Probing the Extragalactic Background Light with VERITAS

Elisa Pueschel
University College Dublin
28th Texas Symposium on Relativistic Astrophysics
15 December 2015
The Extragalactic Background Light

→ COB = Cosmic optical background    → CIB = Cosmic infrared background
→ Light from stars, galaxies, etc    → Light reprocessed by dust

Imprint from reionization, star formation, galaxy evolution
Unresolved sources? Dark matter decay? Exotic physics?
Extragalactic Background Light: Strategy

- TeV γs interact with EBL γs via pair production
- VERITAS energy range $\rightarrow \lambda_{EBL} \ 0.1 - 40 \ \mu m$
- Quantify attenuation as optical depth along line of sight
- More distant, higher energy $\rightarrow$ more attenuation

$\gamma \rightarrow e^+ e^-$

More distant, higher energy $\rightarrow$ more attenuation

$\gamma$ at TeV energies, one can derive the TeV optical depth to the observed spectrum from Fermi data as a proxy for the intrinsic spectra.

The opacity can be determined from models of the EBL if its evolution is known and, independently, from TeV energy fluxes corresponding to the wavelength at which the slope of the EBL spectrum changes.

Determining the TeV flux of PKS 2155-304 using a one-zone SSC model. Comparing the model results with observations, they derived the TeV flux of PKS 2155-304.

The convergence between observational limits on the EBL and the TeV opacity to this blazar, and found it to be consistent with most EBL models.

The opacity for 3C 66A is typical of most blazars listed in Table 2. The discrepancy between the EBL and the ground would then be simply attributed to our still incomplete knowledge of the intrinsic spectrum.

The sharp drop of the EBL intensity at UV and shorter wavelengths be simply attributed to EBL attenuation.

$F_{\gamma} \left( \frac{E}{c} \right) = \frac{C_0}{C_{20}} \frac{1}{C_{21}}$.

EBL model from Gilmore 2012. Determining the TeV opacity from observations requires the sharp drop of the EBL intensity at UV and shorter wavelengths.

$F_{\gamma} \left( \frac{E}{c} \right) = \frac{C_0}{C_{20}} \frac{1}{C_{21}}$.

EBL model from Gilmore 2012.

$F_{\gamma} \left( \frac{E}{c} \right) = \frac{C_0}{C_{20}} \frac{1}{C_{21}}$.

EBL model from Gilmore 2012.

$F_{\gamma} \left( \frac{E}{c} \right) = \frac{C_0}{C_{20}} \frac{1}{C_{21}}$.

EBL model from Gilmore 2012.

$F_{\gamma} \left( \frac{E}{c} \right) = \frac{C_0}{C_{20}} \frac{1}{C_{21}}$.

EBL model from Gilmore 2012.

$F_{\gamma} \left( \frac{E}{c} \right) = \frac{C_0}{C_{20}} \frac{1}{C_{21}}$.

EBL model from Gilmore 2012.

$F_{\gamma} \left( \frac{E}{c} \right) = \frac{C_0}{C_{20}} \frac{1}{C_{21}}$.

EBL model from Gilmore 2012.

$F_{\gamma} \left( \frac{E}{c} \right) = \frac{C_0}{C_{20}} \frac{1}{C_{21}}$.

EBL model from Gilmore 2012.
EBL Imprint on Blazar Spectra

→ VHE (>100 GeV) emission strongly attenuated by EBL
→ HE (>10 MeV) emission minimally attenuated
→ Proxy for intrinsic spectrum

Intrinsic spectrum:

\[ \frac{dN}{dE} \propto E^{-\Gamma} \text{ or} \]
\[ \frac{dN}{dE} \propto E^{-\Gamma} \exp \left( -\frac{E}{E_C} \right) \]

or…?

Observed spectrum:

\[ \frac{dN}{dE} \propto \left( \frac{dN}{dE_{\text{int}}} \right) \exp(-\tau_{\gamma\gamma}) \]
→ Four 12m IACTs located in southern AZ
→ Davies-Cotton design, 499 PMTs
→ Energy range: 100 GeV to > 30 TeV
→ Energy resolution: 15% at 1 TeV
→ Angular resolution: 0.1° at 1 TeV
→ Field of view: 3.5°
→ Peak effective area: 100,000 m²
Sources Used

Strongly detected sources:

1ES 2344+514, z=0.044, 45h
1ES 1959+650, z=0.048, 19h
RGB J0710+591, z=0.125, 101h
H 1426+428, z=0.129, 75h
1ES 0229+200, z=0.14, 112h
1ES 1218+304, z=0.182, 117h
1ES 1011+496, z=0.212, 27h
MS 1221.8+2452, z=0.218, 8h
1ES 0414+009, z=0.287, 80h
PG 1553+113, z=0.49, 93h

Observations taken 2007 - Feb 2015

Energy range of spectra determines range $\lambda_{EBL}$ probed
Building Blocks: Generic EBL Models

→ Grid points $[\lambda, \text{EBL intensity}]$ define ensemble of splines/EBL models

→ Require grid points satisfy direct constraints on EBL intensity

77440 models considered

→ For each EBL model, calculate opacity $\exp(\tau_{\gamma\gamma})$ for $z$ & energy

→ Account for EBL evolution

$$n_{EBL} \propto (1 + z)^3 \rightarrow n_{EBL} \propto (1 + z)^3 \cdot f_{evo}, \quad f_{evo} = 1.2$$
Building Blocks: Source Spectra

example observed spectrum

$\times \exp(\tau_{\gamma\gamma})$ to deabsorb

example deabsorbed spectra
Two Methods

**Method I**

1. Fit w. power law
2. Fit w. power law + exp. cut-off
3. Take best fit

Keep EBL model if:
\[ \Gamma > 1.5 \]
\[ \Gamma > \Gamma_{\text{Fermi}} \]

based on Mazin 2007

**Method II**

Keep EBL model if:
\[ \chi^2 \leq \chi^2_{\text{min}} + 1 \]
\[ \rightarrow 68\% \text{ confidence band} \]

based on Lorentz 2015
Method I Results

→ **Combination**: retain models that are acceptable for ALL sources

→ **Systematic uncertainty**: soften fitted spectral index by 10% (propagating uncertainty on energy resolution)
Method II Results

→ **Combination**: sum individual confidence bands, find mean & RMS
→ **Systematic uncertainty**: remove sources one by one, find maximum change in confidence band
Comparison to Previous Results

\[ n \int_\lambda \nu I_\nu(\lambda) \, d\lambda \left[ \text{nW m}^{-2} \text{sr}^{-1} \right] \]

- Method I
- Method II
- H.E.S.S. 2013
- Biteau & Williams 2015
Conclusions.

- New VERITAS constraints on EBL

- Sources
  - 10 sources, redshifts $z=0.044 - 0.49$
  - Add more sources, more data (long-term plan objects)

- Constraints
  - Two methods
    - Agree well with each other & existing constraints
  - Increase granularity of $[\lambda, \text{EBL intensity}]$ grid
  - Increase granularity of $[z, \text{energy}]$ opacity calculation

Thanks for your attention!