MASS-LOSS RATE ESTIMATION FOR THE MASSIVE BINARY 4U 1538−52/QV NOR

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ABSTRACT

We present an analysis of archival RXTE data of the X-ray binary source 4U 1538−52/QV Nor. The RXTE observatory made one complete binary cycle observation on January 1997 and 2001, respectively. The X-ray continuum data are well described by an absorbed Negative Positive power laws Exponentials (NPEX) component modified by an iron emission line at 6.4 keV and a cyclotron absorption line at 20 keV. Using a simple spherically symmetric wind model to describe the X-ray absorption variations as a function of orbital phase, we inferred a wind mass-loss rate from the companion star of $(1.3 - 2.5) \times 10^{-6} \ \ M_{\odot}/yr$. Our results are consistent with those obtained by the Ginga X-ray observatory. We have also analyzed X-ray flux variations over the binary orbit and we have found a sharp increase at orbital phase 0.34 in both set of data. However, the increase at orbital phase 0.66 is significantly different in the two observations.

Key words: X-rays: binaries.

1. INTRODUCTION

Supergiant X-ray binaries (SXBs) are an interesting astrophysical laboratory to study the nature of the mass loss from OB star in these systems. Usually, they contain either an accreting neutron star or a black hole orbiting within a few stellar radii of the supergiant companion star. Photoelectric absorption estimations through an orbital period provide useful information to test models of the stellar wind of OB stars. The X-ray source is viewed through the stellar wind and being affected by photoelectric absorption in the X-ray spectrum depending on the orbital phases. The absorption increases around the times of eclipse ingress and egress as the compact object passes behind the dense innermost regions of the wind. The accretion process that takes place in SXBs with X-ray luminosities around 10^{36} erg/s is the gravitational capture of a fraction of the stellar wind by the compact object. The Castor, Abbott and Klein (CAK, 1975) radiatively driven wind theory predicts mass loss rates and terminal velocities for the winds from O stars, early B stars and B supergiants. Steady state theories predict velocity functions in the supersonic regimes of early star winds and mass loss rates that are in general agreement with observations of ultraviolet P Cygni line profiles. One of the SXB systems is the 3.73 day eclipsing system 4U 1538−52 where the optical companion is the B0 I star QV Nor at a distance of ∼5.5 kpc. The pulse phase averaged X-ray spectrum of this source has been well described by the absorbed Negative Positive power laws EXponential component (NPEX) modified by a fluorescence emission iron line at 6.4 keV and the fundamental Cyclotron Resonant Scattering Feature (CRSF) at 20 keV (Rodes et al. 2008, in press). In this work we present our mass loss rate estimation and the X-ray luminosity variations against the orbital phase, using two RXTE observations that covers nearly an orbital period each of 4U 1538−52/QV Nor made in 1997 January and 2001 January, respectively.

2. OBSERVATIONS

Pointed observations of 4U1538−52 were made with the Proportional Counter Array (PCA) and High Energy X-ray Timing Experiment (HEXTE) instruments on RXTE in early 1997 and early 2001. To obtain an appropriate model for the X-ray spectra, we used data from both PCA and HEXTE taking the energy range 3−20 keV and 17−100 keV, respectively. Spectral extractions and background subtractions for both instruments were performed using the FTOOLS package and spectral models were applied using XSPEC. These software packages were provided by NASA HEASARC. We have used the best fit orbital ephemeris from Makishima et al. (1987) to obtain the exact orbital phase for each observation.

3. RESULTS AND CONCLUSIONS

The continuum model that gives the best fit to the PCA and HEXTE spectra in the 3−100 keV band is the NPEX model. Photoelectric absorption by cold material with cosmic abundance, an iron emission line around 6.4 keV and a CRSF around 20 keV are also required to obtain an acceptable fit (Rodes 2007). The X-ray luminosity and absorption properties of 4U 1538−52/QV Nor will be modeled assuming the neutron star is deeply embedded in a radiatively driven stellar wind and the X-rays are powered by material captured from the wind. We assume a simple spherically symmetric wind model where the radial flow velocity takes the form:

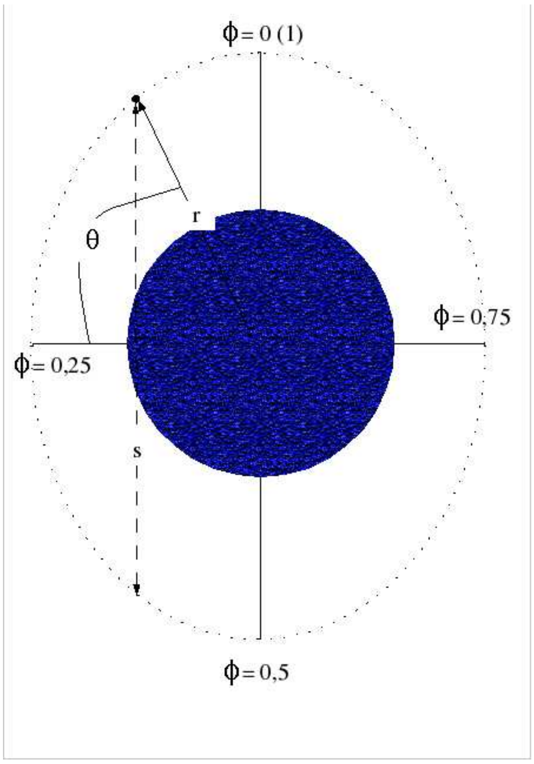

Figure 1. Schematic view of the binary system. For simplicity we have assumed a circular orbit whose parameters r, s and θ are shown. The orbital phase 0 (1) indicates the eclipse.

$$v_w(r) = v_\infty \left(1 - \frac{R_c}{r}\right)^\alpha , \qquad (1)$$

where v_∞ is the terminal velocity of the wind, R_c is the radius of the companion star, r is the distance from the centre of the companion star and α is the velocity gradient (often in the range 0.7−1.2 for early type stars). Conservation of mass requires:

$$\rho_w = \frac{\dot{M}_c}{4\,\pi\, r^2\, v_w} , \qquad (2)$$

where $\dot{M}_c$ is the mass loss rate from the primary and w is the wind density. Combining equations 1 and 2 and integrating the wind density along the line of sight to the X-ray source, it will be possible to find a model which describes the variation in N_H with orbital phase properly. Defining s as the distance through the stellar wind along the line from the compact object toward the observer (see Fig. 1), we have:

$$N_H = \int_0^s n_H\, ds = n_H\, s = n_H\, 2\, r\, \sin\theta\, . \qquad (3)$$

The angle θ is related to the orbital phase and equation 3 can be rewritten by:

$$N_H = \frac{\dot{M}_c}{4\,\pi\, r^2\, v_\infty\, \left(1 - \frac{R_c}{r}\right)^\alpha}\; 2\, r\, \sin\left(\frac{\pi}{2} - 2\,\pi\,\phi\right) . \qquad (4)$$

In our analysis procedure, we have performed a fit of the model defined by equation 4 to the column densities determined from our model spectral fits and thereby estimated range value for mass loss rate (see Fig. 2).

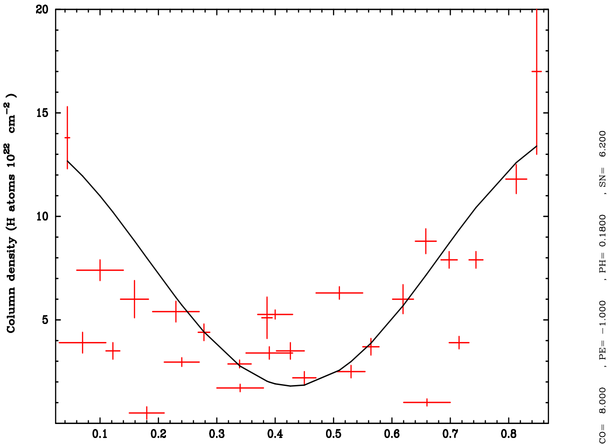

Figure 2. Column density (NH) as a function of orbital phase. The values derived from the spectral fits to the RXTE spectra are plotted. The solid line shows the function $N_H = CO + SN \sin\left(\frac{2\,\pi\,(X-PH)}{PE}\right)$, which is fitted to our data. The bars indicate the uncertainties at 90% confidence level.

According to Abbott (1982) stars of luminosity class I have escape velocities of 690±50 km/s and terminal velocities in the range 1400−2800 km/s. The parameter α describes the velocity gradient and assuming a value of 0.8 (Friend and Abbott 1986), the primary radius is 17 $R_\odot$ (Crampton et al. 1978) and the binary separation is 27.5 $R_\odot$ (Crampton et al. 1978). Therefore, the mass loss rate can be estimated from:

$$SN = \frac{\dot{M}_c}{2\,\pi\, r\, v_\infty\, \left(1 - \frac{R_c}{r}\right)^\alpha} , \qquad (5)$$

and obtaining a value of $(1.3 - 2.5) \times 10^{-6} \quad M_\odot/yr$. This result is on the upper fringe of values found for stars of the same luminosity of QV Nor from radio and UV data. On the other hand, it is consistent with the mass loss rate estimated by Clark et al. (1994) using Ginga observations.

We have also analysed the variation of the X-ray luminosity against the orbital phase (see Fig. 3). To estimate the X-ray flux we used several continuum models as a blackbody plus a comptonization, a disk blackbody plus a comptonization, a cutoff power law and the NPEX (Rodes 2007). The X-ray luminosity orbital modulation shows nearly the same shape in the phase interval 0−0.5 in both set of data, presenting a maximum value around orbital phase 0.34. However, the modulation is significantly different in the orbital phase interval 0.5−1 in the two observations. Indeed the maximum in orbital phase 0.66 is significantly different in the two data sets. This means there is major changes in the large scale wind structure.

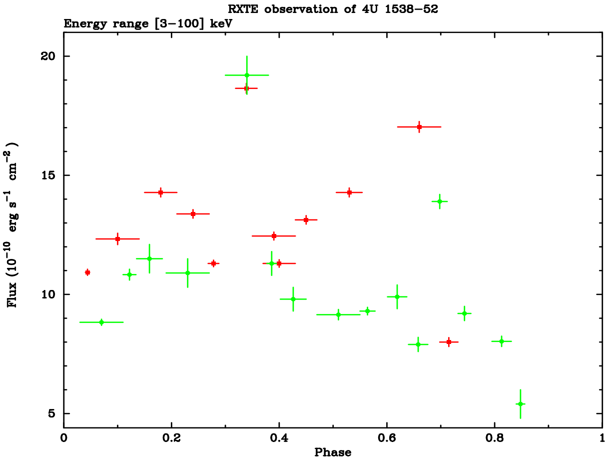

Figure 3. X-ray flux variations against the orbital phase in the energy range 3−100 keV. Red squares: values derived from phase averaged spectra for observations in 2001. Green circles: values derived from phase averaged spectra for observations in 1997. Flux uncertainties are given at 1 σ level.

The spectral analysis reveals that the X-ray flux is $\sim (5-20) \times 10^{-10}$ erg s^{-1} cm^{-2} in the 3−100 keV range. Thus, assuming a distance from the source of 5.5 kpc, we obtained a X-ray luminosity of $\sim (2-7) \times 10^{36}$ erg/s. Even the maximum value of luminosity is far below the Eddington limit for a canonical 1.4 $M_\odot$ neutron star two orders of magnitude. This is consistent with the picture that the neutron star is accreting from a wind from the companion star rather than being fed via Roche lobe overflow.

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