Intergalactic magnetic field constraints through gamma-ray observations of the extremely high-energy peaked BL-Lac candidate HESS J1943+213

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ABSTRACT

Extreme High-frequency-peaked BL Lac (EHBL) objects, a subclass of blazars characterised by a synchrotron peak frequency exceeding 10^{17}Hz, and, in some cases, an inverse Compton peak energy exceeding 1 TeV, are ideal sources to study the InterGalactic Magnetic Field (IGMF) due to the hardness of their spectrum. HESS J1943+213 is a Very High Energy (VHE, >100 GeV) γ-ray source shining through the Galactic Plane discovered by HESS. Recently, also VERITAS published a VHE spectrum spanning from 200 GeV up to about 2 TeV consistent with that of HESS within the errors (photon index=2.8). The archetypal EHBL source is 1ES 0229+200 which has a redshift z=0.14 and a similar VHE slope (photon index=2.9). Since the observed flux of HESS J1943+213 at 1 TeV is more than a factor of two larger, and its redshift is bigger (z<0.23), a much larger reprocessed power is expected, which allowed us to study the magnetic field strength with great accuracy. We used the simulation code CRpropa 3 to simulate the cascade emission assuming different IGMF configurations and a detailed analysis of the 10 years of Fermi-LAT data to extend the observed VHE spectrum down to 5 GeV. Comparing the cascade spectrum with the combined spectra from Fermi-LAT and Cherenkov telescopes we derived a lower limit on the IGMF strength of the order of 6e-14 G which is at least a factor of 4 larger than previously published results obtained with the source 1ES0229+200. Effects of the duty cycle are also taken into consideration.

HESS J1943+213

- HESS J1943+213 is an EHBL (extremely weak emission lines, synchrotron peak exceeding 10^{17}Hz) shining through the galactic plane, detected at VHE by HESS and VERITAS in 2011 and 2018 [2,3]
- The source is also detected by the Fermi-LAT in 10 years of data with TS=213 (4FGL 1944.0+2117)
- Its redshift is 0.21 [1]
- VHE spectral index is 2.83 +/- 0.22

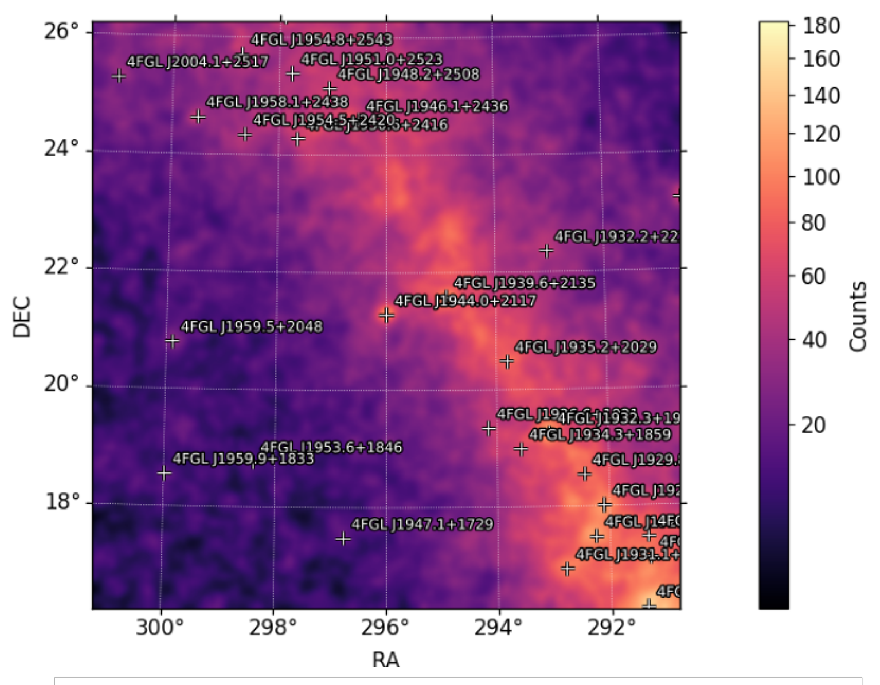

Fig 1: Fermi-LAT 10 years event map around the source (5-500 GeV)

THE INTERGALACTIC MAGNETIC FIELD

The intergalactic mgnetic field (IGMF) has been hypothesized to exist as a consequence of early universe phase transitions, it is characterized by the RMS strength and the correlation length λ (average length over which the magnetic field is homogeneous). Its detection could shed light on the origin and time evolution of galactic magnetic fields[10,12]

- Its small hypothesized strength makes it undetectable with classical astrophysical tracers such as Zeeman splitting and Faraday rotation, by which only upper limits can be derived [11]
- It can be detected exploiting the deflection of electromagnetic cascades generated in the gamma-gamma interaction from TeV photons against the EBL. If the IGMF exists, the cascade will be depleted and is expected to form a halo around the source (pair halo)
- The lack of cascade emission from the point source can then be used to constrain the IGMF strength[6]

INTRINSIC SPECTRUM

- The gamma-band (5GeV-4TeV) intrinsic flux fit is consistent with a simple power law (Fig. 2).
- The VHE flux, responsible for the cascade emission, is larger than that of the 1ES 0229+200 (Fig. 3), the source that so far gave the strongest constraints for the IGMF. HESS J1943 also has a larger redshift (0.21) than that of 1ES 0229+200 (0.14), which also increases the amount of cascade component
- We considered the minimum cascade model (power law with exponential cut-off) from the VHE intrinsic spectrum by imposing both the consistency within 90% CL from the best fit to the data and DSA limit for the photon index[4], obtaining 2080GeV and 1.5 for the cut-off energy and the photon index respectively (Fig. 4)

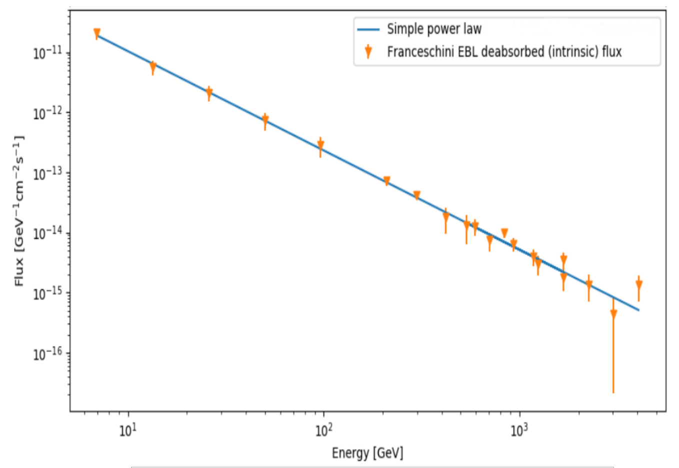

Fig 2: Gamma band best fit to the intrinsic flux of HESS J1943+213

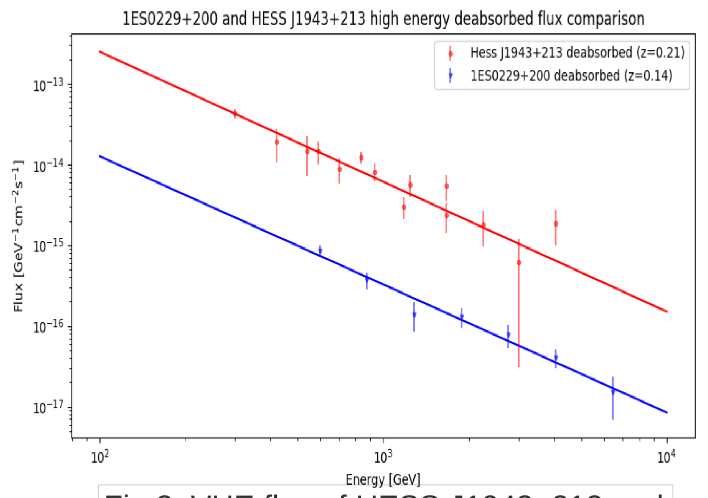

Fig 3: VHE flux of HESS J1943+213 and 1ES 0229+200, compared

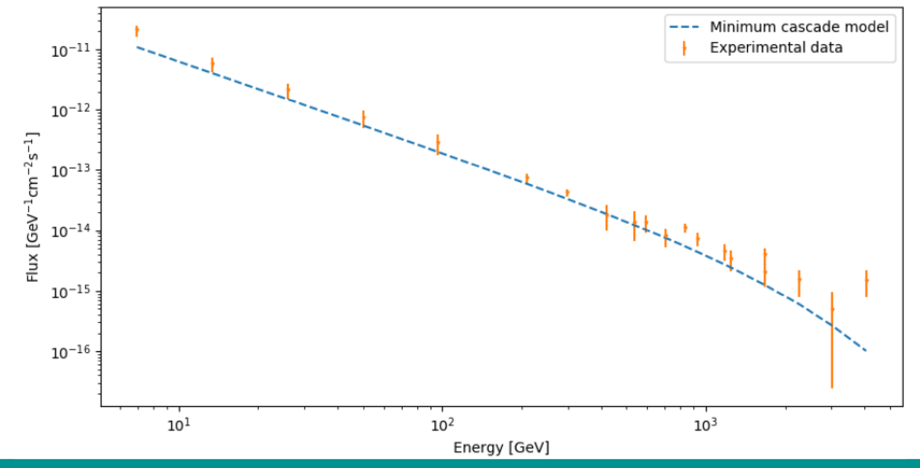

Fig. 4: Intrinsic emission model under conservative hypotheses, compared with observed de-absorbed data

SIMULATIONS AND IMPLICATIONS FOR THE IGMF

- The simulations of the source emission, the propagation and subsequent interaction of electro-magnetic partticles have been simulated with CRpropa 3[7]. The magnetic field has been simulated with the built-in generator as a turbulent kolmogorov spectrum (Fig. 6).
- Its resulting casacade emissions with several magnetic field configurations have been compared with the Fermi-LAT data until consistency was reached (90% CL) at $6\cdot10^{-14}$ G (Fig. 5), **increasing by an order of magnitude** the lower limit for the IGMF obtained with comparable analyses [8,9]
- It variability of the source has also been accounted for in a dedicated analysis. In this case, the lower limit for the IGMF becomes smaller for 8 years of activity but the difference becomes negligible for larger activity times (Tab. 1 and Fig. 7)

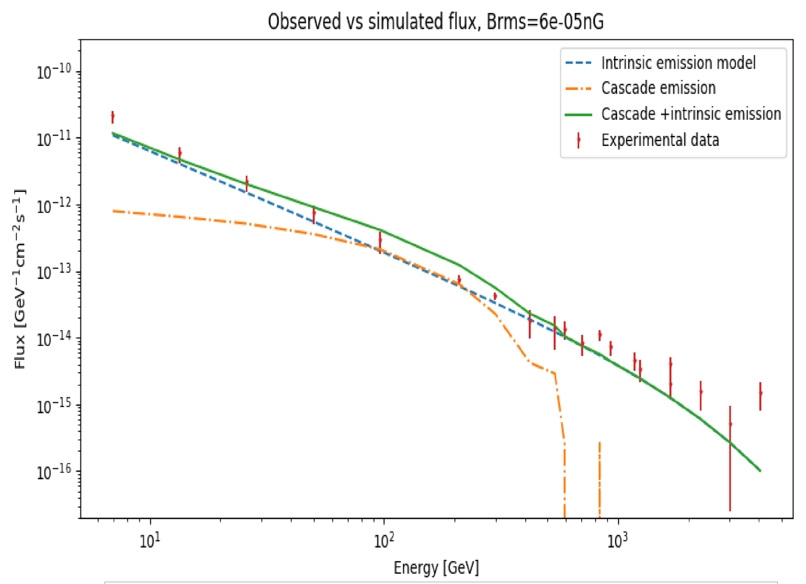

Figure 5: Expected vs observed flux for the lower limit obtained for the IGMF

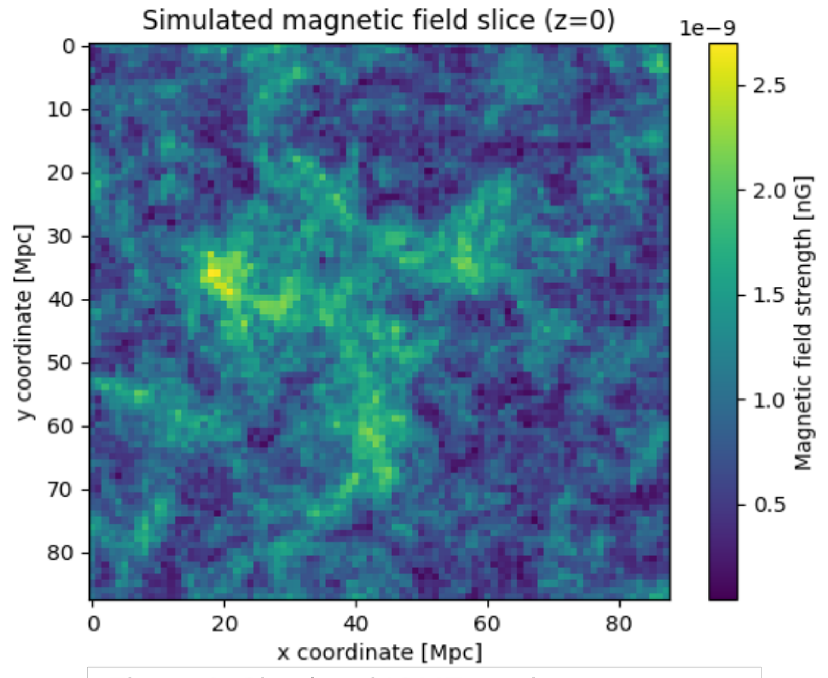

Figure 6: Simulated IGMF patch

Source name	IGMF strength limit [G]
1ES0229+200[8]	10^{-15} (10^{-18} if variable)
1ES0229+200[9]	$3\cdot10^{-16}$
HESS J1943+200	$6\cdot10^{-14}$ ($7\cdot10^{-15}$ if variable)

Table 1: Magnetic field constraints comparison across studies that use similar hypotheses

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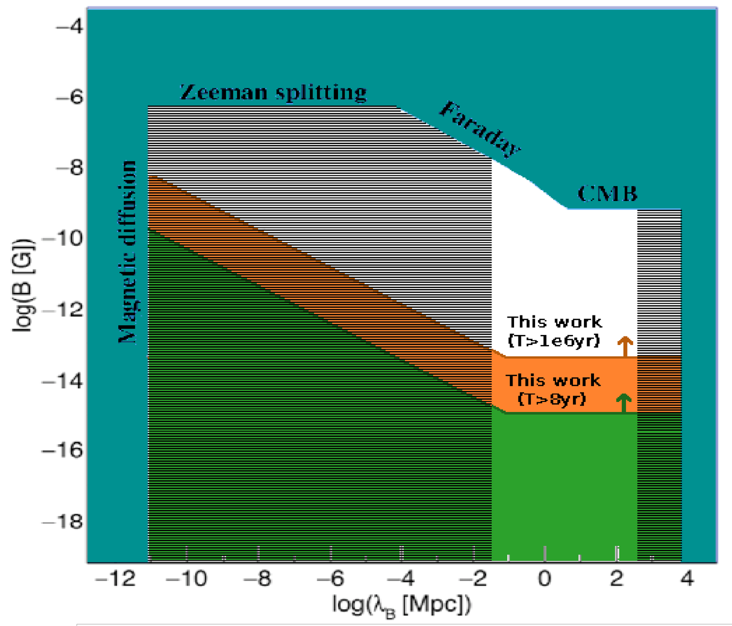

Figure 7: Expected vs observed flux for the lower limit obtained for the IGMF

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