H.E.S.S. Blazar Observations: Implications for EBL Models and GLAST

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Outline

• H.E.S.S. Observations
• Semi-Analytic Models – a handle on the astrophysics imprinted on the EBL (extragalactic background light)
  – $\Lambda$CDM and large scale structure
  – Galaxy formation
  – Star formation
• Measuring the EBL
  – Galaxy counts
  – Absolute photometry
  – $\gamma\gamma$ attenuation
• What can GLAST tell us?
• Conclusions
H.E.S.S. Summary

- **High Energy Stereoscopic System**
  - Array of 4 Air Cherenkov Telescopes in Namibia
  - $E \geq 0.1$ TeV
  - $\Delta E/E \sim 0.15$
  - Angular resolution: $\sim 0.1^\circ$
  - Sensitivity: $\sim 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ (at 1 TeV, 100 hr)

- **The Observations**: 2 of 3 highest redshift BL Lac objects detected at TeV energies
  - H 2356–309, $z = 0.165$
    - June – Dec 2004
  - 1ES 1101–232, $z = 0.186$
    - March 04 – June 05
H.E.S.S. EBL Models

- Open symbols: resolved sources (galaxy counts)
- Filled: absolute photometry
Accounting for EBL Attenuation

- Recall Paolo’s caveat: We don’t know the intrinsic spectrum of blazars, so dividing by the attenuation factor can be misleading.
- What do/can we know about blazar spectra?
  - Lower energy synchrotron emission suggest power-law particle distributions
  - Shock acceleration is typically invoked ⇒ theoretical limits on particle distribution: $p \geq 1.5$, where $dN_e/d\Gamma \propto \Gamma^{-p}$
- Electron inverse Compton (and synchrotron) produce photon spectra with $\Gamma = (1 + p)/2$, where $dN/dE \propto E^{-\Gamma}$. Proton interactions will give $\Gamma \sim p$. So, expect $\Gamma \geq 1.25$.
- Anything harder requires processes unusual primary particle distribution – monoenergetic population, etc.
Intrinsic power-law recovered in almost all cases, except for models including IRST/NIRB measurements.

Most "natural" intrinsic spectra found for EBL just above lower limits implied by galaxy counts.
Ingredients of the EBL

- Comprises almost all of the radiated energy of the Universe post-inflation
- Optical/UV from stars and AGNs
- Far IR (50-1000 microns) from reprocessing of OUV by dust
Modeling the EBL

- Semi-Analytic (“forward” evolution) Models (SAMs; e.g., Primack, Sommerville, and collaborators):
  - Gaussian density fluctuations from Inflation
  - Large scale structure from $\Lambda$CDM ($\Omega_m \sim 0.3$, $\Omega_\Lambda \sim 0.7$, $h \sim 0.7$)
  - Collapse and mergers of dark matter haloes
  - Cooling and shock heating of gas
  - Star formation and evolution (IMFs, supernova feedback, ISM enrichment)
  - Effects of dust (absorption and re-emission)
- “Backward” evolution models (e.g., Stecker, Malkan, & Scully 2005)
  - These models do not generally include galaxy SED evolution nor the effects of galaxy mergers, both of which likely contribute significantly to FIR.
Impact of EBL Measurements

- Constrains intrinsic SEDs of sources and their redshift distribution
- e.g., Primack et al. 2000: IMFs (initial mass functions) differ in shape, primarily at $M < M_{\text{Sun}}$, and in metallicity.
More recent SAM calculation

- Cosmology now constrained by WMAP
- OUV fitted at the galaxy count level (in agreement with HESS)
- Accounting for FIR is still a challenge.

Primack et al. 2005: 

\[ \lambda F_{\lambda} \text{[erg/s/cm}^2\text{sr]} \]

\[ 0.1 \quad 1 \quad 10 \quad 100 \quad 1000 \]

\[ \lambda[\mu m] \]
EBL contribution from galaxy counts


- Caveat: “50% of flux from resolved galaxies with V>23 mag lie outside the standard apertures used by photometric packages.”
Absolute Photometry

- Optical/UV: HST/ground-based (Bernstein, Freedman, & Madore 2002)
- NIR (1—4μm):
  - DIRBE (Wright & Reese 2000)
  - +2MASS (Cambresy et al. 2001)
  - IRST (Matsumoto et al. 2005)
- Foregrounds – diffuse Galactic light (DGL), stars, zodiacal, airglow – are a major hurdle. EBL is ~1% foreground level.
GLAST LAT Project

GLAST Simulations

- 3C 279 for 1 year ($\Gamma=1.96, \sim 33k$ events), no diffuse, DC1A
- EBL absorption (Primack05 model) with $z = 0.538, 3, 6, \text{ and } 3$ (scaled by 70)
- Model fits: broken power-law, log-parabola (Massaro et al. 2005)
GLAST Simulations w/ Diffuse

- 1 yr, 3C 279 (x70), z=3, w/ GALPROP and extragalactic diffuse
Conclusions

• H.E.S.S. observations imply near minimal EBL in OUV
  ⇒ a more direct view of intrinsic spectra blazars
• But if true, galaxy formation models will struggle to account for FIR
• Possible “outs”:
  – high UV component (ruled out for EBL…disk?)
  – very hard blazar spectra ⇒ unusual particle acceleration
  – Lorentz invariance violation
• GLAST constraints on EBL will require bright, hard spectra blazars at z > 2 - 3, e.g., 3C 279-like, x10 - 100 more luminous (or like PKS0528+134, but with harder intrinsic spectrum)
More on FIR difficulties

- Star formation history and FIR galaxy counts:

![Madau Plot](image1)

![FIR Counts](image2)