Fermi-LAT Observations of the Earth Gamma-Ray Emission

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Dominant gamma-ray production mechanisms are Bremsstrahlung of $e^-$ and $e^+$ (below ~50 MeV) and the decay of pions and kaons (higher energy).
Data Selections and Exposure

Data

- 1\textsuperscript{st} year Standard high-quality photons (P6V3 Diffuse)
- $\theta_{LAT} < 65$ deg

Exposure

- Split into 41 energy bins in log\textsubscript{10} between 80 MeV and 1 TeV
- Mask out common regions with low exposure
Data Sets

- Launch & Early Orbit (July 15 – 29, 2008) and Limb Observation (September 30, 2008)
- $\sim 10^6$ sec of livetime
- $\sim 10^7$ Earth diffuse photons
- 218 photons with $E > 100$ GeV
- 16 photons with $E > 500$ GeV
Exposure Maps and Flux Maps

Exposure Maps

More exposure in the north

Flux Maps

East-West effect clearly visible, getting smaller at higher energy
• Spectra from different regions
  – Softer for the inner part of the earth because the forward-scattered secondaries tend to have higher energy than the backward-scattered ones

• Power-law spectrum for the rim at \( E > 30 \) GeV with the fitted spectral index of \(-2.79 \pm 0.06\)
  – Good agreement with the cosmic ray (CR) spectral index of \(-2.75\)

• Reasonable agreement with the previous measurement by SAS-2
East-West Effect from the Earth Magnetic Field

- This plot is for the earth rim ($60 < \theta_{nadir} < 75$)
  - North = 0 deg
  - East = 90 deg
  - South = 180 deg
  - West = 270 deg
- The east-west effect is stronger at low energy as expected
- Above 30 GeV, the profile can be fitted well with a flat line
Radial Flux Profile

- Earth center is at 0 deg, rim at ~ 68 deg
- The dash lines are the PSF of each energy bin
- The profiles get narrower for higher energy
- Note the change in x-scale for the two bottom plots
Earth Atmospheric Column Density

- Gamma-ray intensity as a function of nadir angle is scaled to compare with the line-of-sight atmospheric column density calculated from 2 models.
- For $\theta_{nadir} > \sim 68.3$ deg, the atmosphere is thin enough for the interactions to be in the “thin target regime,” resulting in good correlations between PSF-deconvolved gamma-ray intensity and atmospheric column density.
- At $\sim 10$ g cm$^{-2}$, the air becomes optically thick for gamma ray.
Comparison with Proton Fluxes

- Gamma ray intensity for $68.6 < \theta_{nadir} < 68.9$ deg (thin target regime) compared with scaled proton intensity.

- For p-p interactions, $\sim 0.17$ of proton energy converts into that of gamma ray, and we assume the same energy conversion factor.

- Also, scale down proton intensity by 0.7 to match that of gamma-ray at 1 GeV.

- Ratio of gamma-ray and scaled proton intensity shows good correlations (shown in the inset).
Conclusion

- The spectral and spatial properties of the cosmic-ray induced gamma ray emission from the Earth have been obtained using the early Fermi-LAT data
  - Add more than 3 decades of the energy spectrum from 200 MeV to 500 GeV
  - The rim spectral index above ~10 GeV follows that of the CR
  - The east-west effect is observed up to 30 GeV
  - The radial profile can be resolved for $E > 10$ GeV and can be used to study CR-atmosphere interaction
  - The Earth gamma ray proves useful for instrumental calibrations