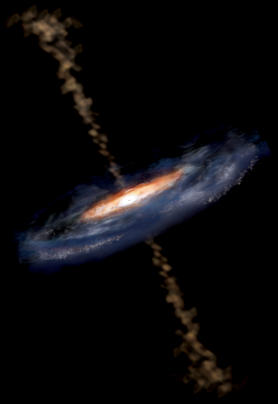
Probing UHECR with Photons



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Simplified Picture

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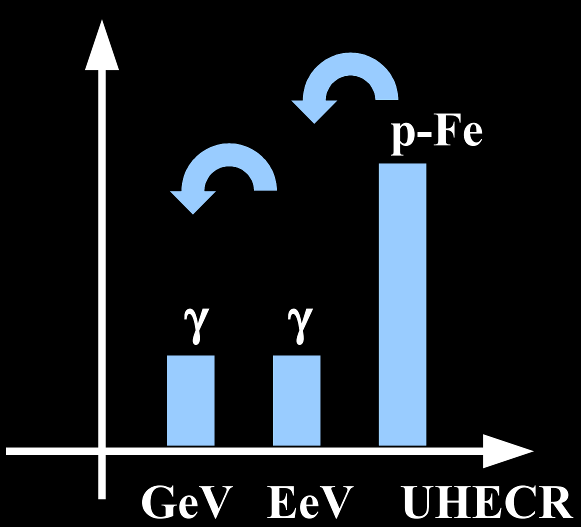
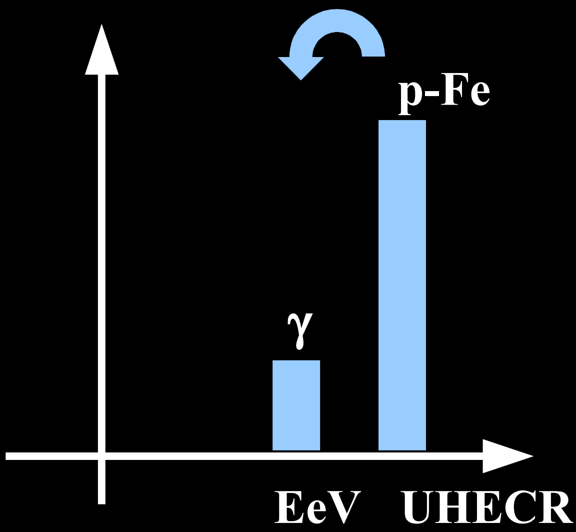
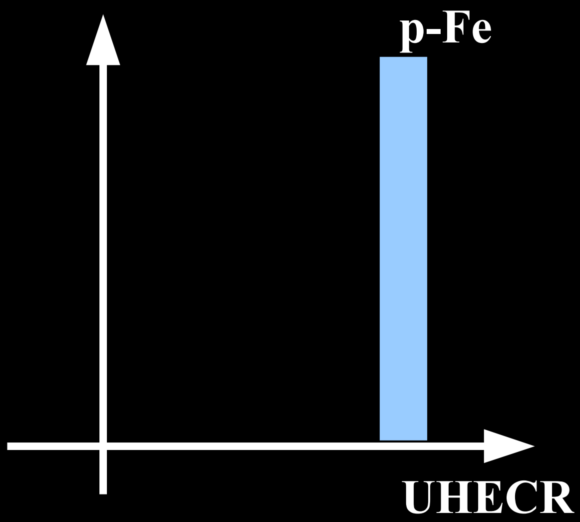
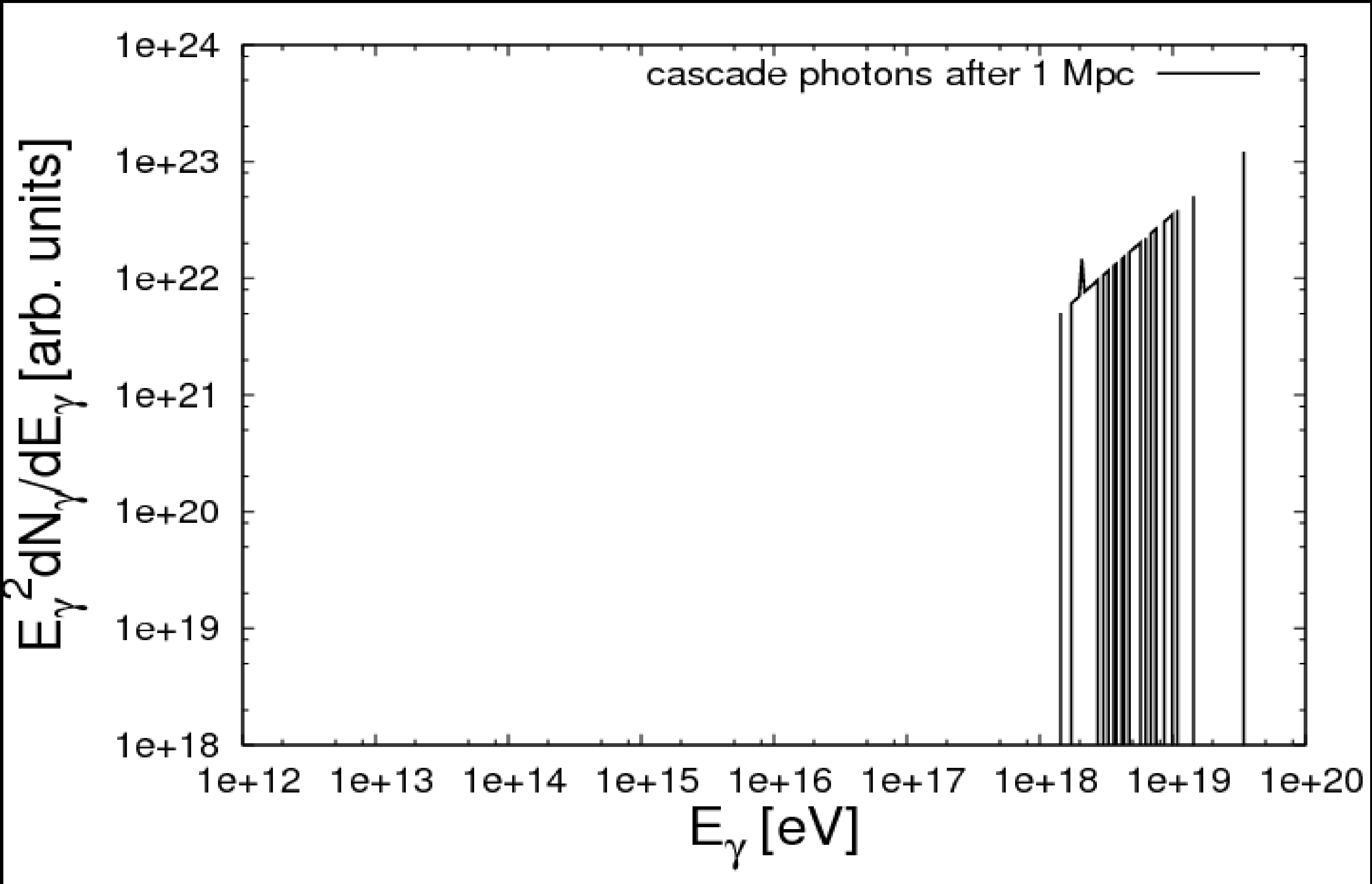
Density of Targets + Optical Properties of Medium







Development of Cascade



UHECR from AGN

CR with energies above 10^{19} eV:

$$E^2_{\rm CR}\frac{dN}{dE}\Big|_{19} \sim 20 \text{ eV cm}^{-2}\text{ s}^{-1}\text{ sr}^{-1}$$

$$\frac{L}{V} \sim 10^{37} \text{ erg Mpc}^{-3}\text{ s}^{-1}$$

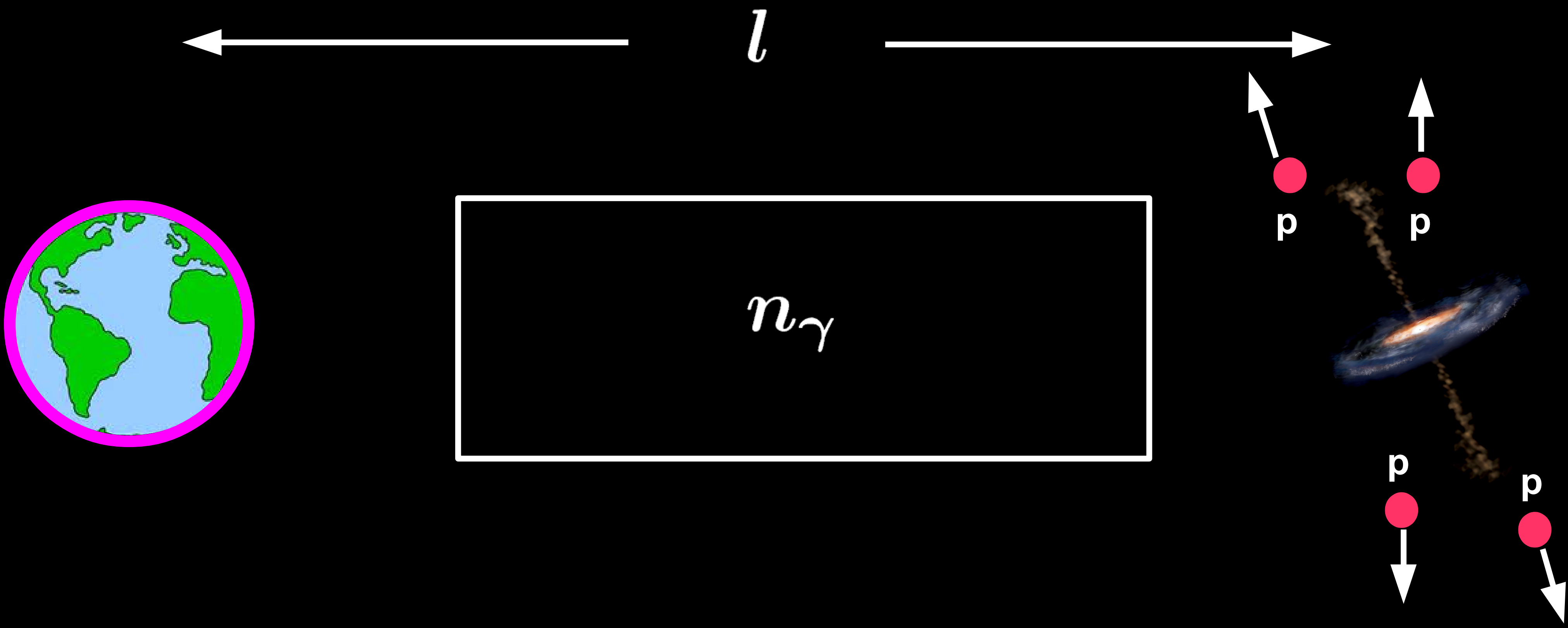
Many weak sources → Few strong sources

Flux	**0.01**	**0.1**	**1**	**10**	Auger events/yr
Luminosity	10^{40}	10^{41}	10^{42}	10^{43}	erg/s @50 Mpc
Number	**3000**	**300**	**30**	**3**	within 100 Mpc

→

$$E^2_\gamma\frac{dN}{dE}\Big|_{\rm Crab} > 3 \text{ eV cm}^{-2}\text{ s}^{-1}$$

Gamma-Rays from AGN: Different Scenarios



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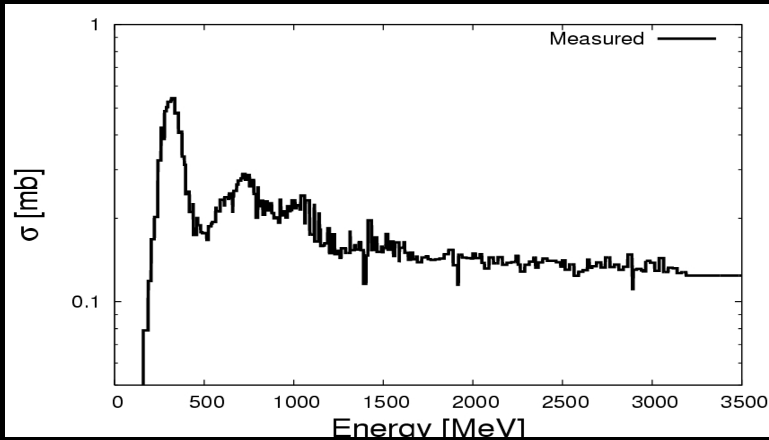
Different Interaction Scales

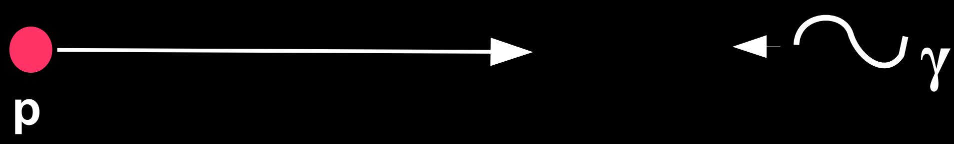
resonant-type cross sections

$> 10^{18}$ eV protons and nuclei

0.5 mb

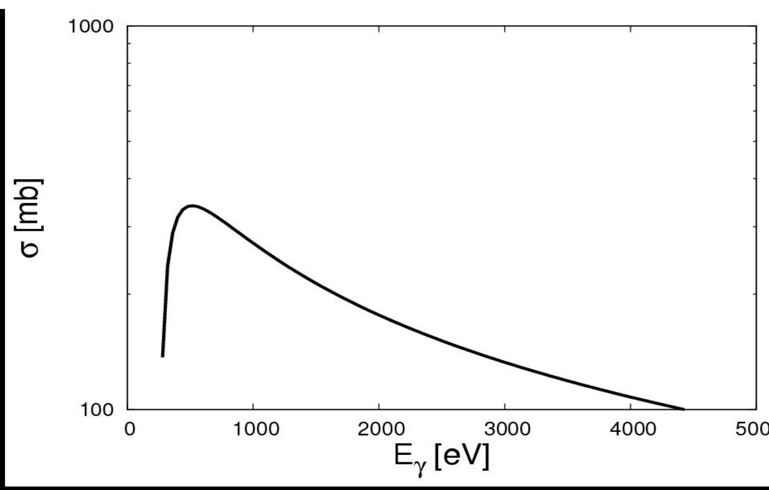


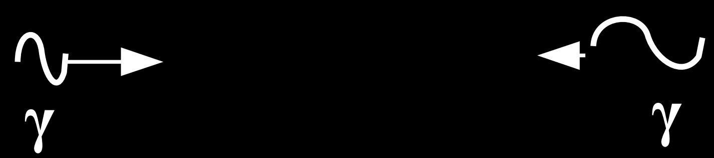
(primaries)



(secondaries)

200 mb





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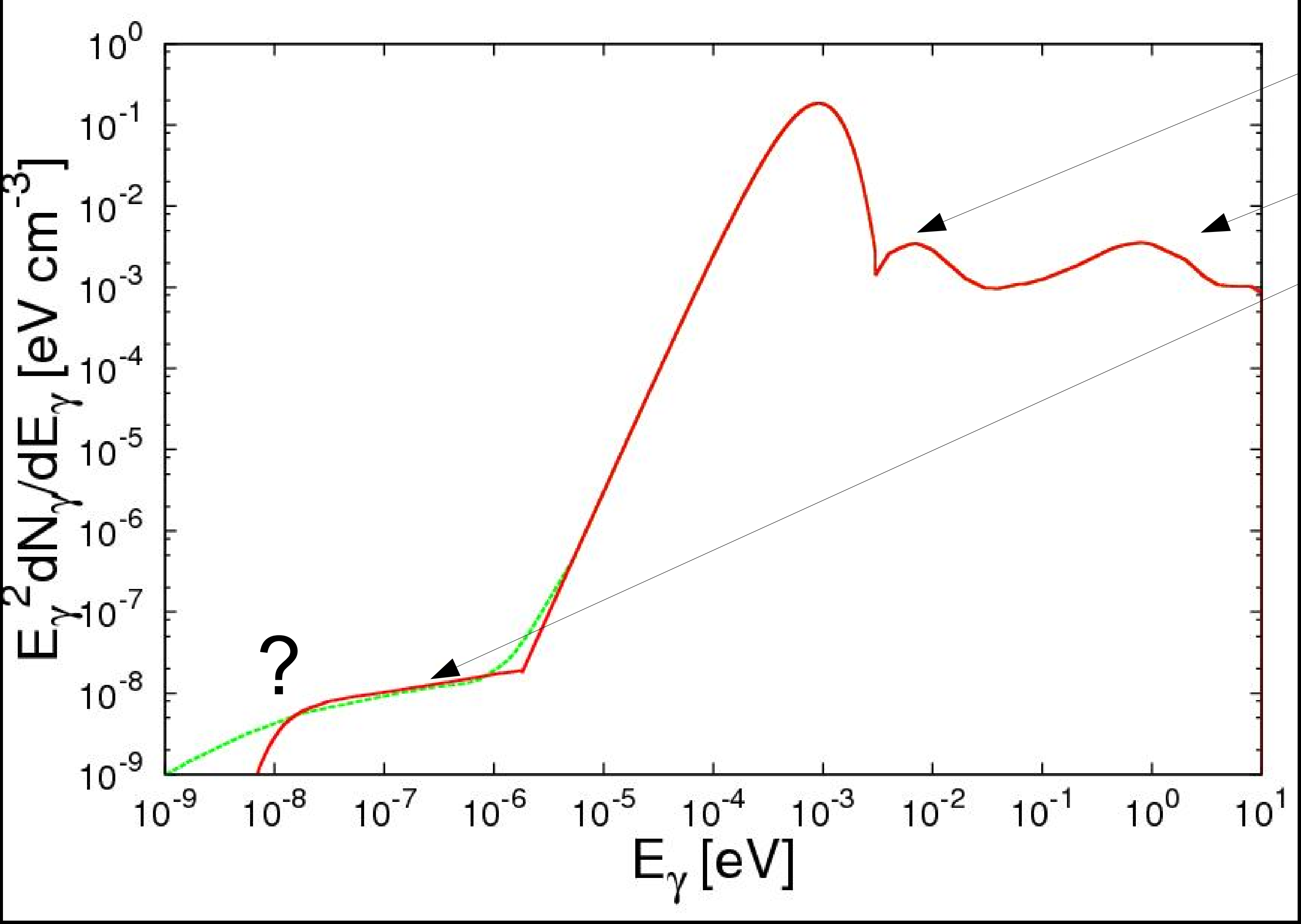
Cosmic Background Radiation Fields



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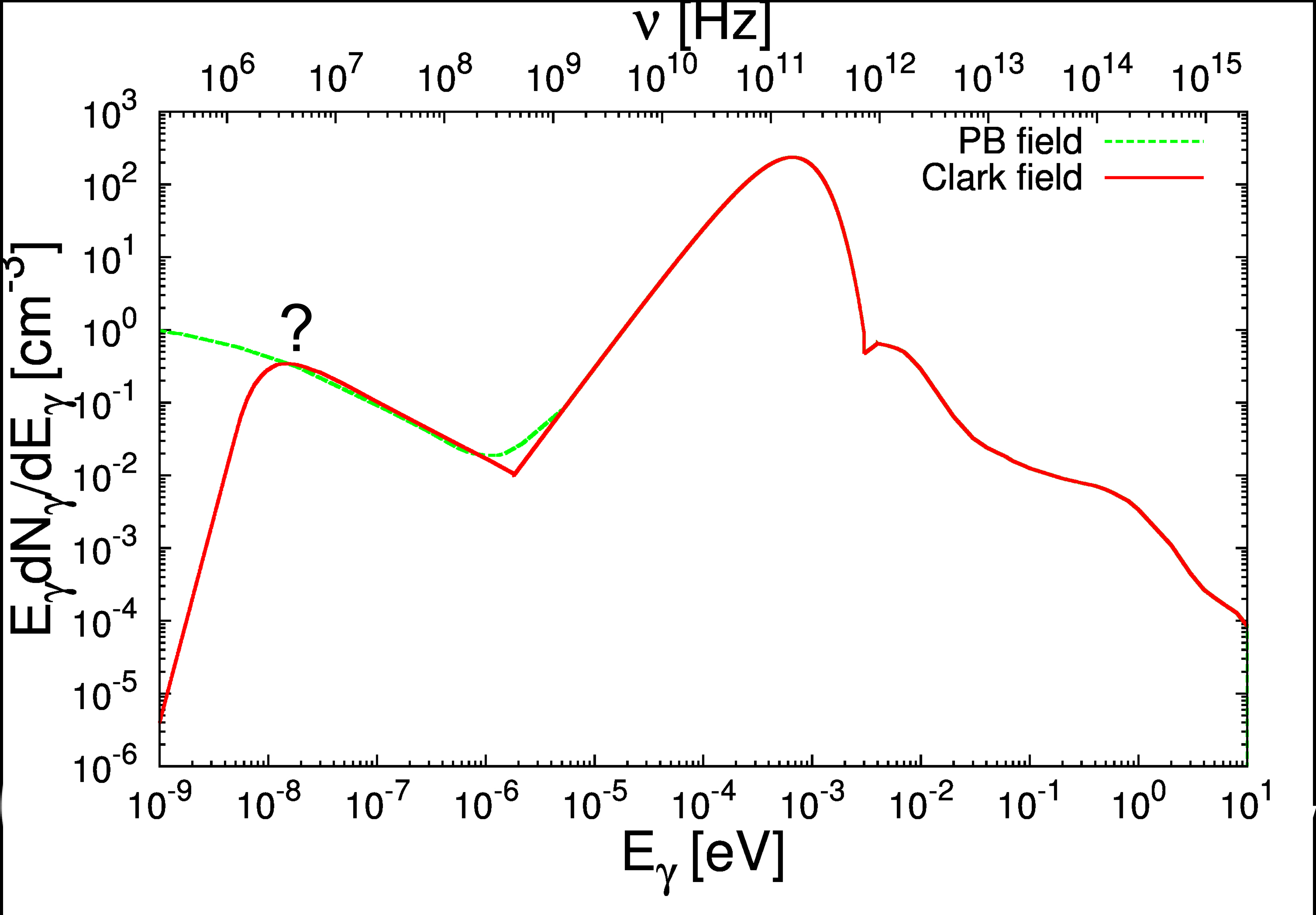
Cosmic Background Radiation Fields

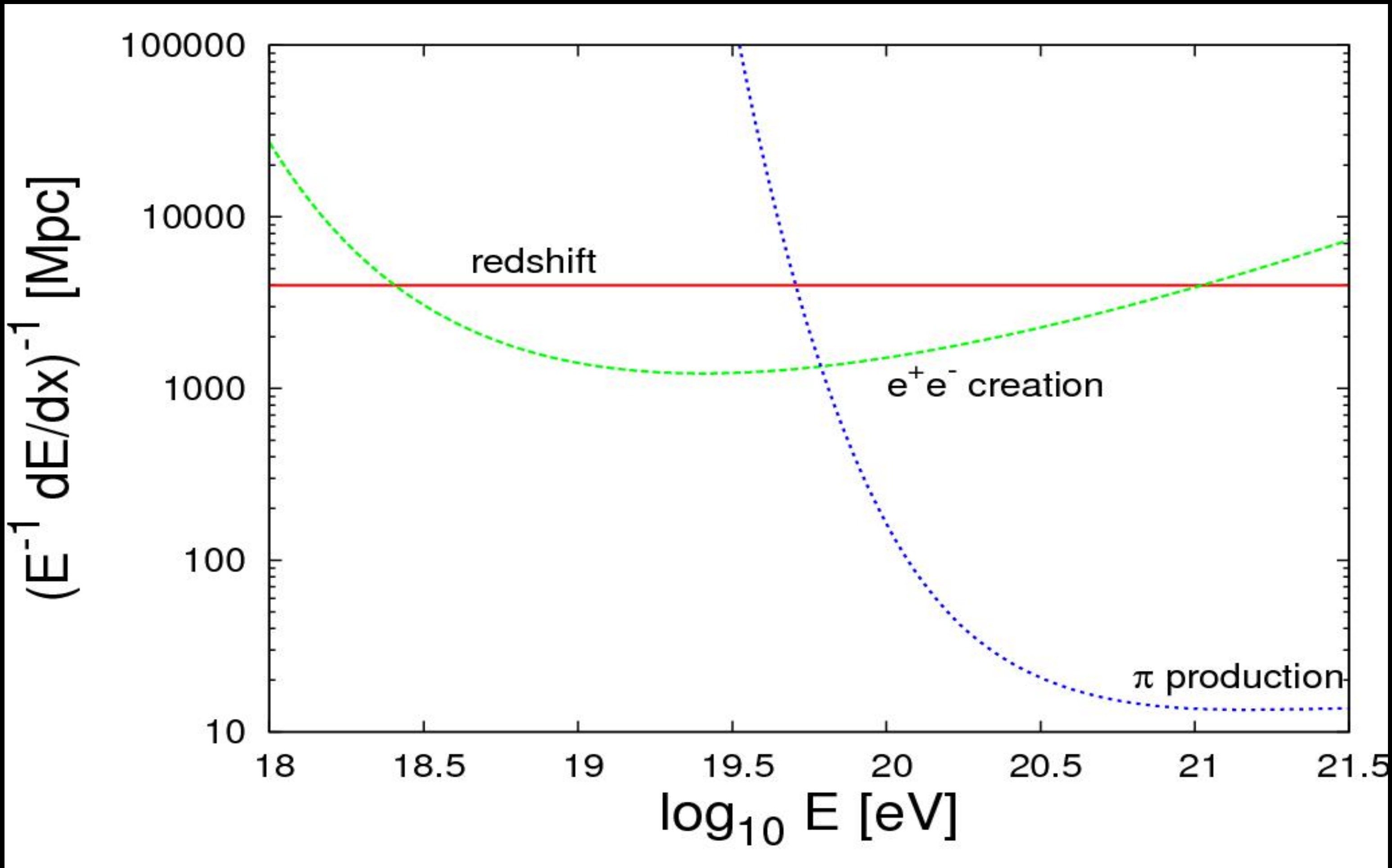


The Impedance of Background Radiation to High Energy Protons

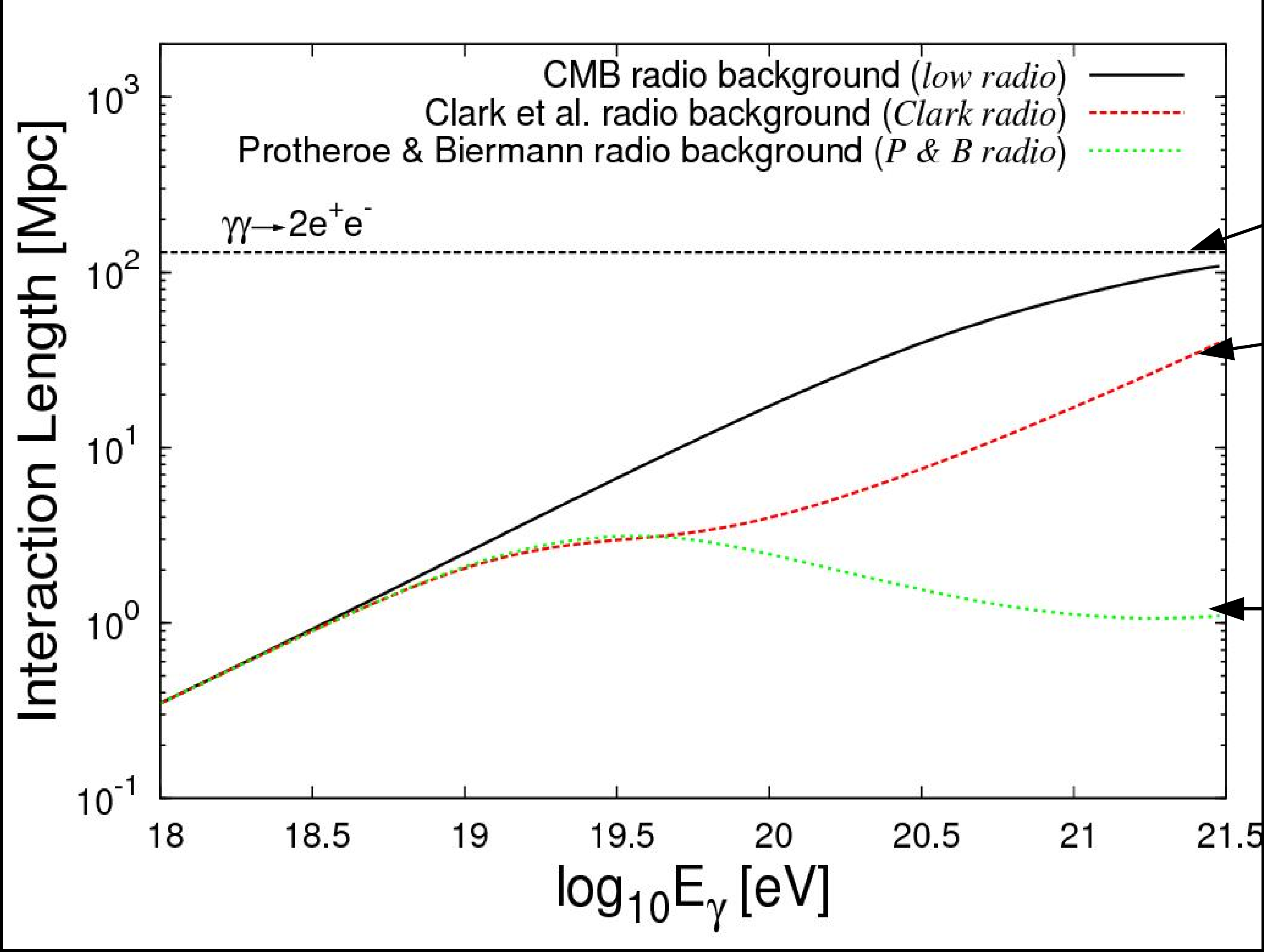
$$R = \frac{1}{2\Gamma_p^2} \int_0^\infty \frac{1}{\epsilon_\gamma^2} \frac{dn_\gamma}{d\epsilon_\gamma} d\epsilon_\gamma \int_0^{2\Gamma_p \epsilon_\gamma} d\epsilon_\gamma' \epsilon_\gamma' \sigma_{p\gamma}(\epsilon_\gamma') K_p$$

where R is the energy loss rate

where K_p is the proton inelasticity



The Impedance of Background Radiation to High Energy Photons

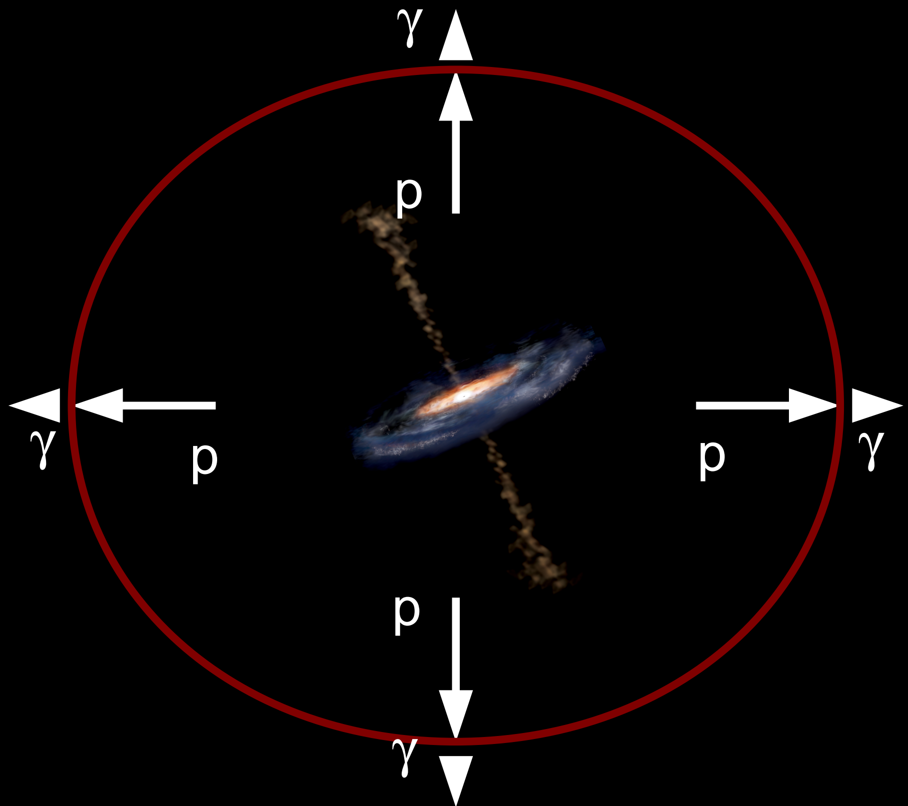


“*low radio*” background

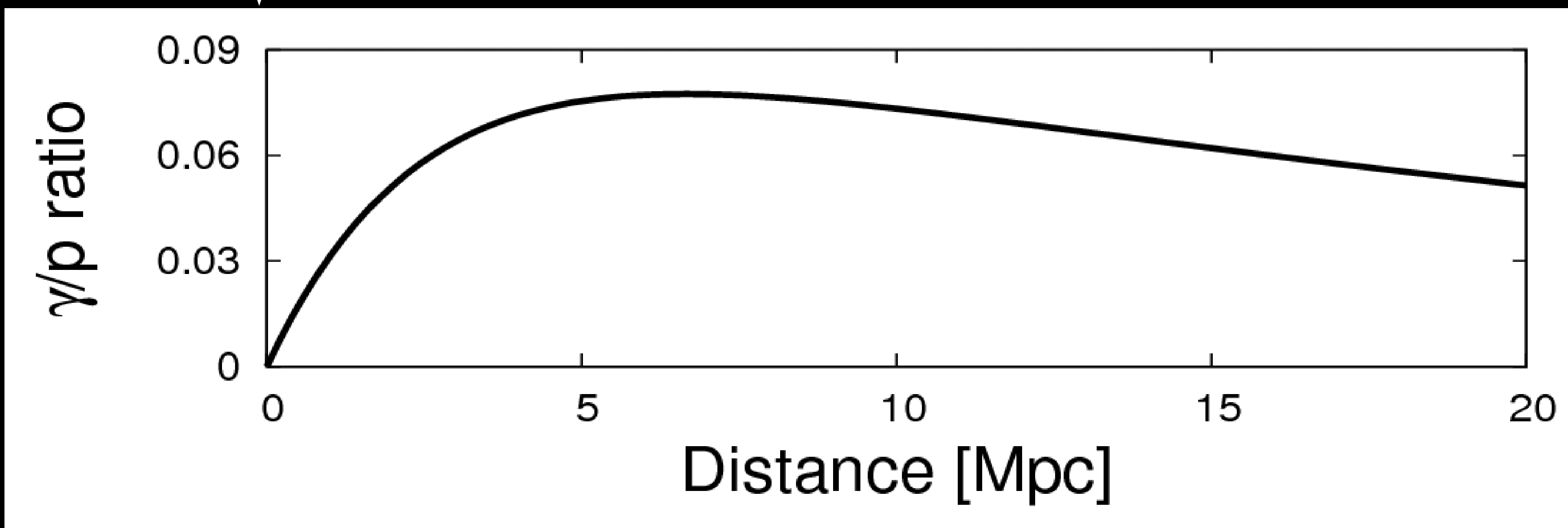
“Clark *radio*” background

“P & B *radio*” background

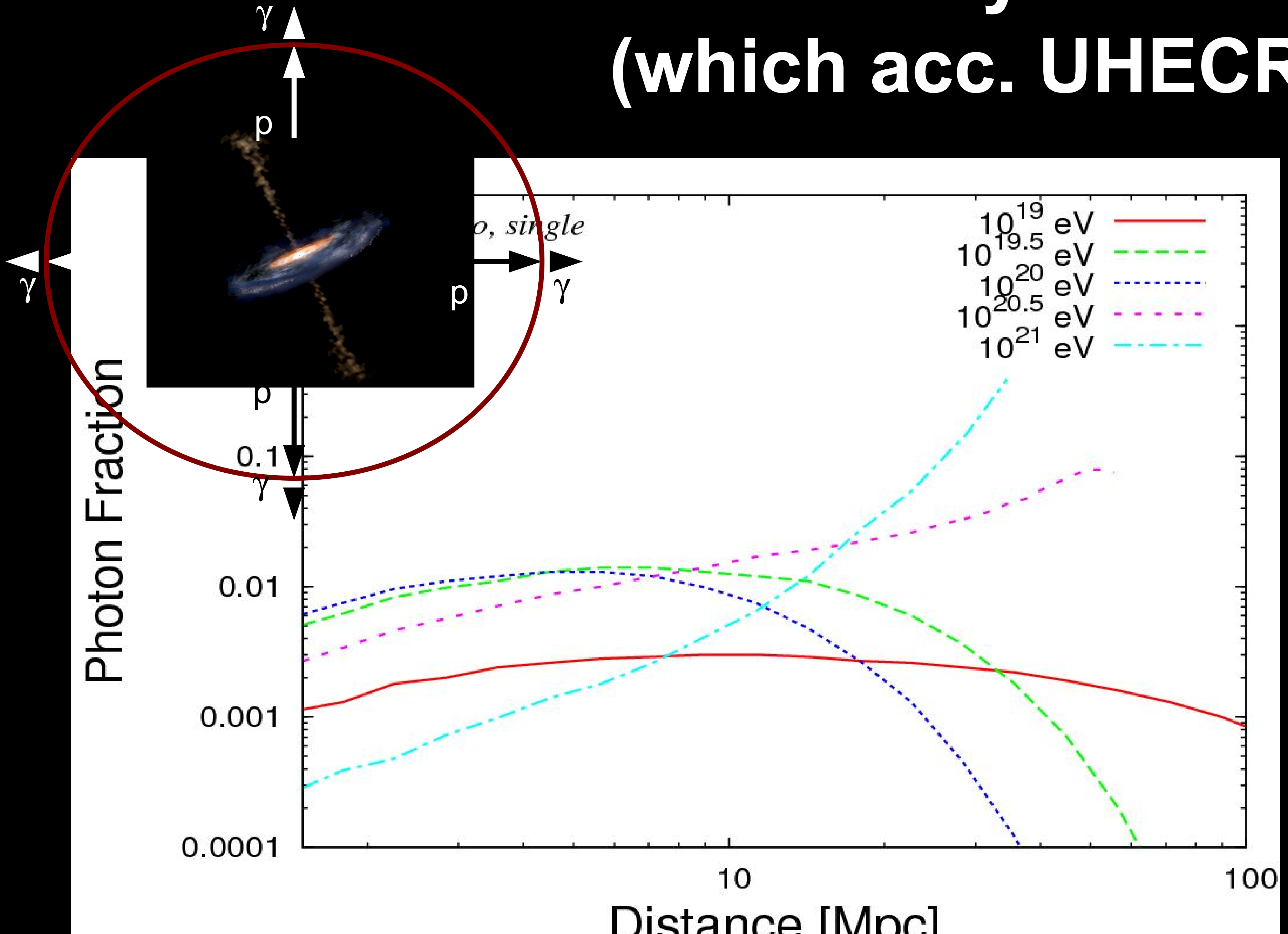
The Halo Around Heavenly Bodies (which acc. UHECR)



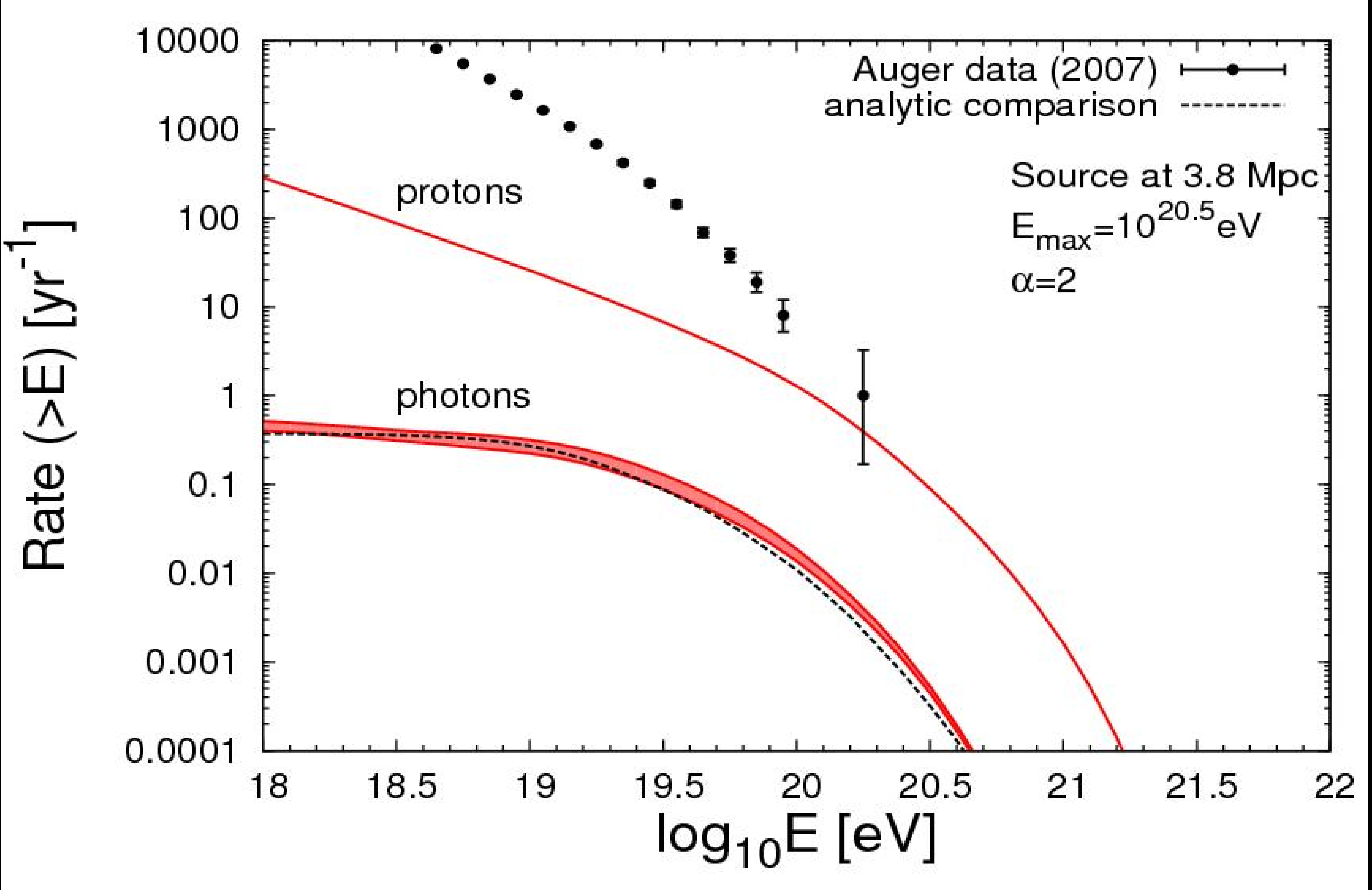
10^{19} eV γ − ray



The Halo Around Heavenly Bodies (which acc. UHECR)



Cen A as a Local UHECR Source



EeV Cascades

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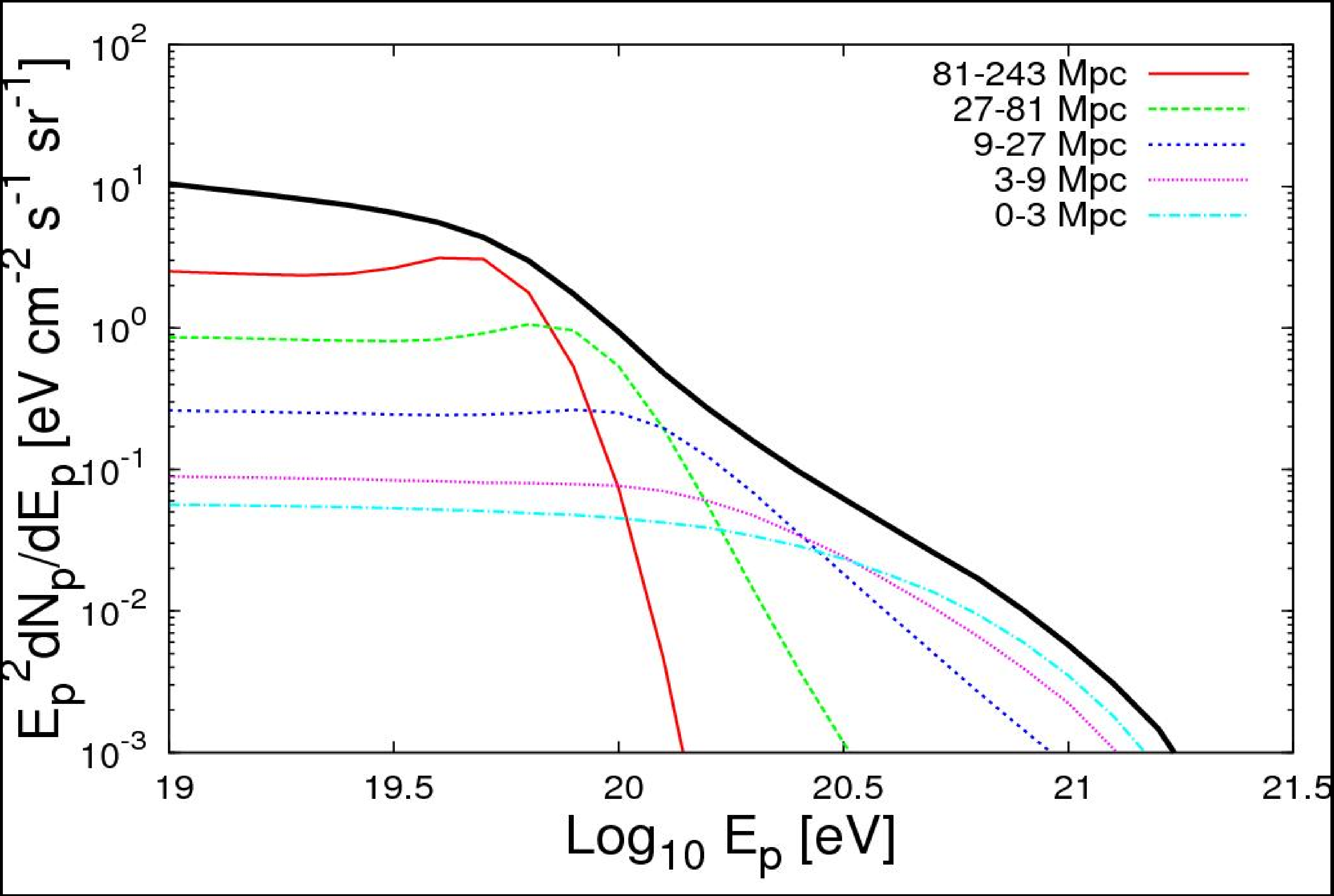
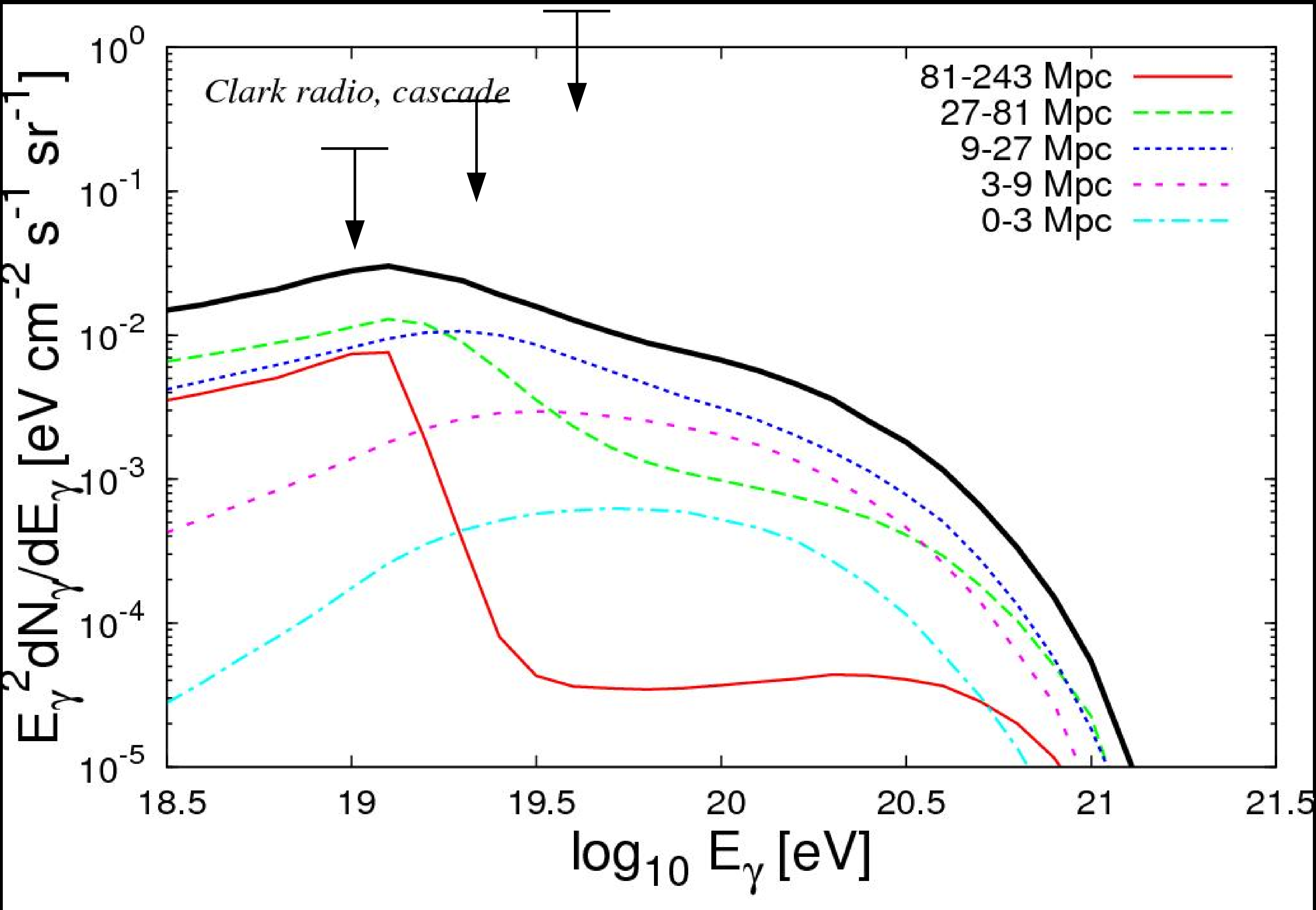
Arriving <u>proton</u> Flux from Different Shells

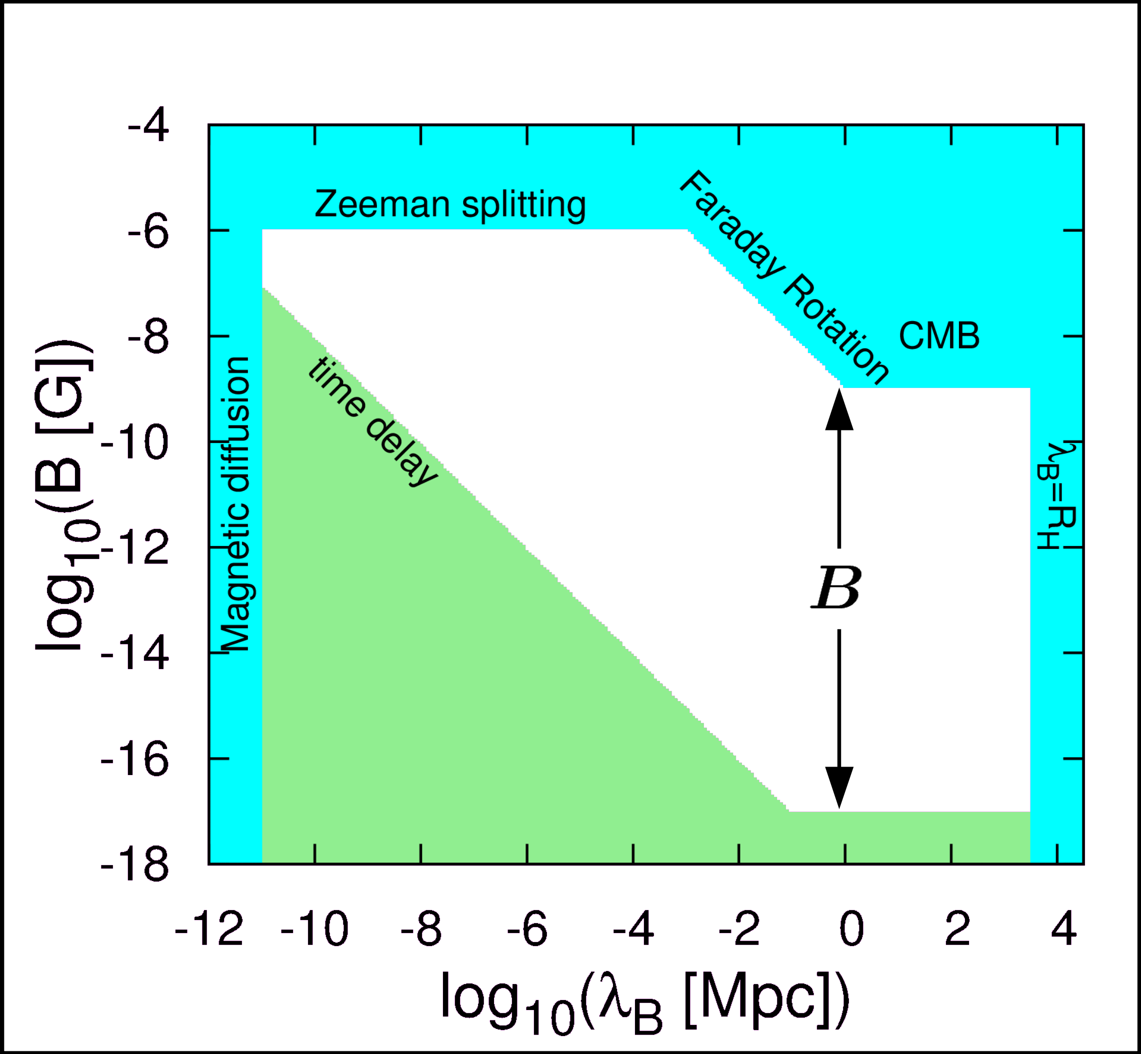


.....associated photon flux from Different Shells



Extragalactic Magnetic Fields

B



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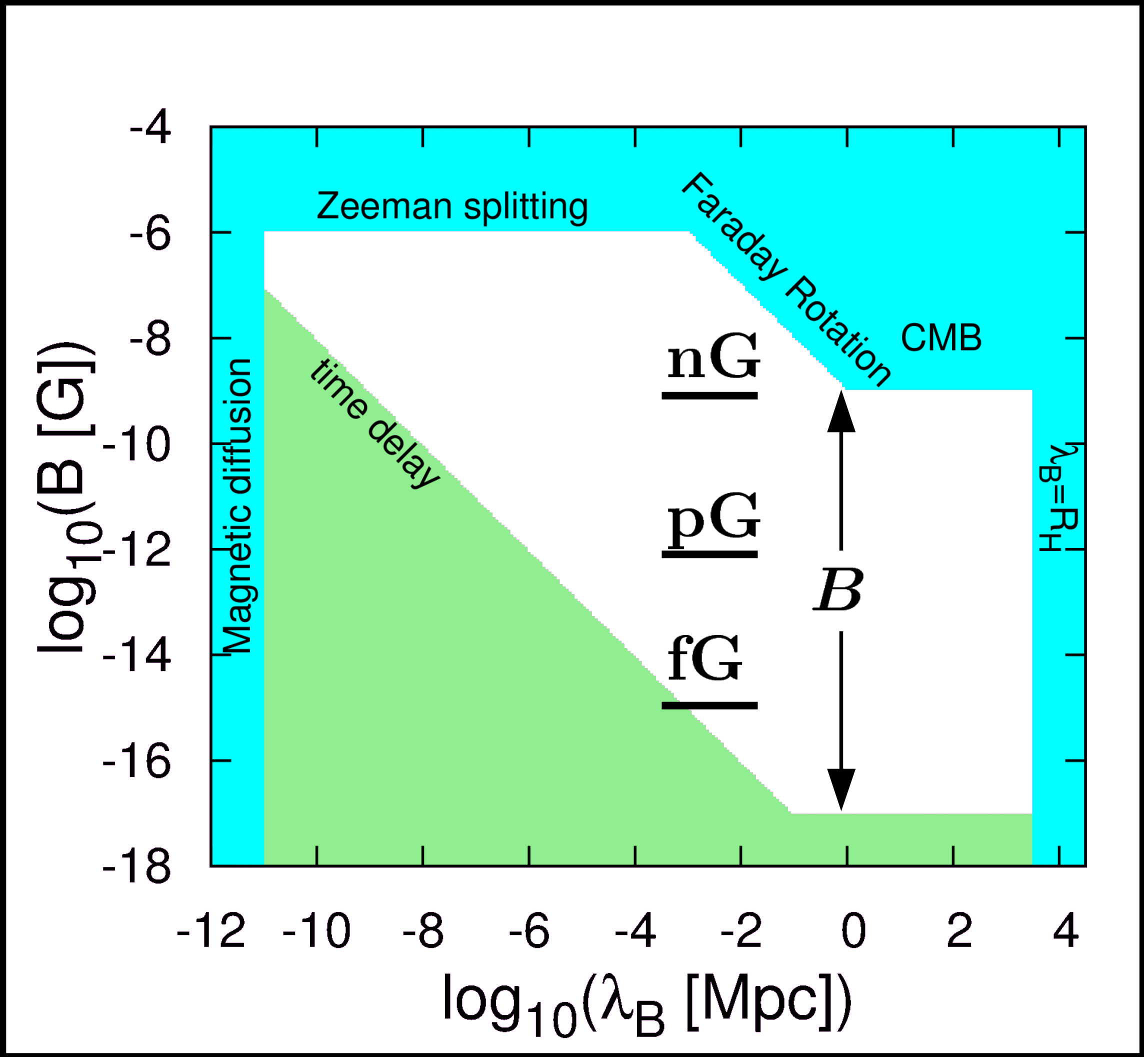
Extragalactic Magnetic Fields

B



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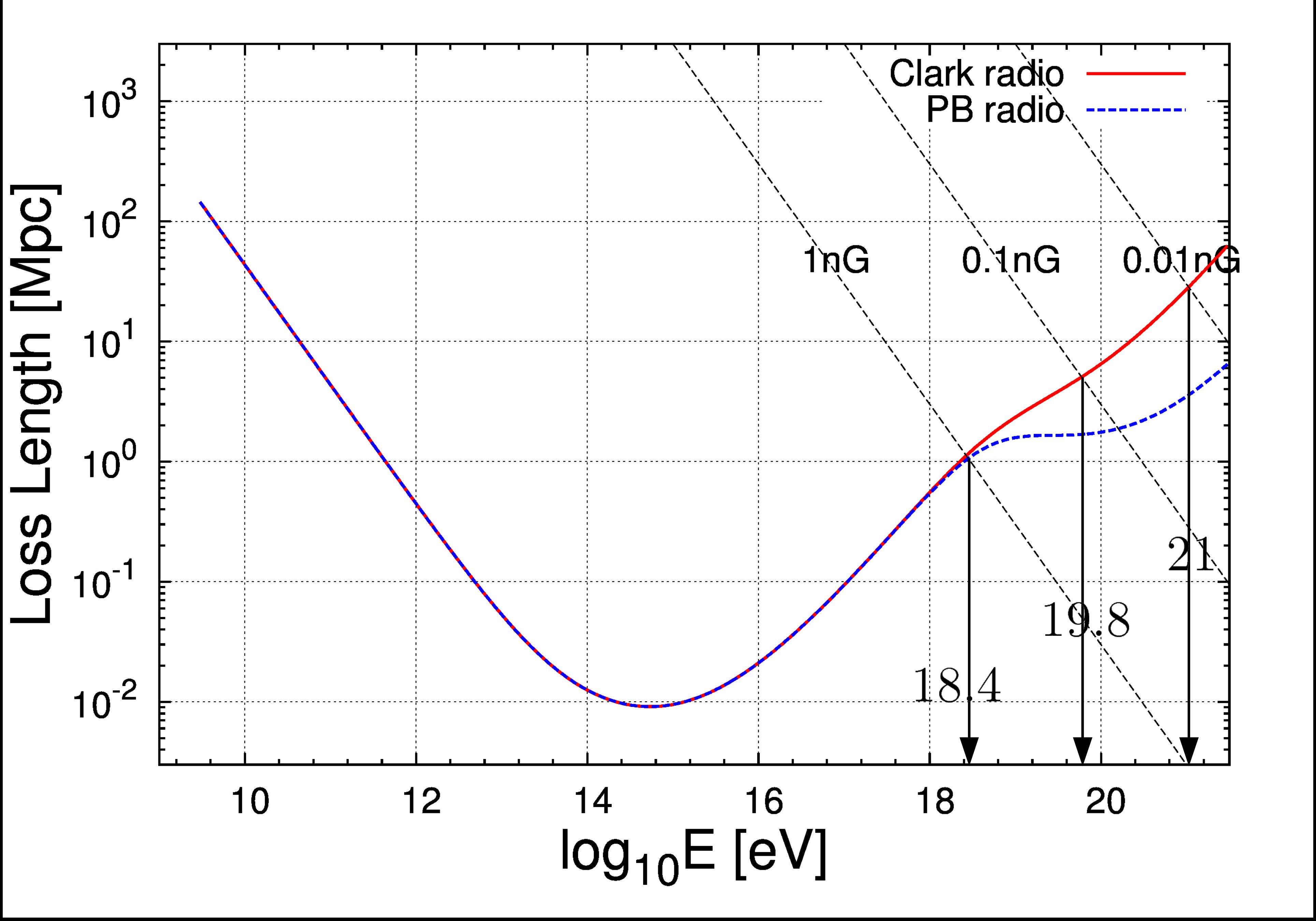
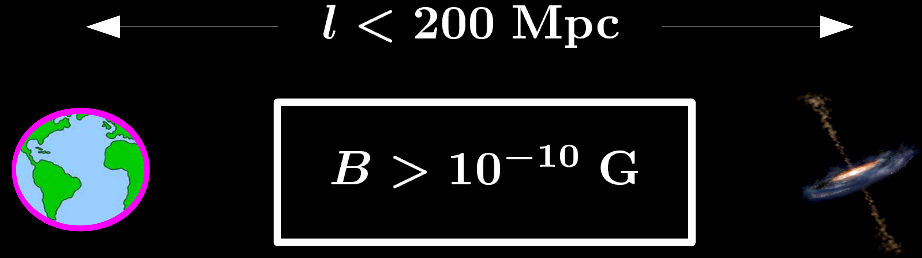
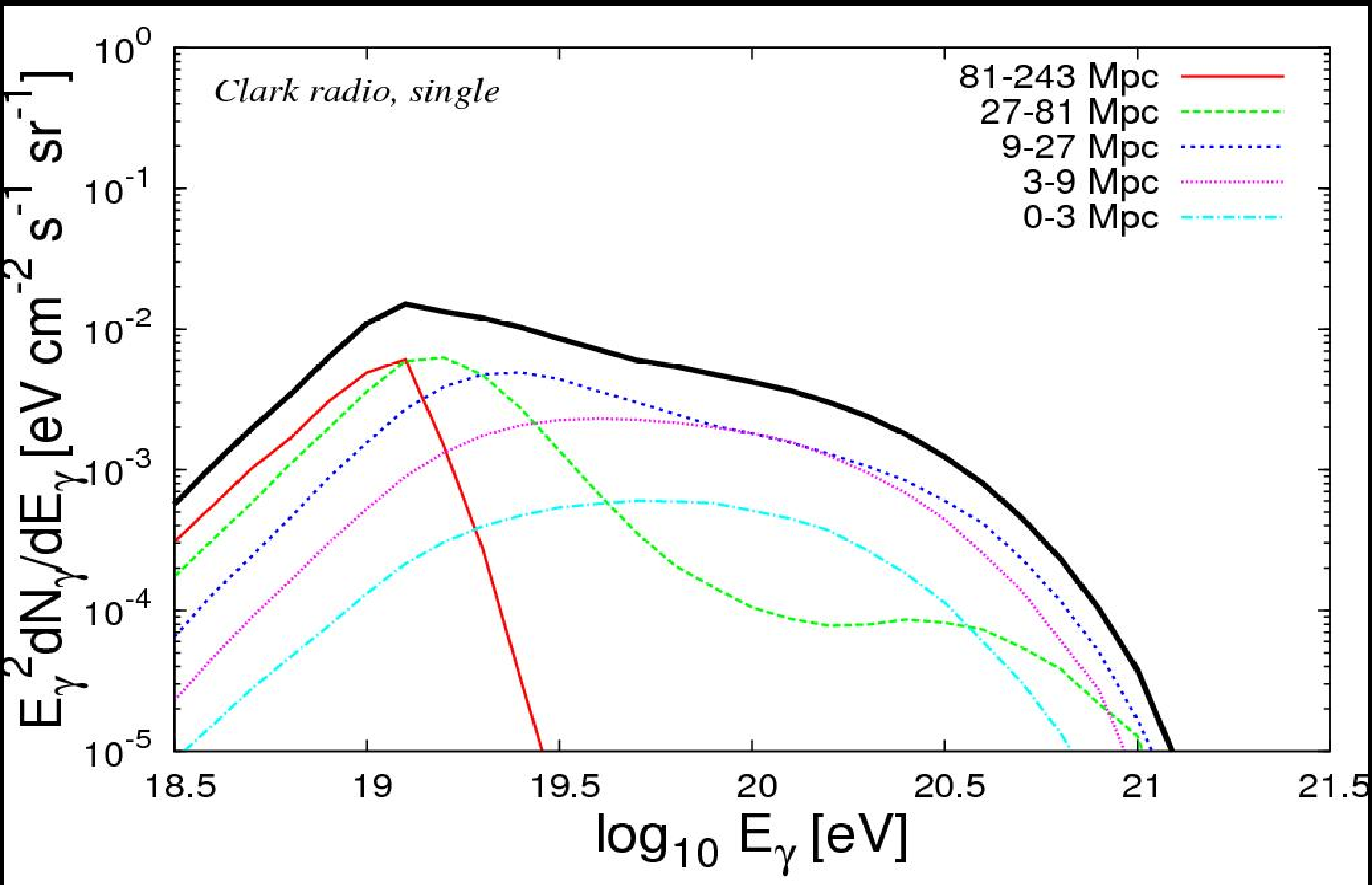
UHE Electron Cooling in Extragalactic Space

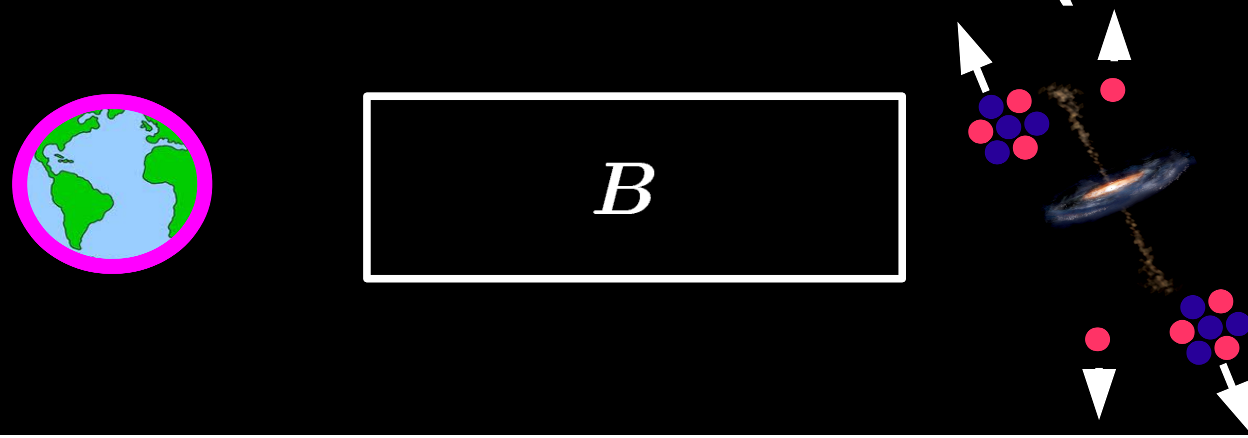


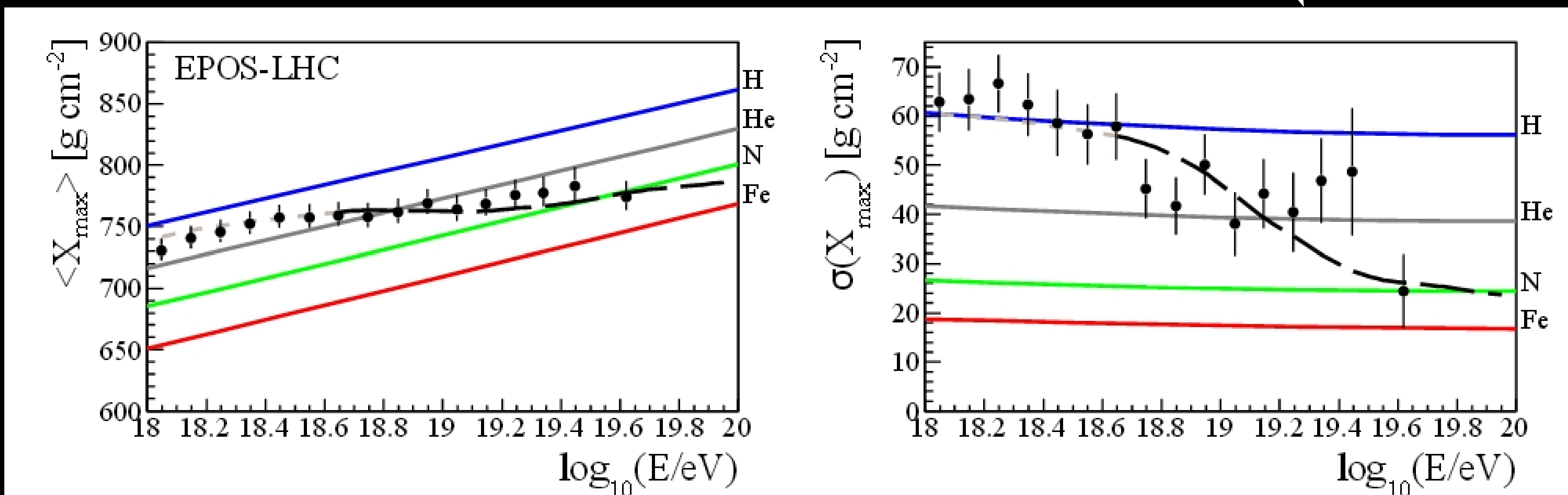
Arriving photon Flux from Different Shells (B>0.1 nG)





The X_{max} Data From Auger Fluorescence Detectors (2013)





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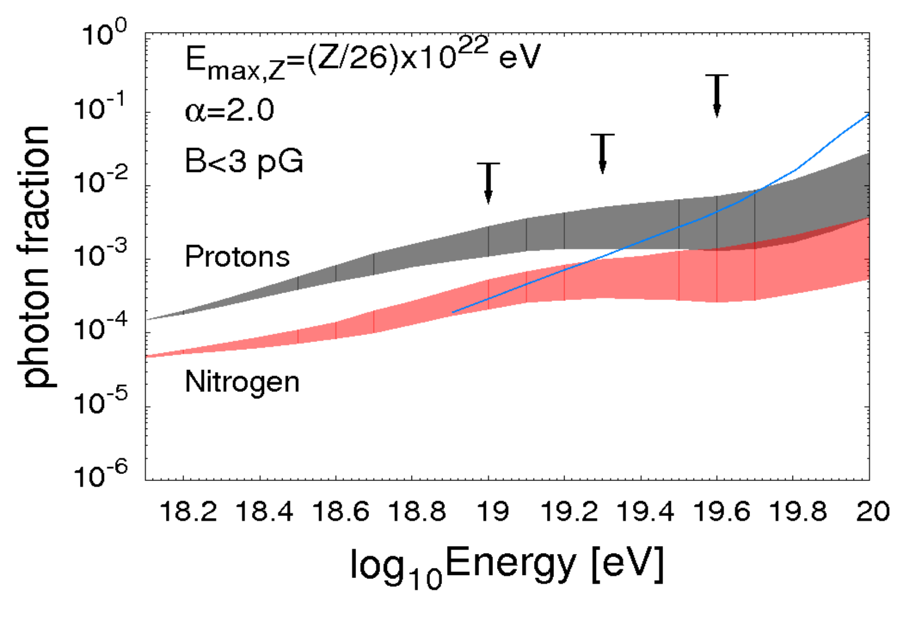
Photon Fraction for Different UHECR Composition Models

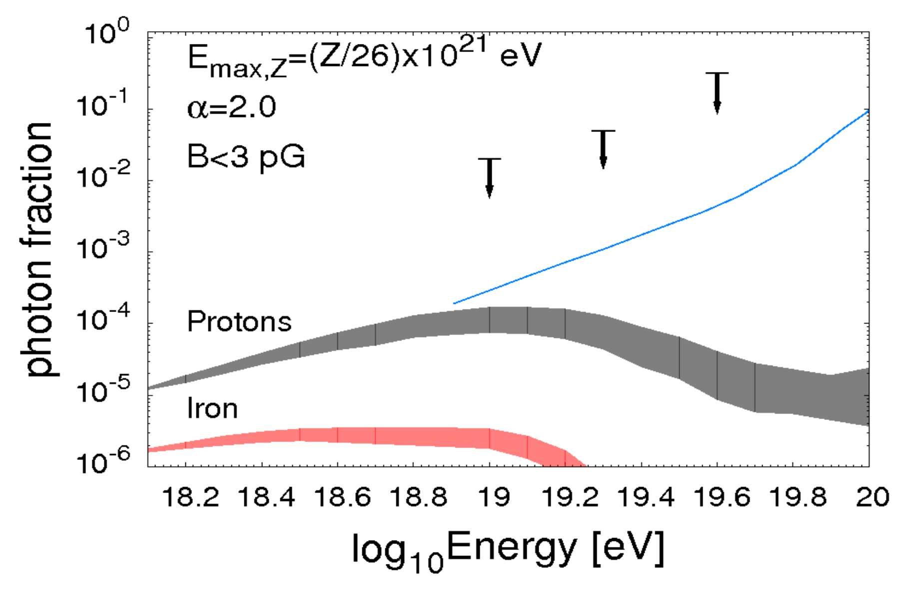
Nitrogen (Z=7)

$$E_{\rm max} = (Z/26)10^{22}{\rm eV}$$



Iron (Z=26)

$$E_{\rm max} = (Z/26)10^{21}{\rm eV}$$



GeV Synchrotron/Cascades (strong B-fields)

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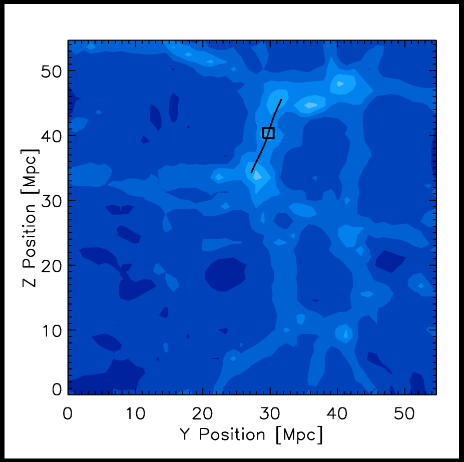
Arriving Synchrotron Flux (B>0.1 nG)

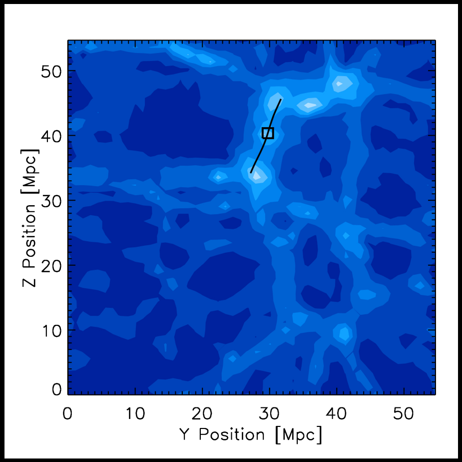
$L_{E,19} = 10^{42}$ erg s^{-1}

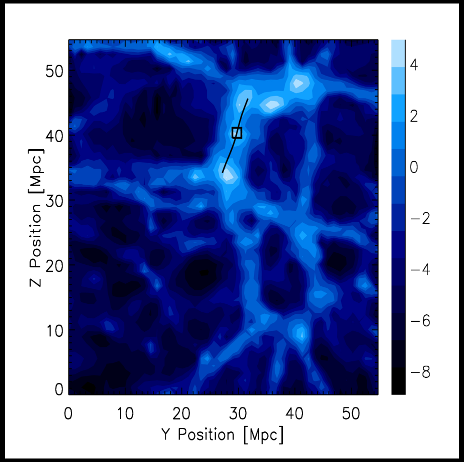
Kotera et al. (astro-ph/1011.0575)

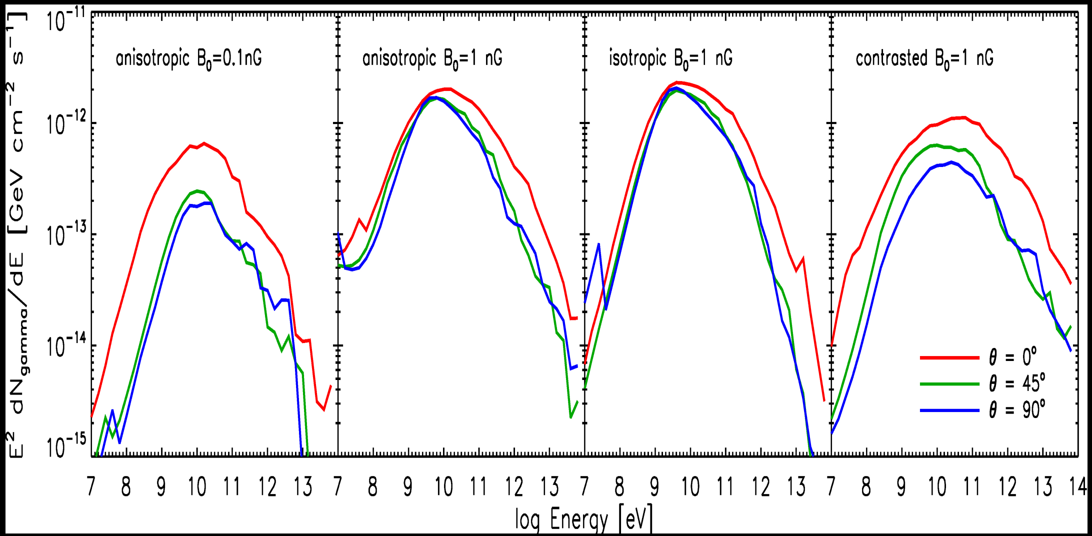
$\longleftarrow \quad l = 100$ Mpc $\quad \longrightarrow$

$B = 10^{-9}$ G









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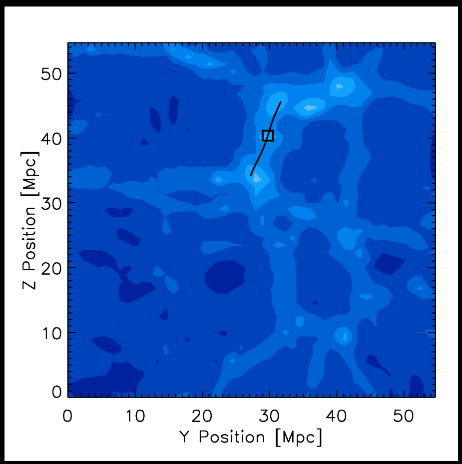
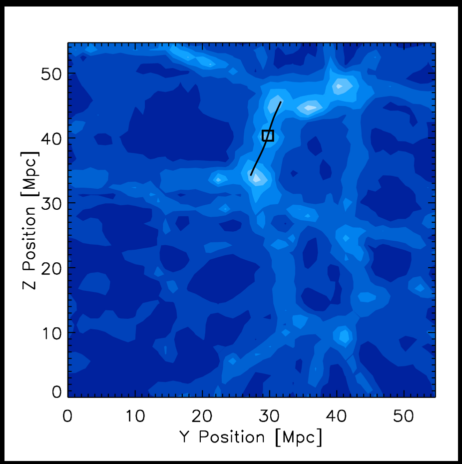
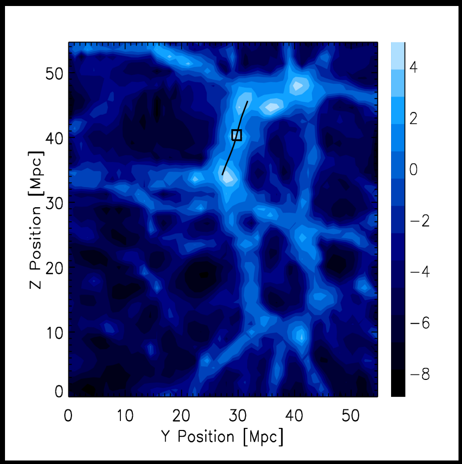
Arriving Synchrotron Flux (B>0.1 nG)

Kotera et al. (astro-ph/1011.0575)





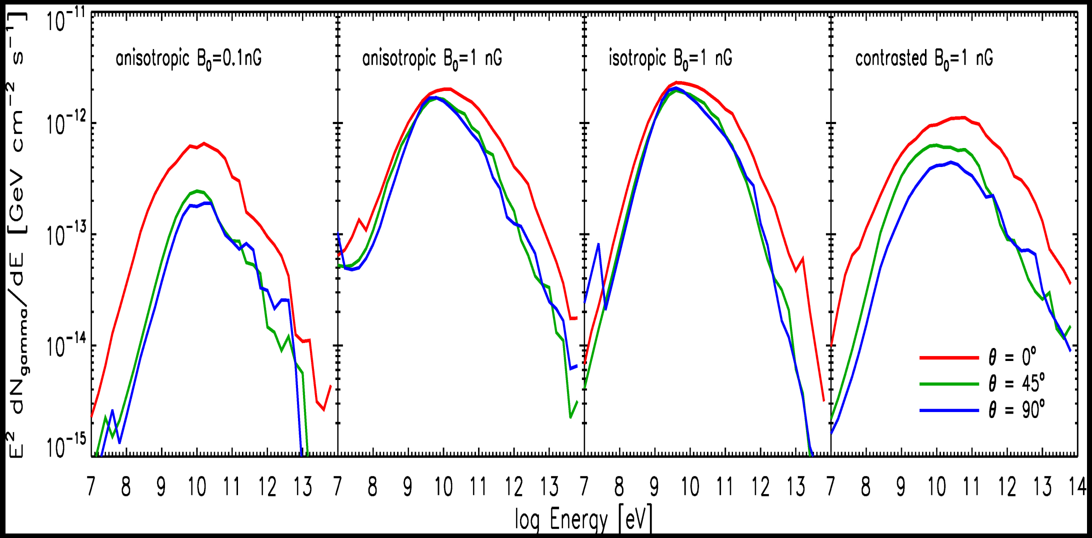


$L_{E,19} = 10^{42}\ \mathrm{erg s^{-1}}$

$d = 100\ \mathrm{Mpc}$

→

$E^2 dN/dE \sim 0.5\ \mathrm{eV cm^{-2} s^{-1}}$



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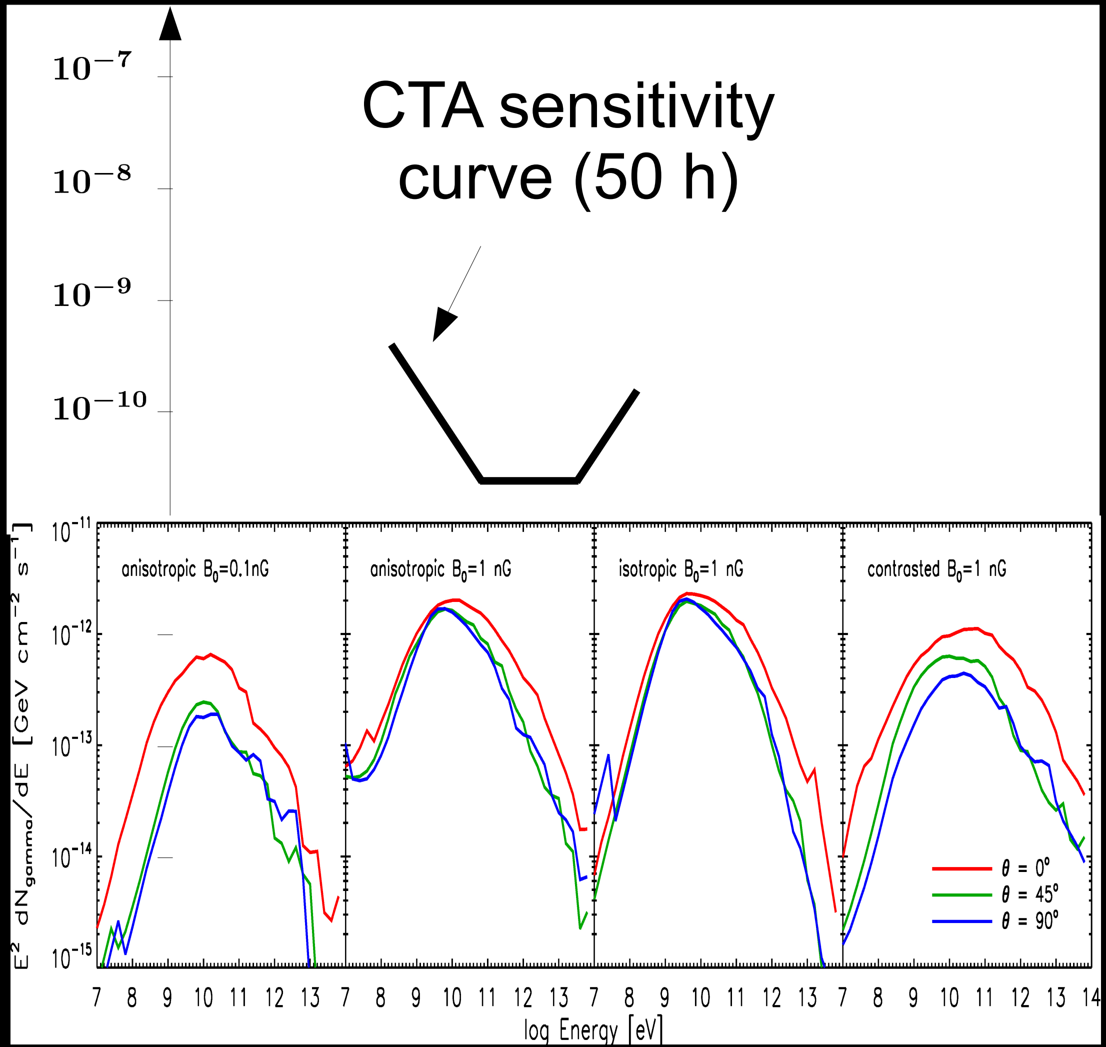
Arriving Synchrotron Flux (B>0.1 nG)

Kotera et al. (astro-ph/1011.0575)



ie. only possible with CTA for bright nearby sources scenario

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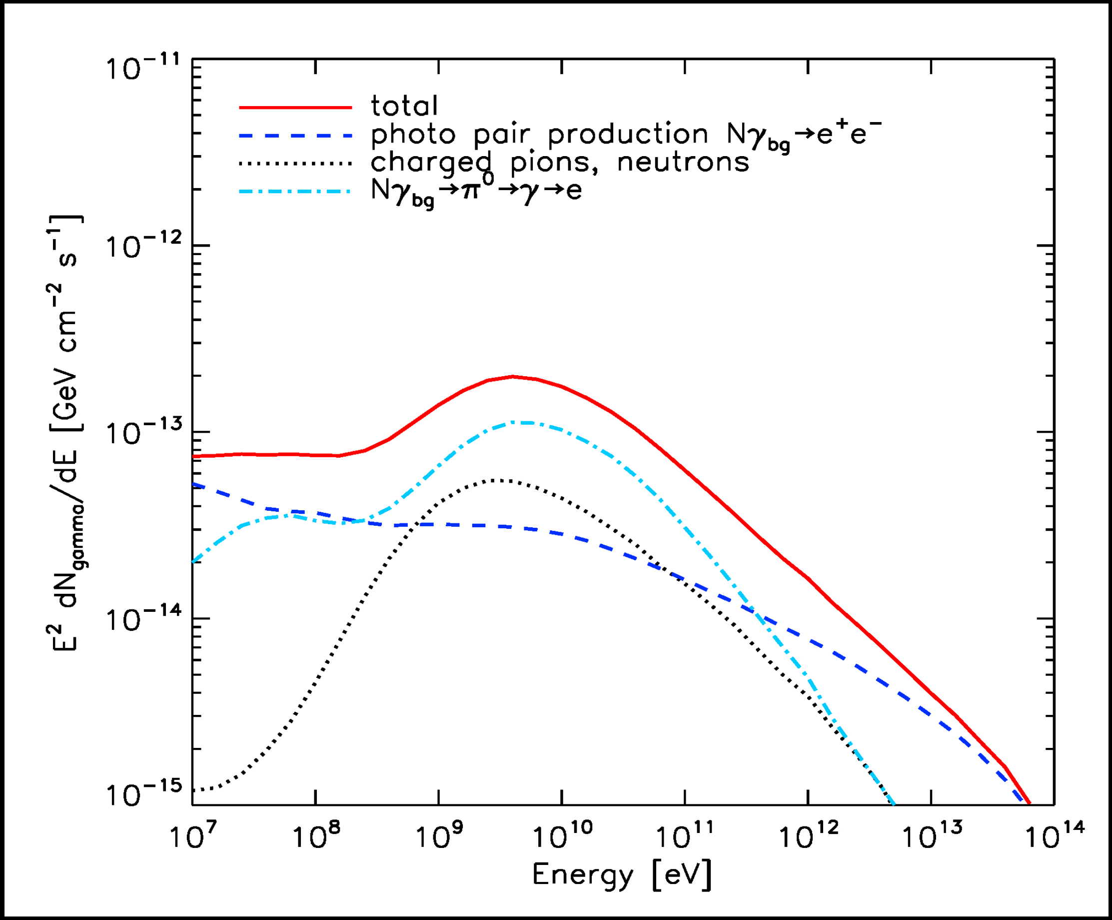
Arriving Synchrotron Flux for Fe only Composition (B=1 nG)

taken from Kotera et al. (astro-ph/1011.0575)



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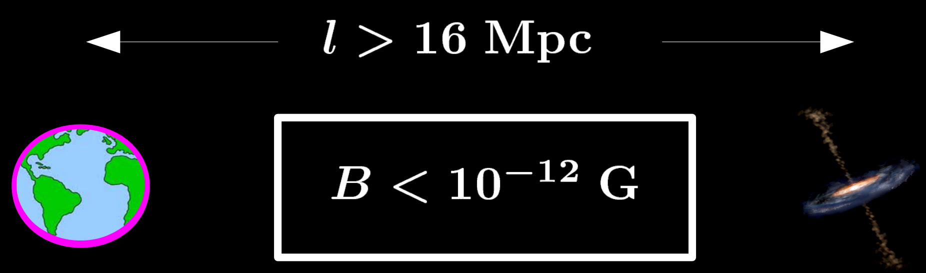
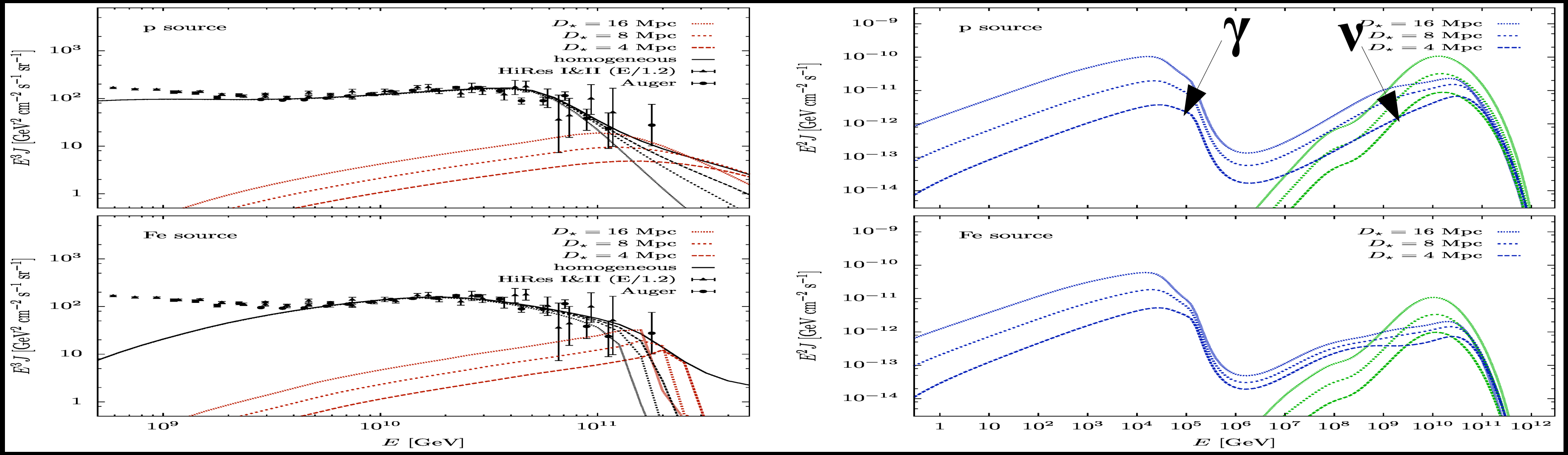
Cascades in <pG B-Fields



Ahlers et al. (astro-ph/1105.5113)



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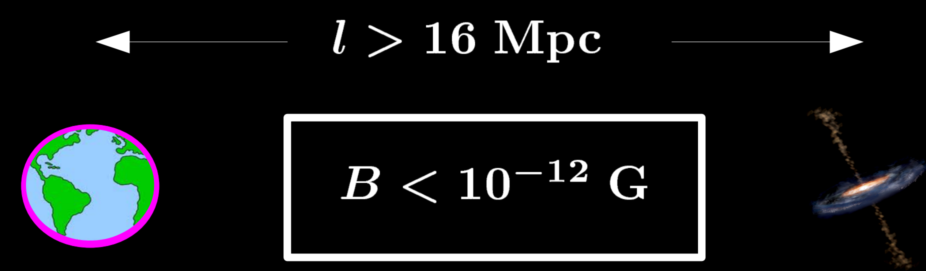
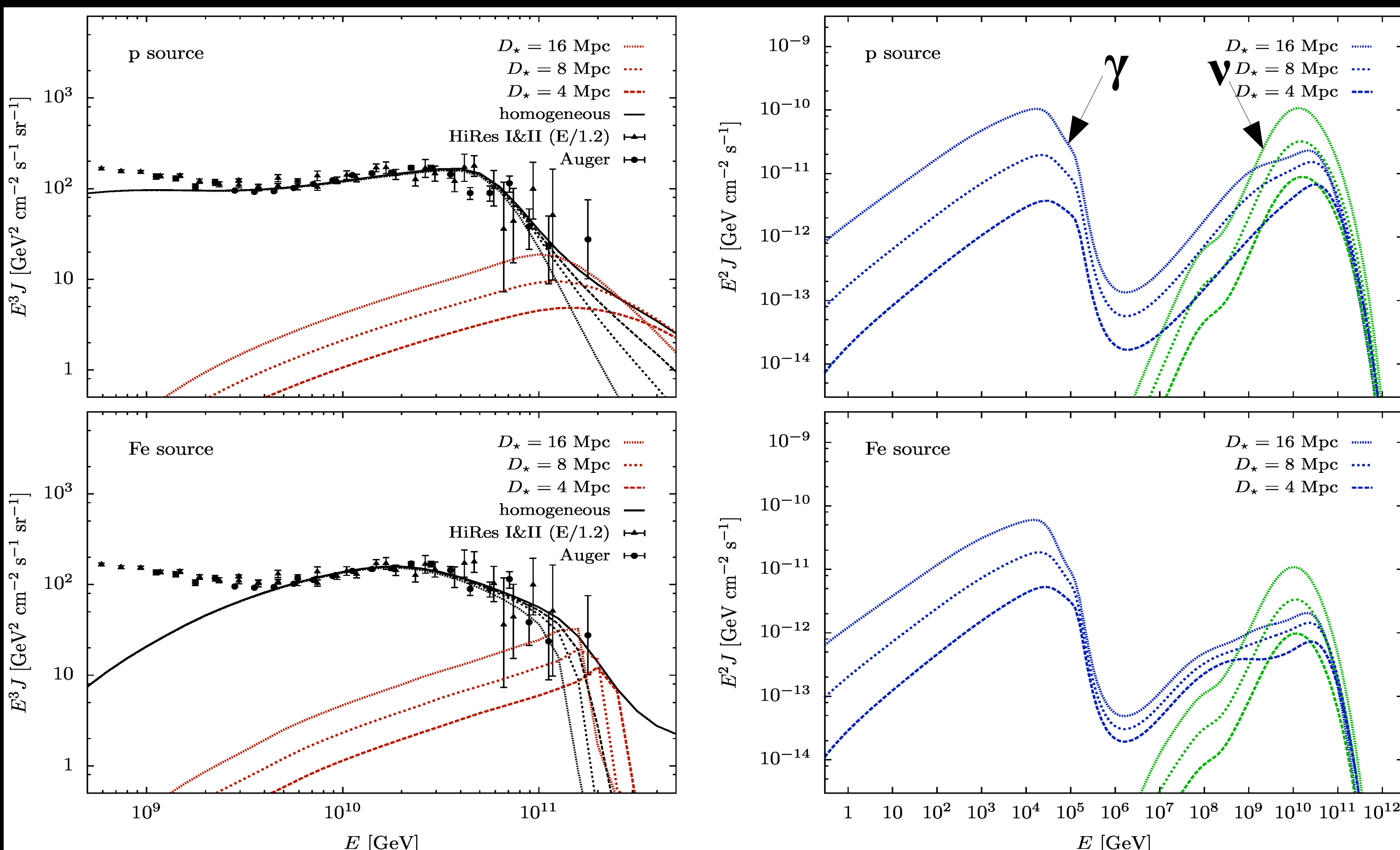
Cascades in <pG B-Fields



Ahlers et al. (astro-ph/1105.5113)



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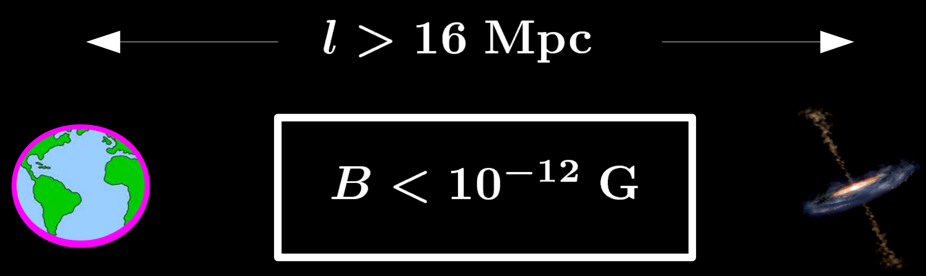
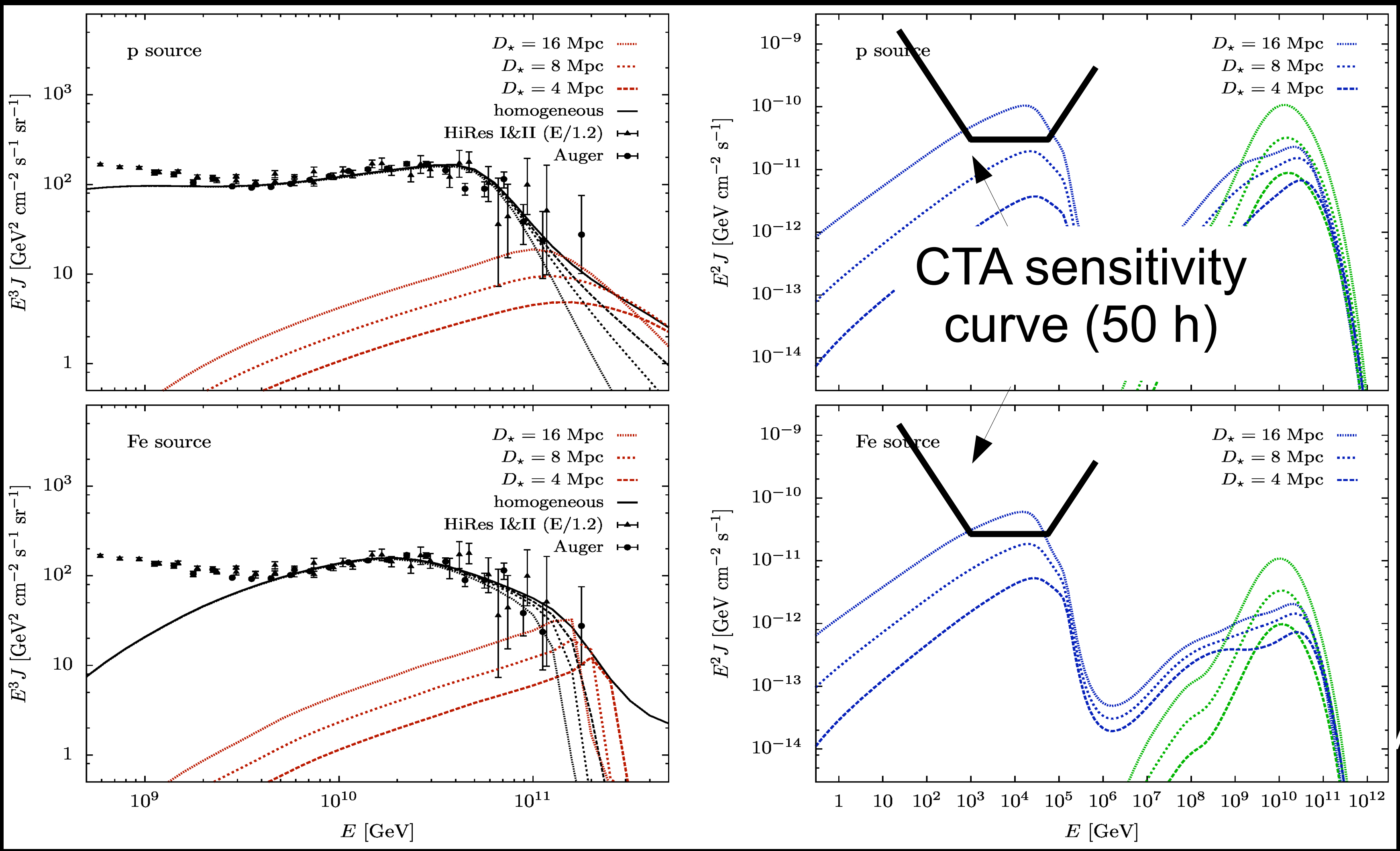
Cascades in <pG B-Fields



Ahlers et al. (astro-ph/1105.5113)



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Steady or Variable Fluxes?

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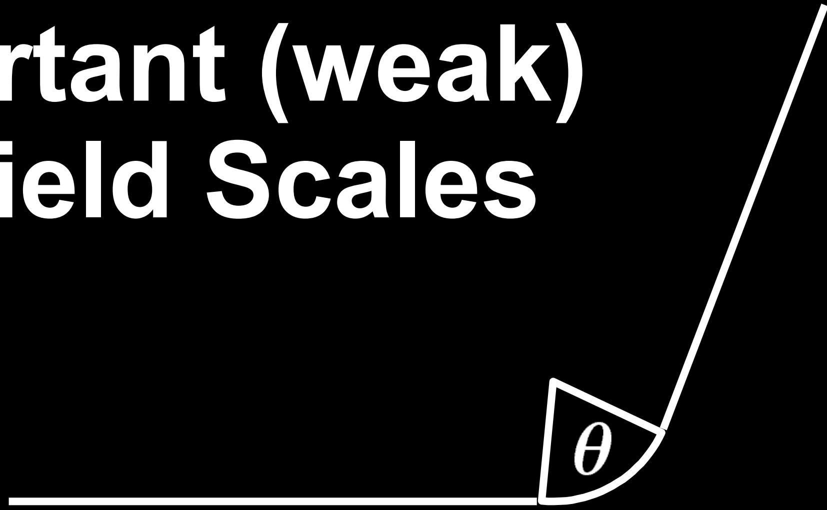
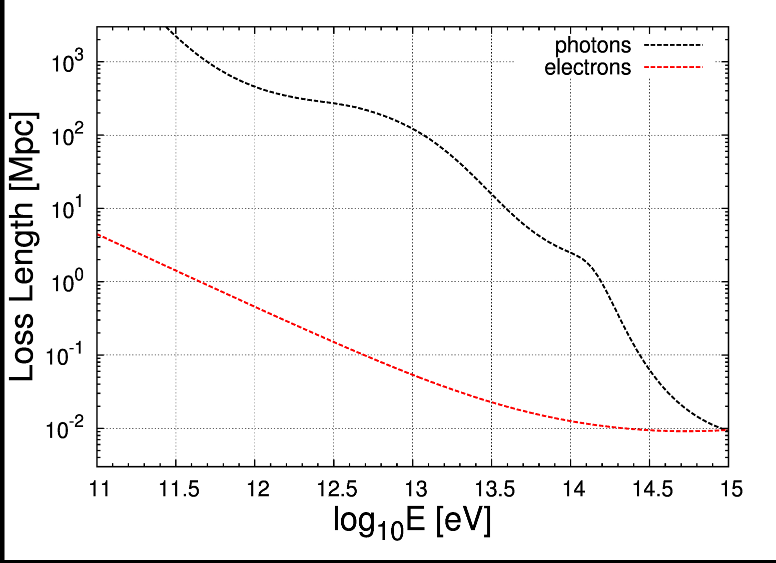
Important (weak) B-Field Scales





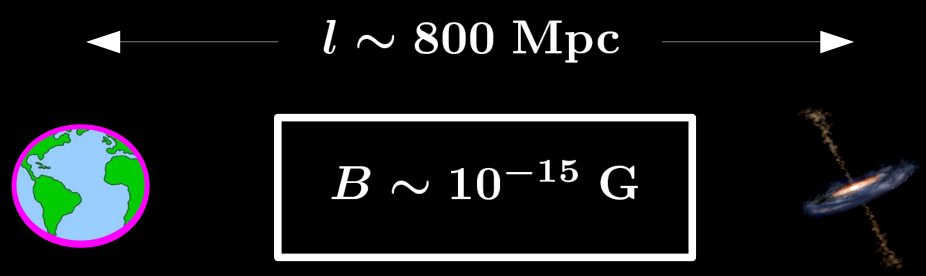
$$\theta = \frac{ct_{\rm cool}}{R_{\rm lar}}$$

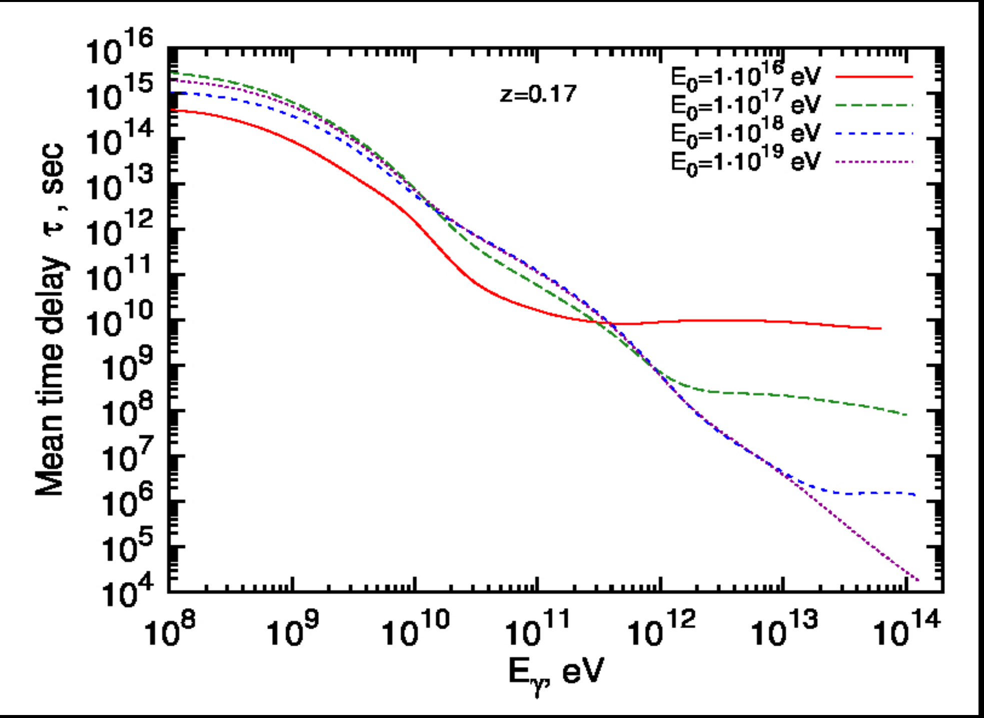
$$ct_{\rm cool}(10^{13}\ {\rm eV}) \approx 0.1\ {\rm Mpc}$$

$$R_{\rm lar} = \left(\frac{E_e}{10^{13}{\rm eV}}\right)\left(\frac{0.1\ {\rm pG}}{B}\right) 0.1\ {\rm Mpc} \longrightarrow \theta \sim 1\ {\rm rad.}$$

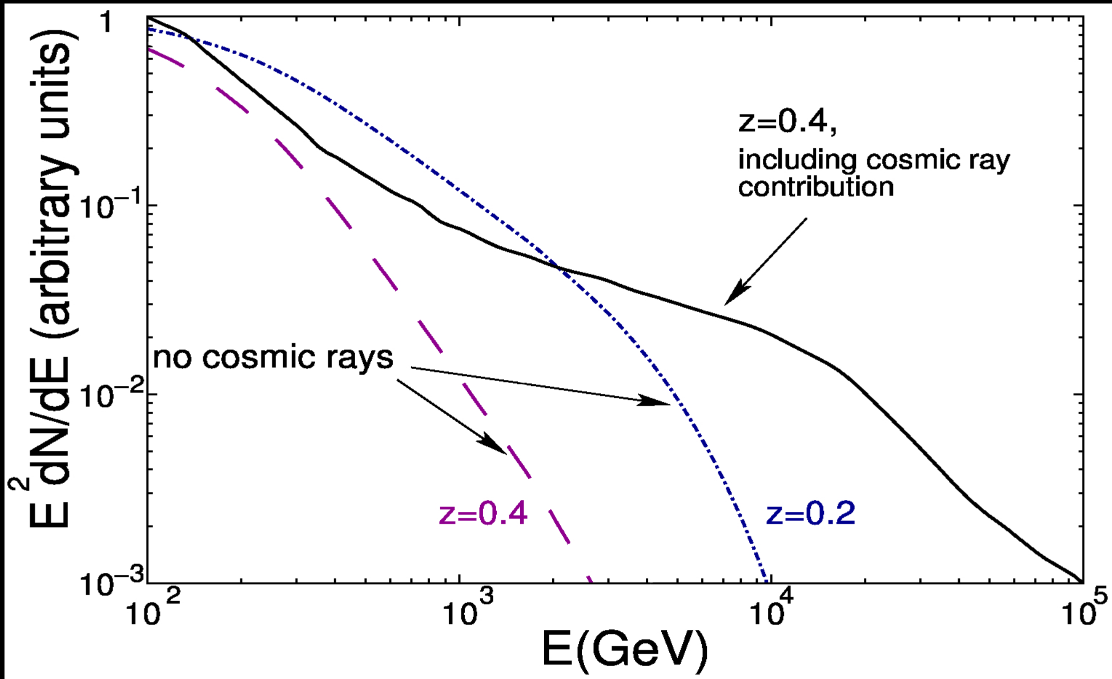
$$R_{\rm lar} = \left(\frac{E_e}{10^{13}{\rm eV}}\right)\left(\frac{\rm fG}{B}\right) 10\ {\rm Mpc} \longrightarrow \theta \sim 10^{-2}\ {\rm rad.}$$

Cascades in >pG B-Fields

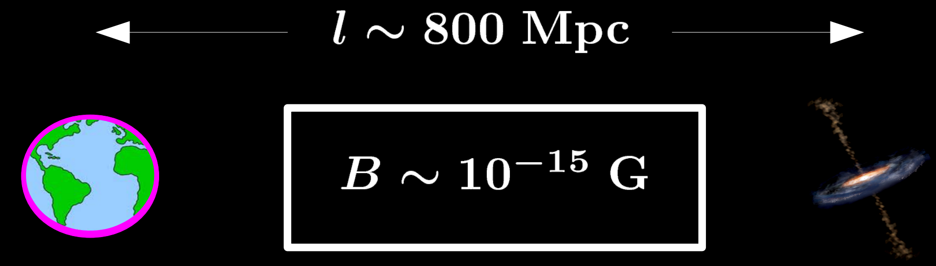




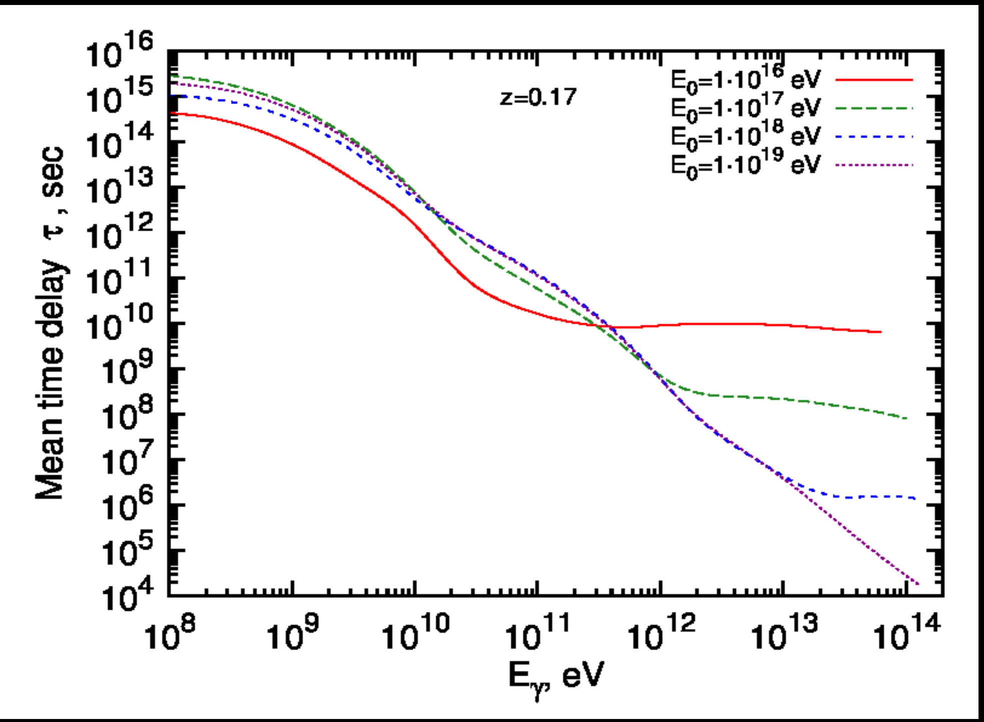
Prosekin et al. (astro-ph/1203.3787)

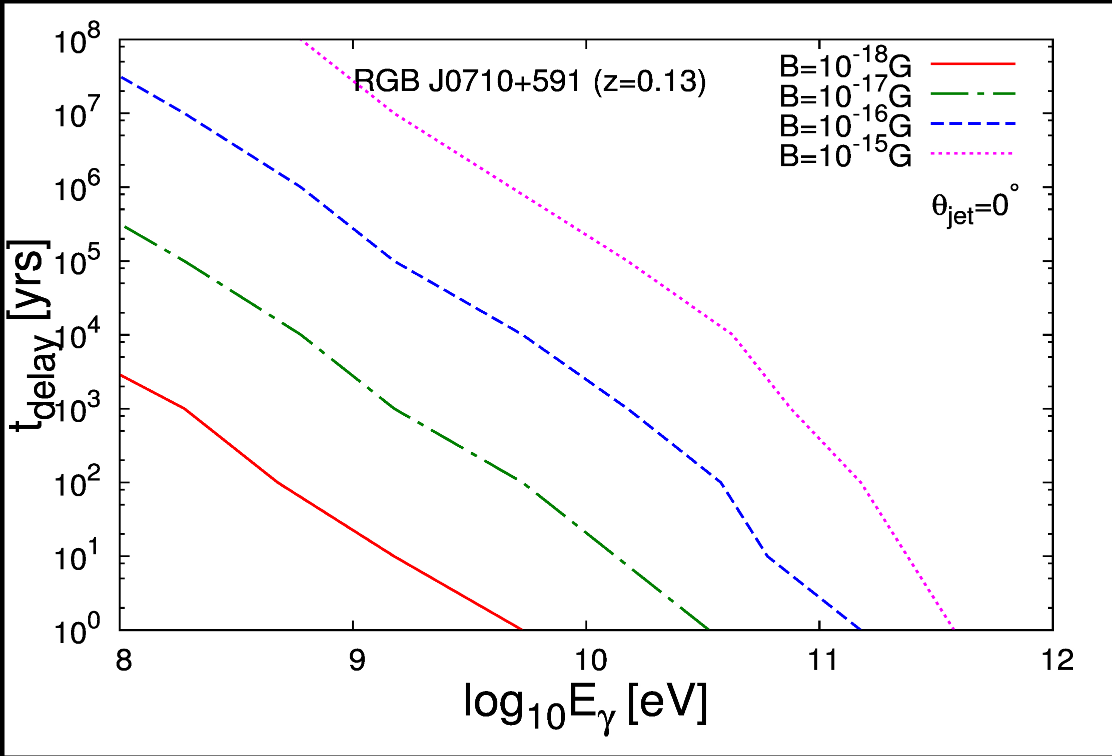


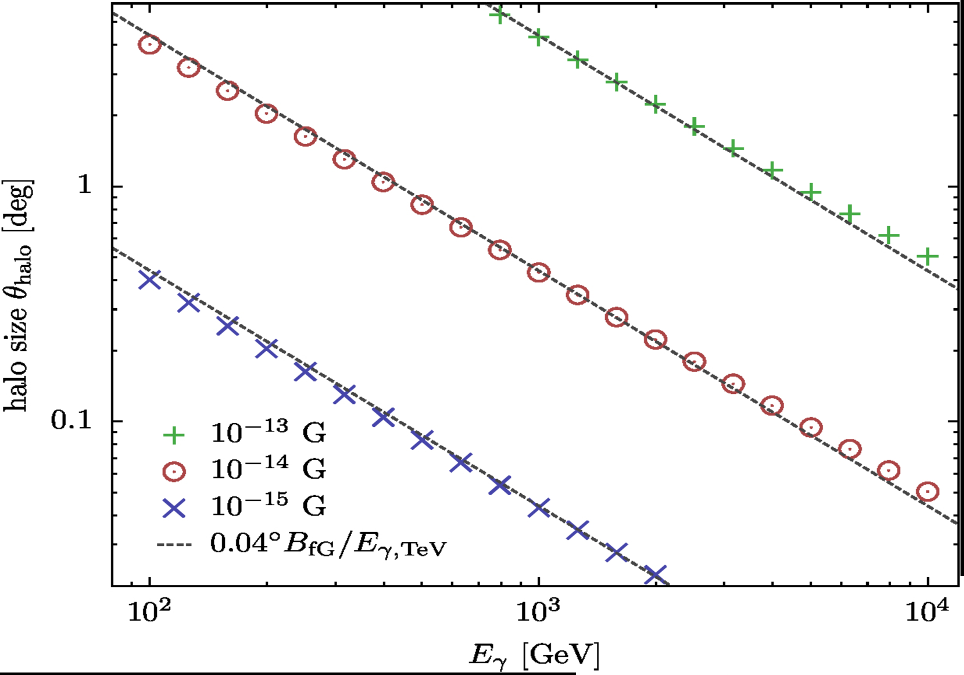
Cascades in >pG B-Fields



Prosekin et al. (astro-ph/1203.3787)

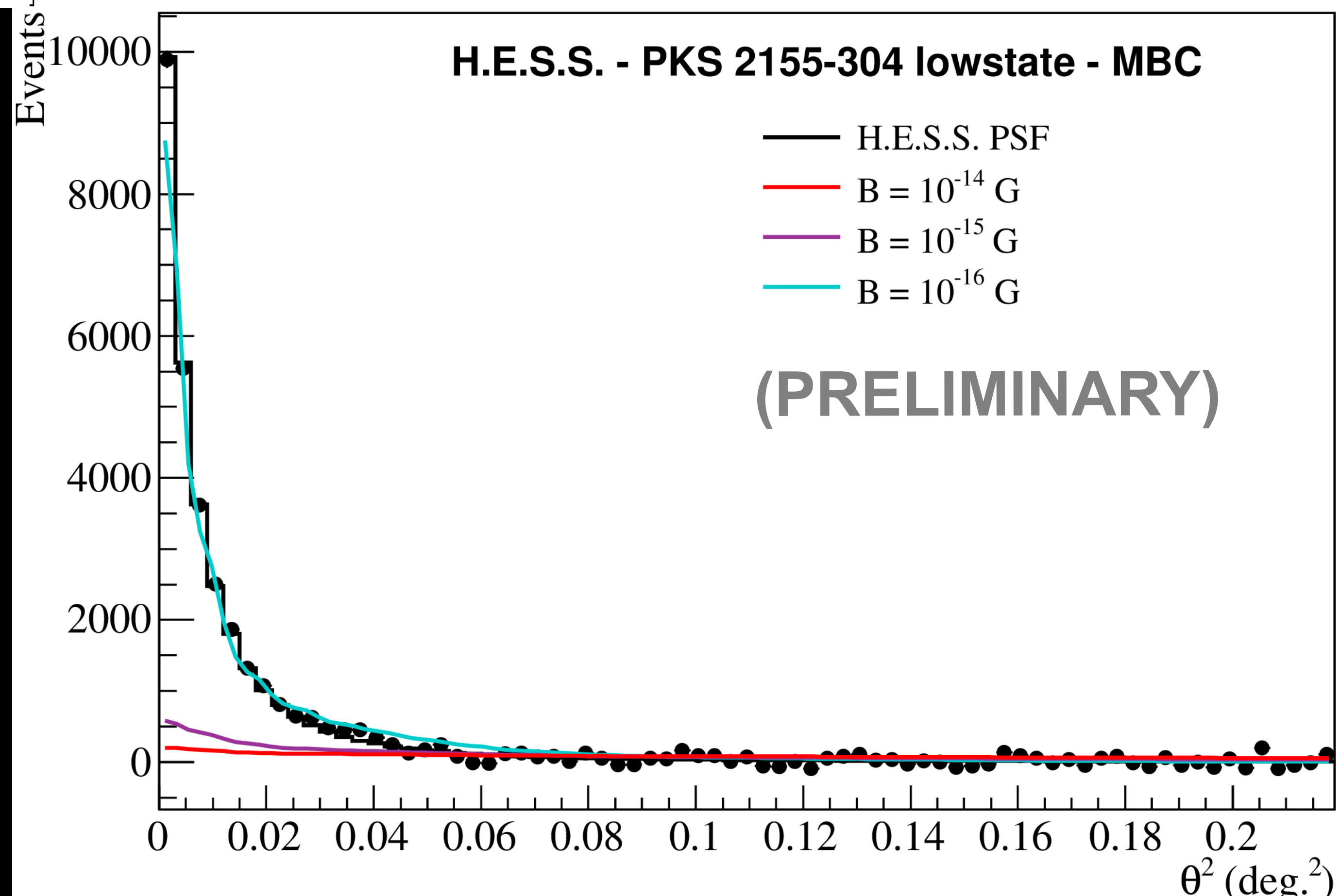




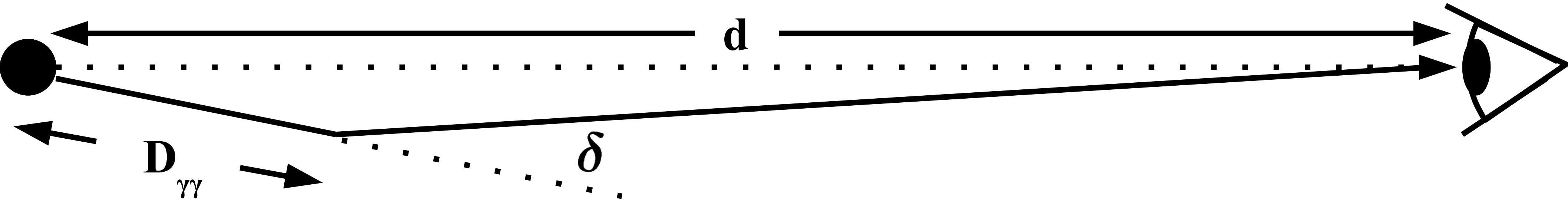


Ahlers et al.
(astro-ph/1105.5113)

Will we Know a Cascade If We See One?

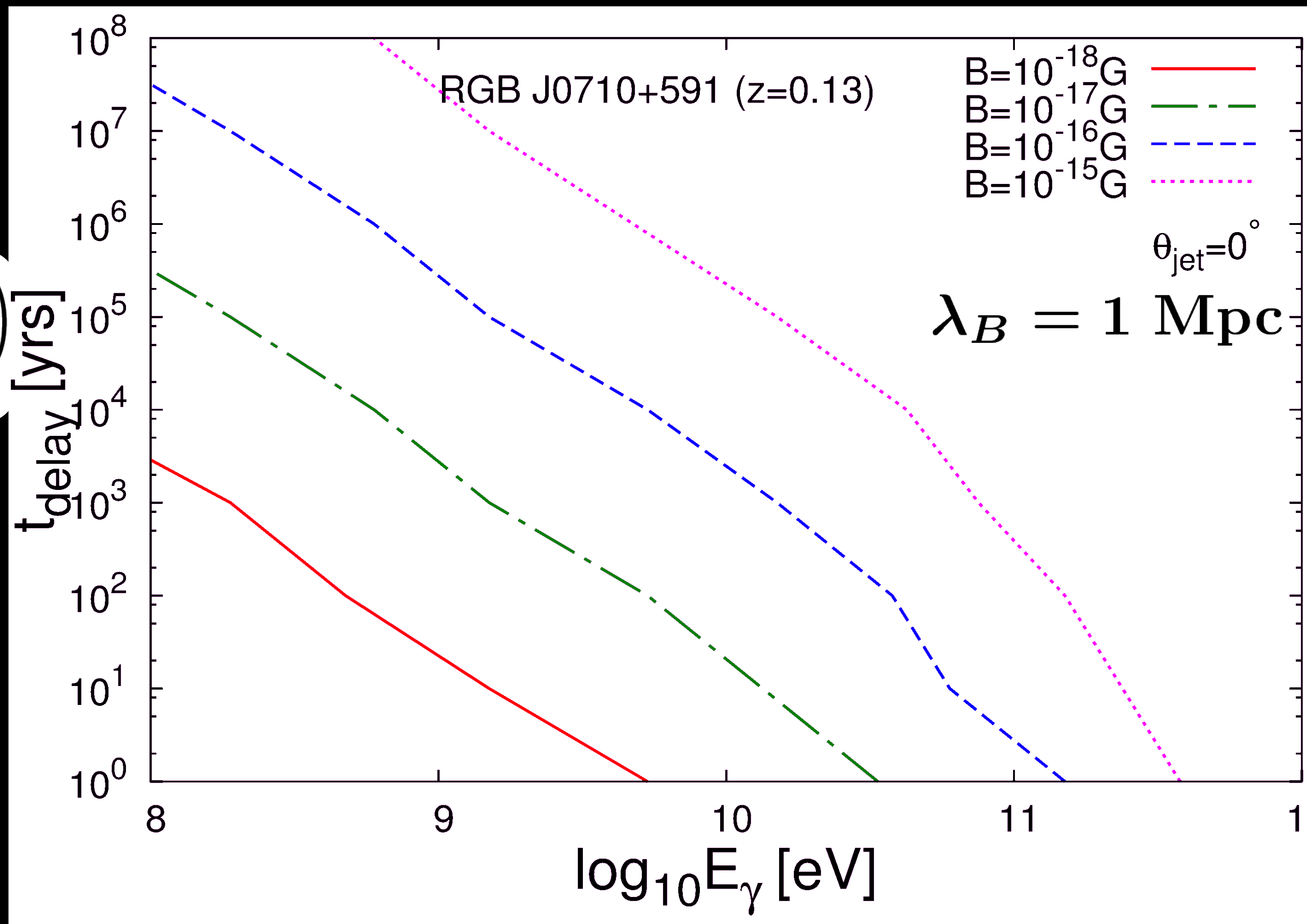


Time Delay Effects for Different B-field Strengths



For $D_{\gamma\gamma} \ll d$

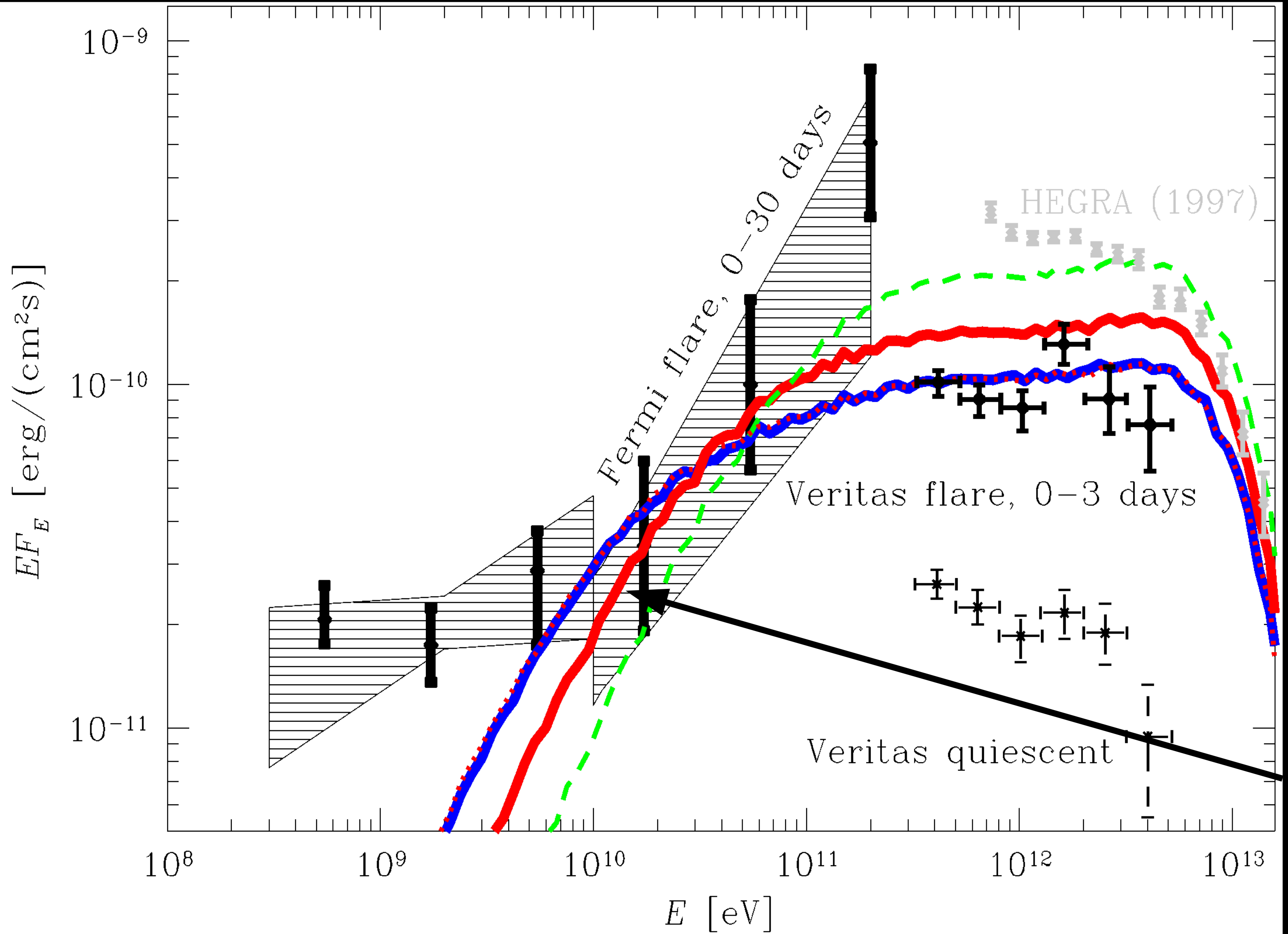
$$t_{\mathrm{delay}} \sim \delta^2_{\mathrm{max}} \left(\frac{D_{\gamma\gamma}}{c}\right)$$



Will we Know a Cascade If We See One?

Example: Mrk 501 orphan flare (2009)

astro-ph/1104.2801



10^{-16} G

$10^{-16.5}$ G

10^{-17} G

spectral slope is fixed by theory

Conclusion

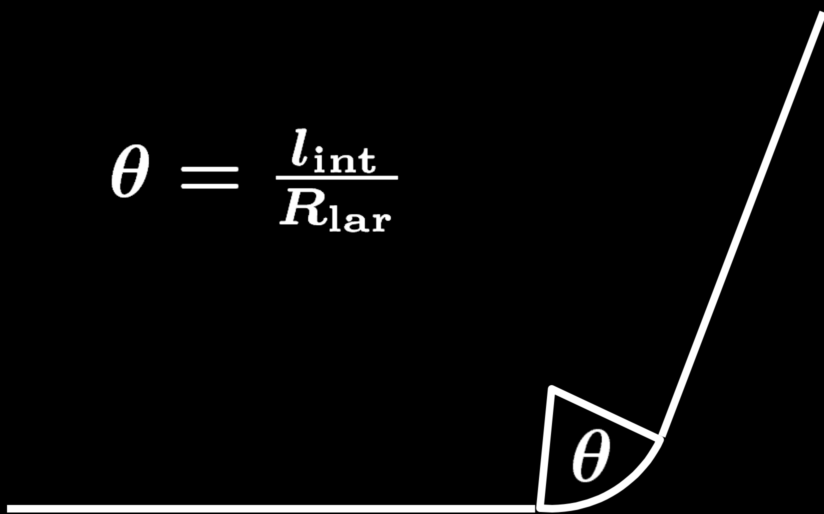
The detection of photon component of UHECR would provide definitive evidence that the UHECR cut-off is due to losses

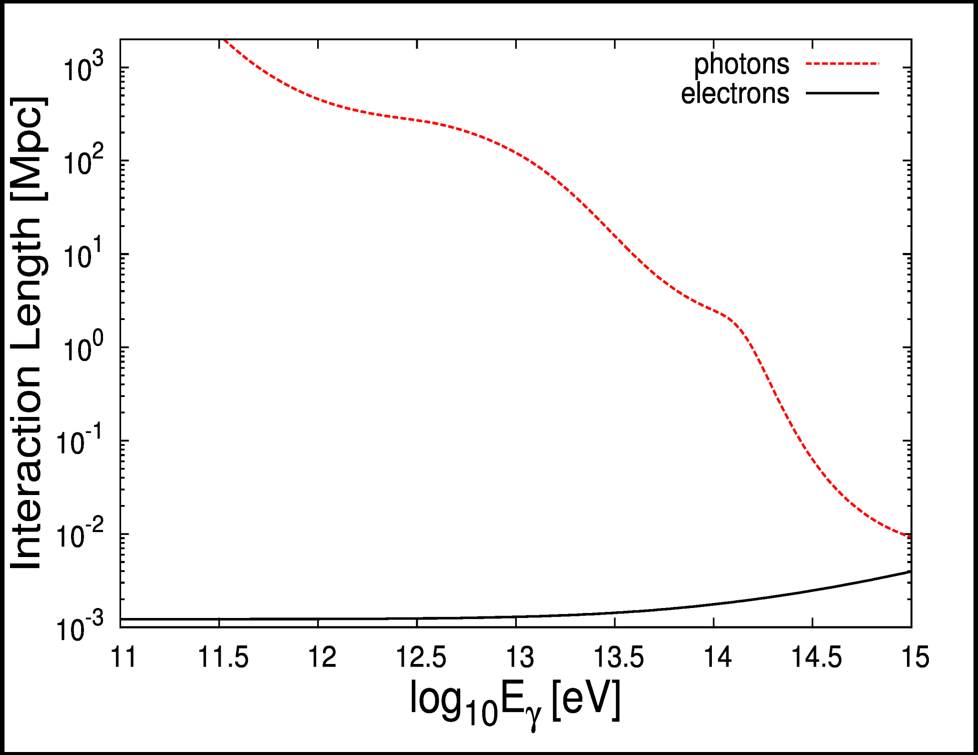
The EeV photon fraction together with the shape of the cut-off in the UHECR spectrum contain useful information about the local (~10s Mpc) UHECR sources. Both Auger + JEM-EUSO have great potential for probing such a component.

The multi-GeV photon component provides an ideal probe for more distant sources. Both angular + temporal signatures can be indicative of a cascade origin. Presently, HESS2, and in the future CTA will be able to probe such emission scenarios.

Important (weak) B-Field Scales

$$\theta = \frac{l_{\rm int}}{R_{\rm lar}}$$





$$l_{\rm int} \approx 1 \text{ kpc}$$

$$R_{\rm lar} = \left(\frac{E_e}{10^{12}\text{eV}}\right)\left(\frac{\text{pG}}{B}\right) \text{ kpc} \longrightarrow \theta \sim 1 \text{ rad.}$$

$$R_{\rm lar} = \left(\frac{E_e}{10^{12}\text{eV}}\right)\left(\frac{\text{fG}}{B}\right) \text{ Mpc} \longrightarrow \theta \sim 10^{-3} \text{ rad.}$$