

Signatures of axion-like particles from the conversions of gamma-rays in intra-cluster magnetic fields

Manuel Meyer, Dieter Horns, Luca Maccione, Alessandro Mirrizi, Daniele Montanino, Marco Roncadelli
[Based upon [arXiv:1207.0776](https://arxiv.org/abs/1207.0776)]

Institut für Experimentalphysik
University of Hamburg

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on Axions WIMPs and WISPs,
Chicago

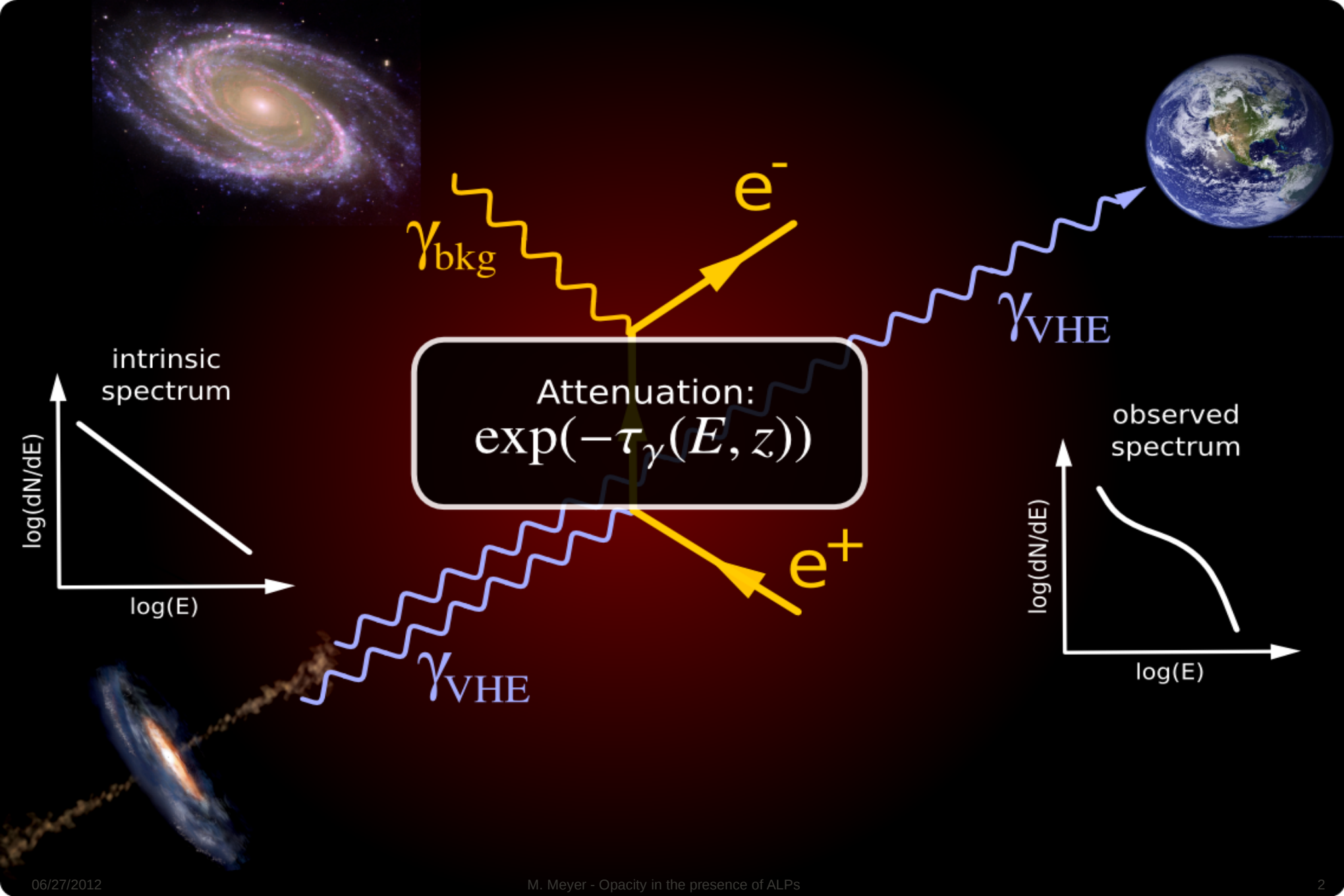
LEXI

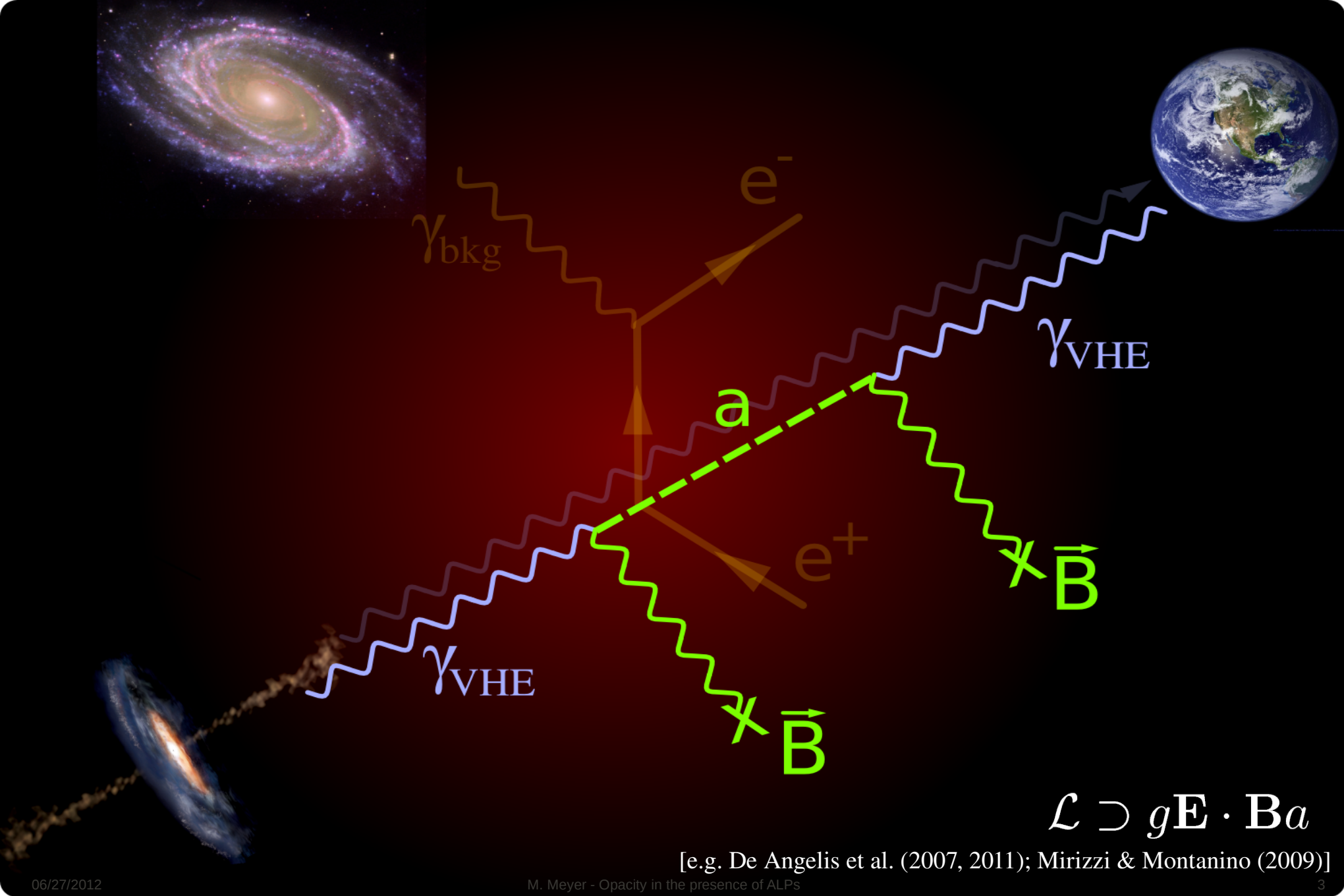
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$$\mathcal{L} \supset g\mathbf{E} \cdot \mathbf{B}a$$

[e.g. De Angelis et al. (2007, 2011); Mirizzi & Montanino (2009)]

$$|\vec{B}_{\text{IGMF}}| \lesssim 1 \text{ nG}$$

Intergalactic
Medium
O(100 Mpc)

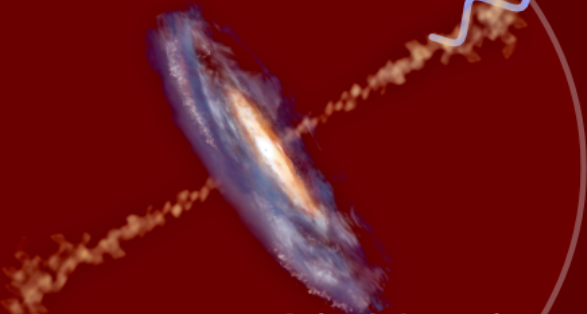
$$|\vec{B}_{\text{GC}}| \sim 1 \mu\text{G}$$

Galaxy Cluster O(Mpc)

$$|\vec{B}_{\text{host}}| \sim 1 \mu\text{G}$$

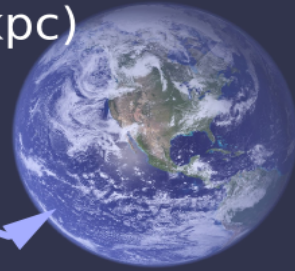
Host Galaxy ~ O(10 kpc)

$$|\vec{B}_{\text{src}}| \sim 1 \text{ G}$$

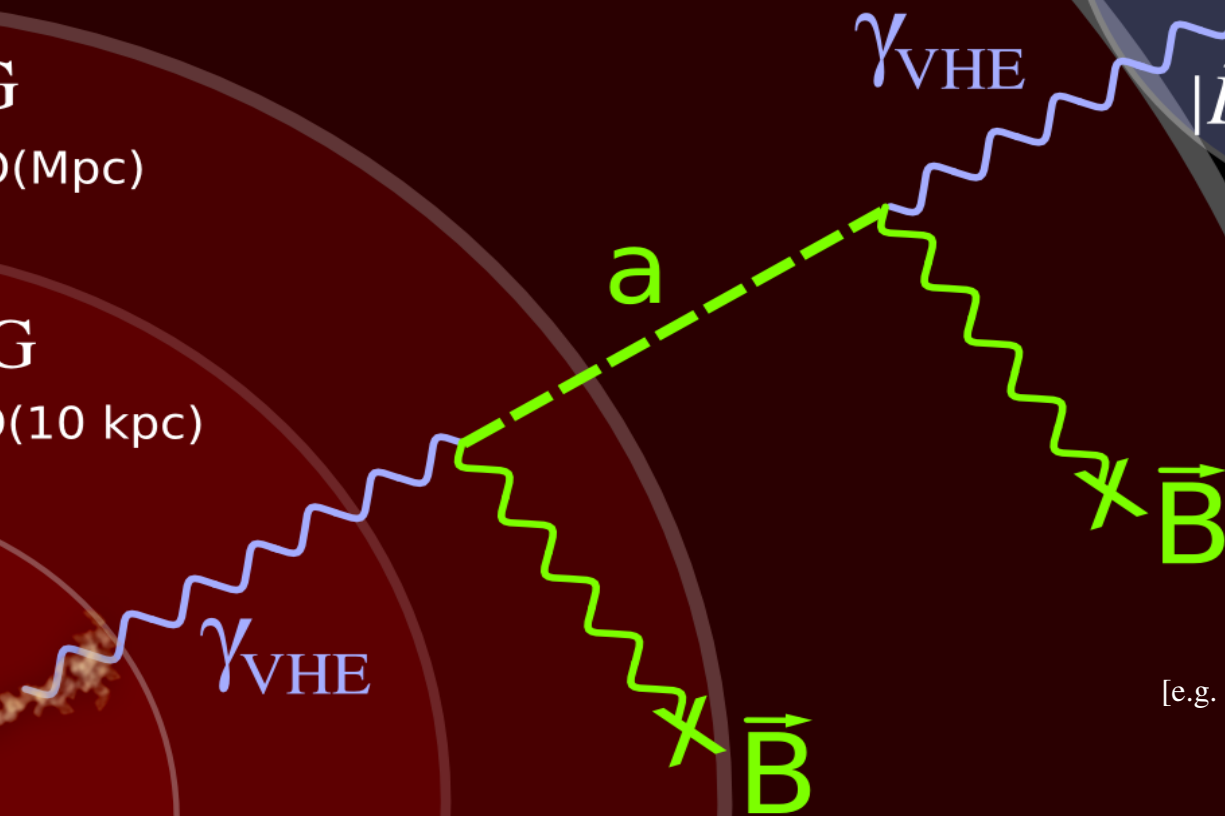


Source, ~ O(100 pc)

Milky Way
O(10 kpc)



$$|\vec{B}_{\text{GMF}}| \sim 1 \mu\text{G}$$



[e.g. De Angelis et al. (2007, 2011),
Mirizzi & Montanino (2009),
Sánchez-Conde et al. (2009),
Domínguez et al. (2011),
Tavecchio et al. (2012)]

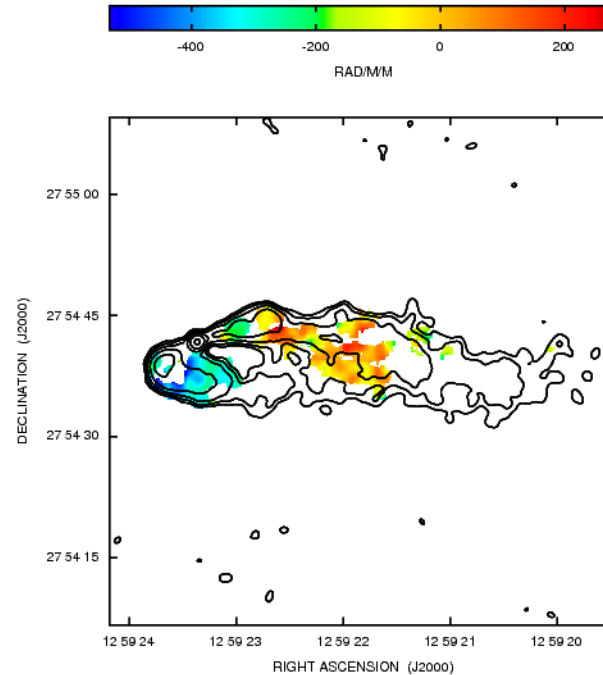
Evidence for B -fields in galaxy clusters

- **Non-thermal (synchrotron) emission** of the intra-cluster medium
- **Rotation measure** measurements

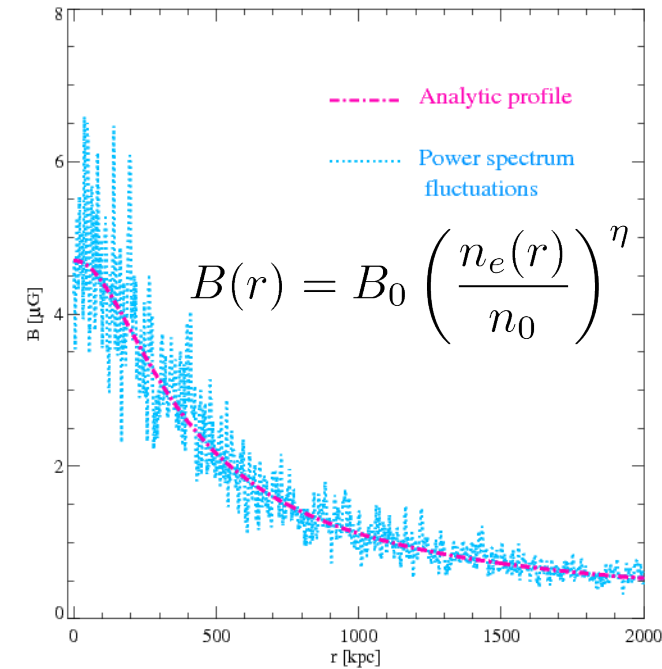
$$\Delta\Psi = \Psi - \Psi_0 = \lambda^2 \text{RM}$$

$$\text{RM} = 812 \int_0^L n_e B_{\parallel} dl \quad (\text{rad m}^{-2})$$

- Field strengths between **0.1 and 10 μG**
- **Extent: up to 5 Mpc**
- Magnetic field follows **thermal electron distribution $n_e(r)$**
- Turbulent structure with typical **domain lengths of 10 kpc**



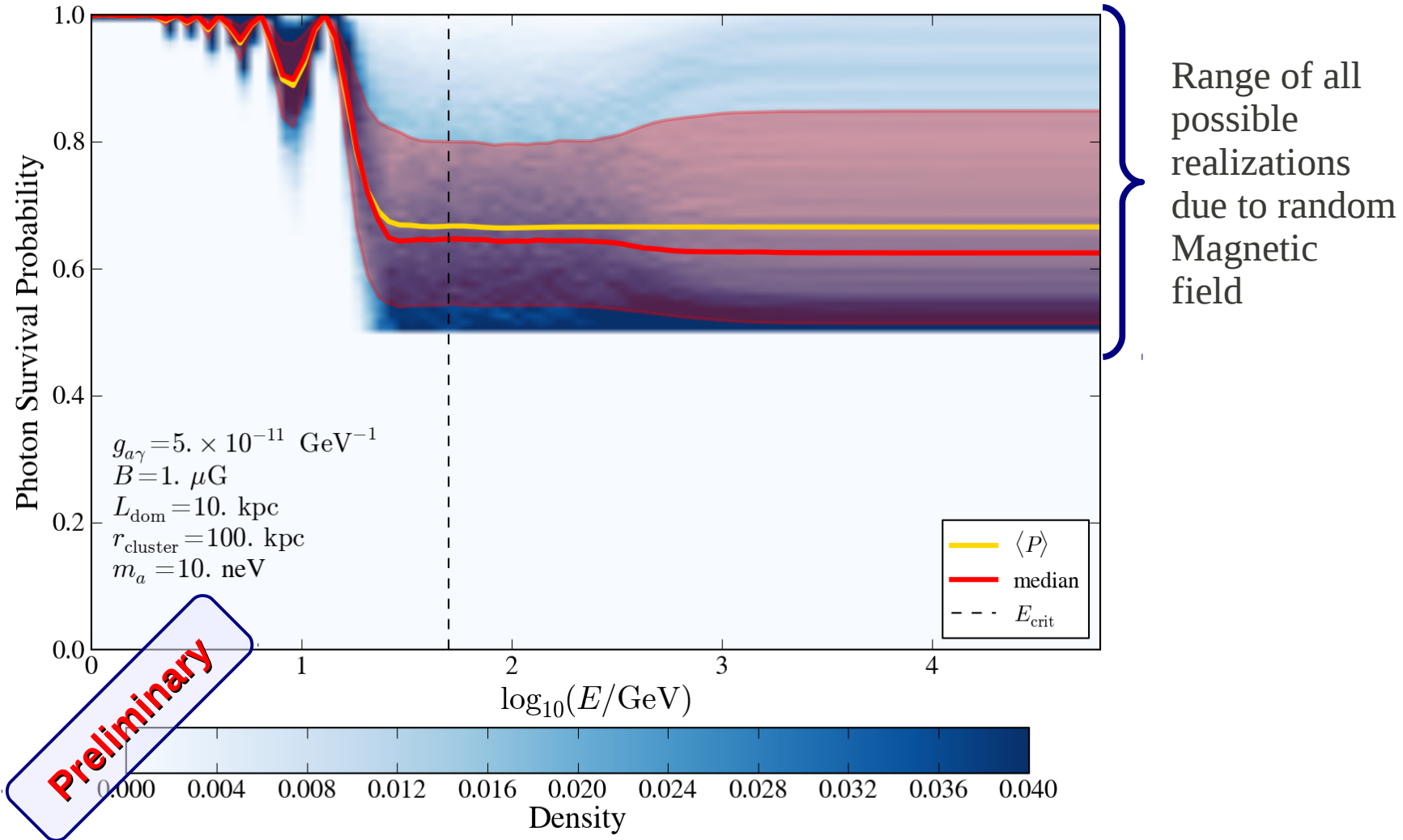
Rotation measure + 5 GHz contours of radio galaxy NGC 4869 in the Coma cluster



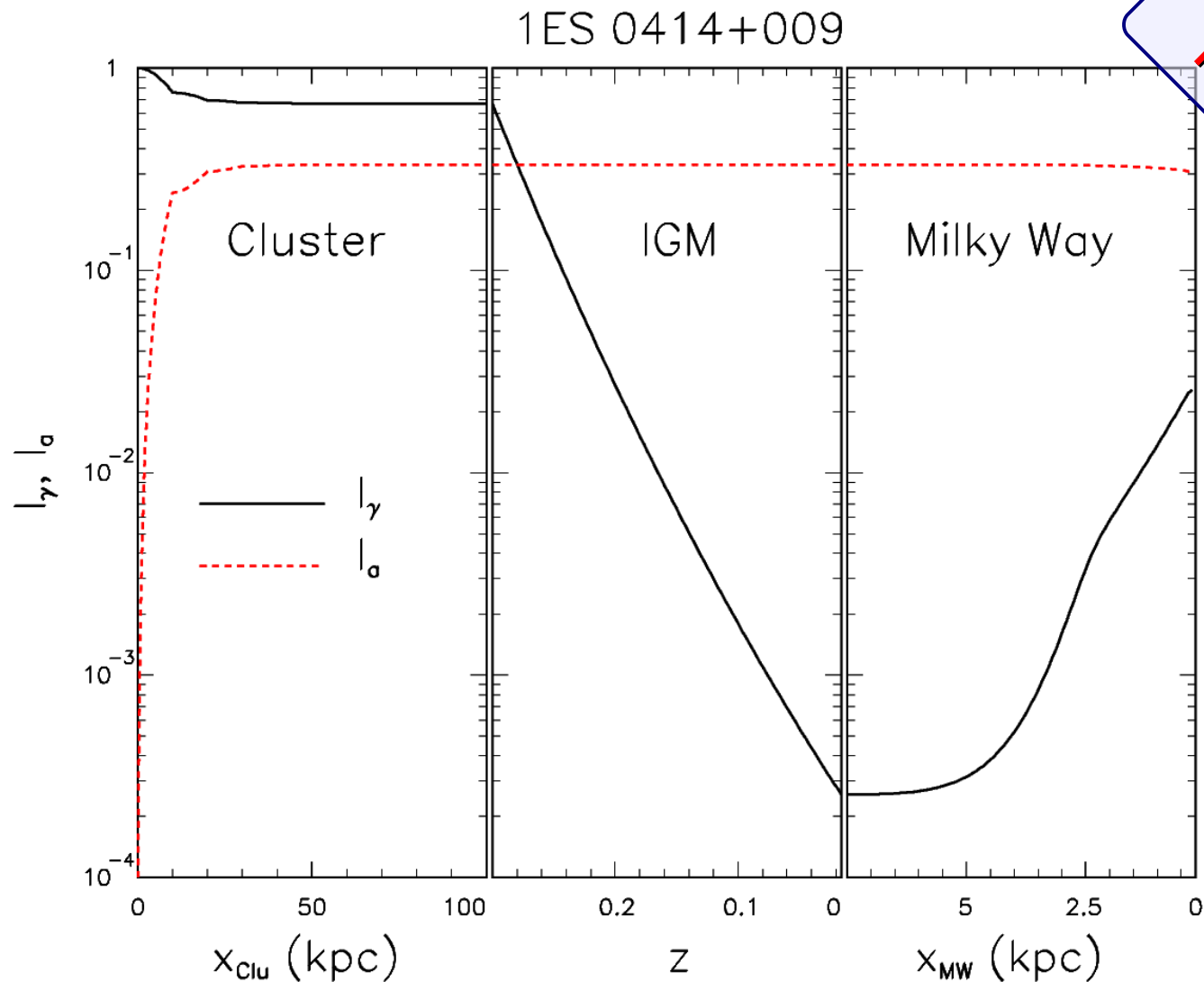
Simulated magnetic field (blue line) along with analytical profile (magenta line) of the Coma cluster

[Bonafede et al. (2010), A&A, 513, A30, see also Feretti et al. (2012), arXiv: 1205.1919 for a review]

Conversion in a galaxy cluster



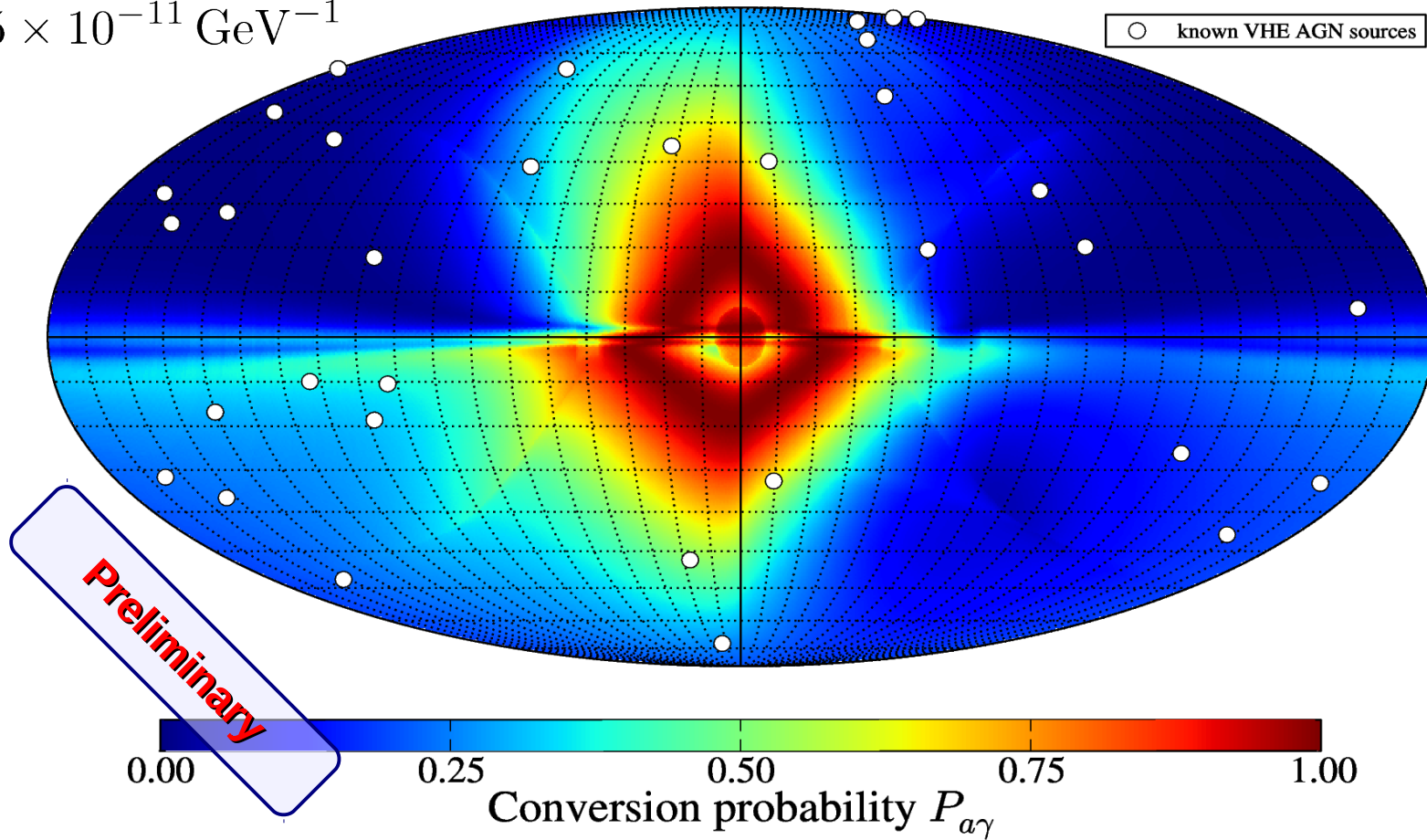
Evolution of the photon – ALP beam



Preliminary

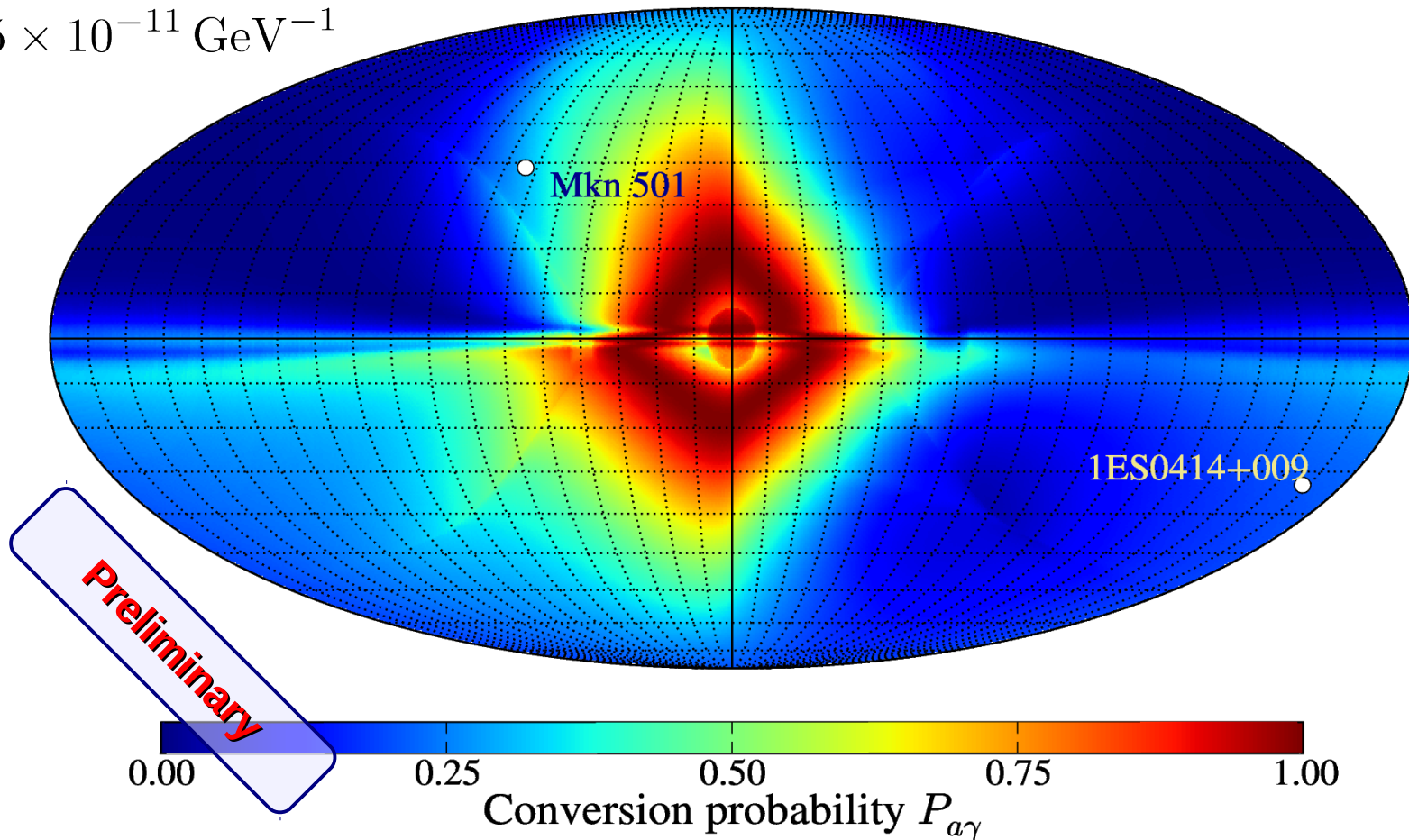
Reconversion in the Milky Way

$$g_{a\gamma} = 5 \times 10^{-11} \text{ GeV}^{-1}$$

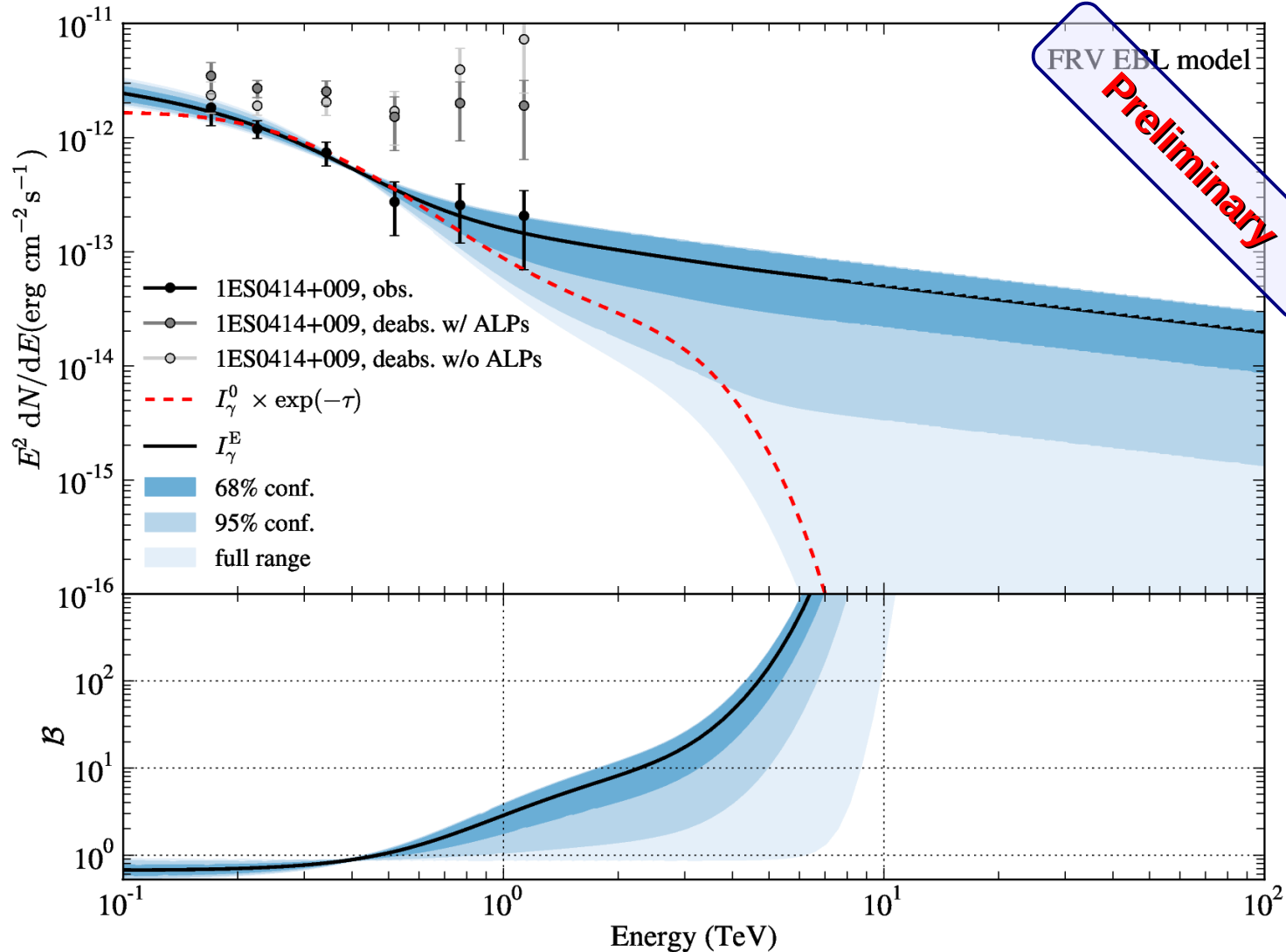


Reconversion in the Milky Way

$$g_{a\gamma} = 5 \times 10^{-11} \text{ GeV}^{-1}$$



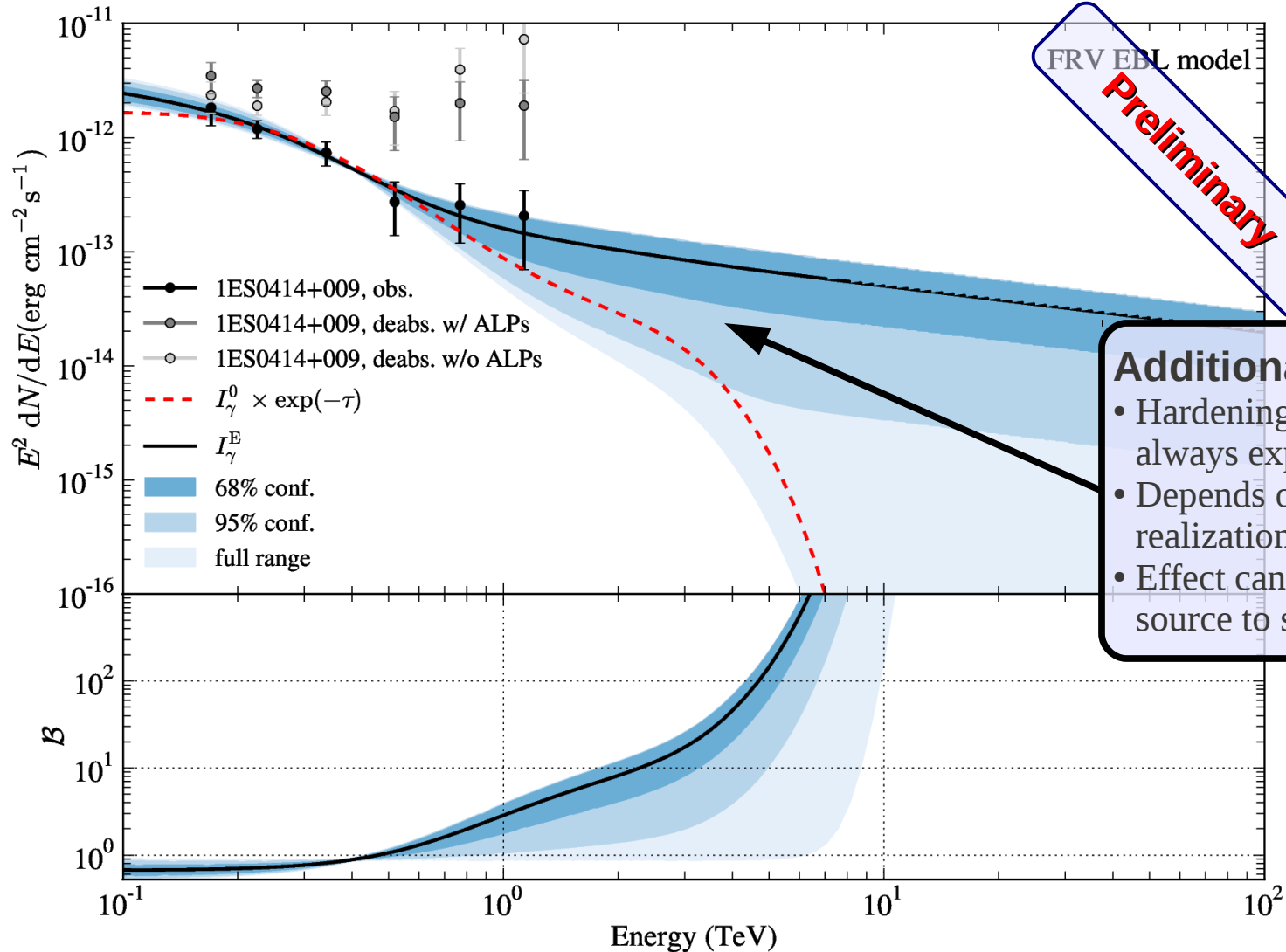
Spectral signatures of ALPs for 1ES 0414+009



I_γ^E
 Observed photon
 flux on earth
 w/ ALPs

[EBL model:
 Franceschini
 et al. (2008)]

Spectral signatures of ALPs for 1ES 0414+009

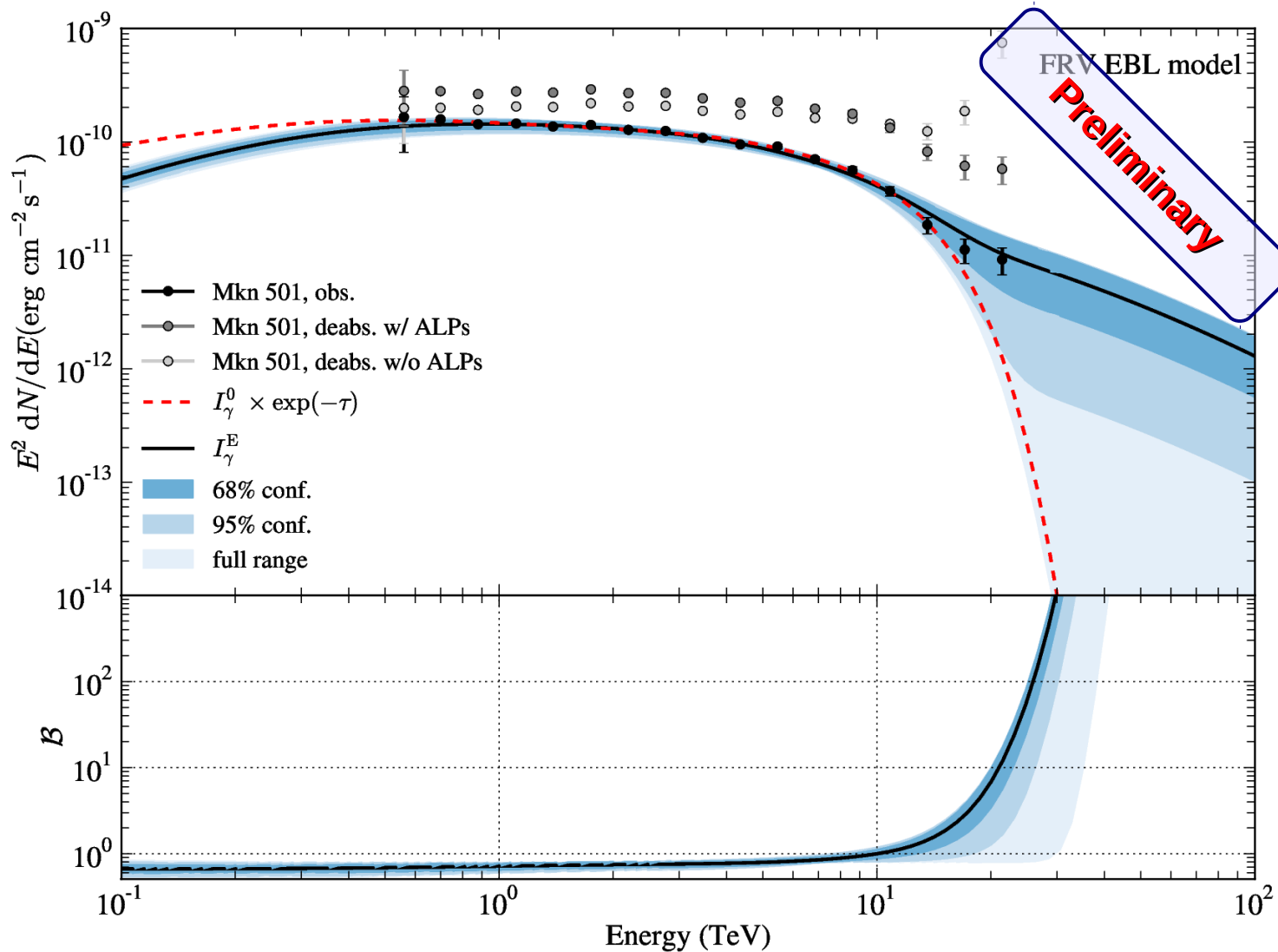


Additional feature:

- Hardening of the source not always expected
- Depends on actual realization of B -field
- Effect can vary from source to source

[EBL model: Franceschini et al. (2008)]

Spectral signatures of ALPs for Mkn 501



[EBL model: Franceschini et al. (2008)]

Summary and Conclusions

- **ALPs alter the opacity of the universe** in an energy and redshift dependent way
- **Intra-cluster and Galactic magnetic fields well established**, strength of the order of μG , **mechanism relies on *measured* B-fields only**
- **Flux enhancement in optical thick ($\tau_\gamma > 1$) regime**, depending on B -field strength and configuration, and AGN environment
- With data from **CTA, detections of ALP signatures are possible and / or scenarios can be severely constrained**
- Other mechanism (e.g. formation of electro-magnetic cascade) can also affect the opacity [see e.g. Aharonian et al. (2012), arXiv:1206.6715]