When a Standard Candle Flickers

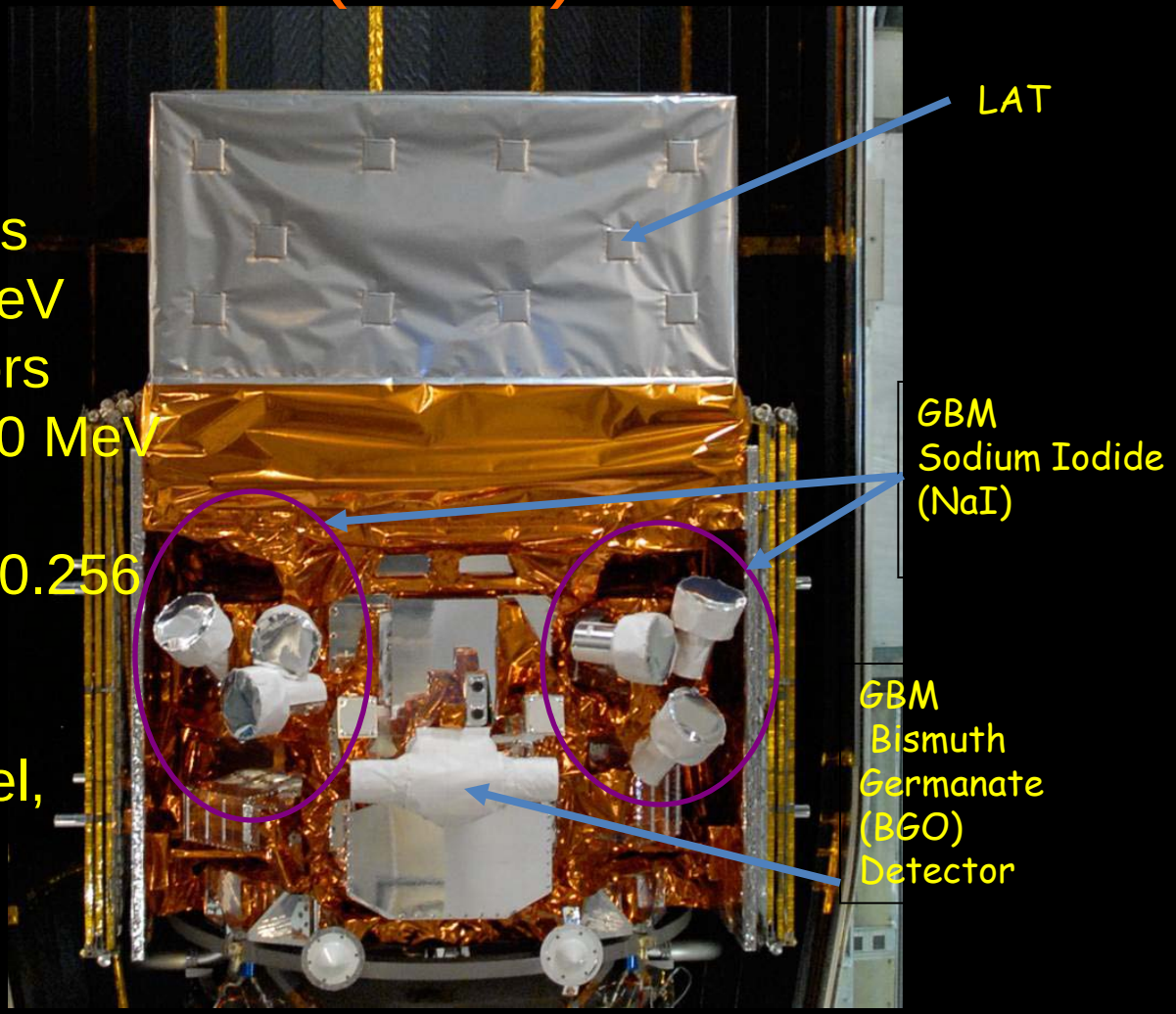
Colleen A. Wilson-Hodge (NASA/MSFC), M.L. Cherry (LSU), E. Beklen (METU/SDU), P.N Bhat, M.S. Briggs (UAH), A. Camero-Arranz (NSSTC), G.L. Case (LSU), V. Chaplin, V. Connaughton (UAH), M.H. Finger (USRA), J. Greiner (MPE), K. Jahoda (NASA/GSFC), P. Jenke (NPP/NASA/MSFC), R.M. Kippen (LANL), C. Kouveliotou (NASA/MSFC), E. Kuulkers (ISOC), C.A. Meegan (USRA), L. Natalucci (INAF-IASF), W.S. Paciesas, R. Preece (UAH), J.C. Rodi (LSU), N. Shaposhnikov (CRESST/NASA/GSFC), D. Swartz (USRA), A. von Kienlin (MPE)

Introduction

- The Crab is the only bright steady source in the X-ray sky.
- The Crab consists of a pulsar wind nebula, a synchrotron nebula, and a cloud of expanding ejecta.
- On small scales, the Crab is extremely complex and turbulent.
- X-ray astronomers have often used the Crab as a standard candle to calibrate instruments, assuming its spectrum and overall flux remains constant over time.

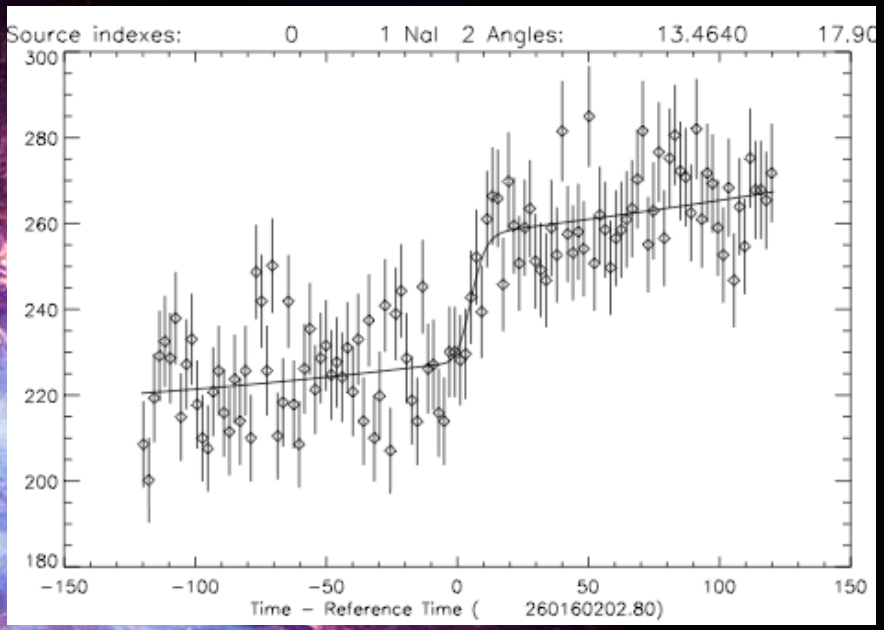
Fermi Gamma Ray Burst Monitor (GBM)

- GBM
  - 12 NaI detectors
    - 8keV - 1 MeV
  - 2 BGO detectors
    - 150 keV - 40 MeV
  - CTIME data
    - 8 channel, 0.256 s
  - CSPEC data
    - 128 channel, 4.096s



GBM Earth Occultation Technique

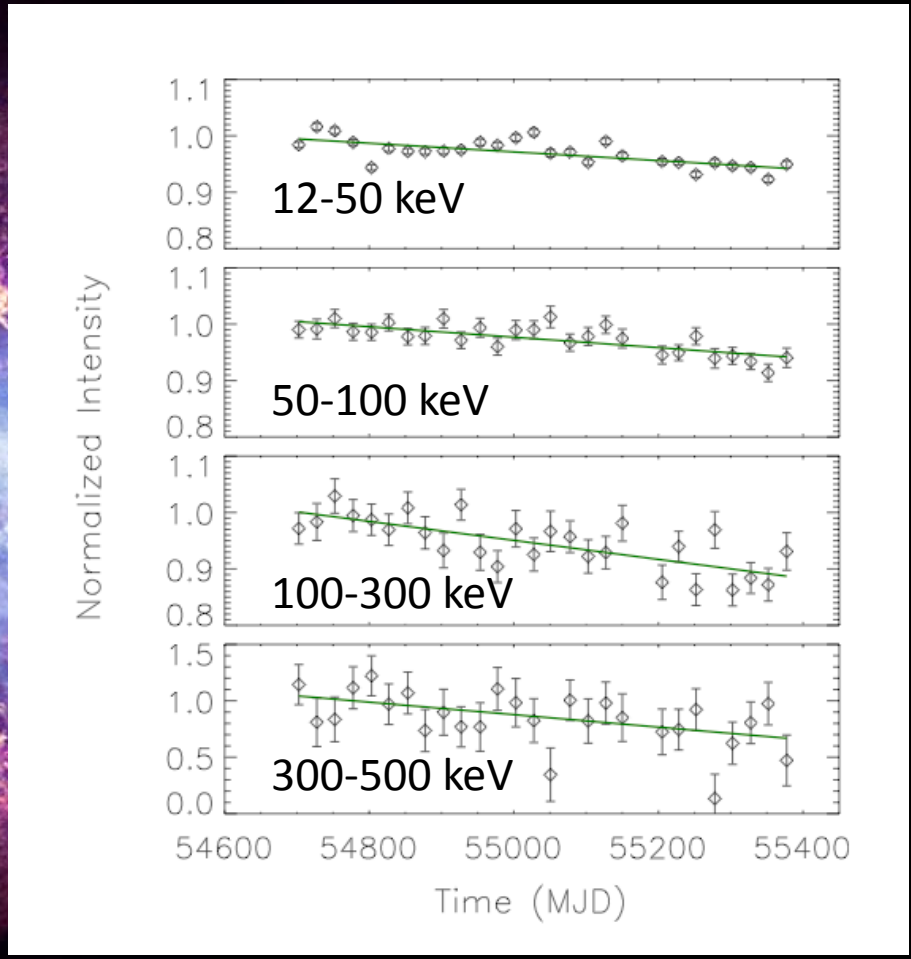
- Current catalog includes 83 sources, primarily recently active X-ray binaries, the Crab, 4 AGN, 2 SGRs, and the Sun
- Fluxes for cataloged sources measured by fitting the change in count rate due to Earth occultation
- Source model: assumed spectrum convolved with changing detector response and atmospheric transmission
- 8 energy bands in NaI or BGO detectors
- 6 persistent and 2 transient sources detected above 100 keV; 50+ sources detected <100 keV.



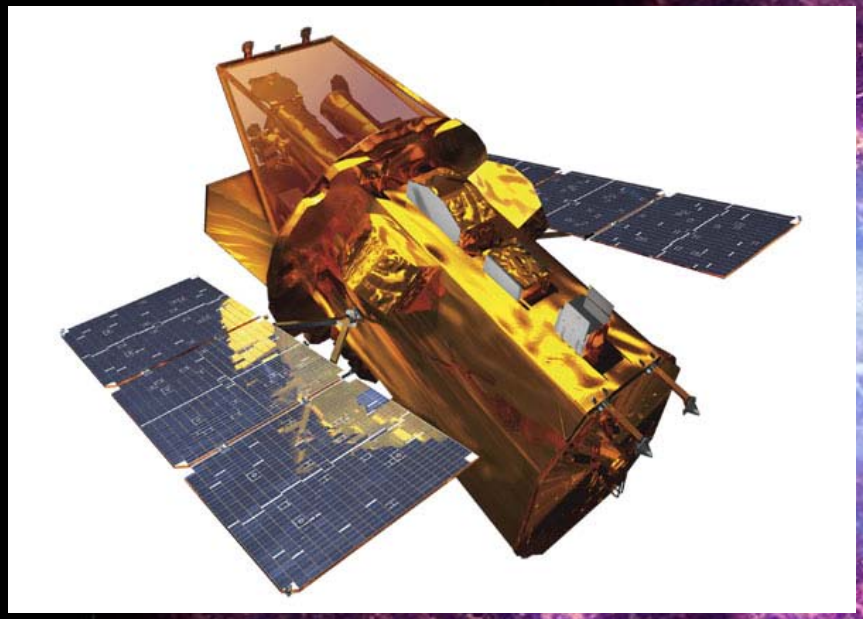
- Over 85% of sky viewed every orbit
- Entire sky viewed every ~26 days
- Sensitivity exceeds CGRO/BATSE below 25 keV and above ~1 MeV
- No solar constraints

GBM Observations of the Crab Nebula

- 25-day averages
- Normalized to long-term average in each band
- Decline in Crab flux:
  - 5.4 ± 0.4% 12-50 keV
  - 6.6 ± 1.0% 50-100 keV
  - 12 ± 2% 100-300 keV
  - 39 ± 12% 300-500 keV
- Decline becomes larger as energy increases
- No changes in GBM response or calibration



Swift BAT Transient Monitor

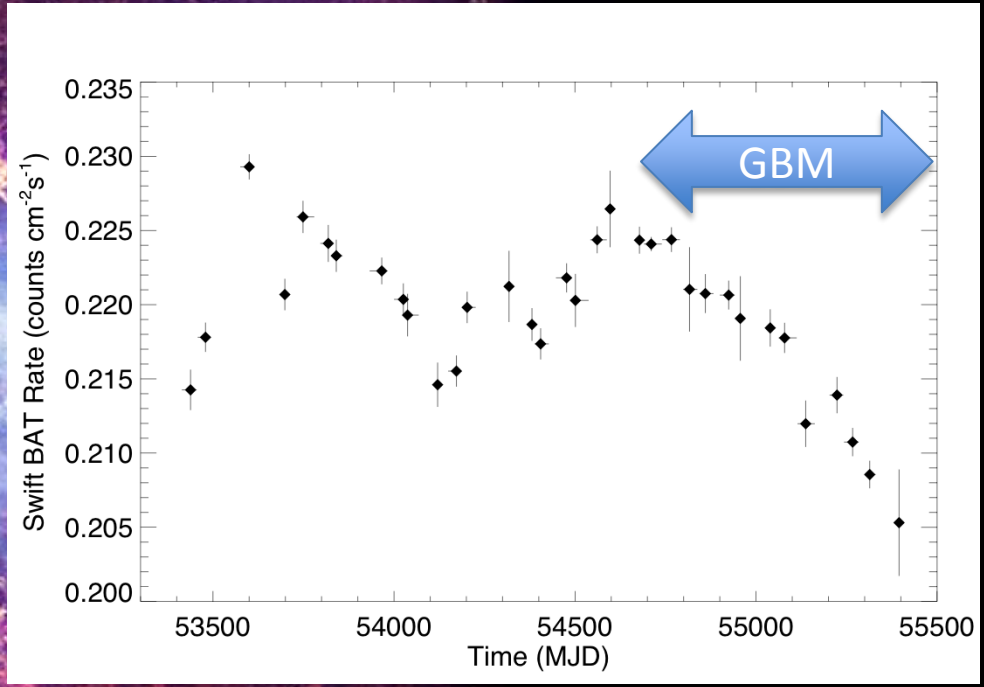


- Swift Burst Alert Telescope (BAT)
- 2 steradian field of view
- Scaled maps in 15-50 keV band
- Maps on timescales >64s
- Corrections for geometry, varying numbers of detectors, material in the field of view, etc.

http://swift.gsfc.nasa.gov/docs/swift/results/transients/index.html

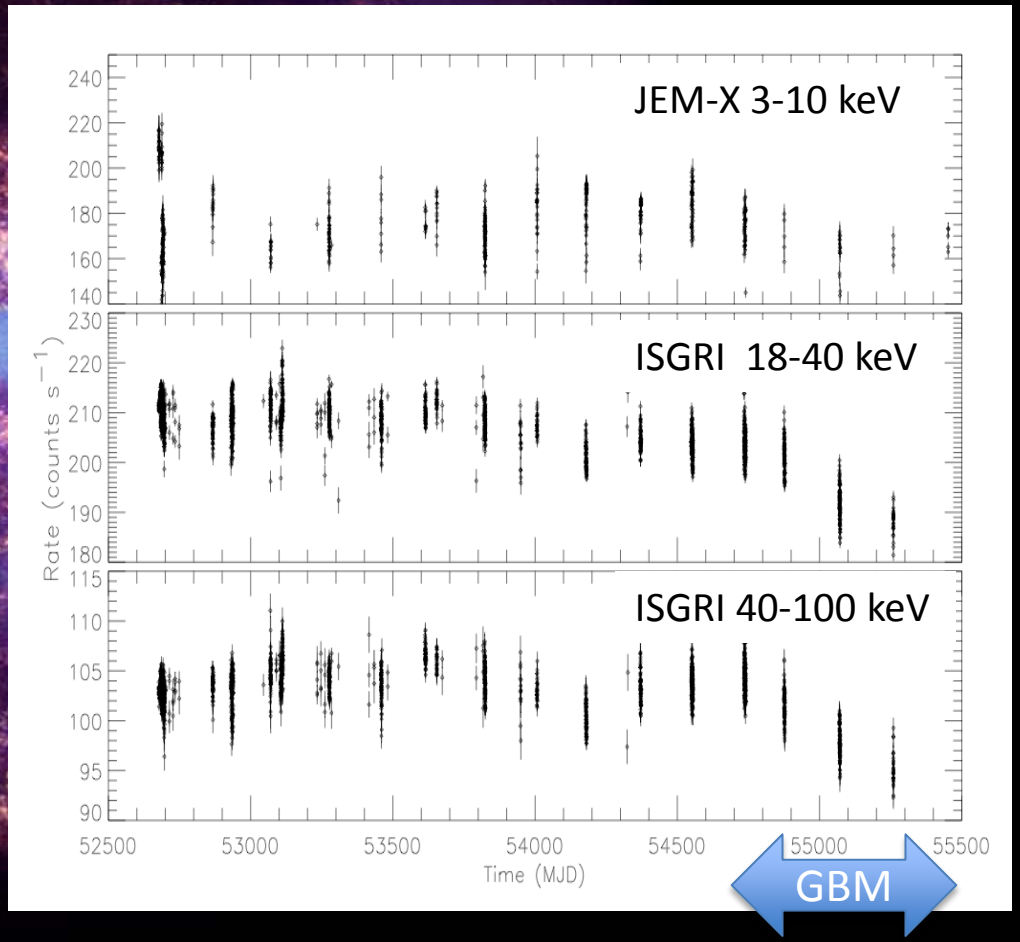
Swift BAT Transient Monitor: Crab Light Curve

- Points shown are ~50 day averages
- Constructed from orbital light curves
- Selected good data (data quality flag =0)
- Restricted partial coding fractions to >80%
- Excluded bright flaring intervals from A0535+26
- Flux decline of ~4.5% observed during overlap with GBM



INTEGRAL ISGRI and JEM-X Crab Light Curves

- Publically available Crab observations
- Produced using OSA 9.0
- Offset <10° (ISGRI); < 3°(JEM-X)
- Corrections based upon constant Crab are omitted.
- During the overlap with GBM, a ~5% decline is seen in the 18-40 and 40-100 keV bands



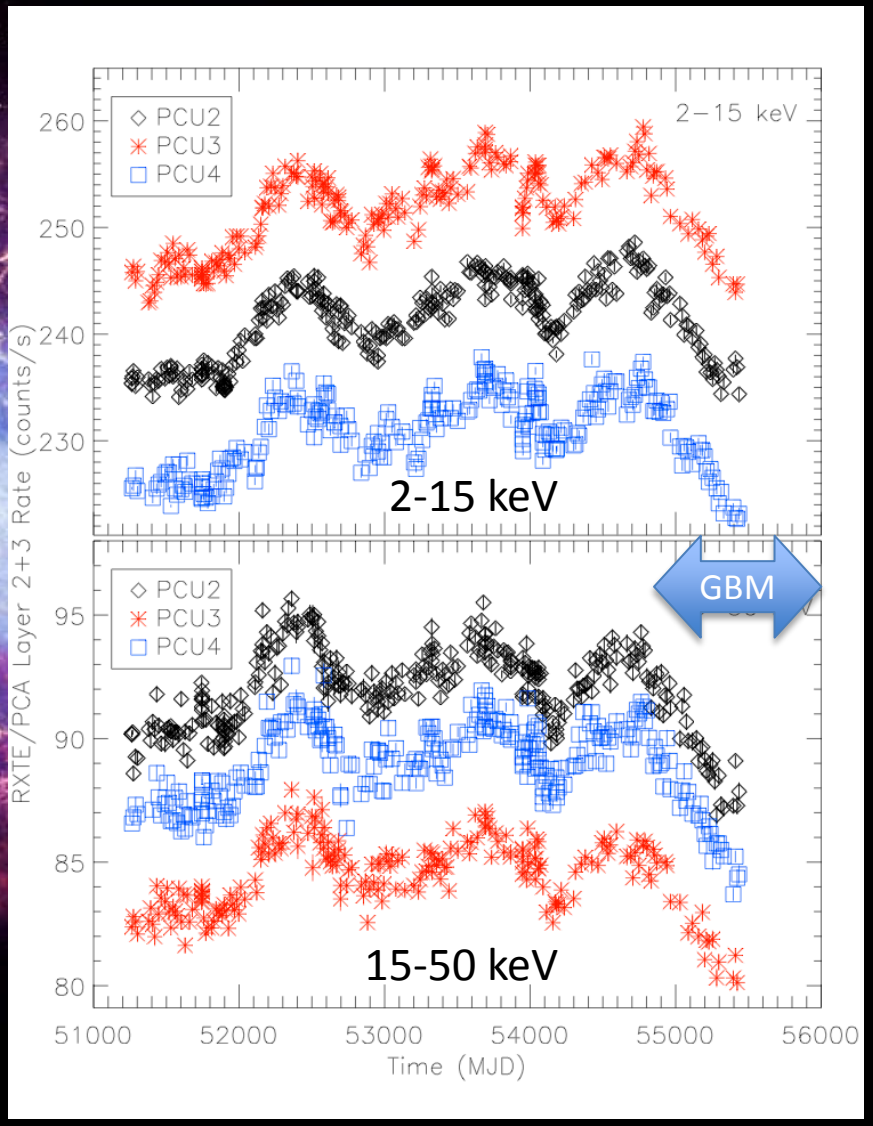
http://integral.esac.esa.int/BULGE/SOURCES/Crab/Crab.html

Rossi X-ray Timing Explorer (RXTE)

- Proportional Counter Array (2-60 keV)
- 1 deg FWHM field-of-view
- Last gain change for the PCA in March 1999
- More than 400 observations with same channel-to-energy conversion
- Response Time Dependence
  - Gradual change in energy edges with time
  - Xe Leakage into the Propane Layers

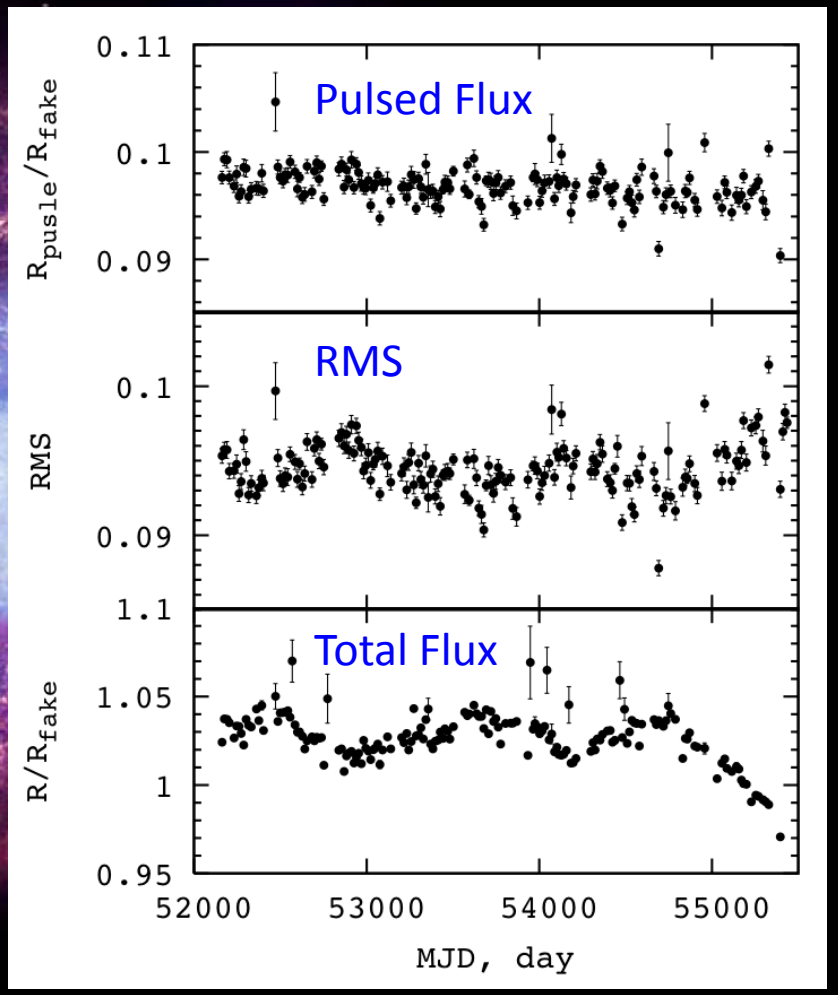
RXTE PCA Crab Light Curve

- Extracted light curves using standard 2 data
- Observations shorter than 300 s were excluded
- Background subtracted and deadtime corrected
- Corrected for response time dependence using response predicted count rate and by selecting layers 2+3
- Variations of ~5% visible in the GBM era in all 3 PCUs



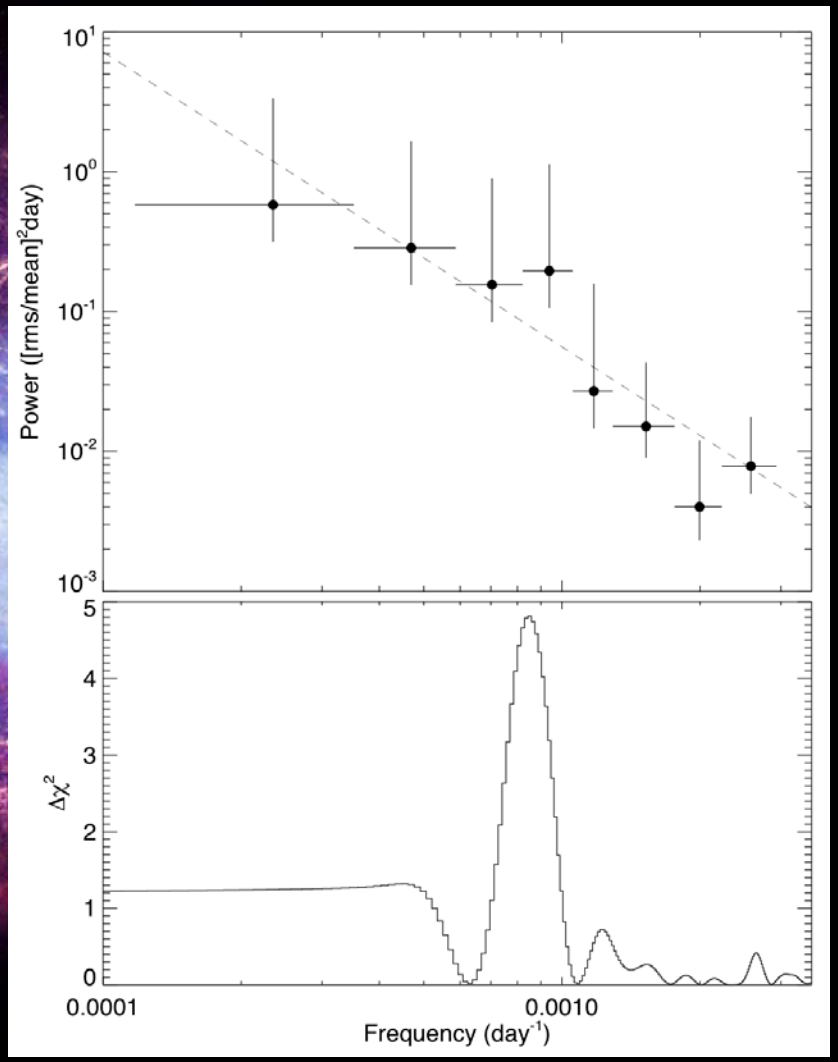
RXTE Crab Pulsed Flux

- Event mode data (250μs, 129 channel)
- 3.2-35 keV, all PCU2 layers
- Pulsed flux shows stead decrease at 0.2% per year – consistent with pulsar spin down.
- The larger ~5% per year variation not seen in pulsed emission
- Likely has nebular origin



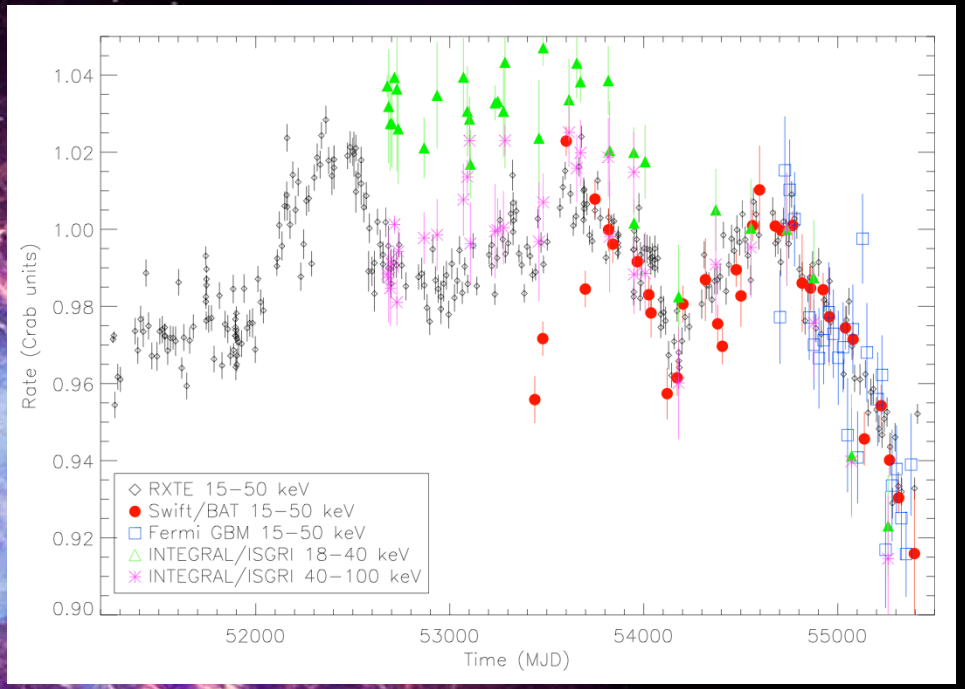
RXTE PCA – Search for Periodicity

- PCA light curve has 3 peaks. Is there a periodicity?
- Power spectrum from evenly binned 15-50 keV PCU 2 data (3 bins per year). Power law index 2.1±0.4
- Frequency search – fitted quadratic + sinusoid.
- Highest peak 1176±96 days, only 2σ



Comparing Instruments

- Light curves for each instrument are normalized to its average rate from MJD 54690-54790.
- RXTE/PCU2 (15-50 keV)
  - Black Diamonds
- BAT (15-50 keV)
  - Red Circles
- ISGRI (18-40 keV)
  - Green triangles
- ISGRI (40-100 keV)
  - Pink asterisks
- GBM (15-50 keV)
  - Blue squares



Instruments on four separate spacecraft show ~5% yr^{-1} decline in Crab flux

Summary & Conclusions

- Four instruments (Fermi/GBM, RXTE/PCA, Swift/BAT, INTEGRAL/ISGRI) show a ~5% (50 mCrab) decline in the Crab from 2008-2010.
- This decline appears to be larger with increasing energy and is not present in the pulsed flux, implying changes in the shock acceleration, electron population or magnetic field in the nebula.
- The Crab is known to be dynamic on small scales, so it is not too surprising that its total flux varies as well.
- Caution should be taken when using the Crab for in-orbit calibrations.