SOLAR SYSTEM GAMMA-RAY ASTRONOMY WITH FERMI OBSERVATORY

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The Large Area Telescope (LAT), one of two instruments on the Fermi Gamma-ray Space Telescope (formerly GLAST, launched on June 11, 2008) is a pair conversion detector designed to study the gamma-ray sky in the energy range from 20 MeV to 300 GeV. Fermi has detected high-energy gamma rays from the quiet Sun and the Moon, during the first few months of the mission, thus opening a new window for detailed gamma-ray science in the Solar System. This emission is produced by interactions of cosmic rays; by nucleons with the solar and lunar surface, and electrons with solar photons in the heliosphere. The heliospheric emission is produced by inverse-Compton scattering and is predicted to be very extended. While both Sun and Moon were detected by EGRET on CGRO with low statistics, Fermi provides high-quality detections on a daily basis allow variability to be addressed. Such observations will provide a probe of the extreme conditions near the solar surface, and monitor the modulation of cosmic-rays over the inner heliosphere, impossible by any other means. Since at minimum of of the solar activty Galactic cosmic rays have their maximum flux, we expect the gamma-ray emission to be brightest at this time. Fermi is the only gamma-ray mission capable of detecting the quiet Sun and monitoring it over the full 24^{th} solar cycle. We present preliminary analyses and flux estimation for the Moon and the Sun quiet emission.

1 Introduction

The possibility of a solar quiet gamma-ray emission has been first proposed by Hudson et al., pointing out the detection capabilities of the EGRET mission [1]. The gamma emission is produced by interactions of high-energy cosmic rays (CR) with the Sun. The quiet Sun emission is expected to have two different components: the first one is the γ-ray albedo generated by the CR nuclei interactions on the solar surface. The second one is due to the Inverse-Compton (IC) scattering of CR electrons with solar photons in the heliosphere. This last component is predicted to be extended in a large region around the Sun [2 3]. The Moon emission is expected by the interaction of CR nucleons with the lunar surface (albedo).

EGRET observed high-energy gamma radiation from the Moon with an energy spectrum consistent with an albedo model [4]. Althought a similar interaction of CR occurs on the Sun, EGRET has not observed the quiet solar emission and reported a 95% confidence upper limit on the Sun gamma flux of about 2.0×10^{-7} photons $cm^{-2}\ s^{-1}$ at $E > 100\ MeV$ [5]. More recent studies [6] of EGRET solar data using both disk and halo contributions yielded a total flux of $(4.44 \pm 2.03) \times 10^{-7}$ photons $cm^{-2}\ s^{-1}$ for $E > 100\ MeV$ from the Sun, with the disk component exstimated about 1/4 of the total flux.

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	Sun	Moon
Expected Flux ($\times$ 10^{-7} ph $cm^{-2}sec^{-1}$)	4.3 [2,3]	5.0 [4]
Egret Flux ($\times$ 10^{-7} ph $cm^{-2}sec^{-1}$)	4.44±2.03 [6]	5.55±0.65 [6]
	not observed by Egret [5]	4.7±0.7 [5]

Table 1: The expected and computed EGRET fluxes ($E > 100MeV$) for the Sun and the Moon.

2 Data selection and reduction

In this paper we analyze Fermi data collected during the first 6-month of the mission, from August 2008 to January 2009, selecting photon energies above 100 MeV. During the months covered by this analysis, the Sun is at the beginning of the 24^{th} solar cycle and hence in a period of minimum activity. As the Sun and the Moon are moving sources, we developed a code in order to perform the analysis of the data in a source-centred system: the events were mapped onto a celestial coordinate system centred on Sun and Moon instantaneous position. Coordinates were computed using JPL libraries [7] taking into account parallax corrections. In our analysis, the main sources of background are the galactic and extragalactic emission in the source centered frame. In order to have a better sensitivity to the Sun and Moon emission, other sources of background has been reduced with the following selections:

- Zenith angle $<$ 105° in order to exclude the Earth albedo;
- the Sun or the Moon should be at least 30 under or above the galactic plane in order to reduce the diffuse components and avoid the brightest sources on the galactic plane;
- the angular separation between Moon and Sun should be more than 10°, in order to remove the Moon emission component from the Sun and viceversa;

3 Sun and Moon detection

Figures 1 show the gamma-ray emission from the Sun and the Moon obtained in a 6-month accumulation of photons from August 2008 to January 2009 at energies above 100 MeV.

In order to evaluate the background, we use the "fake" source method, consisting in a "fake" source moving along the same path of the real source, but 30° displaced. In this way, the source net flux results as the difference between the total flux from the source and the flux from the "fake" source, using the same angular selection. Other methods can be used to compute the flux from a source, mainly based on a the maximum likelihood analysis [8,9]. Their application to our studies will be discussed in more detailed analysis.

Following this simple method, we have obtained a flux of (6.0±1.0) $\times$ 10^{-7} photons cm^{-2} s^{-1} for $E > 100$ MeV from the Moon; a preliminary value of the total flux for the Sun (albedo and IC component) gives (4.0±1.0) $\times$ 10^{-7} photons cm^{-2} s^{-1} for $E > 100$ MeV.

In the table 1 the expected and the EGRET fluxes above 100 MeV are reported for the Sun and the Moon. The results obtained show a good agreement with the theoretical expectations and prevoius results reported by EGRET.

4 Conclusions

In this paper we demonstrate the observing capabilities of Fermi-LAT by presenting images of the Moon and quiet Sun accumulated over the first six months of the Mission. We also report the first exstimation of flux from the Sun and the Moon, showing the good agreement with

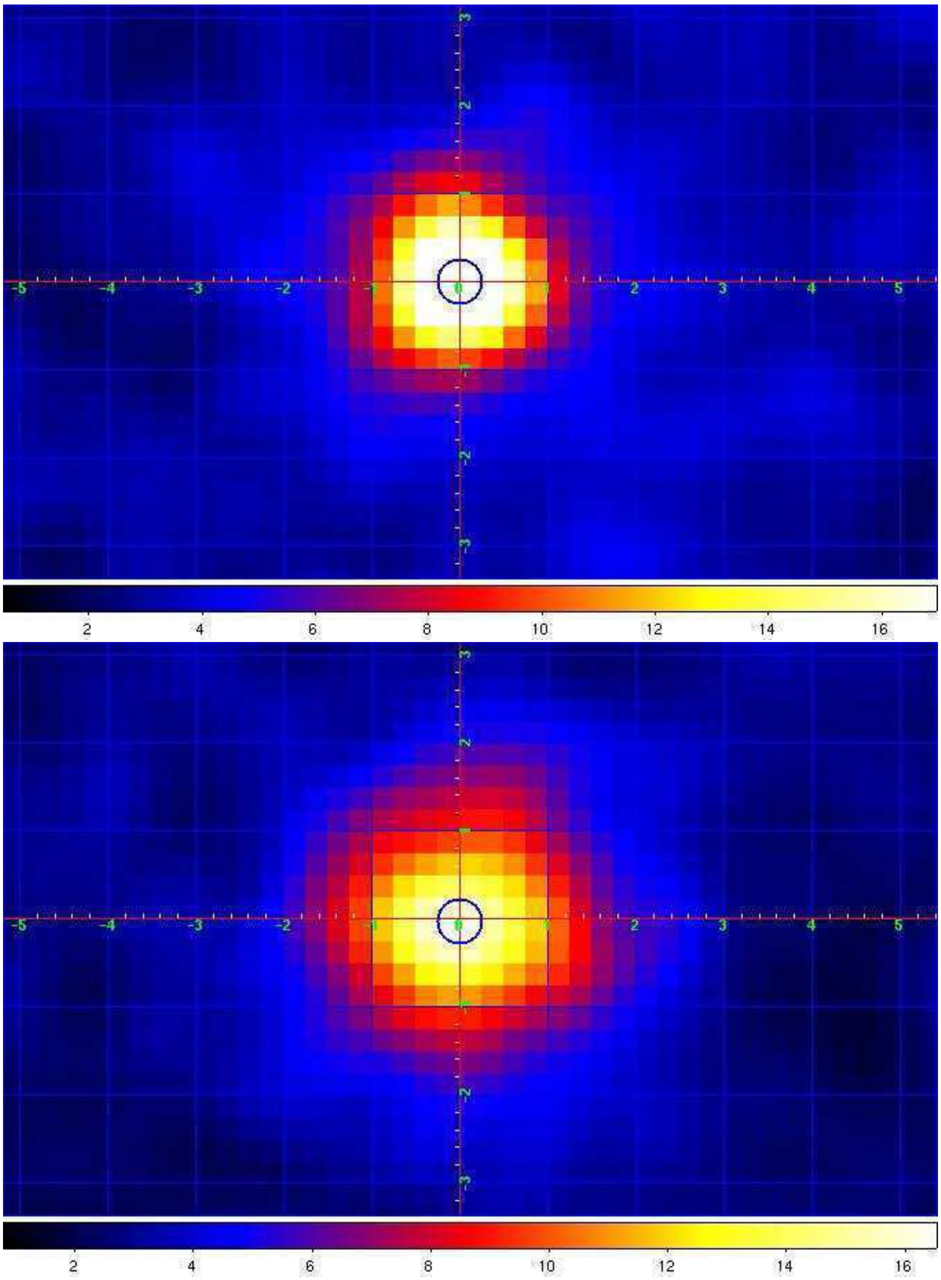

Figure 1: Sun (upper plot) and Moon (lower plot) gamma ray emission observed between August 2008 and end of January 2009. The images show the count map for $E > 100MeV$ photons in a coordinate frame centred on the source position, the bin width used is $0.25°$. The image is then slightly smoothed; the colour bar scale used is proportional to the counts. A circle corresponding with the average Sun and Moon radius has been superimposed.

the previous observations and the theoretical evaluation. Dedicated methods will be used to compute fluxes from our Solar System sources in more detailed analysis. These results indicate that Fermi data analysis will provide fundamental information about the Sun and Moon emission and the modulation of cosmic ray fluxes during the solar cycle.

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