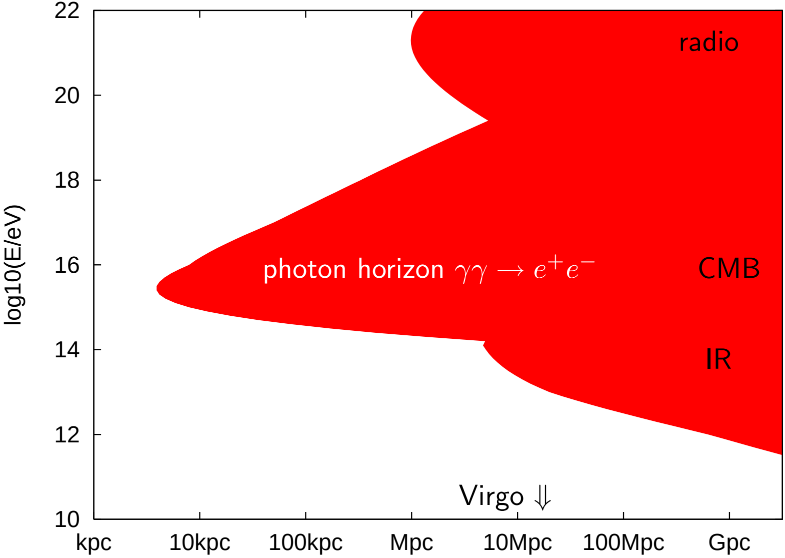
Mean free path of photons



Origin of cascade photons:

- UHECRs:
  - Photon and neutrino production relatively tight connected:
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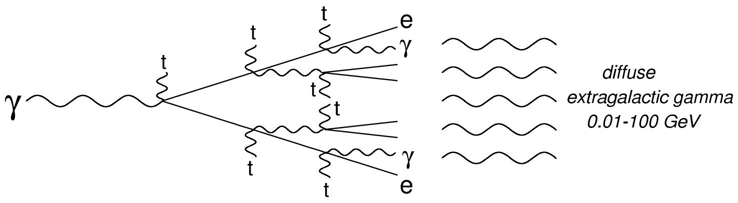

Diffuse cascade flux:

- analytical estimate: [Berezinsky, Smirnov '75]

$$
J_\gamma(E) = \begin{cases} K(E/\varepsilon_{\rm X})^{-3/2} & \text{at} \quad E \leq \varepsilon_{\rm X} \\ K(E/\varepsilon_{\rm X})^{-2} & \text{at} \quad \varepsilon_{\rm X} \leq E \leq \varepsilon_{\rm a} \\ 0 & \text{at} \quad E > \varepsilon_{\rm a} \end{cases}
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- three regimes:
  - Thomson cooling:

$$E_\gamma = \frac{4}{3}\frac{\varepsilon_{\rm bb} E_e^2}{m_e^2} \approx 100\,{\rm MeV}\left(\frac{E_e}{1{\rm TeV}}\right)^2$$

  - plateau region
  - above pair-creation treshold $s_{\rm min} = 4E_\gamma \varepsilon_{\rm bb} = 4m_e^2$: flux exponentially suppressed

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inserting in energy conservation,

$$E_\gamma dn_\gamma = q_e(E_e) dE_e \,,$$

gives

$$J(E_\gamma) \propto E_\gamma^{-3/2}$$

Diffuse flux, analytical estimate for plateau region:

- energy conservation and $N_e/N_\gamma = \text{const.}$

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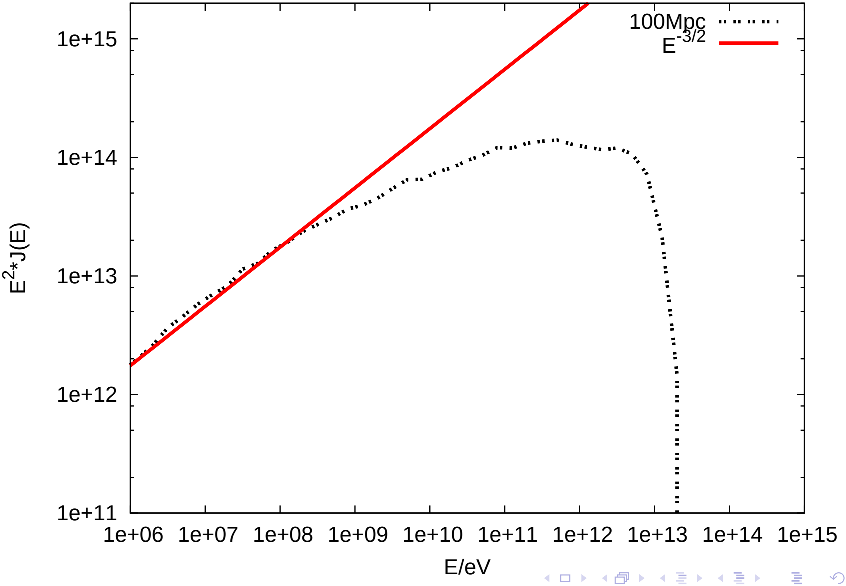
Monte Carlo vs. analytical estimate: single source



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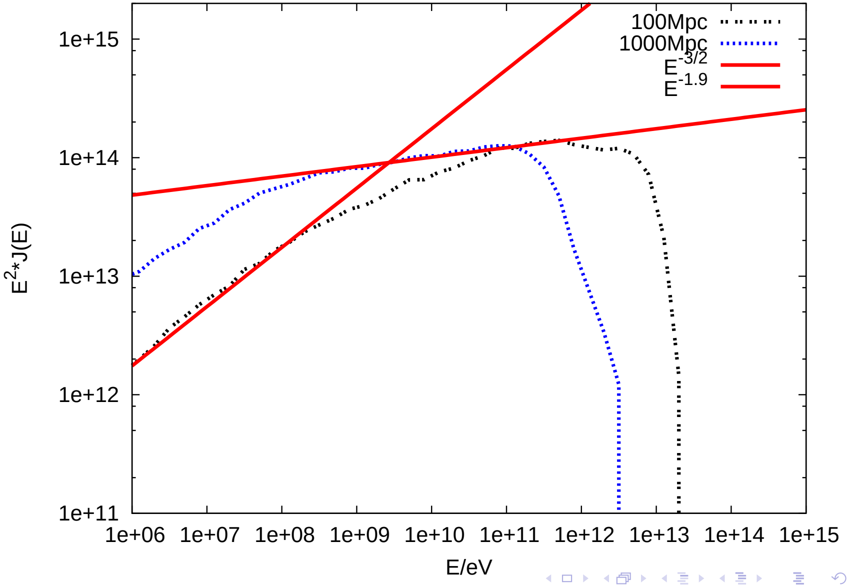
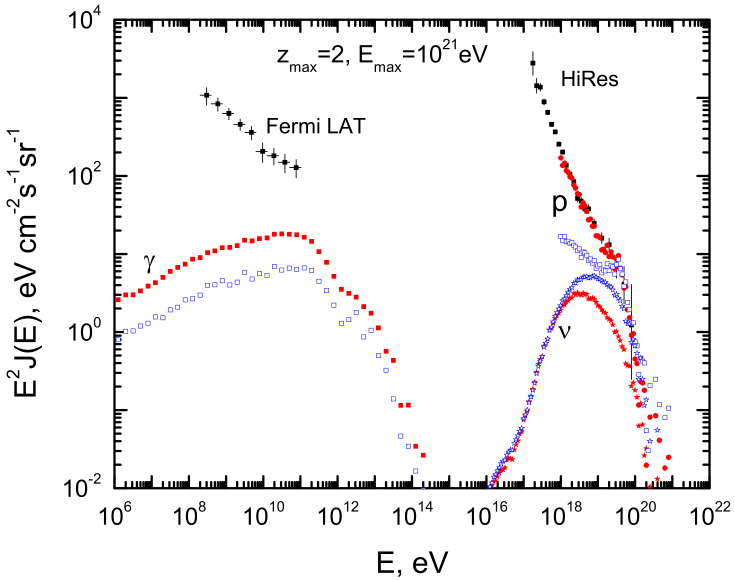


Fermi-LAT vs. UHECR data: no evolution

[*Berezinsky et al. '10*]



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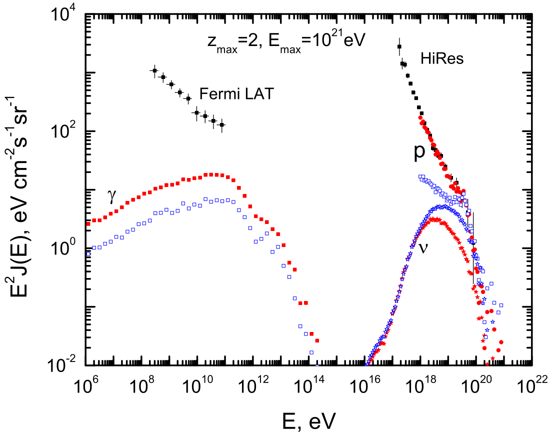
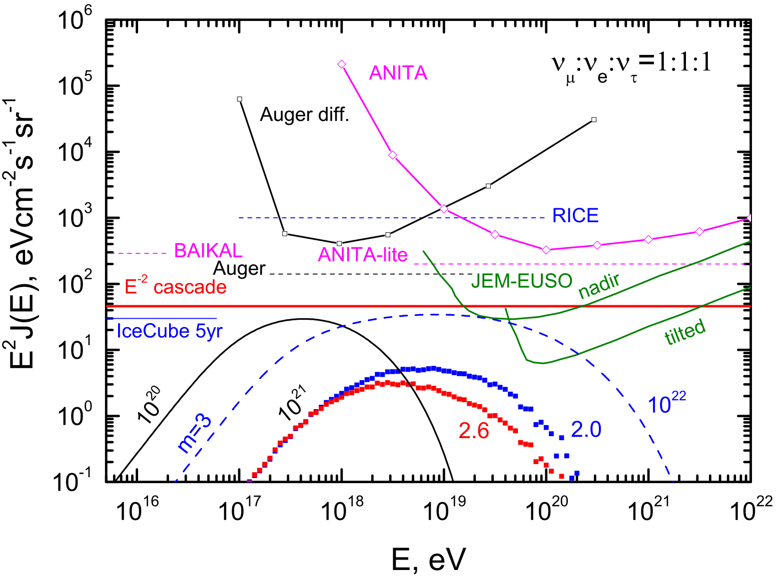


integrating $EJ(E)$ gives bound $\omega_{\rm cas} \lesssim 6 \cdot 10^{-7}\,{\rm eV/cm^3}$

Cascade limit for cosmogenic neutrinos

[Berezinsky et al. '10]



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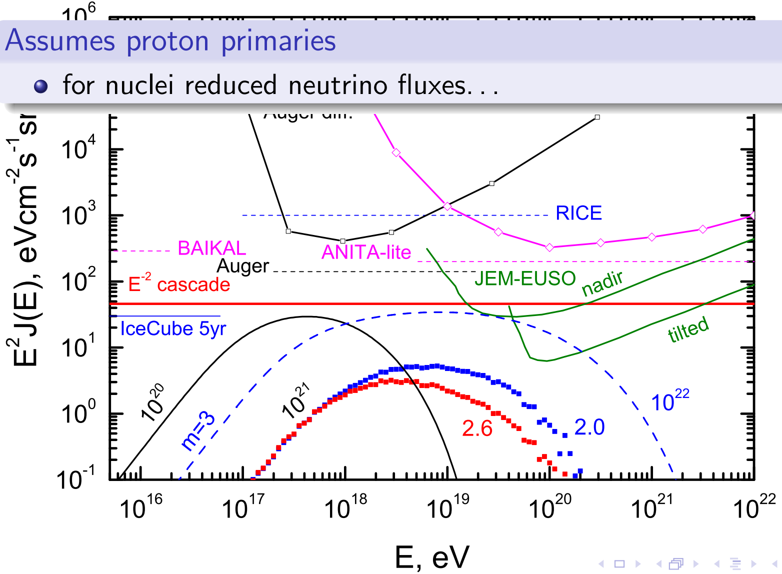

Assumes proton primaries

- for nuclei reduced neutrino fluxes. . .

Gamma-rays and extragalactic magnetic fields (EGMF)

- Observations only in clusters,
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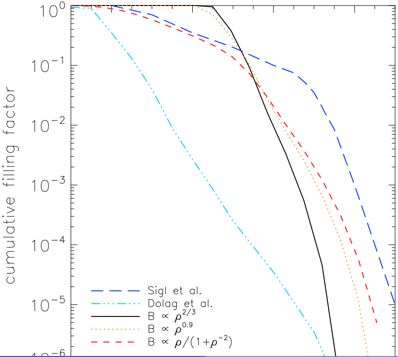

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- Plaga '95: EGMFs deflect and delay cascade electrons

  $\Rightarrow$ search for delayed "echoes" of multi-TeV AGN flares/GRBs

Influence of EGMF on flux from single source: deflections

- deflection of electrons:

$$\vartheta \sim \frac{l_{\rm cool}}{R_L} \propto E_e^{-2}$$

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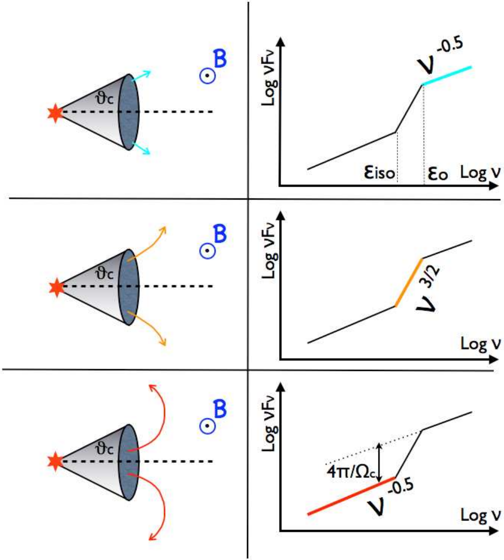

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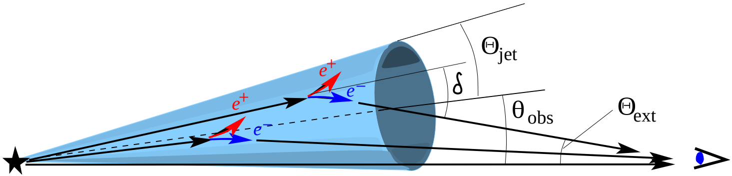

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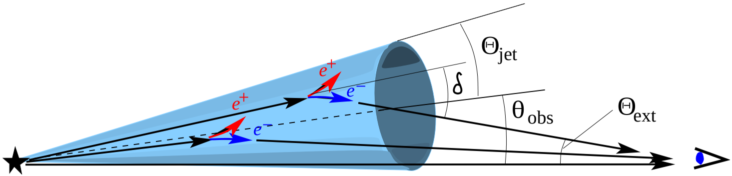

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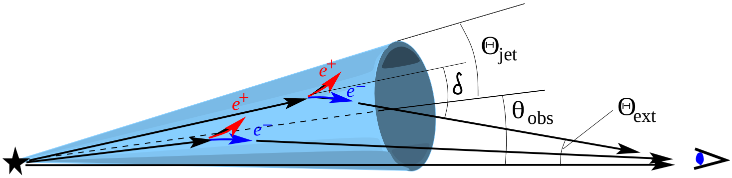

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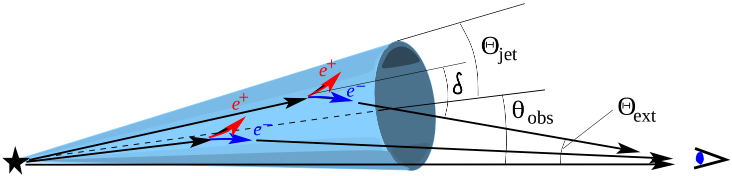
Observer misaligned with jet:

[*Neronov et al. '10*]



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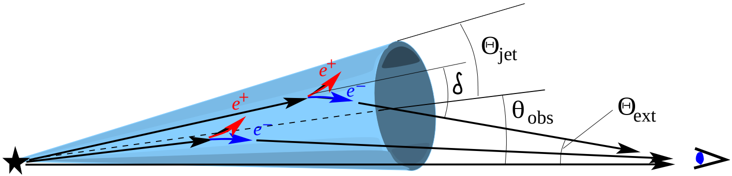

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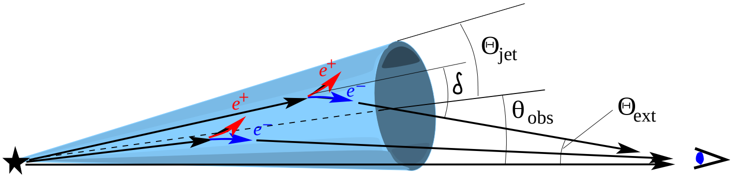

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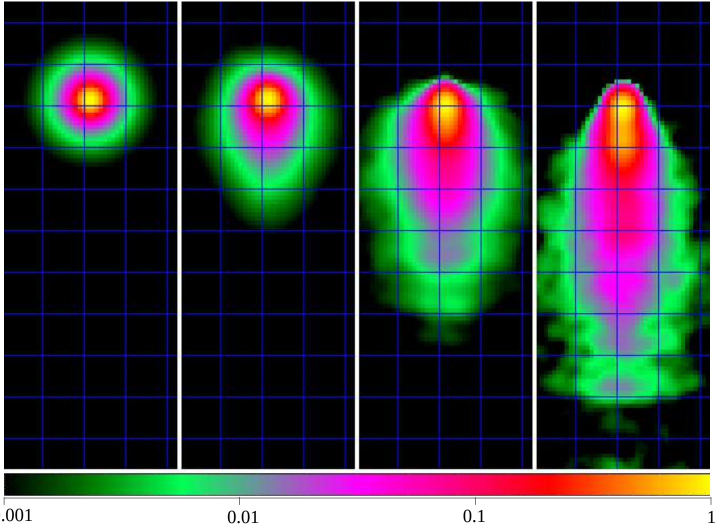
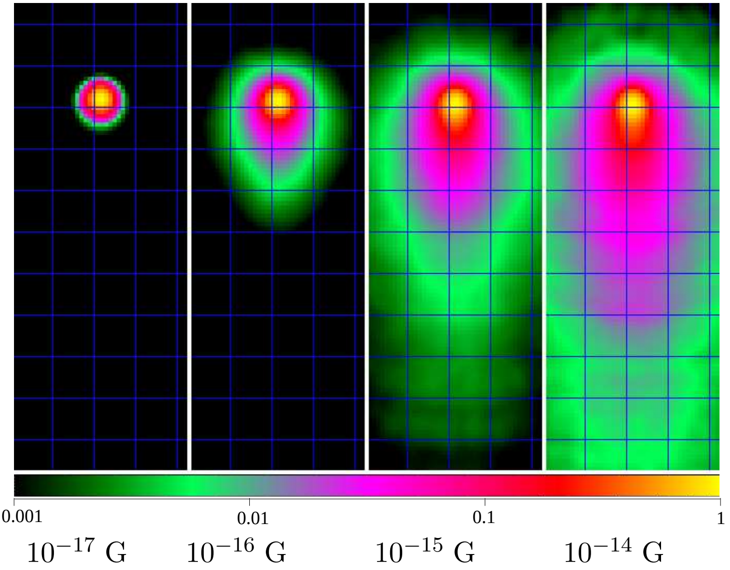
Asymmetric halos around TeV blazars ("GeV jets"):

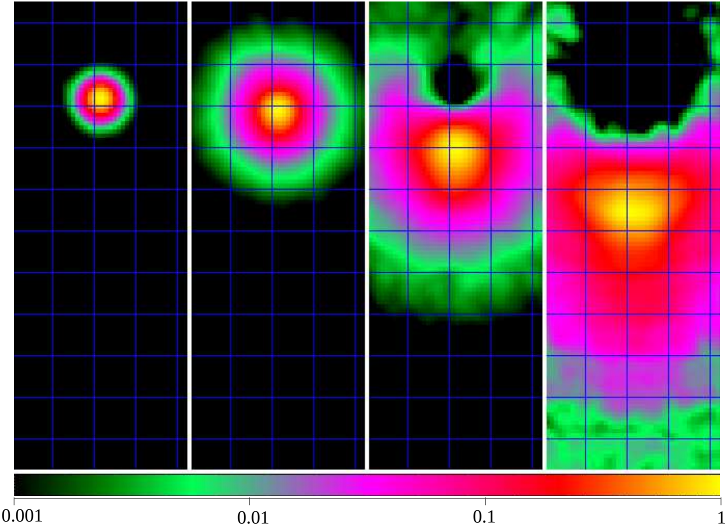


$\vartheta_{\rm obs} = 0^\circ$ $\vartheta_{\rm obs} = 3^\circ$ $\vartheta_{\rm obs} = 6^\circ$ $\vartheta_{\rm obs} = 9^\circ$

“GeV jets”: B dependence



“GeV jets”: time dependence of flares

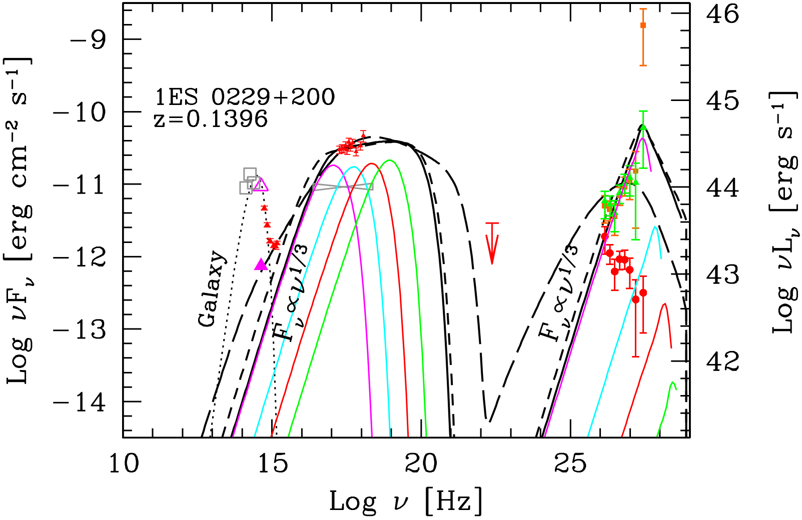


$0 < T_{\rm delay} < 10^5$ yr $\quad$ 3×10^6 yr$< T_{\rm delay} < 10^7$ yr

Lower limit on EGMF:

[A. Neronov, I. Vovk '10, F. Tavecchio et al. '10]

- choose blazar: large z, stationary, low GeV, high multi-TeV emission



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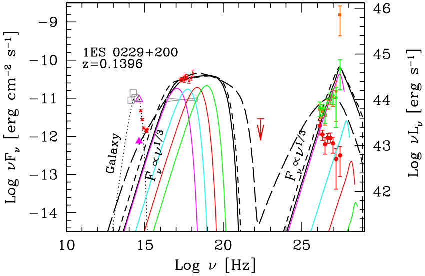

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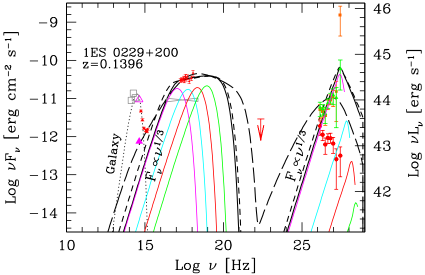

- TeV photons cascade down:
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- open questions:
  - influence of EGMF structure?
  - time-dependence for flaring sources?

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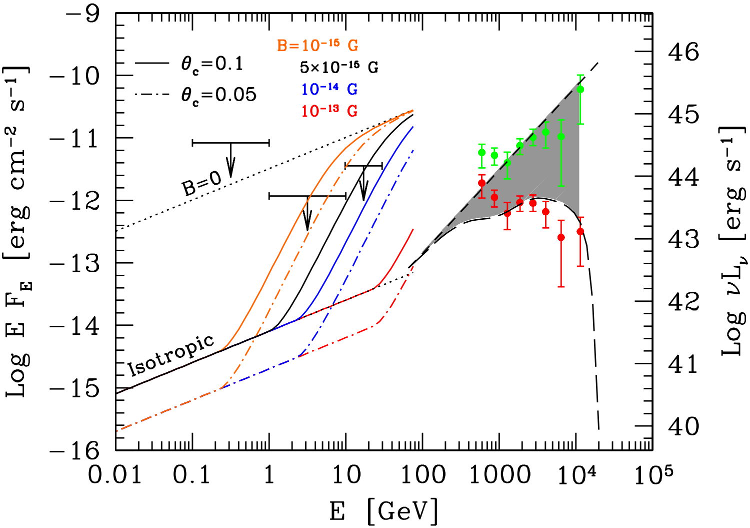

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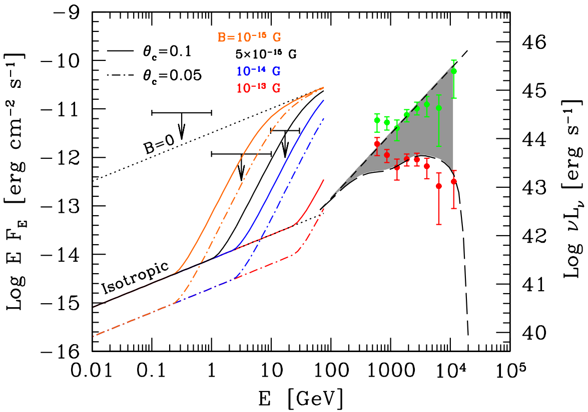

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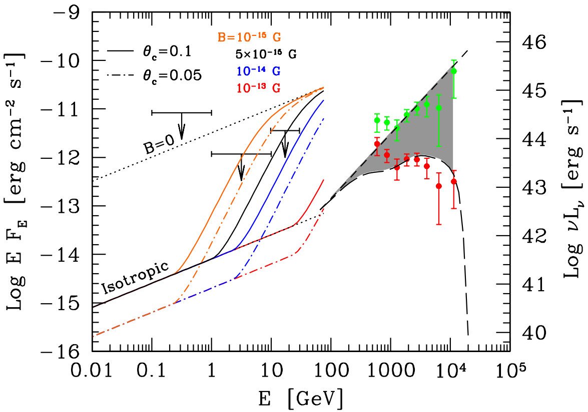

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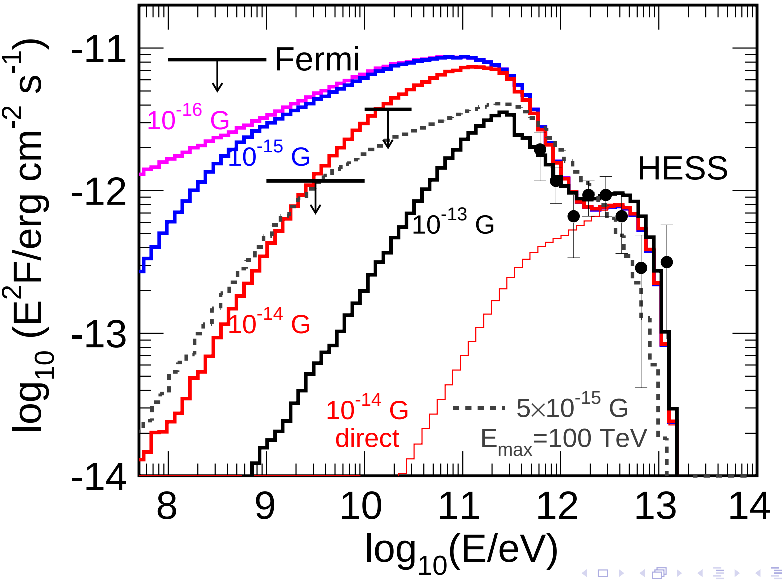
Lower limit on EGMF: uniform field

[*Dolag et al. '10*]



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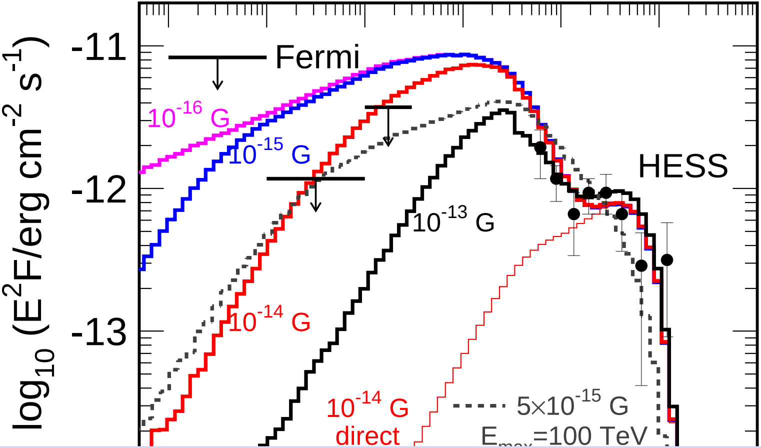


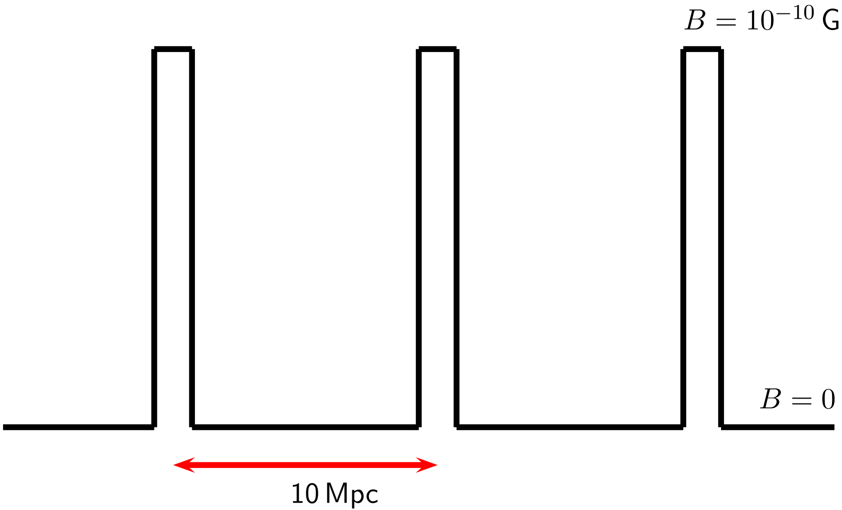
for coherence lengths $\lambda \lesssim l_{\rm int} \sim 5$kpc:

$\Rightarrow$ bound improves as $\lambda^{1/2}$

Lower limit on filling factor:

[Dolag et al. '10]

- model filaments by a top-hat:



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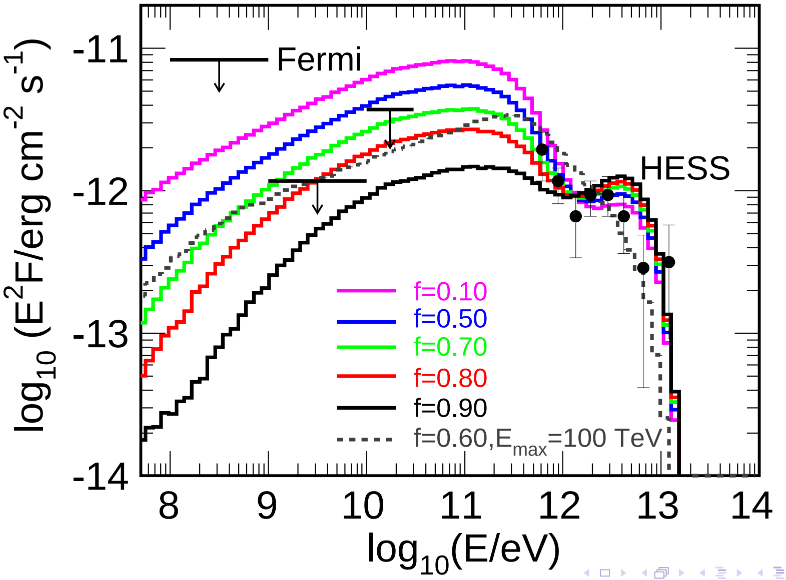

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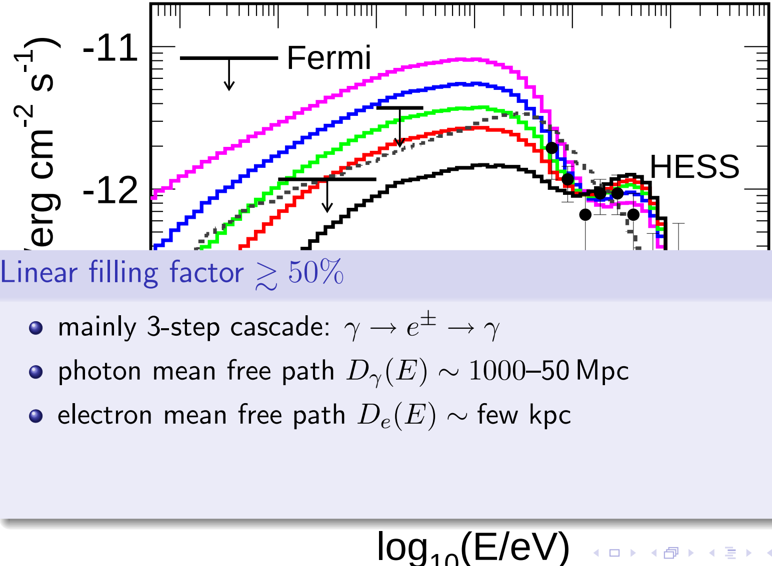

Linear filling factor $\gtrsim 50\%$

- mainly 3-step cascade: $\gamma \to e^{\pm} \to \gamma$
- photon mean free path $D_\gamma(E) \sim 1000$–50 Mpc
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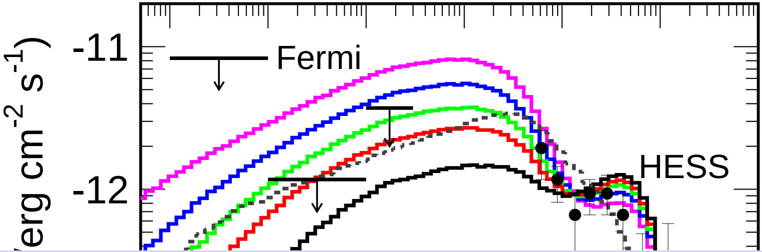

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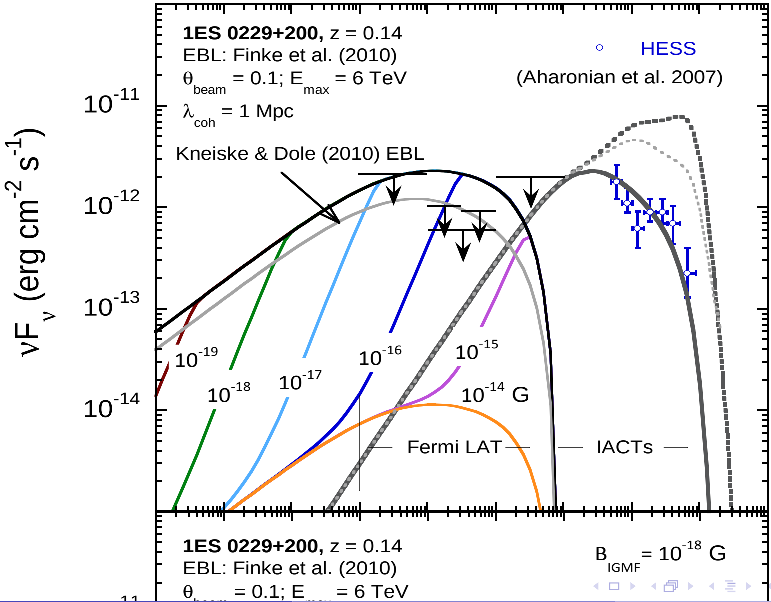
$\Rightarrow$ electrons are created "everywhere" and feel B only close to interaction point

log$_{10}$(E/eV)

Effect of time-delay

[*Dermer et al. '10*]



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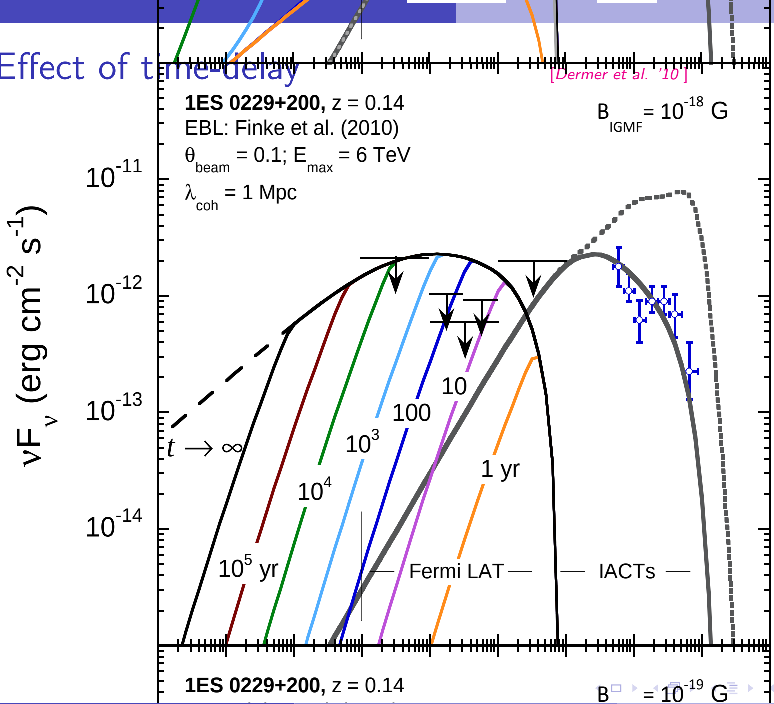

How to create EGMFs in voids?

- primordial fields:
  - inflation
  - phase transitions (QCD, electroweak)
  - reionization
- astrophysical (require seed fields):
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- astrophysical (require seed fields):
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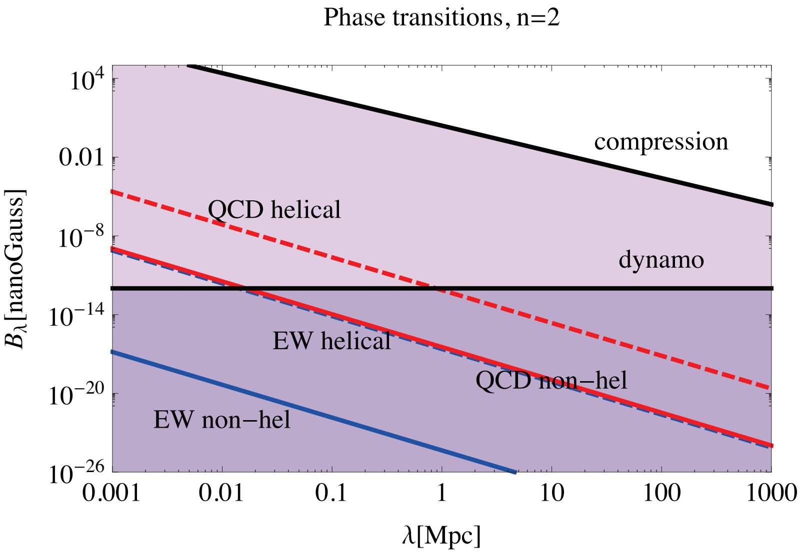
  - – outflows colliminated
  - – $B > 0$ and $B = 0$ plasma does not mix
  - – contamination with heavy elements

Expectation for "causally" generated fields: [Caprini, Durer,...]



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- for a Gaussian field

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  energy density $\rho = 4\pi\int_0^\infty k^2 S(k)$

  helicity density $h = 4\pi\int_0^\infty kH(k)$

- characterized by B_λ and coherence length L_c

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$\Rightarrow$ $\langle B_i(x) B_j(y) \rangle$ has compact support $\Rightarrow$ $[\cdots]$ is analytic function

  - analyticity & finite $\rho \Rightarrow B_\lambda \sim B_0(L_c/\lambda)^{5/2}$

Primordial magnetic fields:

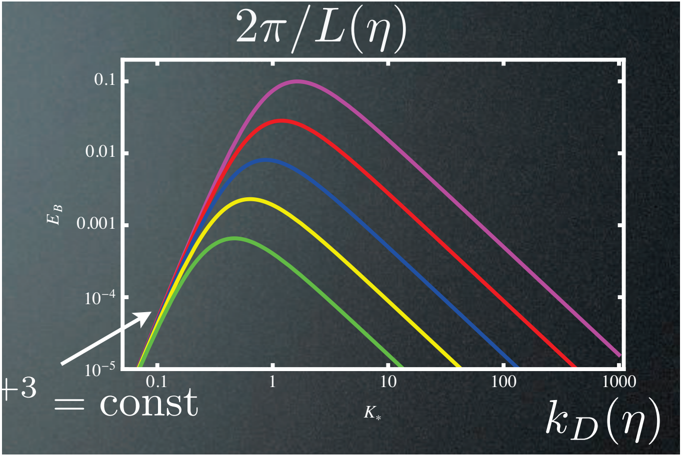
- for a Gaussian field

$$\langle B_i(k) B_j^*(k') \rangle = \delta(k - k') \left[\left(\delta_{ij} - \hat{k}_i \hat{k}_j \right) S(k) + i\varepsilon_{ijl} k^l H(k) \right]$$

- characterized by B_λ and coherence length L_c
- inflation: "acausal", $L_c \gg H_0^{-1}$ possible
- phase transitions:
  - require 1./2.order transition
  - "causal", $L_c(t_*) \lesssim H(t_*)^{-1}$
  - $\Rightarrow$ $\langle B_i(x) B_j(y) \rangle$ has compact support $\Rightarrow$ $[\cdots]$ is analytic function
  - analyticity & finite $\rho \Rightarrow B_\lambda \sim B_0 (L_c/\lambda)^{5/2}$
- how are fields evolving after creation?

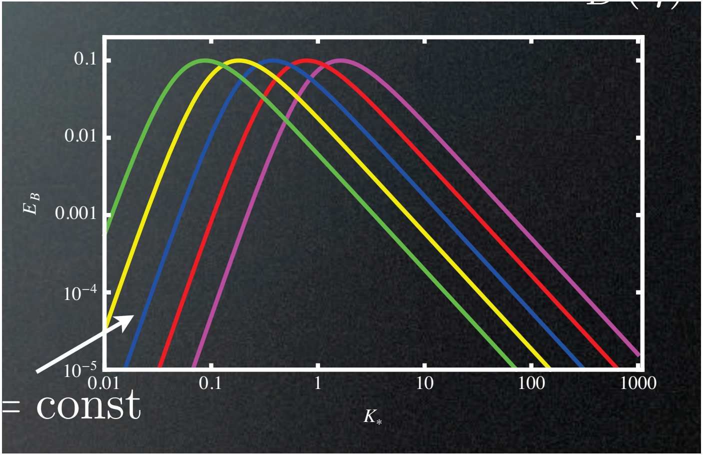
Evolution of primordial magnetic fields:

- non-helical fields: damped above k_D, below $B \propto 1/a^2$



Evolution of primordial magnetic fields:

- helical fields: fluctuations are tranferred to larger scales $1/k$



Evolution of primordial magnetic fields:

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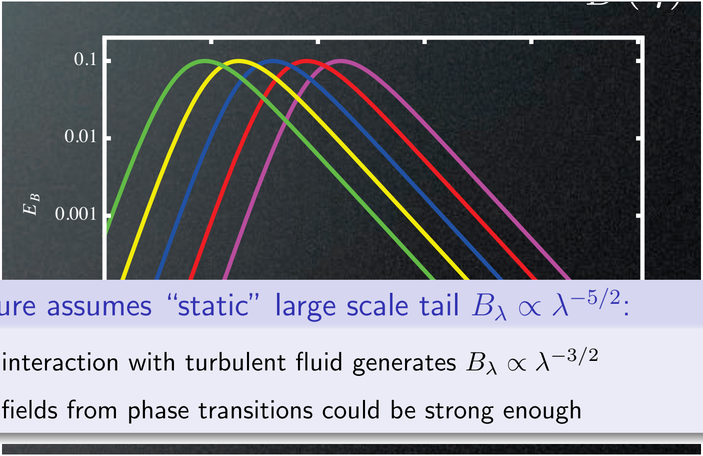

Picture assumes "static" large scale tail $B_\lambda \propto \lambda^{-5/2}$:

- interaction with turbulent fluid generates $B_\lambda \propto \lambda^{-3/2}$

$\Rightarrow$ fields from phase transitions could be strong enough

Summary

- Fermi non-observation of TeV blazars requires EGMF

$\Rightarrow$ quantitative conclusions:

  - sure: large filling factor $f \gtrsim 0.5$
  - bound on EGMF: depends on assumed Δt, $B \gtrsim 10^{18}$ G

- can be improved by more/longer simultanous observations
- limit $\Rightarrow$ detection: CTA?
- cascade limit from Fermi data reduced by factor ~ 7

$\Rightarrow$ km^3 neutrino telescope cannot detect cosmogenic neutrinos

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