Short-term Variability Studies of the Crab with Fermi-LAT

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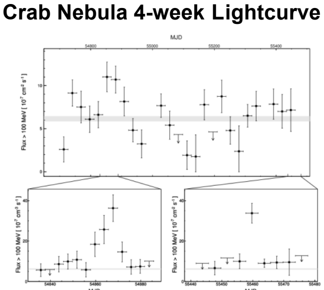
Summary: This work examines systematic errors in Fermi-LAT analysis of the combined Crab nebula and pulsar flux and their impact on short-term variability studies.

ABSTRACT

Short GeV flares observed from the Crab raise interesting questions about the acceleration of electrons to high energy in the nebula. Abdo et al. [1] use four-day intervals to evaluate flares detected in February 2009 and September 2010. That binning is well-suited to reliably detecting the flaring nebula in an off-pulse selection, avoiding the bright foreground of the pulsar which cannot be spatially separated. Alternatively, the combined pulsar and nebula flux can be used to search for additional structure within the flare as reported in Balbo et al. [2]. However, this brings in additional systematic errors due to the complexity of the combined emission and the notably soft index of the synchrotron component of the nebula. In order to accurately assess variability on shorter intervals, the systematic errors inherent in analyzing the total flux from the pulsar and nebula must be characterized. This work examines sources of systematic errors in the analysis of the combined Crab flux and their impact on variability studies using intervals shorter than four days.

Crab Nebula 4-week Lightcurve [1]

Figure 1



Crab Nebula 4-day Lightcurves

The Crab Nebula produced bright GeV outbursts (Fig. 1) in February 2009 and September of 2010 [1]. The flares are short in duration (~16 and ~4 days), however, further studies of day and sub-day variability can provide additional insight into the flare mechanism. Short integration intervals expose systematic errors in LAT measurements that depend on placement in the FOV and the orbital location. The bin arrangement also gains importance. Here we explore a binning scheme tuned to a particular target and the general stability of the LAT measurements at sub-day timescales.

Exposure in the LAT

Figure 2a

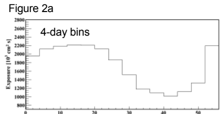


Figure 2b

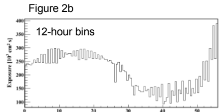
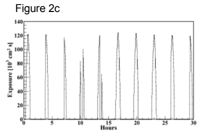


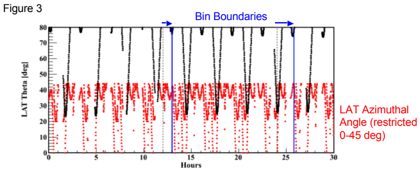
Figure 2c



Point source exposure (shown here for Geminga) varies moderately over the ~56 day precession period of the Fermi orbit (Fig. 2). Variations within a day are dominated by South Atlantic Anomaly (SAA) passages. The observation pattern has a lesser impact (Fig. 2b, 2c). The placement of time bin edges becomes important on sub-day timescales.

Transit-Selected Lightcurve Binning

Figure 3



Transit-selected binning (blue lines in Fig. 3) shifts fixed bin boundaries (black dashed) to times when a source is not gaining exposure due to being outside the field of view (Theta > 66°) or occulted by the Earth, or to Fermi passing through the SAA.

Flux Stability Studies

Figure 4a

Geminga 4-week Lightcurve

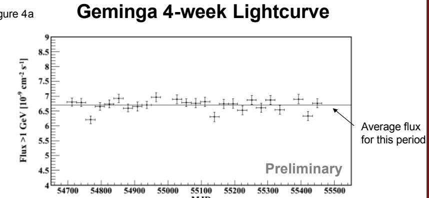
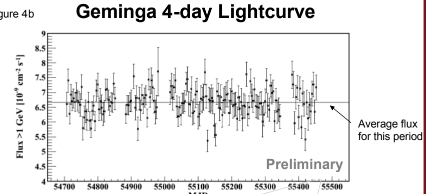


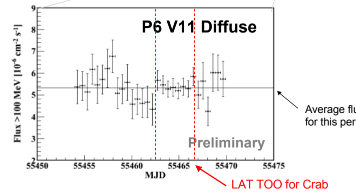
Figure 4b

Geminga 4-day Lightcurve



Geminga 12-hour Transit-selected Lightcurve

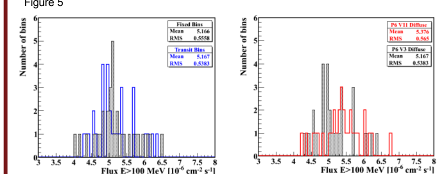
Figure 4c



The Geminga Pulsar is a bright, steady LAT source. At ~15° away from the Crab, it probes systematic errors in the flux lightcurve for a similar background environment and exposure pattern to the Crab.

Effect of IRF and Binning on Lightcurves

Figure 5

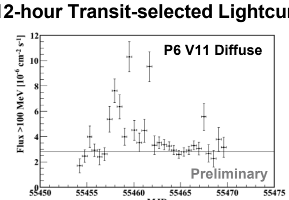


The RMS of the flux for Geminga decreases for transit-selected binning. The minor shift in flux between P6 V11 Diffuse and P6 V3 Diffuse IRFs is expected due to corrections to the effective area. The increased RMS for P6 V11 may be due to use of the orbit-averaged point spread function as compared to a Theta-dependent PSF in P6 V3. However, P6 V11 Diffuse using the transit-selected binning is a better choice for this study.

September 2010 Crab Flare
12-hour Transit-selected Lightcurve

Figure 6

Flux of Pulsar and Nebula



This Crab lightcurve (Fig. 6) shows 12-hour variability of the combined flux from the pulsar and nebula for the binning and analysis configuration studied in Geminga. Transit-selected binning gives an average interval of 12.7 hours per bin. The Crab is typically observable for 28% of the interval (~50% for TOO observations). Note that time spent near the edge of the FOV contributes less exposure than on-axis observations (e.g. Fig. 2c).

The general structure is in good agreement with [2]. The flux of the first sub-peak differs, but this is caused by strong sensitivity to the bin choice. Although some systematic effects remain in the lightcurves, the 12-hour variation seen in the September 2010 flare comfortably exceeds them.

The P6 V11 Diffuse response functions are applied here, however, additional work may further improve sub-day timescale analysis. Similar studies are of particular interest for the new Pass 7 reconstruction of the LAT data, which enhances efficiency near 100 MeV.

[1] Abdo et al. 2011, *Science*, 331, 739

[2] Balbo et al. 2011, *A&A*, 527, L4