Hard X-ray Variations in the Crab Nebula

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Abstract

In the first two years of science operations of the Fermi Gamma-ray Burst Monitor (GBM), August 2008 to August 2010, a ~7% (70 mcrab) decline was discovered in the overall Crab Nebula flux in the 15 - 50 keV band, measured with the Earth occultation technique. This decline was independently confirmed with four other instruments: the RXTE/PCA, Swift/BAT, INTEGRAL/IBIS, and INTEGRAL/SPI. The pulsed flux measured with RXTE/PCA from 1999-2010 was consistent with the pulsar spin-down, indicating that the observed changes were nebular. From 2001 to 2010, the Crab nebula flux measured with RXTE/PCA was particularly variable, changing by up to ~3.5% per year in the 15-50 keV band. These variations were confirmed with INTEGRAL/SPI starting in 2003, Swift/BAT starting in 2005, and Fermi GBM starting in 2008. Before 2001 and since 2010, the Crab nebula flux has appeared more stable, varying by less than 2% per year. I will present updated light curves in multiple energy bands for the Crab Nebula, including recent data from Fermi GBM, Swift/BAT, INTEGRAL and MAXI, and a 16-year long light curve from RXTE/PCA.

Observations & Results

GBM

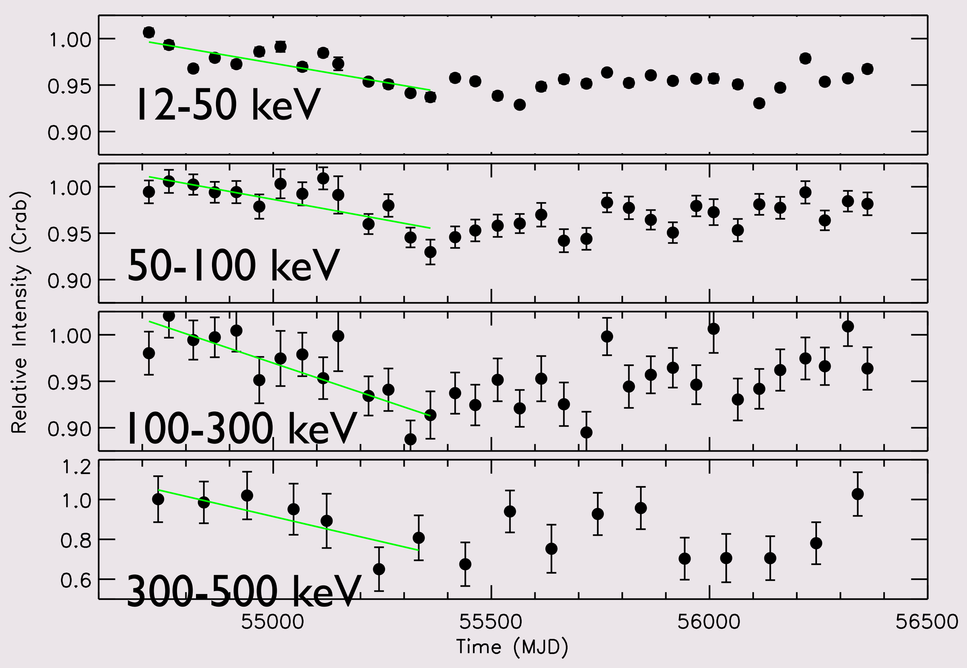

Figure 1: GBM 50-day average Crab light curves measured using Earth Occultation for 12-50, 50-100, 100-300, and 300-500 keV. From MJD 54690-55390 (marked with a green line), the Crab rate decreased steadily by: 5.4±0.4%, 6.6±1.0%, 12±2%, and 39±13% in these bands.

RXTE/PCA

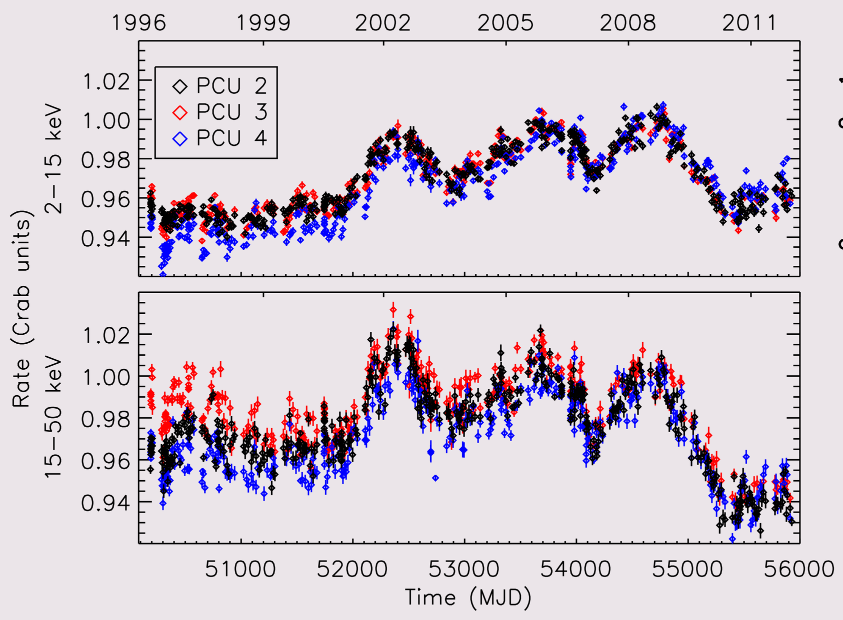

Figure 2: RXTE/PCA total Crab rates for layers 2+3 of PCU 2 (black), PCU 3 (red), and PCU 4 (blue) in the 2-15 and 15-50 keV bands, respectively, for the entire 16-year RXTE mission. The Crab rate in PCU 2 declined by 5.1±0.2% and 6.8±0.3% in the 2-15 and 15-50 keV

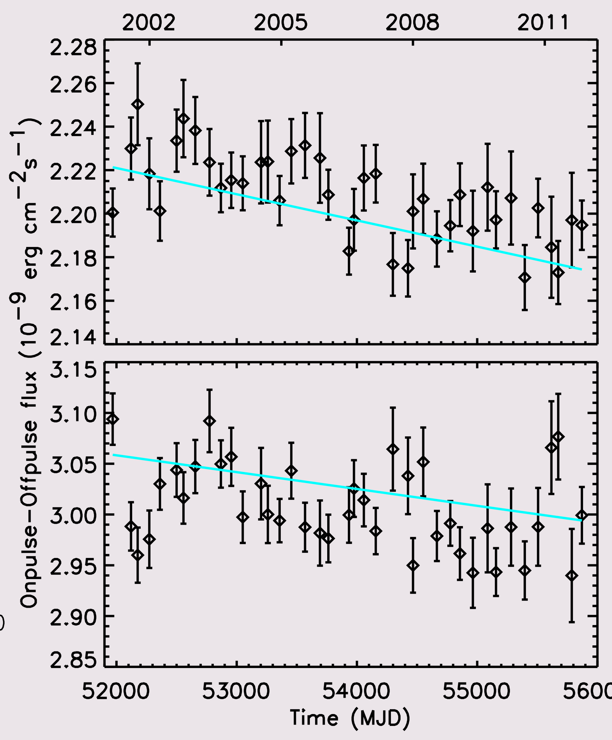

Figure 3: RXTE/PCA Crab pulsed flux measured using phase resolved spectroscopy with event mode data (Top: 3-10 keV, Bottom 15-50 keV). The solid light blue line shows the ~0.2% decrease expected from pulsar spin-down, which is consistent with the observations.

INTEGRAL

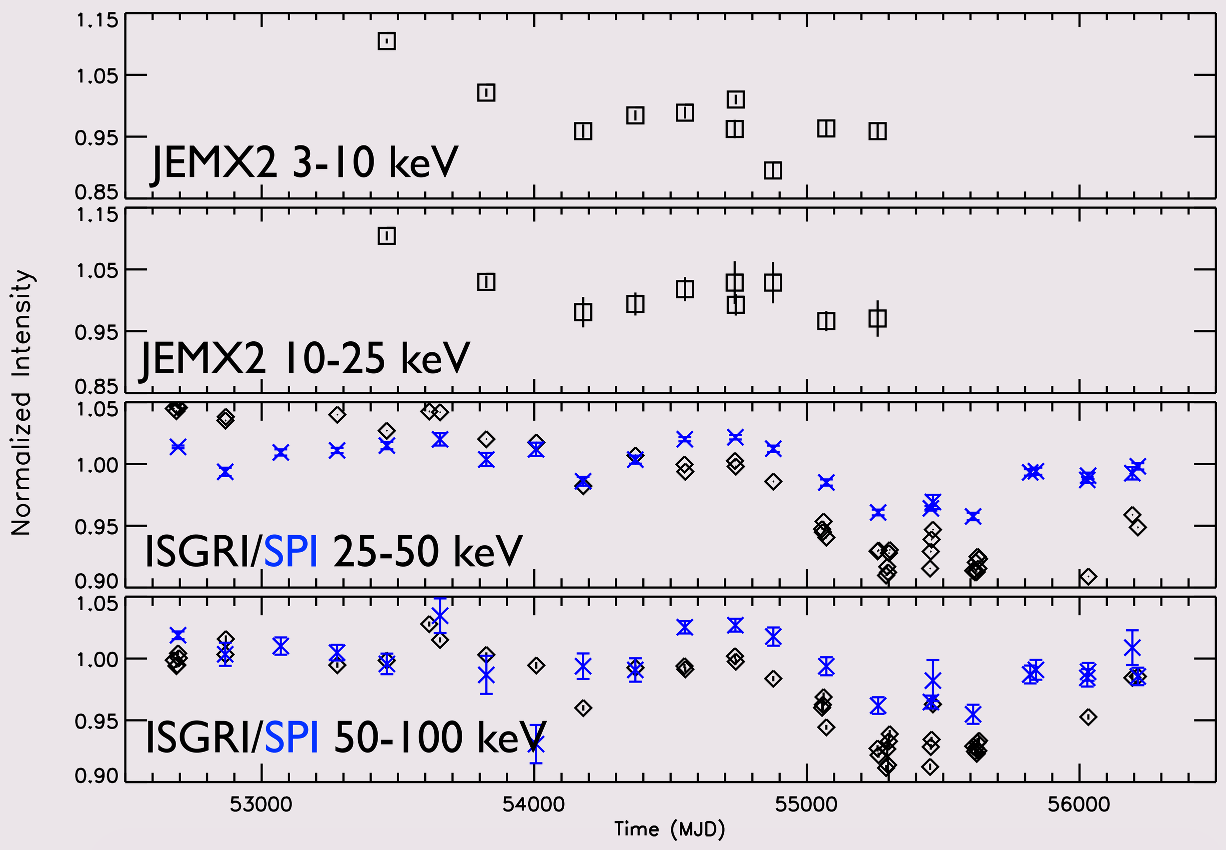

Figure 4: INTEGRAL 3-day revolution averaged light curves of the Crab measured in the 3-10 and 10-25 keV bands with JEM-X (black squares), the 25-50, and 50-100 keV bands with ISGRI (black diamonds) and SPI (blue crosses). The scatter in the JEM-X data is large compared to the observed Crab variations, especially below 10 keV. From MJD 54690-55390, the ISGRI 15-50, 50-100, and 100-300 keV fluxes decreased by 8.2±1.1%, 8.3±1.1%, and 5.7±1.0%, respectively.

Swift/BAT

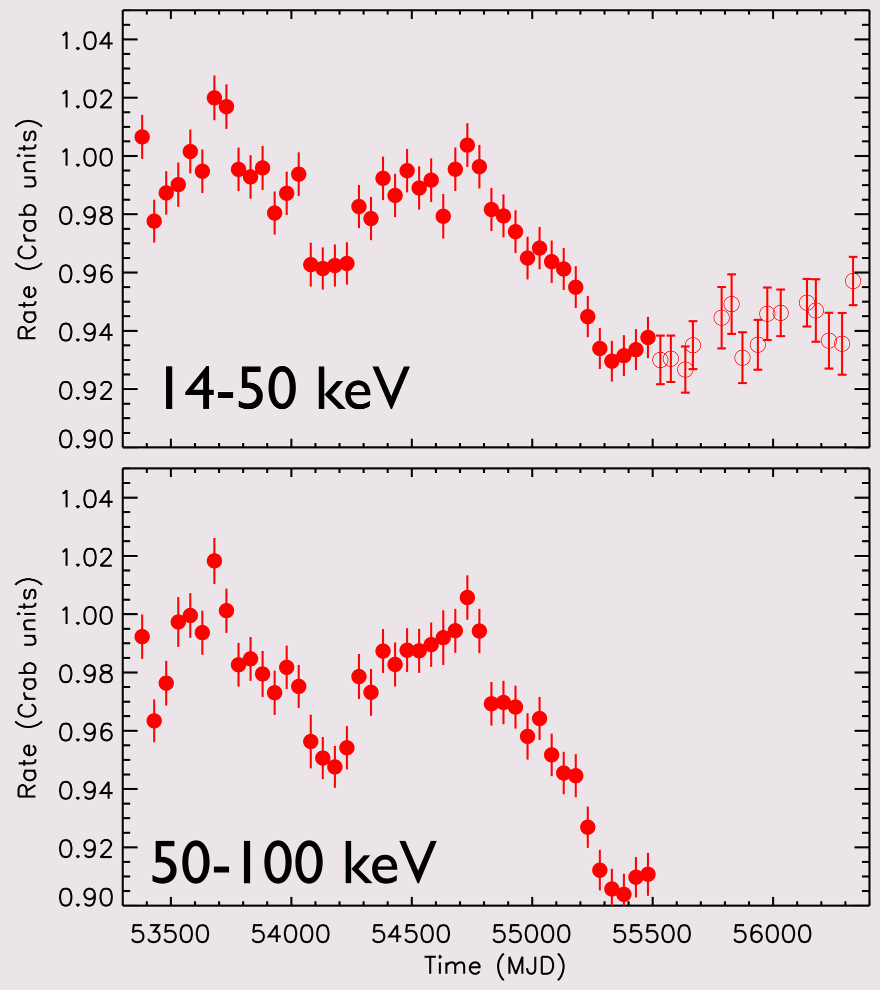

Figure 5: Swift/BAT 50-day average Crab light curves in the 14-50 and 50-100 keV bands. Systematic errors of 0.75% of the observed rate are included in the error bars. The Crab rate declined by 6.7±0.7 and 10.4±0.8% in these two bands from MJD 54690-55340. BAT survey and transient monitor data are denoted with filled and open circles, respectively.

Summary & Conclusions

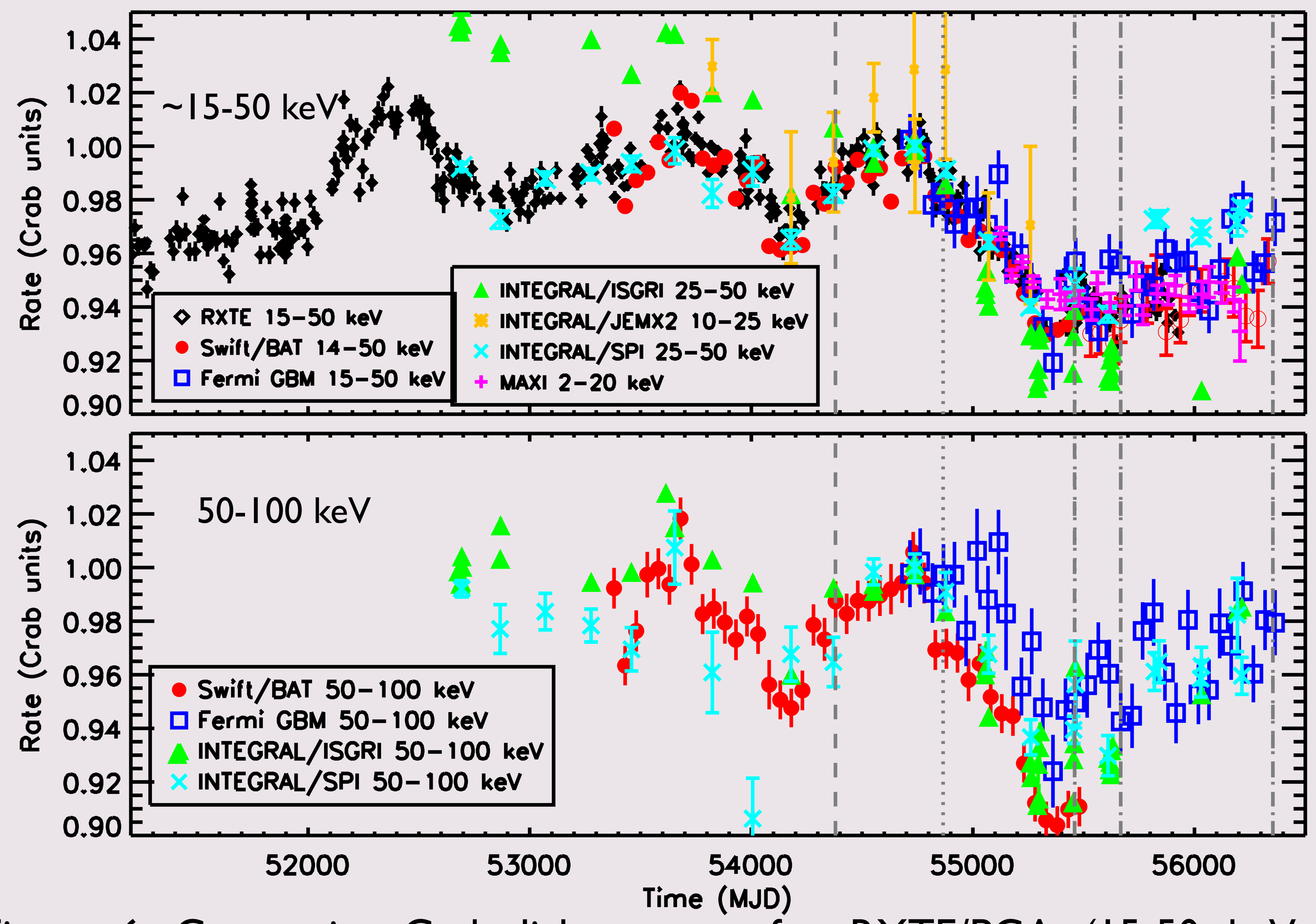

Figure 6: Composite Crab light curves for RXTE/PCA (15-50 keV - black diamonds), Swift/BAT (Top: 14-50 keV, Bottom: 50-100 keV - red filled circles), Fermi/GBM (Top 15-50 keV, Bottom:50-100 keV - blue open squares), INTEGRAL/SPI (Top: 25-50 keV, Bottom: 50-100 keV - light blue x's), INTEGRAL/ISGRI (Top: 25-50 keV, Bottom: 50-100 keV - green filled triangles), INTEGRAL/JEM-X2 (10-25 keV, gold asterisks), and MAXI (2-20 keV - magenta crosses). Each data set has been normalized to its mean rate in the time interval MJD 54690-54790. All error bars except Swift/BAT include only statistical errors. Times of high energy flares observed with AGILE (dashed lines) and Fermi LAT (dotted lines) are shown for reference.

All instruments agree well from 2008 to 2010, with all instruments registering a decline in the Crab 15-50 keV flux of ~7% (70 mcrab) over two years starting at MJD 54690, with a similar decline in the 50-100 keV band. PCA, BAT, and SPI continue to agree back to the start of the Swift mission. For GBM, Swift, INTEGRAL/ISGRI, and SPI, the latest measurements (<50 keV) have nearly reached the 2007 minimum while higher energy measuremets (>50 keV) have exceeded the 2007 minimum. Prior to the beginning of the Swift mission, the PCA light curves show continued variations extending back to MJD 52000, which are consistent with SPI 25-50 keV measurements, but not ISGRI 25-50 keV measurements. Beginning at ~MJD 54000 there is a strong correlation among the results from the seven independent instruments with very different signal to noise characteristics and observing techniques: Earth occultation (GBM), coded mask imaging (BAT, SPI, & ISGRI), and collimated detectors (PCA). The range of techniques strengthens the case that the variation is intrinsic to the Crab. We found no correlations between these observed variations and variations in the INTEGRAL/SPI anti-coincidence detector count rates or GBM background count rates, evidence against a local background origin and further support for a Crab origin. The pulsed flux stability suggests that the observed variations are nebular. No hard X-ray response to the gamma-ray flares is evident.

In summary, the widely held assumption that the Crab is a standard candle, suitable for normalizing instrument response functions and calibrating X-ray instruments, is now in question. The Crab is varying at a level of ~3.5% per year. This variation is seen in the nebular emission, and so apparently results from changes in the shock acceleration or the nebular magnetic field. Recent measurements show that the flux is slowly recovering, especially at higher energies (GBM & SPI).

For further details and references, see: Wilson-Hodge et al. 2011, ApJ, 727, L40.

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13th Meeting of the AAS High Energy Astrophysics Division, Monterey, CA, April 7-11, 2013