When a Standard Candle Flickers: The Dimming of the Crab Nebula

Gary Case
Louisiana State University

IACHEC, Frascati, Italy, 11 April 2011

Collaborators

GBM Occultation Team:

C.A Wilson-Hodge (NASA/MSFC), M.L. Cherry, J. Rodi (LSU), A. Camero-Arranz, M.H. Finger (USRA), P. Jenke, C. Kouveliotou (NASA/MSFC), V. Chaplin, V. Connaughton, W.S. Paciesas (UAH), E. Beklen (METU/SDU)

GBM Instrument Team:

P.N. Bhat, M.S. Briggs, R. Preece (UAH), J. Greiner, A. von Kienlin (MPE), R.M. Kippen (LANL), C. A. Meegan (USRA)

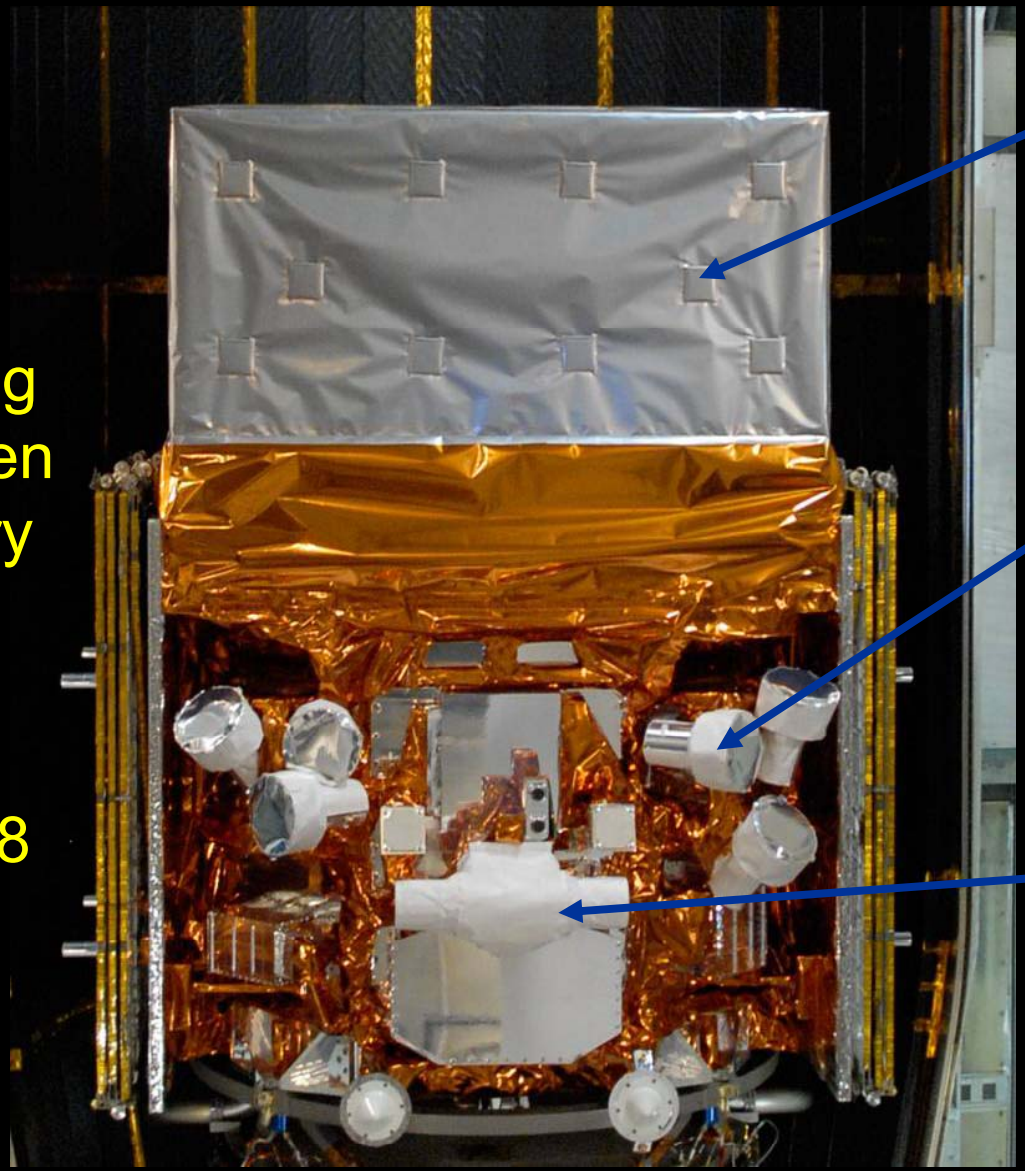
Co-authors representing other instruments:

W.H. Baumgartner (NASA/CRESST), N. Gehrels, K. Jahoda (NASA/GSFC), H. Krimm (CRESST/NASA/GSFC/USRA), E. Kuulkers (ESA/ESAC), N. Lund (DNSC), L. Natalucci (INAF-IASF), N. Shaposhnikov, G.K. Skinner (UMD/CRESST/NASA/GSFC), D. Swartz (USRA), R. Diehl, X.-L. Zhang (MPE)

The *Fermi* Satellite

Fermi (nee GLAST)

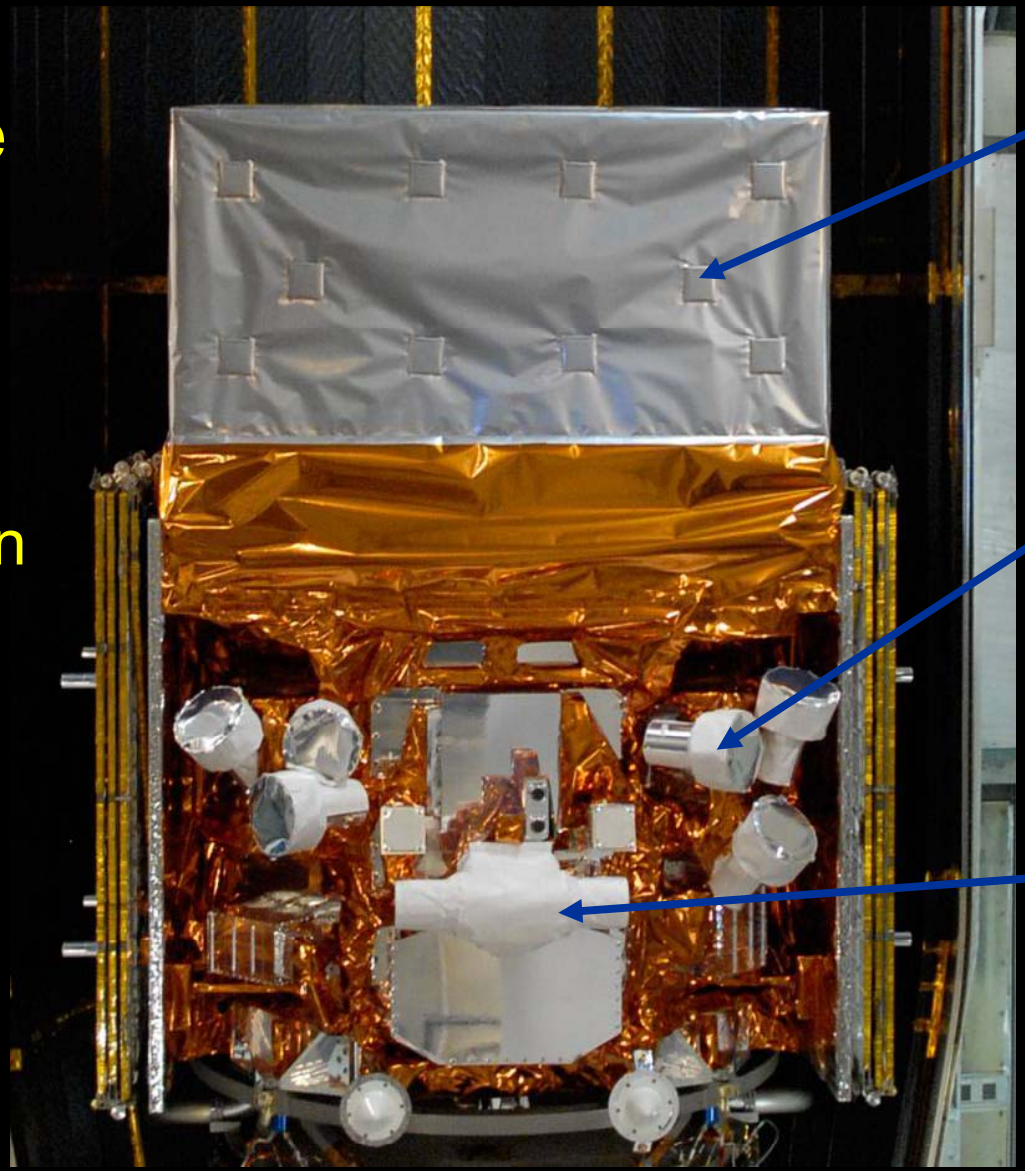
- 550 km orbit
- 25.6^{o} inclination
- Operates in scanning mode, rocking between ±50^{o} from zenith every orbit
- Performs slow roll every orbit
- Launched June 2008
- Science ops began August 2008



The *Fermi* Satellite

Large Area Telescope (LAT)

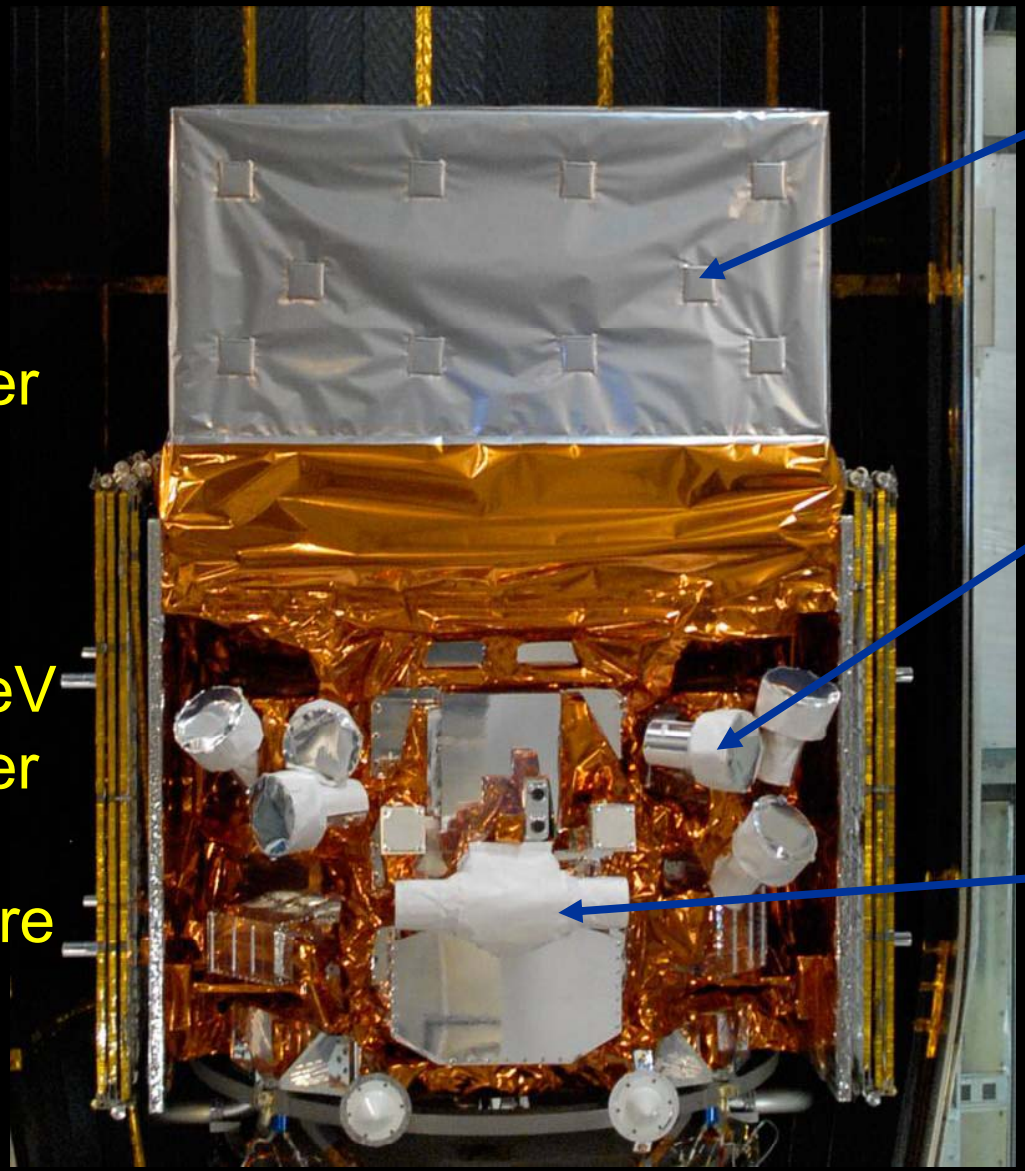
- Pair tracker and calorimeter
- 20 MeV - 300 GeV
- Point source location ~1 arcmin



The *Fermi* Satellite

Gamma-ray Burst Monitor (GBM)

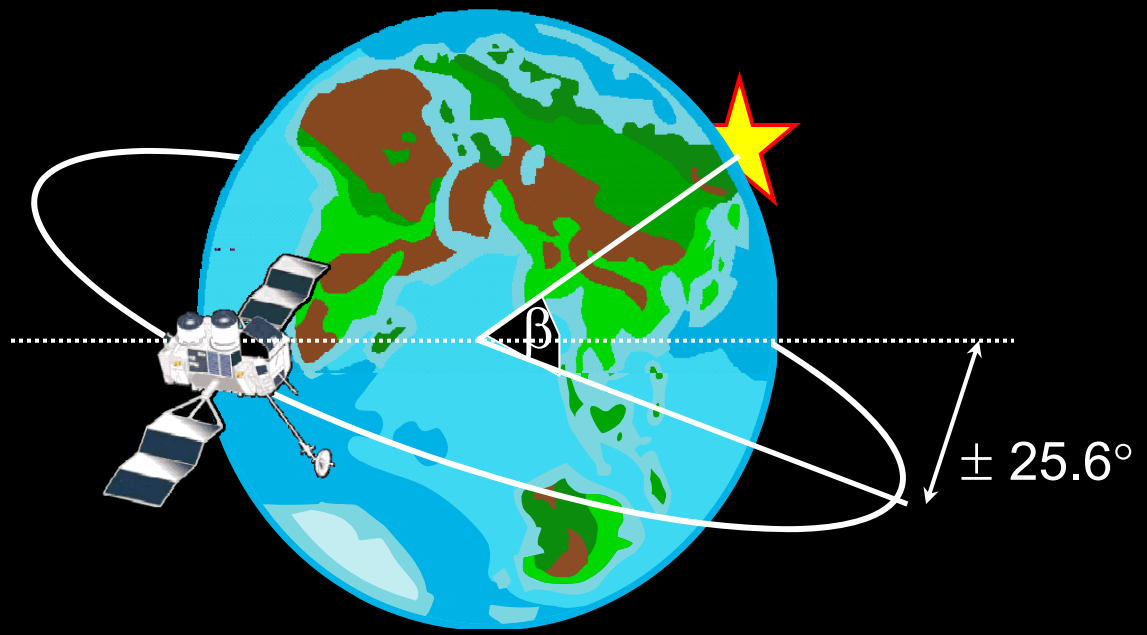
- 12 NaI detectors
  - 12.5 cm diameter x 1.25 cm thick
  - 8 keV - 1 MeV
- 2 BGO detectors
  - 150 keV - 40 MeV
  - 12.5 cm diameter x 12.5 cm thick
- All GBM detectors are non-imaging

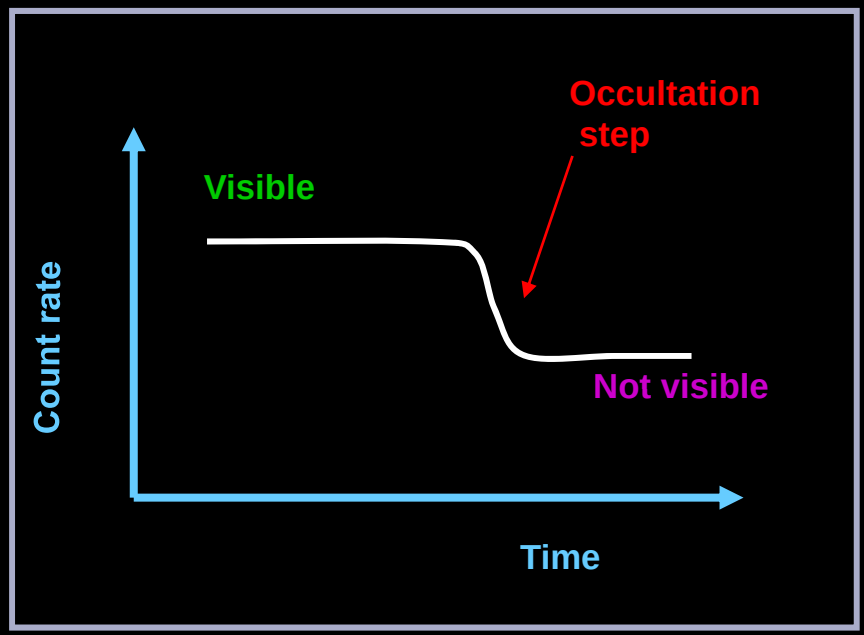


Earth Occultation

Question: How do you measure the intensity of a source if your detector doesn't know where the photon came from?

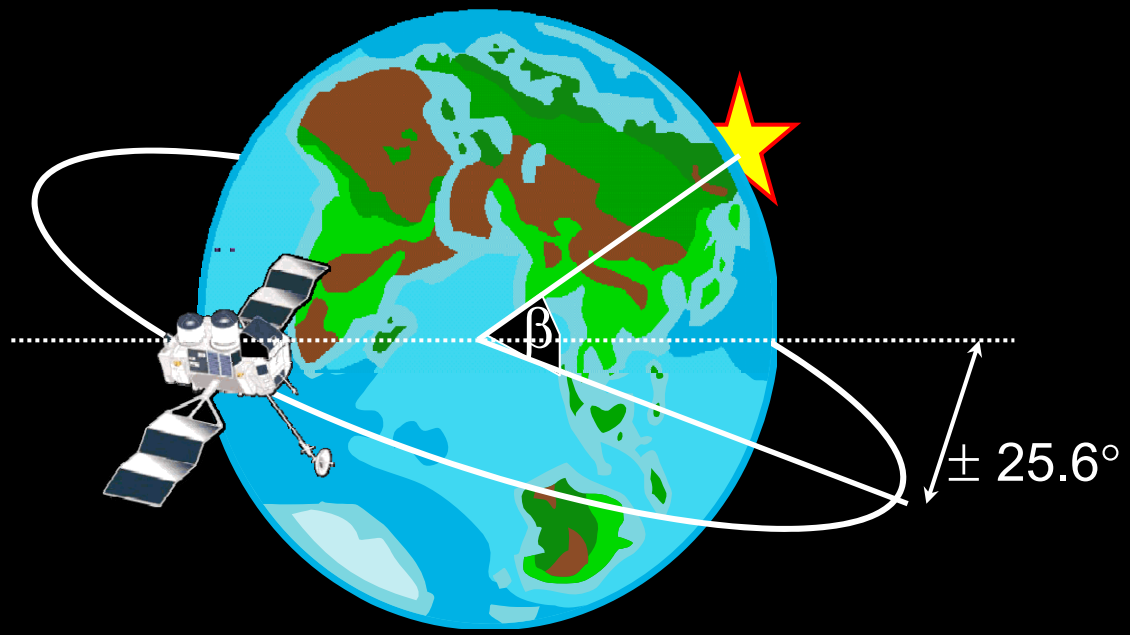
Answer: Earth occultation technique





Occultation Coverage

The diameter of the Earth seen from Fermi is ~ 140°, so roughly 30% of the sky is occulted by the Earth at any one time, and 85% of the sky is occulted in one orbit. The precession of the orbit allows the entire sky to be occulted every ~26 days.

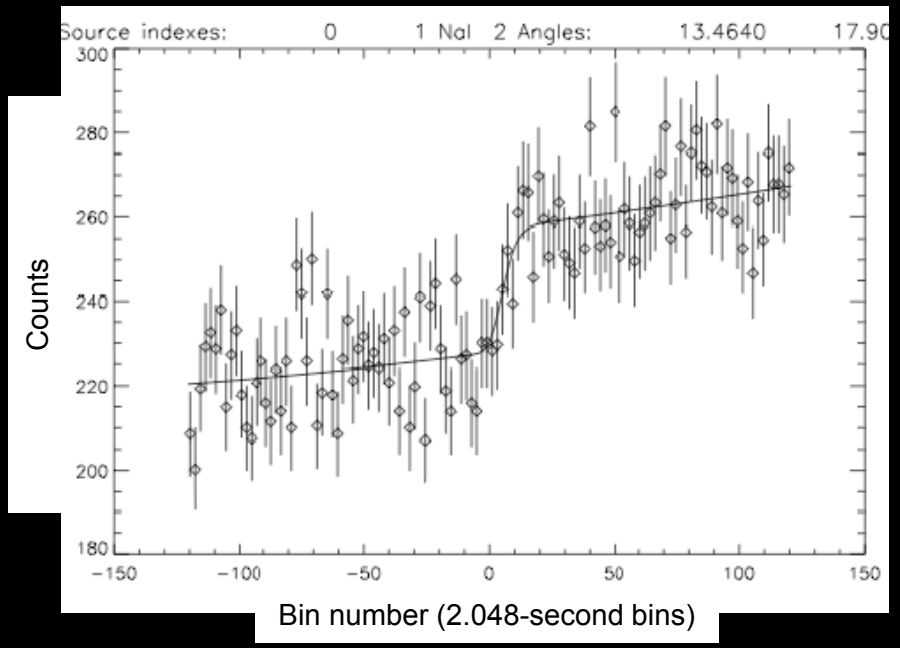


Fermi Orbital Parameters

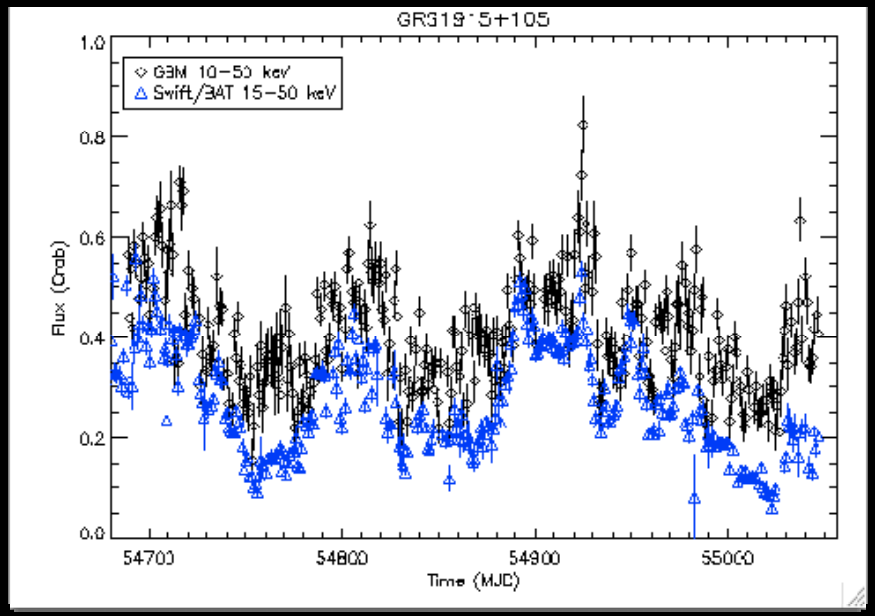
- Altitude ~ 565 km
- Period ~ 96 min
- Inclination ~ 25.6°
- Precession ~ 53 days

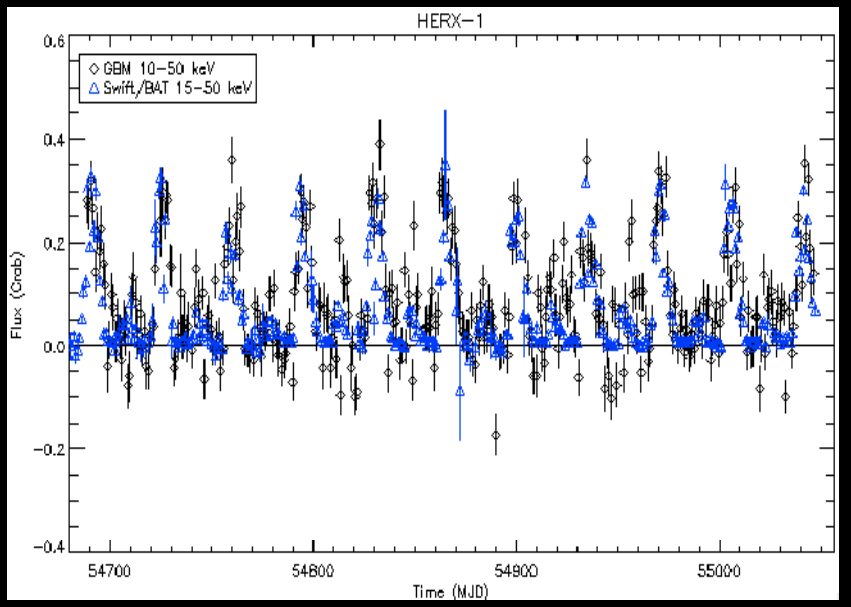
GBM Earth Occultation Technique

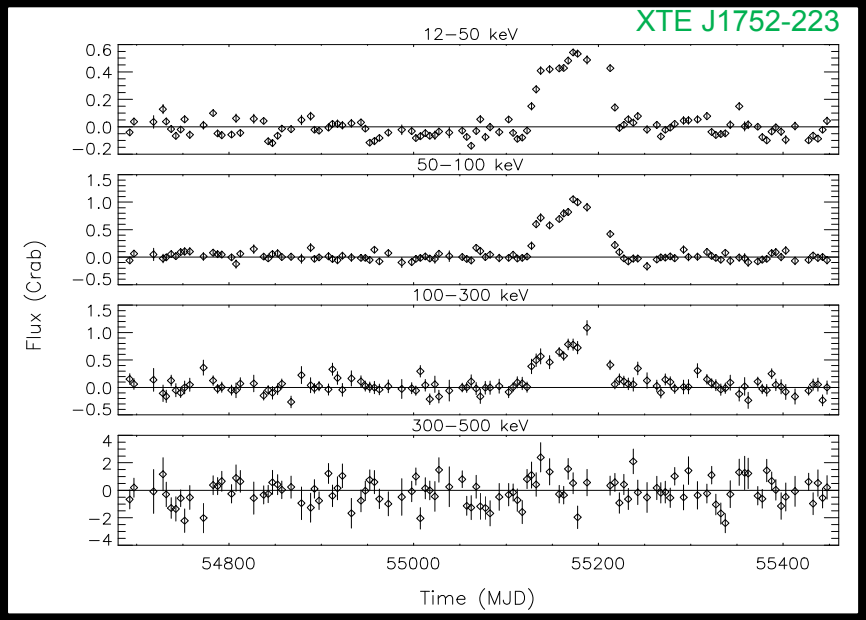
- Current input catalog includes 105 sources, primarily recently active X-ray binaries, the Crab, 10 AGN, 2 SGRs, 3 CVs, and the Sun
- Calculate occultation times and center each step in four minute window for each detector and each energy band (8 energy bands in CTIME data)
- Generate source model: assumed spectrum convolved with changing detector response and atmospheric transmission
- Fit data to source model, plus source models for interfering sources, and quadratic background
- 80+ sources detected <100 keV, 9 sources detected >100 keV

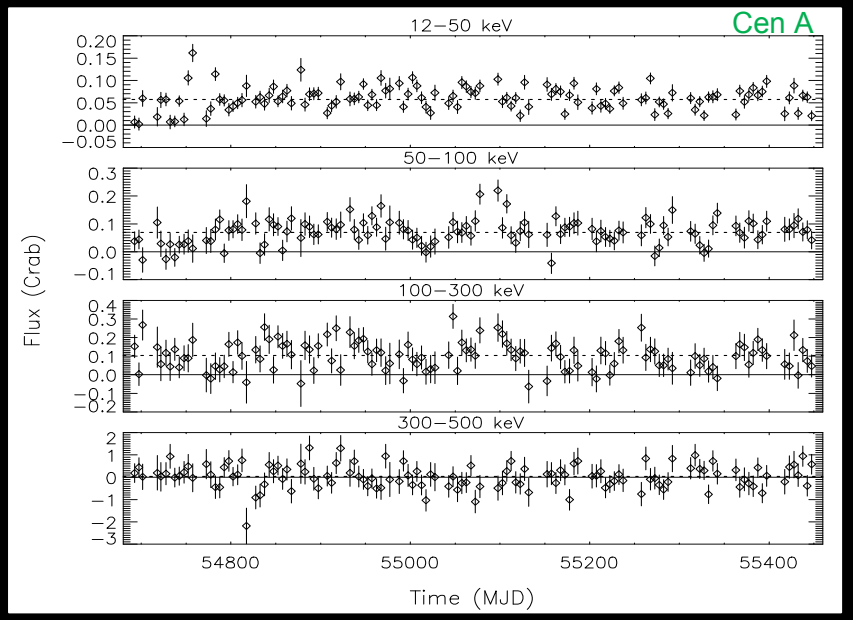


GBM Sample Light Curves



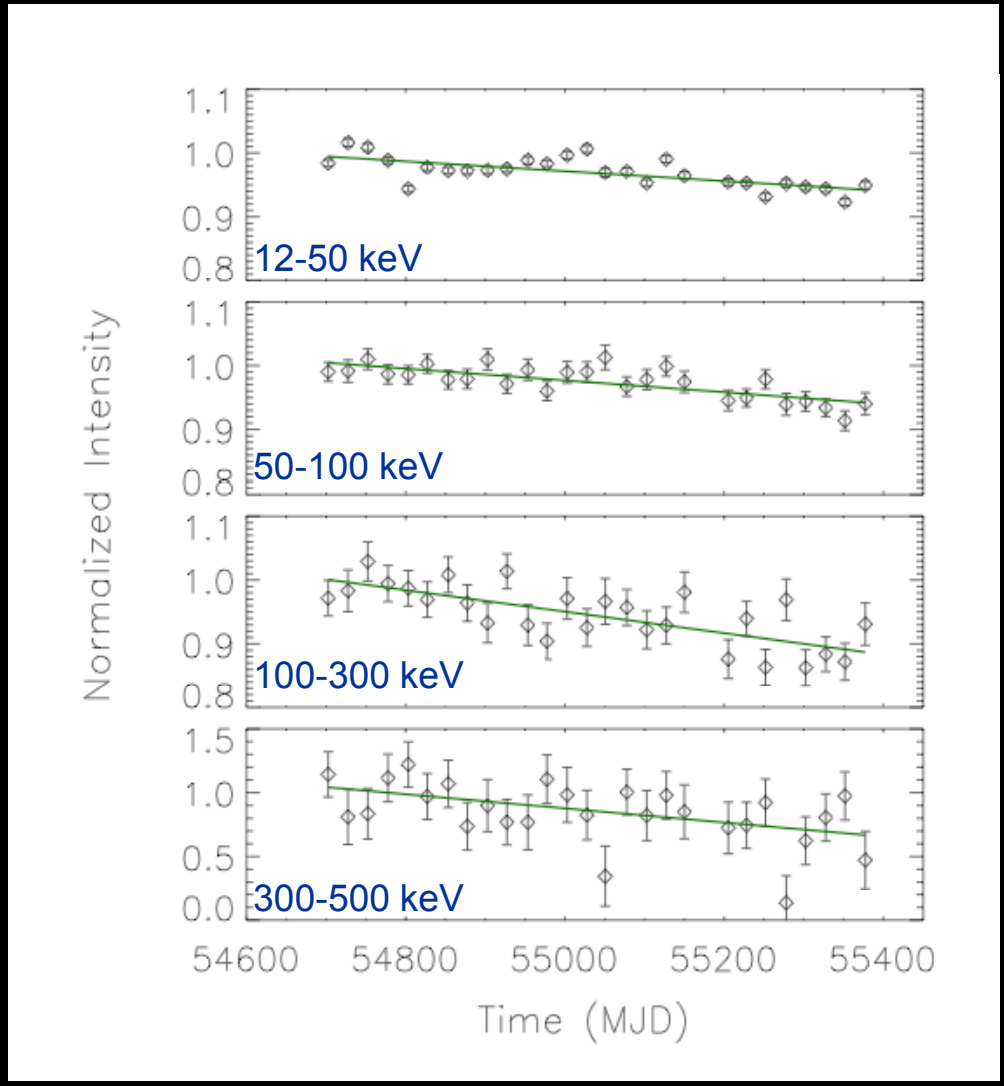




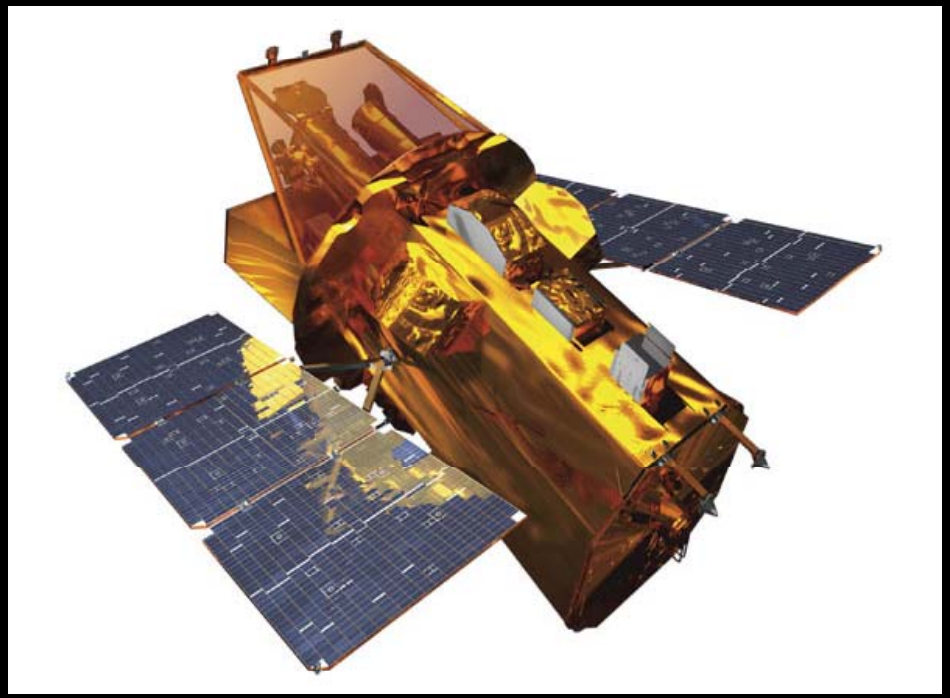


Fermi/GBM: Crab Light Curves

- 25-day averages
- Normalized to the first 100 days 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
- No changes in GBM response or calibration
- Decline appears to become larger as energy increases – spectral softening



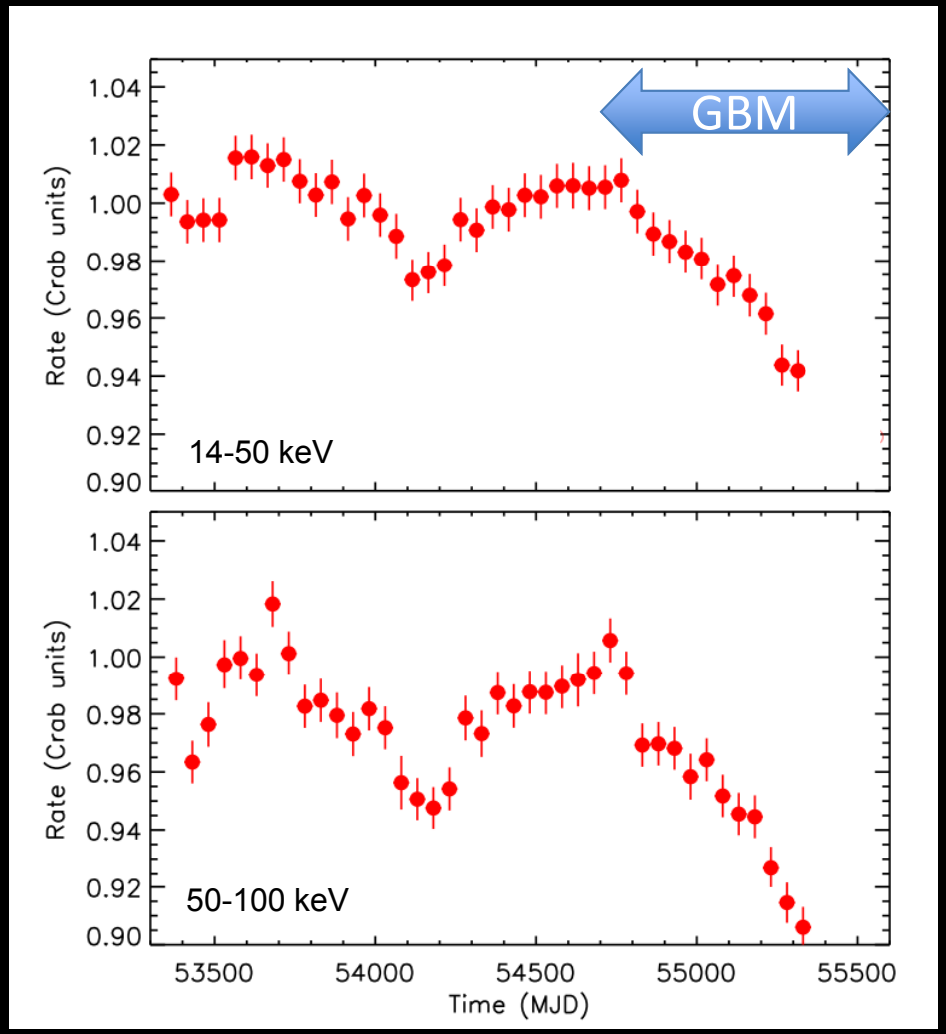
Swift/BAT Transient Monitor



- *Swift* Burst Alert Telescope (BAT)
- Launched in Nov 2004
- Coded aperture telescope with solid state detectors
- 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.

Swift/BAT: Crab Light Curves

- BAT team 65-month Survey to May 2010 + Transient monitor for May – Feb 2011
- Points shown are ~50 day averages in the 14-50 keV and 50-100 keV bands
- Constructed from single pointing light curves
- Restricted to partial coding fractions >85%
- Included systematic error of 0.75% of the rate
- Flux decline of ~6% in 15-50 keV band observed during overlap with GBM (54690-55340)

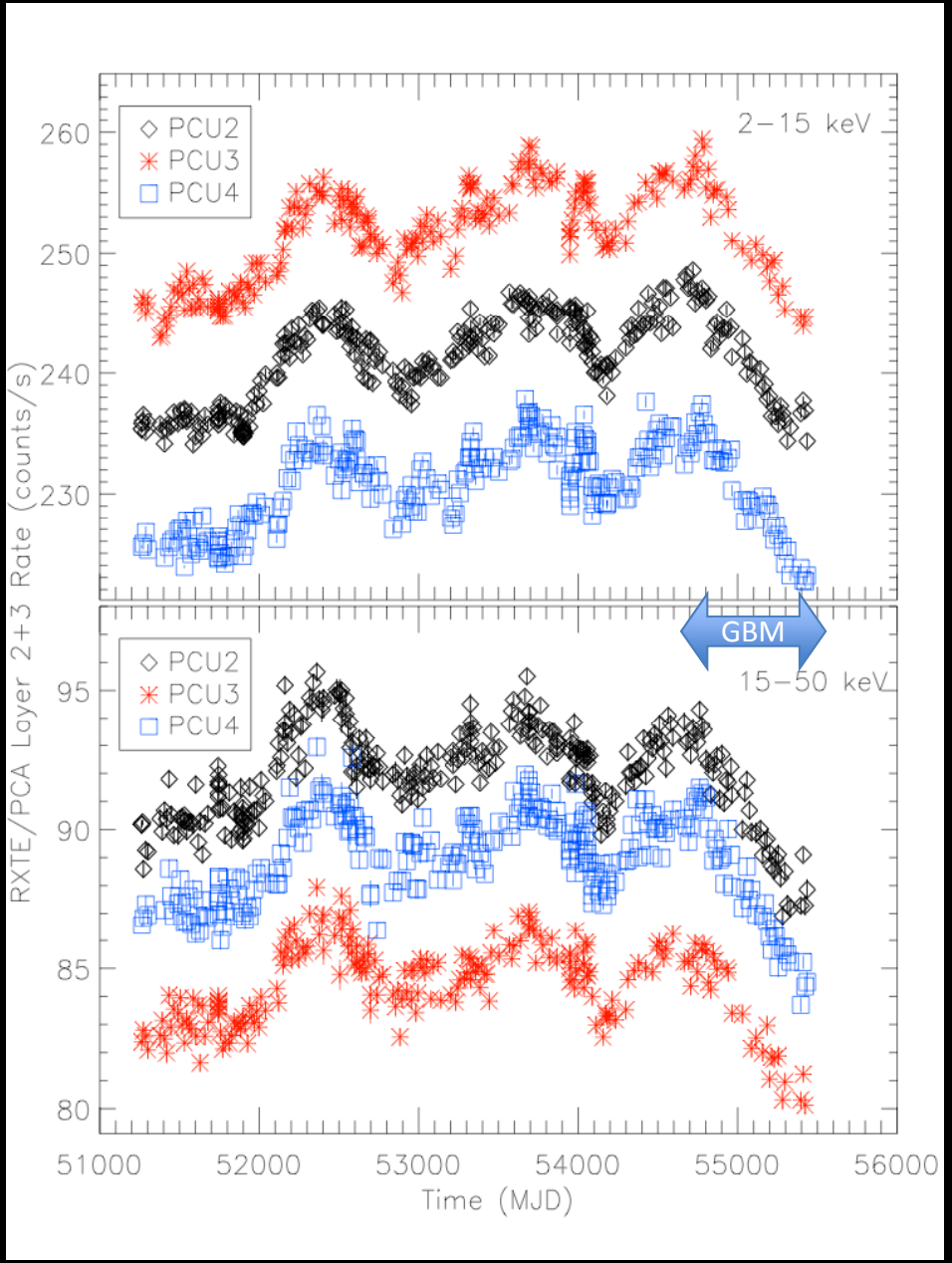


Rossi X-ray Timing Explorer (RXTE)

- Proportional Counter Array (PCA) with mechanical collimation (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 Curves

- Use data from 3 separate PCU detectors
- Background subtracted and deadtime corrected
- Corrected for response time dependence using response predicted count rate and by selecting layers 2+3
- Decrease of 5% in the 2-15 keV and 7% in the 15-50 keV energy ranges visible in the GBM era in all 3 PCUs

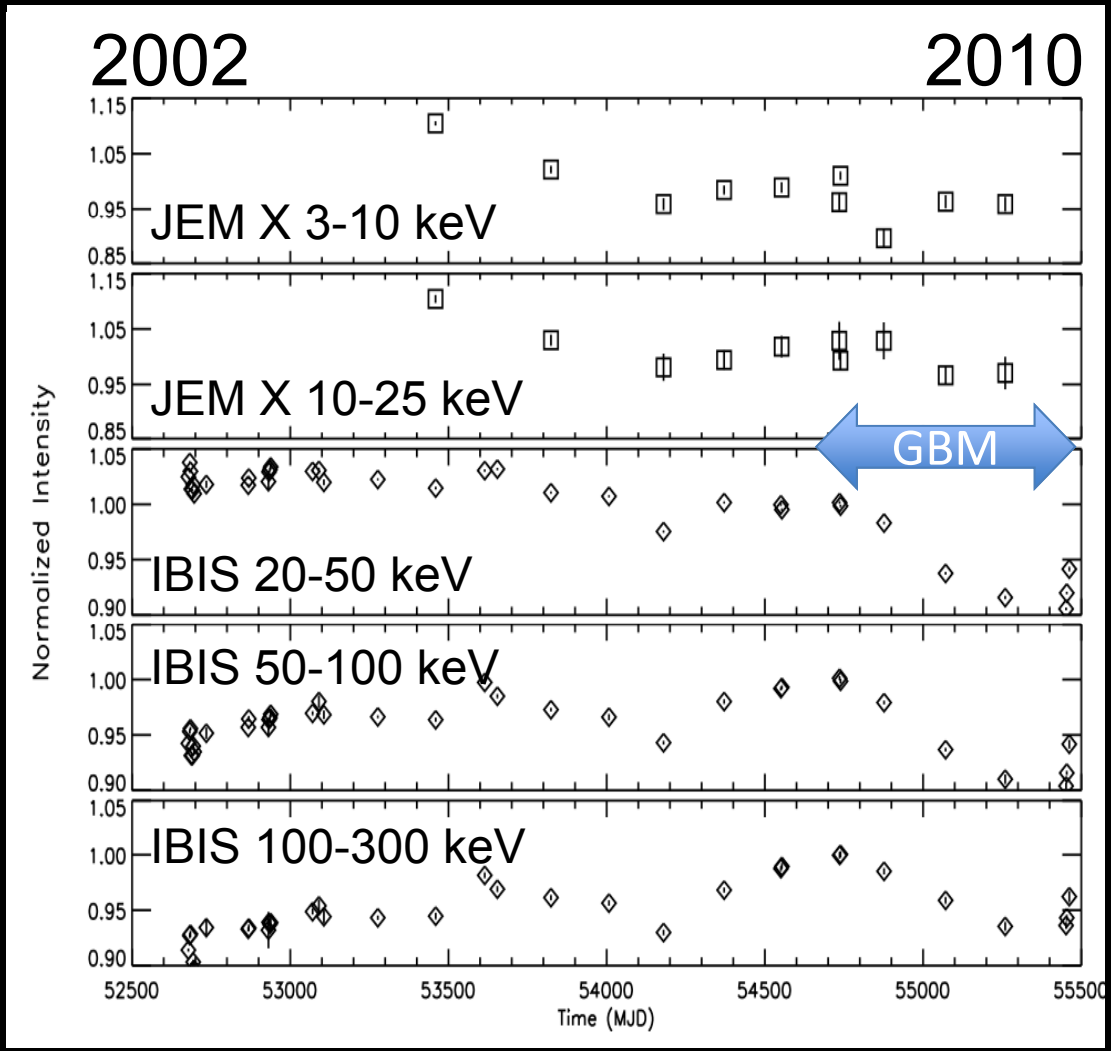


INTEGRAL

- Launched in Oct 2002
- IBIS/ISGRI – coded aperture with solid state detectors
- JEM-X – coded aperture with gas microstrip detectors
- Narrow field of view (8 x 8^{o})
- Elliptical orbit – 72 hour period

INTEGRAL/ISGRI and JEM-X: Crab Light Curves

- Publically available Crab observations
- Offset <10°(ISGRI); < 3°(JEM-X)
- Corrections based upon constant Crab are omitted
- During the overlap with GBM, a ~8% decline is seen in the 20-50 and 50-100 keV bands (54690-55340)

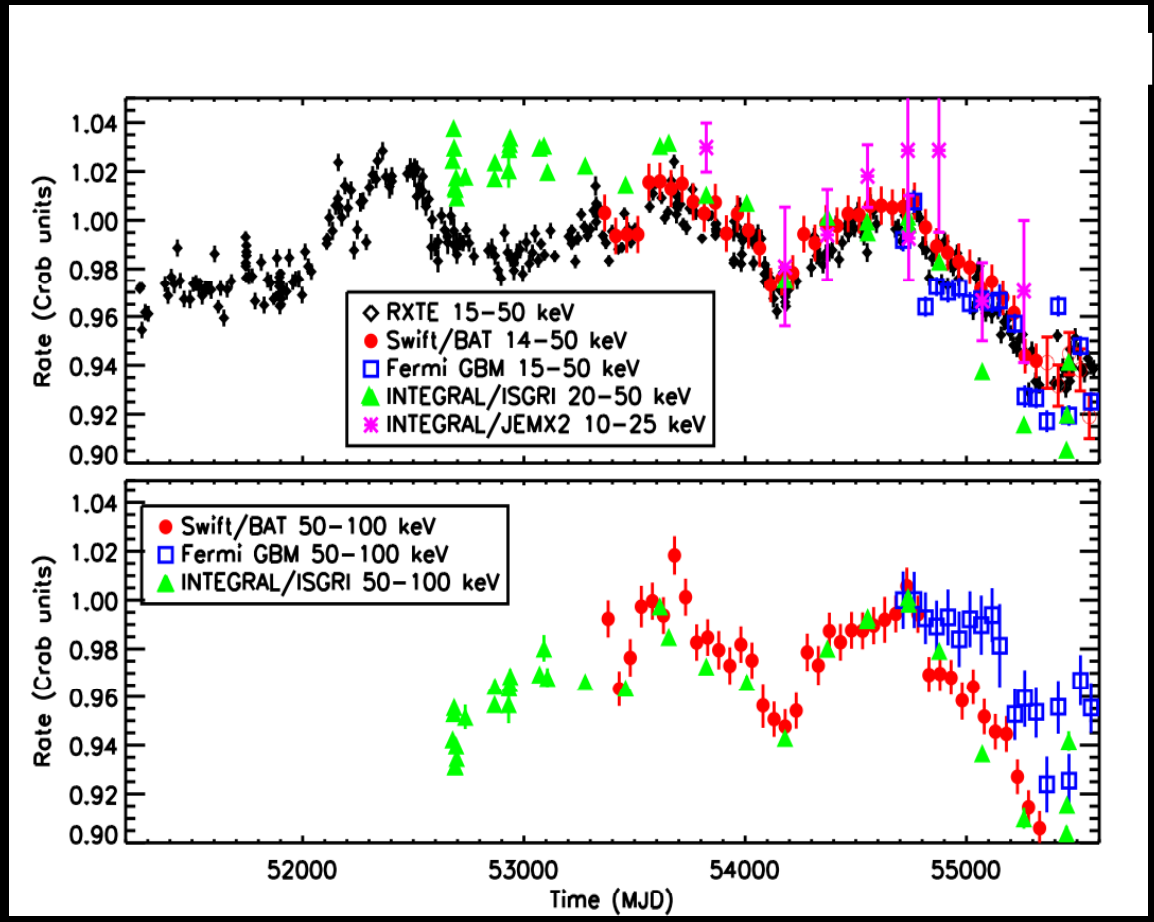


http://integral.esac.esa.int/BULGE/SOURCES/Crab/Crab.html

Comparing Instruments

- Light curves for each instrument are normalized to its average rate from MJD 54690-54790.
- RXTE/PCU2 - Black Diamonds
- BAT - Red Circles
- ISGRI - Green triangles
- JEM-X - Pink asterisks
- GBM - Blue squares

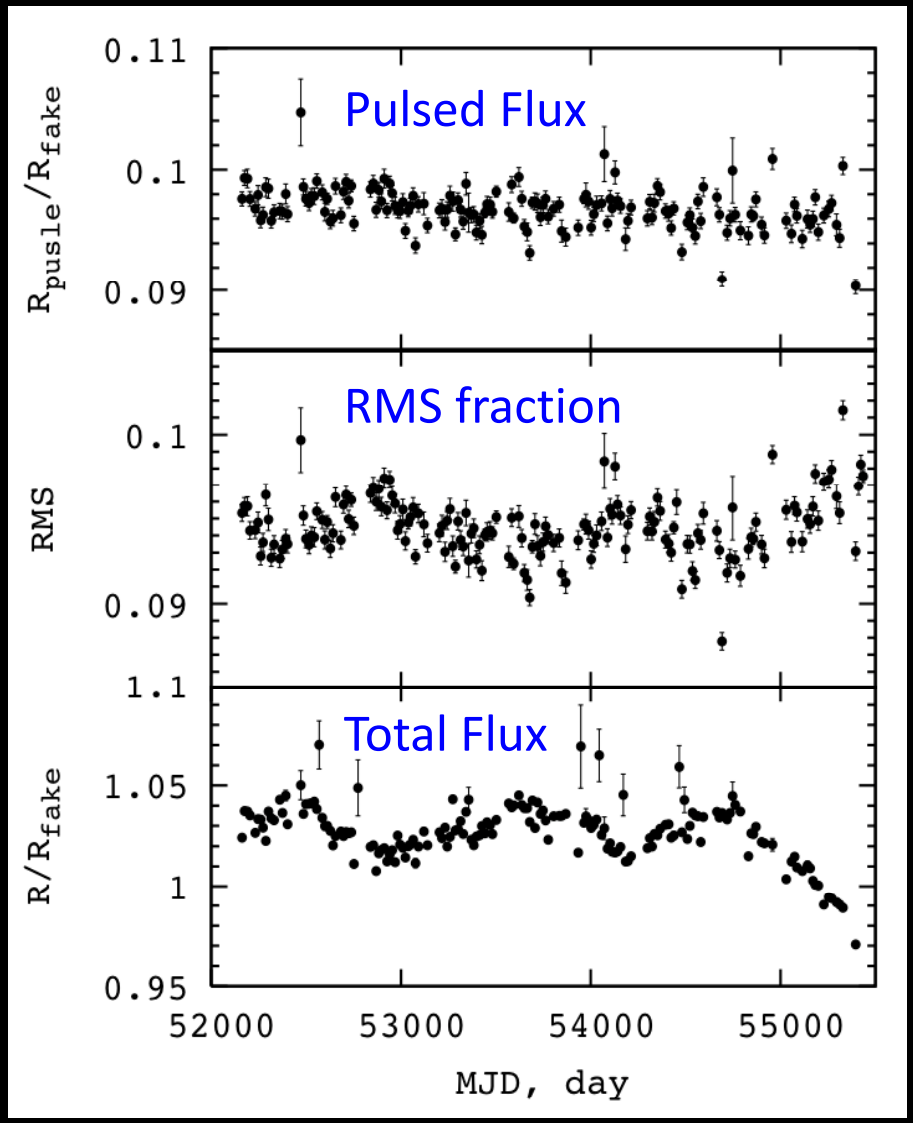
Instruments on four separate spacecraft show ~7% decline in Crab flux since August 2008!



Wilson-Hodge et al. 2011, ApJ, 727, L40

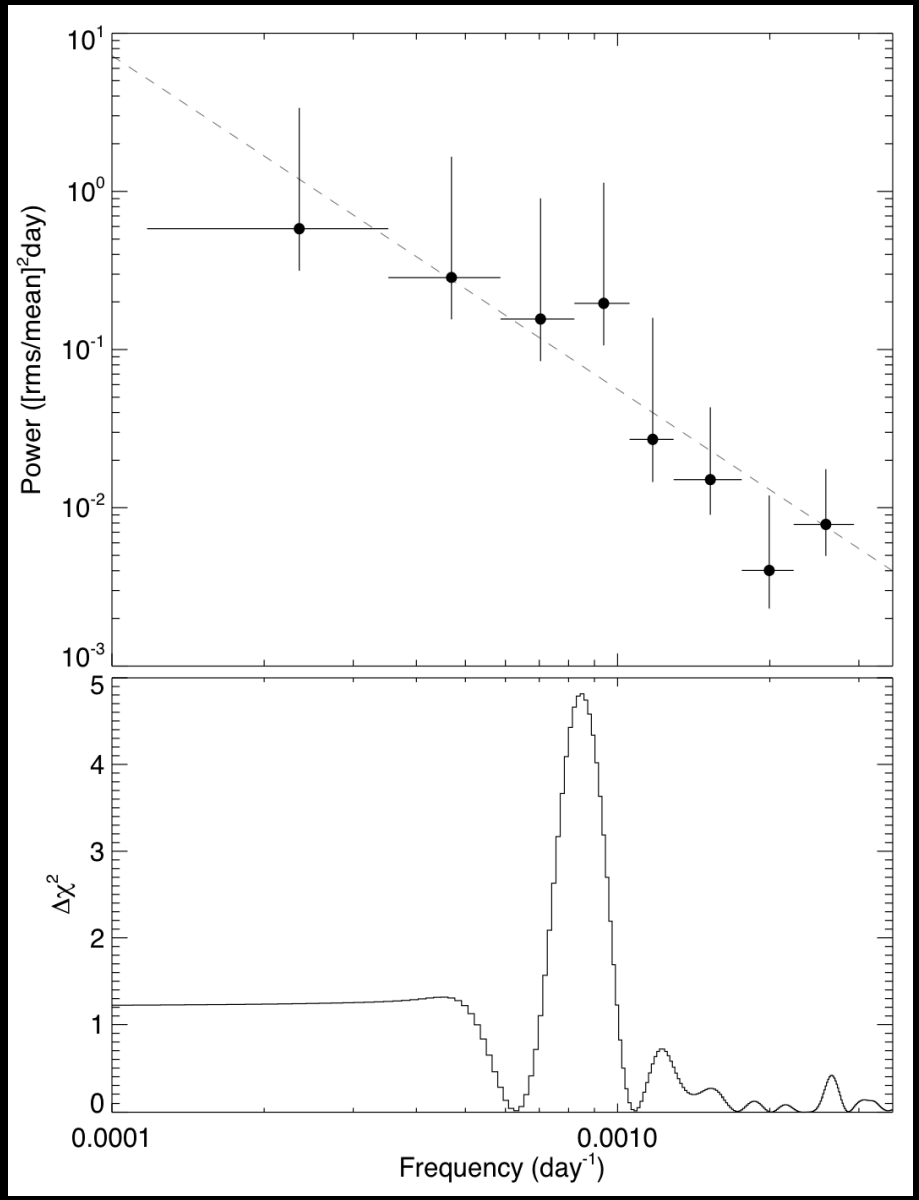
RXTE Crab Pulsed Flux

- 3.2-35 keV, all PCU2 layers
- Pulsed flux shows steady decrease at 0.2% per year – consistent with pulsar spin down.
- The larger ~5% per year variation is not seen in pulsed emission
- Likely has nebular origin

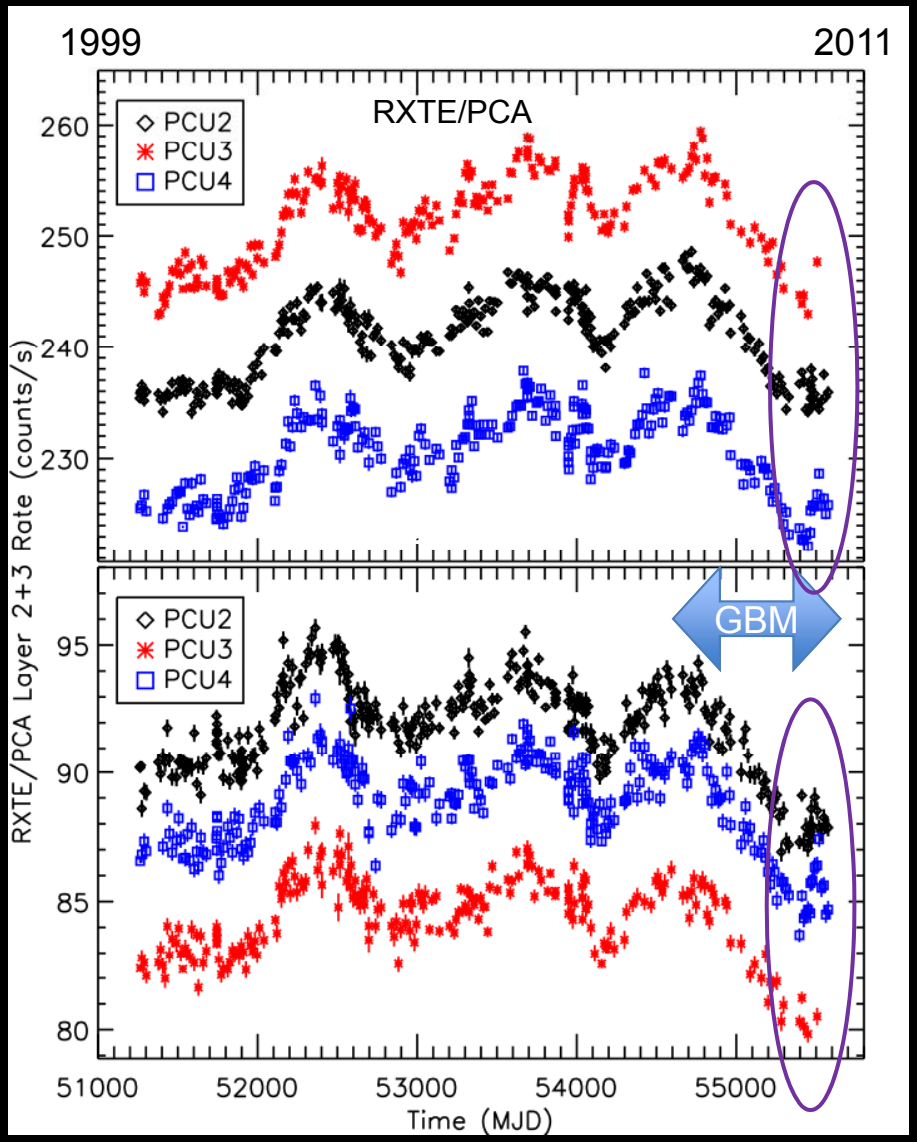


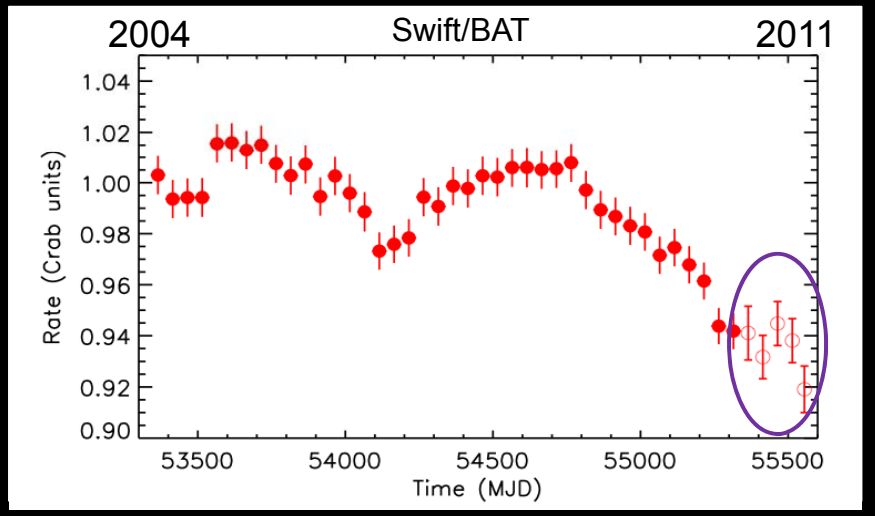
RXTE PCA – Search for Periodicity

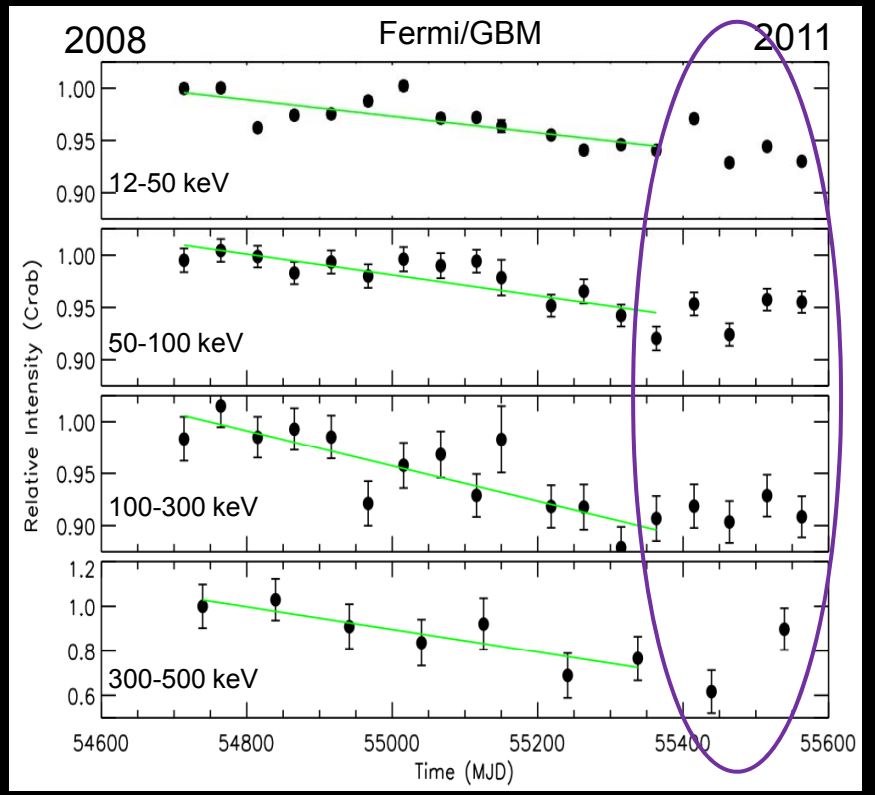
- PCA light curve has 3 peaks. Is there a periodicity?
- Power spectrum from evenly binned 15-50 keV PCU 2 data (3 bins per year). Power law index 2.1 ± 0.4
- Frequency search – fitted quadratic + sinusoid.
- Highest peak 1176 ± 96 days, only 2σ



More Recent Results







Crab has leveled off – increasing now?

Conclusions

- Four instruments (Fermi/GBM, RXTE/PCA, Swift/BAT, INTEGRAL/ISGRI) show a ~7% (70 mCrab) decline in the Crab from Aug 2008 – Aug 2010.

Conclusions

- Four instruments (Fermi/GBM, RXTE/PCA, Swift/BAT, INTEGRAL/ISGRI) show a ~7% (70 mCrab) decline in the Crab from Aug 2008 – Aug 2010.
- This decline appears to be larger with increasing energy – preliminary spectra show evidence of softening at low energies.

Conclusions

- Four instruments (Fermi/GBM, RXTE/PCA, Swift/BAT, INTEGRAL/ISGRI) show a ~7% (70 mCrab) decline in the Crab from Aug 2008 – Aug 2010.
- This decline appears to be larger with increasing energy – preliminary spectra show evidence of softening at low energies.
- Decline is not present in the pulsed flux, implying changes in the shock acceleration, electron population, or magnetic field in the nebula.

Conclusions

- Four instruments (Fermi/GBM, RXTE/PCA, Swift/BAT, INTEGRAL/ISGRI) show a ~7% (70 mCrab) decline in the Crab from Aug 2008 – Aug 2010.
- This decline appears to be larger with increasing energy – preliminary spectra show evidence of softening at low energies.
- Decline is not present in the pulsed flux, implying changes in the shock acceleration, electron population, or magnetic field in the nebula.
- Caution should be taken when using the Crab for in-orbit calibrations!