Long-term Observations of Her X-1 with BATSE

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Abstract. Pulsed emission from Her X-1 has been observed by BATSE during each Main High state throughout the CGRO mission. This long observation set by a single instrument provides new information on long-term behavior of the Her X-1 system. The pulsed emission varies by more than a factor of 3 between different Main High states. Frequency and flux histories do not show a simple relationship between the source intensity and spin behavior, but do show that the source is normally in spinup, and spindown episodes occur at all source flux levels. Orbital analyses are presented, including determination of the orbital period derivative, which is in agreement with Deeter et al. (1991).

INTRODUCTION

The low-mass x-ray binary system Her X-1 has been observed frequently by many observers since its discovery in 1971 [3]. Except during the extended observations of previous all-sky monitors (*UHURU, Ariel 5, HEAO A-4*), determination of pulse frequency and source luminosity were not sufficently frequent to fully characterize the behavior of the source. The typical 20 – 50 keV source flux observed by BATSE is ~130 mCrab, sufficient to obtain high quality pulse profiles (Figure 1) and intensity measurements (Figure 2). With 6 years of BATSE observations in hand we can better determine normal and anomalous behavior of this source. The source is known to undergo large variations in peak flux in the Main High state - it was in an extended low state during part of 1983 [2,4]. BATSE has observed large (factor of ~3) changes in Main High peak source flux in 20 - 50 keV during the mission.

Her X-1 has been observed to mostly spin up between consecutive Main High states. Previous measurements with pointed instruments were too sparse to characterize the occurrence rate of spindown episodes, which were first observed by *UHURU*. We find that spindown episodes with $\dot{\nu}$ greater than 0.2 $pHz \cdot s^{-1}$ in magnitude (as measured by shifts in pulse frequency between Main High states) have occurred at least 5 times since April 1991 and are

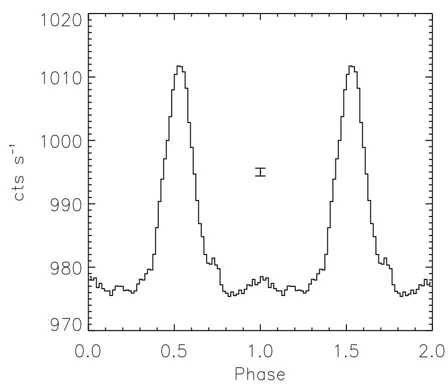

FIGURE 1. Pulse profile for Her X-1 for TJD 9586 - 9593. The counting rate is the sum of background and source contributions. A typical $\pm 1\sigma$ uncertainty is shown at phase 1.0

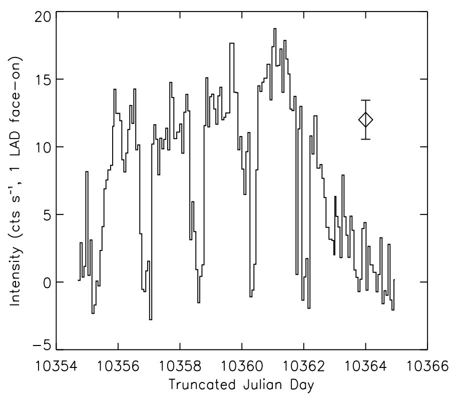

FIGURE 2. Aspect-corrected pulsed intensity history for the Main High state on TJD 10354-10364. A typical $\pm 1\sigma$ uncertainty is shown at TJD 10364.

not confined to times of low source flux. Using data available through 1989, Deeter et al. (1991) found that the orbital period of Her X-1 was decreasing at a rate of $(2.25 \pm 0.27) \cdot 10^{-8} days \cdot yr^{-1}$. BATSE observations (combined with the previous data) give the value shown in Table 1, which has an improved uncertainty, and is consistent with [1].

OBSERVATIONS

For detailed studies of Her X-1 with BATSE folded-on-board data is required. These observations are normally scheduled only during the Main High portions of the 35 day cycle, and consist of 8 - 16 s readouts of epoch-folded 16-energy-channel count-rate histograms (with 64 phase-bin resolution) of selected detectors which view the source direction. Substantial data coverage exists for about 80% of the Main High states since *CGRO* became operational. All states have been observed using the aliased signal of the source using the DISCLA 1.024 s data type.

ANALYSES

Orbital Determination

All data collected during one *CGRO* orbit are barycentered and epoch-folded to produce one pulse profile. In the Fourier domain a best-fit correlation

TABLE 1. Orbital Parameters for Her X-1

$T_{\pi/2}$	JD 2449420.6734653(45)
P_{orb}	1.7001674461(96) $days$
$a_x sin(i)$	13.18549(32) s
$\dot{P}_{orb}$	-1.80(08)$\cdot 10^{-8}$ $days \cdot yr^{-1}$

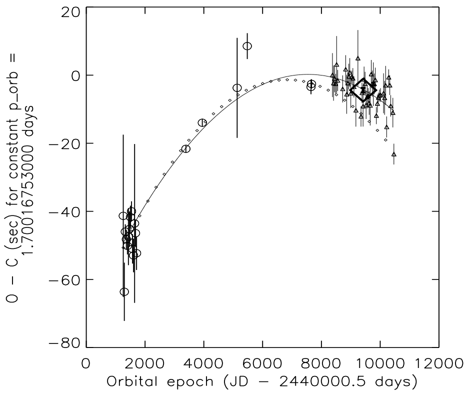

FIGURE 3. Observed minus computed epochs ($T_{\pi/2}$), relative to a constant orbital period model. The solid curve is the best quadratic fit, using all data. The large diamond is the mean BATSE epoch. The dashed curve is a fit excluding the BATSE data.

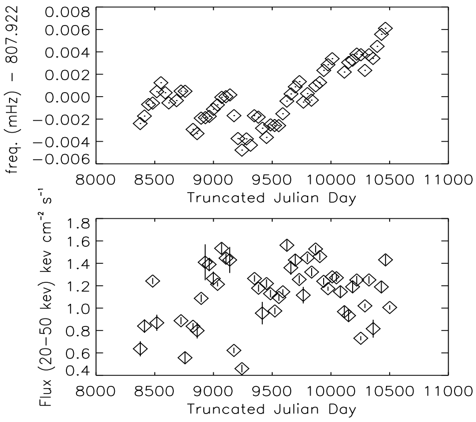

FIGURE 4. History of pulse frequency and Main High peak pulsed flux over the CGRO mission. Flux measurements cannot be made for all intervals, either due to lack of suitable scheduled data or low source intensity.

with a master pulse template is obtained, giving a phase and amplitude. For each Main High interval a χ^2 minimization fit to the pulse phases is performed, with free parameters $T_{\pi/2}, a_x sin(i)$, and the pulse frequency and frequency derivative. The fit was then repeated with $a_x sin(i)$ held constant at the mean of the Main High values, to obtain a separate determination of orbital epoch for each Main High state. The mean $T_{\pi/2}$ and P_{orb} were found by a fit to the orbital epochs. The values obtained are shown in Table 1.

Using the same procedure as Deeter et al. (1991), residual orbital epochs have been compared to expected values for a constant orbital period. Historical and BATSE data are shown in Figure 3. The period is not consistent with a constant value, as also found by Deeter et al. (1991). Fitting the residuals to a quadratic, a value is obtained for $\dot{P}_{orb}$, as shown in Table 1. The fit is not formally satisfactory, with a reduced χ^2 value of about 2 for either the historical data alone, or all of the data. The value we obtain has a smaller uncertainty than [1], and is in agreement with that measurement.

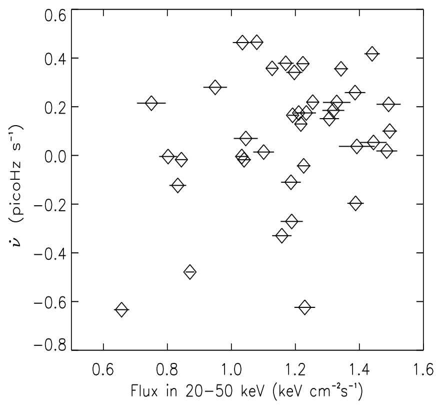

FIGURE 5. Scatterplot of peak Main High flux versus mean frequency derivative (defined as the frequency difference between successive Main High states).

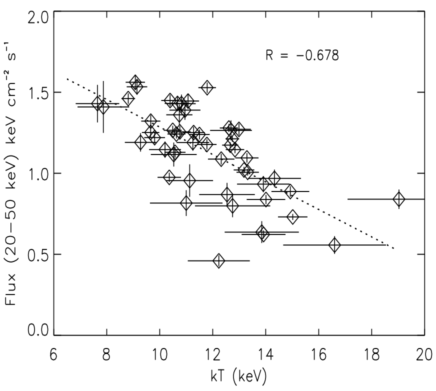

FIGURE 6. Scatterplot of measured flux versus modeled kT, using an optically thin thermal bremstrahlung model. Values are from the *peaks* of each measureable Main High state.

Flux & Pulsar Spin Behavior

Using an on-pulse/offpulse analysis, optically thin thermal bremsstrahlung fits have been made to the average source counting rate over each Her X-1 orbit, excluding eclipse intervals and the prior 0.5 d intervals, to exclude pre-eclipse dips. The intervals at the peak intensity of each Main High state are selected and plotted in Figure 4, lower panel. The pulse frequencies obtained above are shown in the upper panel. Although in [5] we found a correlation between times of spindown and low source flux, that trend has not continued. As shown in Figure 5 there are times of spindown even when the source 20 – 50 keV flux is greater than 1.2 $keVcm^{-2}s^{-1}$. The system spins up between $\sim 75\%$ of the states measured, with the other cases evenly distributed relative to flux level when spindown occurs. Both spinup and spindown are observed at times of low flux.

We note a correlation of the measured flux versus the modeled kT value as shown in Figure 6. These are data selected only from the peaks of each Main High state. The increasing hardness at low flux levels is what would be expected if absorption by varying amounts of obscuring or scattering material was the cause of the flux variations between Main High states. The trend shown here is *not* shown during the traversal of any particular Main High state, as shown in Figure 7. If absorption and/or scattering is the cause of this effect, it is not due to the same material which controls the onset and end of each Main High envelope.

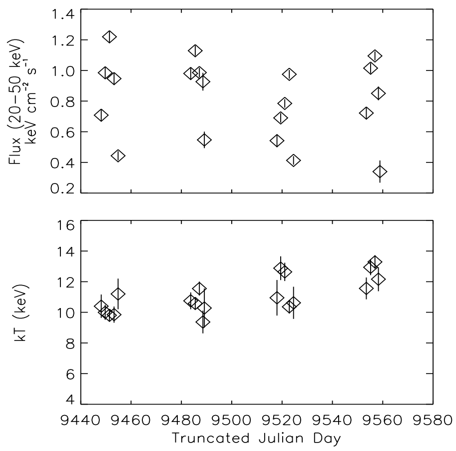

FIGURE 7. Flux and kT history for entire Main High states during TJD 9440 - 9580. Each flux point is averaged over 1 orbit of the system, excluding eclipse intervals, and the 0.5 day interval prior to the eclipse when pre-eclipse dips may occur.

DISCUSSION

The period derivative of Her X-1 is consistent with a constant value using all of the available observations, but with reduced χ^2 values of about 2, suggesting that the mass loss (and angular momentum loss) from the system may be variable on timescales we cannot measure.

There is not a simple relation between the brightness of a Main High state and the neutron star spin behavior, indicating that the hard x-ray flux is *not* simply related to the mass accretion rate. If we are viewing the source through obscuring material even at the peak of the Main High state, we would not observe a simple correlation of flux and spinup rate. It is also possible that variations in the source spectrum may alter the hard x-ray flux even for nearly constant mass accretion rate. Changes of the mass accretion rate on timescales less than 35 d also could explain these observations.

REFERENCES

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