First studies of effect of CMB and EBL on detection of HE γs

CTA-UK Meeting September 2012

Jo Darling

Tim Greenshaw

University of Liverpool

First look at interactions of HE photons in cosmos

- High Energy γs produced in AGNs, PWNs…
- Travel through space & can be detected on earth by HESS, CTA…
- …but don't penetrate through the cosmos forever!

- Observed energy spectrum differs from that at source due to expansion of Universe (red shift) and absorption /interaction of γs in flight

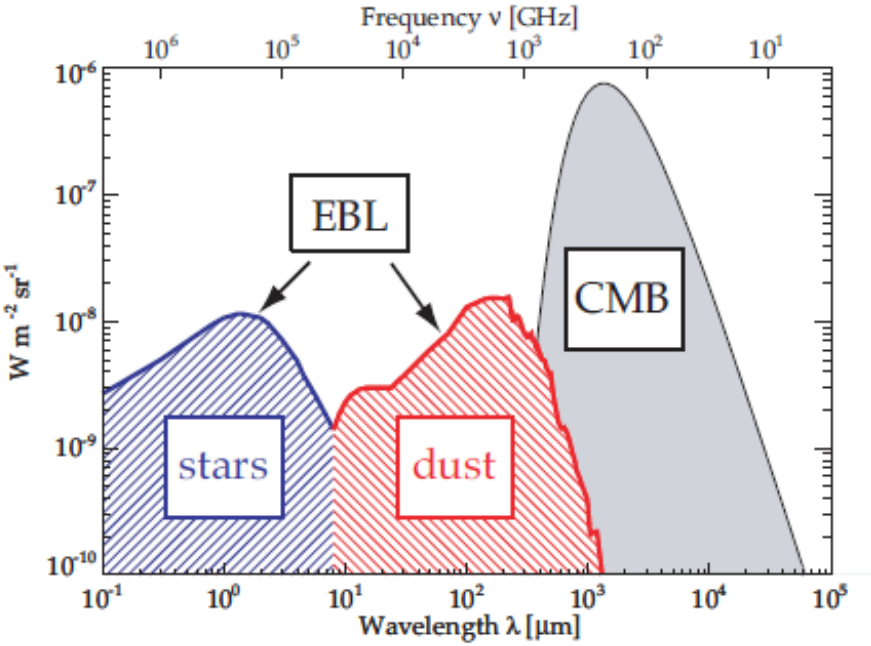


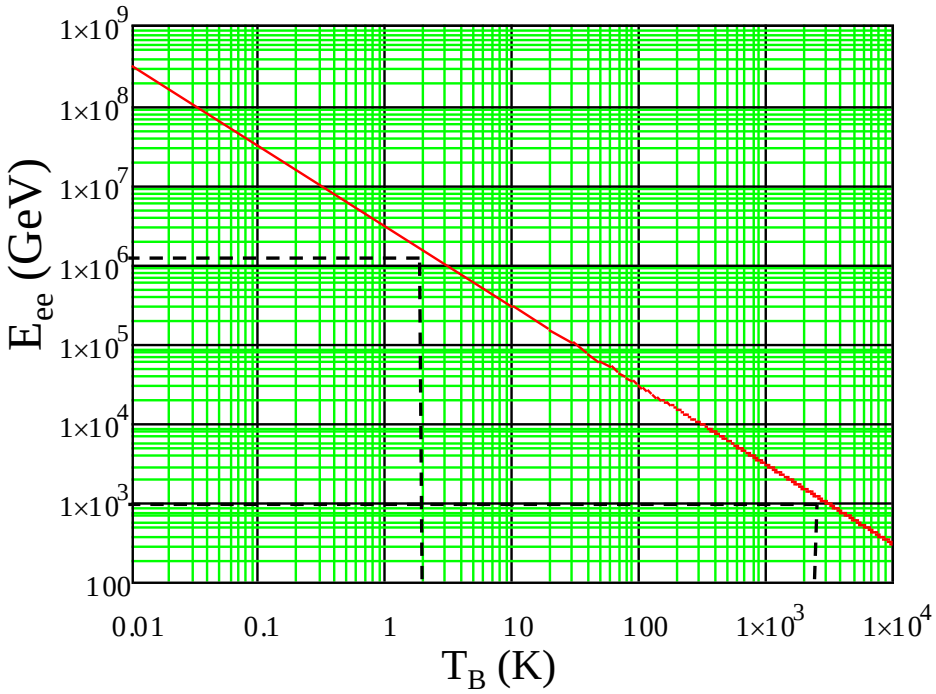
Figure: Schematic Spectral Energy Distributions of most important backgrounds in the universe. http://arxiv.org/abs/0904.0774

First look at interactions of HE photons in cosmos

- For HE γs, primary interaction is pair production, $\gamma\gamma \rightarrow e^+e^-$.
- For this to happen, we need $\sqrt{s} > 2m_e$.
- Hence, for "bath" of γs at temp. T_B, energy $E_B = k_B T$, threshold for HE γ to pair produce is:

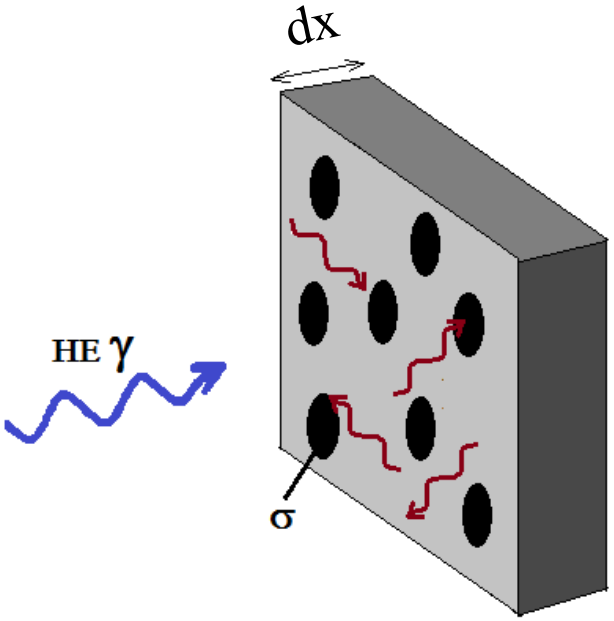
$$E_{ee} = \frac{2m_e^{\,2}}{k_B T_B (1 - \cos\theta)}.$$

- E.g. head-on collisions, in "bath" frame:



- (Threshold for muon production too high to be of direct concern.)

Cross-section for $\gamma\gamma \rightarrow e^+e^-$



- n_γ is the number density of bath photons.

- Cross-section for $\gamma\gamma \rightarrow e^+e^-$ given by:

$$\sigma_{ee} = \frac{4\pi m^2}{s}\left(\left(2+\frac{8m^2}{s}-\frac{8m^4}{s^2}\right)\ln\left(\frac{\sqrt{s}}{2m}+\sqrt{\frac{\sqrt{s}}{2m}-1}\right)-\sqrt{1-\frac{4m^2}{s}}\left(1+\frac{4m^2}{s}\right)\right)$$

- The penetration of γs through this bath is given by:

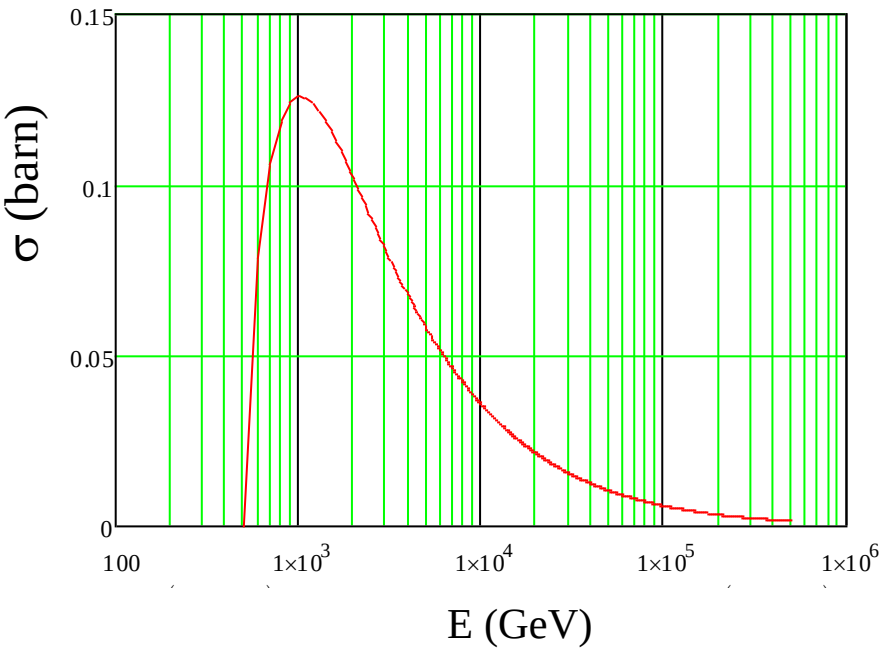
$$N = N_0 \exp\left(-n_\gamma \sigma_{ee} x\right)$$

$$= N_0 \exp\left(-\frac{x}{\lambda}\right).$$

- The penetration depth $\lambda = 1/n_\gamma \sigma_{ee}$.

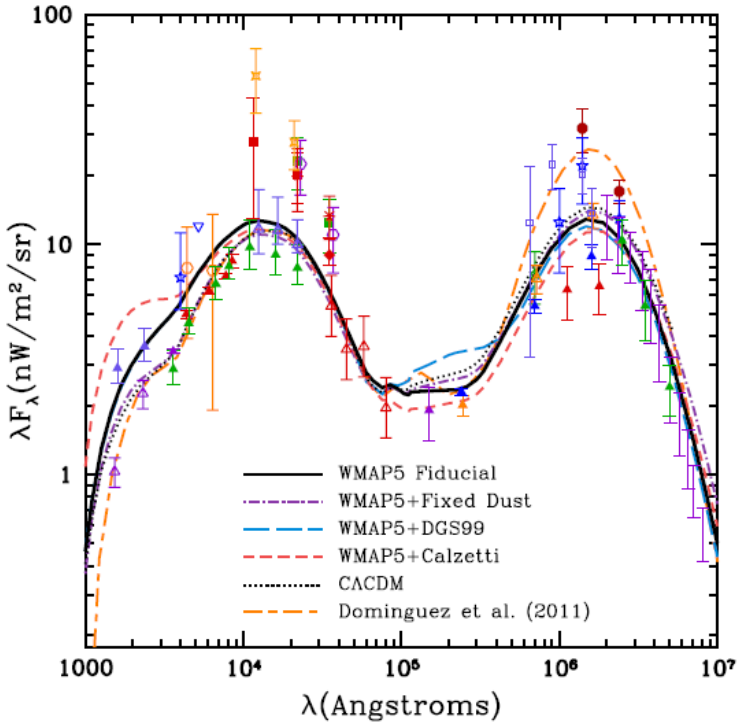
Cross section

- In the “bath” frame, for T_B = 6000K and head-on collision:



Photon spectrum

- To calculate penetration depth need information on “bath” photons.
- Composed of EBL + CMB.
- EBL spectrum:



Predicted EBL spectrum from http://arxiv.org/abs/1104.0669:

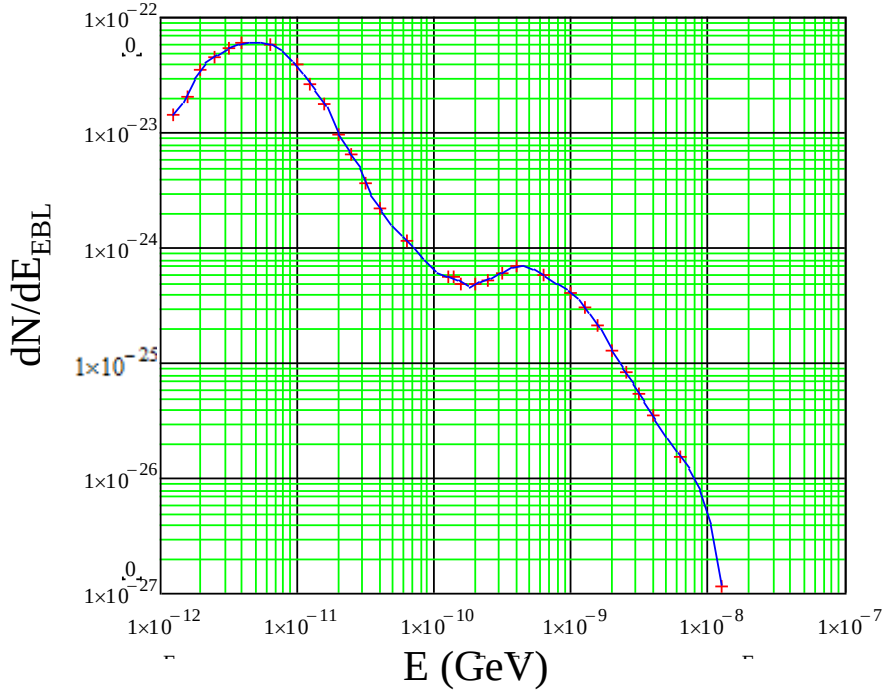
EBL spectrum

CMB spectrum

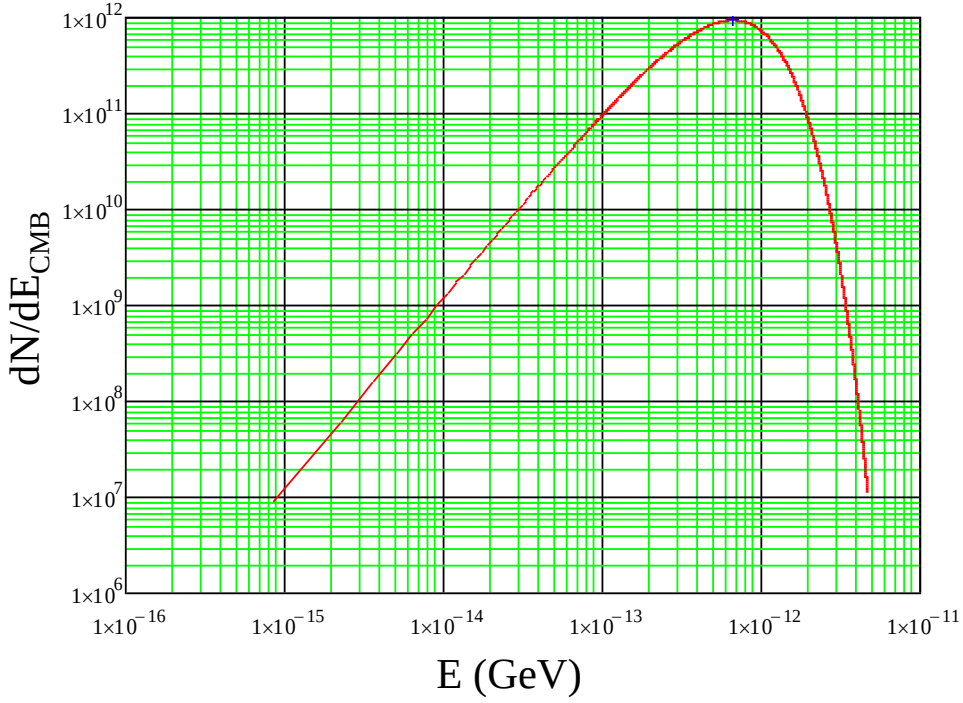
- Use Jacobian transformation of dNdλ to get dNdE:

$$dNdE = \frac{h\ c\ q_e}{E}\ dNd\lambda$$

- Fit using spline functions.

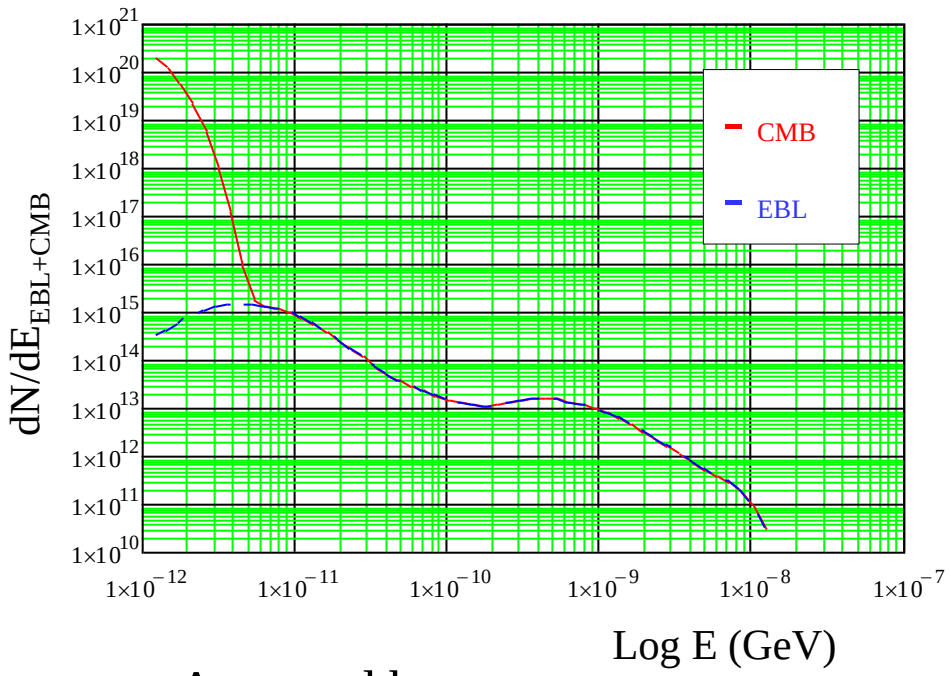


- Black Body at T_{CMB} = 2.7 K:

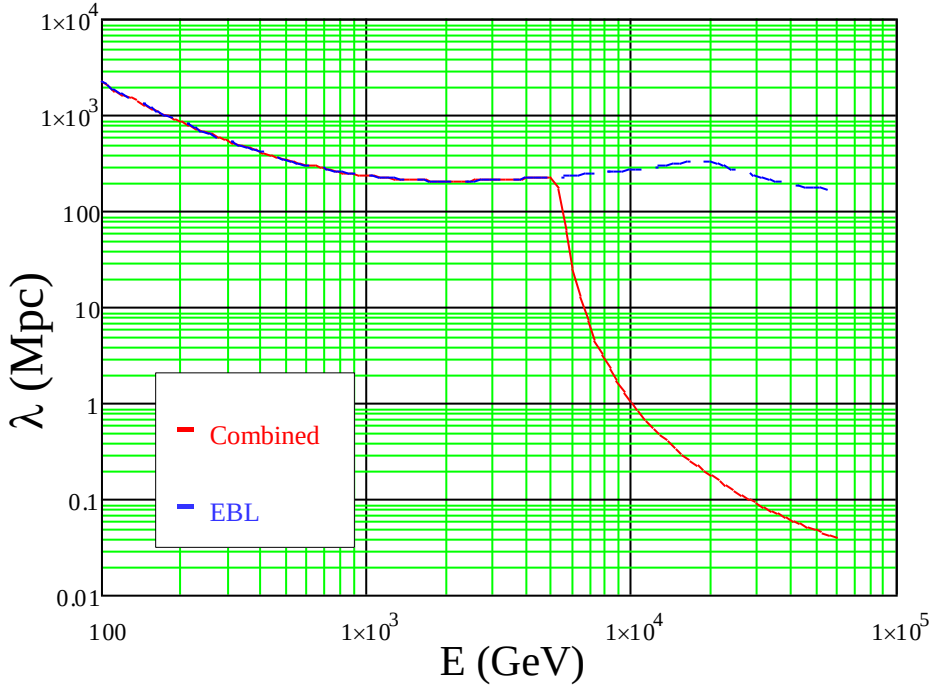


Photon spectrum and interaction length

- Combining EBL and CMB:



- Penetration depth

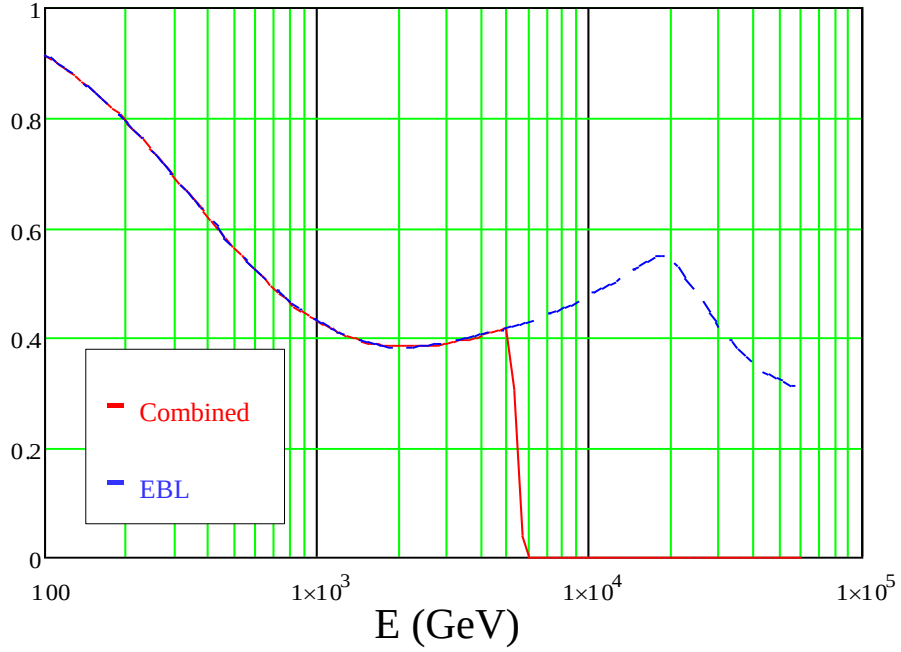


- Assumed here:
  - $n_{CMB} = 420 \times 10^6$.
  - $n_{EBL} = 420 \times 10^2$.

$$\lambda = 1/n_\gamma \sigma_{ee} .$$

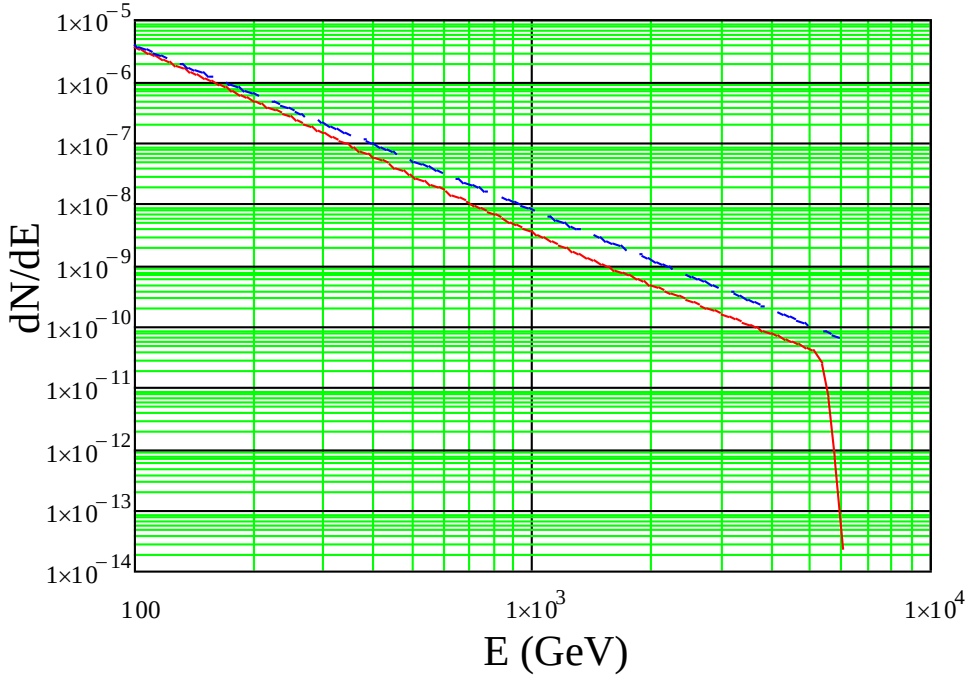
Effects on spectrum of remote source

- How does this photon bath influence the observed spectrum of a remote source?
- Attenuation for source at 200 Mpc (z ~ 0.05).



- Example: assume initial spectrum given by:

$$\frac{dN}{dE} \sim \exp(-\alpha E), \text{ with } \alpha = 2.7.$$



Summary

- Initial study of effect of absorption by EBL and CMB on HE γs detected by HESS, CTA etc.
- Parameterised EBL spectrum and added to CMB spectrum to give some idea of penetration depths for HE γs through the cosmos.
- Photons of energy above a few TeV cannot travel far due to interactions with CMB – HE photons from remote sources could be due to axions.
- Study of absorption of photons with energy up to a few TeV may allow measurement of EBL.
- Need to find and correct mistakes (help appreciated!) and include things like redshift!