ACCRETION DISK DYNAMICS OF HER X–1

S. D. VRTILEK[1,2], F. H. CHENG[1]
1. University of Maryland, College Park, MD 20742, USA
2. CfA, 60 Garden St., Cambridge, MA 02138, USA

1. Introduction

The Her X–1/HZ Her system consists of a neutron star with a rotation period of 1.24 s orbiting a 'normal' stellar companion every 1.7 d. Variation in optical and ultraviolet magnitude is attributed to X-ray heating on the side facing the active neutron star with some contribution from X-ray heating of the disk. The system also has a 35-day period in which the X-ray emission displays so-called main and short 'on' states separated by relative X-ray quiescence. The 1.7-day optical flux variations continue throughout the 35-day period. No clear consensus exists as to the origin of the 35-day period; a popular interpretation is that of occultation of the compact X-ray source by a tilted, precessing, accretion disk.

Each temporal state has its own distinctive spectral behavior. During the main on state the pulse-averaged spectrum is a flat power law with an excess strong thermal component at low energies (a characteristic of many binary X-ray pulsars). Spectral features are detected at 6.4 keV attributed to Fe K–shell, and between 35...58 keV attributed to electron-cyclotron resonance implying a surface magnetic field of $(2...5)\,10^{12}$ G. The pulse profile changes as a function of energy: the pulse peak shifts in phase by 180° between low and high energies and shows less structure in the low energy band. The spectrum also changes as a function of pulse phase: the soft thermal component and the Fe line flux are strongest during the off-peak of the pulse. This implies that the soft X-rays are likely to be reprocessed hard X-rays and the Fe line emission originates at the reprocessing site.

2. The 1993 multiwavelength campaign

The launch of EUVE opened up a new region of the spectrum that is particularly useful for study of the strong soft component. The unusu-

A. Evans and J. H. Wood (eds.), Cataclysmic Variables and Related Objects, 377–380.

ally high galactic latitude and correspondingly low interstellar absorption ($N_H \sim 10^{20}$ cm^{-2}), towards Her X–1/HZ Her make it the *only* X-ray binary system EUVE is able to study. Observations at other wavelengths are also important since the soft component is likely to be reprocessed radiation; our campaign employed IUE, ROSAT, ASCA, GRO/BATSE, and several ground-based observatories in addition to EUVE.

The campaign was scheduled during the high on state of the 35-day cycle but the X-ray flux observed was a factor of 50 below the expected level (Vrtilek et al. 1994). For the second time in Her X–1's recorded history the system had been caught in a so-called 'anomalous low' state. A substantial, unexpected drop in flux at X-ray energies, with no substantial change in absorbing column density; little or no change in UV and optical fluxes; an increase in pulse period; and no pulsed emission above 1.0 keV are some characteristics of the anomalous low state. With the exception of the increase in pulse period and the degree of X-ray flux reduction these characteristics are similar to those observed during 'normal' 35-day low states. Our observations are particularly exciting because the simultaneous multiwavelength coverage enables us to understand the 'lost' X-ray flux.

The ROSAT pulse profile and energy dependence show the normal main on state behavior during the highest X-ray flux observed (a factor of 2 below the expected): a shift of pulse phase by about 180° at 0.9 keV is clearly detected. The pulse period measured by ROSAT, 1.237749(1) s, shows a sharp increase ($7\,\mu$s) from the previous measurement contrary to the usual spin-up. During the lowest X-ray flux observed neither ROSAT nor ASCA detected pulsed emission above 0.9 keV.

Long term observations of Her X–1 by BATSE suggest that the hard X-ray flux of Her X–1 undergoes episodes of reduction that are correlated with spin-down. The correlation between times of low hard X-ray luminosity and episodes of spin-down are predicted by models such as those of Ghosh & Lamb (1979); an *increase* in mass accretion rate ($\dot{M}$) causes the Alfven radius at which material joins the magnetosphere to move inward, thereby *reducing* the drag-producing torques of the field lines threading the disk outside the corotation radius, leading to spin-up.

3. Modelling of the UV and optical continuum

The model used to fit the IUE data is described in detail by Cheng, Vrtilek & Raymond (1995; 1996). We adopt the system geometry of Howarth & Wilson (1983) where changes in X-ray, UV and optical flux during the 35-day cycle are due to a tilted, precessing, accretion disk. The X-ray heating code is adapted from one used to model the UV flux of low-mass X-ray binaries (LMXBs; Vrtilek et al. 1990). A major difference is that, while the

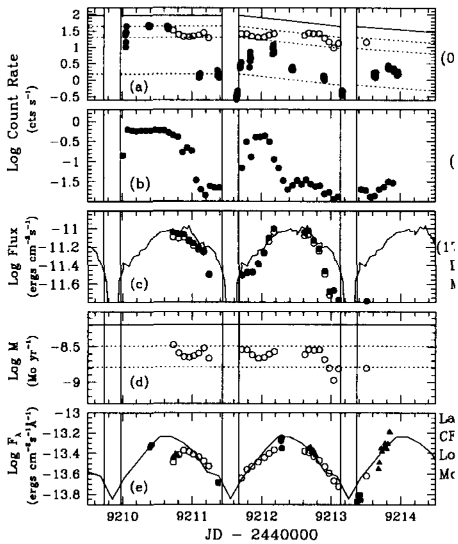

Figure 1. Model with changes in mass accretion rate alone

contribution from the star is negligible in LMXBs, it constitutes 70% of the total flux in UV and optical bands for Her X–1.

We first fit the UV continuum while changing only $\dot{M}$. In Fig. 1 we have plotted the observed (filled circles) and model (open circles) light curves and the $\dot{M}$ values obtained by fits to the IUE data. The solid lines in Figs. 1a,d represent the highest observed X-ray fluxes and mass transfer rates, and in Figs. 1c,e the average of previous observations. The dashed lines in Fig. 1a depict X-ray fluxes at 1/2, 1/4, and 1/40th of the expected values and in Fig. 1d mass transfer rates at 1/2 and 1/4 of the highest observed value. Overall while we get rather good fits to the IUE continuum with changes in $\dot{M}$ only, the predicted reduction in X-ray flux is a fraction of that observed.

To further reduce the X-ray flux we can change the inclination angle of the disk with respect to our line-of-sight as is done to explain the 35-day effect. Going to a point in the 35-day cycle that totally obscures the X-ray flux we find that disk inclination angles above 81° can achieve this. We assume that the X-ray flux when unobscured is proportional to $\dot{M}$ and determine the disk inclination angle required to reduce the X-ray flux to the level observed. We then fit the IUE data for that inclination angle. We find that reductions in $\dot{M}$ by about a factor of 2 and changes in disk inclination angle of up to 20° give good fits to the IUE continuum *and* reduces the X-ray flux appropriately (Fig. 2).

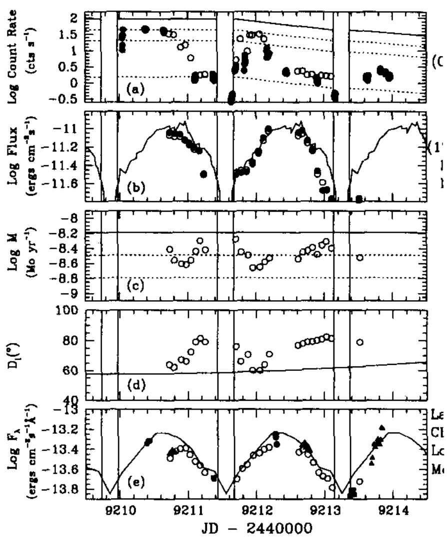

Figure 2. Model with changes in mass accretion rate and disk inclination angle

4. Summary

We interpret the initial drop in count rate accompanied by a change from spin-up to spin-down during our campaign in terms of a reduction in $\dot{M}$. Fits to UV/optical data show that the light curves can be reproduced by assuming a reduction in $\dot{M}$. The decrease in $\dot{M}$ is insufficient to account for the drop in X-ray flux, so disk obscuration must be taking place. The UV/optical/X-ray light curves can be reproduced by a reduction in $\dot{M}$ *and* accompanied changes in disk inclination angle. The change in torque on the neutron star implied by the switch from spin-up to spin-down can act to shift the disk. The lack of pulsations at energies greater than 1 keV is consistent with the interpretation that the hard X-rays are largely occulted. The changes in disk inclination angle may be related to shifts in 35-day period. Simultaneous ultraviolet, optical, and X-ray observations over several 35-day cycles should confirm this effect.

References

Cheng, F.H., Vrtilek, S.D., Raymond, J.C., 1995, Ap. J., **452**, 825
Cheng, F.H., Vrtilek, S.D., Raymond, J.C., 1996, these proceedings, p381
Ghosh, P., Lamb, F.K., 1979, Ap. J., **234**, 296
Howarth, I.D., Wilson, B., 1983, MNRAS, **202**, 347
Vrtilek, S.D., Mihara, T., Primini, F.A., et al., 1994, Ap. J., **436**, L9
Vrtilek, S.D., Raymond, J.C., Garcia, M.R., et al., 1990, A&A, **235**, 162

https://doi.org/10.1017/S0252921100039191 Published online by Cambridge University Press