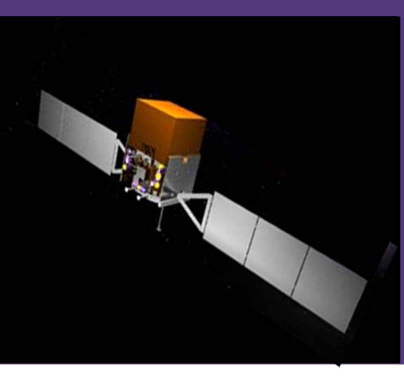
GBM Monitoring of Cyg X-1 During the Recent State Transition



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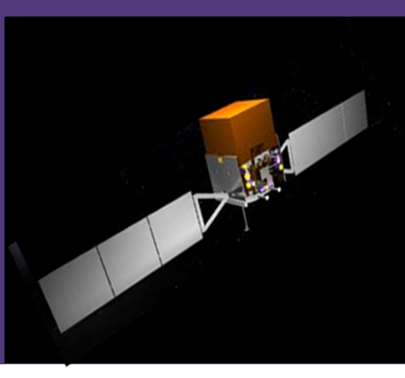

Summary

GBM has been monitoring Cyg X-1 using the Earth occultation technique during its recent state transition. Preliminary light curves and spectra are shown.

Abstract

Cygnus X-1 is a high-mass x-ray binary with a black hole compact object. It is normally extremely bright in hard x-rays and low energy gamma rays and resides in the canonical hard spectral state. Recently, however, Cyg X-1 made a transition to the canonical soft state, with a rise in the soft x-ray flux and a decrease in the flux in the hard x-ray and low energy gamma-ray energy bands. We have been using the Gamma-Ray Burst Monitor on Fermi to monitor the fluxes of a number of sources in the 8-1000 keV energy range, including Cyg X-1. We present light curves of Cyg X-1 showing the flux decrease in hard x-ray and low energy gamma-ray energy bands during the state transition as well as the several long flares observed in these higher energies during the soft state. We also present preliminary spectra from GBM for the pre-transition state, showing the spectral evolution to the soft state, and the post-transition state.

Earth Occultation with GBM

The Gamma-ray Burst Monitor is the secondary instrument onboard the *Fermi* satellite. It consists of 12 NaI detectors 5" in diameter by 0.5" thick mounted on the corners of the spacecraft and oriented such that they view the entire sky not occulted by the Earth. GBM also contains 2 BGO detectors 5" in diameter by 5" thick located on opposite sides of the spacecraft. None of the GBM detectors have direct imaging capability.

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). When a source of gamma rays is occulted by the Earth, the count rate measured by the 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. These steps are fit to a model incorporating the atmospheric attenuation and the changing instrument response, along with a quadratic background, to determine the detector count rate due to a particular source. Up to 31 steps are possible for a given source in a day, and these steps are summed to get a single daily average flux. The technique and initial results are given in Wilson-Hodge et al. (2009) and Case et al. (2011).

The light curves are generated using the GBM CTIME data, with its 8 broad energy channels. The spectra are produced using the GBM CSPEC data, with its 128 energy channels, binned up into 16 energy bands from 10-400 keV. Because our occultation fitting code currently is limited to 8 energy channels at a time, the 16 bin are broken into 2 pieces with separate PHA files generated for the low energy and high energy sections. Both data sets are then fit jointly in XSPEC.

Light Curves

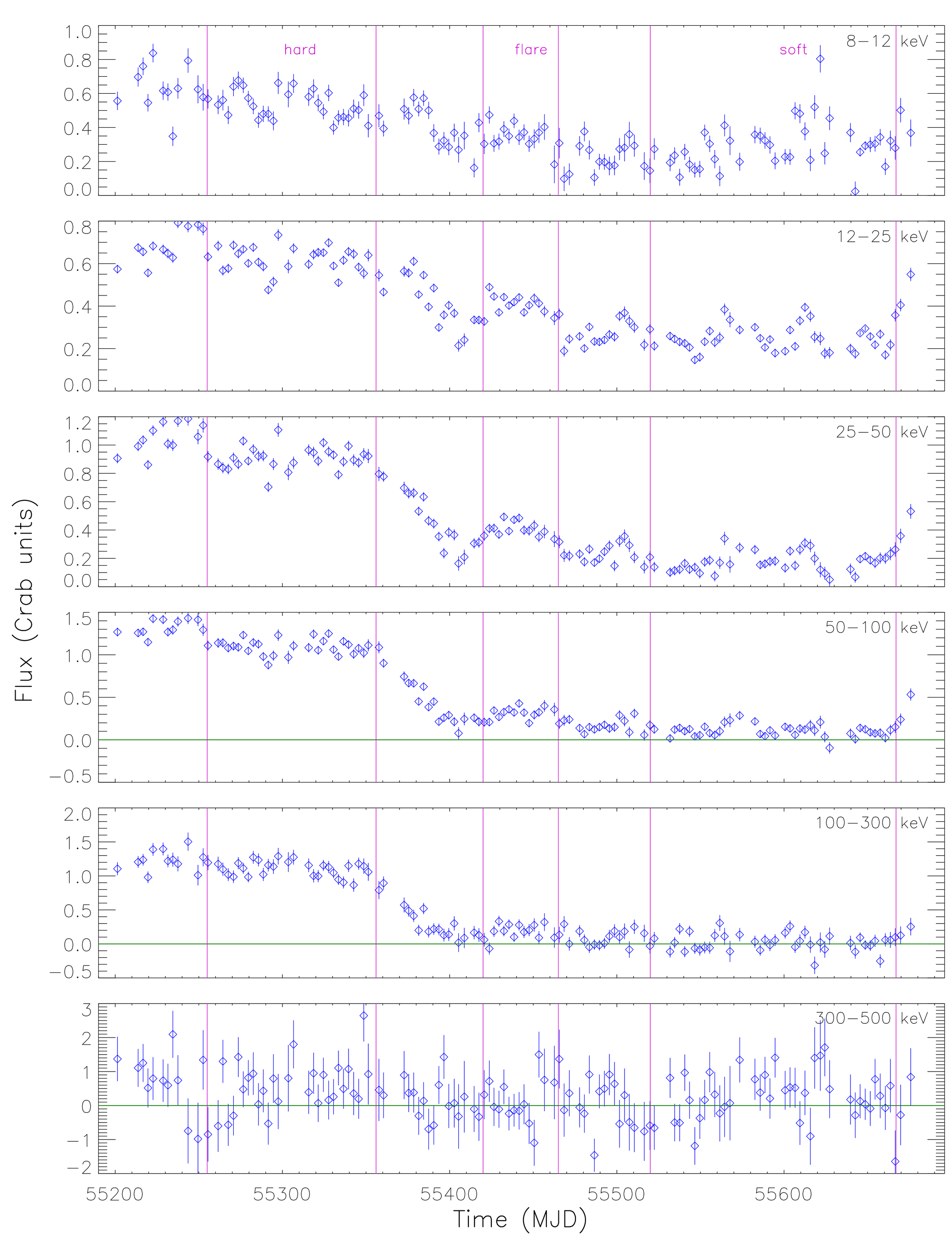

Figure 1: GBM light curves in 6 of the broad CTIME energy bands for Cyg X-1. The data is binned 3 days per data point. The decline was steeper and began sooner for the higher energies. The regions from which spectra were obtained are marked in pink (see Figure 3).

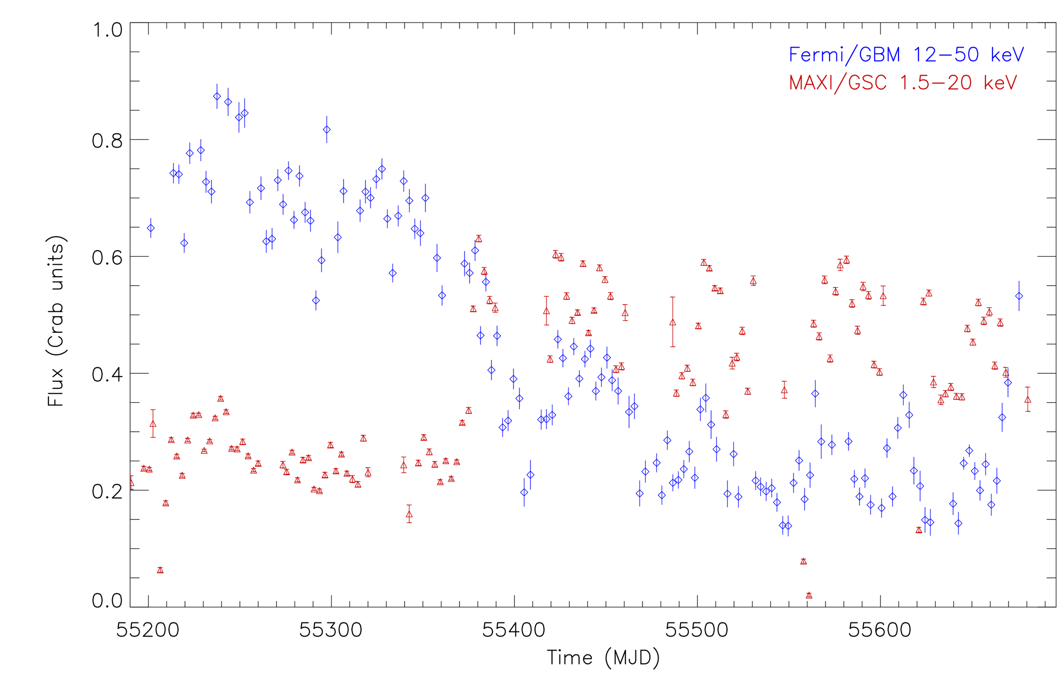

Figure 2: GBM (red) and MAXI/GSC (blue) light curves for Cyg X-1 showing the typical anti-correlation between the soft and hard x-rays as the system transitioned from the hard state to the soft state. The data is binned 3 days per data point.

GBM has been monitoring Cyg X-1 since the beginning of the Fermi mission (MJD 54690). Cyg X-1 had been in the canonical hard state until a hard-to-soft transition began at the beginning of July, 2010 (Negoro et al. 2010; Wilson-Hodge & Case 2010). Figure 1 shows the light curves with 3-day averages for GBM occultation data in 6 broad energy bands from 8-500 keV starting about 150 days before the transition. The transition in the 100-300 keV band appears to begin several days earlier than in the 12-25 keV band, and the initial decline is much steeper in the 100-300 keV band (drops by a factor of ~8) than in the 12-25 keV band (drops by a factor of ~2). Figure 2 shows the MAXI/GSC 1.5-20 keV light curve (also binned 3 days per data point) overlaid on the GBM 12-50 keV broad band light curve showing the typical anti-correlation between the soft and hard x-rays, though once the transition to the soft state was completed, flares are seen together in both the soft x-ray and hard x-ray bands. The decline in the 12-50 keV band appears to lead the decline in the 1.5-20 keV band by a few days. Note that Cyg X-1 currently appears to be making the transition back to the hard state (Grinberg et al. 2011). Unfortunately, Cyg X-1 is not visible to MAXI right now, and MAXI may miss most of the transition back to the hard state.

Spectra

The GBM CSPEC data have been used to generate the count rates for Cyg X-1 in 16 energy bins from 10-400 keV, from which preliminary spectra have been extracted. The average spectrum for the hard state is obtained from the sum of the data from MJD 55253-55357 and is plotted in Fig 3a. Only the 4 detectors with the largest exposure and detector angles <60º are plotted. Following Cadolle Bel et al. (2006), the data are fit to an absorbed Comptonization model with reflection (`wabs (reflect * compTT)` in XSPEC notation). The column density is frozen at $N_H = 0.6 \times 10^{22}$, kT_0 frozen at 0.2 keV, and the inclination angle is fixed at 45º. The fit results are shown in Table 1. The temperature of the Compton cloud and optical depth are slightly lower than, and the reflection component similar to, that reported by INTEGRAL for observations from 2002-2004 (Cadolle Bel et al. 2006). Fitting the GBM data to an absorbed cutoff power law gives essentially the same (but slightly higher) χ^2, with a hard power law index of 1.2 ± 0.02.

The average spectrum in the soft state is shown in Fig. 3b. There are not enough counts in the high energy bins to constrain the Comptonization model, so an absorbed cutoff power law model was used. The fit results are shown in Table 1. All 4 of the NaI detectors that viewed Cyg X-1 with a detector angle <40º are shown.

After the initial decline in the light curve, there was a broad flare lasting ~45 days, with the flare visible in the MAXI soft x-ray band in addition to the GBM bands. The average spectrum is shown in Fig. 3c. Only the 4 detectors with the largest exposure and detector angles <60º are shown. As with the soft state, the Comptonization model is not well constrained, so the spectrum is again fit to an absorbed cutoff power law model. As can be seen in Table 1, the photon index is flatter than that of the soft state, while the cutoff energy is the same as in the soft state, suggesting that the system was in a state intermediate between the hard and soft state.

Hard State – NaI 3,4,7,8

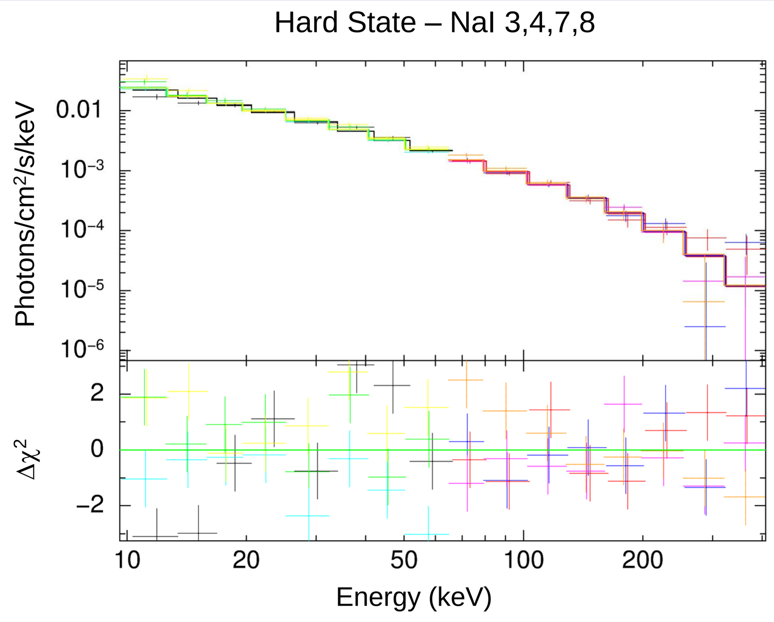

Figure 3a

Soft State – NaI 1,2,4,5

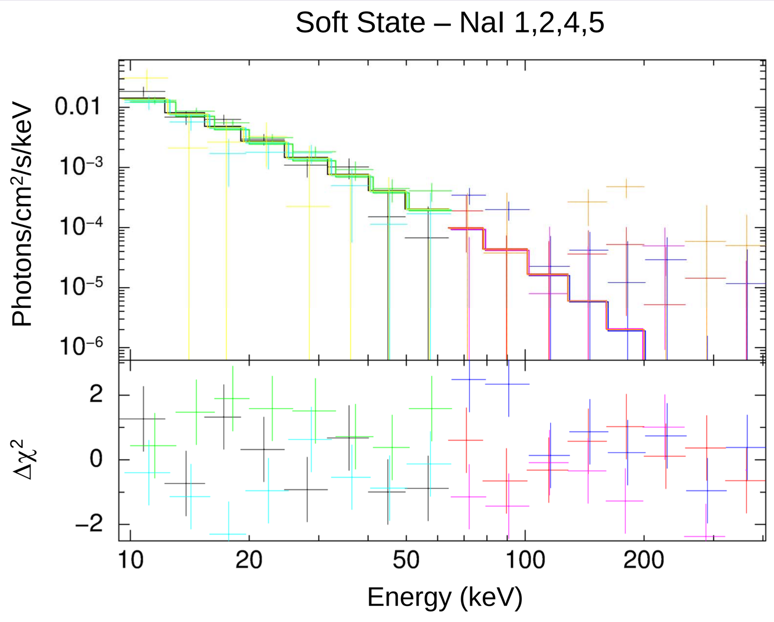

Figure 3b

Table 1

Hard state		Soft state		Flare	
N_H (x10^{22})	0.6 (frozen)	N_H (x10^{22})	0.6 (frozen)	N_H (x10^{22})	0.6 (frozen)
kT_0 (keV)	0.2 (frozen)	α	2.0 ± 0.3	α	1.6 ± 0.1
kT (keV)	47.9 ± 2.6	E_c	53 ± 31	E_c	63 ± 10
τ	1.48 ± 0.07	Norm	2.2 ± 1.5	Norm	1.2 ± 0.2
$\Omega/2\pi$	0.33 ± 0.04	χ^2_ν/ν	1.05/589	χ^2_ν/ν	1.10/957
Norm	0.055 ± 0.004				
χ^2_ν/ν	1.74/2524				

Flare – NaI 8,9,10,11

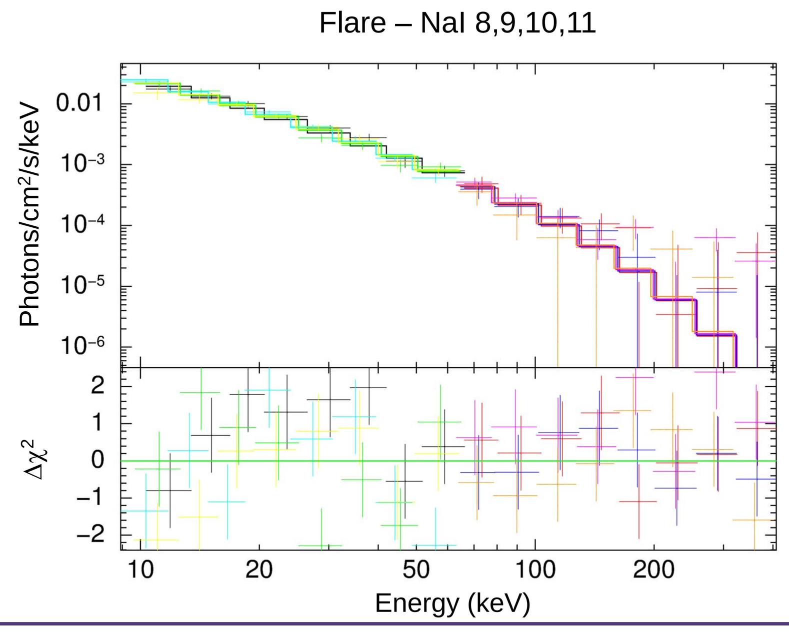

Figure 3c

Summary and Future Work

GBM has been monitoring Cyg X-1 for the last ~2.5 years using the Earth Occultation Technique. Cyg X-1 had been in the canonical hard state until July 2010, when it underwent a transition to the soft state. The GBM light curves suggest that the decline in the higher energies led the decline in the lower energies by several days, and that the declines were steeper in the higher energy bands.

Preliminary spectra have been generated using the GBM CSPEC data. The hard state spectrum is similar to that measured during previous Cyg X-1 hard states. The spectrum around the peak of the first flare after the transition suggests that Cyg X-1 was in an intermediate state before dropping back into the soft state.

Cyg X-1 is apparently making the transition back to the hard state, and we will continue to monitor it, as well as other black hole candidates, for future outbursts and/or state transitions.

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