Gamma-rays and cosmology, inter-galactic magnetic fields

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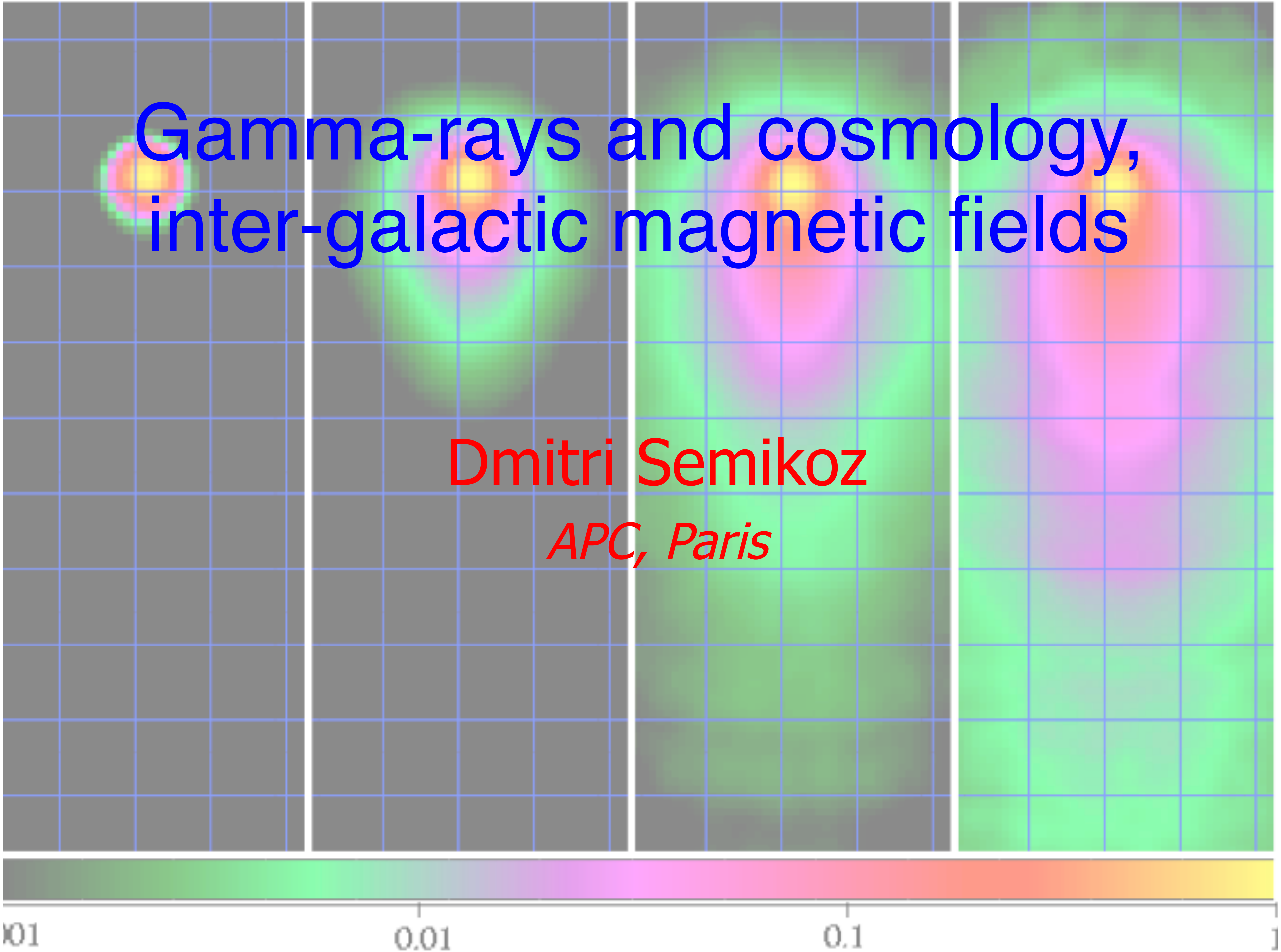
APC, Paris



Contributions Prospectives IN2P3 2020 - GT-04

:

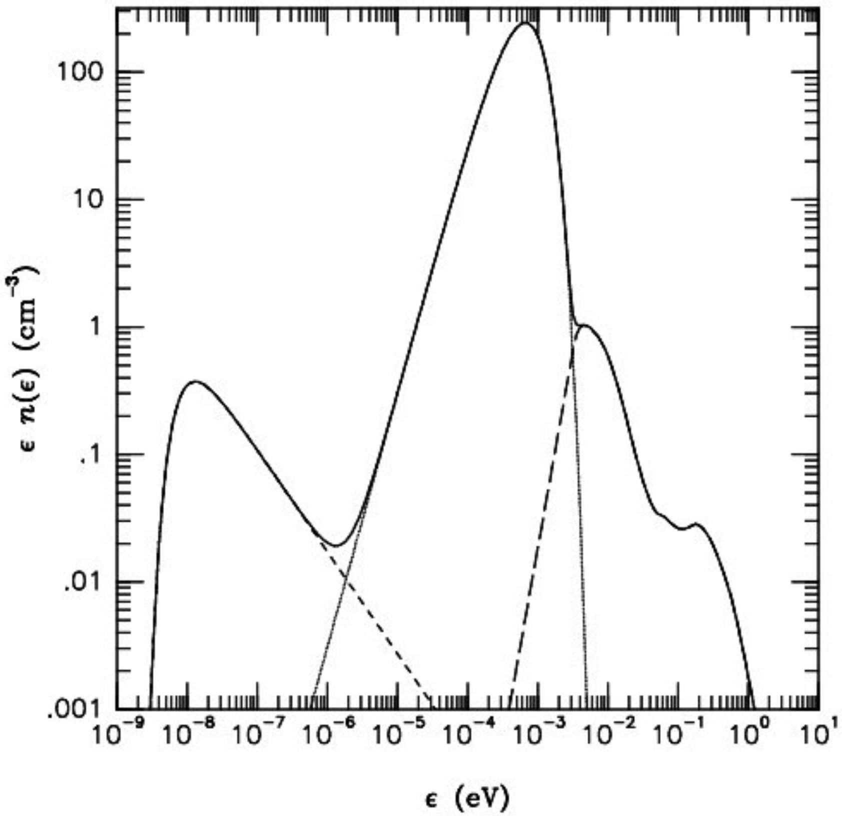
- Gamma-ray cosmology. Principal Author: Jonathan Biteau
- Co-authors: Rémi Adam, Matthieu Béthermin, Barbara Biasuzzi, Julien Bolmont, Johan Bregeon, Arache Djannati-Ataï, Hervé Dole, Gabriel Emery, Steve Fegan, Armand Fiasson, Gilles Henri , Deirdre Horan, Bruno Khéli, Mathieu Langer, Jean-Philippe Lenain, Christelle Levy, Benoit Lott, Julien Malzac, Gilles Maurin, Andrii Neronov, Santiago Pita, Michael Punch, Yann Rasera, David Sanchez, Christophe Sauty, Dmitri Semikoz, Atreyee Sinha, Hélène Sol, Andreas Zech
- **Cosmic magnetic fields.** Principal Author: Dmitri Semikoz
- Co-authors: A.Neronov , S.Pita , Jonathan Biteau

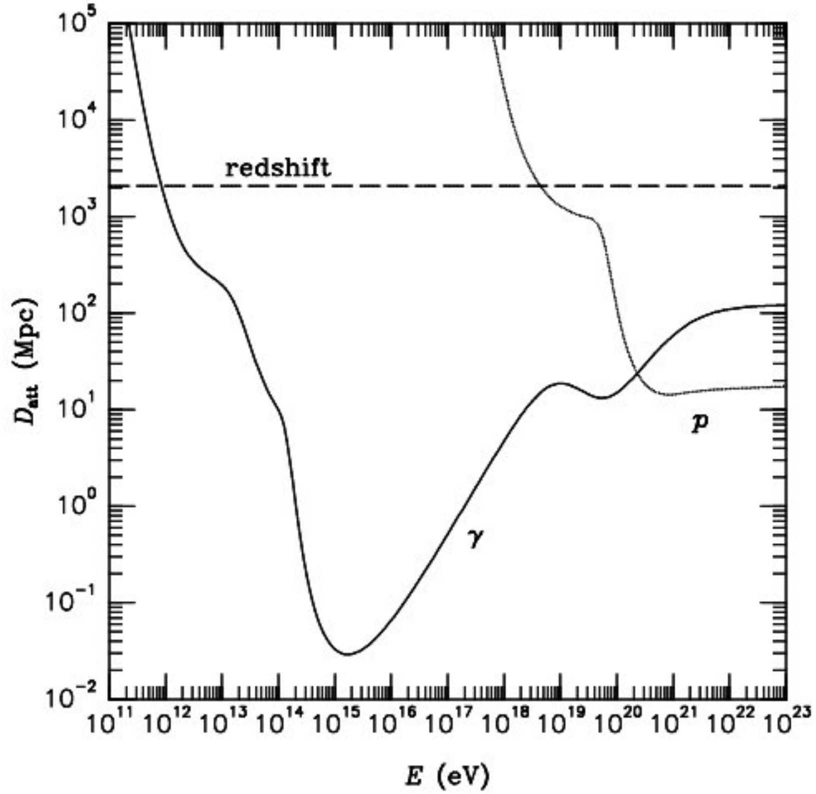
Overview:

- *Extragalactic Background Light (EBL) as H0 probe*
- *IGMF production, evolution and SGWB*
- *IGMF detection with gamma-rays*
- *IGMF detection with UHECR*
- *Conclusions*

Extragalactic Background Light

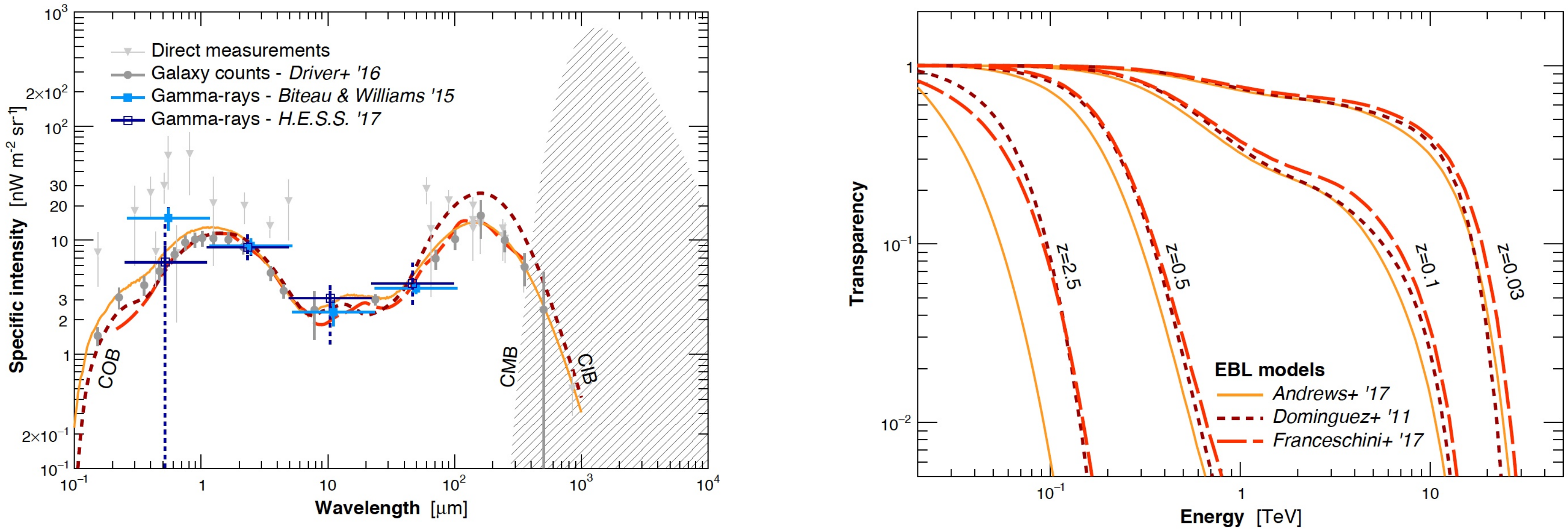
Diffuse backgrounds





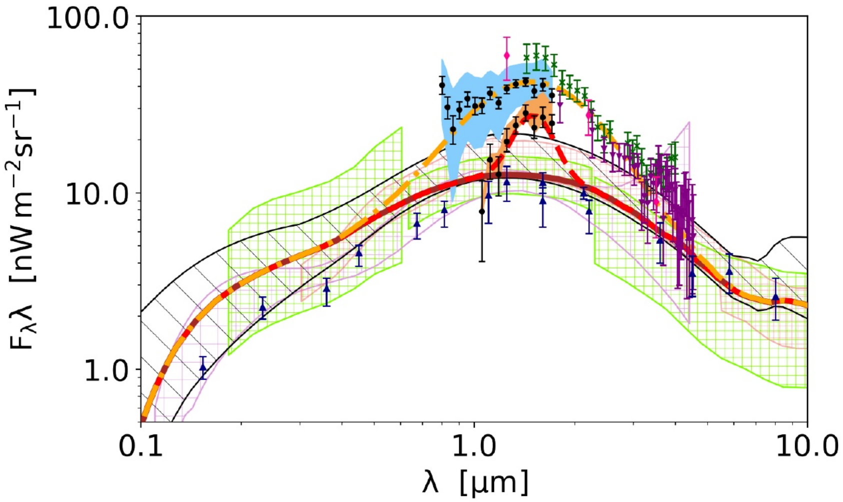
$$\gamma + \gamma \Rightarrow e^{-} + e^{+}$$

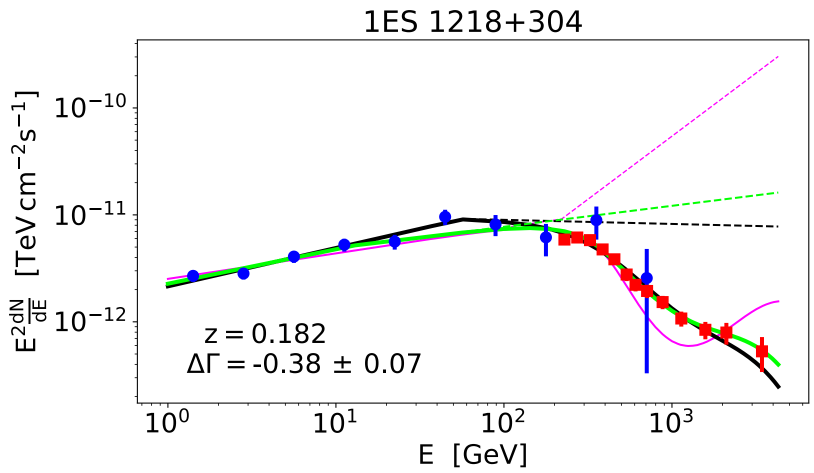
Extragalactic Background Light (EBL) state of art



Left: Constraints on the specic intensity of the EBL at z = 0. Right: gamma-ray transparency as a function of energy and redshift for three state-of-the-art EBL models.

Extragalactic Background Light (EBL) extra features with CTA

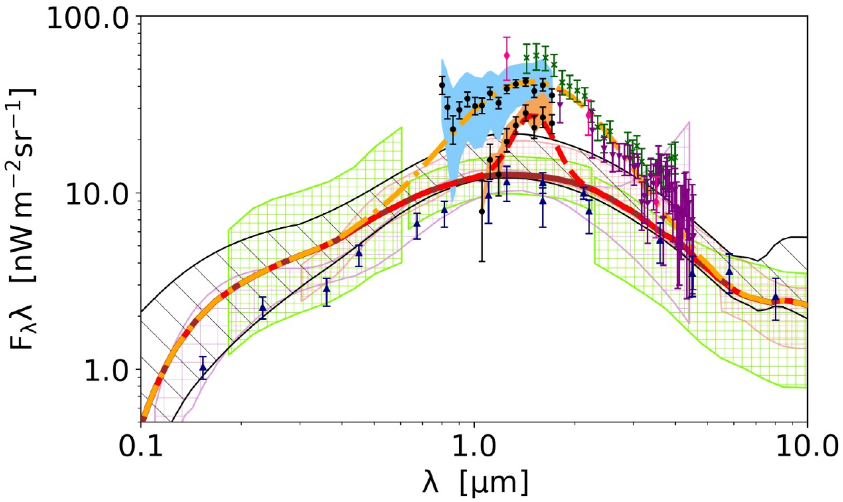


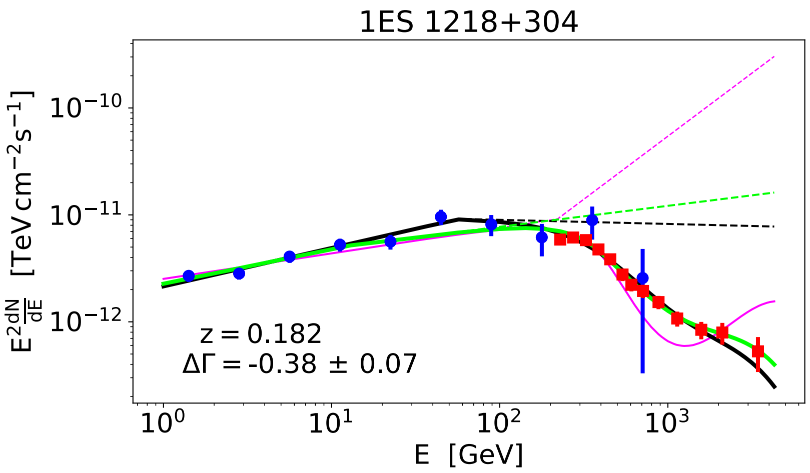


Left: Thin features on top of smooth the EBL: first stars, Dark Matter, etc.
Right: Spectrum of 1ES 1218+304 and imprint of additional contributions to EBL.

A.Korochkin et al, arXiv:1906.12168.

Extragalactic Background Light (EBL) extra features with CTA





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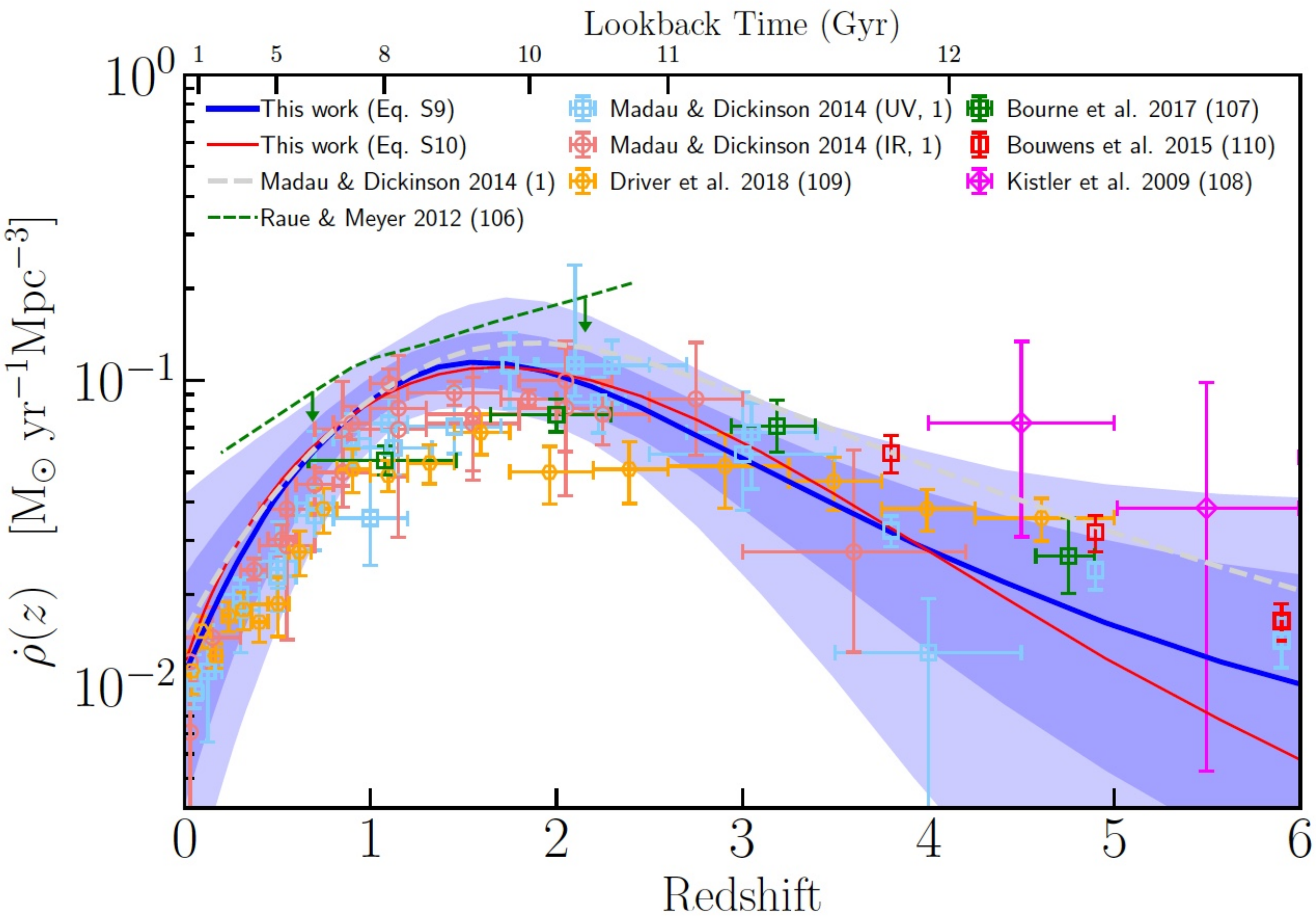
H0 from gamma-ray sources

H0 from pair production

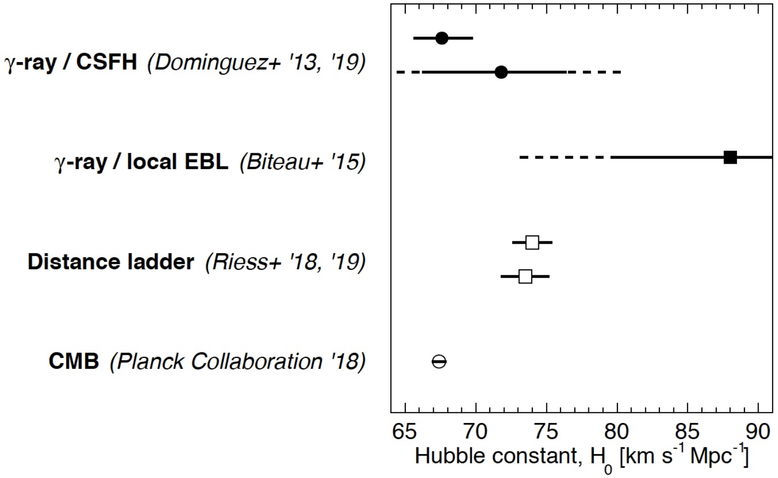
$$\tau(E, z_0) = \int_0^{z_0} \mathrm{d}z \frac{\partial L(z)}{\partial z} \int_{-1}^{1} \mathrm{d}\cos\theta' \frac{1-\cos\theta'}{2} \int_0^{\infty} \mathrm{d}\epsilon' \sigma_{\gamma\gamma}(E', \epsilon', \cos\theta') \frac{\partial n(\epsilon', z)}{\partial \epsilon'}.$$

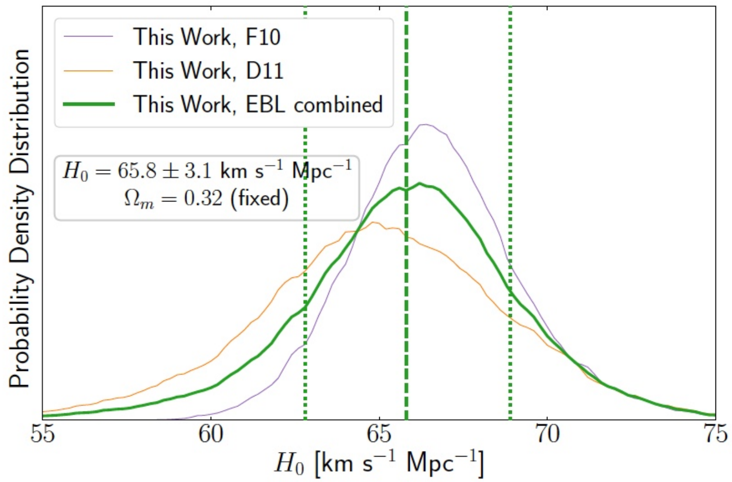
H0 from gamma-rays



Fermi LAT sources+ Cherenkov Telescopes ···

H0 from gamma-rays

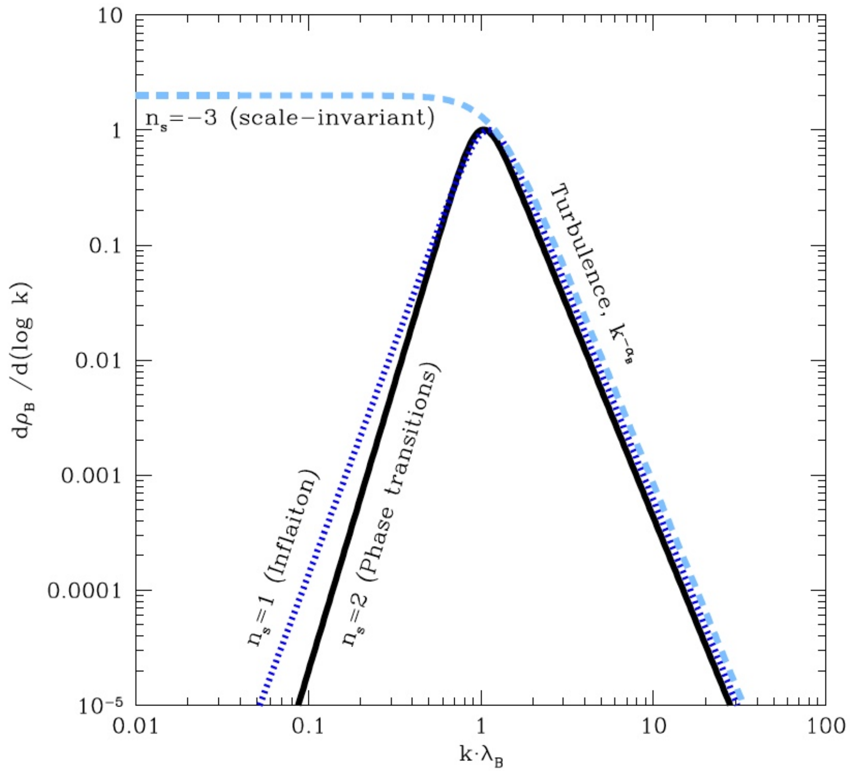




A. Domınguez et al, 1903.12097

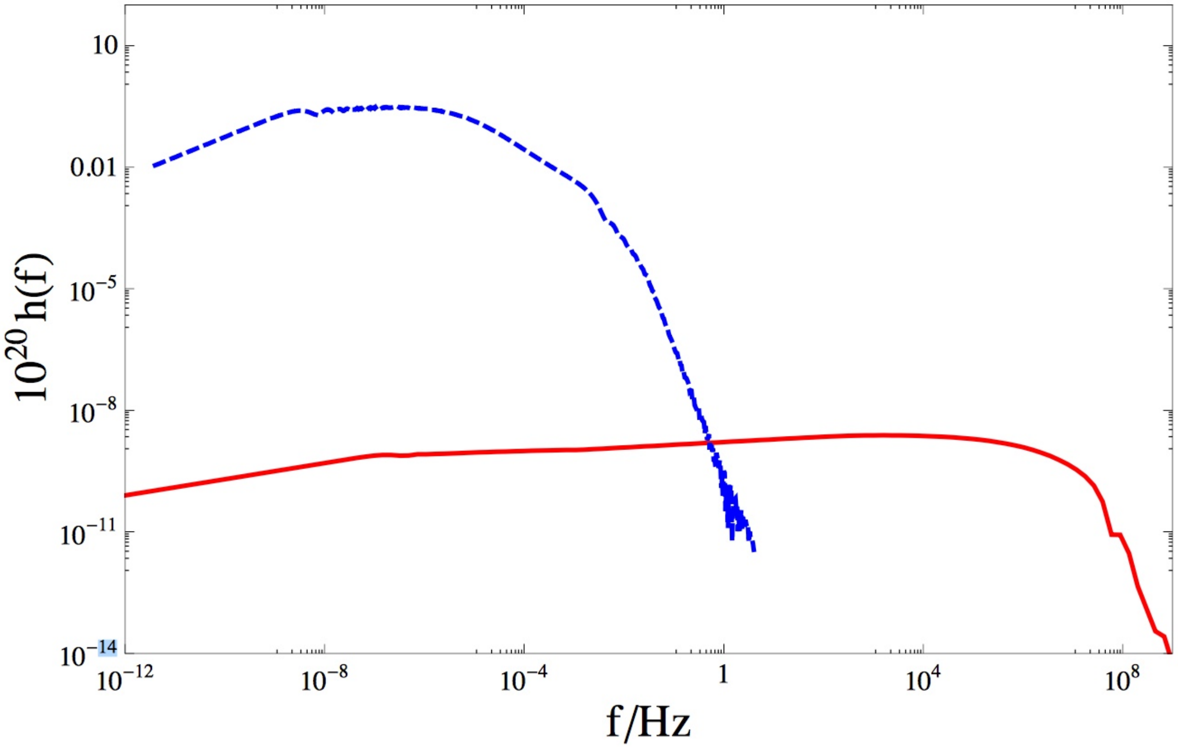
Inter-Galactic Magnetic Field

Produced spectrum of IGMF



From R.Durrer and A.Neronov, A&A Rev. 21 62, [1303.7121].

Production of GW with IGMF in EW phase transition



C. Caprini et al., JCAP 0911 (2009) 001

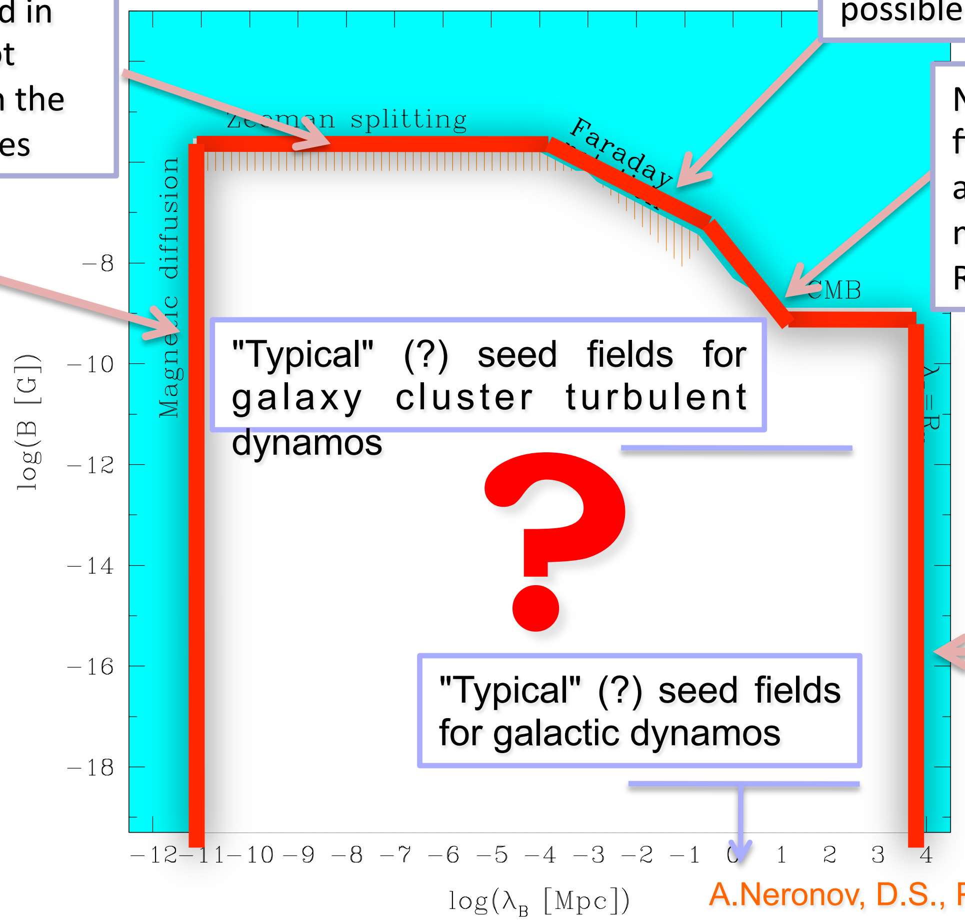
Magnetic fields in IGM

Non-observation of Faraday rotation of polarized radio emission from quasars limits possible magnetic fields in IGM

Magnetic field in the IGM is not stronger than the field in galaxies

Non-observation of magnetic field induced features in the anisotropy of CMB limits magnetic fields produced before Recombination

Resistive decay removes short-correlation length fields in $T<10$ Gyr



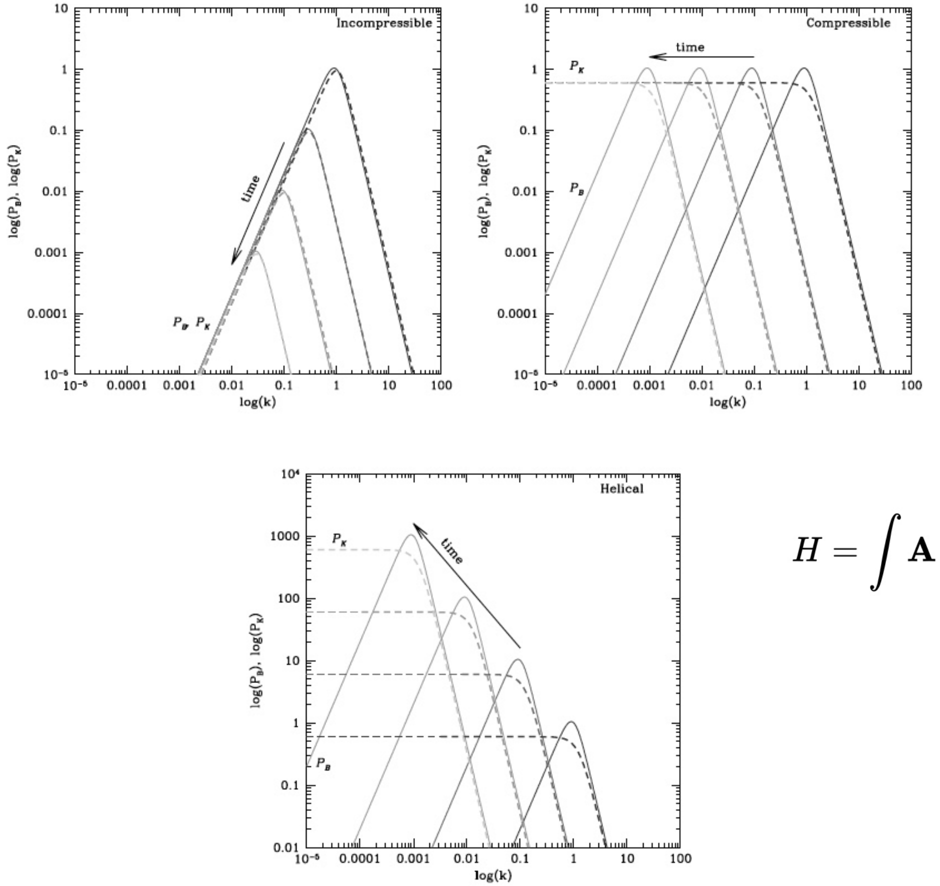
"Typical" (?) seed fields for galaxy cluster turbulent dynamos

"Typical" (?) seed fields for galactic dynamos

Magnetic field homogeneity scale can, in principle, be comparable to the size of the Universe

A.Neronov, D.S., PRD 2009, arXiv:**0910.1920**

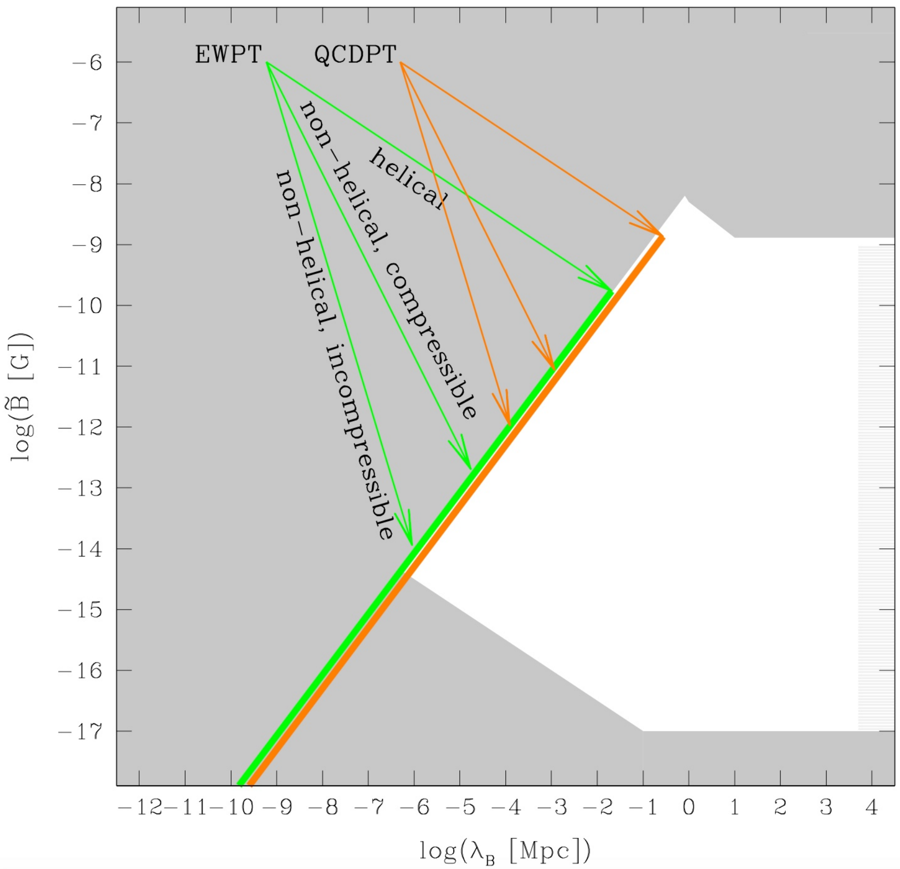
Early Universe evolution of spectrum of IGMF



$$H = \int \mathbf{A} \cdot \mathbf{B} \, d^3\mathbf{r}$$

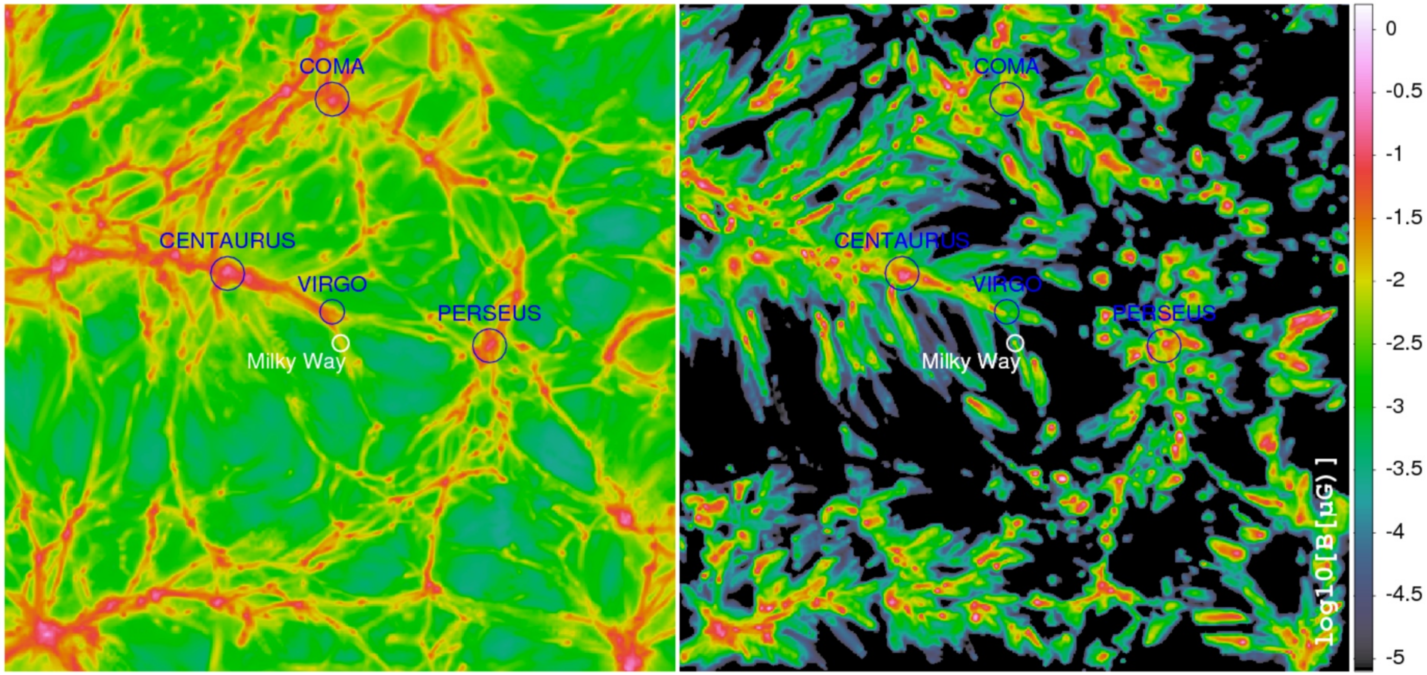
R.Durrer and A.Neronov, A&A Rev. 21 62, [1303.7121].

IGMF from inflation and phase transitions



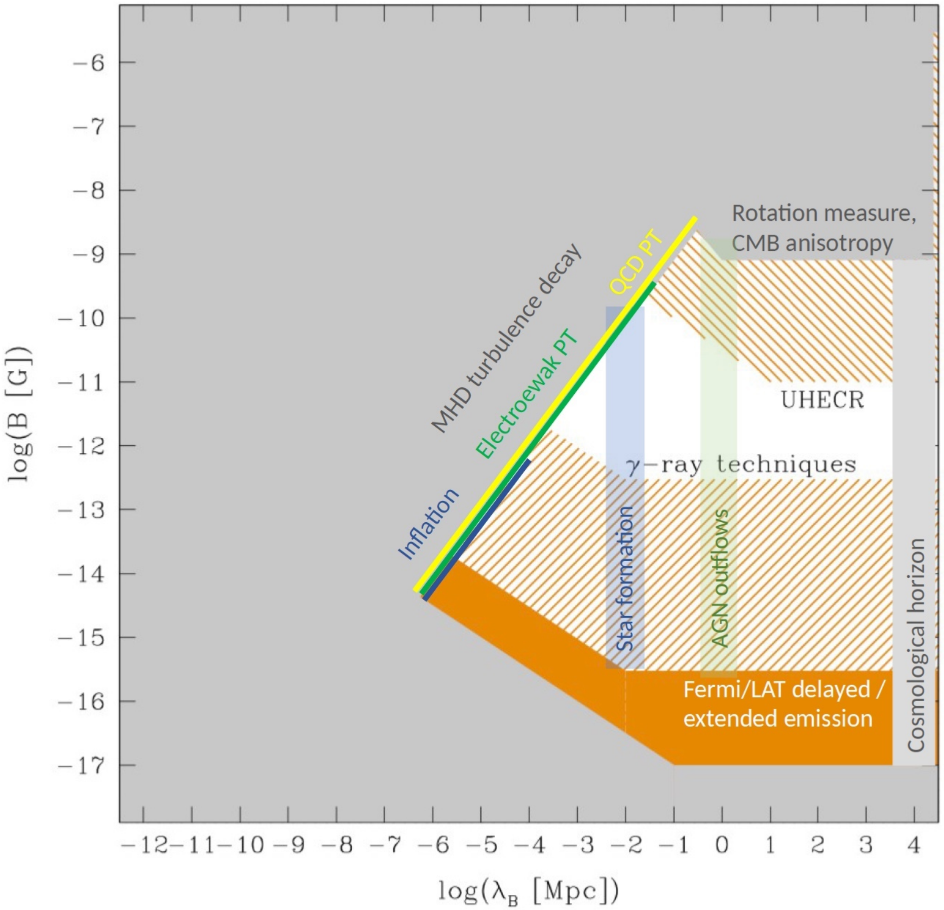
R.Durrer and A.Neronov, A&A Rev. 21 62, [1303.7121].

IGMF evolution and LSS



S. Hackstein et al, **MNRAS (2017) 1-11**, [1710.01353].

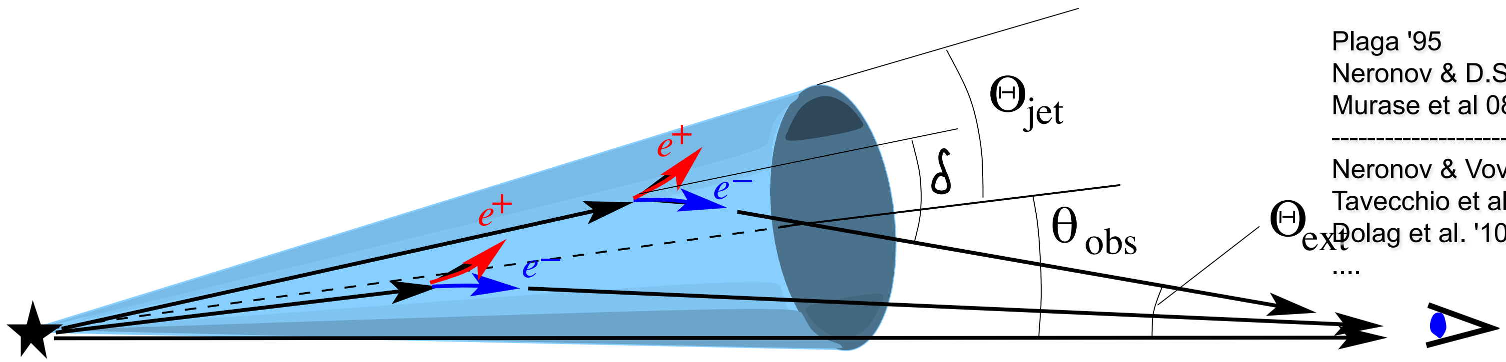
Detection of IGMF



R.Durrer and A.Neronov, A&A Rev. 21 62, [1303.7121].

Inter-Galactic Magnetic Field detection with gamma-rays

IGMF measurement with gamma-ray telescopes



Plaga '95
Neronov & D.S. '07, '09
Murase et al 08

Neronov & Vovk '10
Tavecchio et al. '10
Dolag et al. '10
....

γ-rays with energies above ~0.1 TeV are absorbed by the pair production on the way from the source to the Earth.

$$D_{\gamma_0} = \frac{1}{n_{\rm IR}\sigma_{PP}} \propto 150\ \text{Mpc}\ \frac{4\ \text{TeV}}{\text{E}}\frac{10nW/(m^2 sr)}{(\nu F(\nu))_{IR}}$$

$$E_{\gamma 0} = 2E_e \qquad \lambda_e = \frac{1}{n_{\rm CMB}\sigma_{ICS}} \sim 1\ \text{kpc}$$

e^+e^- pairs re-emit γ-rays via inverse Compton scattering of CMB photons.

Inverse Compton γ-rays could be detected at lower energies.

$$E_\gamma = 12\ \text{GeV}\left(\frac{E_e}{2\text{TeV}}\right)^2$$

Cascade component

- Fraction of electron energy in secondary photons in direction of observer

$$\alpha = \frac{\sum E_\gamma}{E_e}$$

- Fraction of voids on the way of primary photon

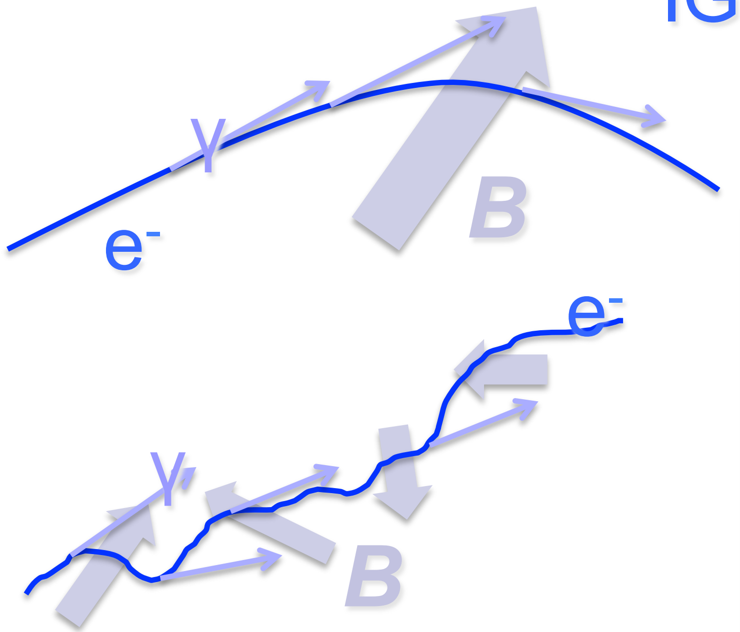
$$D_{void} = \Delta D_{\gamma_0}$$

- Ratio of point source flux at E_γ and $E_{\gamma 0}$

$$R = F(E_{\gamma_0}) / F(E_\gamma)$$

$$F_{ext} = \alpha \cdot R \cdot \Delta \cdot e^{-\tau(E_\gamma, z)} \left\langle F_{PS}(E_\gamma) \right\rangle$$

Dependence of the measurement on the IGMF correlation length



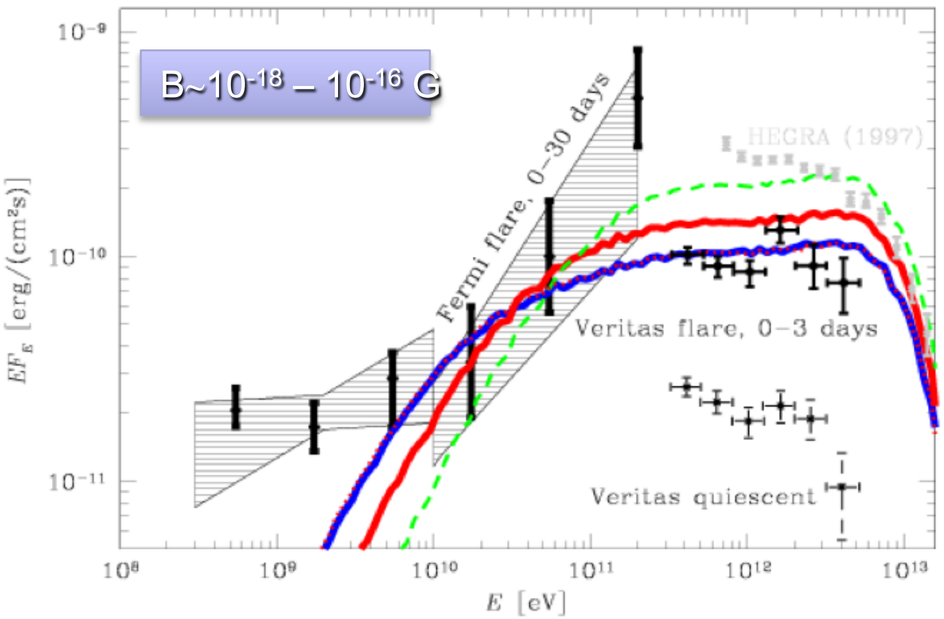
If the correlation length of EGMF is large, deflection angle is

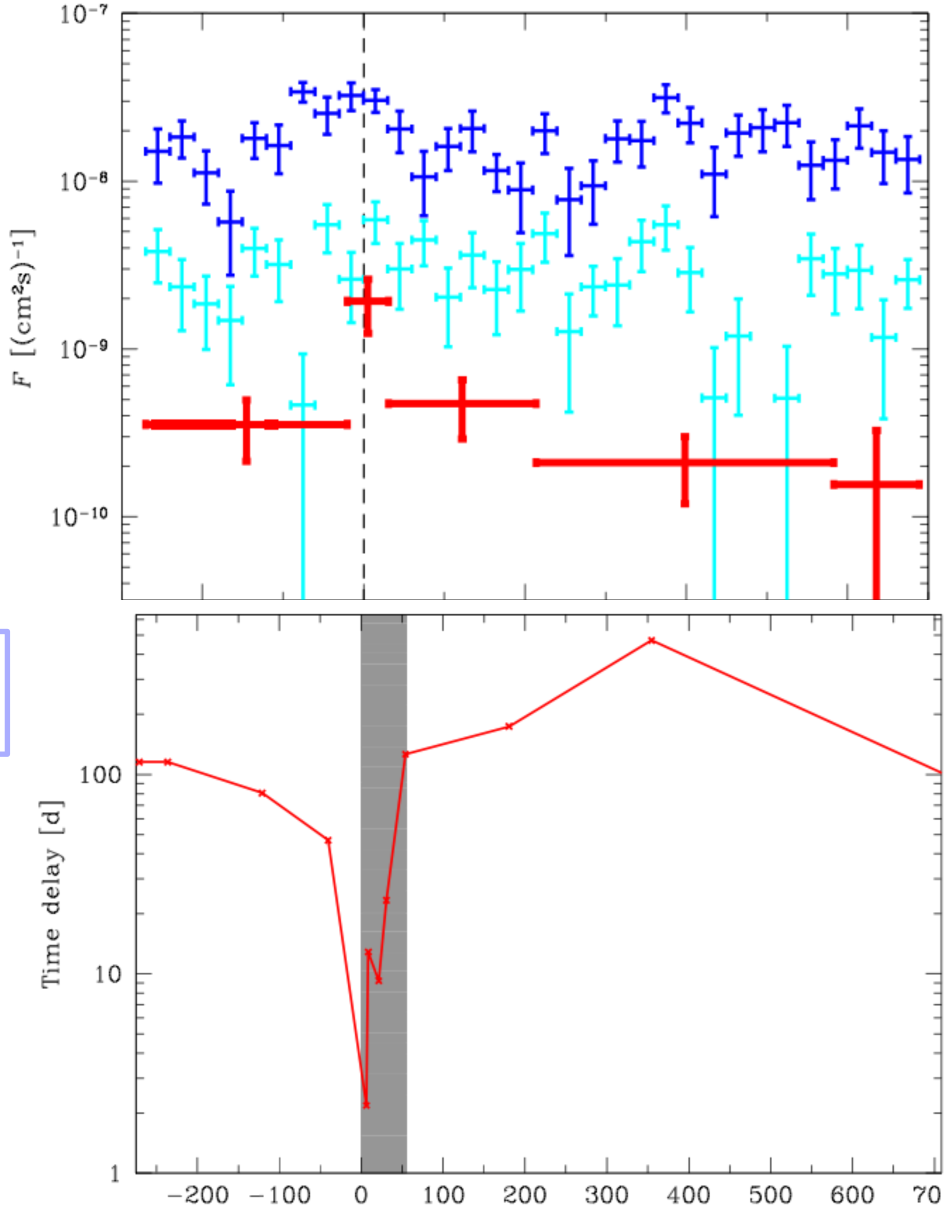
$$\delta = \frac{D_e}{R_L} = 2^O \left[\frac{B}{10^{-16}\mathrm{G}}\right]\left[\frac{E_e}{1\ \mathrm{TeV}}\right]^{-2}$$

If the correlation length of EGMF is small, (λ_B<<D_e) deflection angle is

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

Search for the time-delayed cascade emission





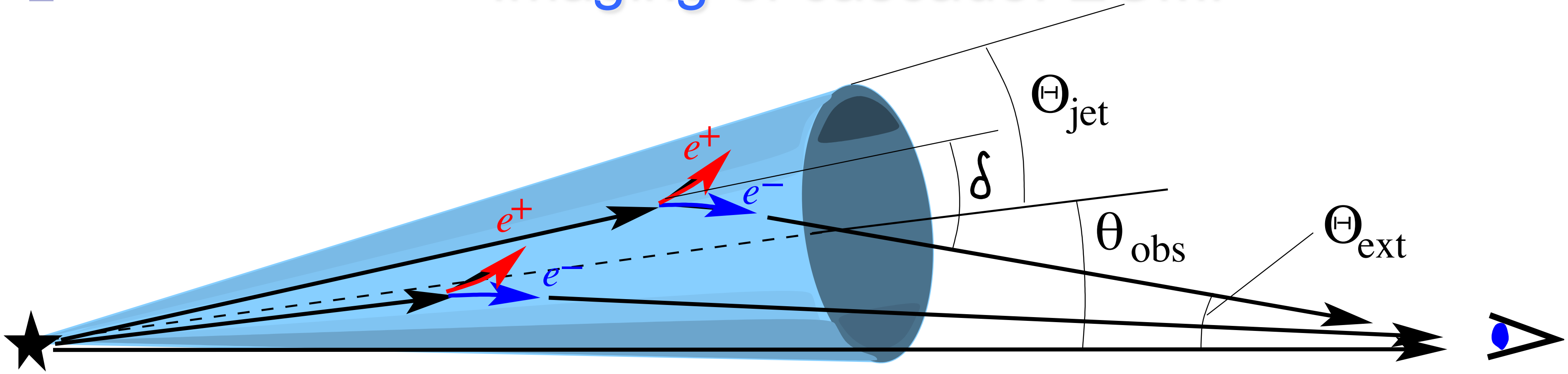
Neronov, DS, Taylor '12

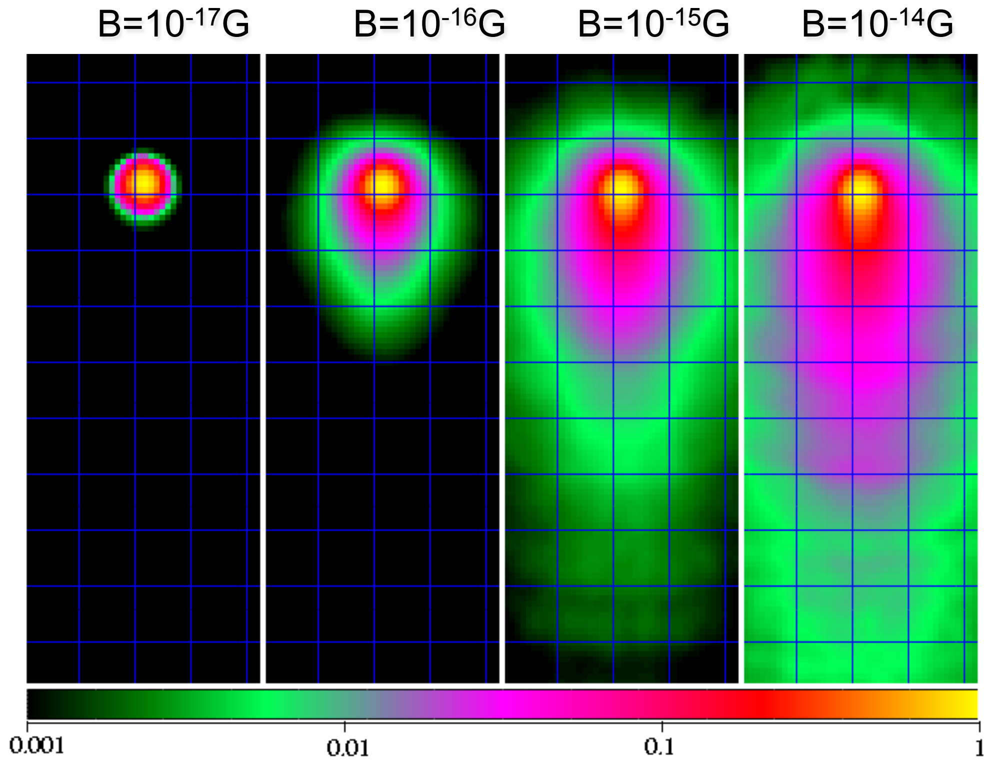
The flare occurred during the multiwavelength campaing, including HE and VHE observations.

Fermi data indicate that the flare lasted 30-50 days, but the VHE observations cover only the first three days of the flare.

Fermi data indicate a peculiar hardening of the spectrum above ~10 GeV during the flare. One possibility for the explanation of the hard component is the cascade emission suppressed at low energies by too-large time delay.

Imaging of cascade: EGMF

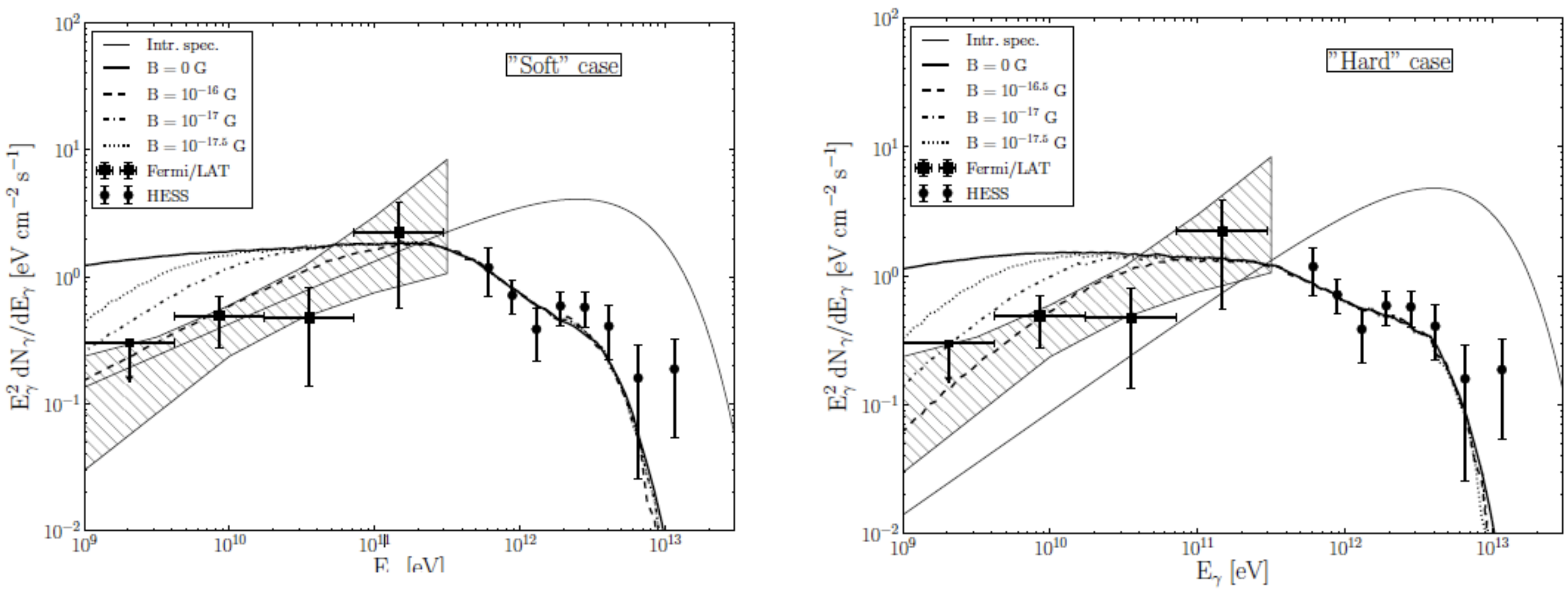




Imaging: cascade component forms an extended emission around initially point source.

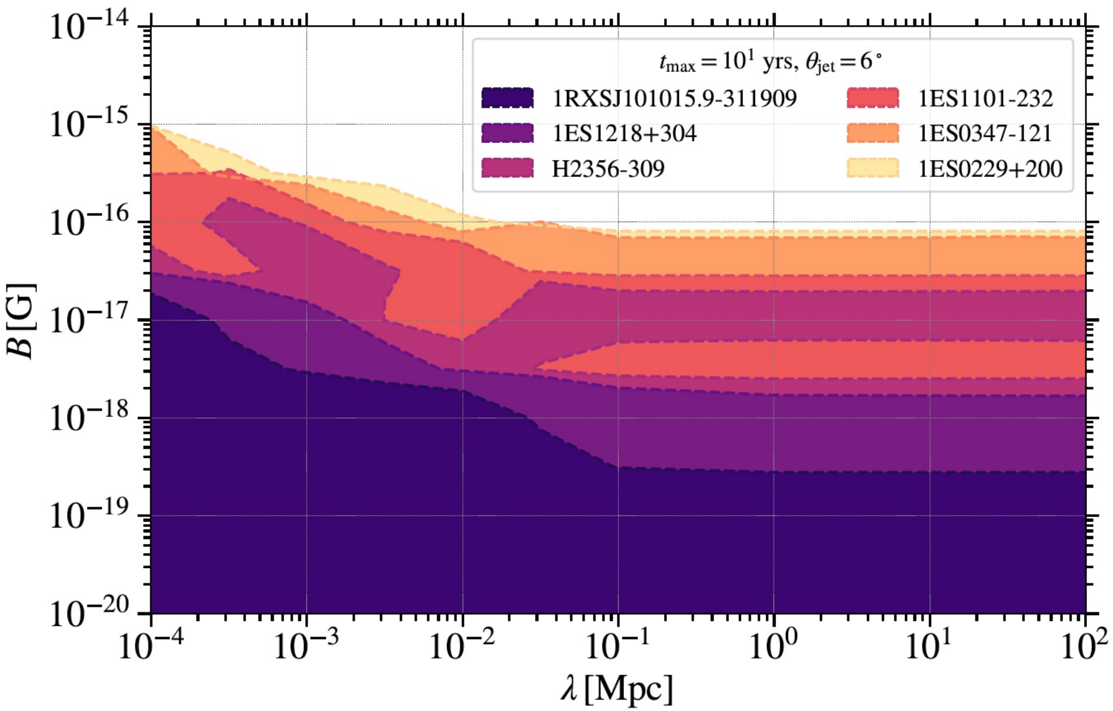
- detectability depends on the telesope PSF and on the scale of angular deflections of e+e- pairs **(i.e. on the strength of EGMF)**

EGMF from spectrum of 1ES 0229+200



From Vovk, Taylor, Neronov, and DS 1112.2534

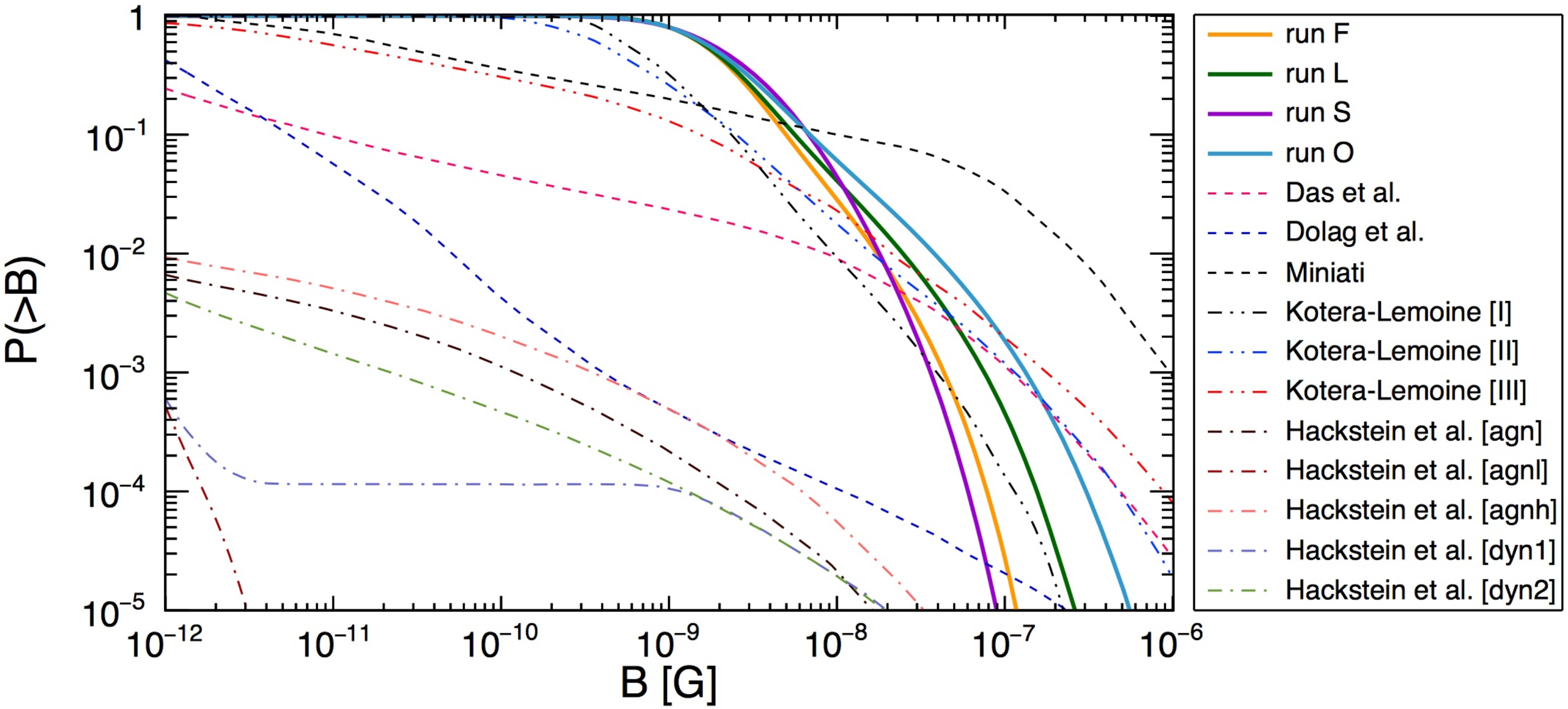
Constraints on IGMF



J.Biteau et al, Fermi-LAT ApJS 237 (Aug, 2018) 32, [1804.08035].

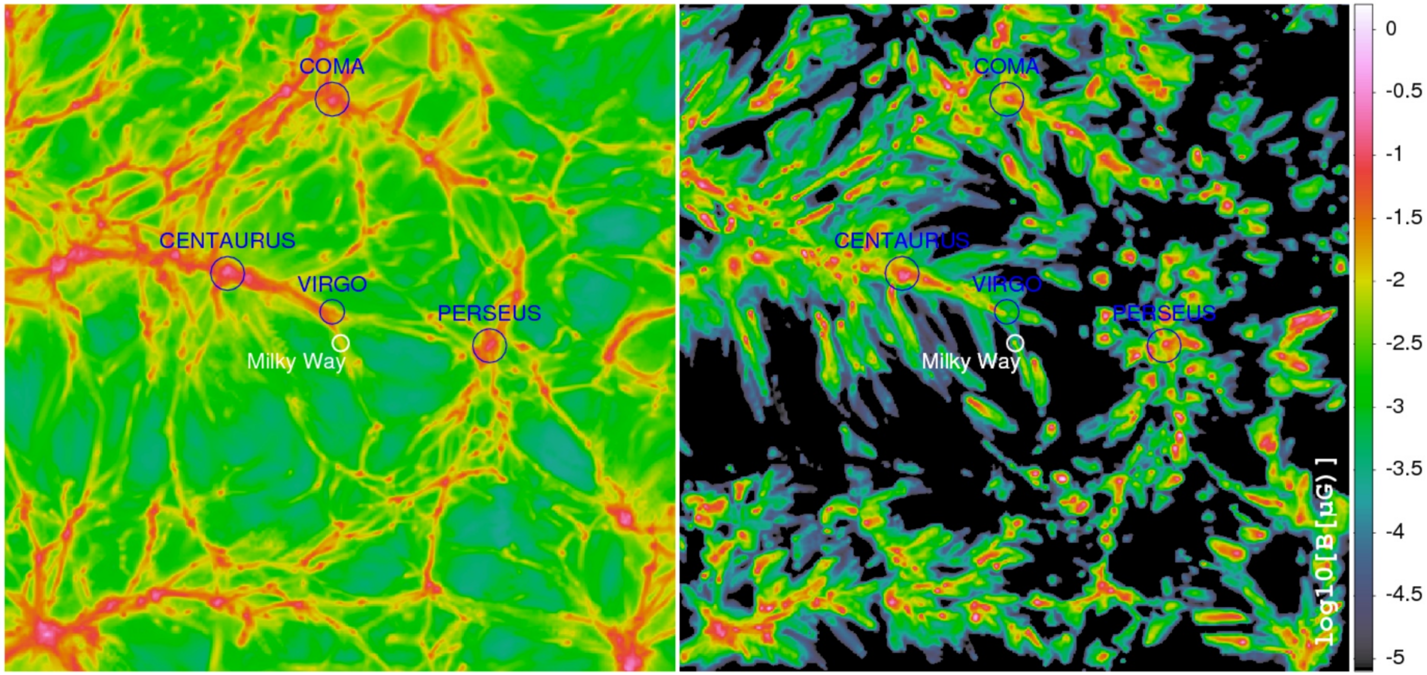
Inter-Galactic Magnetic Field detection with UHECR

IGMF evolution and LSS



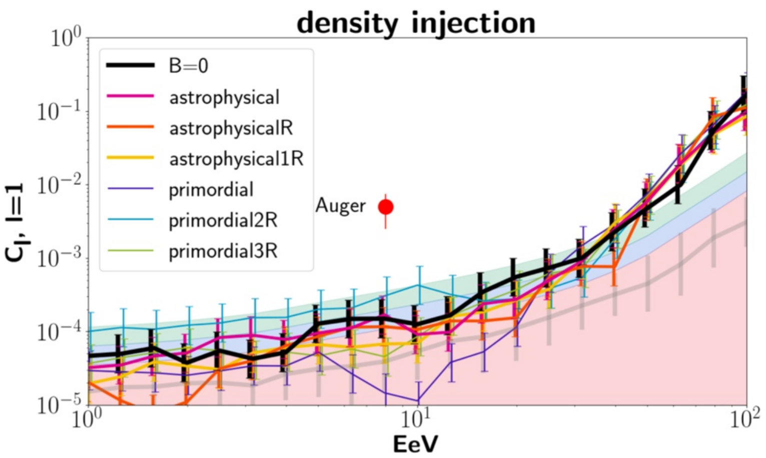
R.Batista et al, **Phys.Rev. D96 (2017) 023010** , [1704.05869].

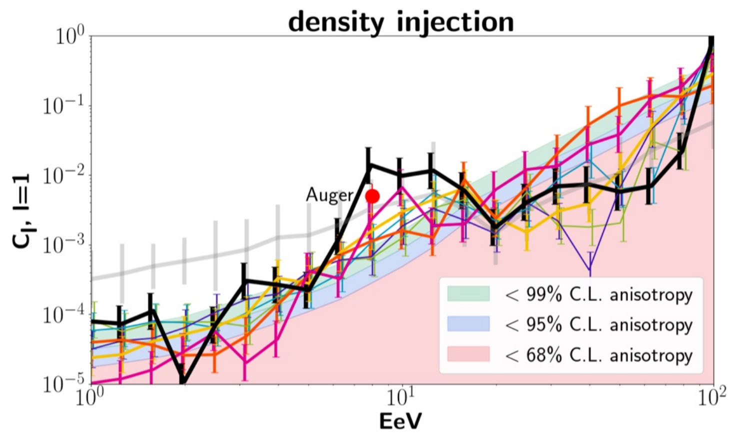
IGMF evolution and LSS



S. Hackstein et al, **MNRAS 475, 2519 (2018)**, [1710.01353].

Auger dipole from IGMF





protons

iron

S. Hackstein et al, **MNRAS 475, 2519 (2018)** [1710.01353].

Summary

- *CTA would provide EBL with high precision measurements, this opens several possibilities to study local features, including contribution of first stars, DM decay, etc*
- *H0 can be independently measured with gamma-rays*
- *Inter-Galactic Magnetic Fields in the voids of LSS can be found from high precision blazar spectra/time delay/ extended emission measurements by CTA*
- *IGMF can be measured by UHECR detection from sources, need in mass measurements for individual events + improved model for Galactic Magnetic Field*

French perspectives for intergalactic magnetic fields

- *CTA: halos/spectral features/time delays in flairs*
- *LISA: stochastic GW*
- *Auger: anisotropy/composition*
- *Theory: modeling of IGMF production in Early Universe, evolution both in Early Universe and with LSS modeling and interpretation halos/spectral features/time delays in flairs in experimental data for directions to individual sources.*