Observations of Pulse Evolution in Her X-1

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Abstract. We present recent *RXTE* observations of pulse evolution in Her X-1 and compare the evolution pattern to that observed earlier with *Ginga*, *HEAO 1* and *Uhuru*. The pulse profile evolves continuously during the $\sim$ 5-day long Short High state of the 35-day cycle and shows dramatic and systematic changes near the end of the $\sim$ 10-day long Main High state.

INTRODUCTION

Her X-1/HZ Her is a unique accretion-powered pulsar system exhibiting a great wealth of phenomena. This eclipsing system contains a 1.24 second period pulsar in a 1.7 day circular orbit with its optical companion HZ Her. In addition, the system displays a longer 35-day cycle that was first discovered as a repeating pattern of High and Low X-ray flux states. A Main High and Short High state, lasting about ten and five days each, respectively occur once per 35-day cycle and are separated by ten day long Low states. X-ray pulsations are visible during the HIGH states but cease during the Low states. The pulse profile exhibits significant and systematic changes during each type of High state. We present detailed observations of the profile changes including the most complete view of the Short High pulse evolution to date.

OBSERVATIONS

The *RXTE* 2-60 keV lightcurve for Her X-1 is displayed in figure 1 showing a consecutive Short-Main High sequence from September-October 1996. No background subtraction has been applied. Simultaneous *BATSE* observations of the 20-70 keV pulsed emission during the Main High are shown in the bottom panel. Note the rapid drop in the hard X-ray pulsed emission near 35-day phase 0.2 while the total flux decreases much more slowly. A time sequence of average pulse profiles in the energy band 2-60 keV is displayed in figure 2. The pulses were formed by folding the Standard 1 data (0.125 sec time resolution) over spans of 1000-2500 seconds. The Main High folding period was determined from *BATSE* monitoring and the Short High was folded using an average period from adjacent Main Highs. Arrival times were converted to the solar system barycenter and then corrected to the neutron star by removing the light travel time delay across the binary orbit prior to folding. Some phase drift is apparent in the Short High pulses showing that a refined period can be achieved. The relative phase alignment of all displayed Main and Short High pulses has been determined from pulse phase ephemeris extrapolations [1].

A 2-37 keV lightcurve for Her X-1 from *Ginga* observations is displayed in figure 3 showing a consecutive Main-Short High state sequence from April-May 1989. Background and aspect corrections have been applied. A time sequence of pulse profiles in 1.0-4.6 keV and 9.3-14 keV energy bands are shown in figure 4. The insets on the first panel display the 35-day phase (with $P_{35} = 20.5 P_{orb}$ for all figures). The last four pulses of the Main High occupy a span of only 6.7 hours. The *Ginga* observations are described in [1, 2].

Figure 5 shows a sequence of *Uhuru* pulses from [3] from a single Main High. Each pulse is folded from data during a single orbit of Her X-1 denoted by the number in the inset. The second column shows a sequence of *HEAO 1* pulses from [4] with 35-day phase shown in the inset.

PHENOMENOLOGY OF THE PULSE EVOLUTION

Inspection of the figures reveals a pulse evolution pattern that is systematic across both High state types and has been remarkably stable in form over many years of observation. Most profile changes during the Main High occur during the last few days when the flux is declining significantly whereas the profile changes most rapidly near the beginning of the Short High. Smaller random profile changes are sometimes observed that may be related to accretion rate variations.

The first major change in the Main High pulse profile is a deepening near pulse phase 0.25 that starts within the first few days after Turn-On. Otherwise the profile is quite constant in shape for roughly seven days and then the main pulse and interpulse both begin to decay away preferentially on their leading edges at a rate which accelerates during the Main High flux decline. In both *RXTE* and *Ginga* observations rapid changes in the profile occured on timescales of a few hours. Finally a quasisinusoidal profile is left which then disappears after another day or so.

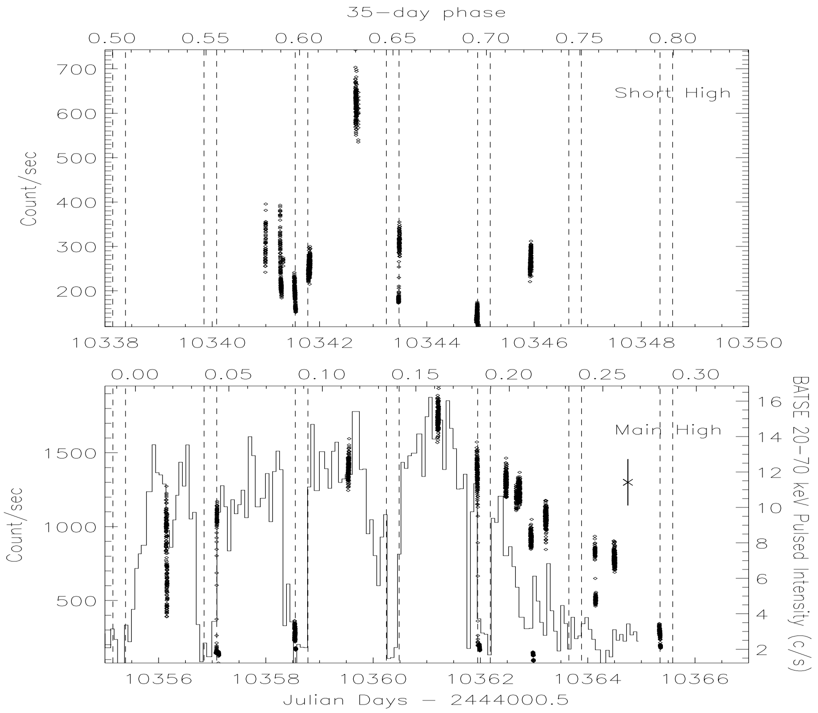

FIGURE 1. The 2-60 keV lightcurve of Her X-1 observed with *RXTE* (diamonds). Eclipse interval marked by dashed lines. *BATSE* pulsed emission lightcurve shown at bottom (histogram) with typical error bar on right.

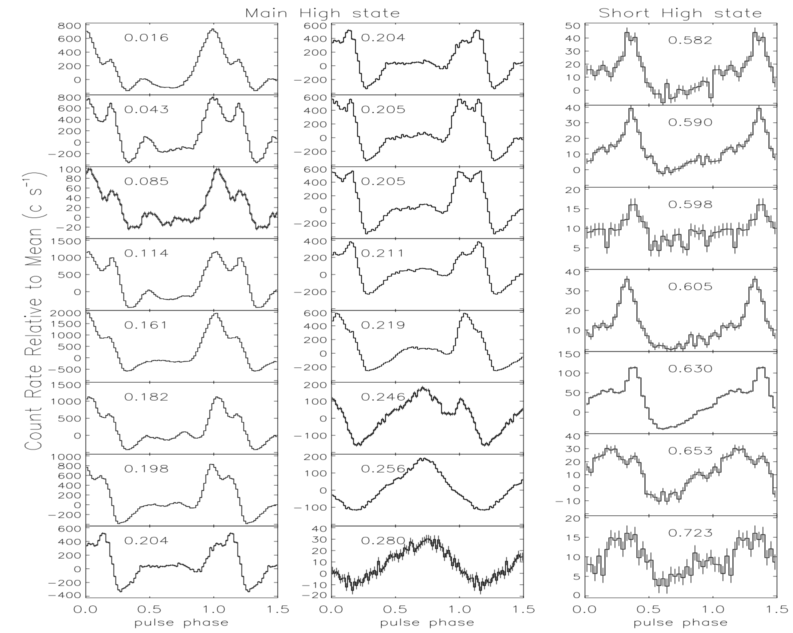

FIGURE 2. *RXTE* observation of pulse evolution in Her X-1 (2-60 keV). The 35-day phase is shown in the inset.

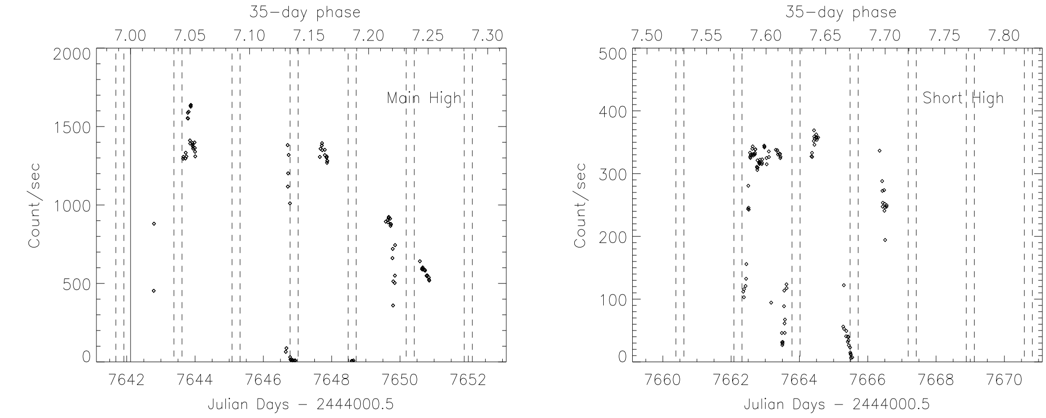

FIGURE 3. The 2-37 keV lightcurve observed with *Ginga*. Eclipse interval marked by dashed lines.

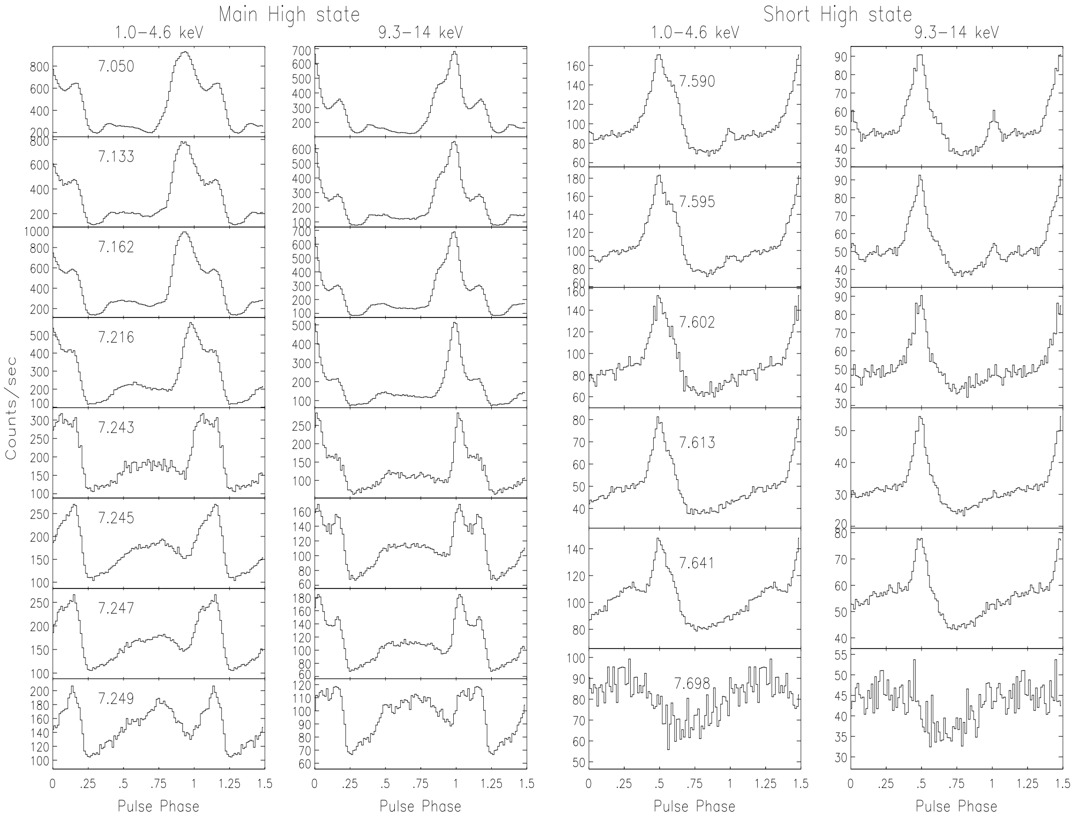

FIGURE 4. *Ginga* observation of pulse evolution in Her X-1 in two energy channels. The 35-day phase is shown in the inset.

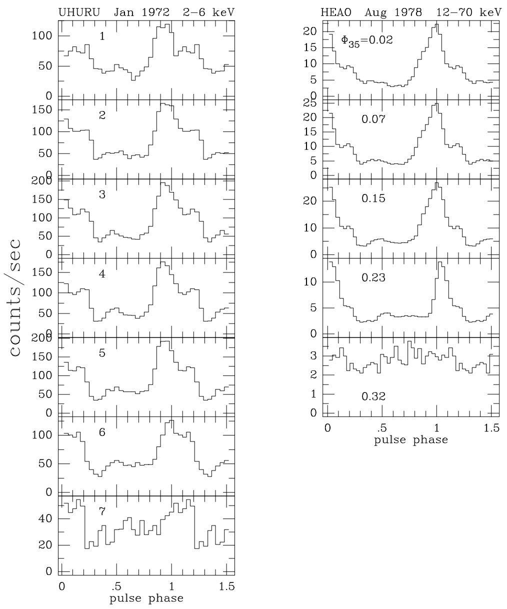

FIGURE 5. *Uhuru* and *HEAO 1* observations of Main High pulse evolution.

The Short High pulse profile initially appears with either one or two peaks. A larger, softer peak near phase 0.5 is always present that corresponds to the interpulse in the Main High pulse. A second harder peak appears at phase 0.0 in the *Ginga* but not the *RXTE* Short High observations. An earlier *Exosat* observation also showed the second harder peak which was initially larger than the softer peak[6]. In both the *Ginga* and *Exosat* observations the hard peak decayed away in the less than one day leaving only the softer peak. The softer peak takes 3-4 days to decay away and apparently narrows in the process, finally leaving only the underlying quasisinusoidal profile.

The Short High quasisinusoidal profile has about 50% the flux of the Main High quasisinusoid and is shifted in phase by 0.5.

The persistant, systematic and apparently repeating evolution of the pulse profile in Her X-1 is a unique phenemonena among the accretion powered pulsars. Some pulsars, such as EXO 2030+375, have shown systematic pulse profile changes, but these have all been associated with transient changes in the X-ray luminosity. The Her X-1 profile evolution is clearly a different type of phenomena and may play a key role in furthering our understanding of the pulse emission process.

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