Physics of cosmological cascades and observable properties

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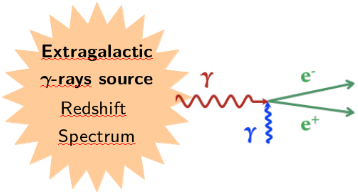
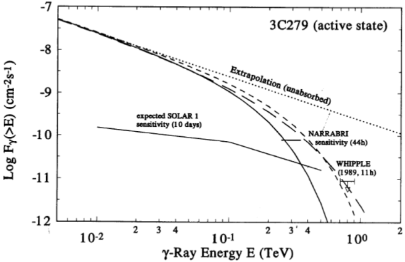
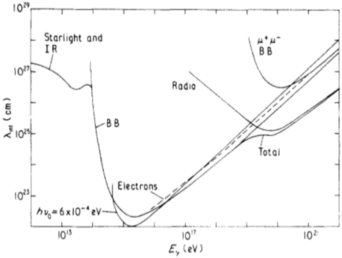
Universe opaque to γ-rays





Stecker et Al 1992



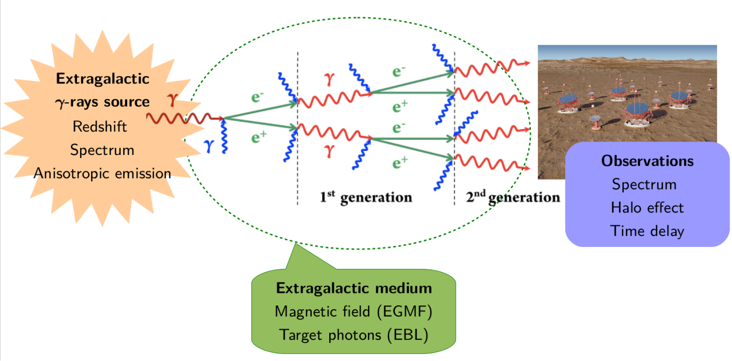
Wdowczyk et Al 1972

- γ-rays + low energy photons

$\Rightarrow$ pair production

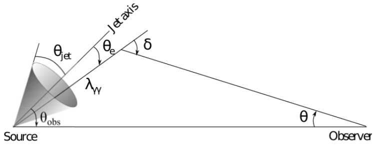
$\Rightarrow$ high energy cut-off

Cosmological electromagnetic cascade



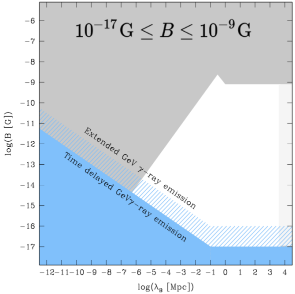
Interactions

γ-rays $\rightarrow$ pair production
e^+/e^- $\rightarrow$ inverse Compton scattering



Origin?

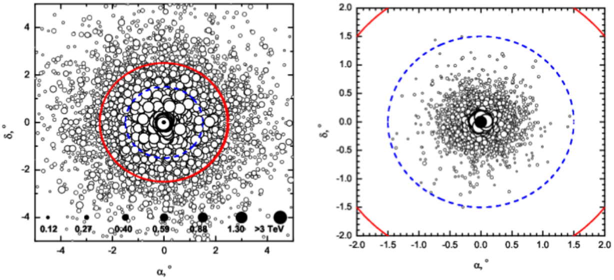
- Galaxies and Clusters $\rightarrow$ $B \approx 10^{-5} G$
- Created during the inflation or during phase transition (QCD or Electroweak decoupling)
- Associated to large structure development



Durrer & Neronov 2013

B and λ_B D'Avezac et al. 2007; Neronov & Vovk 2010; Kachelriess 2010

Chirality Long & Vachaspati 2015; Batista et al. 2016

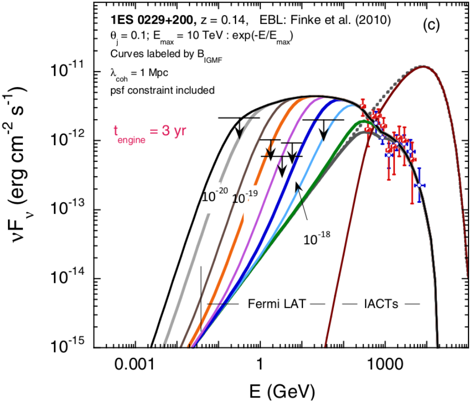


Elyiv et al 2011

D_s	120 Mpc
EGMF	10^{-14}G and 10^{-15}G
FoV	1.5° (MAGIC - blue), 2.5° (HESS - red)

Chen 2016	Fermi data → halos ?
Veritas 2017	individual BL Lacs → no halos

Time delay & Spectrum



Dermer et Al 2011

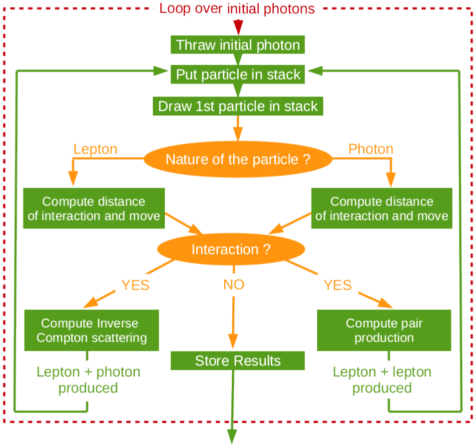
- Photons arrival time and energy correlated (Plaga et Al 1995)
- Strong dependency on the EMGF strength
- Neronov et Al 2009 → non zero-EGMF

Analytic expressions

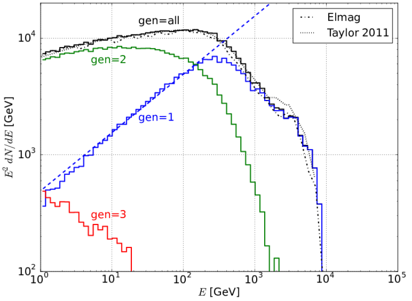
Fast but a lot of approximations

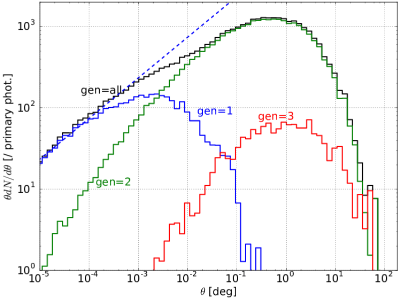
MC simulations

Slower but take into account multiple generations, 3D, cosmology
Other codes: Settimo & De Domenico 2015; Arlen et al 2014; Kachelriess et al 2012 (Elmag); Taylor 2011; Oikonomou et al. 2014; Essey et al. 2011



Distributions & generations





Source 557 Mpc, mono-energetic (100 TeV)

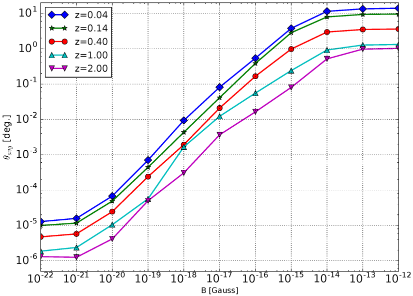
EGMF 3×10^{-16}G

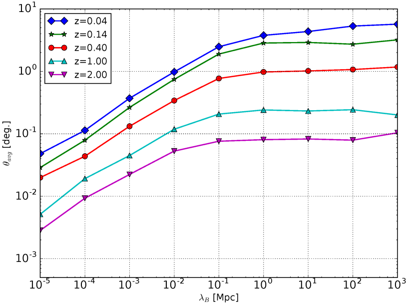
gen. 1 fits well with analytic expressions

gen. 2 dominates the spectrum (GeV) and the halo (few degres)

observations: implies cuts on the angle (PSF, FOV) $\rightarrow$ second generation must be handle with care

EGMF (amplitude and coherence length)





$B > 10^{-14} G$: lepton trapped $\rightarrow \lambda_{\gamma\gamma}$ source halo

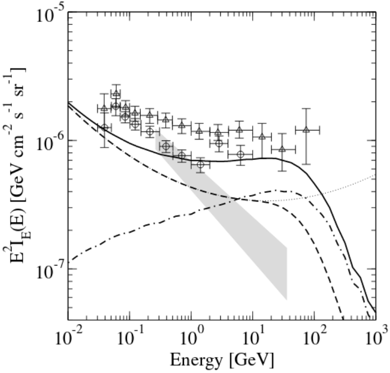
$B < 10^{-14} G$: B increases, halo and time delay also

$B < 10^{-21} G$: intrinsic extension of the cascade

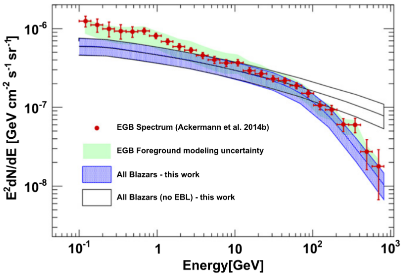
$\lambda_B > 1 Mpc$: uniform magnetic field $\rightarrow$ independence

$\lambda_B < 10 kpc$: random walk $\rightarrow \theta_{avg} \propto \lambda_B^{1/2}$

Cascades contribution to the extragalactic gamma-ray background



Venters et Al 2010



Ajello et Al 2015

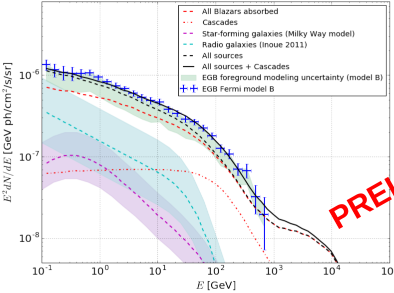
data EGRET (271 sources with 93 blazars)

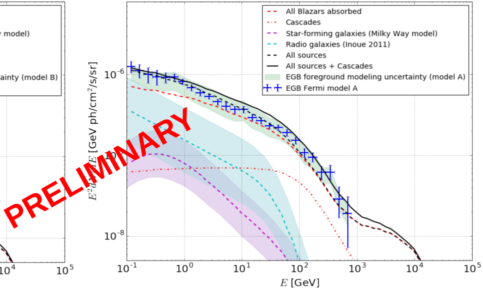
EGB Cascades (dash dot) contribution $E > 10$ GeV

data Fermi (403 blazars)

EGB Blazars $\simeq 70\%$, no cascade

Cascades contribution to the extragalactic gamma-ray background





- sources only $\rightarrow$ below data points
- adding cascades $\rightarrow$ compatible with data points

- sources only $\rightarrow$ compatible with data points
- adding cascades
  $\rightarrow$ reach the upper limit of systematic uncertainties
  $\rightarrow$ possible excess between 10 GeV and 100 GeV

Article

- https://doi.org/10.1093/mnras/stw3365
- https://arxiv.org/abs/1701.00654
- review of the parameters space on cascades observables
- simulation code available: https://gitlab.com/tfitoussi/cascade-simulation

Cascades contribution to EGRB

- Preliminary work
- Excess has to be checked