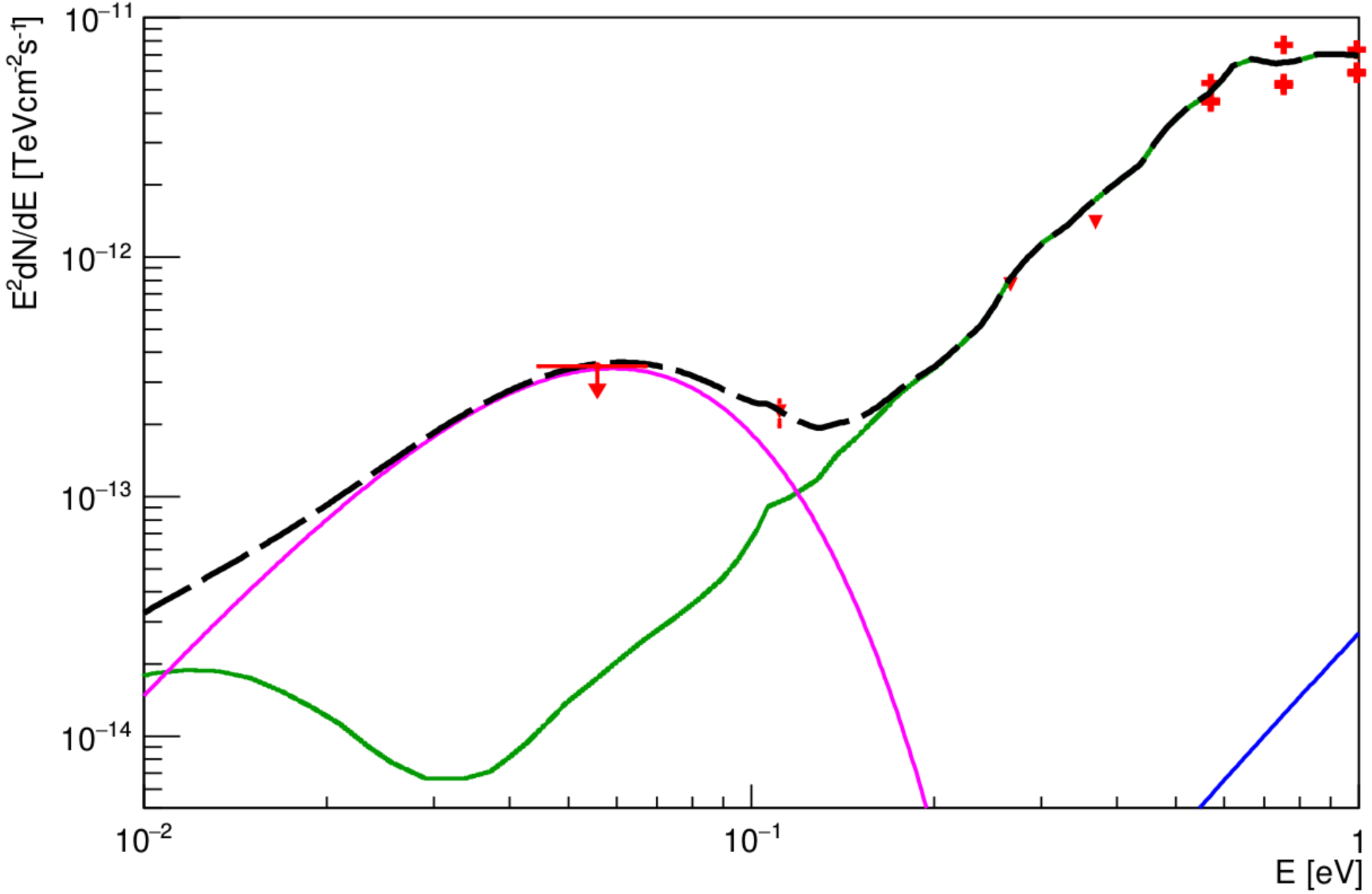
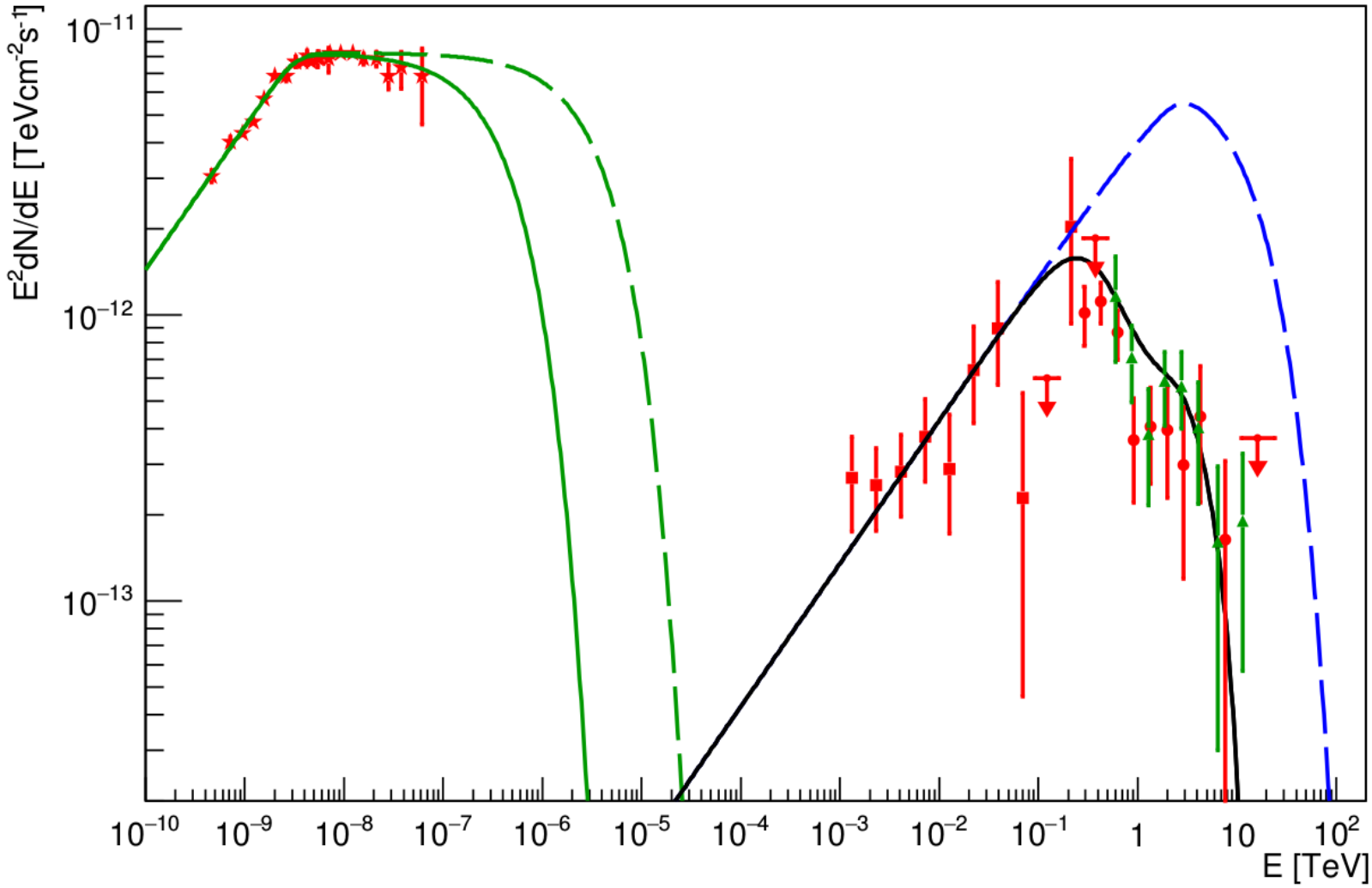
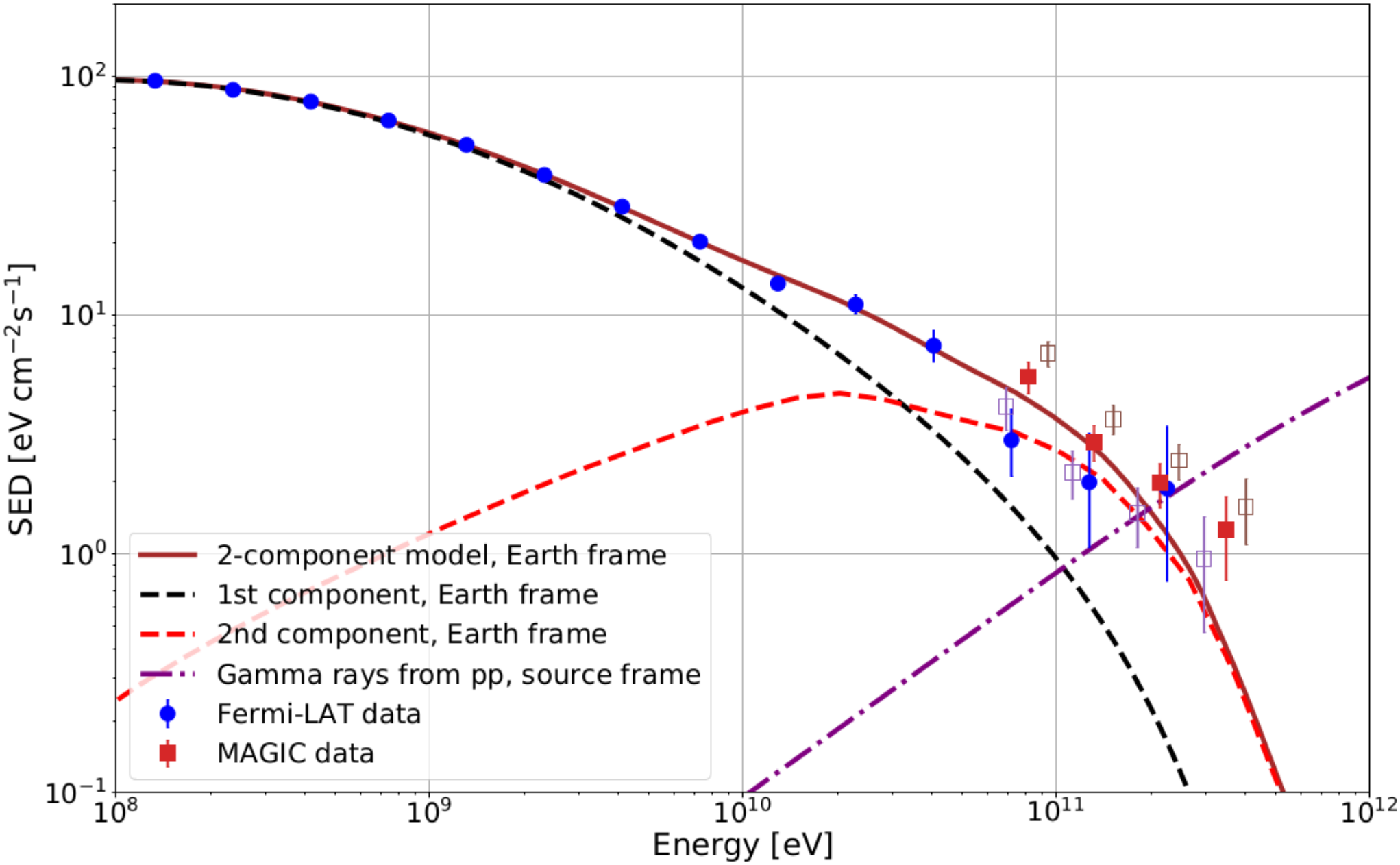

E^2dN/dE [TeVcm^{-2}s^{-1}]
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-2}
10^{-1}
1
E [eV]

Table 1. Basic parameters of the proposed model.

Parameter	Meaning	Value	Units
E_b	IR photon energy	6×10^{-2}	eV
B	Magnetic field strength	0.9	mG
E_{me}	Maximal energy of primary electron	100	TeV
K_{cs}	IC SED peak dominance	0.42	



FSRQ PKS 1510-089 in the low state: excess of gamma-rays above the low-energy log-parabolic component from electromagnetic cascades?



Conclusions

I) The EGMF strength is largely unconstrained: even B= 10 aG is still a viable value!

II) γ-ray – UHECR connection is not obvious in extreme blazars!

III) A new understanding for extreme blazars – cascades from primary ~sub-PeV or PeV electrons or γ-rays?

IV) Low-state γ-ray emission of PKS 1510-089 – indication for pp γ-rays with subsequent EM cascades?