Lower and Upper Bounds on the Cosmic TeV Gamma-ray Background

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Fermi has resolved 30% of the CGB at ~1 GeV and more at higher energies (see Di Mauro’s talk).
Components of the Cosmic GeV Gamma-ray Background

- Blazars (Ajello+’15), Radio gals. (YI’11), & Star-forming galaxies (Ackermann+’12) make up almost 100% of CGB from 0.1-1000 GeV.

- Next frontiers will be
  - Anisotropy (e.g. Ando & Komatsu ’06, Ackermann+’11, Camero+’13, Shirasaki+’14)
  - Cosmic MeV Gamma-ray Background (e.g. YI+’08, Ajello+’09, YI+’13)
  - Cosmic TeV Gamma-ray Background (This talk)
Cosmic TeV Gamma-ray Background

- Above 1 TeV, there is no gamma-ray data, though it is important for neutrino studies.

- extragalactic \textit{pp} scenario for IceCube events is constrained by the CGB (Murase+’13; Bechtol+’15).
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extragalactic pp scenario for IceCube events is constrained by the CGB (Murase+’13; Bechtol+’15).
• TeV gamma-ray photons are absorbed by EBL

• electron-positron pairs are created

• pairs scatter CMB via inverse-Compton process
  • 1 TeV (primary) \( \rightarrow \sim 1 \) GeV (secondary)

• Note: plasma instability may suppress the cascade
  (Broderick+’12, but see also Sironi & Giannios ‘14)
• Cascade component from the TeV background can not exceed the Fermi data (Coppi & Aharonian ’97, YI & Ioka ’12, Murase+’12, Ackermann+’14).

• No or negative evolution is required -> low-luminosity BL Lacs show negative evolution (Ajello+’14).
Galaxy Counts: Lower Bound on the Cosmic Optical/Infrared Background

Stars

Dust

\(YI+13\)
TeV blazar sample

- Select 36 blazars the default TeVcat catalog.
- Low-state data are available for 31/36.
- 3FGL SED data for the GeV data.
- Radio galaxies and star-forming galaxies are not included yet.

$E^2dN/dE$ [TeV/cm$^2$/s]

YI & Tanaka in prep.
Lower Bound on the Cosmic Gamma-ray Background

- TeV blazar counts give lower limit on to the cosmic gamma-ray background.
- Fermi has resolved more portion of the TeV sky than IACTs do?
- CTA survey will be important (YI, Totani, & Mori 10; Dubus, YI, +’13)

YI & Tanaka in prep.
• Current limit at 0.3-10 TeV is

$$3 \times 10^{-5} \left( \frac{E}{100\text{GeV}} \right)^{-1} \text{[MeV/cm}^2\text{s/sr]} < E^2 \frac{dN}{dE} < 5 \times 10^{-5} \left( \frac{E}{100\text{GeV}} \right)^{-0.7} \text{[MeV/cm}^2\text{s/sr]}$$

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Bounds on the Cosmic TeV Gamma-ray Background

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Summary

- Cosmic TeV gamma-ray background is not well investigated yet.

- Current GeV gamma-ray background gives upper limits on the TeV gamma-ray background through the cascade argument.

- Ensemble of low-state TeV blazar flux gives lower limit on to the cosmic gamma-ray background.

- Current limit on the TeV background is

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VHE EGB Model

\[ E^2 \frac{dN}{dE}(E_{\text{obs}}) = \frac{cE_{\text{obs}}^2}{4\pi} \int_0^{z_{\text{max}}} dz \left| \frac{dt}{dz} \right| (1 + z) \times \frac{dj}{dE_{\gamma}}[(1 + z)E_{\text{obs}}, z] \exp[-\tau_{\gamma\gamma}(E_{\text{obs}}, z)], \]

\[ j = j_{\text{int}} + j_{\text{cas}} \quad \text{MeV/s/MeV/cm}^3 \]

\[ \frac{dj_{\text{int}}}{dE_{\gamma}}(E_{\gamma}, z) = \begin{cases} j_0 E_{\gamma}^{-\Gamma_{\text{ph}}}(1 + z)^{\beta_{\text{evo}}}, & E_{\gamma} \leq E_{\max}, \\ 0, & E_{\gamma} > E_{\max}, \end{cases} \]

- Parameters are
  - \( \beta_{\text{evo}} \): Cosmological evolution of number density
    - Most of known sources show \( \beta_{\text{evo}} > 0 \)
  - \( E_{\text{max}} \): Maximum energy
  - \( \Gamma_{\text{ph}} \): Photon index
Upper Limit on EGB

- $\beta_{evo}=0$ (no evolution)
- $\Gamma_{ph}=1.5$ (Fermi acc. limit)
- $E_{\text{max}}=60$ TeV
- Normalization is fixed to the EGB data $<100$ GeV.
- No known source classes included.
- Upper limit is consistent with the Fermi VHE EGB obs.

**UL:**

$$E^2 \frac{dN}{dE} < 1.1 \times 10^{-4} \left( \frac{E}{100 \text{GeV}} \right)^{-0.5} \text{MeV/cm}^2/\text{s}/\text{sr}$$
Different Photon Indices

- $\Gamma \approx 1.5$ is the most conservative.
- Harder spectral model is limited by the cascade.
- Softer spectral model is limited by the primary.
Different $E_{\text{max}}$ and evolution

- $\beta>0$ violates the limit.
- $\beta<0$ eases the limit.
- But, no known gamma-ray sources.
- Low $E_{\text{max}}$ ($\sim\text{sub-TeV}$) eases the limit.
- If cosmological,
  - sources should have a hard spectrum and show no or negative evolution.
Components of EGB

- FSRQs (Ajello+’12), BL Lacs (Abdo+’10), Radio gals. (YI’11), Starburst gals. (Stecker & Venters ’11, Ackermann+’12) are guaranteed to contribute to EGB.

- We need to subtract them to evaluate the VHE EGB upper limit.
Upper Limit on EGB w/ known sources

- If we try to explain EGB at <10GeV, the observation violates the limit.

- UL: \( E^2 \frac{dN}{dE} < 4.5 \times 10^{-5} \left( \frac{E}{100 \text{ GeV}} \right)^{-0.7} \text{ MeV/cm}^2/\text{s}/\text{sr} \)
If we try not to violate the limit, residual appears at <10GeV.
**Possible Explanations**

- Hard spectrum with sub-TeV $E_{\text{max}}$ and $\beta<0$
  
- No known sources. TeV HBL? Low-luminosity GRBs?
  
- New Physics: Axion or Lorentz invariance violation?
  
- Dark matter in local?
  
- ~GeV sources
  - pulsars? radio-quiet AGNs?
  
- Foreground uncertainty?
  
- See also Murase+’12

*Our limit is useful for future: Fermi, CTA, & CALET*