Cosmic Very High Energy Gamma-ray Background Radiation

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Cosmic Background Radiation Spectrum

Graph showing the Cosmic Microwave Background (CMB), Cosmic Infrared Background (CIB), and Cosmic X-ray Background (CXB) across different photon energy levels. Various contributions from different sources such as Galaxies, Pop-III Stars, AGNs, Radio-quiet AGNs, Blazars, Radio Galaxies, and Cosmic Background Radiation (CMB) are highlighted.

- **CMB**: Galaxies (Inoue et al. ’13), Pop-III Stars (Inoue et al. ’13), AGNs (All), Radio-quiet AGNs (Inoue et al. ’08), Blazars (Inoue and Totani ’09), Radio Galaxies (Inoue ’11)

- **CIB**: Various contributions from different sources

- **CXB**: Various contributions from different sources

The graph plots the number of photons per unit energy per unit area per unit time per unit solid angle ($E^2 dN/dE$) against photon energy ($E$) in [eV].
Cosmic Gamma-ray Background

- Numerous sources are buried in the cosmic gamma-ray background (CGB).

**Fermi**
3-year survey

$>100$ MeV
Cosmic Gamma-ray Background Spectrum

- Softening around ~400 GeV.
- Fermi resolves CGB more at higher energies?

**CGB Spectrum**

**Fraction of CGB**

Unresolved

Resolved

Ackermann+'14

Funk & Hinton '13

- Unresolved CGB (Bechtol at HEM2014)
- Resolved CGB (Bechtol at HEM2014)

- Total EGB
- IGRB
- Resolved sources, |b|>20°
- IGRB - Abdo et al. 2010

Fraction of CGB against total CGB

Photon Energy [MeV]

Fraction against total CGB

Photon Energy [MeV]

Differential Flux $E^2 dN/dE$ (erg cm$^{-2}$ s$^{-1}$)

Differential Flux $E^2 dN/dE$ (erg cm$^{-2}$ s$^{-1}$)

- Crab Nebula
- Synchrotron
- LAT - 10 yrs (inner Galaxy)
- Inverse Compton
- H.E.S.S. - 100 hrs
- LAT - 10 yrs (extragalactic)
- CTA - 100 hrs
- CTA - 1000 hrs
Unresolved sources

**Blazars**
Dominant class of LAT extragalactic sources. Many estimates in literature. EGB contribution ranging from 20% - 100%

**Non-blazar active galaxies**
27 sources resolved in 2FGL ~ 25% contribution of radio galaxies to EGB expected. (Inoue 2011)

**Star-forming galaxies**
Several galaxies outside the local group resolved by LAT. Significant contribution to EGB expected. (e.g. Pavlidou & Fields, 2002)

**GRBs**
High-latitude pulsars
small contributions expected. (e.g. Dermer 2007, Siegal-Gaskins et al. 2010)

Diffuse processes

**Intergalactic shocks**
widely varying predictions of EGB contribution ranging from 1% to 100% (e.g. Loeb & Waxman 2000, Gabici & Blasi 2003)

**Dark matter annihilation**
Potential signal dependent on nature of DM, cross-section and structure of DM distribution (e.g. Ullio et al. 2002)

**Interactions of UHE cosmic rays with the EBL**
dependent on evolution of CR sources, predictions varying from 1% to 100% (e.g. Kalashev et al. 2009)

**Extremely large galactic electron halo** (Keshet et al. 2004)

**CR interaction in small solar system bodys** (Moskalenko & Porter 2009)
Typical Spectra of Blazars

- Non-thermal emission from radio to gamma-ray
- Two peaks
  - Synchrotron
  - Inverse Compton
- Luminous blazars (Flat Spectrum Radio Quasars: FSRQs) tend to have lower peak energies (Fossati+’98, Kubo +’98)
Cosmological Evolution of Blazars

- FSRQs, LBLs, & IBLs show positive evolution.
- HBLs show negative evolution unlike other AGNs.
Average Blazar SEDs (Ajello+’14)

\[
\frac{dN_\gamma}{dE} = K \left[ \left( \frac{E}{E_b} \right)^{\gamma_a} + \left( \frac{E}{E_b} \right)^{\gamma_b} \right]^{-1} \cdot e^{-\tau(E,z)} \quad [\text{ph cm}^{-2}\text{s}^{-1}\text{GeV}^{-1}]
\]

- Fix $\gamma_a=1.7$ & $\gamma_b=2.6$ for all blazars
- Change $E_b$ for a given photon indices.

\[
\log E_b(\text{GeV}) \approx 9.25 - 4.11\Gamma
\]
**Blazar contribution to CGB**

-Padovani+’93; Stecker+’93; Salamon & Stecker ‘94; Chiang + ‘95; Stecker & Salamon ‘96; Chiang & Mukherjee ‘98; Mukherjee & Chiang ‘99; Muecke & Pohl ’00; Narumoto & Totani ‘06; Giommi +’06; Dermer ‘07; Pavlidou & Venters ‘08; Kneiske & Mannheim ’08; Bhattacharya +’09; YI & Totani ’09; Abdo+’10; Stecker & Venters ’10; Cavadini+’11, Abazajian+’11, Zeng+’12, Ajello+’12, Broderick+’12, Singal+’12, Harding & Abazajian ‘12, Di Mauro+’14, Ajello+’14, Singal+’14

-Blazars explain ~50% of CGB at 0.1-100 GeV.

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**Table:**

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<thead>
<tr>
<th>Energy [MeV]</th>
<th>E^2 dN/dE [MeV cm^2 s^-1 sr^-1]</th>
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<tbody>
<tr>
<td>10^2</td>
<td>10^-5</td>
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<tr>
<td>10^3</td>
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<td>10^4</td>
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<tr>
<td>10^5</td>
<td>10^-2</td>
</tr>
<tr>
<td>10^6</td>
<td>10^-1</td>
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</tbody>
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**Note:**

- EGB total intensity of 1.1 × 10^{-5} ph cm^{-2} s^{-1} sr^{-1}

- Blazars contribute a grand-total of (5-7) × 10^{-6} ph cm^{-2} s^{-1} sr^{-1}

- Resolved sources: ~4 × 10^{-6} ph cm^{-2} s^{-1} sr^{-1}

- Unresolved blazars: ~(2-3) × 10^{-6} ph cm^{-2} s^{-1} sr^{-1} (in agreement with Abdo+10)

**Reference:**

Ajello, YI,+ submitted to ApJL
• Strong+‘75, Padovani+‘93; YI ‘11; Di Mauro+‘13; Zhou & Wang ‘13

• Use gamma-ray and radio-luminosity correlation.

• ~20% of CGB at 0.1-100 GeV.

• But, only ~10 sources are detected by Fermi.
Star-forming Galaxies

- Soltan ‘99; Pavlidou & Fields ‘02; Thompson +’07; Bhattacharya & Sreekumar 2009; Fields et al. 2010; Makiya et al. 2011; Stecker & Venters 2011; Lien+’12, Ackermann+’12; Lacki+’12; Chakraborty & Fields ’13; Tamborra+’14

- Use gamma-ray and infrared luminosity correlation

- ~10-30% of CGB at 0.1-100 GeV.

- But, only ~10 sources are detected by Fermi.
Components of Cosmic Gamma-ray Background

- FSRQs (Ajello+’12), BL Lacs (Ajello+’14), Radio gals. (YI’11), & Star-forming gals. (Ackermann+’12) makes almost 100% of CGB from 0.1-1000 GeV.

- However, we need to assume SEDs at higher energies.
Cosmic Very High Energy Gamma-ray Background
Upper Limit on Cosmic Gamma-ray Background

- Cascade component from VHE CGB can not exceed the Fermi data (Coppi & Aharonian ’97, YI & Ioka ’12, Murase+’12, Ackermann+’14).

- No or negative evolution is required -> HBLs show negative evolution (Ajello+’14).
Extragalactic **pp** scenario (galaxies or clusters) for IceCube events will provide 30-100% of CGB (Murase+’13).

Extragalactic **py** scenario (e.g. FSRQs) depends on the target photon spectra (e.g. Murase, YI, & Dermer ’14, Dermer, Murase, & YI ’14).

We need more data at TeV band!
Be careful. These Fermi data still contain the Galactic diffuse contribution. This is very optimistic estimation.

### Detection of High Performance for Gamma-ray Detection

<table>
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<th>Point Source Sensitivity</th>
<th>$8 \times 10^{-9}$ cm$^{-2}$s$^{-1}$</th>
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<td>Observation Period (planned)</td>
<td>2014-2019 (5 years)</td>
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Expected flux of diffuse gamma-rays in five year Observation Period (planned)

| Energy Range | $0^\circ \leq l \leq 360^\circ$ | $8^\circ \leq |b| \leq 90^\circ$ |
|--------------|---------------------------------|-------------------------------|
| $10^3$ GeV   | $E^2 J(E) [\text{MeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$ | $S_{\gamma} = 8 \times 10^3 T_{\infty} C_2$ |

### Torii-sans slide @ JPS 2013

CALET is coming!
Exposure with Specialized Event Selections

50 months of sky-survey observations

“Low-energy” and “high-energy” event samples both cover full energy range to allow consistency check

Corresponding cosmic-ray background event rates estimated via a dedicated large-scale Monte Carlo simulation

Relative to standard P7 Ultraclean selection, cosmic-ray background rate reduced by factor 3 around 200 MeV (where background rate is highest) and acceptance increased >500 GeV

Bechtol+@HEM14
How many photons are expected?

- $10^{-11}$ photons/cm$^2$/s/str @ 1 TeV
- What about CALET?
  - 1100 photons/600 cm$^2$/1 yr/2 str @ 10 GeV (?)
  - 38 photons/600 cm$^2$/1 yr/2 str @ 100 GeV (?)
  - 0.4 photons/600 cm$^2$/1 yr/2 str @ 1 TeV (?)
- Ignoring systematics.
- Is it possible to study the cosmic VHE gamma-ray background/point sources at TeV band with CALET?
Summary

• CGB at GeV band is composed of blazars, radio galaxies, and star-forming galaxies.

• CGB at TeV band is constrained by CGB at GeV band through cascade emission.
  • Need to check consistency with IceCube neutrino measurements.
  • We need more data at TeV band. CALET?