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RXTE Observations of Her X-1

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Results of two observations (1996 July and 1997 September) of the binary pulsar Her X-1 by the Rossi X-Ray Timing Explorer (RXTE) are presented. We discuss the energy spectra at energies 3–20 keV as measured by the PCA. The data can be described by the sum of two power laws, one of which is modified by absorption in cold material, plus an Iron emission line. In this poster we discuss spectra and color/color diagrams for a pre-eclipse dip observed in 1996 July and we present preliminary results for the 1997 September observation of the 35 day Turn-On.

1. INTRODUCTION

The X-ray binary Her X-1 shows strong variability on several time scales. There are the 1.24 sec spin period of the neutron star, the 1.7 day binary period (resulting in periodic X-ray eclipses and sinusoidally variable pulse arrival times), the 35 d long term variability, and the 1.65 d period of the pre-eclipse dips (Giacconi et al., 1973; Crosa & Boynton, 1980). The 35 day period can be understood as the precession period of a warped accretion disk in the tidal field of the companion. Because the observer sees the disk nearly edge-on, the precessing disk covers the central X-ray source during a substantial portion of the 35 day period. The end of the covering is the "Turn-on" of the main-on state. In addition, a hot X-ray induced accretion disk corona reduces the X-ray signal (energy independently) by Thomson scattering whenever it intercepts the line of sight to the neutron star. As a result the X-ray source is covered twice during a 35 day cycle, once by the accretion disk, and later by the optically thick corona.

2. DIPS

"Dips" are periods of time where the X-ray flux is substantially reduced, but not down to zero (as in eclipses). "Pre-eclipse dips" happen just before eclipses, at binary phases $\sim$ 0.8, while "anomalous dips" happen around binary phase $\sim$ 0.6 (Schandl, 1996; Giacconi et al., 1973). The interpretation of the dips is that cold material intercepting the line of sight absorbs the radiation from the central X-ray source. This is clearly seen when spectra are taken and the column density is determined: $N_{\rm H}$ values of up to a few times $10^{24}\,{\rm cm}^{-2}$ are found. In addition, a non-absorbed component (due to a source coverage of less than 100%) and a reduced, but otherwise unmodified, spectral component are often required (Leahy, 1997; Reynolds & Parmar, 1995; Choi et al., 1994, and references therein). The latter has been modeled either by Thomson scattering or by absorption due to ionized material (Reynolds & Parmar, 1995; Ushimaru et al., 1989).

During a dip, therefore, the spectrum below 20 keV can be described by a partial covering model of the form

$$N_{\rm ph} = N_0 E^{-\alpha} \left(C_1 \exp(-\sigma_{\rm bf} N_{\rm H}) + 1\right) \qquad (1)$$

plus an additional Gaussian emission line at 6.4 keV. The ratio $f = C_1/(1+C_1)$ is a measure of the strength of the absorbed component in the spectrum compared to the total observed flux.

On 1996 July 26 and 27 we observed Her X-1

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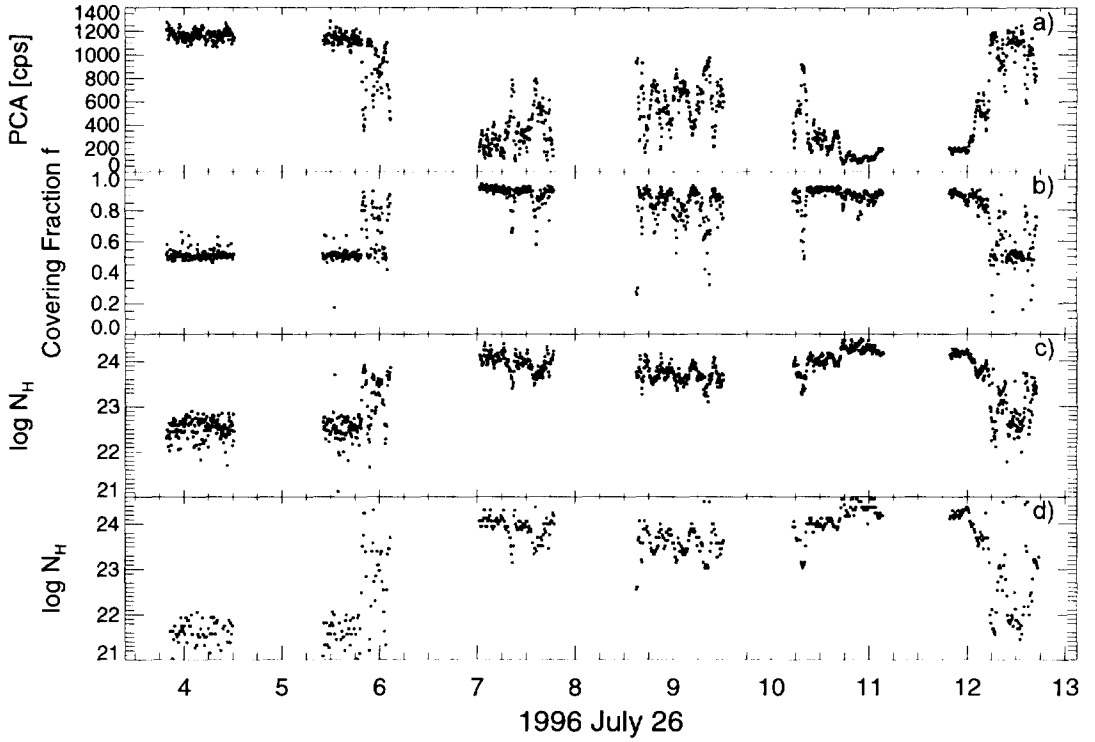

Figure 1. Variation of the PCA count-rate (a), the covering fraction f (b), and the equivalent absorbing column N_H (c,d) for the RXTE observation of 1996 July 26. N_H has been determined both, from spectral fitting (c), and from the color-color diagram(d). The time is in hours from midnight UT, the dip began at 6:00 UT, its end was not seen.

with RXTE for one whole orbit of the neutron star. During this observation, one pre-eclipse dip was seen. In order to understand the spectrum during the dips we extracted individual PCA spectra with a time-resolution of 16 s. We were able to successfully fit these data with the model of eq. (1). The temporal behavior of N_H and of the covering fraction f as well as the observed count-rate are shown in Fig. 1.

Since the uncertainties of the PCA response matrix used for the spectral fitting are especially strong below about 5 keV, i.e. around the Xe L edge, we checked our results with an alternative approach making use of broad band fluxes defined by the following bands:

Band	PCA Channel	Energy [keV]
B0	7–14	3–5
B1	15–18	5–7
B2	19–29	7–11
B3	30–45	11–17

In Fig. 2 three modified color-color diagrams obtained from the data are shown. Due to the E^{-3} proportionality of the absorption cross-section, for low values of N_H only the lower bands are influenced by the absorbing material, while for high values of N_H all bands are influenced. This results in a characteristically curved track in the diagram. Theoretical tracks exhibiting this behavior are shown in Fig. 2(d), where tracks for spectral models with and without a non-absorbed spectral

component are shown. The theoretical track including a non-absorbed spectral component turns at a much smaller N_H compared to the track without the non-absorbed component. Therefore, the hardness-ratios of Fig. 2(a)–(c) show clear evidence for the presence of a non-absorbed spectral component during the dips.

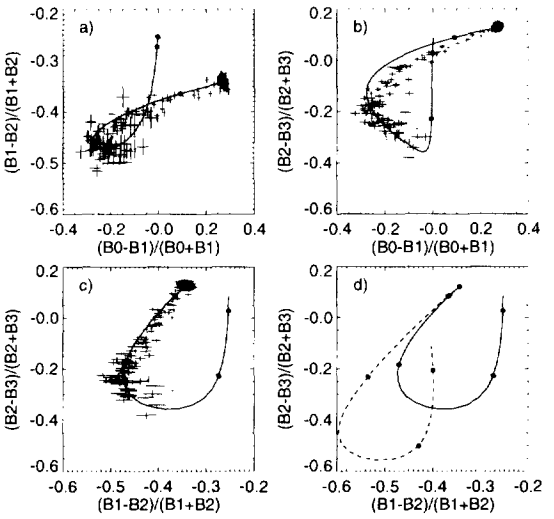

Figure 2. (a)–(c) Modified color-color diagrams and best fit models for the beginning of the dip of Fig. 1. The "blob" in the upper right corner is the non-dip color. (d) Theoretical track for the model parameters of Fig. (c), illustrating the influence of the non-absorbed component (dashed). The dots on the theoretical curves mark the N_H values of 10^{22}, 10^{23}, 10^{24}, 5×10^{24}, and $10^{25}\,cm^{-2}$. See text for further explanation.

By varying the contribution f of the absorbed spectral component to the total spectrum it is possible to fit the theoretical tracks in the diagram to the measured data, minimizing the rms distance between the track and the data. It is then possible to find N_H as a function of time by projecting the measured colors onto the track. Figs. 2(a)–(c) show the best-fit track-model. Although there are discrepancies between the model and the data, the general agreement of the two is good within the dip (evidently, the color-color diagram is insensitive to low values of N_H). The variation of N_H as a function of time found from the color-color diagram agrees with the variation found by fitting (Fig. 1).

3. THE TURN-ON

Her X-1 was observed by RXTE essentially continuously for two days on 1997 September 13/14. The aim of this proposal was to study the 35 day turn-on of Her X-1 with high temporal resolution. Observations of this kind had been done in the early 70s by UHURU and OSO-8, but not with modern X-ray instrumentation.

Fig. 3 shows the RXTE/PCA count rate of the entire observation, together with the lightcurves measured by the RXTE/ASM (public archive) and by CGRO/BATSE (Scott 1997, priv. comm.). The regular gaps are due to Earth occultations. The source flux keeps increasing over the entire observation, with interruptions due to an "anomalous dip", a "pre-eclipse dip" and by the binary eclipse. The time of the "turn-on", defined by a level of 20% of the ON-state flux, was found to be at JD 2450704.9, corresponding to a binary phase of 0.34, the anomalous dip happens from binary phase 0.50 to binary phase 0.63, while the ingress into the pre-eclipse dip is at binary phase 0.82 (using the ephemeris of Stelzer et al., 1997).

As a first rough analysis we have produced spectra for selected time intervals. PCA data over 3.5–20 keV were fitted with the spectral function of eq. (1) using the PCA response matrix, version 2.2.1 (Jahoda, 1997, priv. comm.). In Fig. 3(d) the development of the absorbing column over the entire observation is shown: N_H mirrors the behavior of the count-rate, consistent with the interpretation of these events being due to absorption by intervening cold

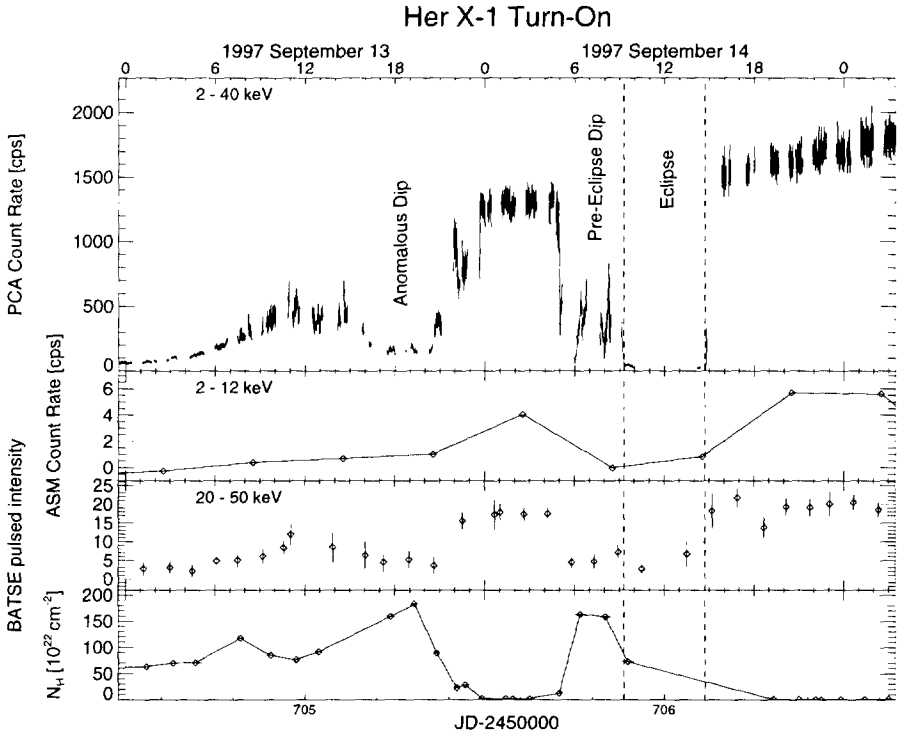

Figure 3. (a)–(c) RXTE/PCA, RXTE/ASM, and CGRO/BATSE count rates of Her X-1 for the time of the 1997 September Turn-on. The beginning and end of the eclipse of Her X-1 are denoted by the dashed line. Error bars for ASM have been omitted for clarity. (d) N_H values determined from the data of panel (a) for the individual orbits of RXTE.

material, except for the first few points for which some other physics, possibly scattering, might have to be invoked.

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