Three years of Fermi GBM Earth Occultation Monitoring: Observations of Hard X-ray/Soft Gamma-Ray Sources

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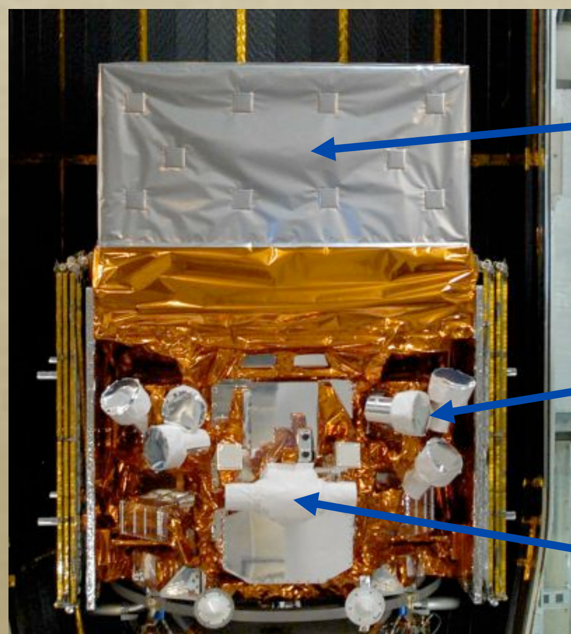
Launched June 11, 2008



Large Area Telescope (LAT)
20 MeV -- 300 GeV

Gamma-ray Burst Monitor

12 NaI detector.
8 keV -- 1000 keV
126 cm^2, 1.27 cm
Triggering, localization, spectroscopy.

2 BGO detector.
200 keV -- 40 MeV
126 cm^2, 12.7 cm
Spectroscopy
Bridges gap between NaI and LAT.

Primary science for GBM is detection of Gamma-ray Bursts

Products

CTIME - 0.512 s time resolution, 8 channels

CSPEC - 4.096 s time resolution, 128 channels

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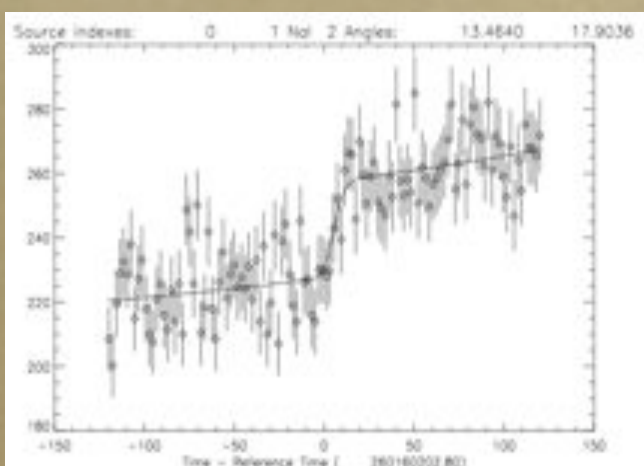
GBM Earth Occultation Project

PI Colleen Wilson-Hodge

All sky X-ray monitor of known sources from 8 keV - 1000 keV



Source Database

Conceptually simple

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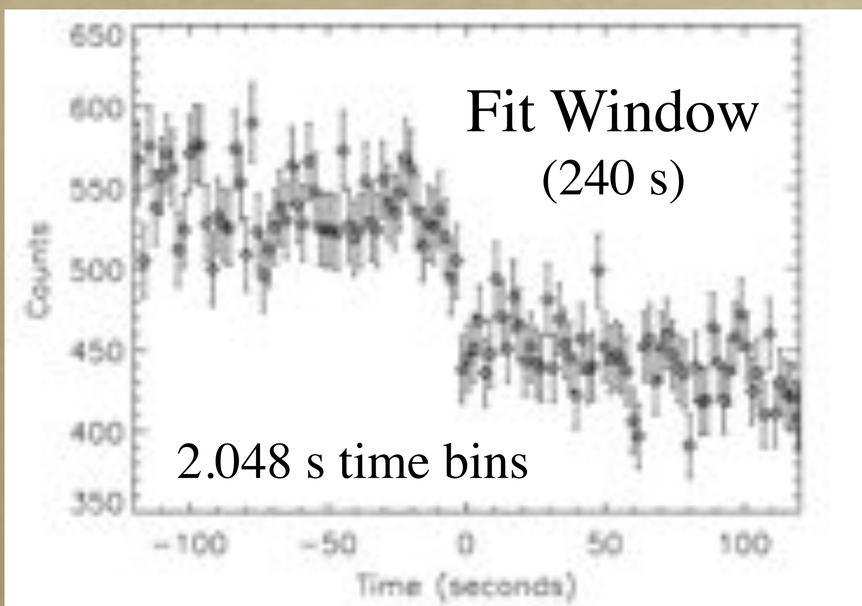
GBM Earth Occultation Method

In practice....



- Predict occultation times
- Determine detectors viewing source of interest
- Fit to each detector and energy channel
  - Background model
  - Model count rates for each source
    - Detector responses
    - Assumed energy spectrum
    - Atmospheric transmission
- Compute best scale factor for all detectors to estimate fluxes.

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Flux Measurements

Each energy channel and each detector is fitted independently

$$F(E_{ch}) = \overline{a}(E_{ch}) * \int_{E_{ph}} f(E_{ph}) dE_{ph}$$

$\overline{a}(E_{ch}) =$ Weighted mean of scale factors for each detector

Systematic Effects

- Accuracy of assumed source spectral model
  - Heavily tested and researched; -3 power-law
- Large variation in background
  - Pre-filtering of data
- Duration of the occultation transition
  - High latitude sources; Limited to 20 seconds
- Inaccuracies in the detector response matrices
  - Remove steps for all possible solar panel blockages
- Occultation limb geometry
  - 52 day precession; Flare database - *Swift*/BAT transient monitor
- Nearby sources
  - Exclude steps if bright source is within 8 s of occultation time

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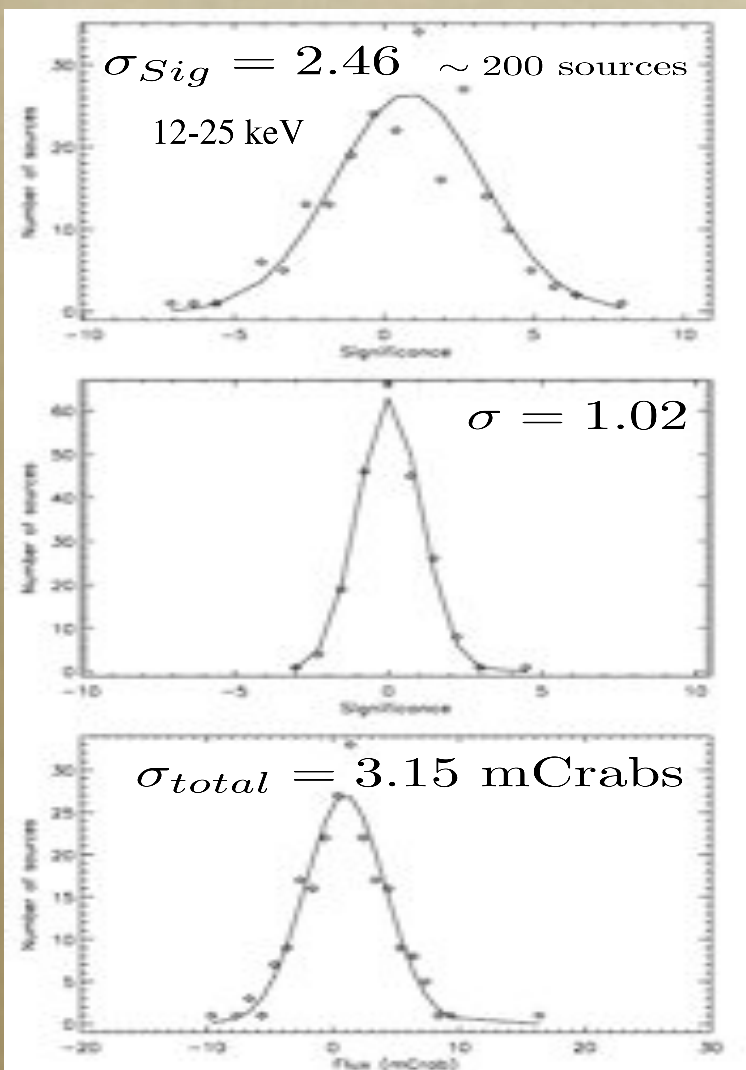
Ghost Source Analysis Systematic Errors



$$k \times \sigma_{total} = \sigma_{stat}$$

$\sigma_{total} =$ Width of flux distribution

$k = 1.0/\sigma_{Sig}$ Scale factor

$$\sigma_{sys}^2 = \sigma_{total}^2 - \sigma_{stat}^2$$

Systematic Error Estimates for GBM Earth Occultation Analysis

Energy Band (keV)	Systematic Error (mCrab)
8–12	3.4
12–25	2.8
25–50	2.2
50–100	1.5
100–300	3.1
300–500	3.4

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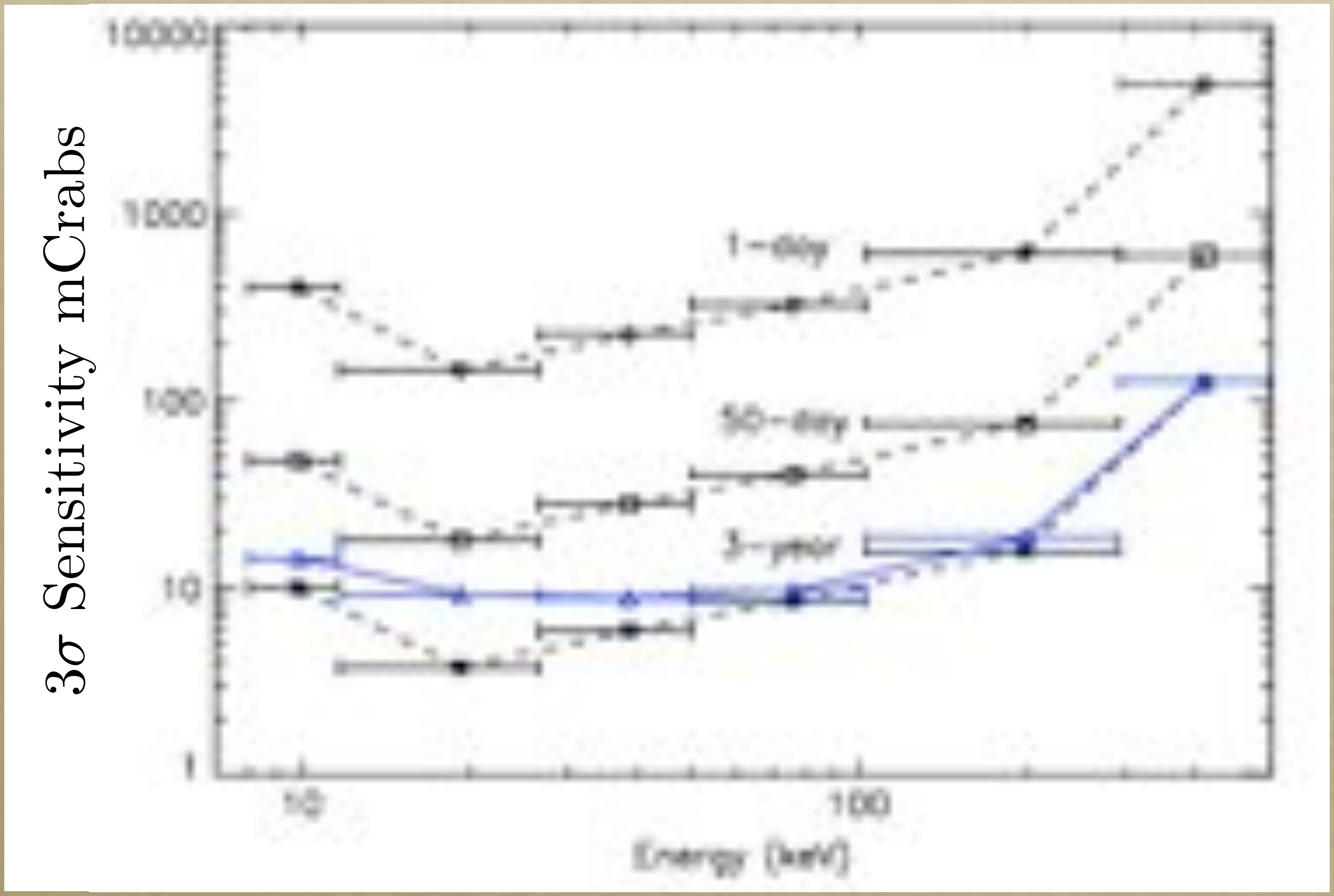
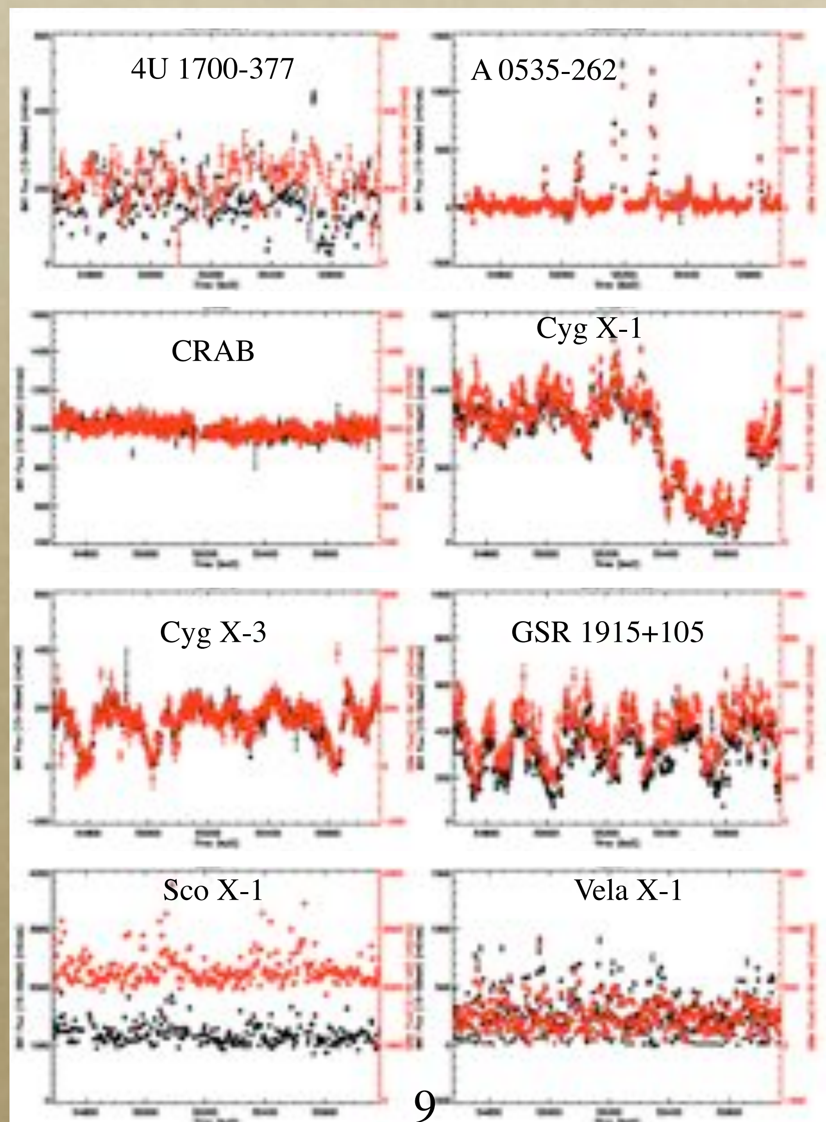
Sensitivity



Comparison Between GBM and *Swift*/BAT

GBM 12-50 keV



Swift/BAT 15-50 keV

2 - 4 day averages

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Three Year *Fermi*/GBM Earth Occultation Catalog

- Source Name
- Ra & Dec
- Category (A, B, T, P, N, I)
- 3 Year Average Flux (mCrabs)
  - 12-25 keV
  - 25-50 keV
  - 50-100 keV
  - 100-300 keV
- Significance
  - 12-50 keV
  - 12-300 keV
- Type

Detection Criteria

- Significance exceeds 5 or 3.5 sigma (Category A and B respectively)
- Detected in the transient search (T) at 5 or 3.5 sigma
- Detected in the orbit folding search at 5 or 3.5 sigma (P)

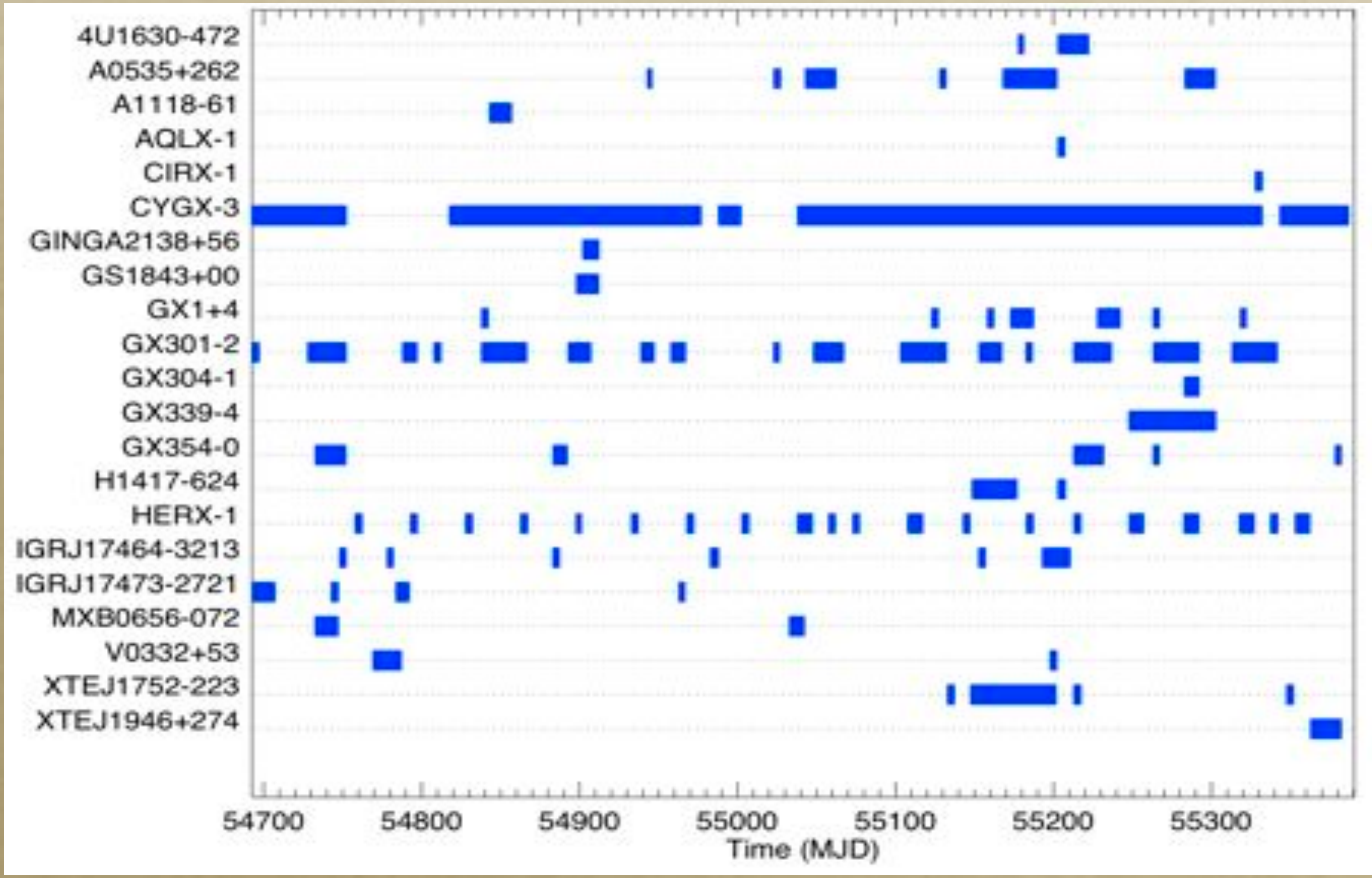
Non-Detections

- Significance less than 3.5 sigma (Category N)
- Significance is negative (Category I) - only 6 sources

Summary of Results

3 Year Catalog	Current
209 Sources (99 detected-A)	215 Sources (104 detected-A)
40 LMXB/NS	40 LMXB/NS
31 HMXB/NS	34 HMXB/NS
12 BHC	14 BHC
12 AGN	12 AGN
1 Star (Sun)	1 Star (Sun)
1 TDE (SWIFT J164449.3+57345)	1 TDE (SWIFT J164449.3+57345)
1 Pulsar/PWN (Crab)	1 Pulsar/PWN (Crab)
1 Galaxy Cluster (Oph Cluster)	1 Galaxy Cluster (Coma Cluster)

Transients Seen with Earth Occultation



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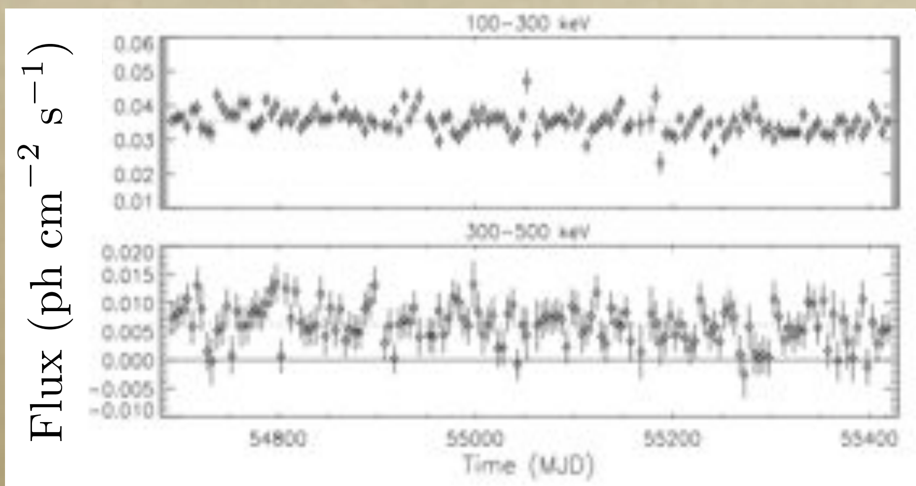
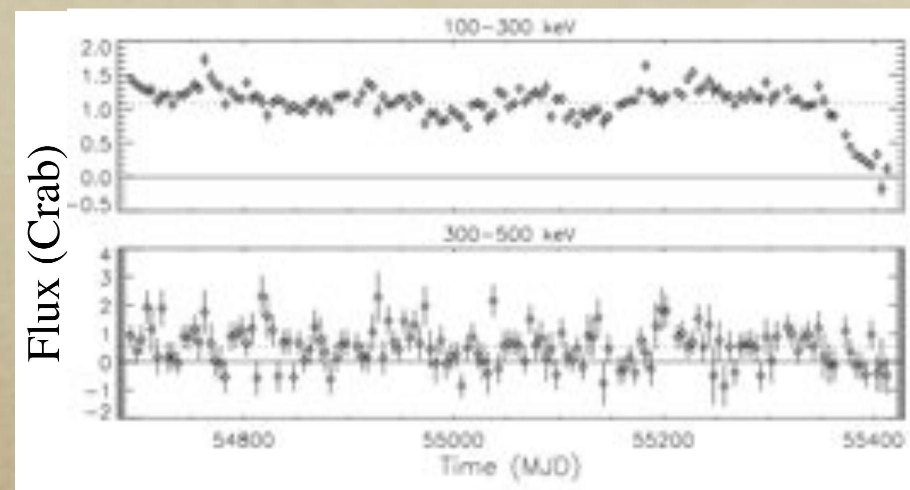
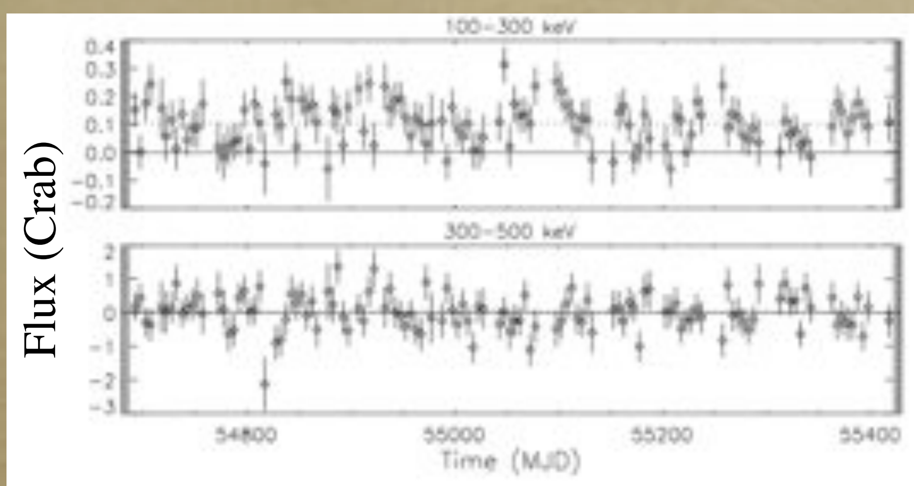
Sources Detected Above 100 and 300 keV



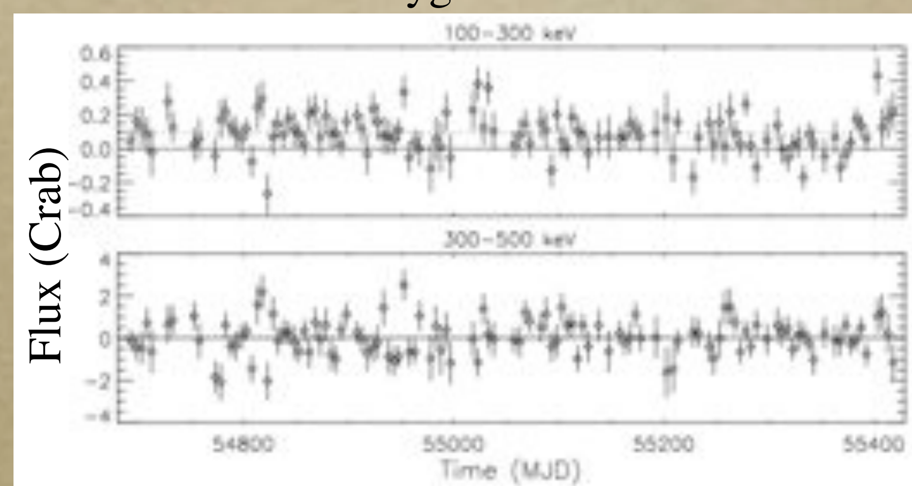
Crab



Cygnus X-1



Centaurus A



1E 1740-29

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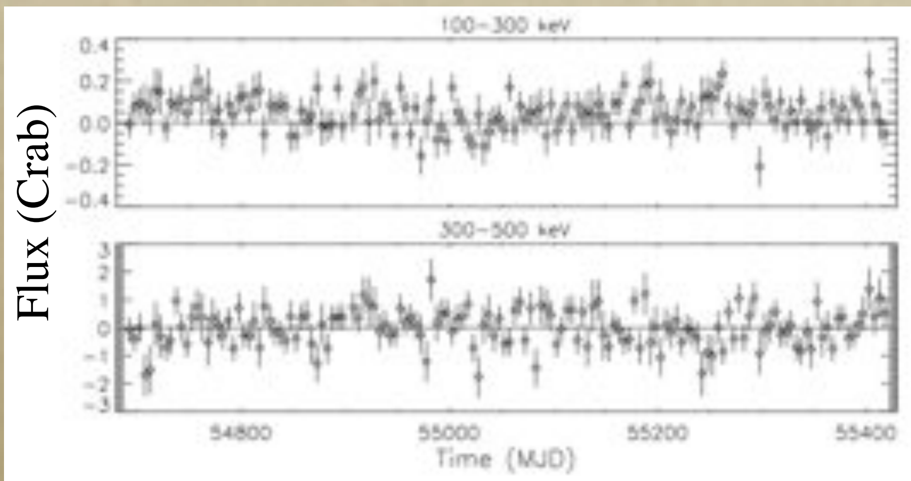
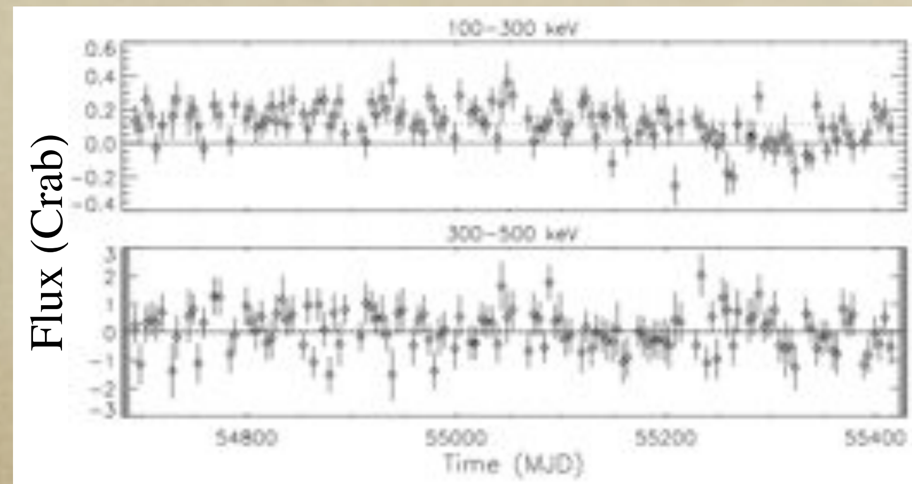
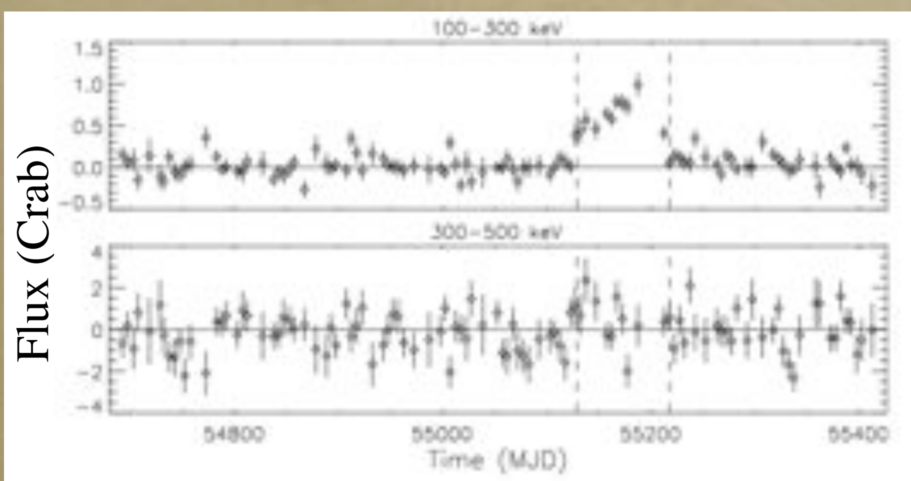
Sources Detected Above 100 and 300 keV



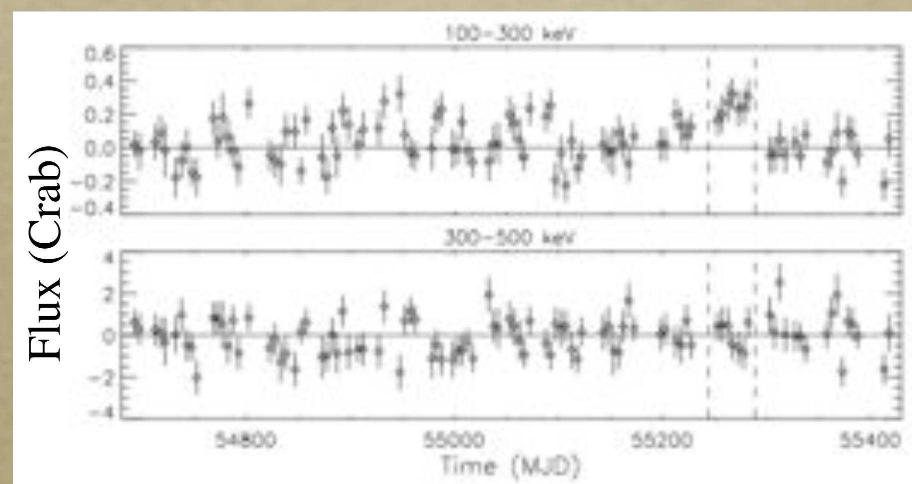
GSR 1915+105



Swift J1753.5-0127



XTE J1752-223



GX 339-4

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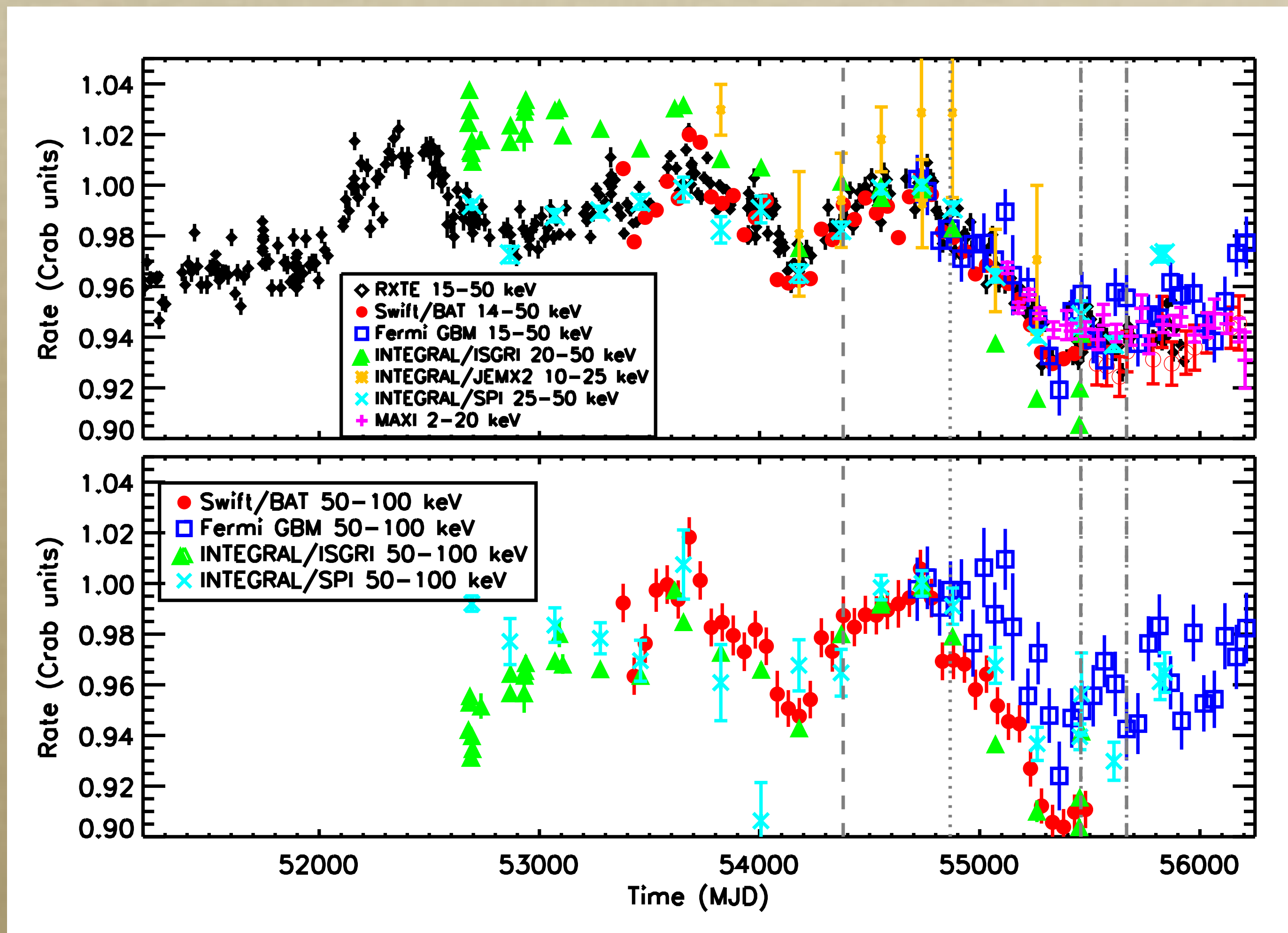
Crab Flux Decline



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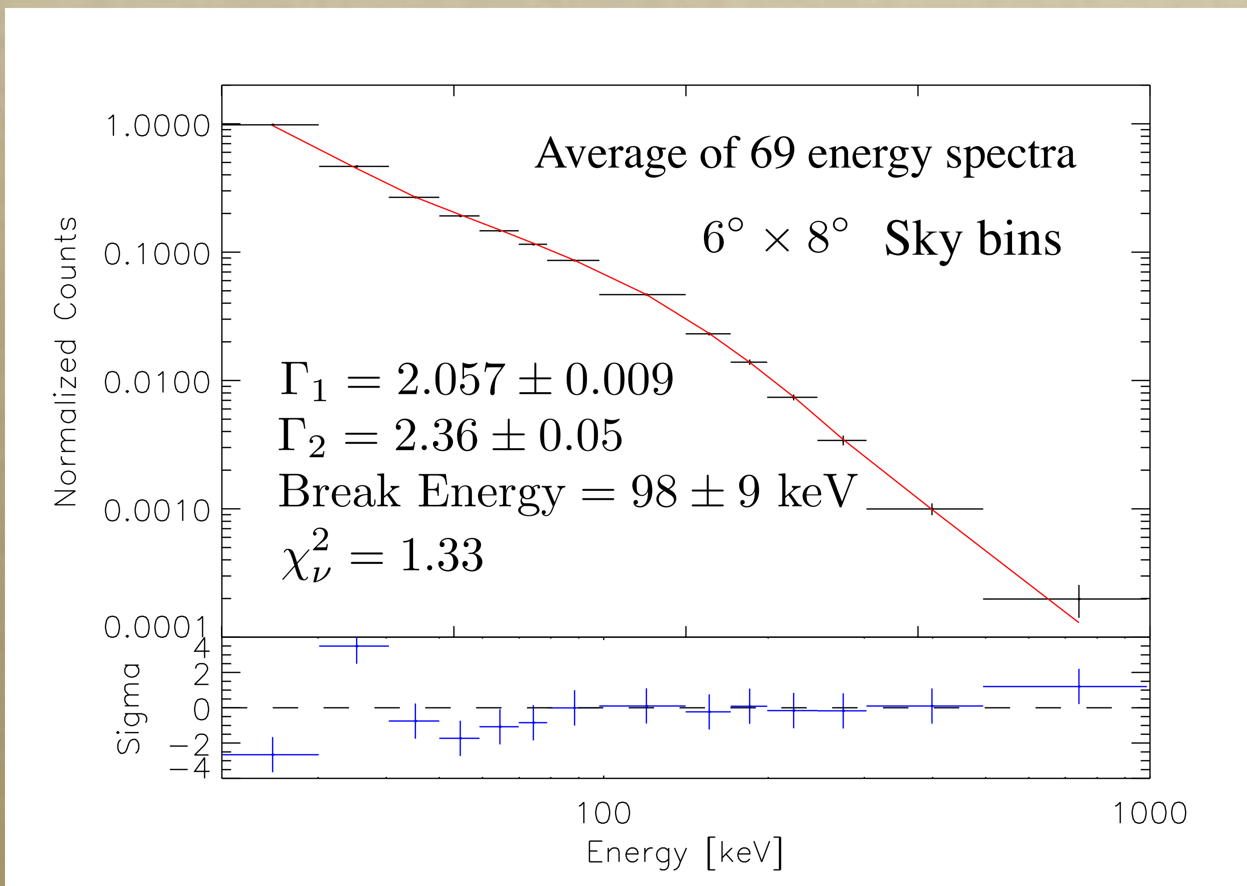
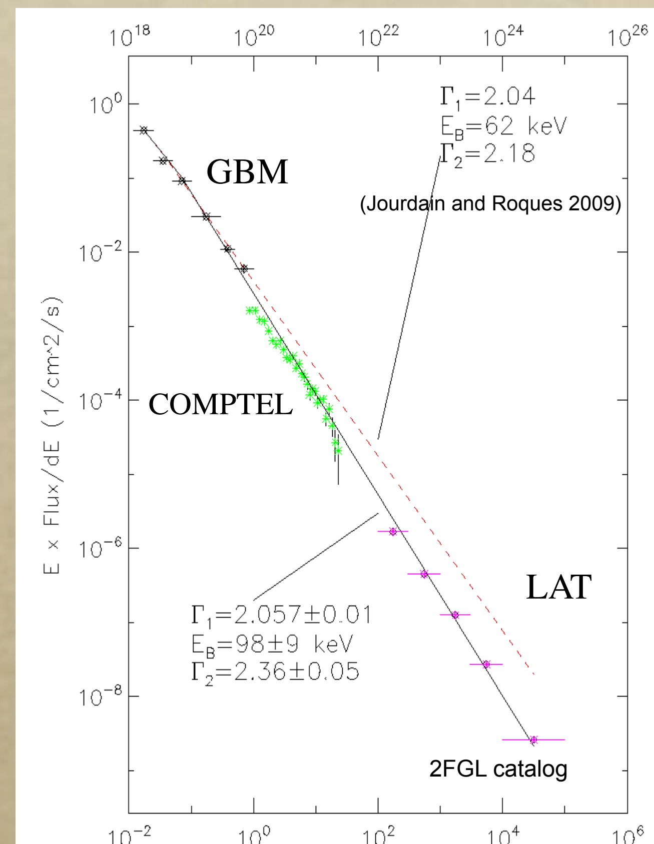
Crab Spectrum





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More spectral analysis coming to our web site in the near future

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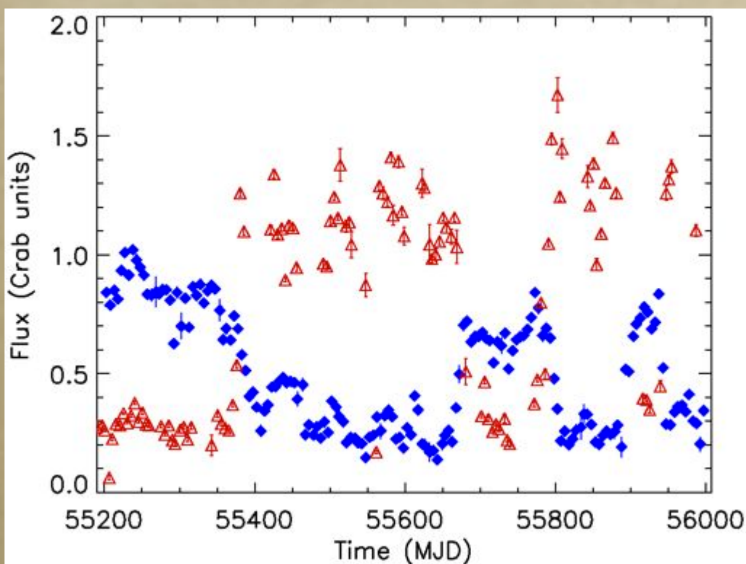
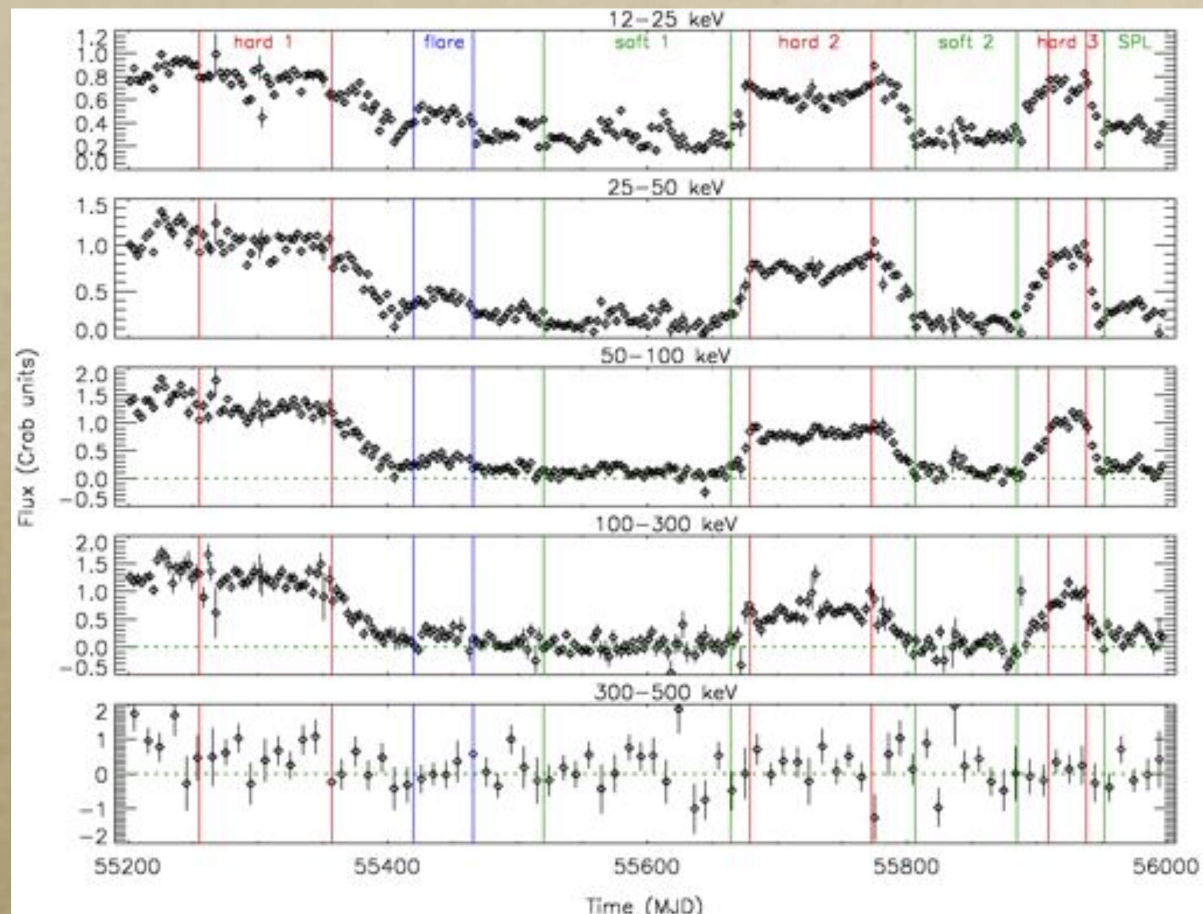
Monitoring of Cygnus X-1 During the 2010-12 State Transitions with the Fermi GBM





◆ GBM 12-50 keV

▲ MAXI/GSC 2-4 keV

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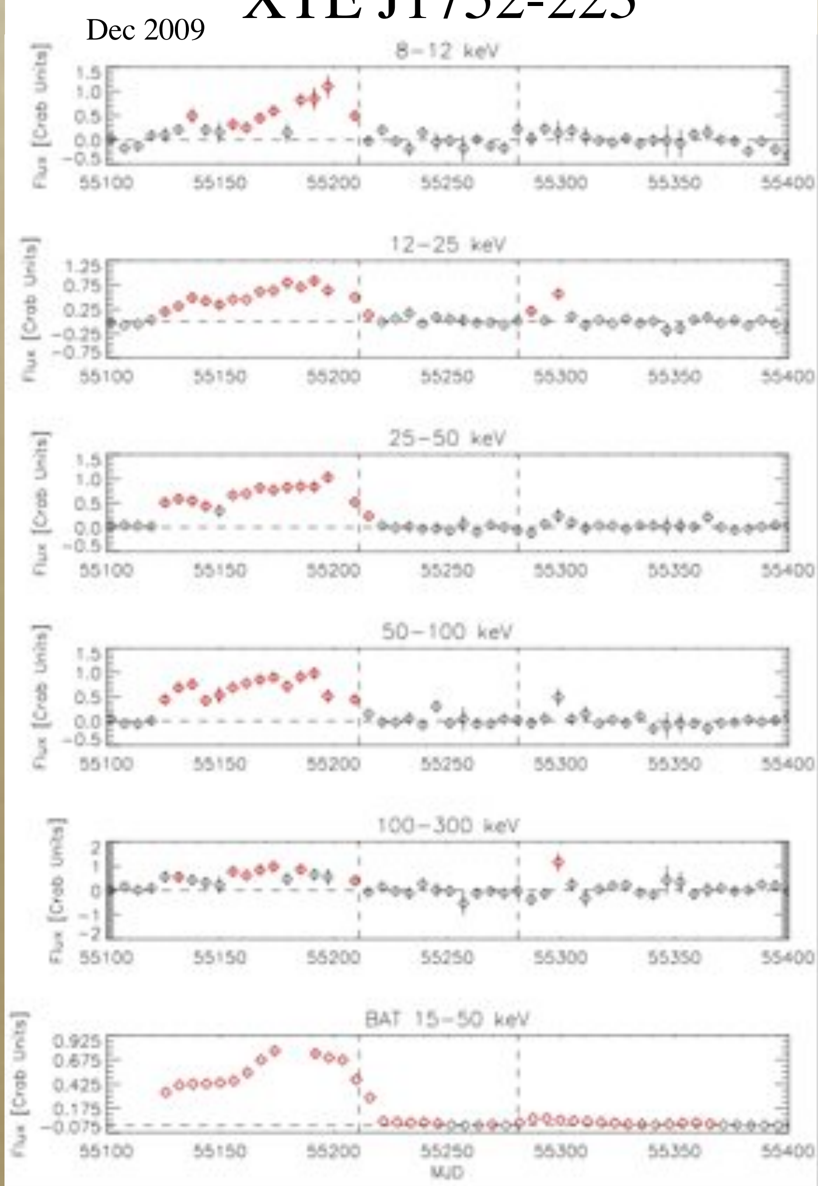
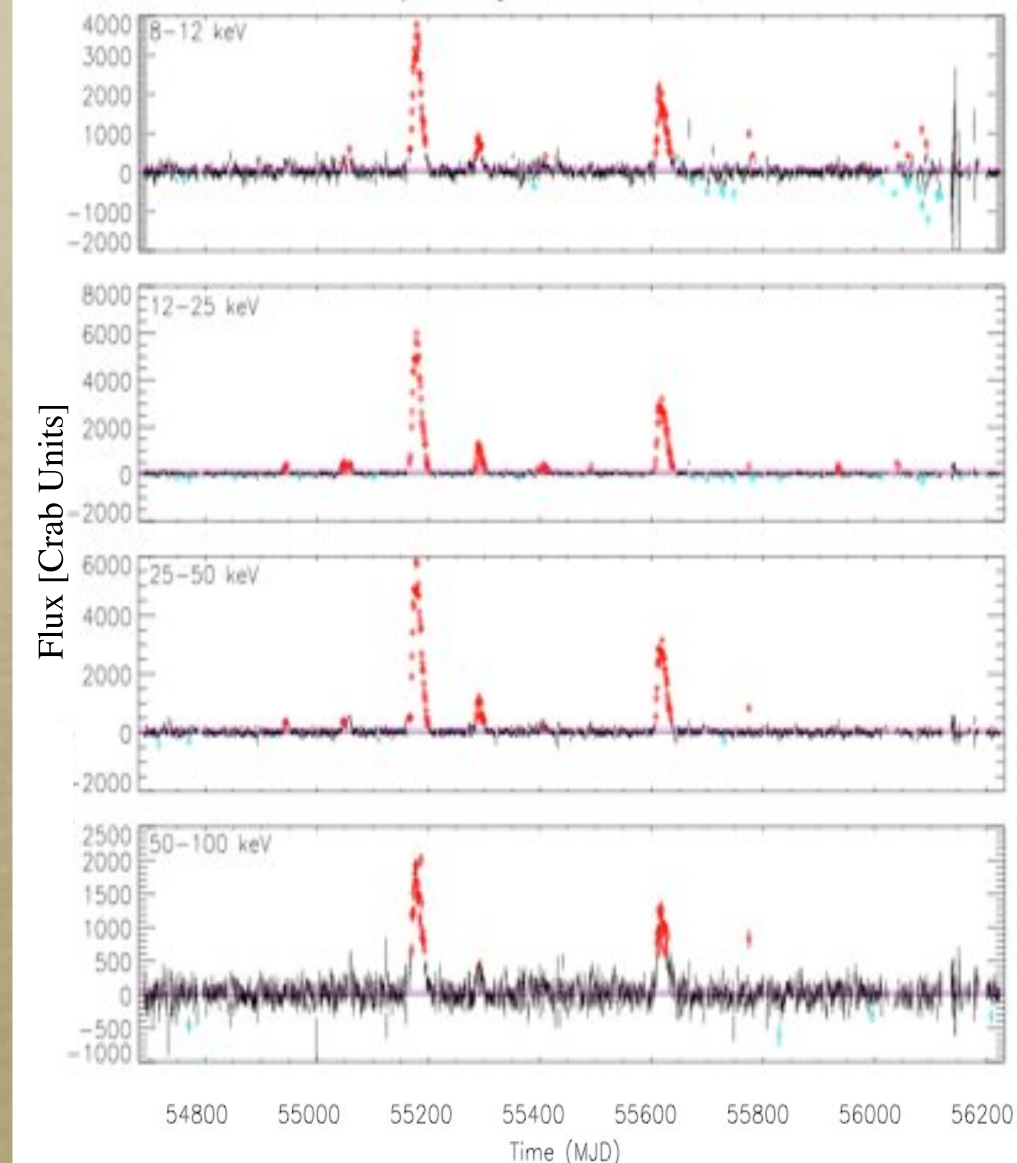
XTE J1752-223



A 0535+262



Thank You

http://heastro.phys.lsu.edu/gbm/

Searching for Un-modeled Sources Using the Earth Occultation Data from the *Fermi* GBM

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Occultation Time

The time where the probability that a 100 keV gamma ray from the source will pass through the atmospheric column is 50%

Atmospheric Transmission function

$$T(E_{\mathrm{ph}}, t) = \exp[-\mu(E_{\mathrm{ph}} A(h(t))]$$

$\mu(E_{\mathrm{ph}})$ — mass attenuation coefficient of gamma rays at photon energy E_{ph} in air

$A(h(t))$ — air mass along the line of sight at a given altitude $h(t)$ based on the U.S. Standard Atmosphere (1976)

Fitting

- Each detector which views the source of interest within 60 degrees of the detector normal is included in the fit
- Observed count rate model for each detector is:

$$r(t, E_{ch}) = b_0(E_{ch}) + b_1(E_{ch}) * (t - t_0) + b_2(E_{ch}) * (t - t_0)^2 + \sum_{i=1}^{n} a_i(E_{ch}) * S_i(t, E_{ch})$$

$b_0(E_{ch}), b_1(E_{ch}), b_2(E_{ch}) =$ Quadratic background coefficients

$a_i(E_{ch}) =$ Fitted scale factors for each source model

$S_i(t, E_{ch}) =$ Source models for source of interest and all other sources included in the fit window

$$S(t, E_{ch}) = R(E_{ph}, E_{ch}, t) \left(T(E_{ph}, t)) * \int_{E_{ph}} f(E_{ph}) dE_{ph} \right)$$

$f(E_{ph}) =$ Assumed source spectrum

$T(E_{ph}, t) =$ Atmospheric transmission

$R(E_{ph}, E_{ch}, t) =$ Time dependent detector response

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Interfering sources in fit window

Each source in the database is identified as:

- > 500 mCrabs — Strong - Always include in fit out to 90 degrees
- > 150 mCrabs — Moderate - Always include in fit out to 60 degrees
- > 50 mCrabs — Weak - Always include in fit out to 40 degrees
- Quiescent - Never include in fit unless it is flaring

Flare database

Public *Swift*/BAT transient monitor data

- 50 mCrabs $\leq$ Source $<$ 150 mCrabs - Weak
- 150 mCrabs $\leq$ Source $<$ 500 mCrabs - Moderate
- Source $\geq$ 500 mCrabs - Strong

If an interfering source meets the criteria for any detector it is included for all detectors

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Additional Considerations

Eclipsing sources

10 sources in the catalog are eclipsing

Sun-Solar flare database

- Class M or X flares - Strong
- Class C flares - Moderate
- Class B flares - Weak

Pre-Filtering data

Usually removes class M and X flares as well as SAA entrances and exits

Post-Filtering

Occultation steps are removed if:

- The source of interest occults within 8 s of a bright source
- The occultation lasts for longer than 20 s (high latitude sources)
- The space craft is rapidly slewing with a spin rate $> 0.004 \text{ rad s}^{-1}$
- Individual steps are $> 10\sigma$ or $> 3.5\sigma$ from the mean if sources intensities reach 150-500 mCrab or < 150 mCrabs respectively
- The time of the fit window is associated with a solar flare

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