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

Gamma-ray Burst Monitor

- 2 BGO detector.
- 200 keV -- 40 MeV
- 126 cm², 12.7 cm
- Spectroscopy
- Bridges gap between NaI and LAT.

Large Area Telescope (LAT)
- 2 BGO detector.
- 20 MeV -- 300 GeV

Gamma-ray Burst Monitor
- 12 NaI detector.
- 8 keV -- 1000 keV
- 126 cm², 1.27 cm
- Triggering, localization, spectroscopy.

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
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
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.
Flux Measurements

Each energy channel and each detector is fitted independently

\[ F(E_{ch}) = \bar{a}(E_{ch}) \times \int_{E_{ph}} f(E_{ph}) dE_{ph} \]

\[ \bar{a}(E_{ch}) = \text{Weighted mean of scale factors for each detector} \]
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
Ghost Source Analysis Systematic Errors

\[ k \times \sigma_{\text{total}} = \sigma_{\text{stat}} \]

\[ \sigma_{\text{total}} = \text{Width of flux distribution} \]

\[ k = 1.0/\sigma_{\text{Sig}} \quad \text{Scale factor} \]

\[ \sigma_{\text{sys}}^2 = \sigma_{\text{total}}^2 - \sigma_{\text{stat}}^2 \]

- \( \sigma_{\text{Sig}} = 2.46 \sim 200 \text{ sources} \)
- \( \sigma = 1.02 \)
- \( \sigma_{\text{total}} = 3.15 \text{ mCrabs} \)

<table>
<thead>
<tr>
<th>Energy Band (keV)</th>
<th>Systematic Error (mCrab)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8–12</td>
<td>3.4</td>
</tr>
<tr>
<td>12–25</td>
<td>2.8</td>
</tr>
<tr>
<td>25–50</td>
<td>2.2</td>
</tr>
<tr>
<td>50–100</td>
<td>1.5</td>
</tr>
<tr>
<td>100–300</td>
<td>3.1</td>
</tr>
<tr>
<td>300–500</td>
<td>3.4</td>
</tr>
</tbody>
</table>
Sensitivity

3σ Sensitivity mCrabs

Fermi
Gamma-ray Burst Monitor
Comparison Between GBM and Swift/BAT

GBM 12-50 keV

Swift/BAT 15-50 keV

2 - 4 day averages
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

<table>
<thead>
<tr>
<th>Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>209 Sources (99 detected-A)</td>
<td></td>
</tr>
<tr>
<td>40 LMXB/NS</td>
<td></td>
</tr>
<tr>
<td>31 HMXB/NS</td>
<td></td>
</tr>
<tr>
<td>12 BHC</td>
<td></td>
</tr>
<tr>
<td>12 AGN</td>
<td></td>
</tr>
<tr>
<td>1 Star (Sun)</td>
<td></td>
</tr>
<tr>
<td>1 TDE (SWIFT J164449.3+57345)</td>
<td></td>
</tr>
<tr>
<td>1 Pulsar/PWN (Crab)</td>
<td></td>
</tr>
<tr>
<td>1 Galaxy Cluster (Oph Cluster)</td>
<td></td>
</tr>
</tbody>
</table>

## Current

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<tr>
<th>Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>215 Sources (104 detected-A)</td>
<td></td>
</tr>
<tr>
<td>40 LMXB/NS</td>
<td></td>
</tr>
<tr>
<td>34 HMXB/NS</td>
<td></td>
</tr>
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<td>14 BHC</td>
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Transients Seen with Earth Occultation
Sources Detected Above 100 and 300 keV

- Crab
- Centaurus A
- Cygnus X-1
- 1E 1740-29

Flux (Crab)

Flux (ph cm$^{-2}$ s$^{-1}$)
Sources Detected Above 100 and 300 keV

- GSR 1915+105
- Swift J1753.5-0127
- XTE J1752-223
- GX 339-4

Case et al. 15

P. Jenke
Crab Flux Decline

C. A. Wilson-Hodge et al.

P. Jenke
Crab Spectrum

Average of 69 energy spectra

\[ \Gamma_1 = 2.057 \pm 0.009 \]
\[ \Gamma_2 = 2.36 \pm 0.05 \]
Break Energy = 98 \pm 9 keV
\[ \chi^2 = 1.33 \]

6° \times 8° Sky bins

More spectral analysis coming to our web site in the near future
Monitoring of Cygnus X-1 During the 2010-12 State Transitions with the Fermi GBM

- GBM 12-50 keV
- MAXI/GSC 2-4 keV

G. L. Case et al.
Dec 2009

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

James Rodi
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

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

- \( \mu(E_{\text{ph}}) \): mass attenuation coefficient of gamma rays at photon energy \( E_{\text{ph}} \) 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:

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

- \( b_0(E_{ch}), b_1(E_{ch}), b_2(E_{ch}) = \) 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

\[ S(t, E_{ch}) = R(E_{ph}, E_{ch}, t) \left( T(E_{ph}, t) \ast \int_{E_{ph}} f(E_{ph}) dE_{ph} \right) \]

- \( f(E_{ph}) = \) Assumed source spectrum
- \( T(E_{ph}, t) = \) Atmospheric transmission
- \( R(E_{ph}, E_{ch}, t) = \) Time dependent detector response
Interfering sources in fit window

Each source in the database is identified as:

- Strong - Always include in fit out to 90 degrees
- Moderate - Always include in fit out to 60 degrees
- 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 ≤ Source < 150 mCrabs - Weak
- 150 mCrabs ≤ Source < 500 mCrabs - Moderate
- Source ≥ 500 mCrabs - Strong

If an interfering source meets the criteria for any detector it is included for all detectors
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
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 spacecraft 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 source intensities reach 150-500 mCrab or $< 150$ mCrabs respectively
- The time of the fit window is associated with a solar flare