

When A Standard Candle Flickers: Crab Nebula Variations



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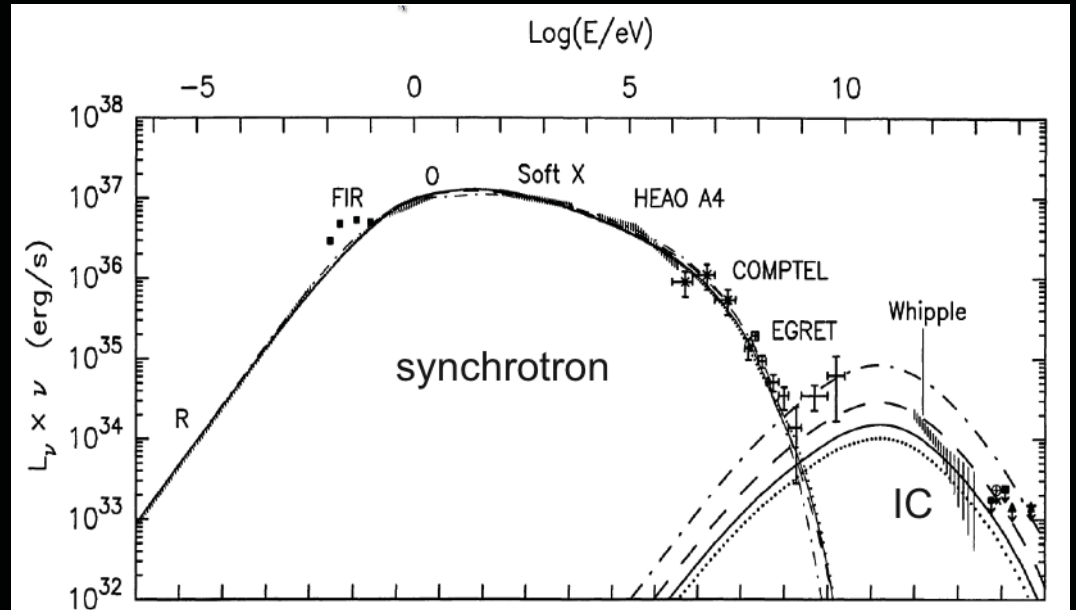
MAXI data from <http://maxi.riken.jp>

Suzaku data from Kouzu et al. 2013, PASJ, 65, 74

Outline

- Introduction
- Year-scale variability of the Crab
(8-500 keV)
- Hours to Day-scale high energy flaring
(>100 MeV)
- Summary & Conclusions

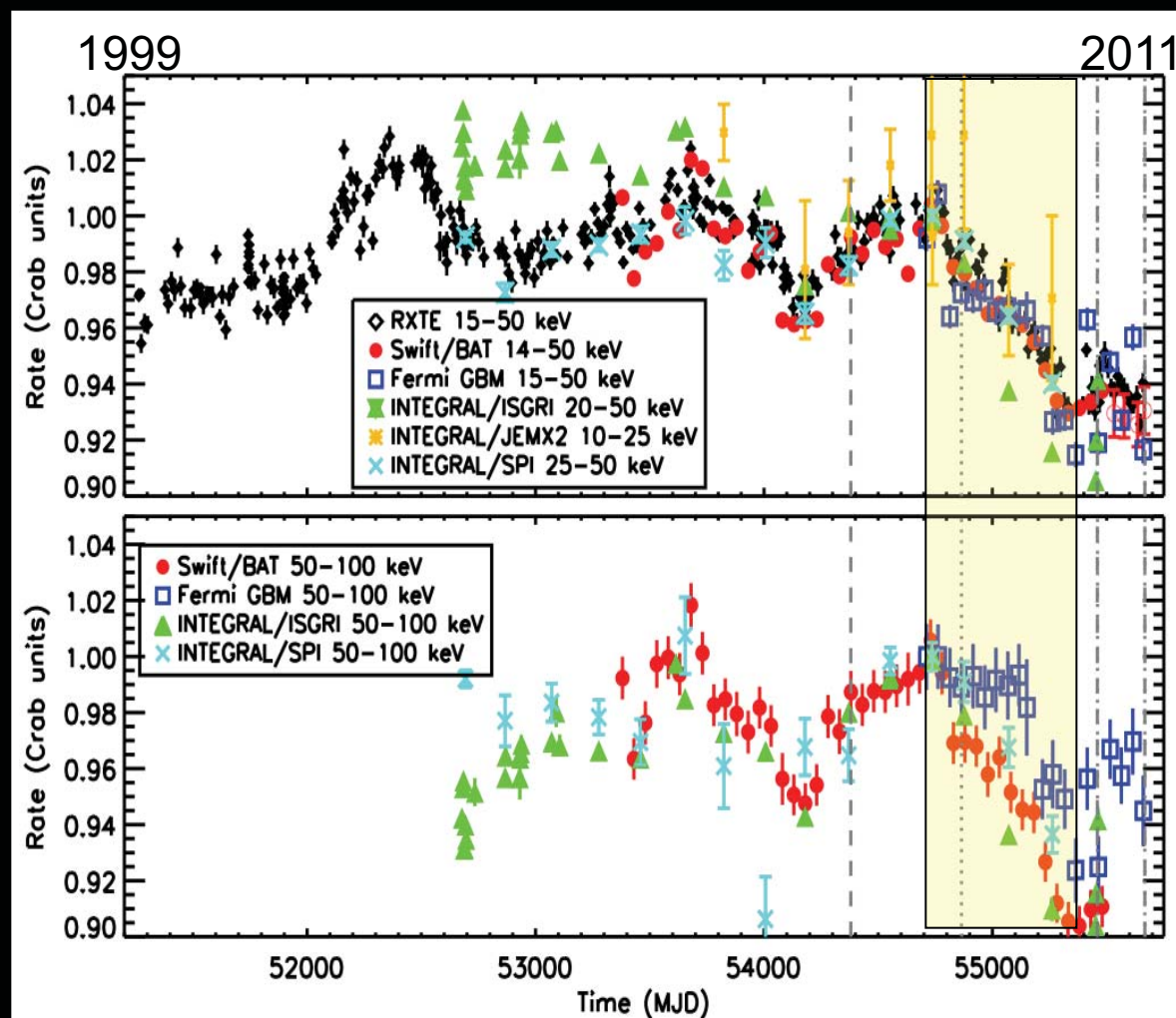
Introduction



- 1054 AD Supernova at 2 kpc
- Consists of a pulsar, pulsar wind nebula, and a cloud of expanding ejecta
- Energy spectrum: synchrotron & inverse Compton components

The Crab Nebula 1999-2011

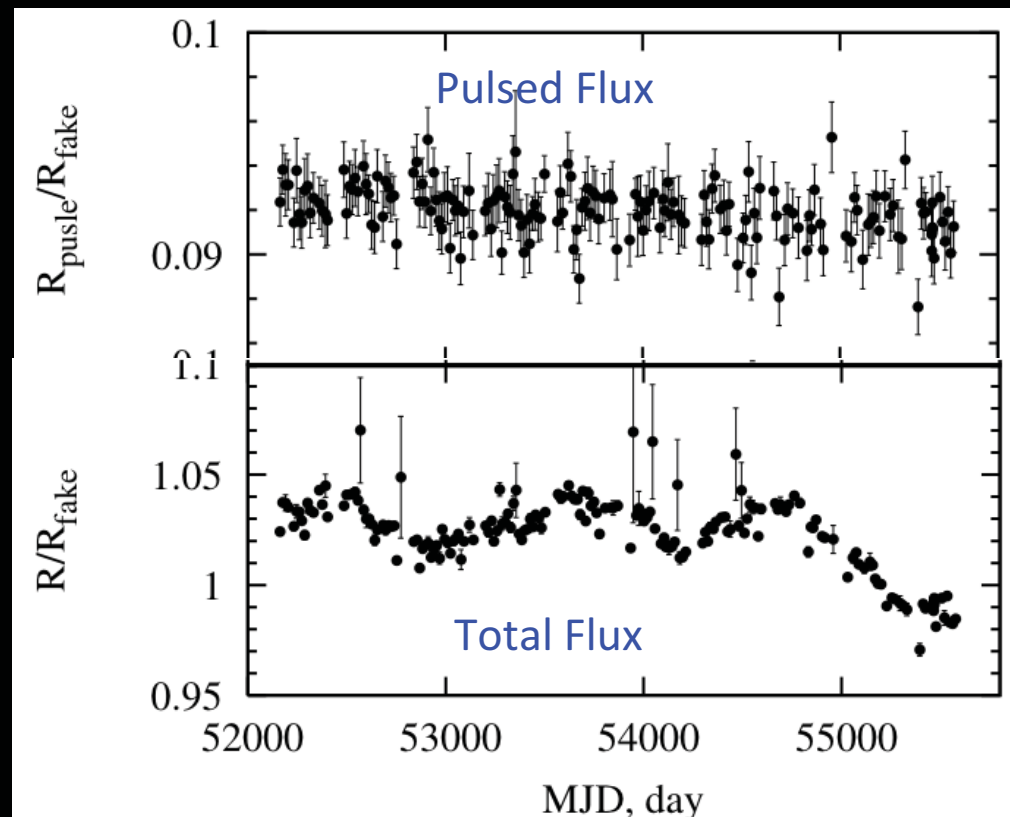
- Light curves for each instrument are normalized to its average rate from MJD 54690-54790.
- RXTE/PCU2 - Black
- BAT - Red
- IBIS/ISGRI - Green
- JEM X2 - orange
- SPI - Light blue
- GBM - Blue squares
- Instruments on four separate spacecraft show $\sim 7\%$ decline in Crab (nebula+pulsar) flux from summer 2008 to summer 2010.



Wilson-Hodge et al. 2011, ApJ, 727, L40;
Wilson-Hodge et al. 2011, PoS(HTRS 2011), 043

RXTE Crab Pulsed Flux

- Event mode data (250 μ s, 129 channel)
- 3.2-35 keV, all PCU2 layers
- Pulsed flux shows steady decrease at 0.2% per year – consistent with pulsar spin down.
- The larger \sim 3.5% per year variation is not seen in pulsed emission
- Likely has nebular origin



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

Hard X-ray Spectral Variations?

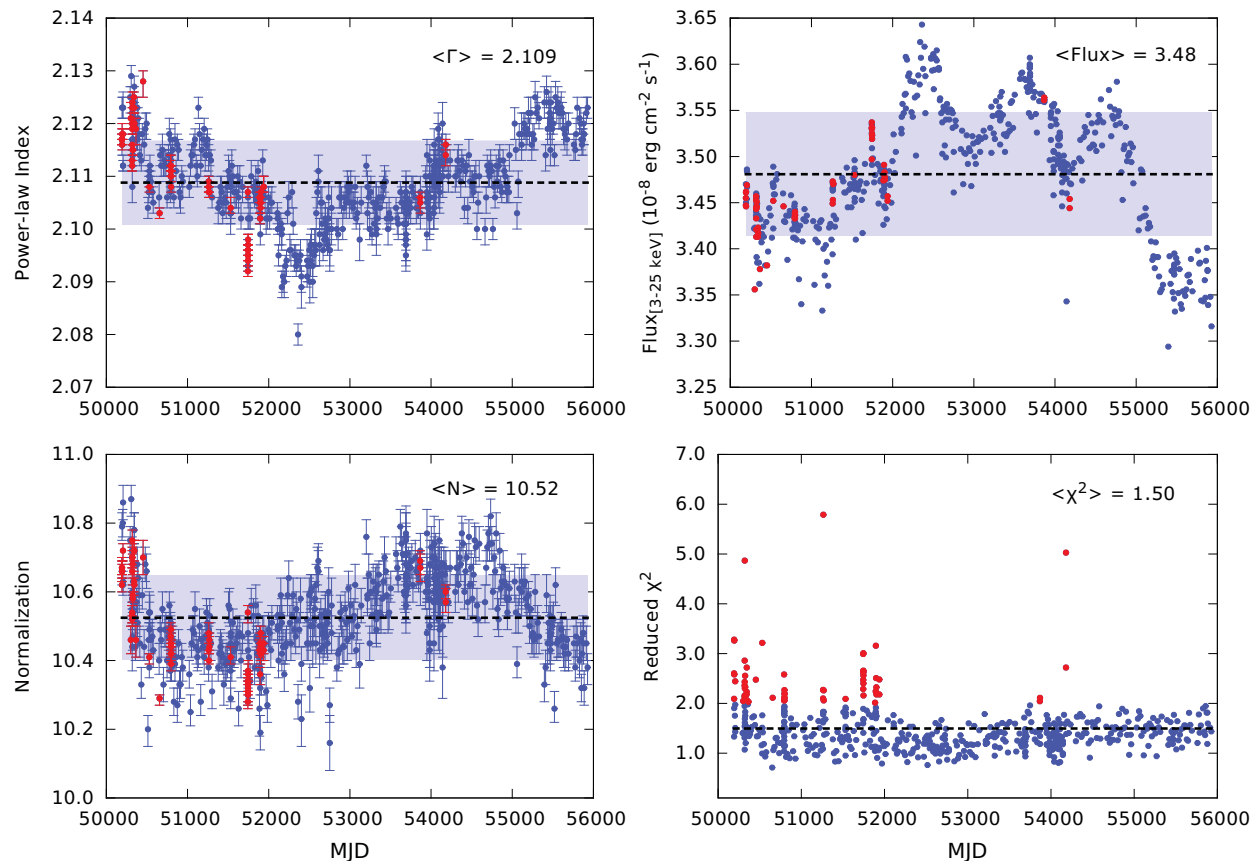
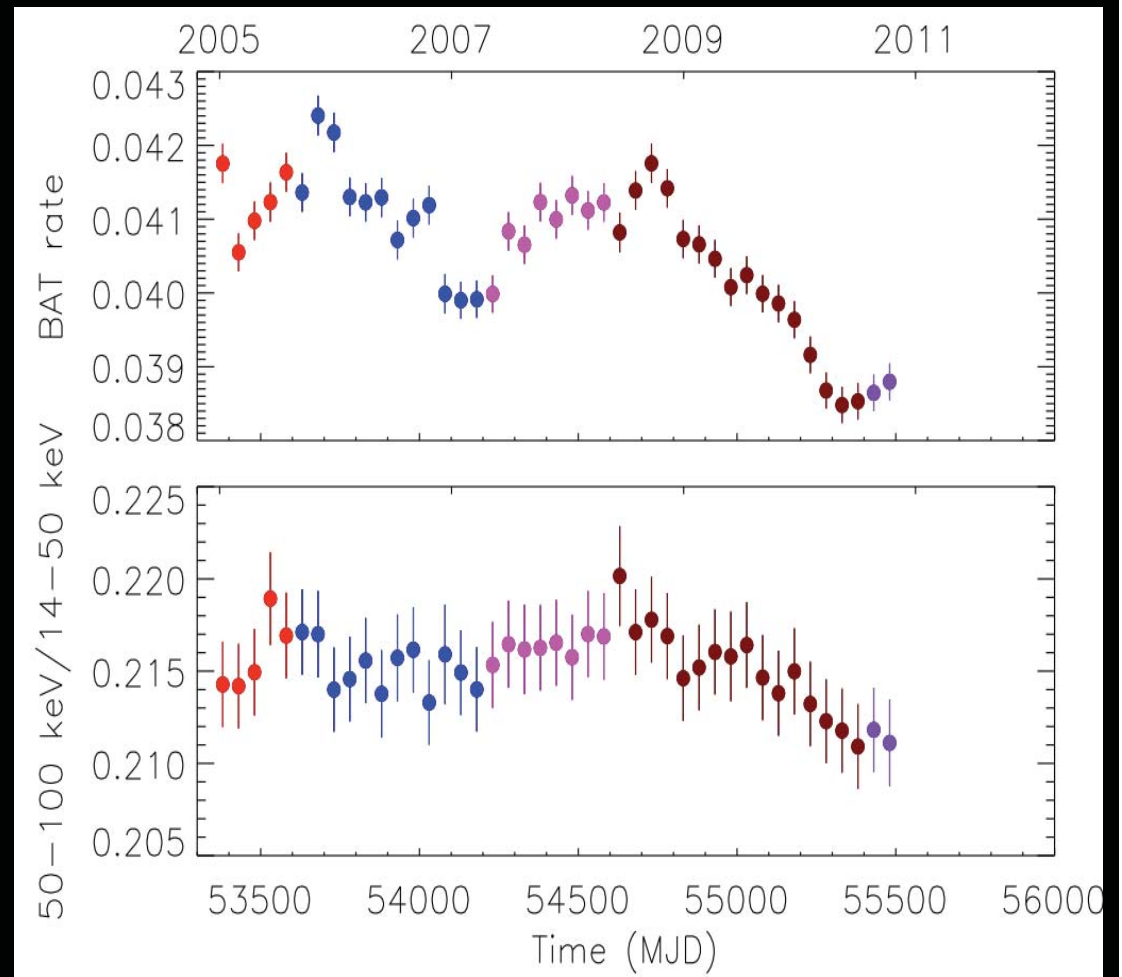


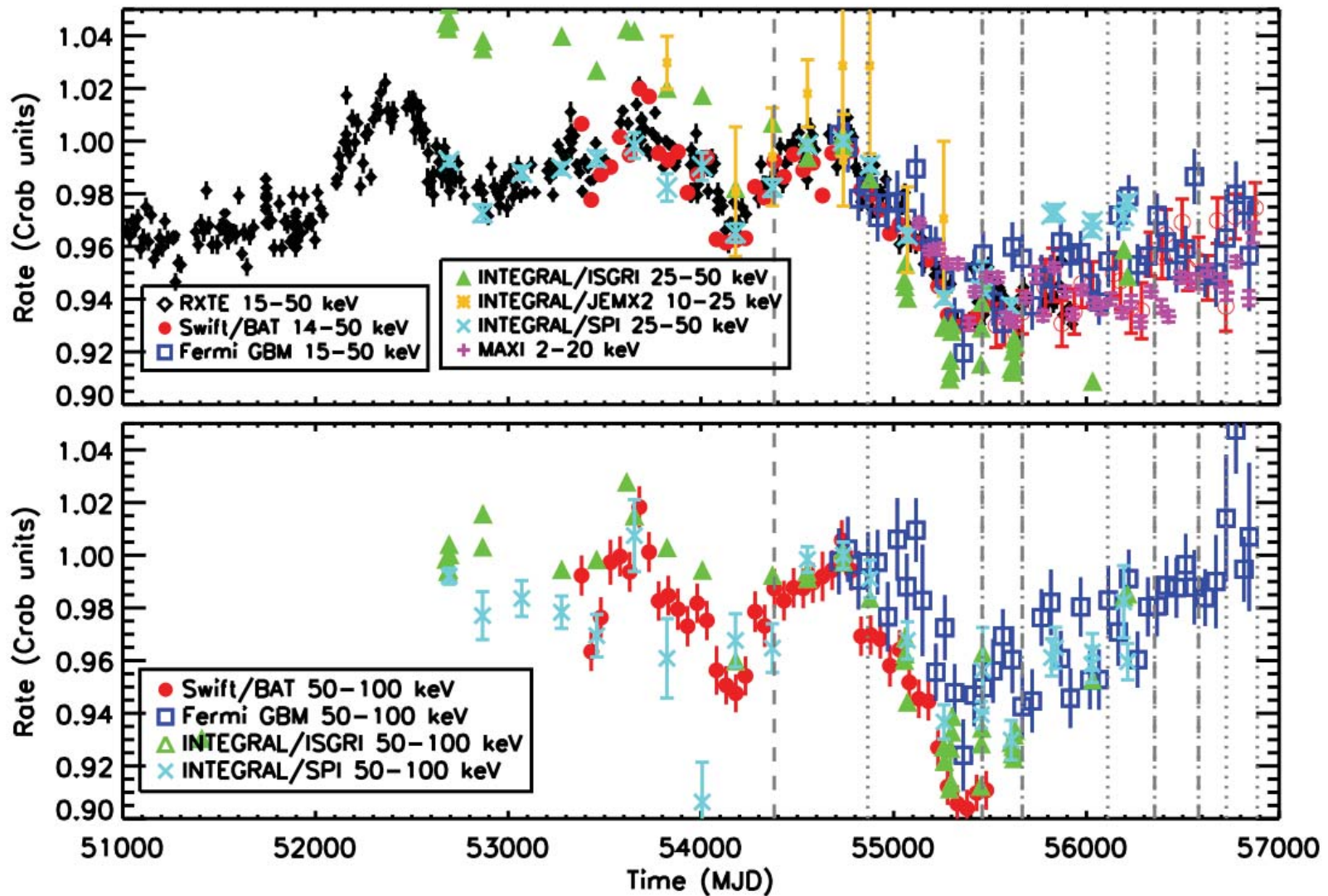
FIG. 1.— Results of fitting 554 PCU-2 spectra of the Crab to an absorbed power-law model with a fixed column depth of $N_{\text{H}} = 3.45 \times 10^{21} \text{ cm}^{-2}$. Panels show photon index, normalization, flux, and χ^2_{ν} resulting from the individual fits. Average values are marked with dashed lines and the shaded regions in the first three panels indicate their standard deviations. Data points in red correspond to fits with $\chi^2_{\nu} > 2$.

Evidence for Softening in Swift/BAT

- Color scheme matches RXTE Softening during 2008-2010 decline
- Earlier intervals consistent with constant hardness
- Hardness ratios 14-50 keV/50-100 keV BAT 58-month survey data
- 50-day averages

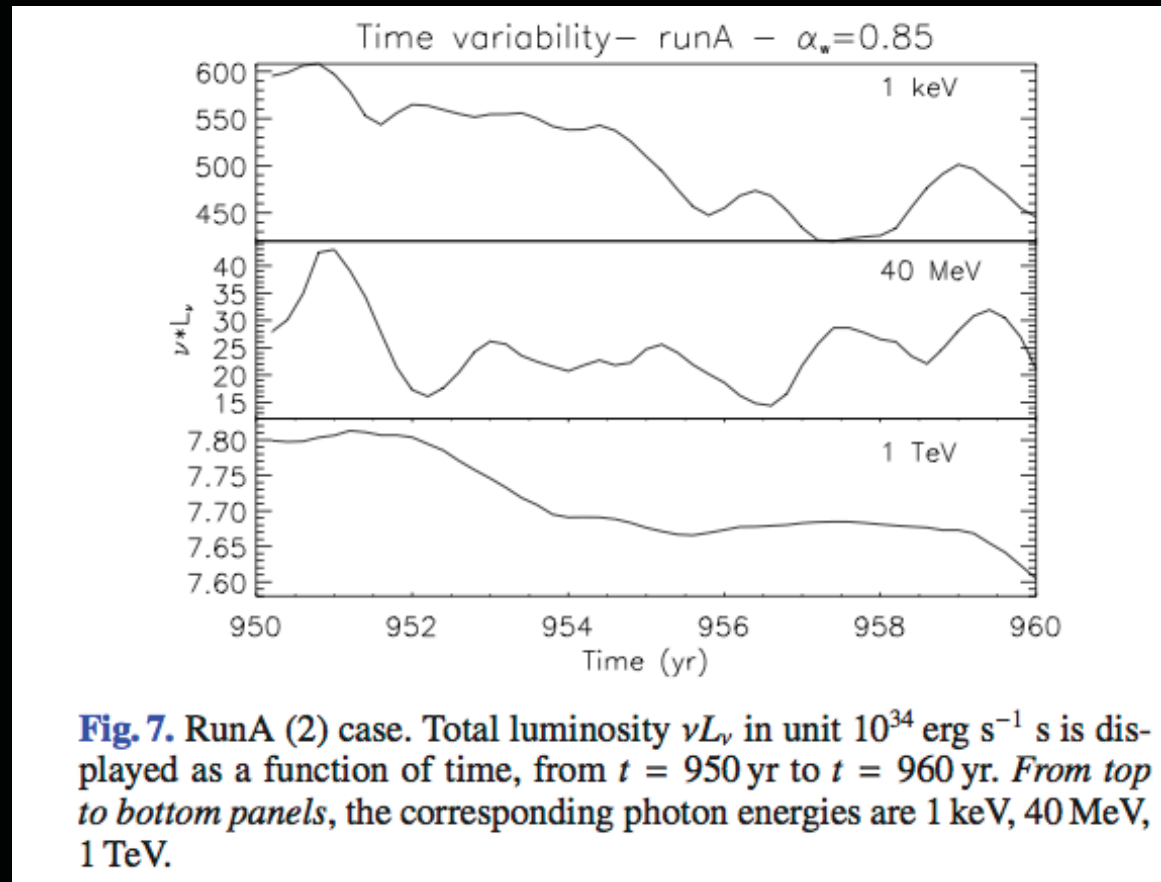


Current Hard X-ray Light Curve



Predicted Time Variability

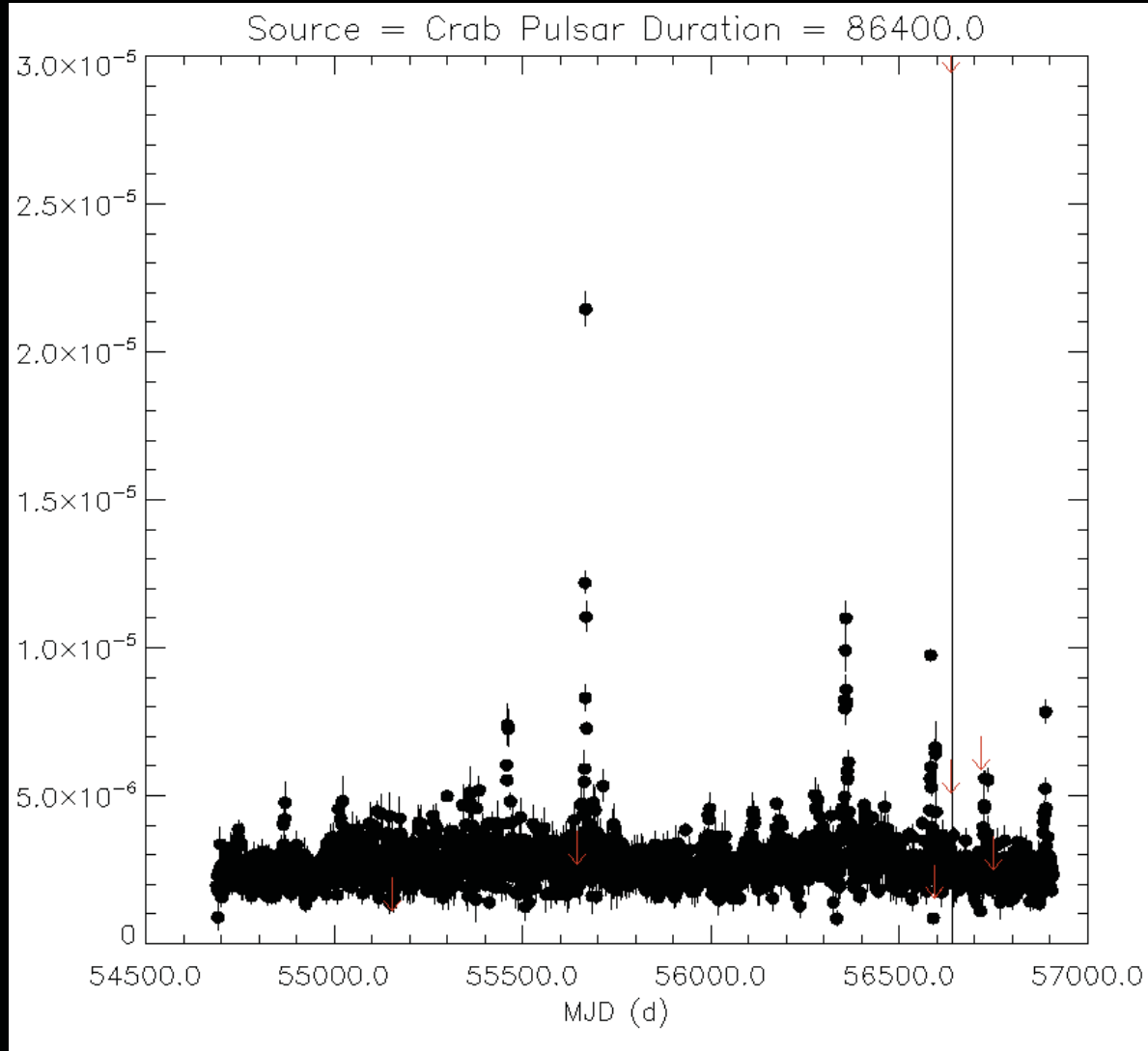
- Using MHD simulations, Volpi et al (2009) found characteristic timescales of 1-2 years at energies <0.75 MeV.
- The magnitude of the variations is larger than observed at lower energies



Volpi et al. 2009, A&A 485, 337

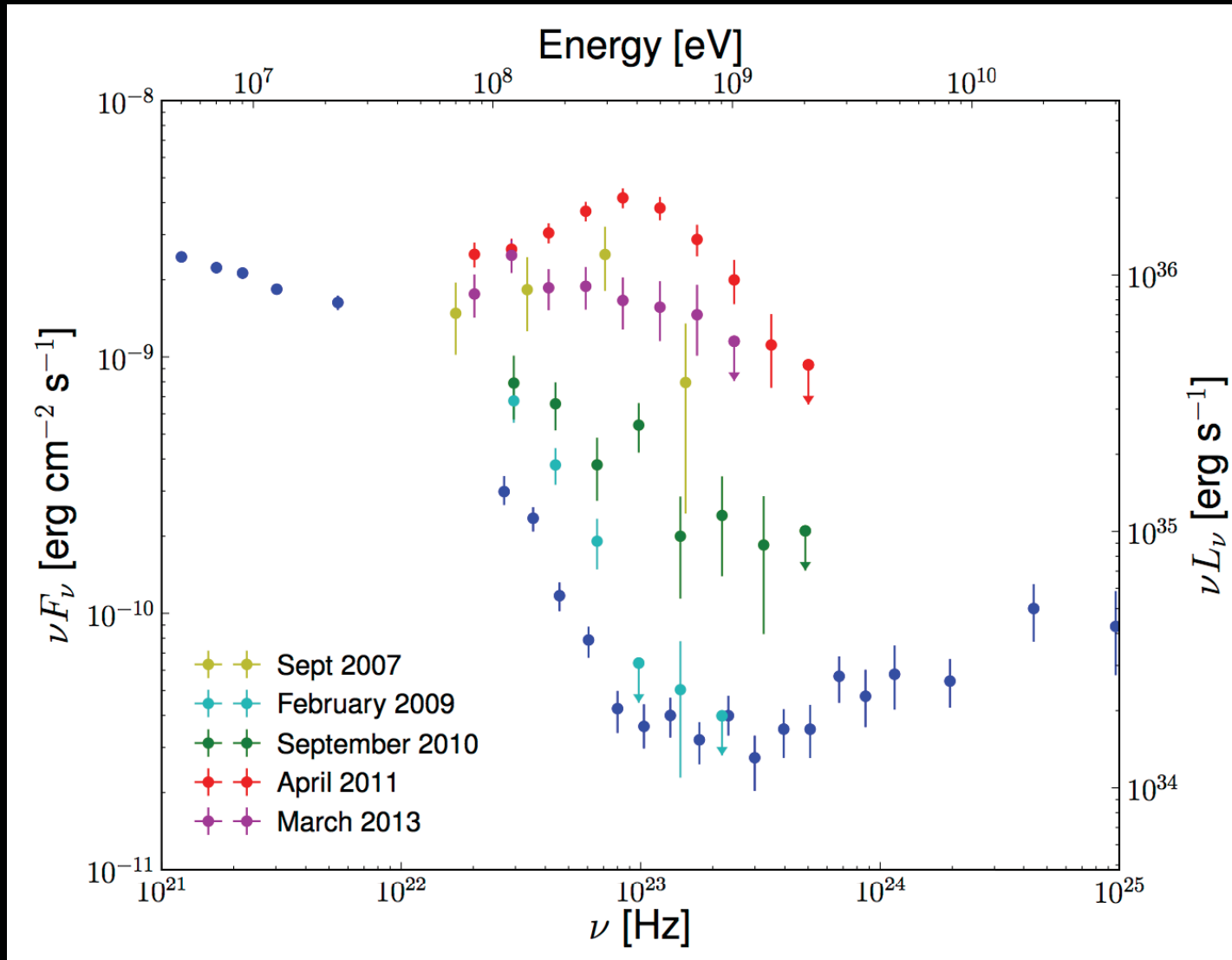
High Energy (MeV-GeV) Flaring

100 MeV - 300 GeV Flux (Nebula + Pulsar)



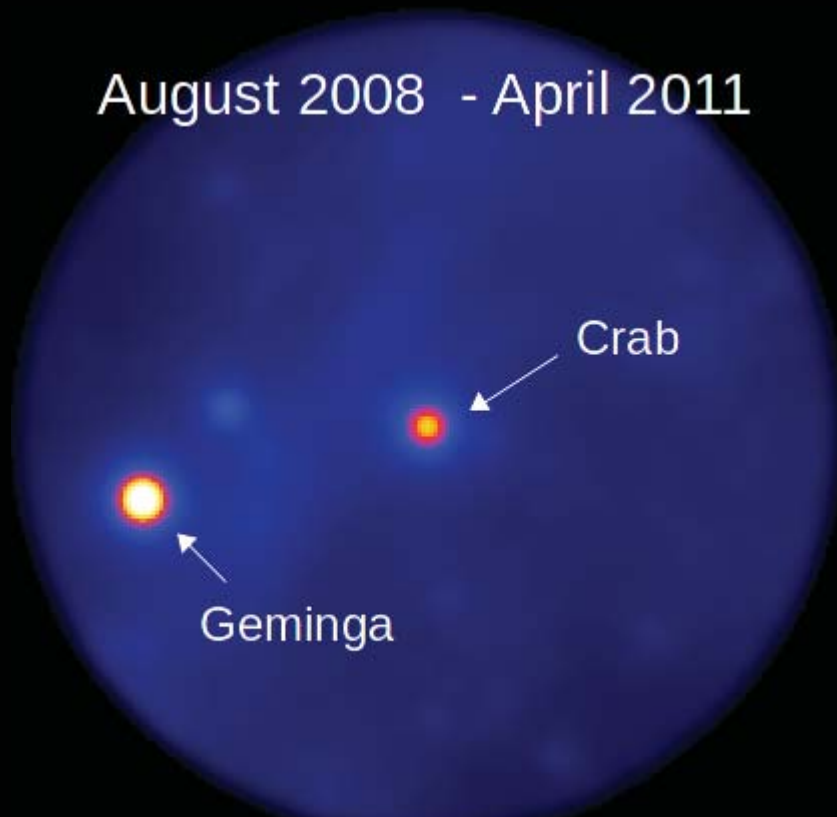
<http://fermi.gsfc.nasa.gov/ssc/>

Flare Spectra

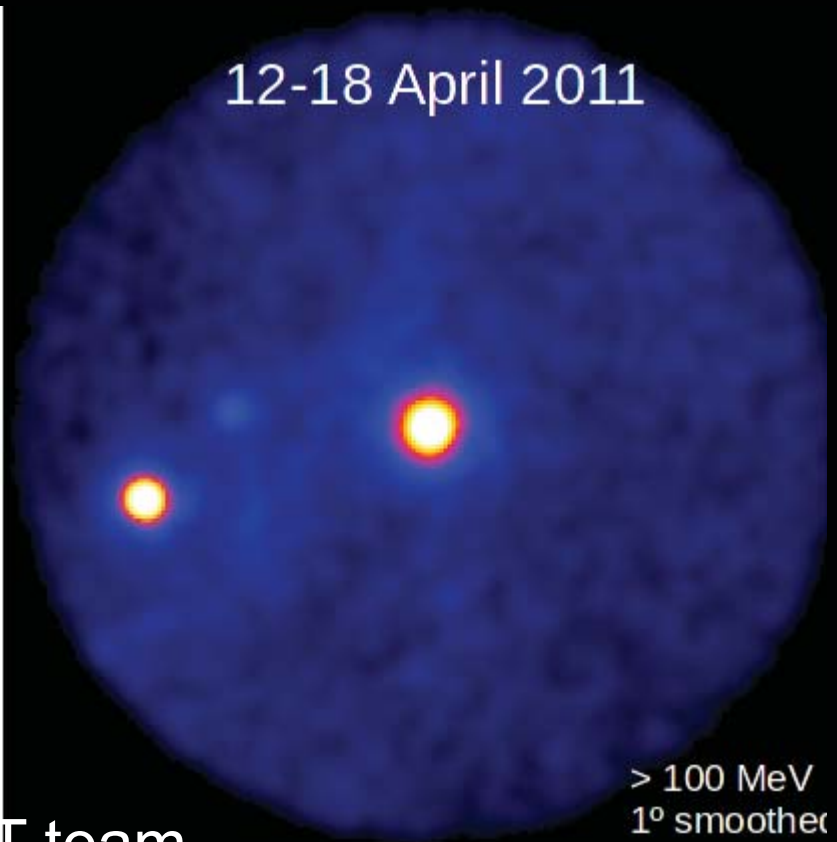


April 2011 Crab Flare

August 2008 - April 2011



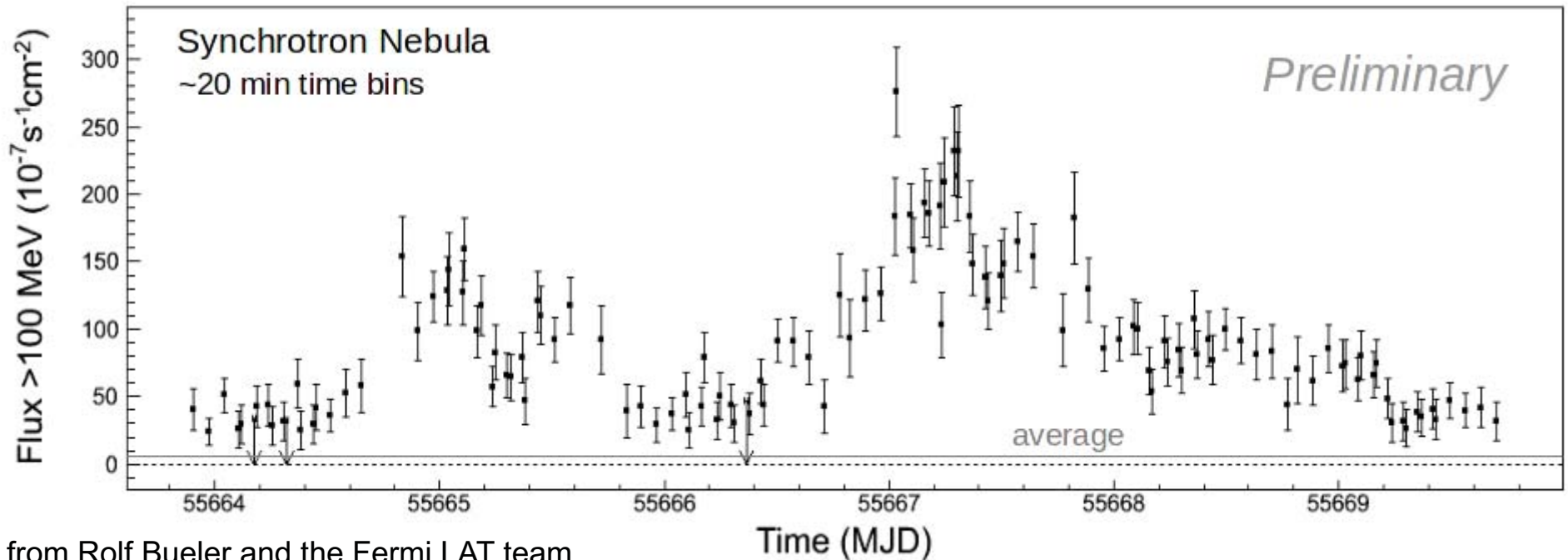
12-18 April 2011



from Rolf Bueller and the Fermi LAT team

- April 2011 Flare is 30 times brighter than the average level!
- Also seen with AGILE

April 2011 Flare Light Curve



- Rapid variability (< 1 hour) \rightarrow region size is $< 0.04''$
- Demonstrates the brightness of the flare and sensitivity of LAT
- No correlated behavior in other wavebands

Summary & Conclusions

- The Crab Nebula shows both long-term and short timescale variability.
 - In Hard X-rays the Crab flux has returned to near 2008 levels, showing variations of up to $\sim 3.5\%/year$
 - At higher energies, 7 flares have been reported between 2007 and 2014, seen with AGILE and Fermi LAT
- The location and mechanism producing both types of variability is still mysterious.