Modeling the Extragalactic Background Light from Stars and Dust

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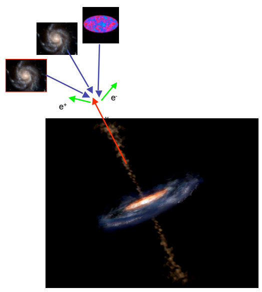
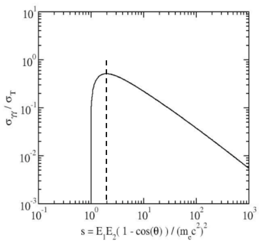
We present a model of the extragalactic background light from the infrared through ultraviolet, which is dominated by starlight either through direct emission or absorption and re-radiation by dust. This model is consistent with luminosity density and star formation data at a variety of redshifts, and has implications for the gamma-ray absorption of distant sources such as blazars and GRBs.

ALL MODEL CALCULATIONS ARE AVAILABLE AT THE WEBSITE:
http://www.phy.ohiou.edu:~finke/EBL/

The *Extragalactic Background Light (EBL)* is the background radiation from all the stars in the universe that have ever existed. It spans the far *infrared*, through the *optical* and into the *ultraviolet*. The UV/optical is from direct stellar radiation, while the infrared is from stellar radiation absorbed and re-emitted by dust. EBL photons absorb γ-rays by creating electron-positron pairs, and thus it is important for γ-ray astronomy.





Above: γγ absorption cross section with peak marked.

EBL MODELING

The *stellar emissivity (or luminosity density)* as a function of redshift can be found by integrating over *the star formation rate (SFR)*, *initial mass function (IMF)*, and *stellar spectrum*, which depends on the star's mass and age. Its age will determine where it is on the HR diagram. Dust extinction (Driver et al. (2008) is also included.

$$\epsilon j_\epsilon^{stars}(z) = m_e c^2 \epsilon^2 \frac{dN}{dt\, d\epsilon\, dV} = \epsilon^2 f_{esc}(\epsilon) \int_{m_{min}}^{m_{max}} dm\ \xi(m)\ \dot{N}_*(\epsilon; m, t_*(z)) \times \int_z^{z_{max}} dz_1 \left|\frac{dt_*}{dz_1}\right| \psi(z_1)\ .$$

IMF; Stellar spectrum; Dust absorption; SFR

From the stellar emissivity, the dust emission is computed self consistently, assuming a three component dust model.

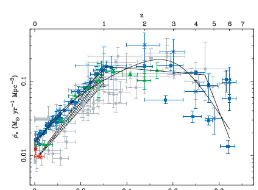
$$f_n \int d\epsilon\, \frac{1}{f_{esc}(\epsilon)}[1 - f_{esc}(\epsilon)]\, j_\epsilon^{stars}(z) = \int d\epsilon\, j_{\epsilon,n}(\Theta_n)$$

Dust emissivity

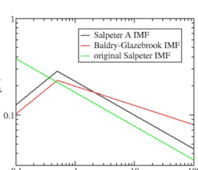
Component	n	f_n	T_n [K]	Θ_n $[10^{-9}]$
Warm Large Grains	1	0.60	40	7
Hot Small Grains	2	0.05	70	12
PAHs	3	0.35	450	76

Finally, once the emissivities are known, the EBL energy density can be calculated as a function of redshift.

$$\epsilon u_{EBL}(\epsilon; z) = \int_z^{z_{max}} dz_1 \frac{\epsilon'' j_{\epsilon''}(z_1)}{(1+z_1)} \left|\frac{dt_*}{dz_1}\right|$$



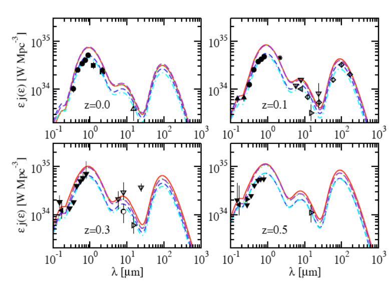
Left: collection of SFR data from Hopkins and Beacom (2006) with different fits, including Cole et al. (2001) parameterization (smooth curve).

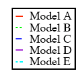


Above: IMFs used in Modeling

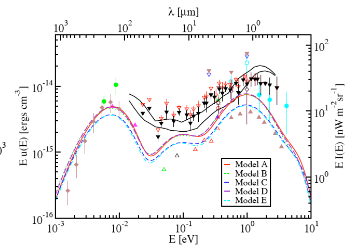
We used five different combinations of IMF and SFR, all of which fit the SFR data from Hopkins & Beacom about the same:

- *Model A*: Cole et al. (2001) SFR and Salpeter A IMF
- *Model B*: Hopkins & Beacom (2006) SFR using Cole et al. (2001) parameterization and Salpeter A IMF
- *Model C*: Hopkins & Beacom (2006) SFR using Cole et al. (2001) parameterization and Baldry & Glazebrook (2003) IMF.
- *Model D*: Hopkins & Beacom (2006) SFR and Salpeter A IMF
- *Model E*: Hopkins & Beacom (2006) SFR and Baldry & Glazebrook (2003) IMF



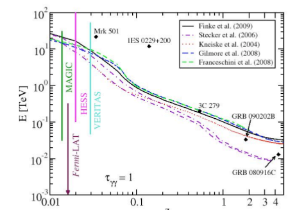


Above: Collection of luminosity density data and model predictions. Model C fits the data the best. See Finke, Razzaque, & Dermer (2009) for references for the data.



Above: Collection of EBL energy density measurements and limits. See Finke, Razzaque, and Dermer (2009) for references for the data. Lower limits are from galaxy counts, with a few minor inconsistencies with models. Upper limits, from TeV γ-ray blazar observations (Finke & Razzaque 2009; Mazin & Raue 2007), are consistent with models.

ABSORPTION OF GAMMA-RAYS



Above: The plot of $\tau_{\gamma\gamma}$ = 1 for a variety of recent EBL models, and the highest energy photons observed from certain blazars and GRBs observed with Cherenkov γ-ray telescopes and the *Fermi*-LAT. *Left*: The TeV spectrum of several blazars observed (black) and deabsorbed with our model (red). See Finke, Razzaque, & Dermer (2009) for references for γ-ray observations.

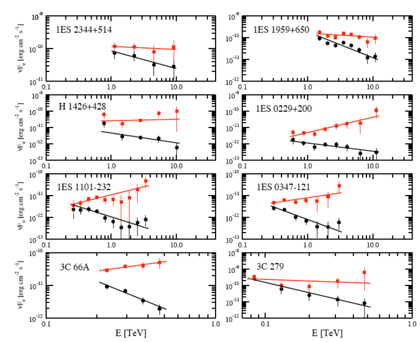


TABLE 3
Deabsorbed TeV Blazars

Blazar	Redshift	Observed Γ	Deabsorbed Γ	ξ	Reference
1ES 2344+514	0.044	2.54 ± 0.18	2.10 ± 0.68	4.7	Schroedter et al. (2005)
1ES 1959+650	0.047	3.18 ± 0.17	2.18 ± 0.33	4.7	Aharonian et al. (2003a)
1ES 1426+428	0.129	2.60 ± 0.60	1.91 ± 0.58	2.2	Aharonian et al. (2003b)
1ES 0229+200	0.139	3.09 ± 0.26	1.07 ± 0.45	1.8	Aharonian et al. (2007c)
1ES 1101-232	0.186	2.94 ± 0.20	1.27 ± 0.46	5.7	Aharonian et al. (2007a)
1ES 0347-121	0.188	3.10 ± 0.25	1.56 ± 0.43	6.5	Aharonian et al. (2007b)
3C 66A	0.444	4.10 ± 0.72	1.28 ± 0.98	19.6	Acciari et al. (2009)
3C 279	0.536	4.11 ± 0.68	2.33 ± 0.89	16.0	Albert et al. (2008)

CONSTRAINING REDSHIFT WITH THE EBL

The gama-ray observations of distant sources such as blazars and gamma-ray bursts can be used to constrain the redshifts of sources. This has been demonstrated by several papers by the Fermi collaboration.

The upper limit on redshift is found by finding the redshift that satisfies:

$$\frac{\int_{E_{max}}^{\infty} dEf(E)\exp[\tau_{\gamma\gamma}(E,z)]}{\int_{E_{max}}^{\infty} dEf(E)} < P$$

Where f(E) is the observed spectrum, P is the probability limit desired, and E_{max} is the highest energy photon from a source (blazar or GRB).

This technique is demonstrated with the GRB 080916C. The highest energy photon observed from this GRB is 13 GeV and it has a redshift of z=4.35 (Abdo et al. 2009). However, if we pretend the highest energy photon observed was 70 GeV in time bin "d", and using the EBL model of Finke, Razzaque, & Dermer (2009), we get the redshift constraints:

$z < 0.84$ (one sigma)
$z < 4.09$ (three sigma)

This demonstrates how the EBL can be used to constrain the redshifts of future GRBs.

References:

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