# Evidence for strong Extragalactic Magnetic Fields from Fermi observations of TeV blazars

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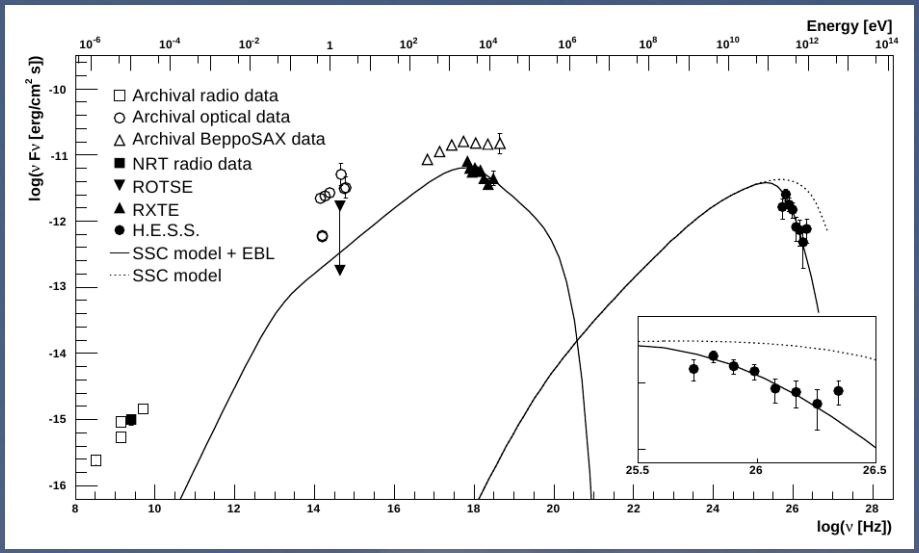
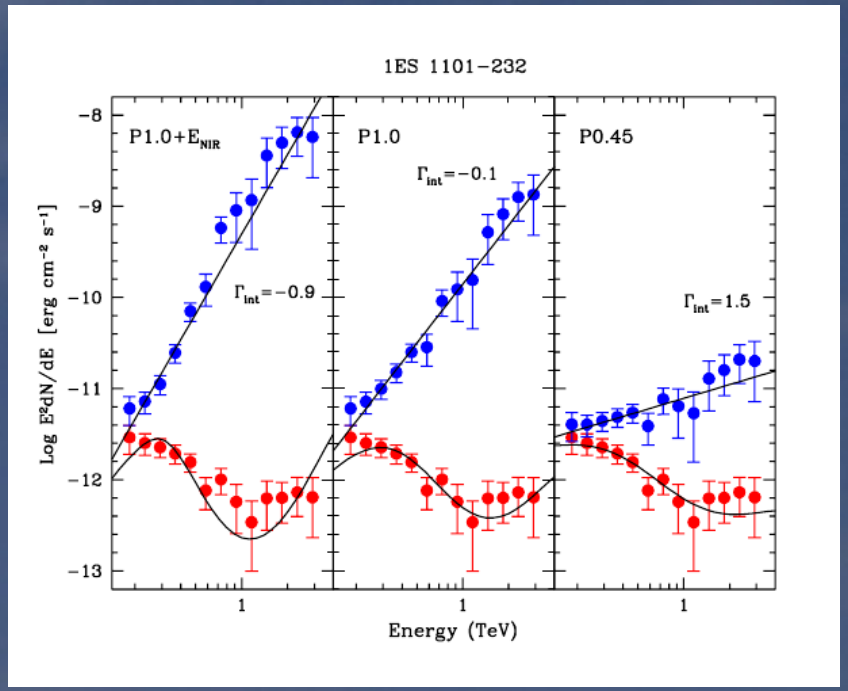
# TeV emission from blazars

TeV emission from distant blazars is absorbed on the Extragalactic Background Light (EBL)




SED of H 2356−309. Aharonian et.al., A&A 455, 461-466 (2006)




Aharonian et.al. Nature 440:1018-1021, 2006

In the recent years TeV observations of blazars started to be used for putting constrains on EBL

# Secondary ɣ-ray emission from electromagnetic cascade

**Blazar**

TeV
ɣ rays

Electron-positron pairs

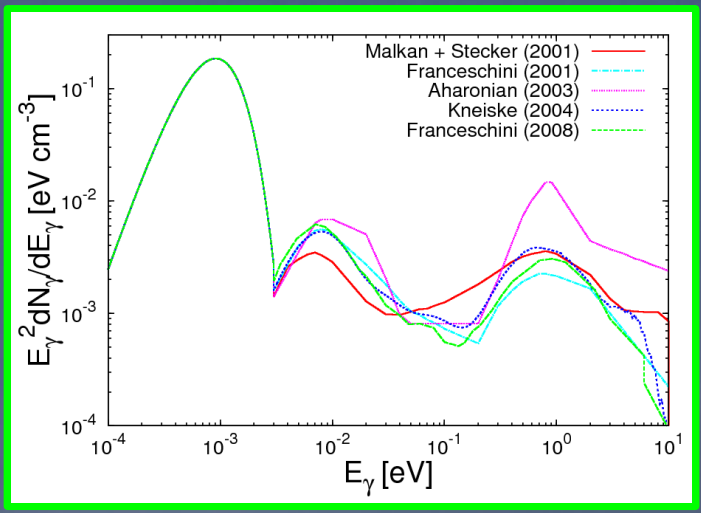
$E_e \approx E_{\gamma 0} / 2$

**EBL**

**CMB**

Secondary GeV ɣ rays

$E_\gamma = (4/3)\, \varepsilon_{CMB}\, (E_e / m_e c^2)^2 \approx$
$\approx 88\, [E_{\gamma 0} / 10\ \mathrm{TeV}]^2\ \mathrm{GeV}$

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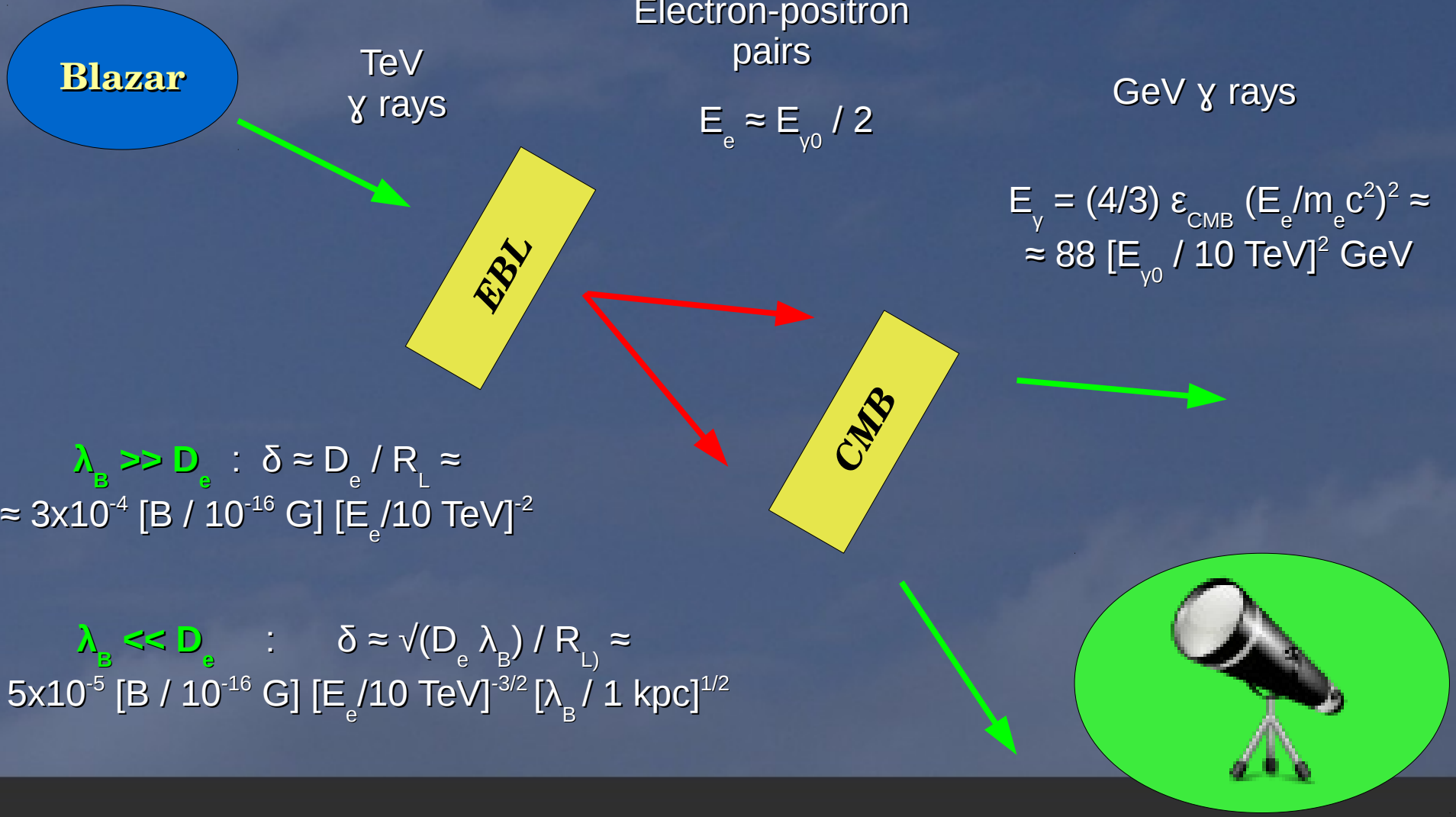
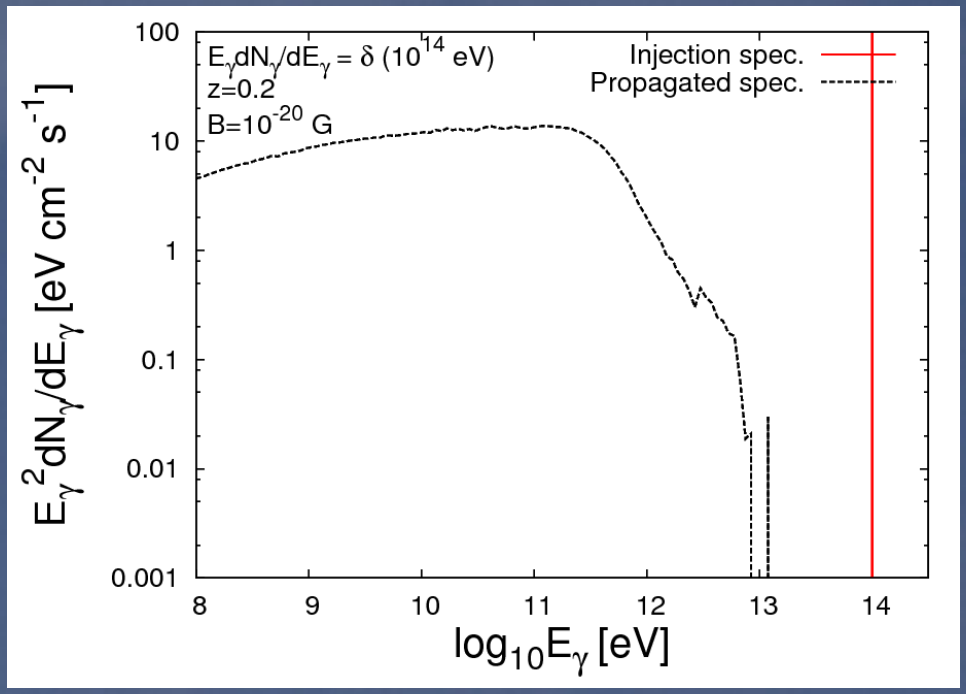
***Evidence for strong EMF from Fermi observations of TeV blazars***

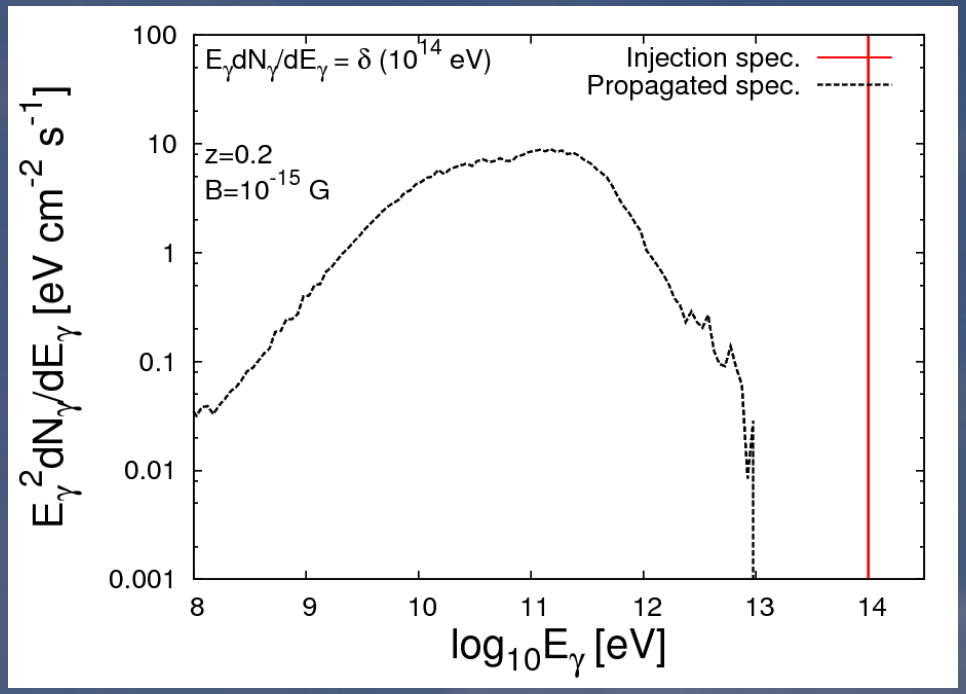
TeVPA 2010, Paris, 21.07.2010

# Secondary ɣ-ray emission from electromagnetic cascade



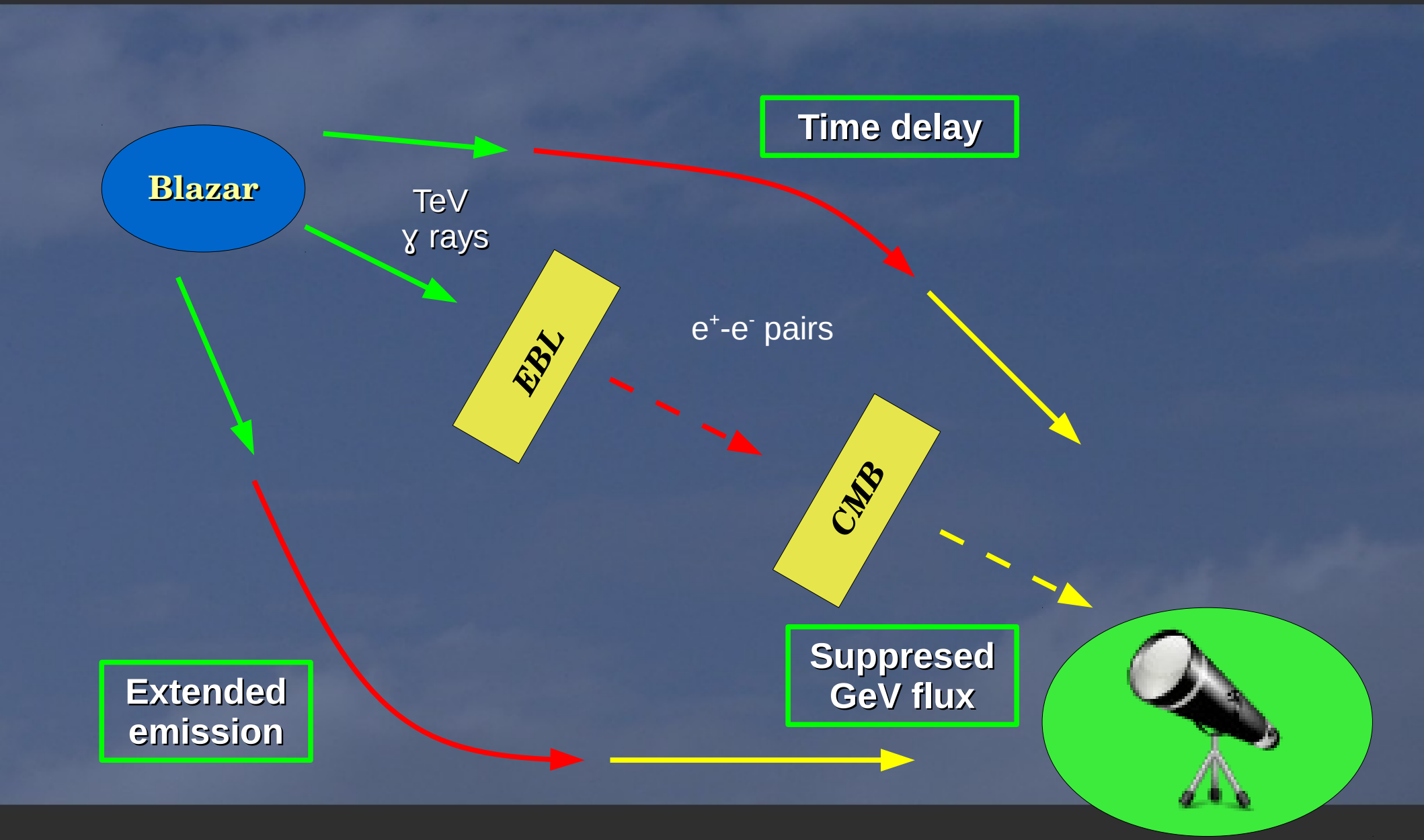
# Spectral appearance of electromagnetic cascade




Courtesy of Andrew Taylor

# Secondary ɣ-ray emission from electromagnetic cascade

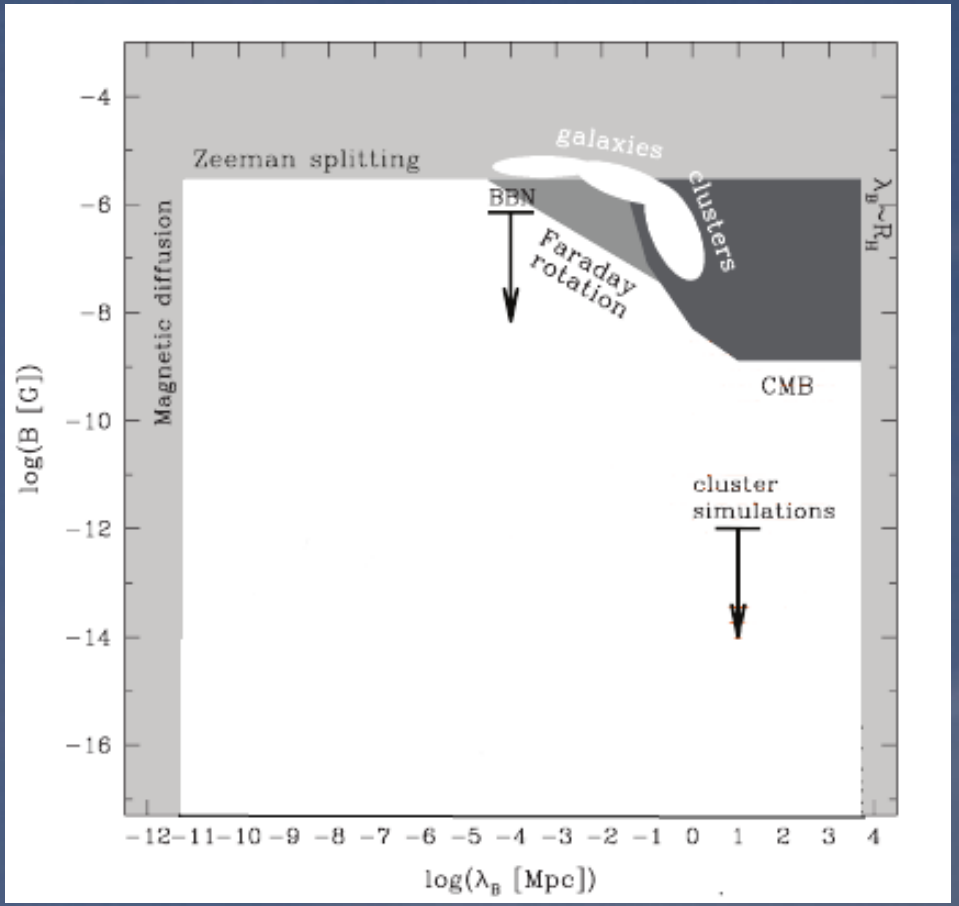


# Extragalactic magnetic field (EMF)

Two different broad classes of models of EMF could be identified:

"Astrophysical" models: EMF were formed at the epoch of galaxy formation. Resulting EMF should be strong near galaxies, but very weak in the space far away from galaxies

"Cosmological" models: EMF were formed prior to formation of galaxies. Resulting field should fill the whole Universe



# Looking for the suppression of GeV flux

Fermi/LAT satellite observes in GeV band.
Public data are available since August 2008.

Lower energy electrons are deviated by larger angles.
➡ The size of extended cascade source is larger at lower energies.

Fermi/LAT point spread function (PSF):
$\Theta \approx 2^{\circ}[E_{\gamma} / 1\ \mathrm{GeV}]^{-0.8}$ (95% of signal)

If PSF at 10 GeV taken as a reference, halo is bigger PSF if $B>B_{PSF}$:

$$B_{PSF} \approx 6 \times 10^{-17}\, \tau\, [E_{\gamma,min} / 10\ \mathrm{GeV}]\ \mathrm{G},\ \lambda_B > D_e$$

$$B_{PSF} \approx 8 \times 10^{-16}\, \tau\, [E_{\gamma,min} / 10\ \mathrm{GeV}]^{3/4}\, [\lambda_B / 1\ \mathrm{kpc}]^{-1/2}\ \mathrm{G},\ \lambda_B < D_e$$

In this case we start to loose the flux from point-like blazar.
➡ A way to look for EMF.

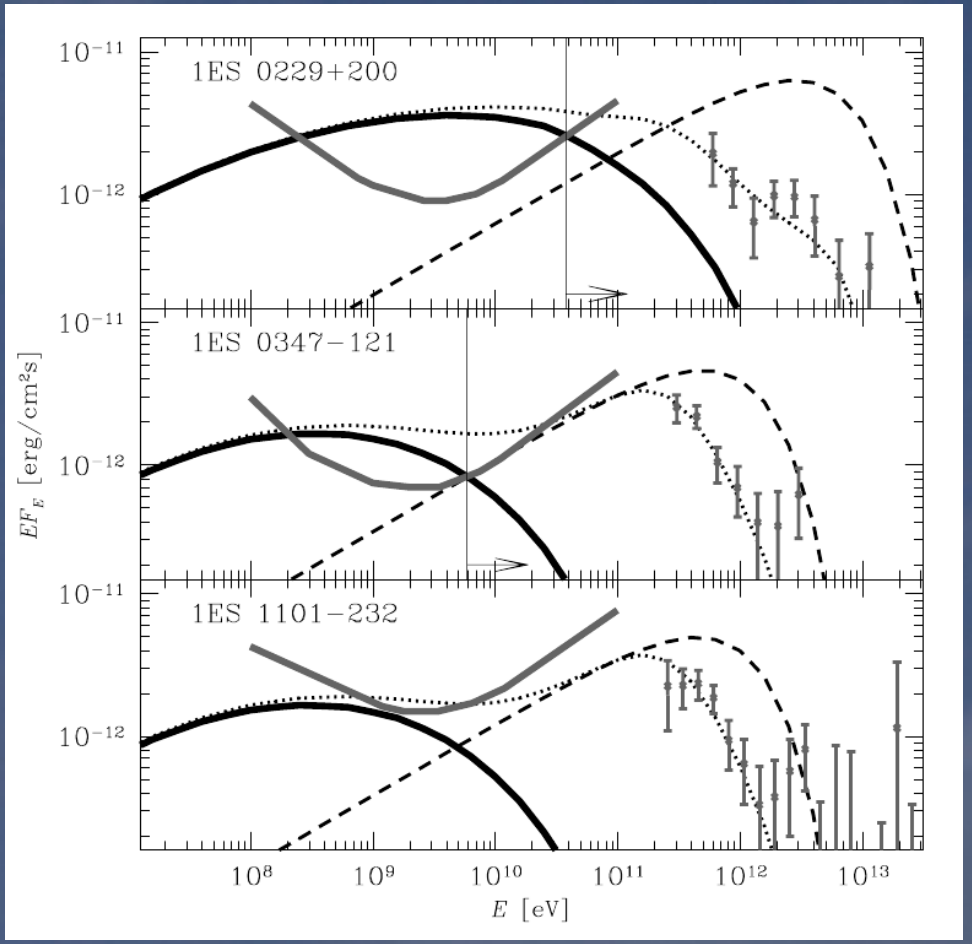
# Observed suppression of GeV flux

4 TeV blazars were selected for the analysis based on their high redshifts and hard TeV band spectra:

1ES 0229+200 (z = 0.14),
H 2356-309 (z = 0.165),
1ES 1101-232 (z = 0.186),
1ES 0347-121 (z = 0.188).

None of them was detected with Fermi/LAT.

Upper limits of their flux in GeV band put constrains on the possible cascade contribution and, thus, on the parameters of EMF.




A. Neronov and Ie. Vovk, Science 328, 73 (2010)

# Derived constrains on EMF

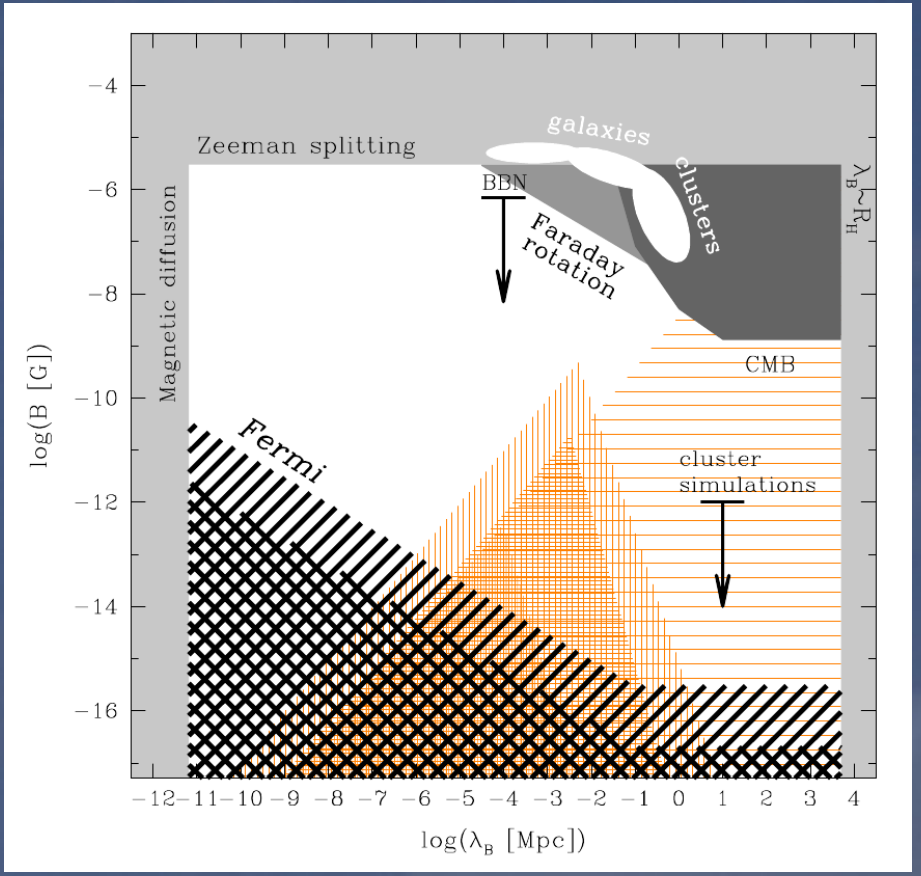
The black hatched region shows the lower bound on the EGMF derived in this work.

Orange hatched regions show the allowed ranges of B, $\lambda_B$ for magnetic fields generated at the epoch of:

Inflation (horizontal hatching)

the electroweak phase transition (dense vertical hatching),
QCD phase transition (medium vertical hatching),

epoch of recombination (rear vertical hatching)




A. Neronov and Ie. Vovk, Science 328, 73 (2010)

# Summary

Observed absence of predicted cascade emission provides
**the first evidence for the existence of strong magnetic field in the voids of the Large-Scale Structure.**

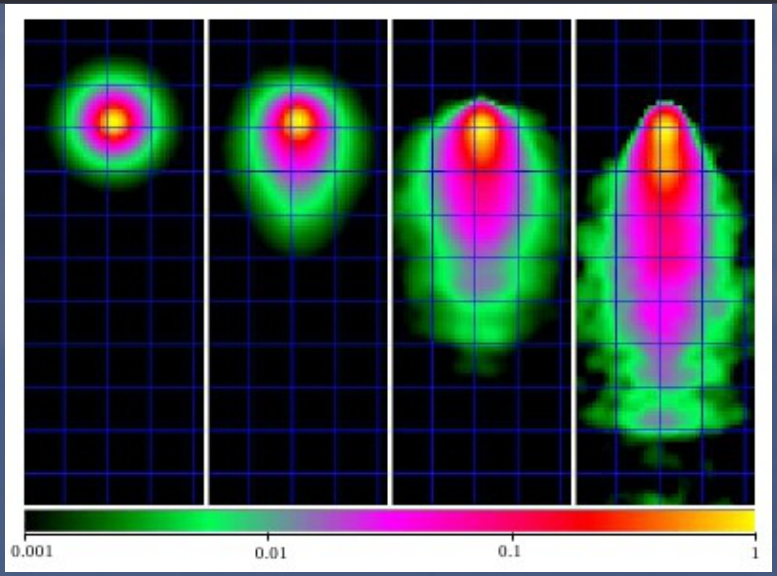
The reported here lower bound is
(for correlation lengths above ~ 1 MPc)
**$B \sim 3 \times 10^{-16}$ G**

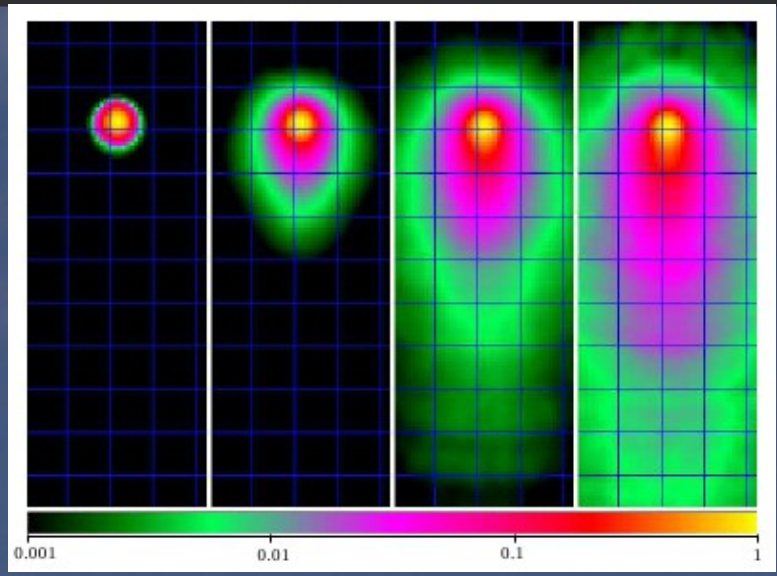
Evidence for the existence of magnetic fields in voids provides a strong argument in favor of cosmological origin of “seed” magnetic field.

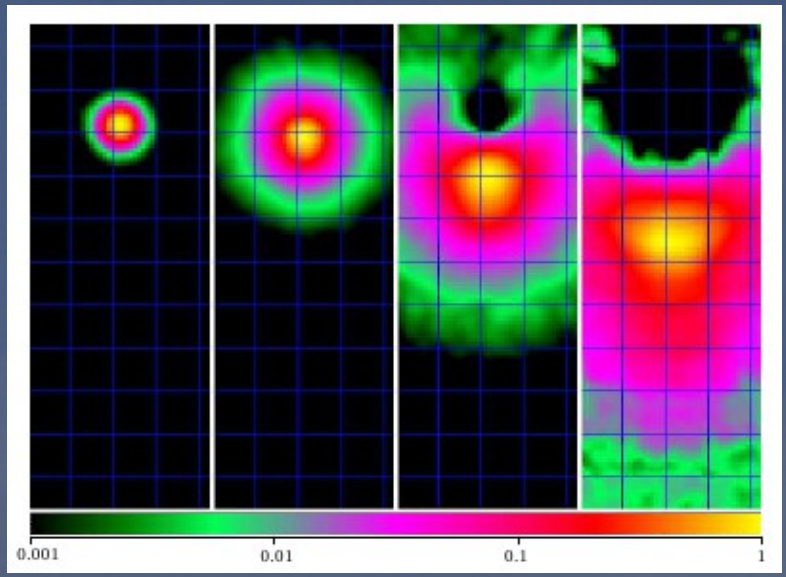
The lower bound reported here excludes substantial parts of allowed parameter space for all the classes of cosmological magnetogenesis models.

Thank you for your attention!

# Appearance of extended emission

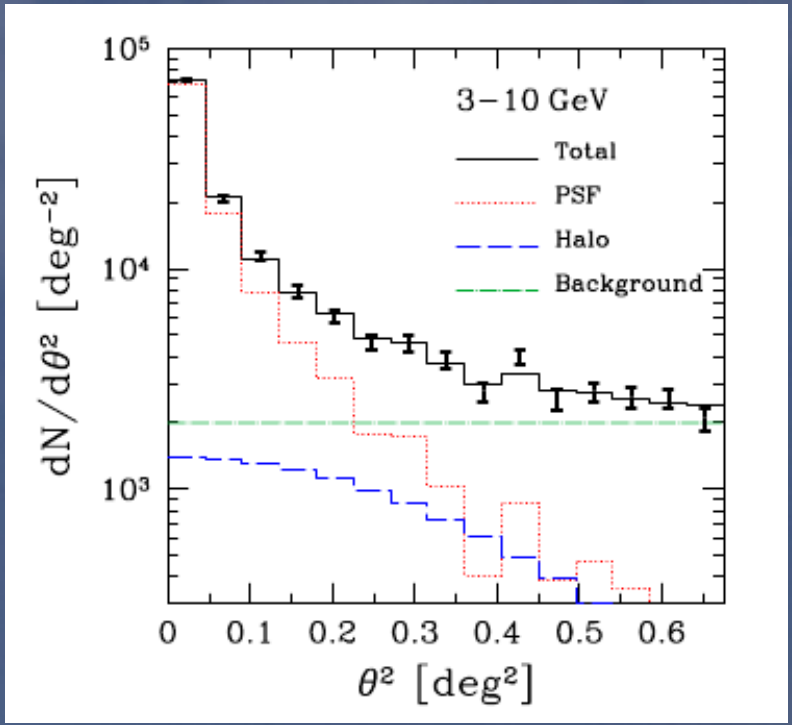


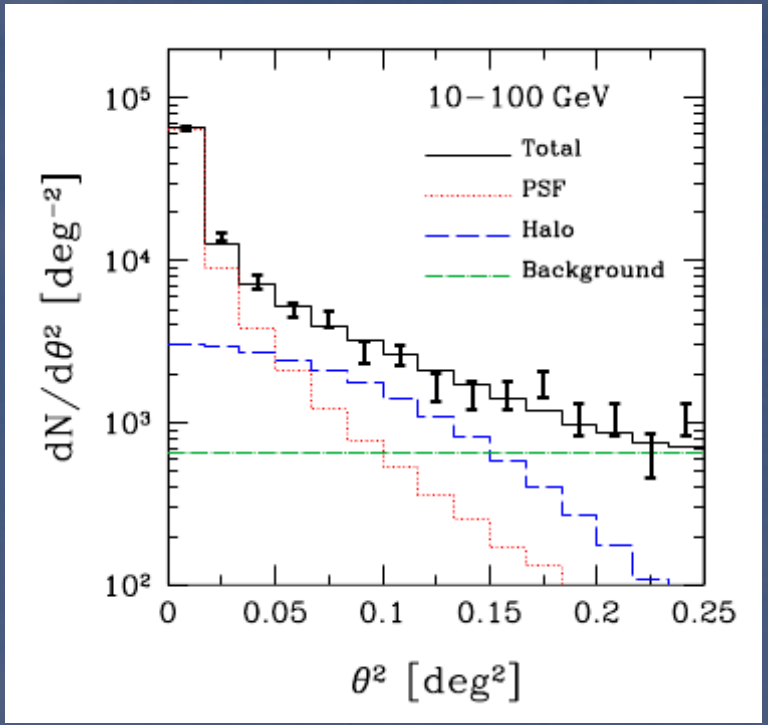




Neronov et. al.,
arXiv:1002.4981v1

# Discovery of gamma-ray halos around AGNs



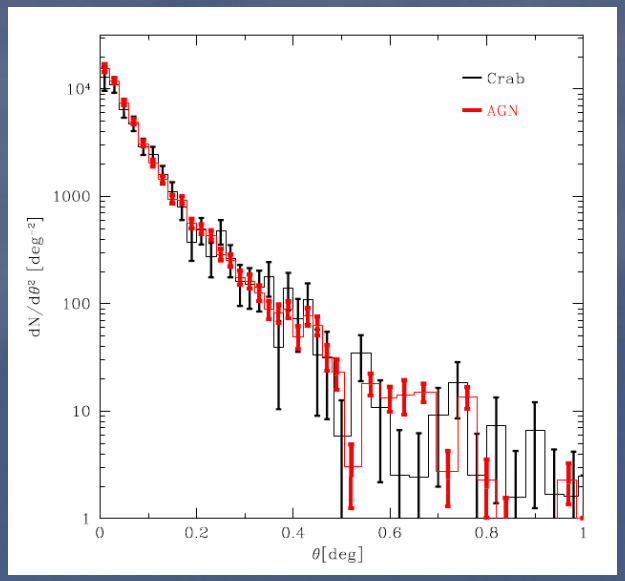



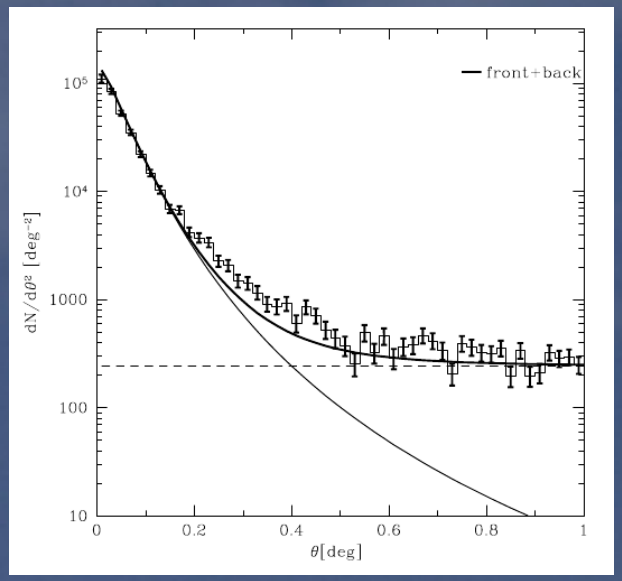

Sh. Ando, A. Kusenko, arXiv:1005.1924

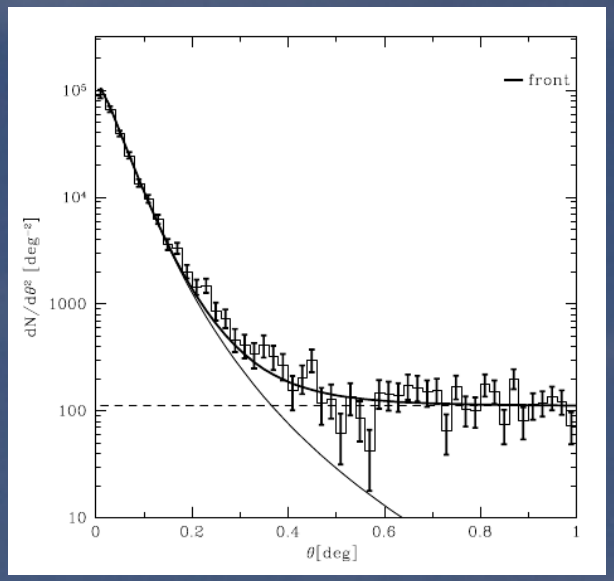
There are halos, thus there should be magnetic field...

**Is anything missing?**

# Discovery of gamma-ray halos around AGNs ?




Neronov et.al., arXiv:1006.0164

**There are no halos observed.**
**Difference between approximation and real PSF found.**