Solar System Gamma-Ray Astronomy with Fermi Observatory

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on behalf of Solar System Working group and Fermi LAT Collaboration
Solar System observation capabilities with Fermi

- Solar Activity expected to peak around 2011
- Fermi will operate for nearly the entire duration of solar cycle 24
Solar System observation capabilities with Fermi (2)

- Fermi is the only satellite capable of making solar observations >30 MeV
- Coordinated measurements between LAT gamma-ray and GBM (10 keV-25 MeV)
- Comparison with RHESSI (1 keV –20 MeV)
- Comparison with energetic solar particle observations (ACE, STEREO, SOHO, WIND) and ground based experiments (Milagro) for flaring Sun alerts
- About ten high-energy flares expected
Sources in Solar System

- “$\gamma$-ray albedo” due to CR interactions with surface material

- Moving sources

- Sources:
  - The Moon (albedo)
  - The Sun (albedo + inverse Compton)
  - The Earth

- Potential Sources
  - Asteroids in different populations:
    - Main Asteroid Belt (MBAs)
    - Jovian and Neptunian Trojans (Trojans)
    - Kuiper Belt Objects (KBOs)
  - Other planets
Fermi: the Sun track in the sky

Gamma-ray counts track of the SUN

Fermi-LAT Sky
(100MeV-300GeV, 1 month, Aug.03-Sept.03,2008). Evtclass: diffuse, IRFS: P6_V1_DIFFUSE. Map scale 0.5deg/px, smooth kernel 2px, reduced scale limits 95% (saturated and bad imaging of galactic plane and bright sources, but enhanced constraint of the small photon count excess along the path of sun).
Analysis and Background estimation approach

- **Analysis in Moving Coordinates**
  - SUN is moving about 1°/day
  - MOON is moving about 15°/day

- **Ideas for background estimate**
  - Background model: a fit of the diffuse emission model to the whole sky
  - A “fake” source method
    - A fake source follow the path of the real source but 30 degrees away (passes through the same areas on the sky but at different times)
    - The source flux is the total flux minus the fake source

- Fluxes computed with both approaches
  - Very similar results obtained
The “fake source” idea

True moon position

Standard fake moon
30° from true moon

Alternative fake moons
(±30°/±60° L from true moon)
~6 months of Moon Observations and fluxes

- Total Flux (>100 MeV) = $1.57 \times 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}$
- Fake Moon Flux (>100 MeV) = $1.08 \times 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}$
- Source Flux (>100 MeV) = $4.9 \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$ (preliminary)
- Expected Flux $\sim 5 \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$ (@ solar min) (Moskalenko&Porter‘08)
- EGRET Flux (>100 MeV) = $(4.7\pm0.7) \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$ (Thompson+‘97)
  = $(5.55\pm0.65) \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$ (Orlando&Strong‘08)
Moon Spectra

Moon net spectrum Aug-Dec 2008

Fermi LAT preliminary

Flux (photons cm$^{-2}$ s$^{-1}$ MeV$^{-1}$)

Normalized counts s$^{-1}$ MeV$^{-1}$

Energy (MeV)

limb (outer 5’)
center (inner 20”)
of the Moon disk

Moskalenko & Porter’07

Pion decay
Inverse-Compton scattering of solar photons in the heliosphere by Galactic CR electrons: the emission is predicted to be extended

- electrons are isotropic
- photons have a radial angular distribution

Moskalenko '06
Orlando&Strong'08
The Quiet Sun: first 5 months of observation

Counts map >100 MeV
Pixel size 0.25°
Sun disk

Source Flux (>100 MeV) ~ $4 \times 10^{-7}$ cm$^{-2}$ s$^{-1}$ (albedo+IC, preliminary)

Expected IC Flux (>100 MeV) ~ $4.3 \times 10^{-7}$ cm$^{-2}$ s$^{-1}$ (@ solar min, Moskalenko'06)

EGRET Flux (>100)
= $(4.44 \pm 2.03) \times 10^{-7}$ cm$^{-2}$ s$^{-1}$ (albedo+IC)
(Orlando&Strong'08)
not observed (Thompson '97)
Sun Movie

- Aug 08
- Sept 08
- Oct 08
- Nov 08
- Dec 08
- Jan 09
Flaring Sun phenomenology

- Flare are energetic phenomena occurring in solar atmosphere
  - Release of energy in the magnetic field
  - Up to $10^{32}$ ergs released (between few minutes to tens of minutes)
  - Large flare at maximum of solar cycle
  - Observed smaller flares (in energy and time)
  - Located in solar corona and chromosphere
  - Heat plasma and accelerated electrons, protons and heavier nuclei
  - Electromagnetic radiation produced
Sun Flare modeling

Products of accelerated particle interactions

- Electrons: X- and γ-ray bremsstrahlung
- Ions:
  - Excited nuclei $\rightarrow$ γ-ray line radiation (1-8 MeV)
  - Escape to space
  - Neutrons $\rightarrow$ 2.23 MeV capture line
  - Radioactive nuclei $\rightarrow$ $e^+ \rightarrow \gamma_{\text{f11}}$
  - $\pi \rightarrow \gamma$ (decay, $e^+$ bremsstrahlung, $\gamma_{\text{f11}}$)
Conclusions

- During the first months of data taking Fermi has observed the quiet Sun and the Moon.
- Preliminary fluxes have been calculated with different methods.
- We need more statistics for accurate spectra determinations.
- Exciting physics expected:
  - Solar flares monitoring
  - CR cascade development in the solar atmosphere
  - Study of the extragalactic diffuse emission
  - *Fermi* LAT energy and flux calibration