Gamma-ray observations of blazars And Extragalactic Magnetic Fields

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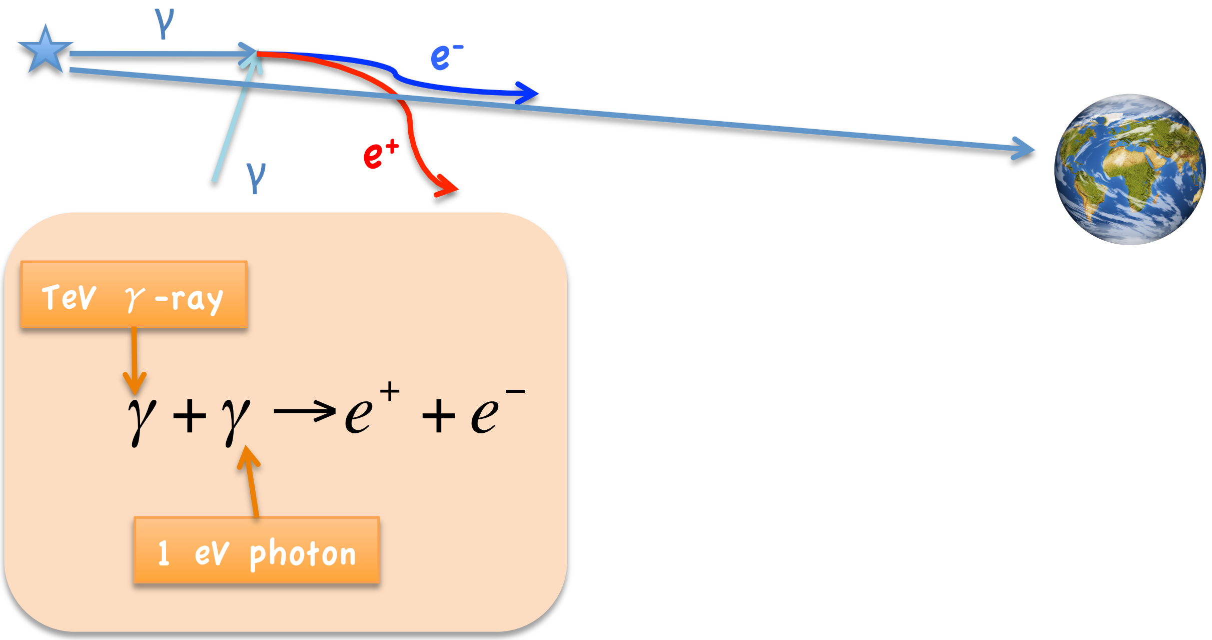
Overview

1. Attenuation of γ-rays via pair production on EBL
   Inverse Compton cascade γ-rays from e^+e^- pairs
   - detectability of the signal
   - the role of ExtraGalactic Magnetic Fields (EGMF)

2. Problem of the origin of magnetic fields in galaxies and galaxy clusters
   - dynamo/turbulence/compression of initial “seed” fields
   - origin of the seed fields:
     - ✔ astrophysical?
     - ✔ cosmological?

3. Detection of the seed fields with γ-ray telescopes
   - Fermi

Attenuation of γ-rays via pair production on EBL



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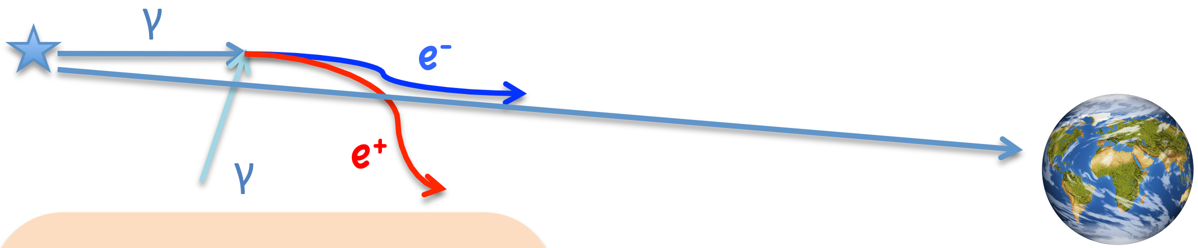
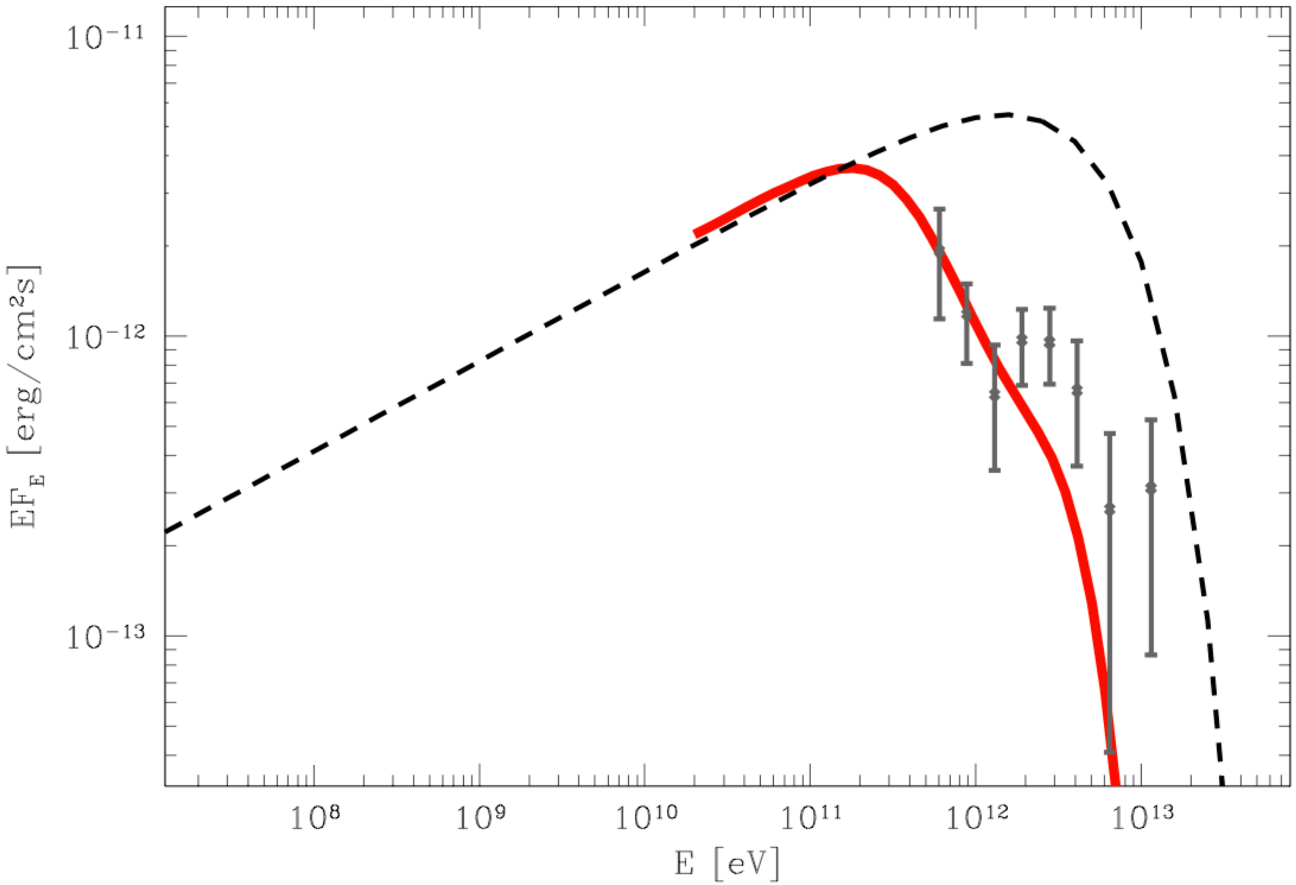


TeV γ-ray

$$\gamma + \gamma \rightarrow e^{+} + e^{-}$$

1 eV photon



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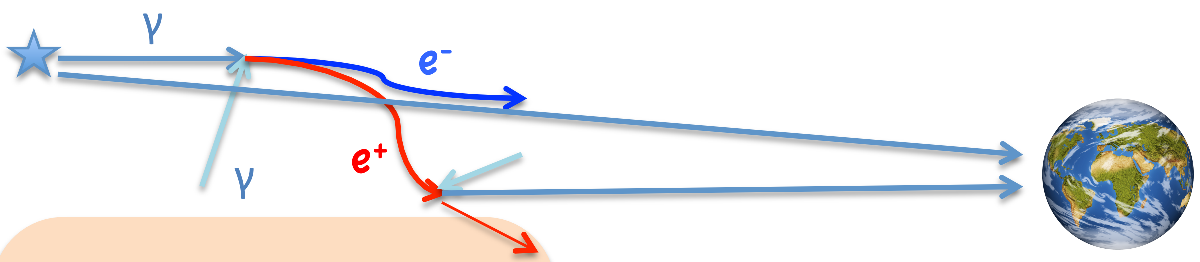


TeV γ-ray

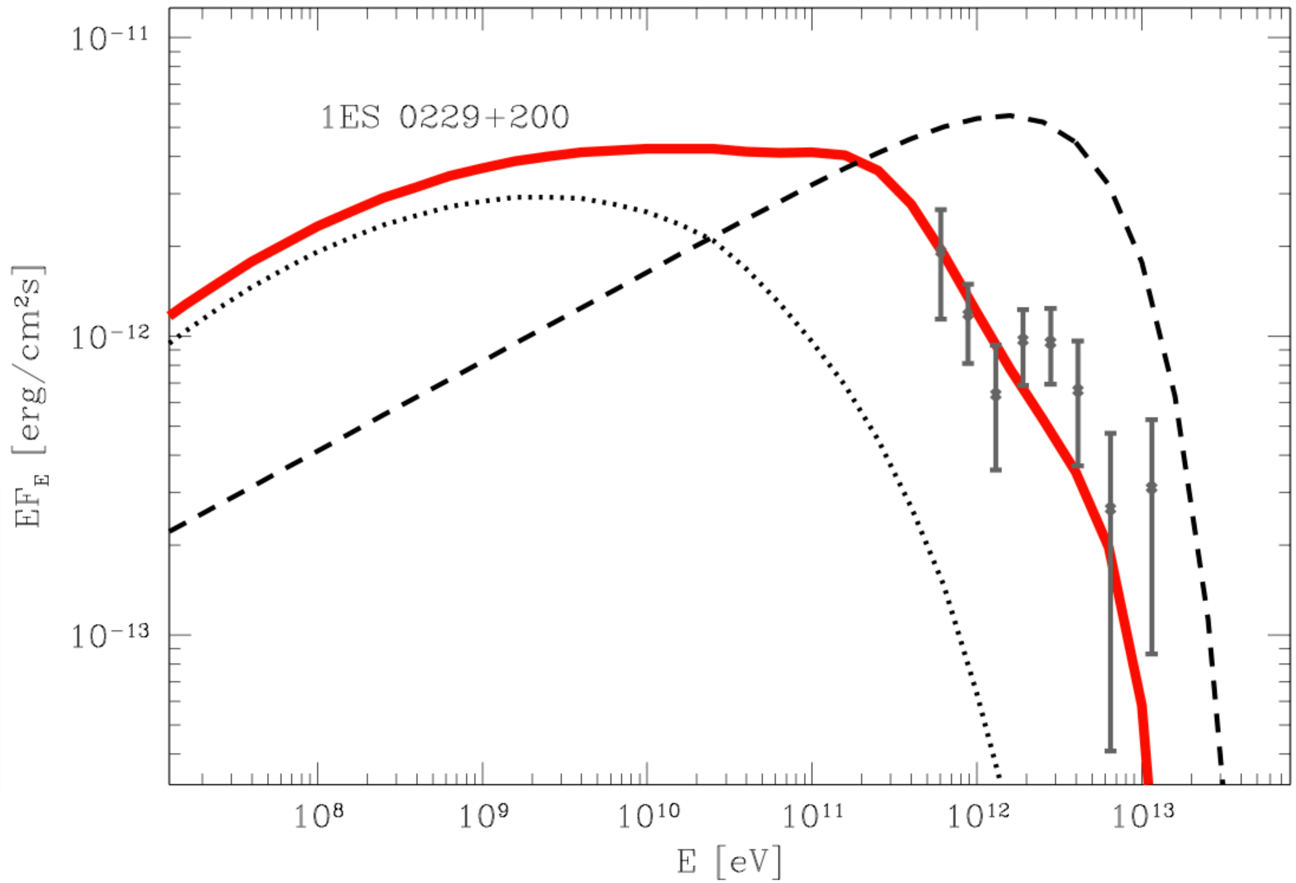
$$\gamma + \gamma \rightarrow e^+ + e^-$$

1 eV photon

GeV γ-ray

$$e^\pm + \gamma \rightarrow e^\pm + \gamma$$

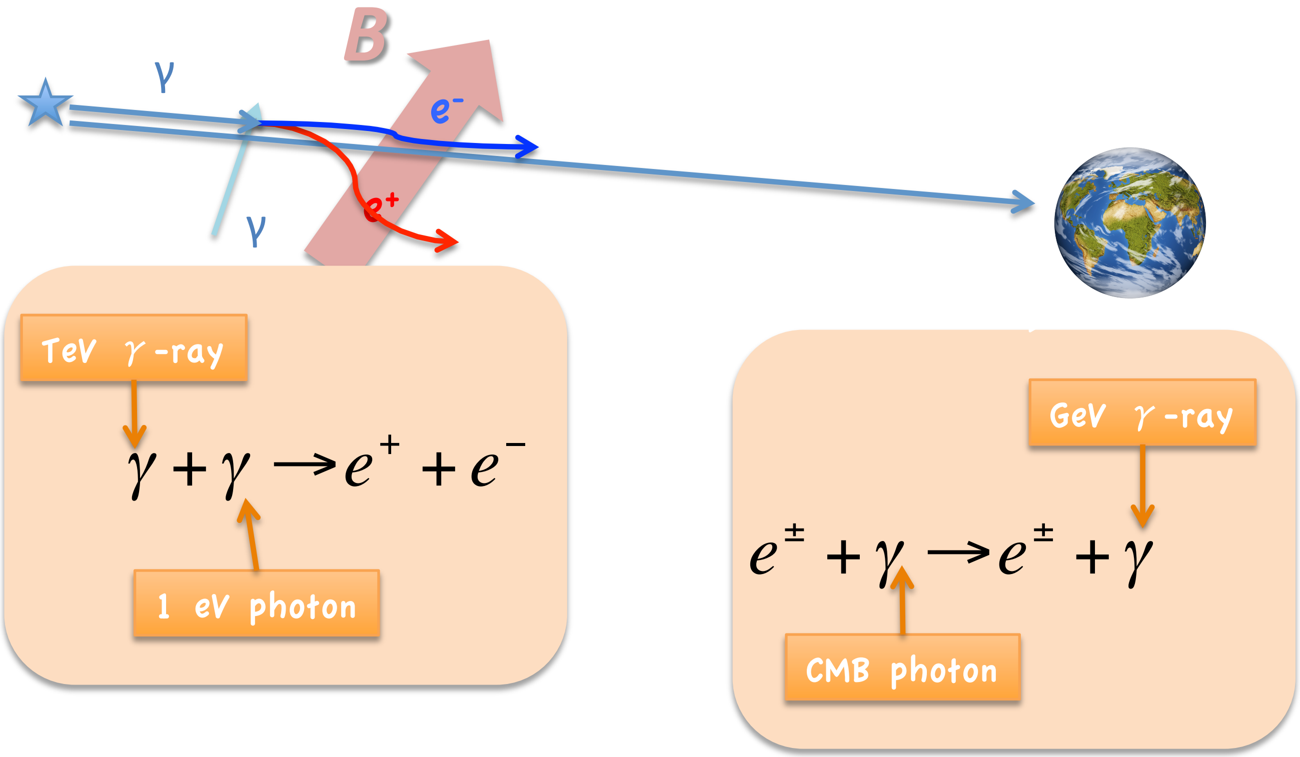
CMB photon



γ-rays from cascade on EBL

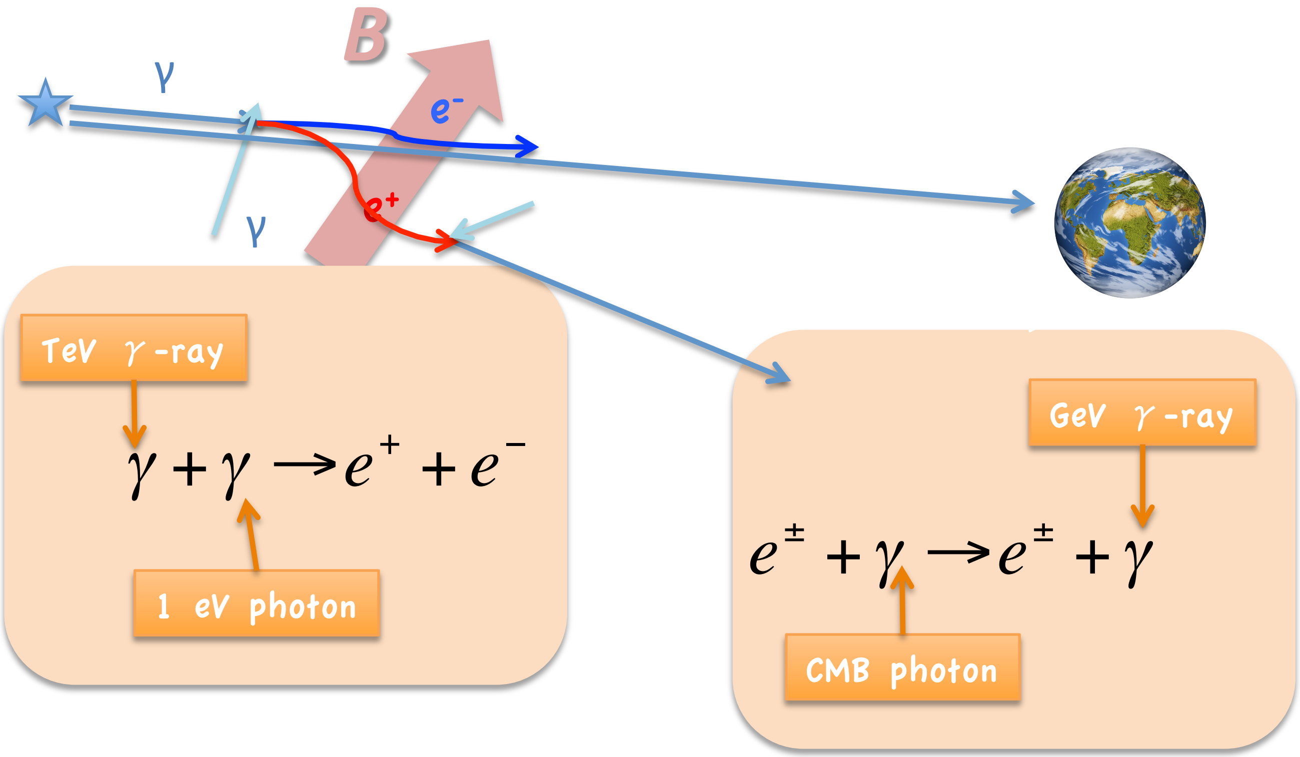
- Is cascade γ-ray emission detectable?
- How to distinguish the cascade γ-ray signal from the direct source signal?

γ-rays from cascade on EBL



Trajectories of e^+e^- pairs are deflected by Extragalactic Magnetic Fields (EGMF), if such fields are present in intergalactic medium.

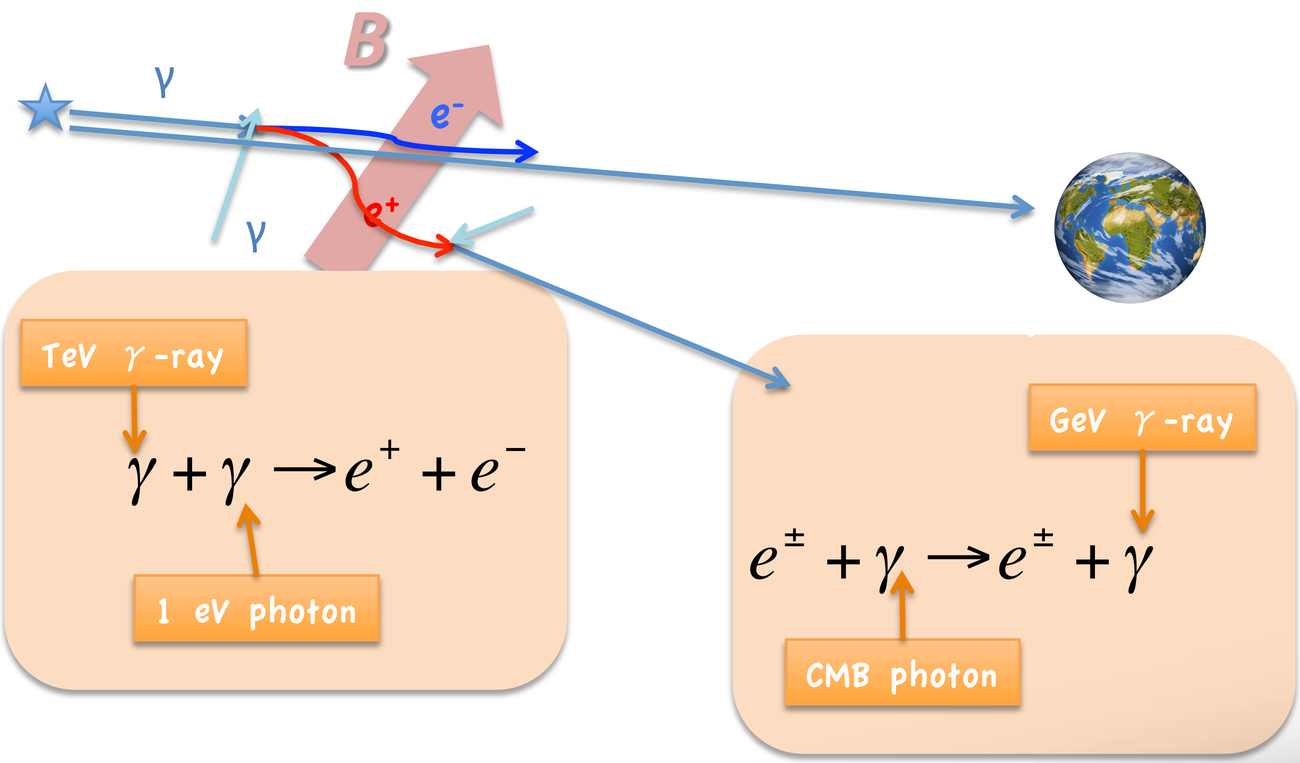
γ-rays from cascade on EBL



Trajectories of $e^{+}e^{-}$ pairs are deflected by Extragalactic Magnetic Fields (EGMF), if such fields are present in intergalactic medium.

If the primary γ-ray was emitted along the line of sight, secondary cascade γ-rays produced by deflected electrons/positrons are not emitted along the line of sight.

γ-rays from cascade on EBL



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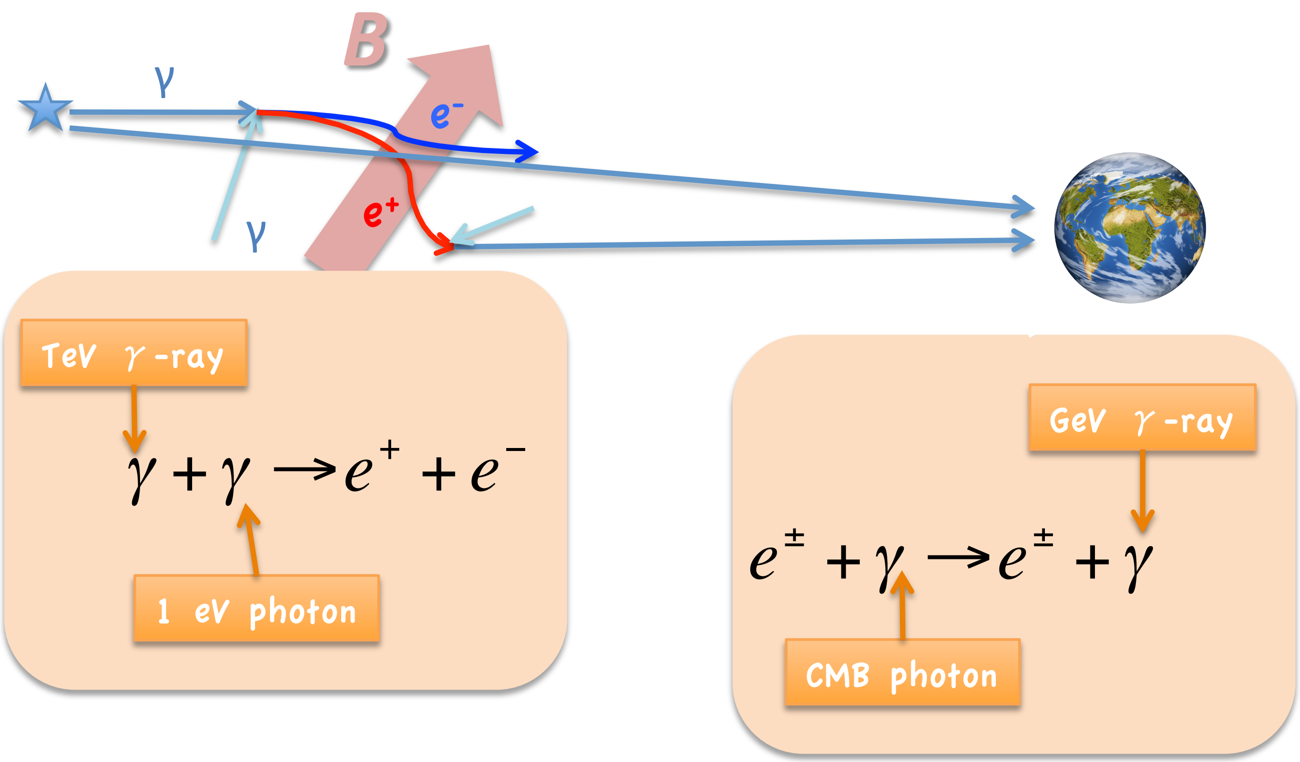
Cascade emission is not detectable…..

γ-rays from cascade on EBL



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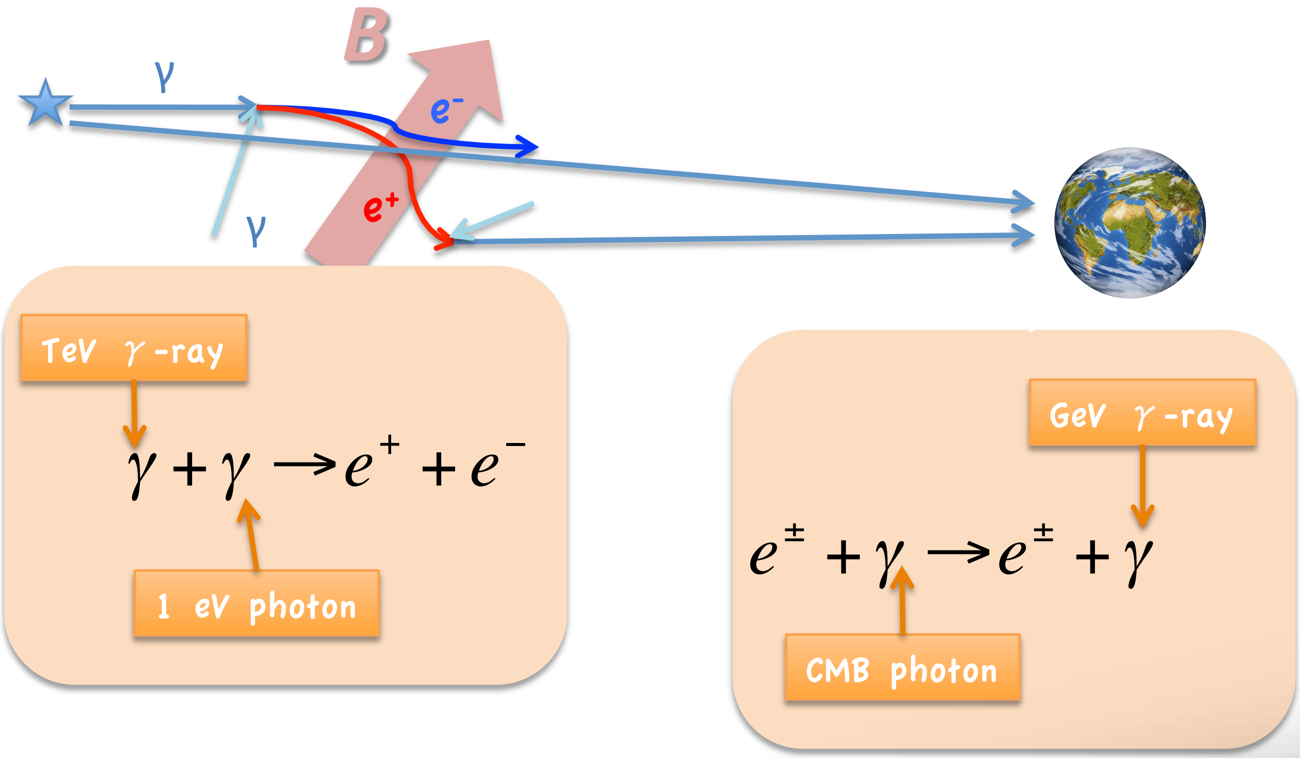
γ-rays from cascade on EBL



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Cascade emission ~~is not~~ could be detectable.....

γ-rays from cascade on EBL

- Cascade γ-ray emission is detectable if

  a) If EGMF is weak, so that e^+e^- pairs are not deflected

  b) If deflections of e^+e^- pairs by EGMF are smaller than initial opening angle of primary γ-ray beam ($\Theta \sim \Gamma^{-1}$).

  c) If primary γ-ray emission from the source is isotropic (independently of EGMF).

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Plaga (1995), Murase et al. (2008)

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Neronov & Semikoz (2007)

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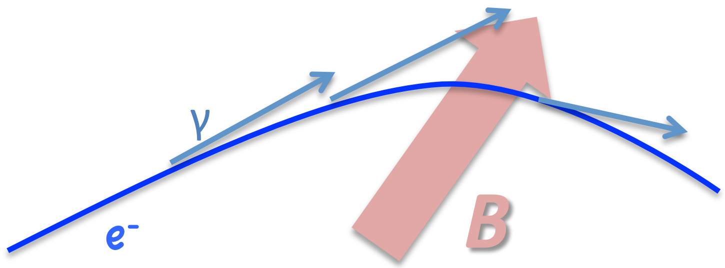
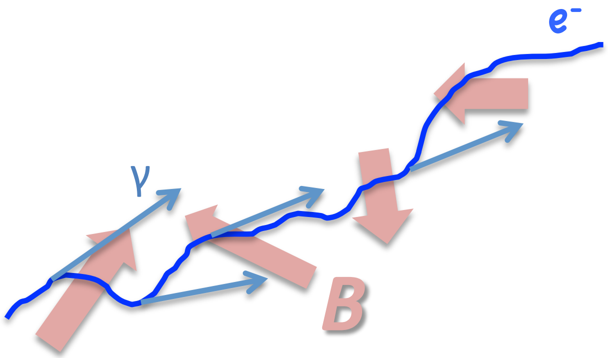
Aharonian, Coppi & Voelk (1993)

EGMF



If the correlation length of EGMF is large, deflection angle is

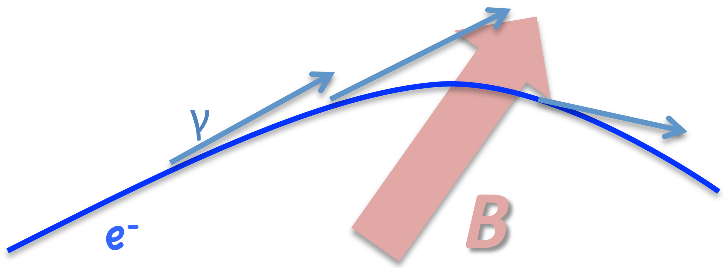
$$\delta = \frac{D_e}{R_L} = 2^O \left[\frac{B}{10^{-16}\mathrm{G}}\right]\left[\frac{E_e}{1\ \mathrm{TeV}}\right]^{-2}$$



If the correlation length of EGMF is small, ($\lambda_B << D_e$) deflection angle is

$$\delta = \frac{\sqrt{D_e \lambda_B}}{R_L} = 1^O \left[\frac{B}{10^{-16}\mathrm{G}}\right]\left[\frac{E_e}{1\ \mathrm{TeV}}\right]^{-3/2}\left[\frac{\lambda_B}{10\ \mathrm{kpc}}\right]^{1/2}$$

EGMF



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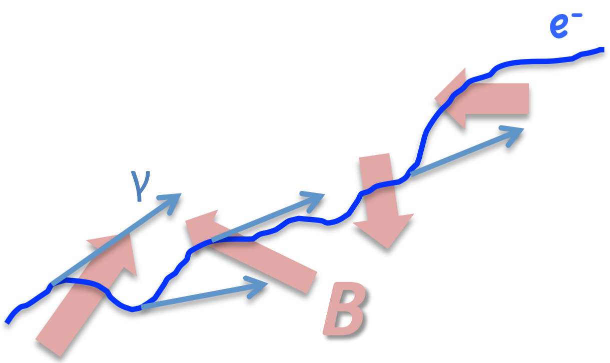

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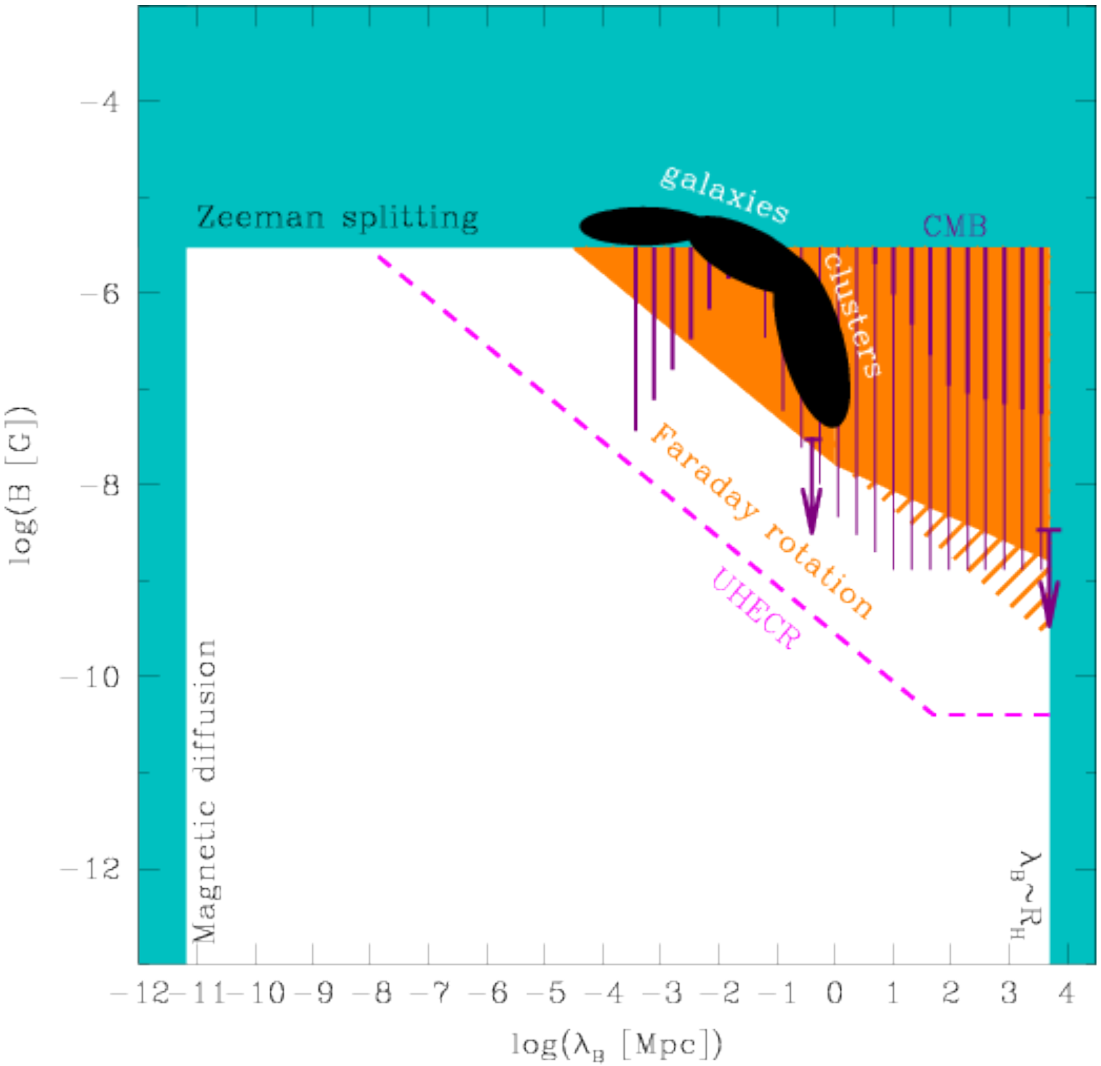
To find if the cascade emission is detectable, one needs to know not only the strength, but also the correlation length of EGMF

EGMF



Neither the strength nor the correlation length of EGMF are known. Upper limits obtained by various measurements / arguments exist.

Problem of the origin of magnetic fields

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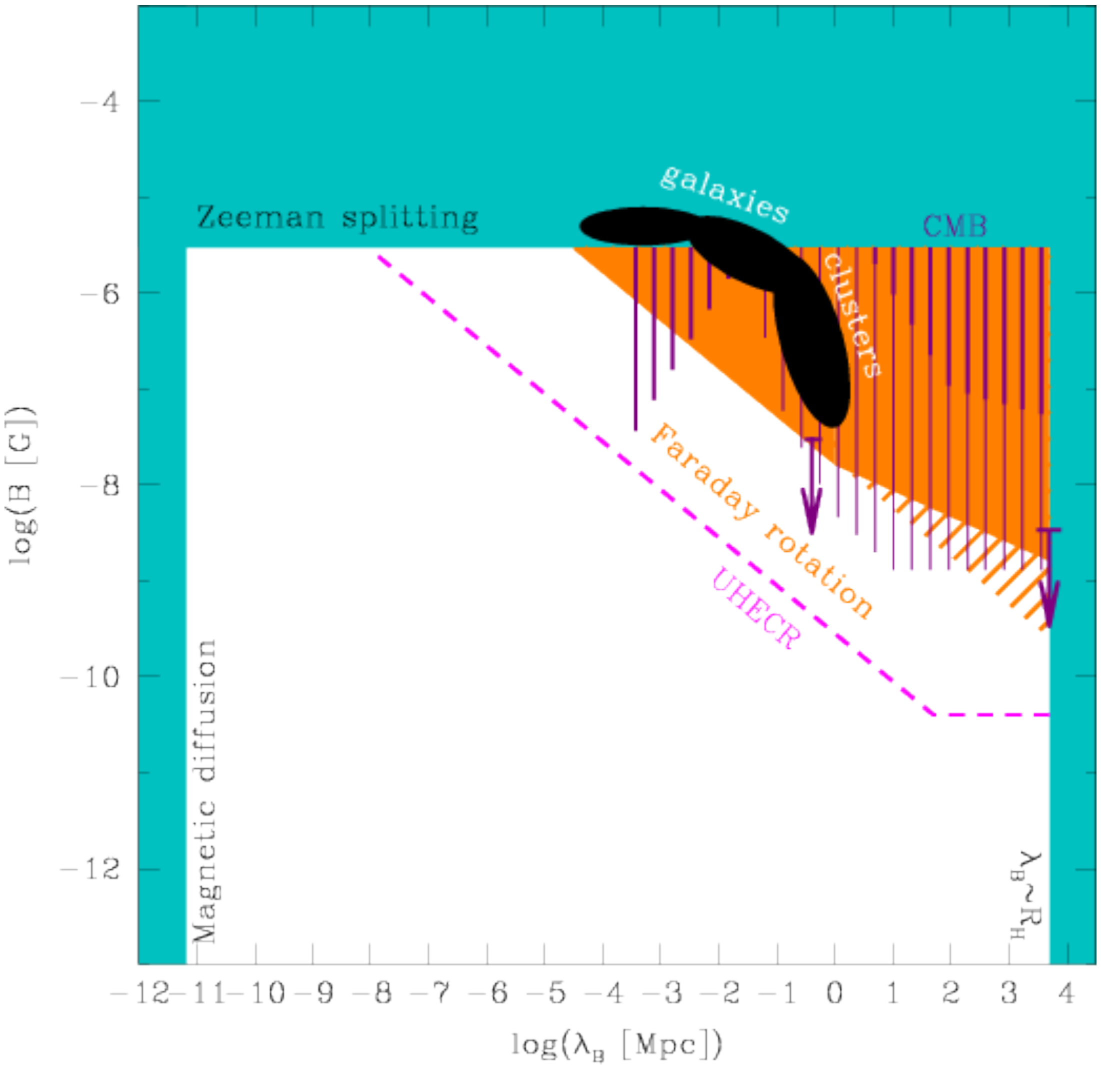

Magnetic fields in spiral and elliptical galaxies reach 1-10 μG.

Galactic magnetic fields are thought to be produced via "$\alpha-\omega$ dynamo" amplification of "seed" magnetic fields of the strength $B \geq 10^{-21}$ G.

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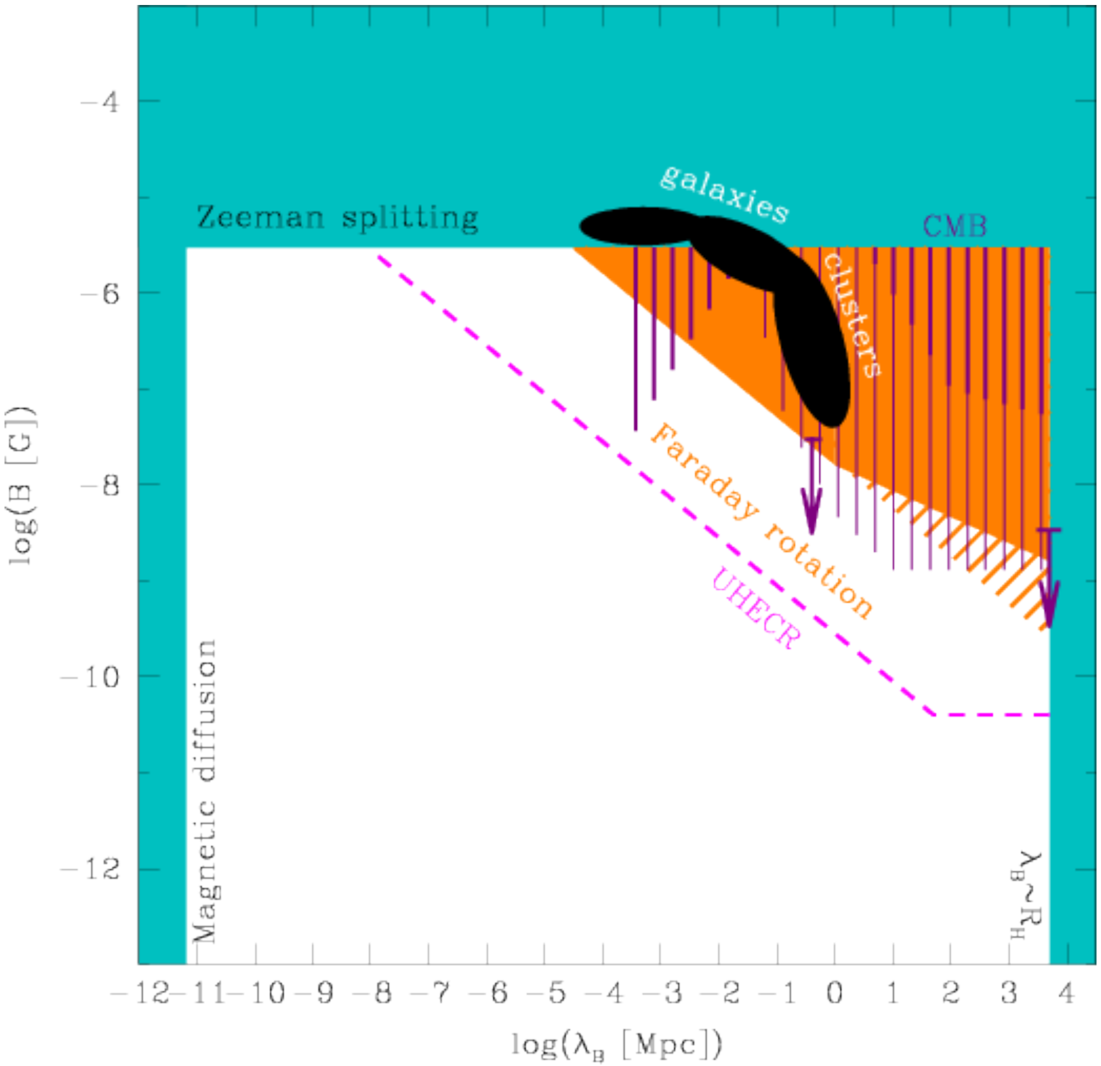

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Magnetic fields in the cores of galaxy clusters reach 1-10 μG.

Cluster magnetic field are thought to be produced via compression and turbulent amplification of "seed" magnetic fields of the strength $B \leq 10^{-12}$G.

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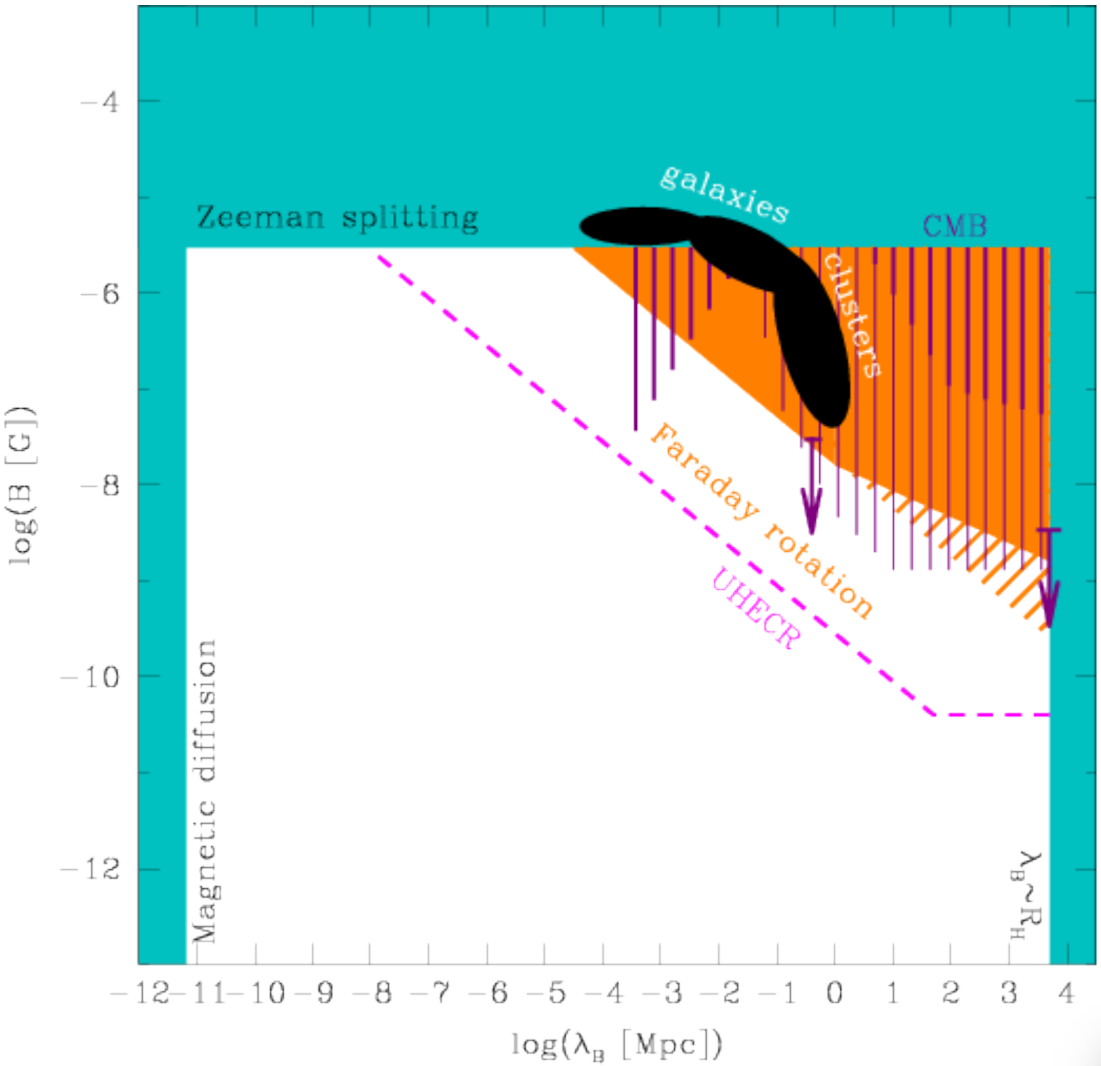

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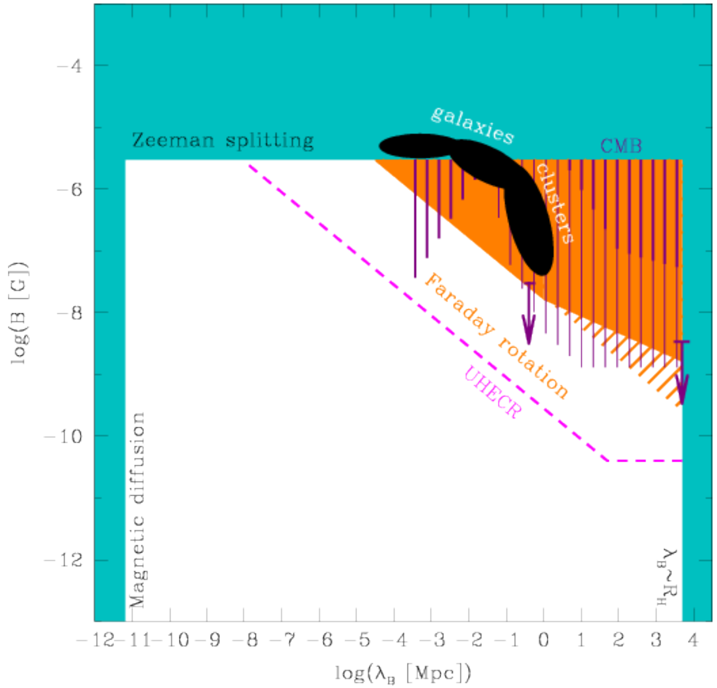
The initial "seed" fields have never been detected. Their nature is unknown.

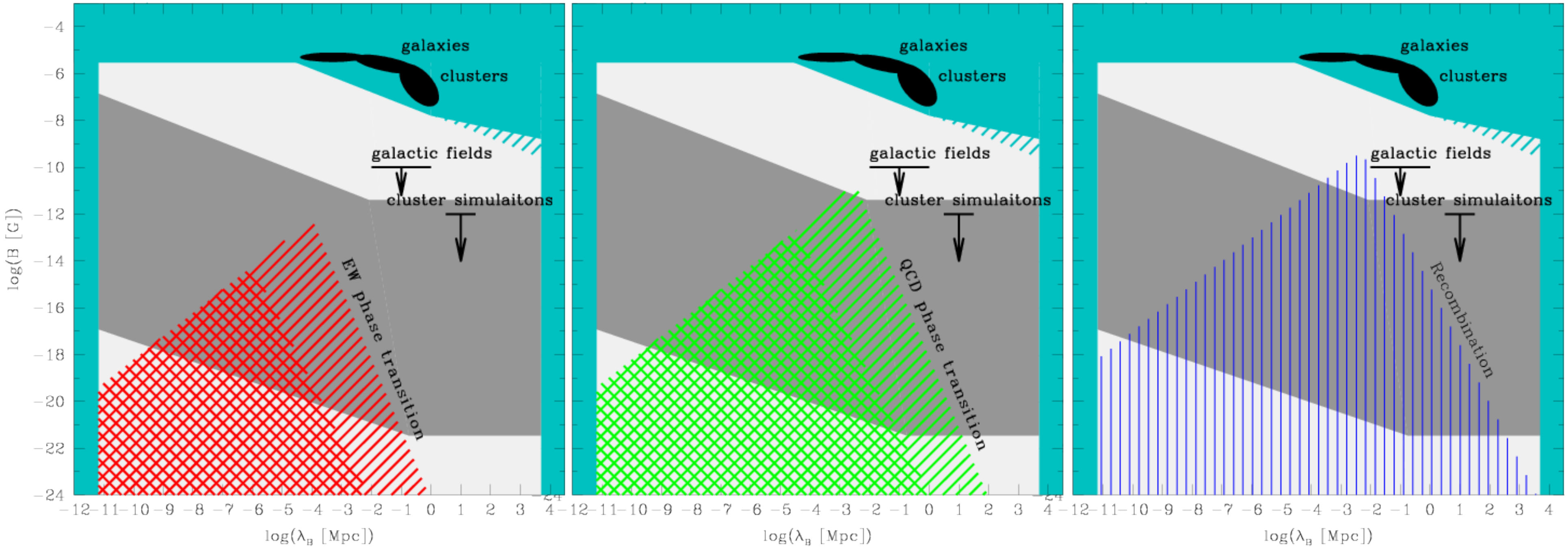
Problem of the origin of magnetic fields



Existing models of the "seed" fields could be divided on

- cosmological seed fields
- astrophysical seed fields

Problem of the origin of magnetic fields



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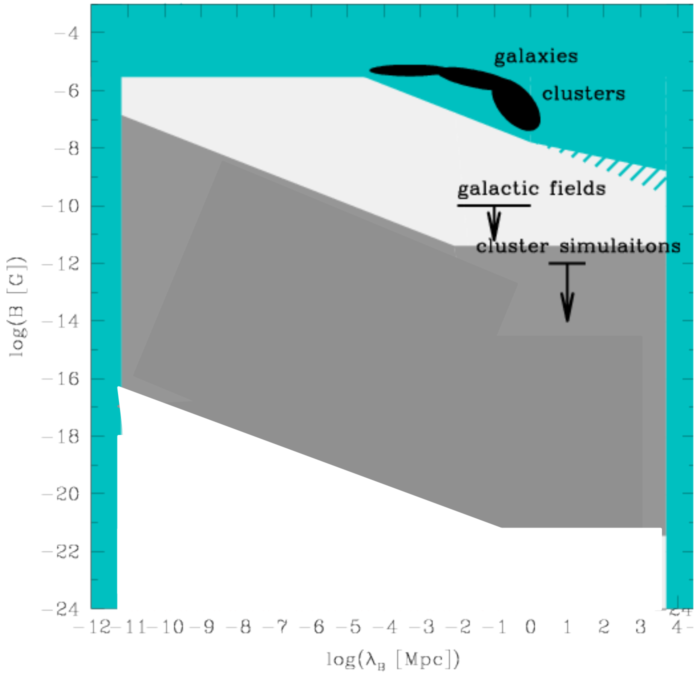
Cosmological seed magnetic fields could be produced at the moments of phase transitions in the Universe:

- epoch of Inflation
- Electroweak phase transition
- QCD phase transition
- epoch of CMB decoupling / recombination

Problem of the origin of magnetic fields



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Astrophysical seed magnetic fields could be produced via separation of - (e^-) and + (p) charged fluids in plasma ("Biermann battery effect") during

- LSS formation: gravitational collapse of proto-galaxies
- Ejections from the first supernovae
- Ejections from AGN (100 kpc-scale jets)

No non-negligible magnetic fields outside galaxies/clusters are predicted

Detection of the seed fields with γ-ray telescopes

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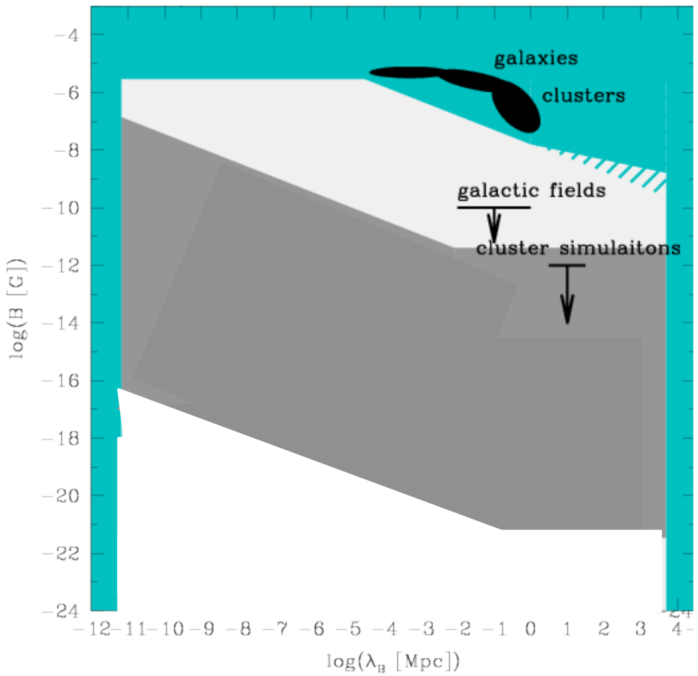

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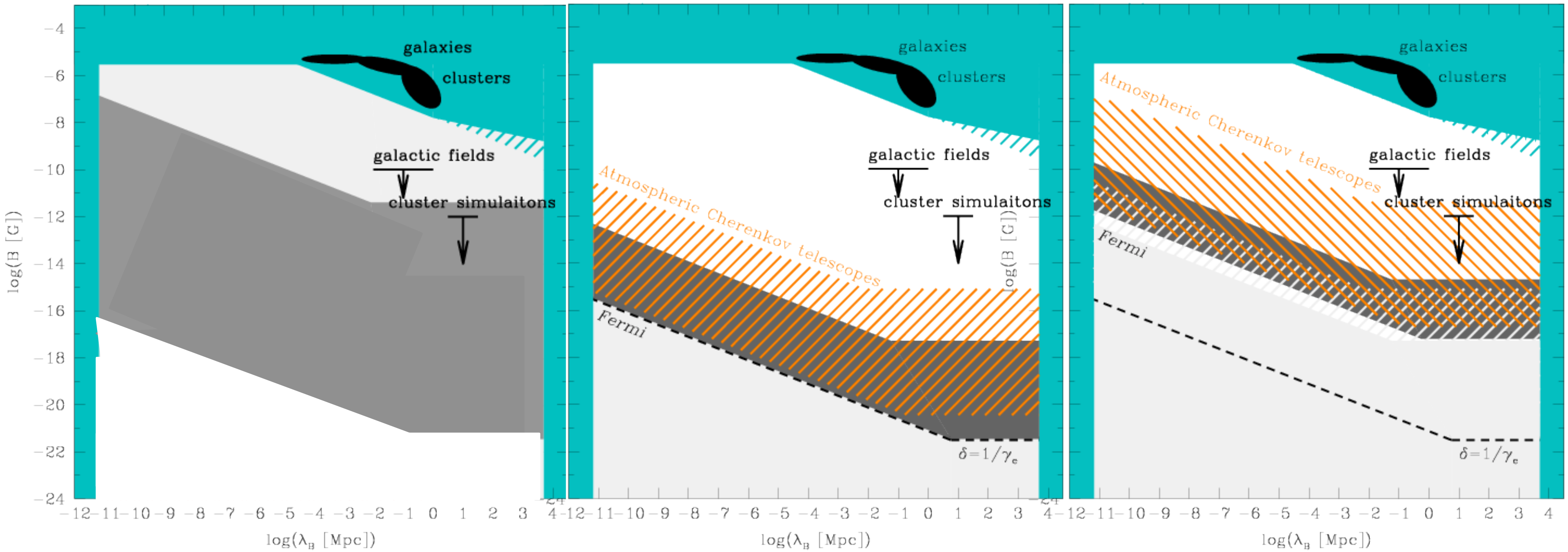

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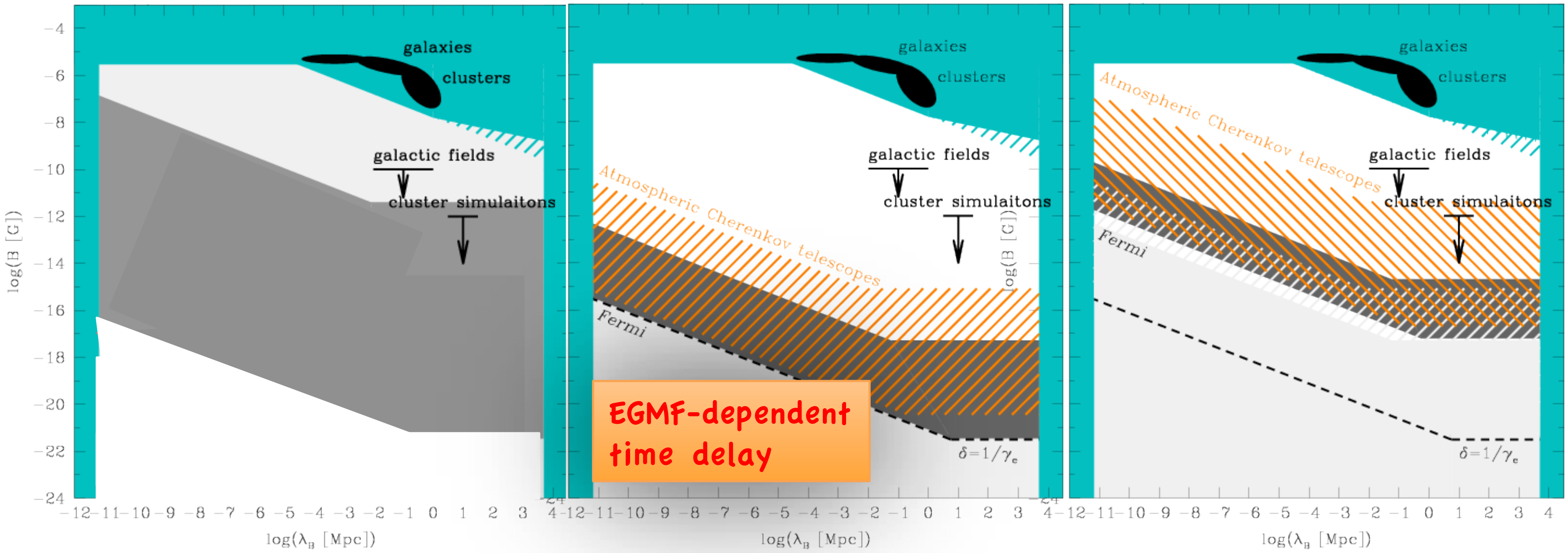

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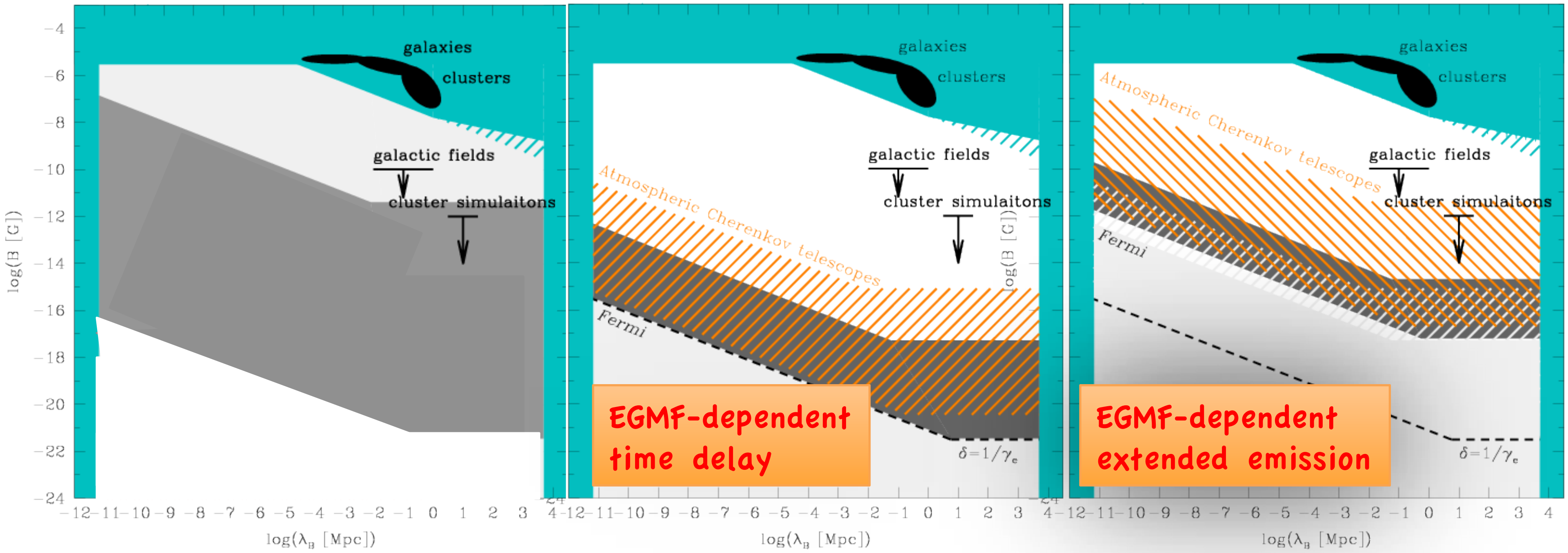
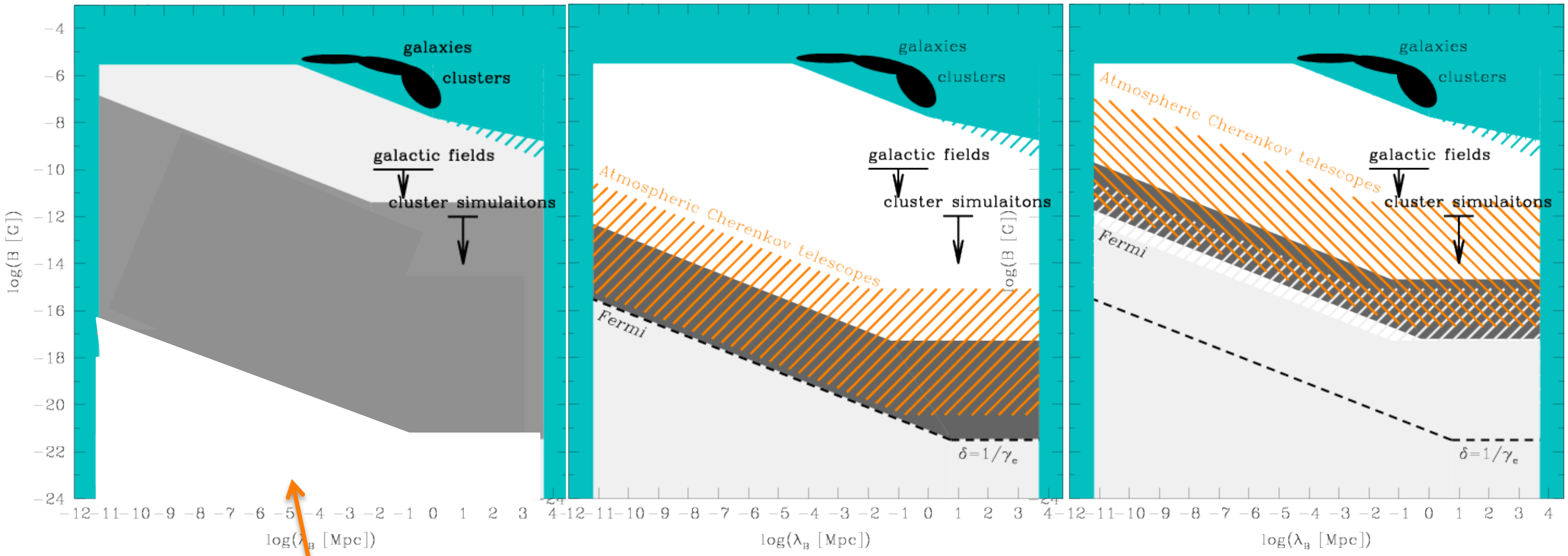
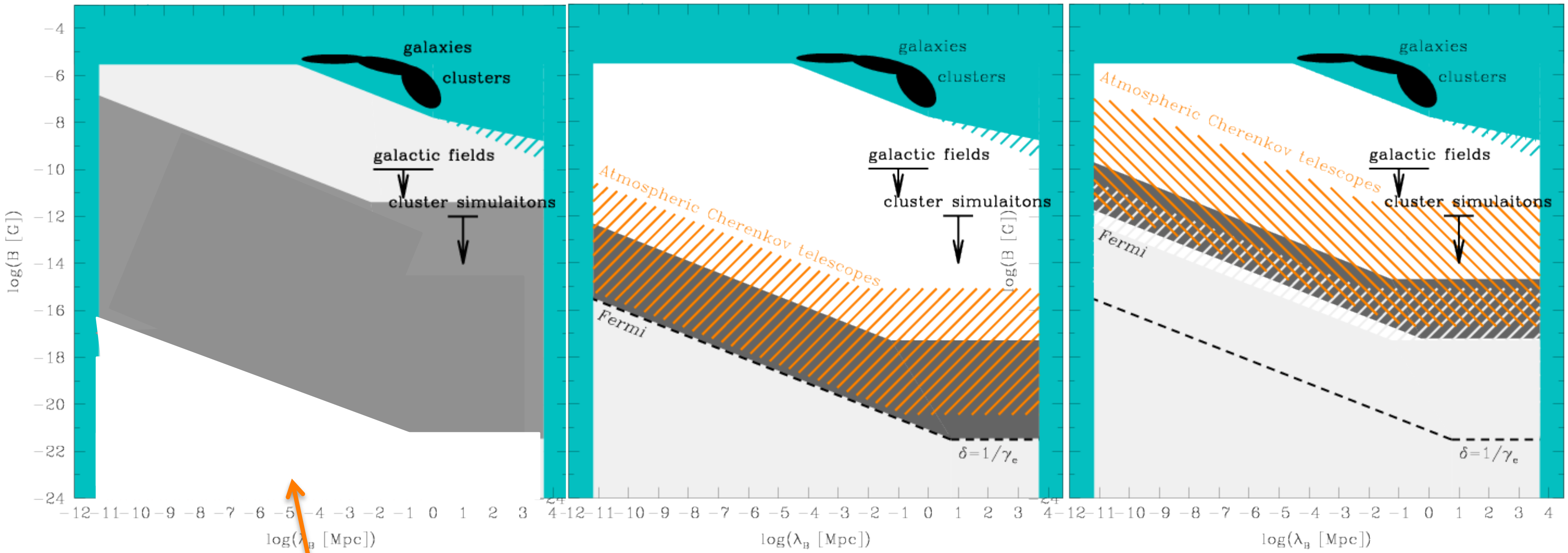


Detection of the seed fields with Fermi



Could EGMF be just B≈0?

Detection of the seed fields with Fermi



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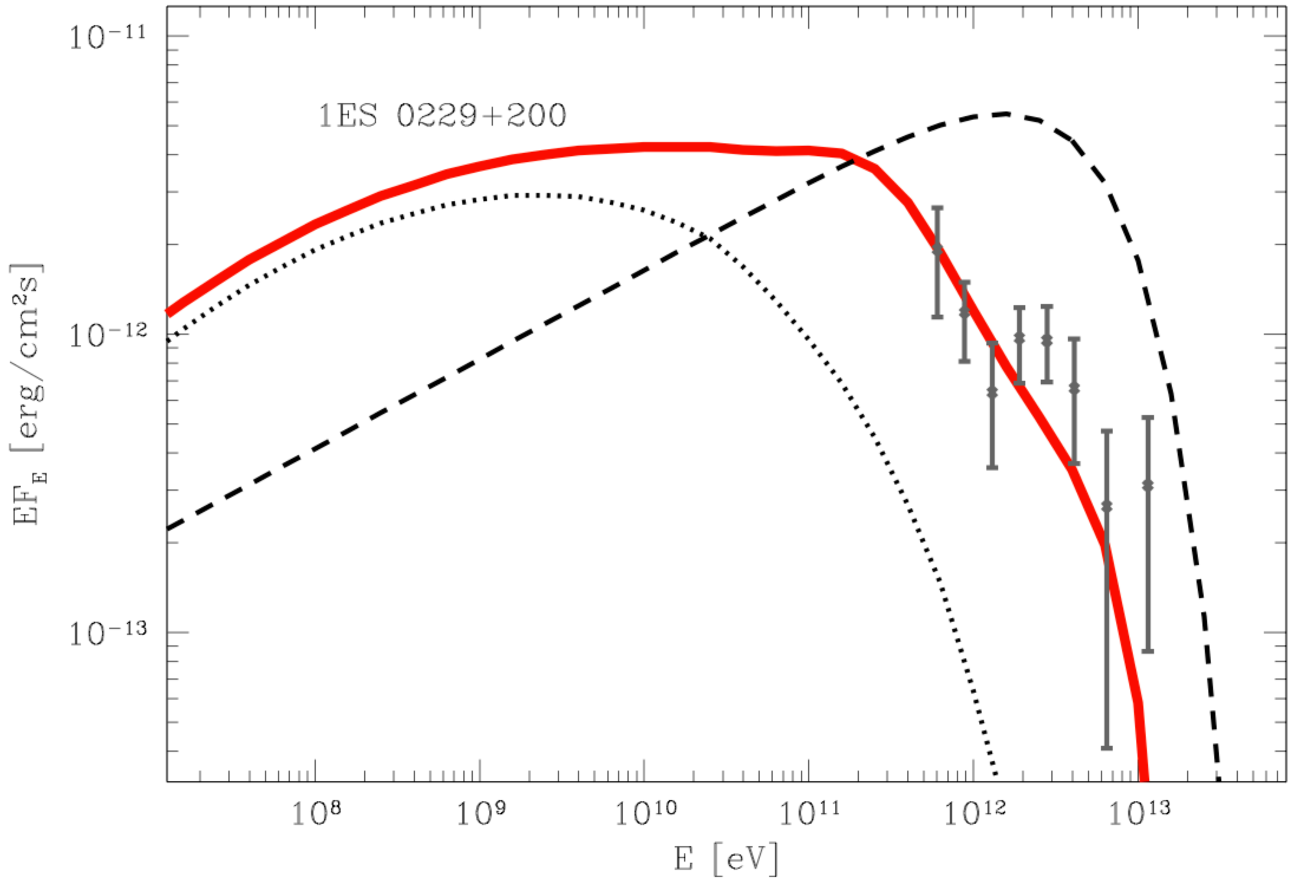
- All secondary cascade emission is detectable as an additional component of point source flux

Detection of the seed fields with Fermi



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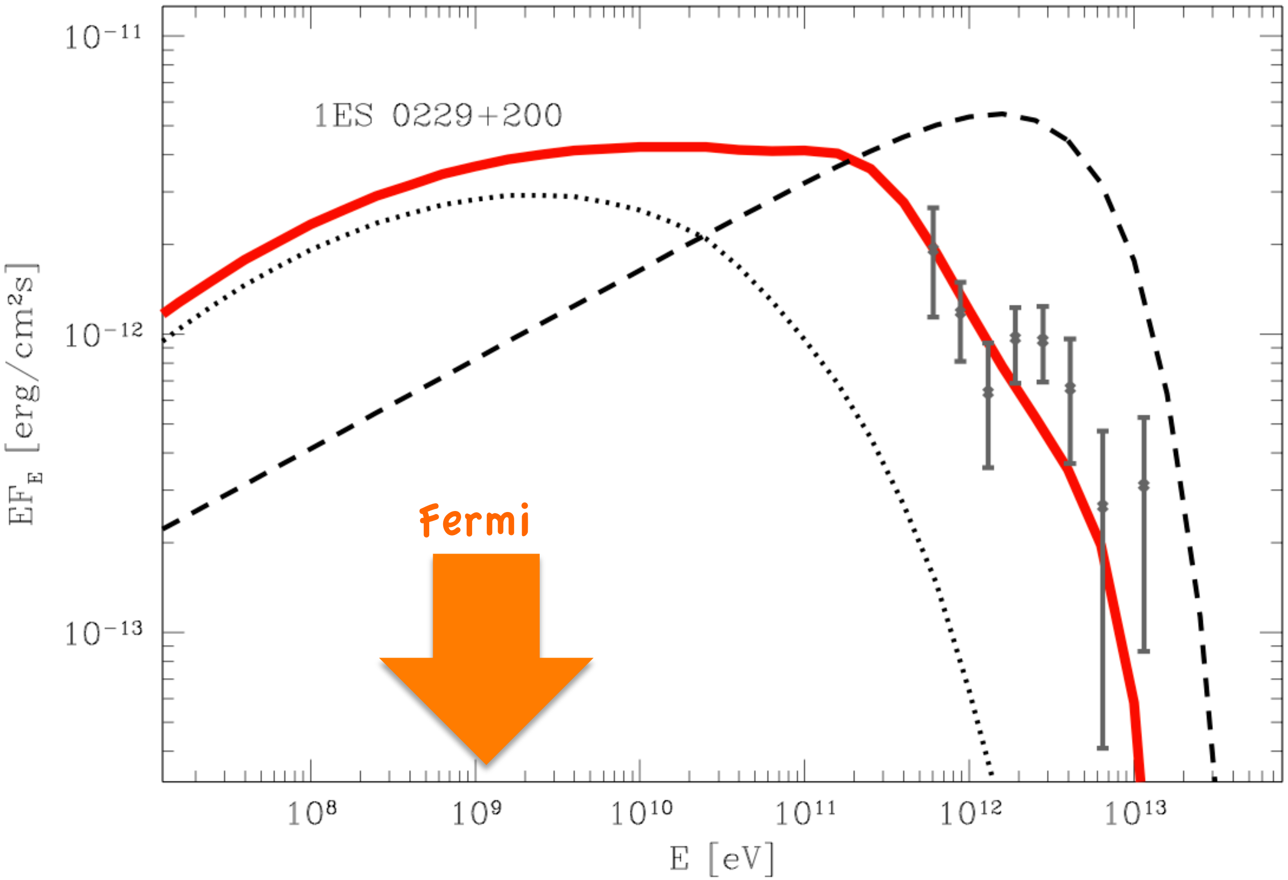

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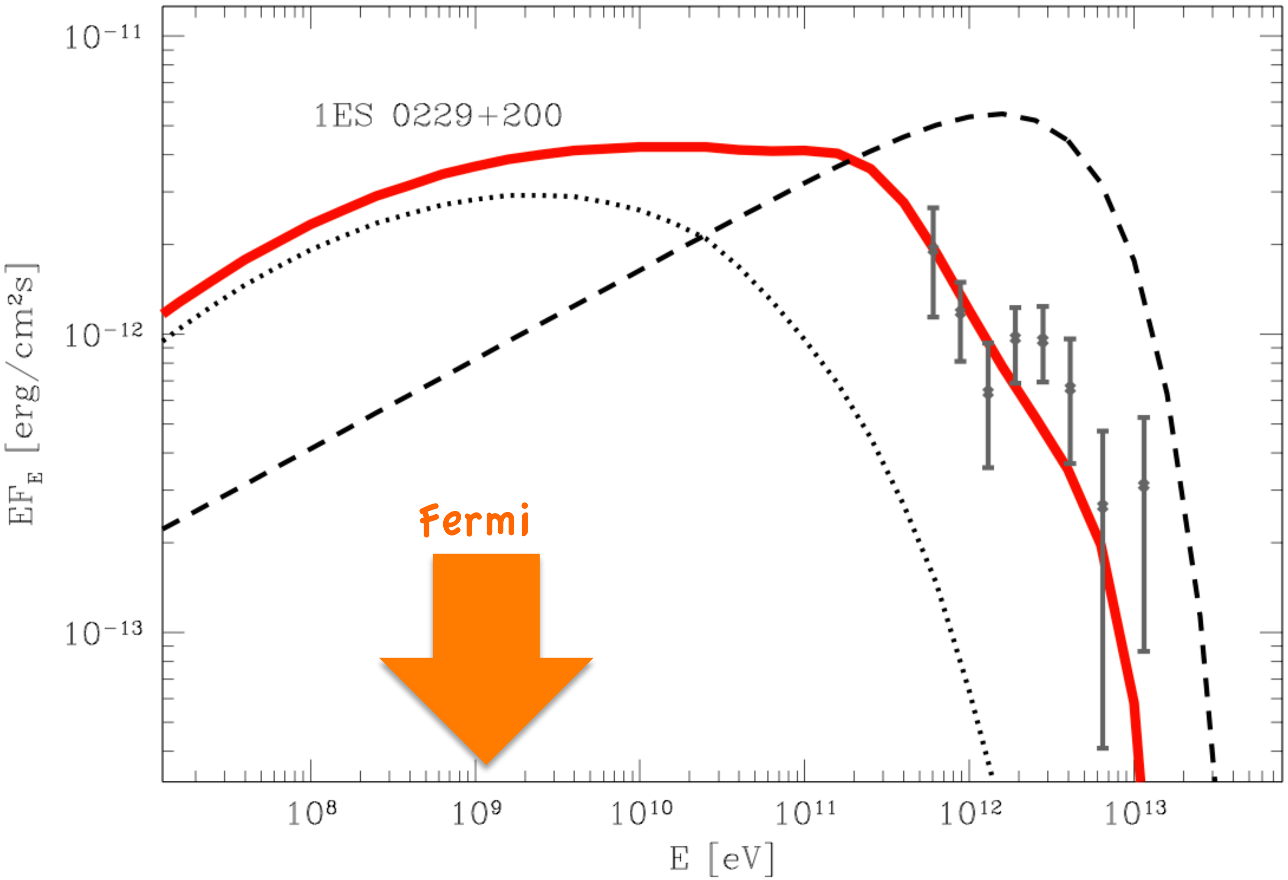
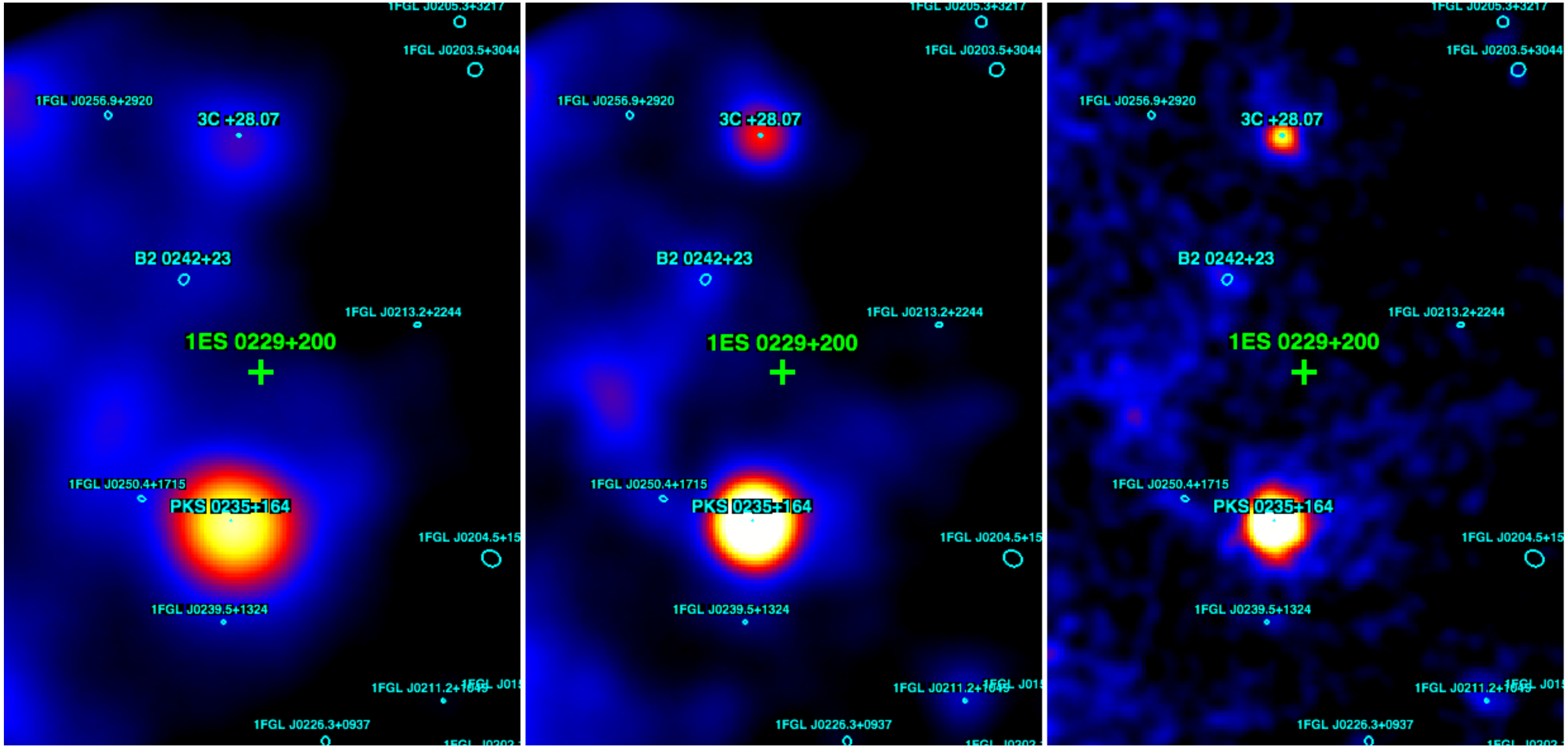


- All secondary cascade emission is detectable as an additional component of point source flux

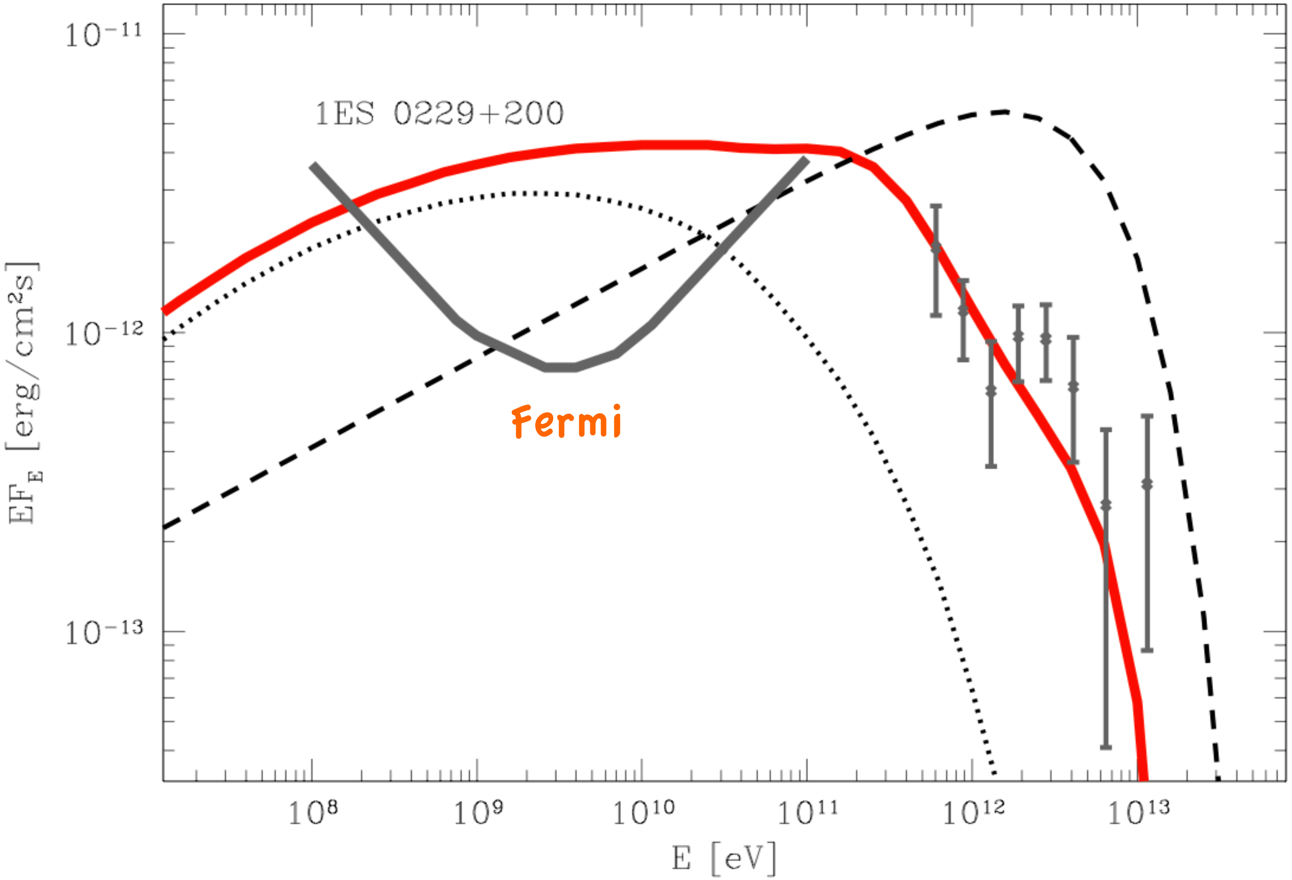
- Cascade emission could, in fact, dominant contribution to the source flux in Fermi energy band

Detection of the seed fields with Fermi



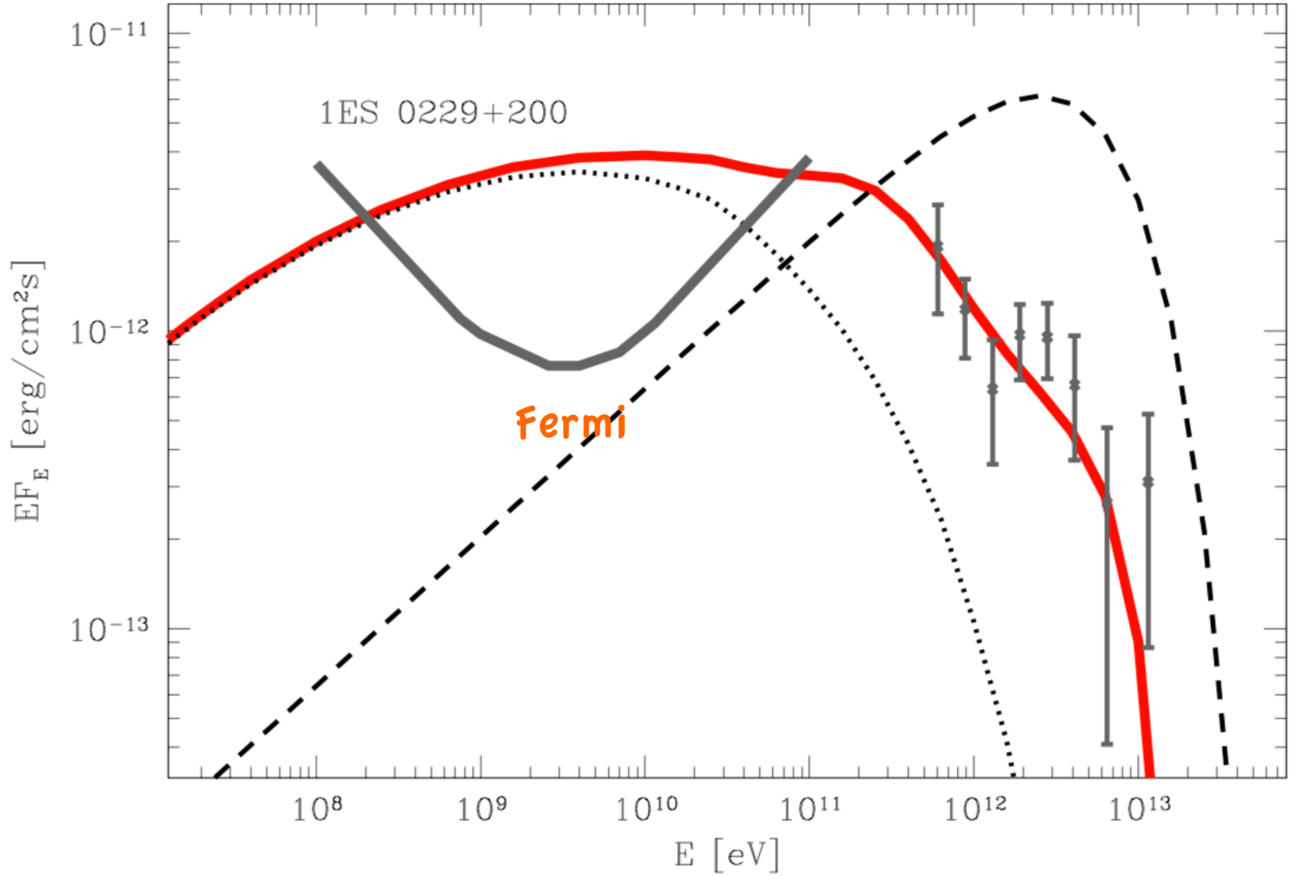
0.1-0.3 GeV　　0.3-1 GeV　　1-300 GeV

Detection of the seed fields with Fermi



- Fermi bound on the source flux imposes restrictions on the direct and cascade component flux.

Detection of the seed fields with Fermi



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$\Gamma \leq 1.6$

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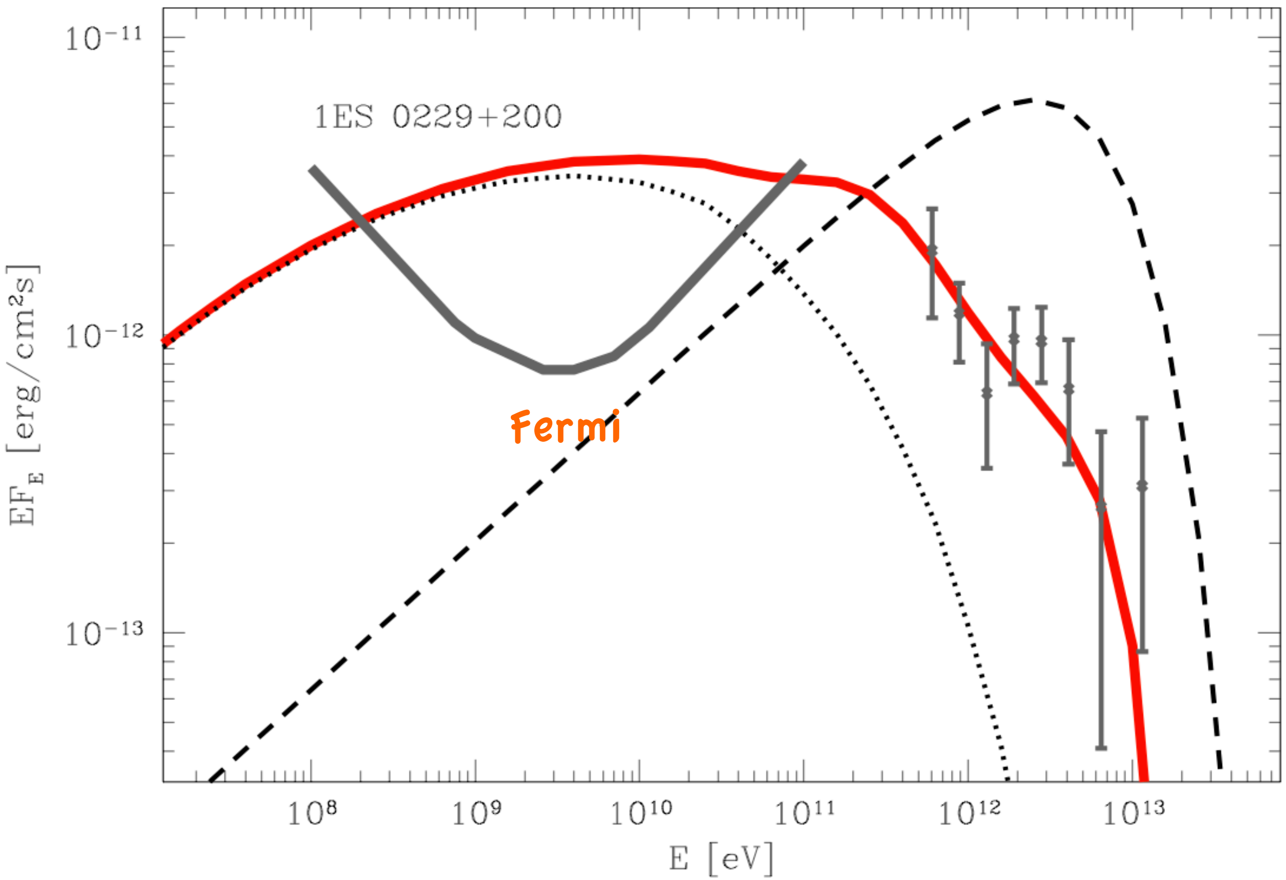

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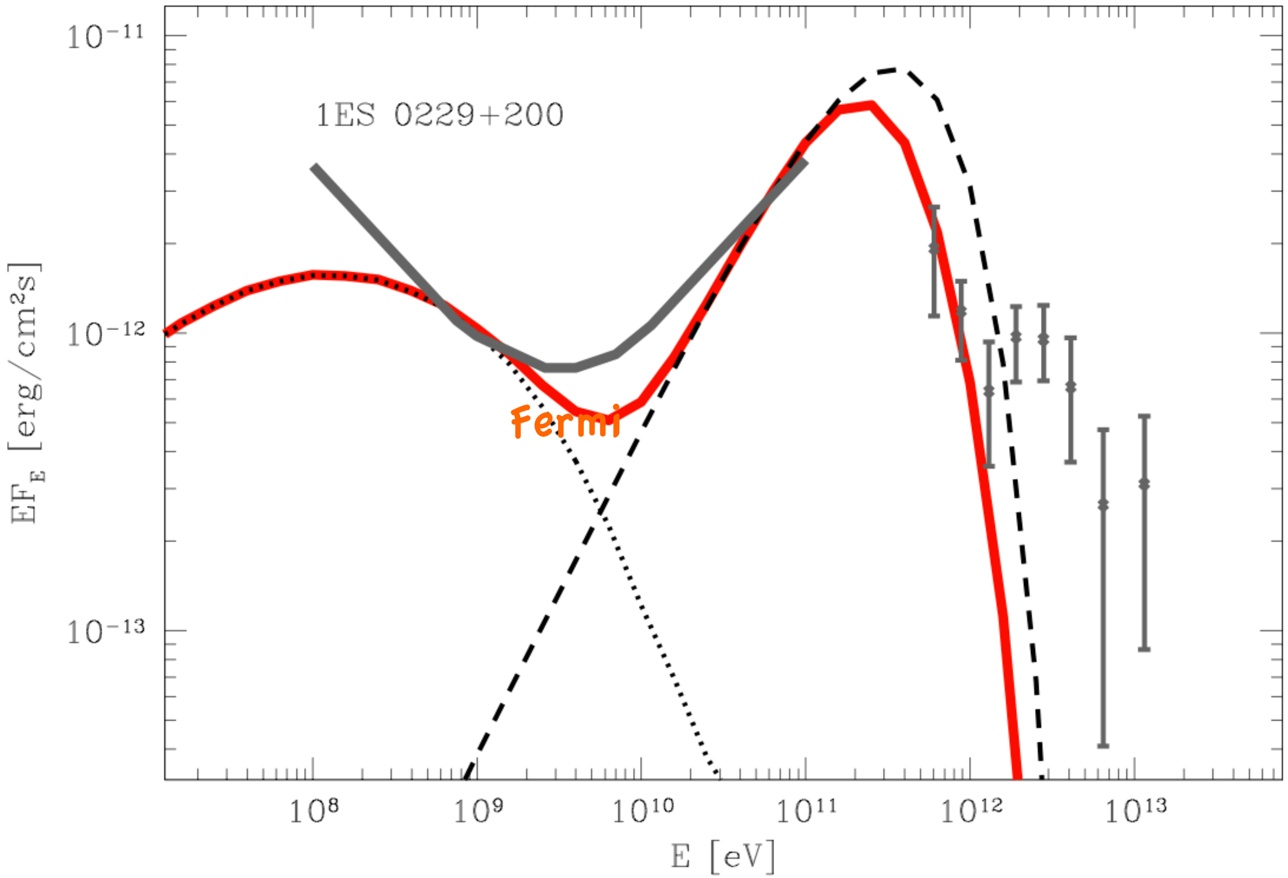

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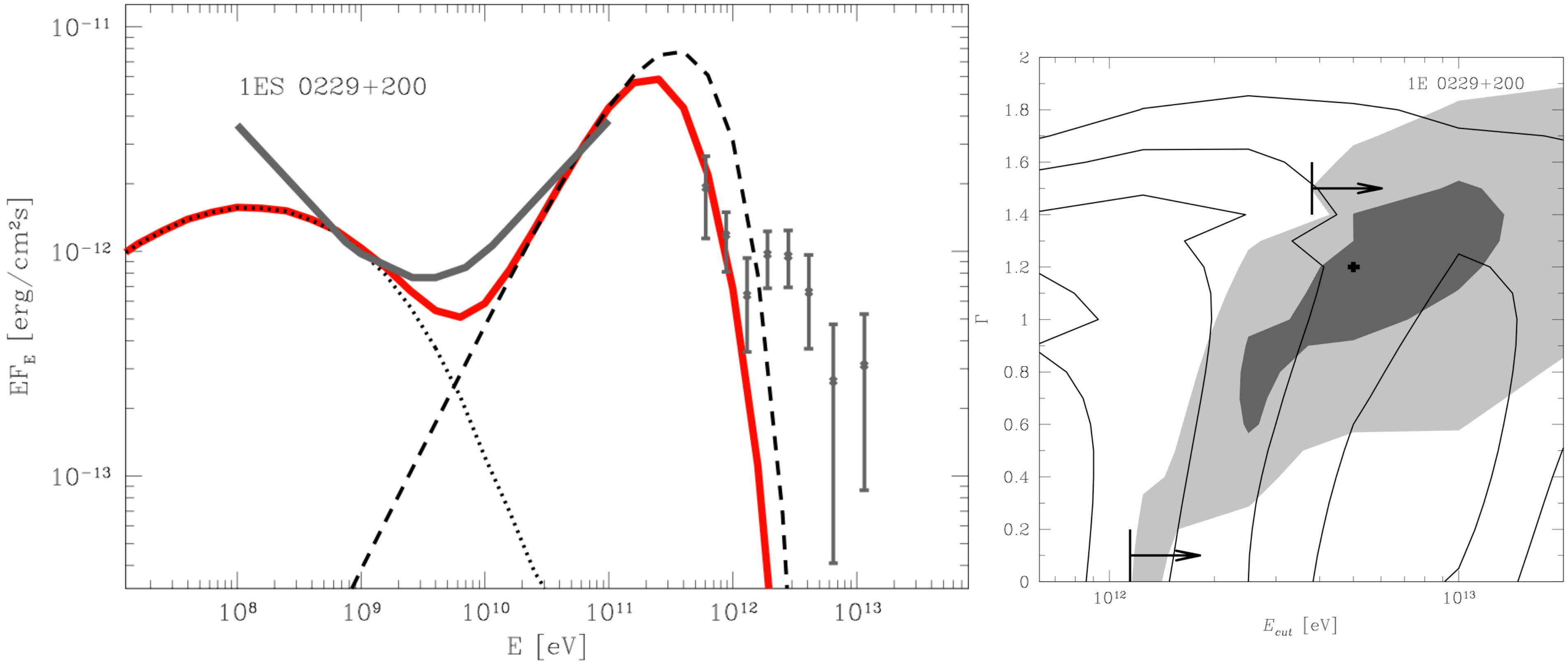

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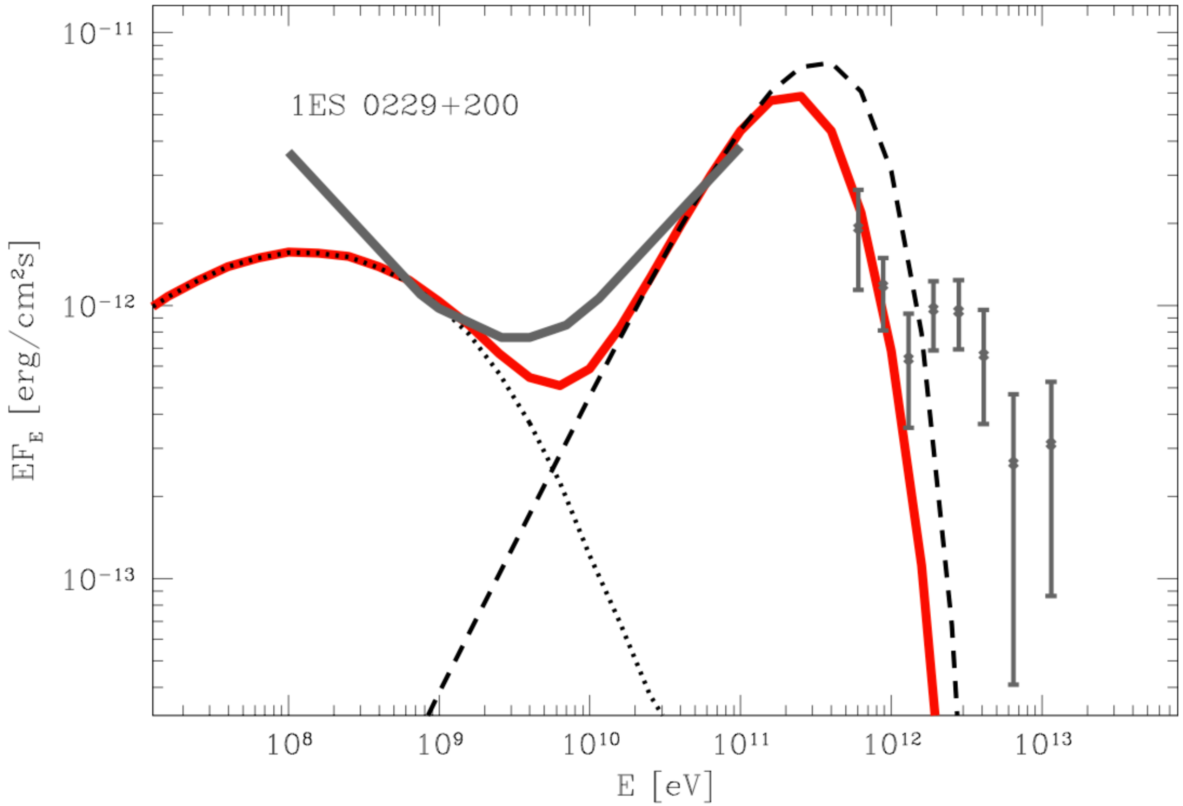

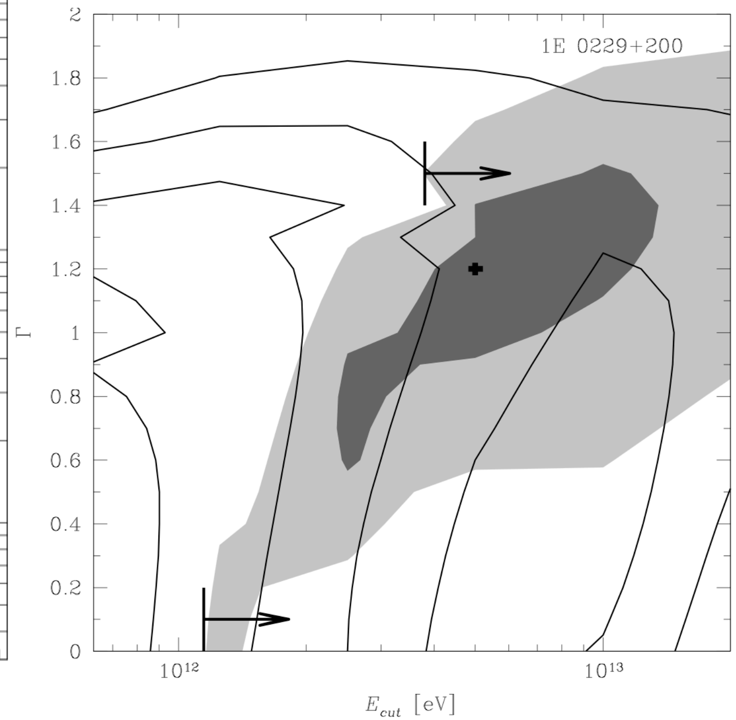

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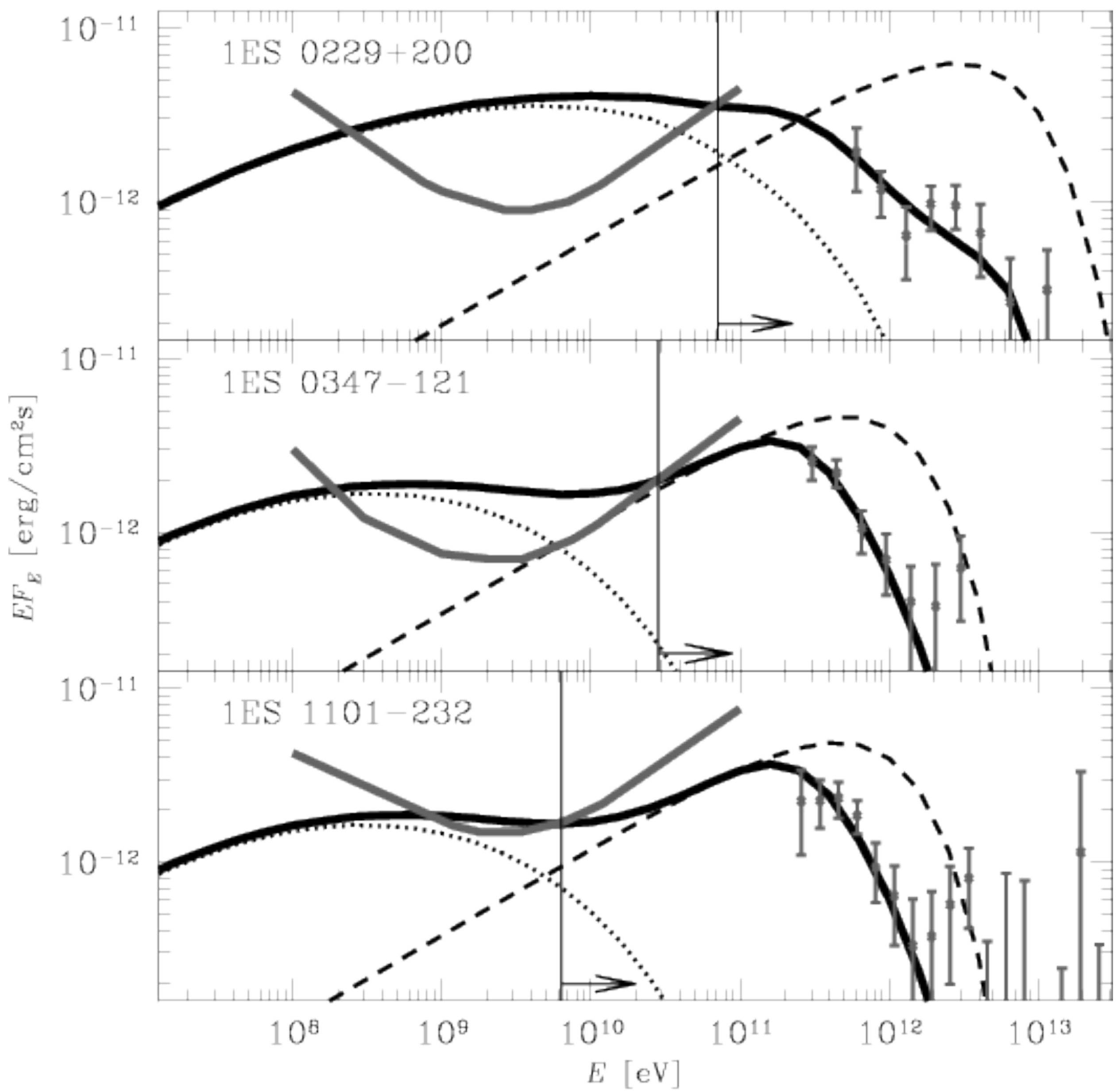
Fermi upper bound on cascade emission flux (assuming zero EGMF) is inconsistent with HESS lower bound on cut-off energy in the intrinsic source spectrum

Detection of the seed fields with Fermi



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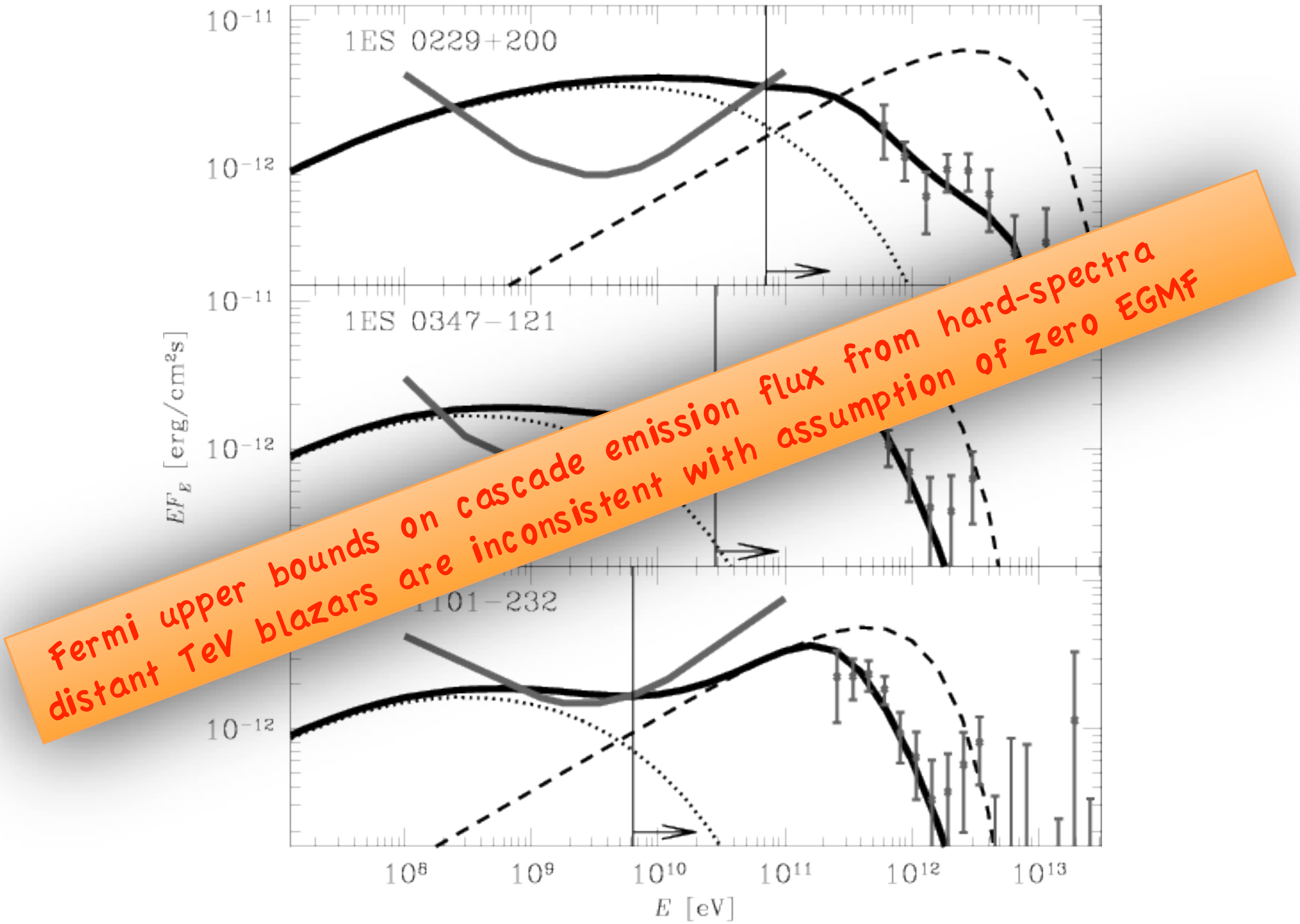

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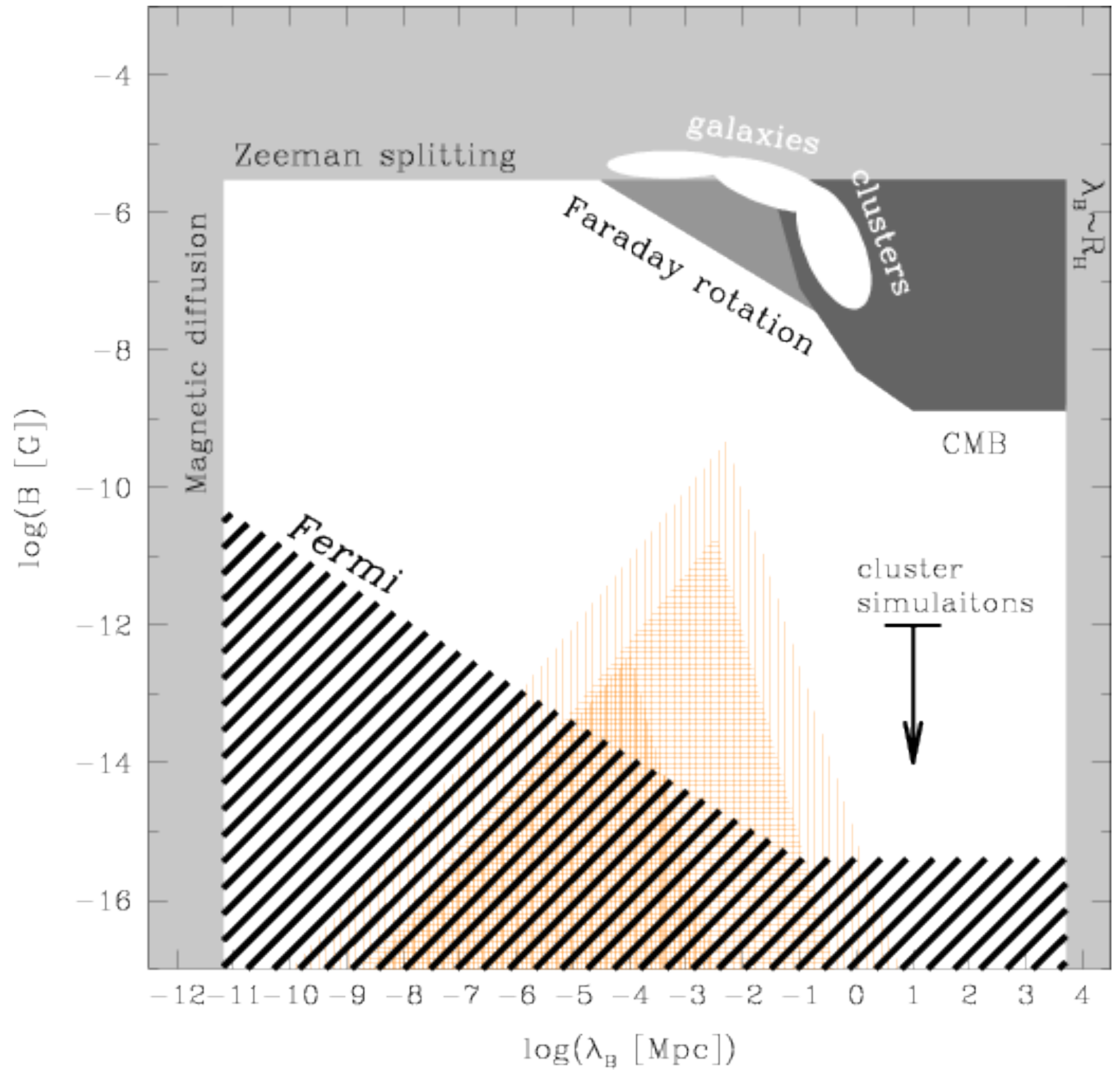

Non-detection of cascade contribution to the point source flux of TeV blazars in Fermi imposes lower bound on the strength of EGMF along the lines of sight toward these sources.

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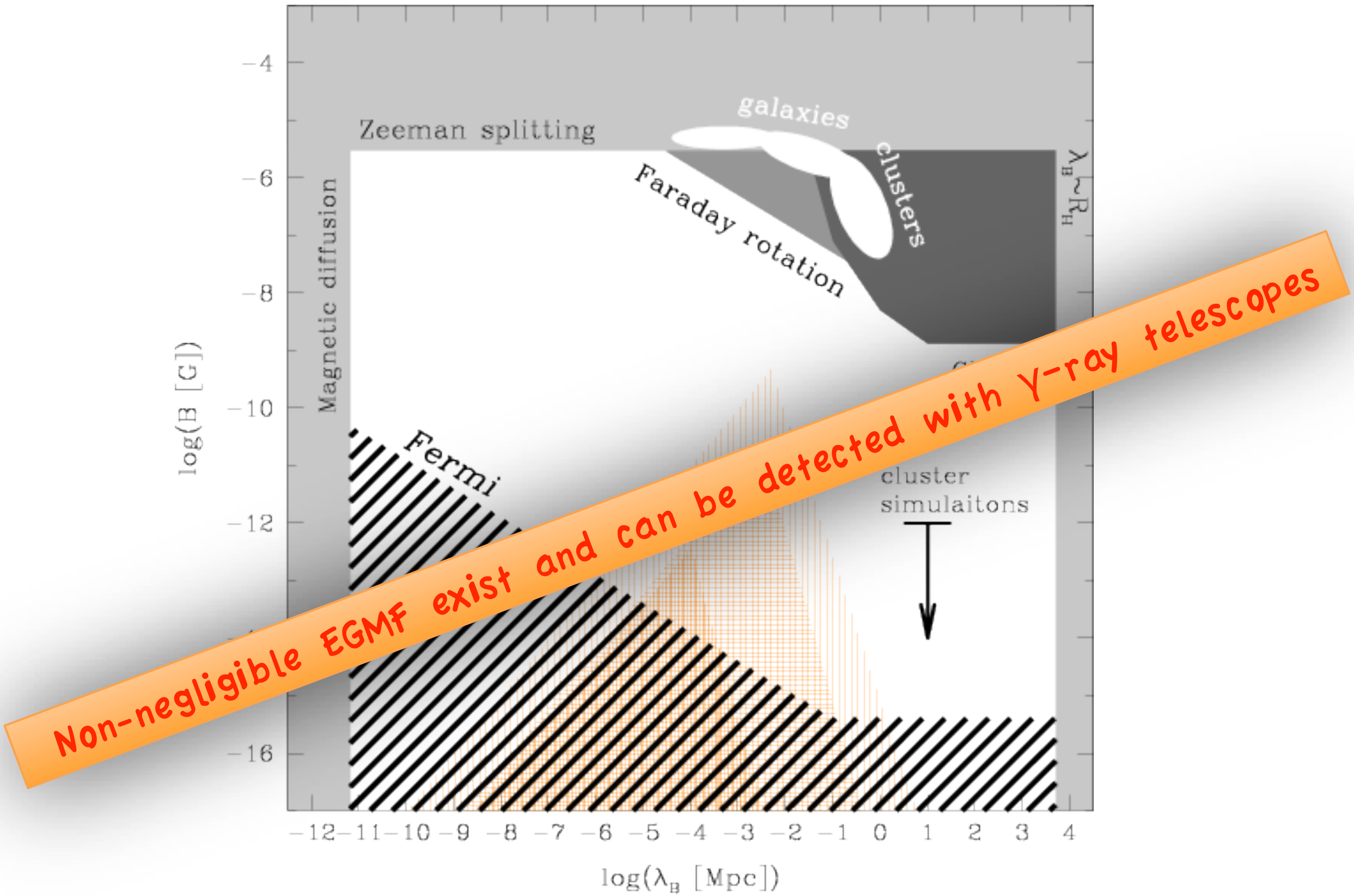

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