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

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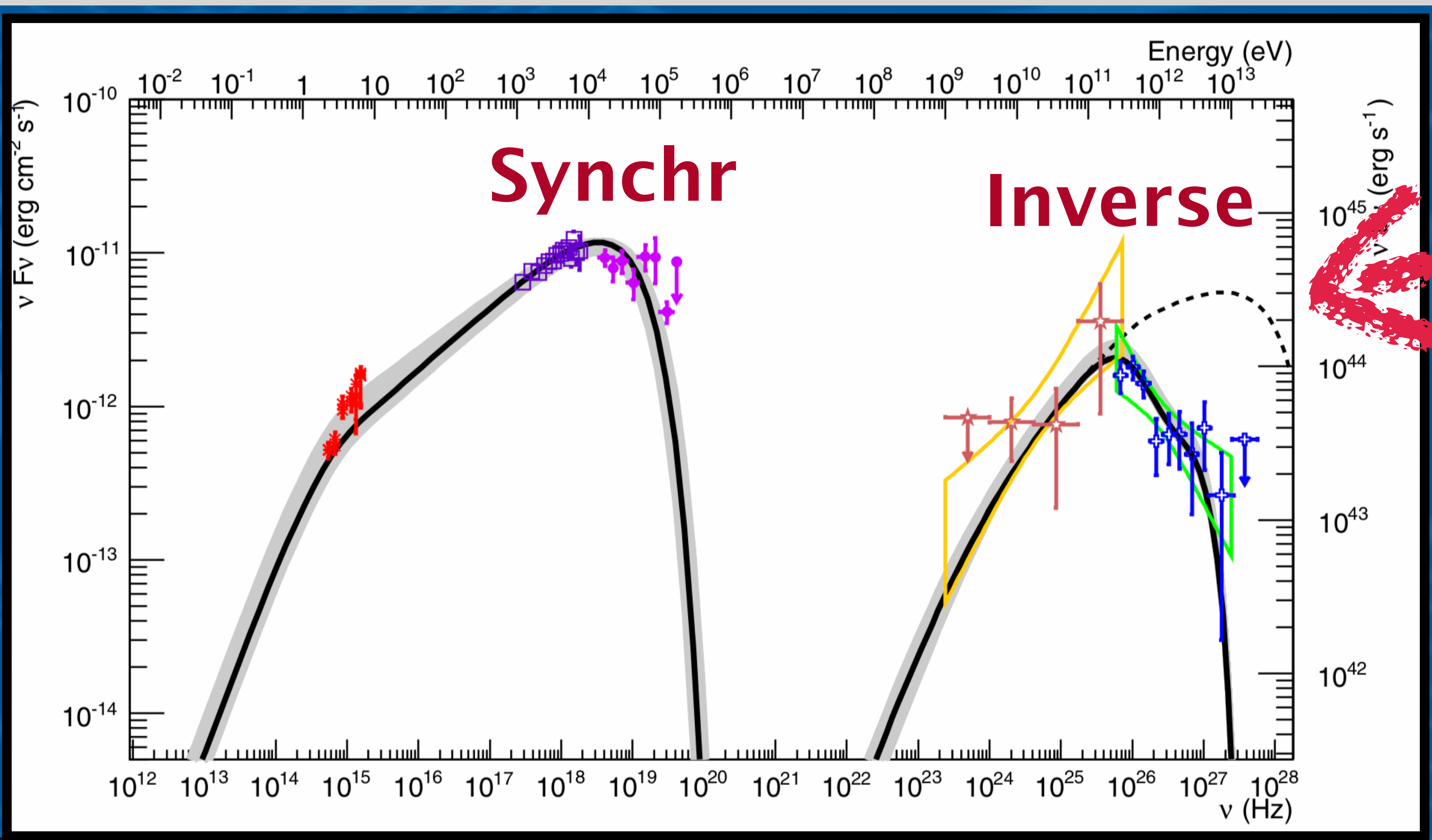
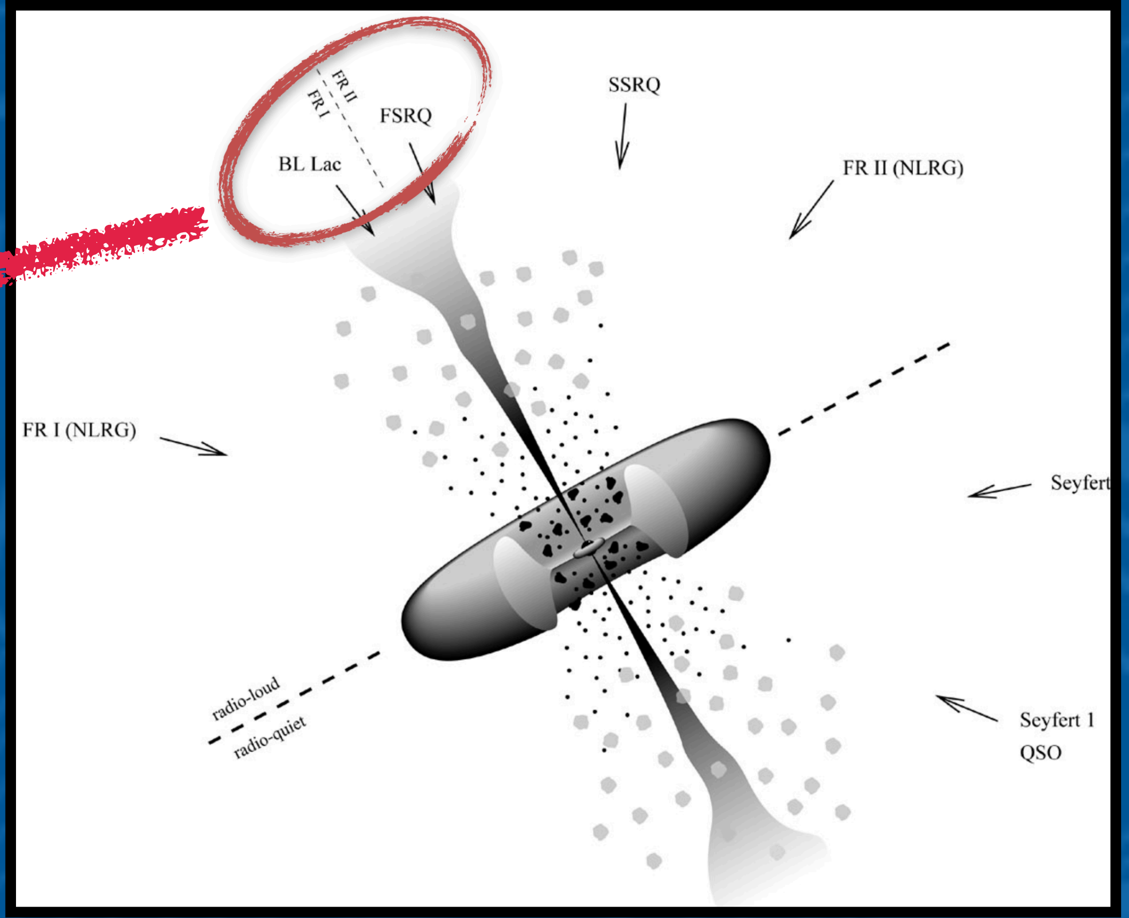
Extreme Blazars (EHBL) and HESS J1943+213

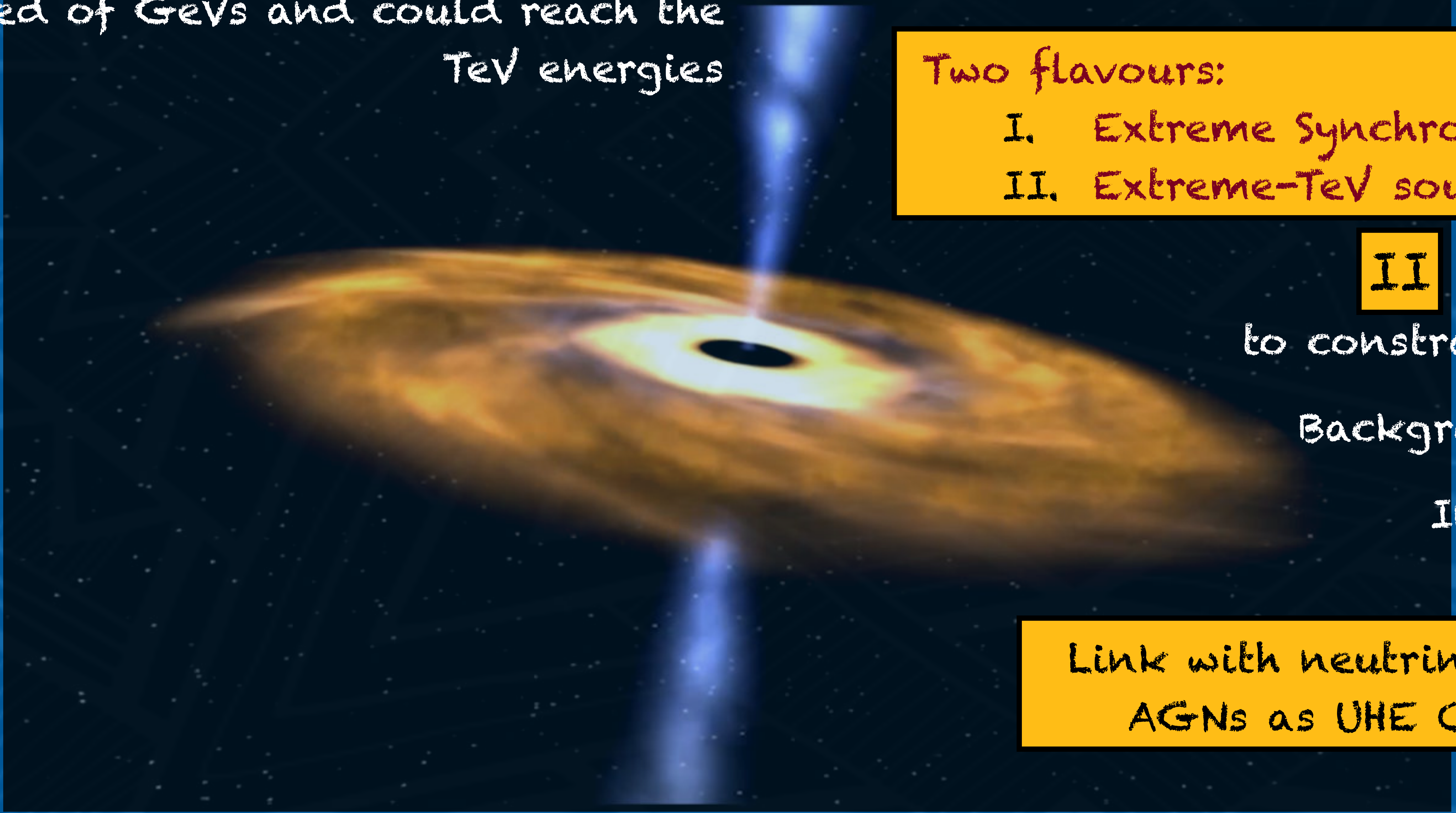
In the SED of Extreme HBLs (EHBLs) the first component (synchrotron peak) is beyond the soft X-ray ($\nu \geq 10^{17}$ Hz, $\Gamma_X < 2$)





Aliu et al. 2014

The second component (IC) exceeds hundred of GeVs and could reach the TeV energies



Two flavours:

I. Extreme Synchrotron source
II. Extreme-TeV source

II → propagation effects in the Universe to constrain the intensity of the Extragalactic Background Light (EBL), the strength of the InterGalactic Magnetic Field (IGMF), fundamental and MM physics

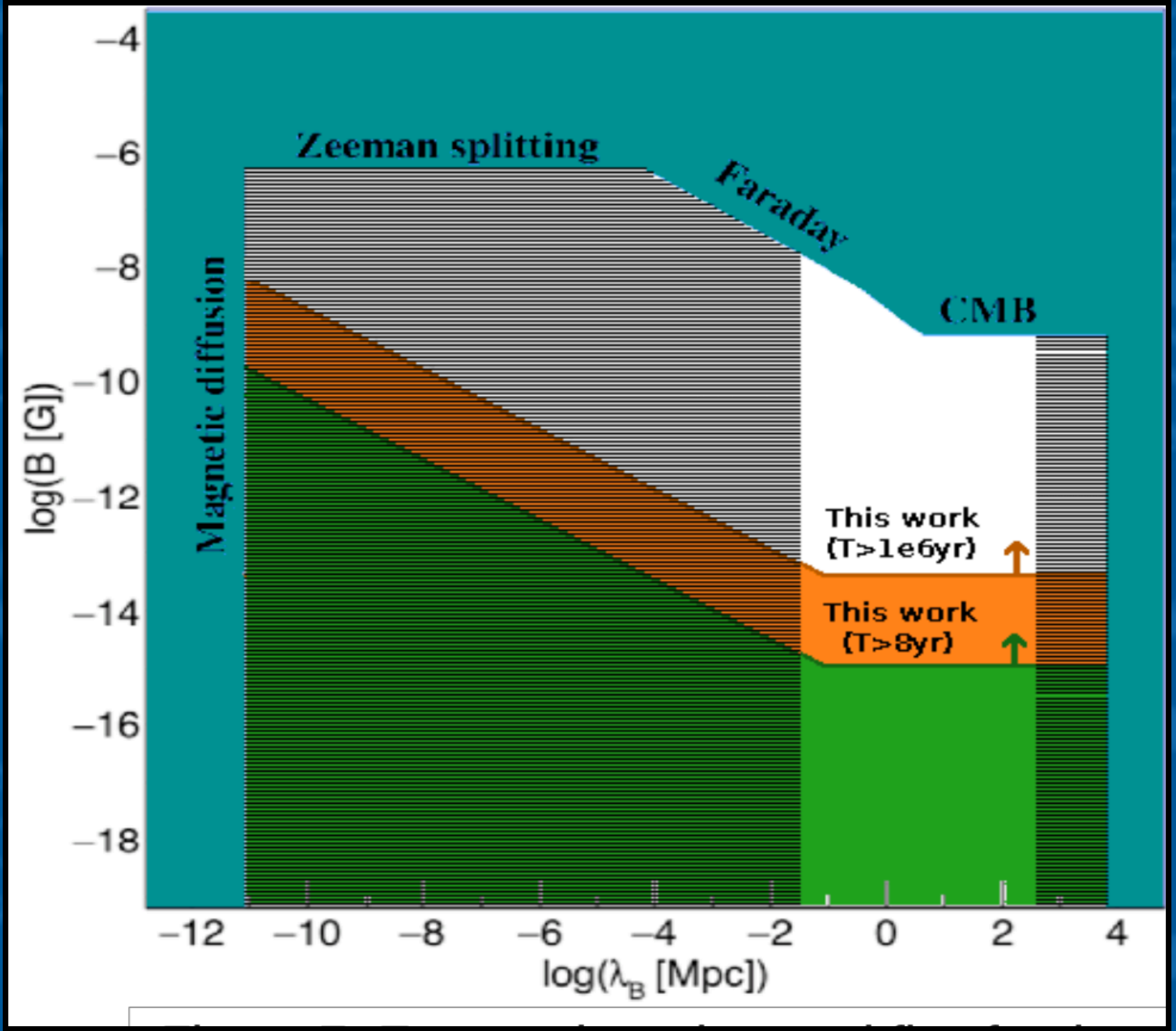
Link with neutrino astronomy, and AGNs as UHE CRs accelerators

Biteau et al. 2020

InterGalactic Magnetic Field (IGMF) constrain with HESS J1943+213

IGMF

- consequence of early universe phase transition
- detection of depleted cascade emission generated by interaction of TeV γ with EBL γ



Analysis, Simulations and Results

- Combined fit Fermi-LAT, HESS, VERITAS (intrinsic spectrum)
- Simulations with CRPropa 3 (cascade emission)
- New value of $6 \cdot 10^{-14}$ G: increasing by an order of magnitude the lower limit for the IGMF

(5 GeV ÷ 2 TeV)

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

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Sofia Ventura[1,2], Stefano Silvestri[4], Paolo Da Vela[3], Giacomo Bonnoli[5]

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

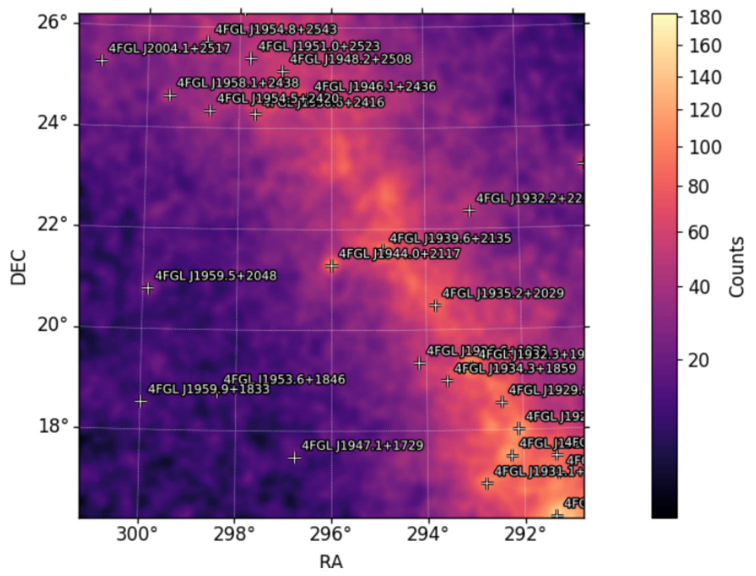

Fig 1: Fermi-LAT 10 years event map around the source (5-500 GeV)

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)

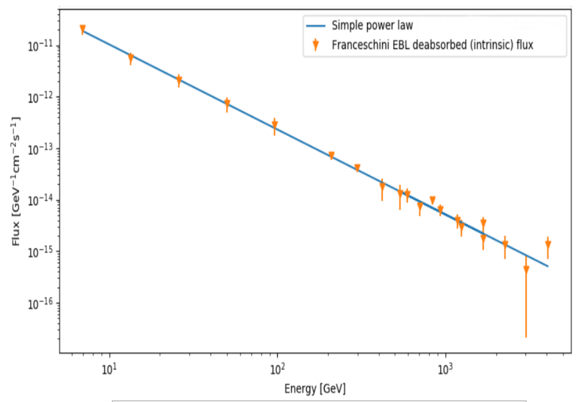

Fig 2: Gamma band best fit to the intrinsic flux of HESS J1943+213

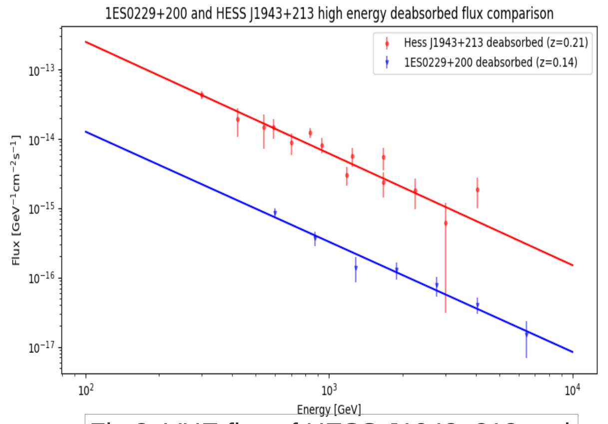

Fig 3: VHE flux of HESS J1943+213 and 1ES 0229+200, compared

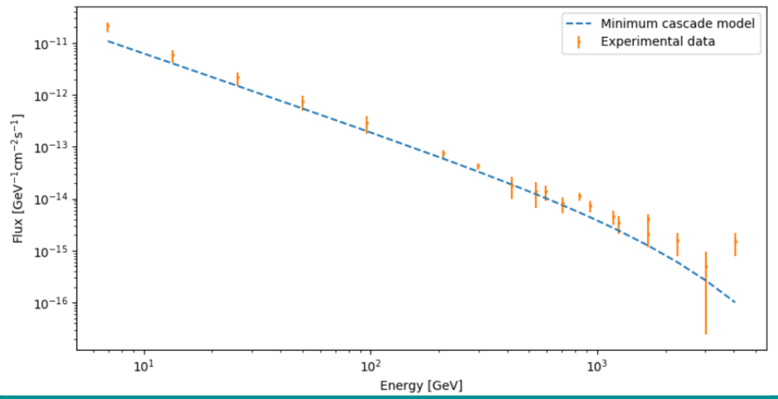

Fig. 4: Intrinsic emission model under conservative hypotheses, compared with observed de-absorbed data

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)

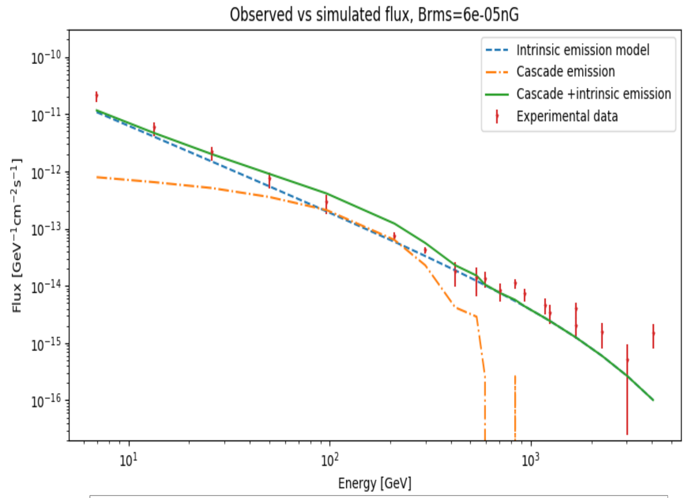

Figure 5: Expected vs observed flux for the lower limit obtained for the IGMF

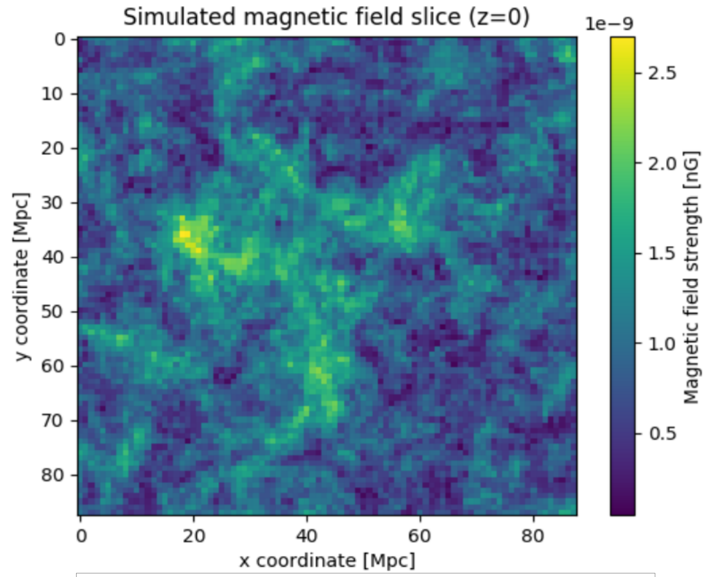

Figure 6: Simulated IGMF patch

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

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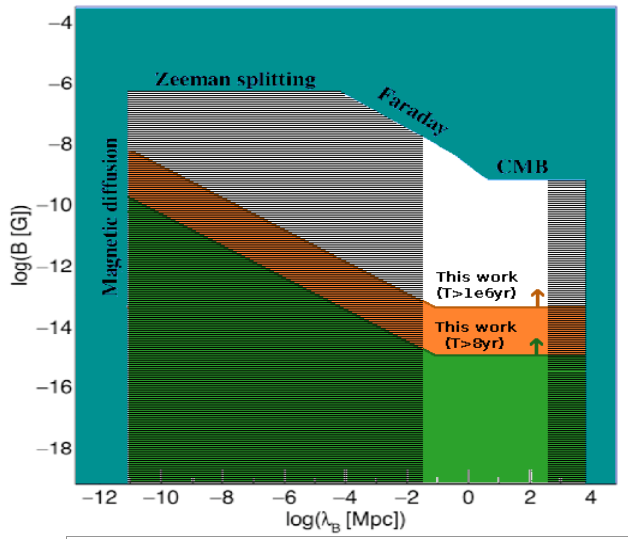

Figure 7: Expected vs observed flux for the lower limit obtained for the IGMF

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