FIRST RESULTS FROM *FERMI* GAMMA-RAY BURST MONITOR EARTH OCCULTATION MONITORING: OBSERVATIONS OF SOFT GAMMA-RAY SOURCES ABOVE 100 keV

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ABSTRACT

The NaI and BGO detectors on the Gamma-ray Burst Monitor (GBM) on *Fermi* are now being used for long-term monitoring of the hard X-ray/low-energy gamma-ray sky. Using the Earth occultation technique as demonstrated previously by the BATSE instrument on the Compton Gamma-Ray Observatory, GBM can be used to produce multiband light curves and spectra for known sources and transient outbursts in the 8 keV to 1 MeV energy range with its NaI detectors and up to 40 MeV with its BGO detectors. Over 85% of the sky is viewed every orbit, and the precession of the *Fermi* orbit allows the entire sky to be viewed every ~26 days with sensitivity exceeding that of BATSE at energies below ~25 keV and above ~1.5 MeV. We briefly describe the technique and present preliminary results using the NaI detectors after the first two years of observations at energies above 100 keV. Eight sources are detected with a significance greater than 7σ: the Crab, Cyg X-1, SWIFT J1753.5—0127, 1E 1740-29, Cen A, GRS 1915+105, and the transient sources XTE J1752—223 and GX 339-4. Two of the sources, the Crab and Cyg X-1, have also been detected above 300 keV.

Key words: gamma rays; galaxies – gamma rays: stars – methods: observational

1. INTRODUCTION

The ability to monitor the gamma-ray sky continuously is extremely important. The majority of gamma-ray sources are variable, exhibiting flares and transient outbursts on timescales from seconds to years. While there are currently several all-sky monitors in the hard X-ray energy range providing daily light curves, e.g., the All-Sky Monitor (ASM) on the * Rossi X-ray Timing Explorer* (RXTE) from 2 to 10 keV (Levine et al. 1996), the Gas Slit Camera (GSC) on the Monitor of All-sky X-ray Image (MAXI) from 1.5 to 20 keV (Matsuoka et al. 2009), and the Burst Alert Telescope (BAT) on *Swift* from 15 to 50 keV (Gehrels et al. 2004), there has not been an all-sky monitor in the low-energy gamma-ray region since the Burst and Transient Source Experiment (BATSE) instrument on the Compton Gamma-Ray Observatory (CGRO), which was sensitive from 20 to 1800 keV (Fishman et al. 1989).

The gamma-ray satellite *Fermi* was launched on 2008 June 11 and commenced science operations on 2008 August 12. *Fermi* contains two instruments: the Large Area Telescope (LAT), sensitive to gamma rays from ~20 MeV to ~300 GeV (Atwood et al. 2009), and the Gamma-ray Burst Monitor (GBM), which is sensitive to X-rays and gamma rays from 8 keV to 40 MeV (Meegan et al. 2009). With its wide field of view, GBM can be used to provide nearly continuous full-sky coverage in the hard X-ray/soft gamma-ray energy range. It is the only instrument currently in orbit that can perform all-sky monitoring above ~150 keV (but below the 30 MeV threshold of the *Fermi* LAT) with usable sensitivity. The *Swift/BAT* sensitivity drops off rapidly above 100 keV, and its energy range effectively ends at 195 keV. *INTEGRAL*, which has a relatively narrow field of view, cannot make continuous observations of a large number of individual sources. Also, GBM is not limited by solar pointing constraints, as are most other instruments, which allows the monitoring of sources at times during which other instruments cannot.

The Earth occultation technique, used very successfully with BATSE, has been adapted to GBM to obtain fluxes for an input catalog of known or potential sources. In this paper, we focus on energies above 100 keV and present preliminary results from the first two years of GBM Science operations. To date, six persistent sources and two transient sources have been detected. In Section 2, we briefly describe the GBM instrument, and in Section 3, we outline the Earth occultation technique as applied to GBM. In Section 4, we present the light curves for the eight sources, and in Section 5, we discuss the results, the GBM capabilities and future work.

2. GBM

*Fermi* consists of 14 detectors: 12 NaI detectors, each 12.7 cm in diameter and 1.27 cm thick (each with effective area ~123 cm² at 100 keV), and 2 BGO detectors, 12.7 cm in diameter and 12.7 cm thick (each with effective area ~120 cm² in the 0.15–2 MeV range). The NaI detectors are located on the corners of the spacecraft, with six detectors oriented such that the normals to their faces are perpendicular to the z-axis of the spacecraft (the LAT is pointed in the +z-direction), four detectors pointed at 45° from the z-axis, and two detectors pointed 20°
occultation within 60° 8 keV to 1 MeV. Typically 3–4 NaI detectors view an Earth form coverage of the unocculted sky in the energy range from use the lower spectral resolution CTIME data. Analyses using channel spectral resolution. The results presented in this paper inal 0.256 s time resolution and 8-channel spectral resolution.

The Crab was 4:5 from the normal to the detector. The time window is centered on the calculated occultation time for 100 keV off the z-axis. Together, these 12 detectors provide nearly uniform coverage of the unocculted sky in the energy range from 8 keV to 1 MeV. Typically 3–4 NaI detectors view an Earth occultation within 60° of the detector normal vector. The two BGO detectors are located on opposite sides of the spacecraft and view a large part of the sky in the energy range ~150 keV to ~40 MeV. It should be noted that none of the GBM detectors have direct imaging capability.

GBM has two continuous data types: CTIME data with nominal 0.256 s time resolution and 8-channel spectral resolution and CSPEC data with nominal 4.096 s time resolution and 128-channel spectral resolution. The results presented in this paper use the lower spectral resolution CTIME data. Analyses using the higher resolution CSPEC data are reserved for future work.

Fermi was launched into an $i = 25.6$ inclination orbit at an altitude of 555 km. The diameter of the Earth as seen from Fermi is ~135°, so roughly 30% of the sky is occulted by the Earth at any one time. One complete orbit of the spacecraft allows over 85% of the sky to be observed. The precession of the orbital plane allows the entire sky to be occulted every ~26 days (half the precession period for the Fermi orbit), though the exposure is not uniform.

3. THE EARTH OCCULTATION TECHNIQUE

Known sources of gamma-ray emission can be monitored with non-imaging detectors using the Earth occultation technique, as was successfully demonstrated with BATSE (Ling et al. 2000; Harmon et al. 2002, 2004). When a source of gamma rays is occulted by the Earth, the count rate measured by a detector will drop, producing a step-like feature. When the source reappears from behind the Earth’s limb, the count rate will increase, producing another step. Figure 1 shows a single step due to a Crab occultation in the count rate in the 12–25 keV band of a single GBM NaI detector observing the occultation nearly face-on. The occultation has a finite transition time due to the effect of absorption in the Earth’s atmosphere. Since the orbital period of the spacecraft is ~96 minutes, the individual occultation steps last for ~8/$\cos \beta$ seconds, where $\beta$ is the occultation angle and is defined as the elevation angle of the source being occulted with respect to the plane of the Fermi orbit. The shapes of the individual occultation steps also depend on energy. The transmission through the atmosphere as a function of time is modeled as $T(t) = \exp[-\mu(E)A(h)]$, where $\mu(E)$ is the mass attenuation coefficient of gamma rays at energy $E$ in air and $A(h)$ is the air mass along the line of sight at a given altitude $h$ based on the US Standard Atmosphere (US Committee on Extension to the Standard Atmosphere 1976). This requires instantaneous knowledge of the spacecraft position, the direction to the source of interest as seen from the spacecraft, and a model of the Earth that includes its oblateness. Changes in chemical content with altitude and changes in the atmospheric height with solar activity are not included in the current atmospheric model.

We have adapted the technique of Harmon et al. (2002) for GBM. This technique involves fitting a model consisting of a quadratic background plus source terms to a short (~4 minutes) window of data centered on the occultation time of the source of interest. For GBM, we have incorporated the changing detector response across the fit window into our source terms. The Ling et al. (2000) approach involved simultaneous fits to an empirical background and numerous source terms over much longer time intervals (typically an entire day), during which each source and the corresponding detector response is assumed constant. The Ling et al. (2000) technique is not practical for GBM data due to the rapidly changing response. In addition, the Ling et al. (2000) method resulted in apparent hard tails for several weak sources that were not confirmed with other instruments (Harmon et al. 2004).

The primary difference in the implementation of the occultation technique between GBM and BATSE arises from the different pointing schemes of the respective missions. CGRO was three-axis stabilized for each viewing period, which typically lasted for two weeks. This meant that a source remained at a fixed orientation with respect to the detectors through an entire viewing period. In contrast, Fermi scans the sky by pointing in a direction $35^\circ$ (2008 August–2009 September) or $50^\circ$ (2009 October–present) north of the zenith for one orbit; it then rocks to $35^\circ$ or $50^\circ$ south for the next orbit, continuing to alternate every orbit unless the spacecraft goes into a pointed mode (which occurs rarely). In addition, the spacecraft performs a roll about the $z$-axis as it orbits. Because the orientation of a source with respect to the GBM detectors varies as a function of time, the detector response as a function of angle must be accounted for. A detailed instrument modeling and measurement program has been used to develop the GBM instrument response as a function of direction (Hoover et al. 2008; Bissaldi et al. 2009), which is incorporated into the occultation analysis. It should be noted that the GBM occultation technique provides measurements in the 8–25 keV and >1500 keV bands, where no usable data were available for the BATSE LADS. GBM has only a Be window on the NaI detectors instead of the plastic scintillator, aluminum honeycomb, and aluminum window that covered the front of the BATSE scintillators (Case et al. 2007). Due to its larger area, BATSE was more sensitive than GBM between 25 keV and 1.5 MeV.

The occultation technique requires an input catalog of pre-determined source locations, and currently we are monitoring 82 sources (Wilson-Hodge et al. 2009b). This catalog contains predominantly Galactic X-ray binaries, but also includes the Crab, the Sun, two magnetars, five active galactic nuclei (AGNs), and two cataclysmic variables. For each day, the occultation times for each source are calculated using the known spacecraft positions. The time of the occultation step is taken to be the time

Figure 1. Single Crab occultation step seen in the CTIME raw counts data of a single GBM NaI detector (NaI 2) in the 12–25 keV band with 2.048 s time bins. The Crab was 4.5 from the normal to the detector. The time window is centered on the calculated occultation time for 100 keV.
for which the transmission of a 100 keV gamma ray through the atmospheric column is 50%. The time at which the atmospheric transmission reaches 50% is energy dependent, e.g., for energies less than 100 keV, a setting step will occur earlier (see Figure 1). This energy dependence is accounted for in the calculation of the atmospheric transmission function, $T(t)$. For each occultation step, a 4 minute window is defined that is centered on the 100 keV occultation time. For each energy band, the count rates in the window are fit separately for each detector viewing the source of interest. In each of these detectors, the count rates are fitted with a quadratic background plus source terms for the source of interest and each interfering source that appears in the window. The source terms consist of $T(t)$ and a time-dependent model count rate, derived from the time-dependent detector response convolved with an assumed source spectrum. Each energy channel and each detector is fitted independently. For each source term a scaling factor is fitted, along with the quadratic background coefficients. When multiple detectors are included in the fit, the weighted mean for the scaling factor of the source of interest is computed for each energy channel. The mean scaling factor is then multiplied by the predicted flux in each energy channel to obtain flux measurements for the source of interest.

We explored the effects of incorrect assumed source spectra using multiple runs of the Earth occultation software for the Crab assuming a canonical spectrum (Toor & Seward 1971), an exponential cutoff spectrum (with a cutoff energy of 30 keV and $e$-folding energy of 13.56 keV), and a power law with a photon index $\alpha = -3$. The measured count rates in each step were consistent within errors, indicating that the assumed spectrum has very little effect for an interfering source. Further we found that the statistical significance of the average flux in each energy channel was consistent for all three assumed spectra. However, the flux values showed systematic effects. For the “incorrect” spectra, which were softer than the canonical spectrum, the low-energy flux (8–100 keV) was systematically high. The higher energy flux (100–500 keV) was consistent for the power-law (index $\alpha = -3$) model, but was systematically low for the exponential model. Therefore, the assumed spectrum does not appear to affect detection significance or fits to other sources. Its only impact is on the reported flux values.

Ideally, each occultation measurement would include the effects of every other source in the sky, but this is not practical to implement. We have adopted a top–down iterative approach for treating interfering sources. Following Harmon et al. (2004), we have implemented a flare database consisting of times when sources are active and broad levels of activity. For our first iteration, we have used public Swift/BAT transient monitor data to populate our flare database. Later iterations will incorporate results from GBM and from the Swift/BAT survey over a wider energy range. If a cataloged source has a 15–50 keV flux of 50 mCrab or larger in Swift/BAT, it is included in the database. Sources are grouped into three classes: (1) $>500$ mCrab, (2) 150–500 mCrab, or (3) 50–150 mCrab. Identical source classes are used in the source catalog for persistent sources. Sources in these classes are included as interfering sources if they undergo Earth occultation in the fit window and if they are within 90$^\circ$, 60$^\circ$, or 40$^\circ$ of the detector normal for classes 1, 2, and 3, respectively. Fainter sources are not currently considered in occultation fits except when they are the source of interest. This paper reports results from our first iteration, in which we treat the brightest sources first to optimize interfering source inclusion. Also, to minimize potential systematic effects due to interfering sources that are missing from our catalog, we are focusing this first results paper on energies above 100 keV where fewer sources are detectable with GBM. In our next iteration, we plan to add additional sources, such as flaring AGN sources for comparison to results from Fermi/LAT. Our code is flexible, so additional source classes can be added if needed to support analysis of fainter sources.

Up to 31 occultation steps are possible for a given source in a day, although typically only 50%–80% of the steps are usable, depending upon source interference and background filtering. These steps are summed to get a single daily average flux. This technique can be used with either the NaI or BGO detectors, though the analysis presented here uses only the NaI detectors. A more complete description of the GBM implementation of the occultation technique will be given by C. A. Wilson-Hodge et al. (2011, in preparation).

4. RESULTS

In Wilson-Hodge et al. (2009b), the measured GBM 12–50 keV light curves are compared to the Swift BAT 15–50 keV light curves for several sources over the same time intervals, and it is seen that the fluxes measured by the two instruments compare well. At energies above the $\sim$195 keV, upper energy limit of the Swift 22 month catalog (Tueller et al. 2010), however, the GBM observations provide the only wide-field monitor available for the low-energy gamma-ray sky. Of the catalog sources being monitored with GBM, six persistent sources have been detected above 100 keV with a statistical significance of at least 7$\sigma$ after two years of observations, as well as two transient sources.

Table 1 gives the fluxes averaged over all 730 days from 2008 August 12 (MJD 54690, the beginning of science operations) to 2010 August 11 (MJD 55419) for the persistent sources, and over the duration of the flares for the transient sources. Also given are the significances for each energy band. The errors are statistical only. The sources are sorted by their detection significance in the 100–300 keV band.

4.1. Persistent Sources

The six persistent sources, Crab, Cyg X-1, Cen A, GRS 1915+105, 1E 1740-29, and SWIFT J1753.5–0127, are detected by GBM at energies above 100 keV. In Figures 2–7, we show light curves for these sources generated from the GBM data in several broad energy bands with five-day resolution. These persistent sources demonstrate the capabilities of the GBM Earth occultation monitoring.

4.1.1. Crab

The Crab emission in the hard X-ray/low-energy gamma-ray regime contains a combination of pulsar and pulsar wind nebula contributions. Figure 2 shows the light curves measured by GBM in four broad energy bands from 12 keV to 500 keV. The spectrum in this regime has been shown by analysis of BATSE occultation data (Much et al. 1996; Ling & Wheaton 2003) and data from SPI on board INTEGRAL (Jourdain & Roques 2009) to agree with the spectrum measured with other instruments at lower X-ray energies, and then to steepen near 100 keV. Results of the BATSE analysis can be described by a broken power law, while results of the SPI analysis suggest a smoothly steepening spectrum.

The SPI spectrum was also fit to a broken power law, with the break energy fixed at 100 keV, $F = A(E/100\text{keV})^{-\alpha}$
Table 1
Fluxes and Significances in GBM Broad High Energy Bands

| Source Name | 50–100 keV | 100–300 keV | 300–500 keV |
|-------------|------------|------------|------------|
|              | Flux (mCrab) | Error (mCrab) | Significance (σ) | Flux (mCrab) | Error (mCrab) | Significance (σ) | Flux (mCrab) | Error (mCrab) | Significance (σ) |
| Cyg X-1     | 1151.0     | 3.7        | 312        | 1130.7     | 6.9        | 163        | 529.0       | 49.5        | 10.7          |
| Crab        | 1000.0     | 3.3        | 307        | 1000.0     | 6.3        | 158        | 1000.0      | 48.0        | 20.9          |
| XTE J1752–223 | 730.8     | 14.2       | 51         | 563.1      | 26.7       | 21         | 226.1       | 204.4       | 1.1           |
| Cen A       | 72.4       | 3.6        | 20         | 104.2      | 6.7        | 16         | 104.5       | 62.0        | 1.7           |
| SWIFT J1753.5–0127 | 121.0 | 4.4        | 28         | 126.8      | 8.2        | 15         | 126.8       | 65.0        | 2.0           |
| 1E 1740–29  | 116.3      | 4.7        | 25         | 92.3       | 8.8        | 11         | 104.5       | 62.0        | 1.7           |
| GRS 1915+105 | 128.1     | 3.6        | 35         | 54.9       | 6.8        | 8.0        | 104.2       | 65.0        | 2.0           |
| GX 339–4    | 399.4      | 18.3       | 22         | 249.5      | 33.8       | 7.4        | 307.4       | 65.0        | 2.0           |

Notes.

a Fluxes are given for MJD 55129–55218 when XTE J1752–223 was flaring.
b 2σ upper limit.
c Fluxes are given for MJD 55244–55289 when GX 339-4 was flaring.

Figure 2. GBM light curve for the Crab. The horizontal scale is in modified Julian days over the 730 day GBM exposure period, and has been binned 5 days per data point. The dashed horizontal lines show the average flux in each of four energy bands increasing from top to bottom. In the bottom plot, the solid line marks the zero flux level. Note that the apparent “flare” near MJD 55180 is due to a giant outburst in the nearby accreting pulsar A0535+262.

Figure 3. GBM light curve for Cyg X-1 over 730 days. The light curve has been binned 5 days per data point. The fluxes are in Crab units, and the dashed and solid lines mark the average flux and zero flux levels, respectively.

light of our recent discovery of a 7% decline in the Crab flux observed with the instruments aboard four different satellites during the time of the GBM mission (Wilson-Hodge et al. 2011). These results demonstrate that GBM is able to see significant emission above 300 keV at a level consistent with the canonical hard spectrum of the Crab. Future analysis with the 128-channel GBM CSPEC data will allow us to improve our determination of the high-energy spectral index for a more significant comparison to INTEGRAL and search for possible time variations of the spectral hardness.

4.1.2. Cyg X-1

Cygus X-1 is a high-mass X-ray binary and was one of the first systems determined to contain a black hole (Bolton 1972; Paczynski 1974). The X-ray emission is bimodal, with the >10 keV emission anticorrelated with the <10 keV emission (Dolan et al. 1977).
In the high gamma-ray intensity (hard) state, where the system spends most of its time, the hard X-ray/low-energy gamma-ray spectrum can be described by a Comptonization model with $kT \approx 50–60$ keV and optical depth $\sim 2$ (McConnell et al. 2002; Ling & Wheaton 2005; Cadolle Bel et al. 2006). However, emission has been observed in excess of the Comptonization model at energies greater than $\approx 200–300$ keV (Nolan et al. 1981; McConnell et al. 2002; Ling & Wheaton 2005), necessitating the addition of a high-energy non-thermal component.

Occasionally, Cyg X-1 makes a transition to a low gamma-ray intensity (soft or thermally dominated) state, where the soft X-ray flux rises dramatically while the hard X-ray/low-energy gamma-ray flux decreases. The hard X-ray/low-energy gamma-ray spectrum in this state can be represented with a single-temperature Comptonization model with $kT \approx 100$ keV (McConnell et al. 2002; Cadolle Bel et al. 2006), which is higher than in the hard state, and a non-thermal tail that extends beyond several MeV. More complex, hybrid thermal/non-thermal models have also been used to describe the soft state spectrum.
which yield electron temperatures similar to the hard state and high-energy power-law tails with index $\sim 2.4-3.7$ (McConnell et al. 2002; Cadolle Bel et al. 2006).

Figure 3 shows the GBM light curves. The light curves show significant variability below 300 keV, with significant emission above 300 keV up until about MJD 55355. Starting at about MJD 55355, the 100–300 keV band emission began to decrease (Wilson-Hodge & Case 2010), dropping from an average level of about 1200 mCrab down to nearly undetectable levels on MJD 55405–55406. On MJD 55374, MAXI detected a rapid rise in the soft 2–4 keV band (Negoro et al. 2010b), which, combined with the decrease in the low-energy gamma-ray flux indicated a transition to a thermally dominated soft state. As of MJD 55419, the one-day average GBM light curves show that the 12–50 keV flux has begun to rise, while the 100–300 keV flux remains at a low level of $\approx 150$ mCrab. We will continue to monitor Cyg X-1 during the thermally dominated state and follow its transition back to the low/hard state.

The GBM light curves (Figure 3) reveal significant emission above 300 keV, consistent with the power-law tail that has been observed when Cyg X-1 is in its low/hard state. The observed GBM flux ratios are $R_{50} = 0.22 \pm 0.001$, $R_{100} = 0.119 \pm 0.001$, and $R_{300} = 0.010 \pm 0.001$, inconsistent with a single power law. For example, a single power law with $\Gamma = 1.7$ would yield flux ratios 0.224, 0.174, and 0.073. Instead, the GBM ratios suggest a spectrum that appears significantly flatter at low energies and but steeper at high energies, consistent with the behavior reported by INTEGRAL (Cadolle Bel et al. 2006) and the CGRO instruments (McConnell et al. 2002).

4.1.3. Cen A

The relatively nearby radio galaxy Cen A is a Seyfert 2 galaxy that is the brightest AGN in hard X-rays/low-energy gamma rays. It has powerful jets aligned at approximately 70$^\circ$ from the line of sight and is seen to vary on timescales of tens of days to years. It has been observed at hard X-ray energies by OSSE (Kinzer et al. 1995), INTEGRAL and RXTE (Rothschild et al. 2006), and at energies $>$1 MeV by COMPTEL (Steinde et al. 1998). The observations below 150 keV are consistent with a hard spectrum with a power-law index $\Gamma \sim 1.8$–1.9. The combined OSSE and COMPTEL data are consistent with a steepening of the spectrum at 150 keV to $\Gamma \sim 2.3$, with the spectrum then extending unbroken to beyond 10 MeV.

The GBM light curve for Cen A is shown in Figure 4. Because Cen A is relatively far below the equatorial plane, with a declination $\delta = -43^\circ$, its beta angle (which ranges between $\delta \pm i$) can be larger than the half-angle size of the Earth as seen from Fermi ($\beta_{\text{Earth}} \approx \pm 67^\circ$). When this happens, Cen A is not occulted. This causes periodic gaps in the light curve, with the period of the gaps equal to the precession period of the orbit.

The fluxes as measured by GBM and given in Table 1 are consistent with the hard spectrum measured by previous instruments, though the GBM flux ratios are more consistent with a slightly softer index of $\Gamma \sim 1.9$ compared to the canonical index of 1.8. The flux ratios measured by GBM are $R_{50} = 0.168 \pm 0.008$ and $R_{100} = 0.134 \pm 0.008$, respectively. An unbroken $\Gamma = 1.9$ power law up to 300 keV would result in flux ratios of 0.178 and 0.129, respectively. A $\Gamma = 1.9$ power law extending up to 500 keV would result in a (300–500 keV)/(12–50 keV) flux ratio of 0.028, while GBM measures essentially no flux above 300 keV, $R_{300} = 0.006 \pm 0.010$. This is consistent with a steepening or cutoff somewhere near 300 keV, which is also consistent with the steepening seen in the combined OSSE–COMPTEL spectra.

4.1.4. GRS 1915+105

The galactic microquasar GRS 1915+105 is a low-mass X-ray binary (LMXB) with the compact object being a massive black hole (Greiner et al. 2001). It has been active and highly variable at both X-ray and low-energy gamma-ray energies since its discovery in 1992 (Paciesas et al. 1995; Case et al. 2005; McClintock & Remillard 2006), and significant emission has been observed out to at least 500 keV (Zdziarski et al. 2001).

The OSSE (Zdziarski et al. 2001) data above 50 keV are consistent with a single power law with index $\Gamma \approx 2.7$–3.1. However, when data from simultaneous RXTE observations are jointly fit with the OSSE data, the combined spectrum is best represented by a hybrid thermal/non-thermal model with a Comptonization component ($kT = 66$ keV) and a high-energy power-law component (Zdziarski et al. 2001). Observations with INTEGRAL/SPI in the 20–500 keV energy range (Droulans & Jourdain 2009) showed evidence for a time-variable thermal Comptonization component below $\sim 100$ keV along with a relatively steady, hard power law at higher energies, indicating that different emission regions are likely responsible for the soft and hard emission.

The GBM daily fluxes integrated over 730 days (Table 1) show significant emission above 100 keV, consistent with the power-law tail seen with other instruments. The GBM light curve (Figure 5) shows distinct variability below 100 keV, with statistics above 100 keV insufficient to determine the level of variability of the emission. The flux ratios observed by GBM ($R_{50} = 0.044 \pm 0.001$ and $R_{100} = 0.010 \pm 0.001$) are close to the flux ratios expected from a power-law spectrum with $\Gamma \sim 3$ ($R_{50} = 0.046$ and $R_{100} = 0.014$).

4.1.5. 1E 1740-29

The black hole candidate 1E 1740-29 (also known as 1E 1740.7–2942) is an LMXB very near the Galactic center. With a large double-ended radio jet, it was the first source identified as a microquasar. The system spends most of its time in the low/hard state (Mirabel et al. 1992; Smith et al. 2002). INTEGRAL observations indicate the presence of significant emission up to at least 500 keV with a steepening of the spectrum near 140 keV (Bouchet et al. 2009). The spectrum can be modeled either with a Comptonization model ($kT = 27$ keV) with a high-energy power-law tail (photon index $\approx 1.9$), or with two superimposed Comptonization components ($kT = 29$ keV and 100 keV).

The GBM results (Figure 6) are consistent with the high-energy component observed when 1E 1740-29 is in the low/hard state. Below 100 keV and above 300 keV, GBM sees approximately 20%–50% higher flux than INTEGRAL, while in the 100–300 keV band, GBM observes approximately 90% of the level reported by INTEGRAL. Flux discrepancies, especially below 100 keV, are believed to be due to unresolved source interference, where another source occulting near in time to 1E 1740-29 is missing from our interfering source list. We are currently investigating this issue.

4.1.6. SWIFT J1753.5−0127

The X-ray nova SWIFT J1753.5−0127 (Figure 7) is an LMXB with the compact object likely being a black hole (Miller et al. 2006; Cadolle Bel et al. 2007). Swift discovered this source when it observed a large flare in 2005 July (Palmer...
et al. 2005). The source did not return to quiescence but settled into a low-intensity hard state (Miller et al. 2006). \textit{Integral} observations (Cadolle Bel et al. 2007) showing emission up to \( \sim \)600 keV were compatible with thermal Comptonization modified by reflection, with evidence for separate contributions from a jet, disk, and corona. We have analyzed the BATSE occultation data from 1991 to 2000 and found no significant emission from this source above 25 keV.

The GBM results are consistent with this source still remaining in a hard state, with significant emission in excess of 100 mCrab above 100 keV. The light curves shown in Figure 7 show that the emission from the higher energy bands declined beginning about MJD 55200, and that it increased again beginning about MJD 55325 and is currently at or just below its two-year average. The spectrum is inconsistent with a single power law, and future work using the GBM CSPEC data will allow a more detailed analysis of the spectrum. We will continue to monitor this source while it is active.

4.2. Transient Sources

4.2.1. XTE J1752–223

The new transient black hole candidate XTE J1752–223, discovered by \textit{RXTE} (Markwardt et al. 2009b), was observed by GBM to rise from undetectable on 2009 October 24 (MJD 55128) to 511 \( \pm \) 50 mCrab (12–25 keV), 570 \( \pm \) 70 mCrab (25–50 keV), 970 \( \pm \) 100 mCrab (50–100 keV), and 330 \( \pm \) 100 mCrab (100–300 keV) on 2009 November 2 (Wilson-Hodge et al. 2009b). The light curve is variable, especially in the 12–25 keV band, where the one-day average flux initially rose to about 240 mCrab (October 25–28), suddenly dropped to non-detectable on October 29–30, then rose again during the period October 31 to November 2 (MJD 55135–55137). The flux remained relatively constant until November 25 (MJD 55160) when it began to rise again, peaking in the high energies on 2009 December 20 (MJD 55185). After an initial slow decline, the high-energy flux rapidly declined back to the pre-flare levels. The light curve for the entire mission to date, with five-day resolution, is shown in Figure 8. The fluxes for XTE J1752–223 in Table 1 are integrated over the days when XTE J1752–223 was observed by GBM to be in a high gamma-ray intensity state, MJD 55129–55218.

\textit{RXTE} measurements indicate a black hole hard state spectrum with a power-law component (\( \Gamma \sim 1.4 \)) superimposed on a weak black body (\( kT \sim 0.8 \) keV). A 6.4 keV iron line is also seen, with combined spectral and timing properties similar to those observed in Cyg X-1 and GX 339-4 (Shaposhnikov et al. 2009). Results from \textit{RXTE}/\textit{HEXTE} analysis have shown evidence for emission up to 200 keV (Muñoz-Darias et al. 2010b), best fit with a broken power law with a break energy near 130 keV, again markedly similar to Cyg X-1. The flux ratios measured with GBM (\( R_{50} = 0.218 \pm 0.005, R_{100} = 0.090 \pm 0.005, R_{200} = 0.006 \pm 0.006 \)) are similar to those observed for Cyg X-1 in its hard state and are consistent with a \( \Gamma \sim 1.7 \) spectrum steepening to at least \( \Gamma \sim 1.9 \) above 100 keV.

4.2.2. GX 339-4

The highly variable LMXB and black hole candidate GX 339-4 (Samimi et al. 1979; Doxsey et al. 1979) is characterized by rapid time variability and low/hard X-ray states similar to those of Cyg X-1 (Harmon et al. 1994; Cowley et al. 2002). The results of analysis of both BATSE (Case et al. 2008) and \textit{Integral} (Caballero-García et al. 2009) data have indicated the presence of high energy emission above 200 keV during previous outbursts, with the \textit{Integral} spectrum fitted by a thermal Comptonization component together with non-thermal synchrotron or self-synchrotron emission possibly originating at the base of a jet.

GX 339-4 was observed by \textit{MAXI} to begin a large flare event starting on 2010 January 3 (Yamaoka et al. 2010). The flux observed by GBM began to increase starting in early 2010 January and continued to increase up to a level of \( \sim \)400 mCrab (12–25 keV), \( \sim \)650 mCrab (25–50 keV), \( \sim \)800 mCrab (50–100 keV), and \( \sim \)550 mCrab (100–300 keV) by early 2010 April, after which it began to rapidly decrease. It returned to quiescence in the higher energy bands by mid-April and in the 12–50 keV band by the end of April. The fluxes for GX 339-4 in Table 1 are integrated over the days when GX 339-4 was observed by GBM to be in a high gamma-ray state, MJD 55244–55289. Similar to Cyg X-1 and XTE J1752–223, the flux ratios measured by GBM (\( R_{50} = 0.223 \pm 0.012 \) and \( R_{100} = 0.075 \pm 0.011 \), with no measurable intensity above 300 keV) appear consistent with a \( \Gamma \sim 1.7 \) power-law steepening above 100 keV to at least \( \Gamma \sim 1.9 \).

Note that there was a weaker double-peaked flare starting around MJD 54888 (Markwardt et al. 2009a) and lasting until around MJD 55000 (see Figure 9). While the light curve in the 100–300 keV band is suggestive of positive emission in this band, it is only marginally significant (\( \sim 5 \sigma \)) with an average flux of 162 \( \pm \) 31 mCrab.

5. CONCLUSIONS AND FUTURE PROSPECTS

Using the Earth occultation technique, the GBM instrument on \textit{Fermi} has been monitoring the gamma-ray sky in the \( \sim \)8–1000 keV energy range, providing daily measurements for a catalog of 82 sources, including 71 X-ray binaries, five AGNs, two magnetars, two cataclysmic variables, the Crab, and the Sun. After the first two years of the \textit{Fermi} mission, the Earth
The GBM light curve for GX 339-4. The light curve has been binned 5 days per data point. The vertical dashed lines at MJD 55244 and MJD 55289 mark the flaring region used to derive the average fluxes in Table 1. The fluxes are in Crab units, and the horizontal solid lines mark the zero flux levels.

The occultation technique applied to the GBM CTIME data has been used to detect six persistent sources and two transients at energies above 100 keV with a significance greater than 7σ, demonstrating the capability of GBM to observe and monitor such sources. Two of the sources, the Crab and Cyg X-1, were detected with high significance above 300 keV. About 70% of the sources in the GBM input catalog have been detected at a significance greater than 7σ in the lower energy bands, and these results will be reported in a future publication (C. A. Wilson-Hodge et al. 2011, in preparation).

Light curves of all eight sources were presented in four broad energy bands from 12–500 keV. The outbursts from the transient sources XTE J1752−223 and GX 339-4 were clearly visible in the 12–50 keV, 50–100 keV, and 100–300 keV broad bands. XTE J1752−223 was a previously unknown source, and the GBM light curves in the hard X-ray/low-energy gamma-ray energy bands are consistent with the initial classification of this object as a black hole candidate in a bright low/hard state. The steep decline of the hard X-ray emission starting around MJD 55215 corresponded to an increase in the soft X-ray flux (Homan 2010; Negoro et al. 2010a), indicating the transition from the low/hard state to a soft state. When XTE J1752−223 returned to the low/hard state around MJD 55282 (Muñoz-Darias et al. 2010a), the hard X-ray emission was below the sensitivity limit of GBM.

The hard emission seen from GX 339-4 is consistent with the bright hard states seen in previous outbursts from this object.

Monitoring of Cyg X-1 at the onset of a recent state transition showed a steady decrease in the 100–300 keV flux that began about 19 days before the soft X-ray flux began to rise. As of MJD 55419, Cyg X-1 remains in a soft state, and we will continue to monitor Cyg X-1 in anticipation of the transition back to the canonical hard state.

While the GBM CTIME data used here do not have enough spectral resolution to produce detailed spectra, the flux ratios between the 12–50 keV broad band and the 50–100, 100–300, and 300–500 keV broad bands for the Crab are generally consistent with those inferred from the measured INTEGRAL spectrum, although the GBM values are more consistent with a slightly harder spectrum above 100 keV. The flux ratios observed for the transient sources XTE J1752−223 and GX 339-4 are similar to Cyg X-1 when it is in its canonical low/hard state, again consistent with these transients being observed in bright low/hard states. Future work will use the GBM CSPEC data, with its 128 energy channels, to examine the detailed spectra for all of these sources, with particular emphasis on the low-energy gamma-ray energy range. Also, the BGO detectors, with their greater sensitivity at higher energies, will be used to obtain additional measurements at energies above 150 keV. Several of the detected sources have spectral breaks or cutoffs in the 100–300 keV range, and we will look for these features and monitor their evolution over time.

We will continue to add to the list of sources being monitored as appropriate. We have detected Cen A with GBM in all energy bands up to 300 keV. BATSE detected several BL Lac objects known to exhibit flaring activity on the timescale of days (Connaughton et al. 1999). The flaring behavior of blazars is sometimes accompanied by a shift upward in the peak of the synchrotron spectrum (e.g., above 100 keV in the 1997 Mrk 501 flare [Petry et al. 2000]), making detection of these sources possible with GBM. Our next iteration of the occultation catalog will include flaring AGNs detected with the Fermi LAT. Additional studies will include other AGNs as well.

We continue to fine tune the algorithms and work to reduce the systematic errors in the flux determination. In the case of the BATSE Earth occultation analysis, there was clear evidence for the presence of sources in the data which were not in the occultation input catalog and which caused uncertainty in the assignment of fluxes to the sources that were in the input catalog. We see similar evidence for these uncataloged sources with GBM, especially below about 50 keV. To address this, our approach is twofold: (1) We compare our GBM measurements with overlapping energy bands from other operating missions and regularly update our catalog as new transient outbursts are observed with GBM or other instruments. Light curves are regenerated if needed after catalog updates. (2) We are developing an imaging technique for GBM to produce an all-sky map of hard X-ray/soft gamma-ray sources. This map will then be used to identify sources not currently in the GBM occultation catalog, to expand the catalog, and to reduce the uncertainties in the measured fluxes.

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