IRON LINE ANALYSIS OF THE X-RAY SYSTEM 4U 1538-52

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ABSTRACT

The X-ray binary pulsar 4U 1538-52 has been observed by the Rossi X-Ray Timing Explorer (RXTE) satellite. We have analysed the X-ray spectra of the high mass binary X-ray pulsar 4U 1538-52 over the energy range from 3 keV to 100 keV using all the available data from the RXTE archives. In this work, we investigate: a) the description of the continuum by physical models and b) the geometry of the emitting plasma from the iron line analysis.

Key words: X-rays: binaries.

1. INTRODUCTION

4U 1538-52 is a high mass X-ray binary system formed by a compact object (neutron star) and a high mass B0 I star ($\sim$ 17 $M_{\odot}$). Uhuru was the first satellite X-ray observatory that detected this system (Giacconi et al. 1974). The neutron star has a spin period $\sim$ 529 s (Davison 1977; Becker et al. 1977). The orbital period is $\sim$ 3.73 days (Clark 2000) and, assuming a distance of 5.5 kpc, the X-ray luminosity is $\sim 4 \cdot 10^{36}$ erg $\cdot$ s^{-1} (Becker et al. 1977; Parkes et al. 1978). The continuum of this system has usually been described either by an absorbed power law modified by a high energy cutoff, a power law modified by a Fermi-Dirac cutoff or two power laws with indices of opposite sign multiplied by an exponential cutoff. However, the direct physical interpretation of the parameters of these continuum models is difficult and we used them to search for cyclotron resonant scattering features or other type of spectral lines. We have found that a blackbody component or an accretion disk consisting of multiple blackbody components plus a comptonization of soft photons in a hot plasma describe all the spectra properly (bb+compTT and diskbb+compTT, respectively). In this work we present the spectrum of 4U 1538-52 in the energy band 3-100 keV and discuss the parameter values from the previous models. These models require an iron emission line at $\sim$ 6.4 keV and a cyclotron absorption feature at $\sim$ 20 keV are added in the model. On the other hand, we investigate the geometry of the system studying the iron line variation.

2. DATA

Spectra were obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASAs Goddard Space Flight Center. RXTE observed this source in three different runs, carried out during 1996, 1997 and 2001. Two of them have spectra for a complete orbital period. We have selected the energy bands 3-20 keV from the Proportional Counter Array (PCA; Jahoda et al. 1996) and 17-100 keV from the High Energy X-ray Timing Experiment (HEXTE; Rotschild et al. 1998) to fit the models. In order to improve the statistical significance of the data, we added the data of both HEXTE clusters. We also binned several channels together of the HEXTE data at higher energies and chose the binning as a compromise between increased statistical significance while retaining a reasonable energy resolution.

3. DISCUSSION AND CONCLUSIONS

3.1. Phase resolved spectroscopy

We performed spectral analysis on the energy spectrum of 4U 1538-52 in the energy range 3-100 keV and obtained the phase resolved spectra using the orbital ephemeris from Makishima et al. (1987). Using previous models, we obtain a reduced chi-squared between 0.50 and 1.19 describing all the spectra very well.

First we have analyzed the parameters deduced from the blackbody plus thermal comptonization model. Assuming a distance of 5.5 kpc, we obtained the luminosity of the source giving values from $2.3 \cdot 10^{36}$ to $7.3 \cdot 10^{36}$ erg/s (RXTE 1997 observation of an orbital cycle) and from $2.9 \cdot 10^{36}$ to $6.7 \cdot 10^{36}$ erg/s (RXTE 2001 observation of an orbital cycle). Under this description, the temperature of the injected soft photons (kT_0) is very high, 0.27-1.50

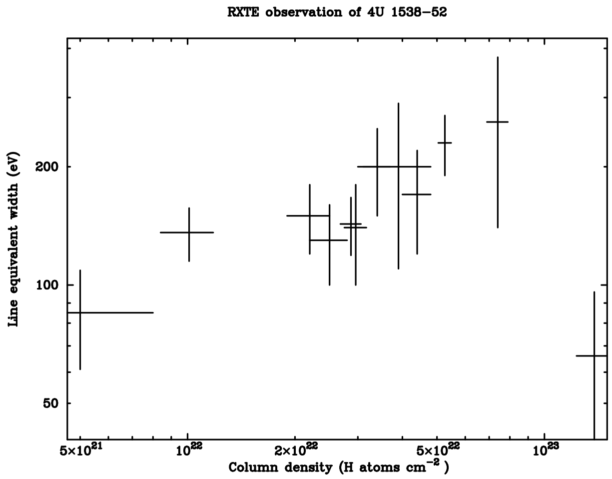

Figure 1. Iron line equivalent width versus column density of hydrogen. The values derived from the spectral fits to the RXTE 2001 spectra is plotted.

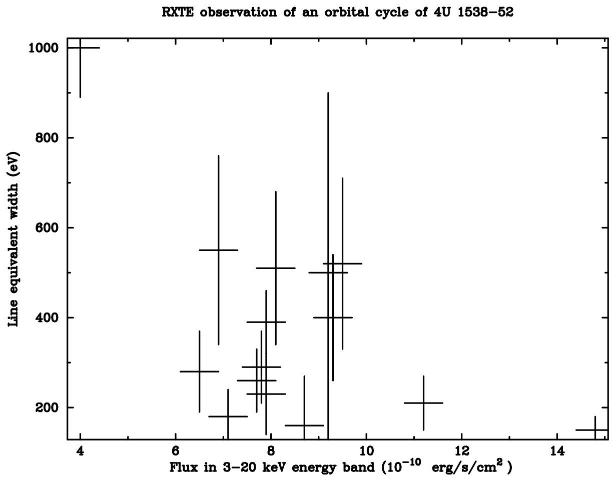

Figure 2. The variation in equivalent width (EW) of the iron emission line with the source flux in 3-20 keV is shown. The EW is high when the source flux is low and it is low when the source flux is high.

keV in 1997 data and 0.96-1.20 keV in 2001 data, while the temperature of the plasma (kTe) is very low, 3.2-8.0 keV and 2.1-5.3 keV, respectively. We compute the radius of the Wien soft photon source by equating the bolometric luminosity of the soft photon source with that of a black body of area $\pi \cdot R_w^2$ (Torrejón et al 2004). For RXTE 1997 data, the radius varies from 0.5 to 10 km in the extreme case indicating an emission from the entire surface or boundary layer instead of a hot spot. While for RXTE 2001 the radius is compatible ($\sim$ 0.5 km) for a polar cap in a neutron star. Although this model describe continuum spectra properly, the parameters are not expected.

On the other hand, the second model gives radius of the Wien soft photon without physical sense (ranging from 0.01 km to 910 km). Although the spectra of this source can be well described by thin comptonization model, the previous values of R_w are unacceptable. Therefore, we conclude that there is no evidence of a disk in this system.

3.2. The fluorescence iron line

We plot the iron line equivalent width versus column density of hydrogen. As we can see in figure 1, there is a good degree correlation of EW on N_H (uncertainties are at 90% confidence level for a single parameter). This is what can be expected if emission comes from a neutral absorbing gas with cosmic abundances which is distributed spherically around the X-ray source. We note that emission line during eclipse was also observed around 6.4 keV, thus indicating the fluorescent emission reprocessed by an extended region of cool matter.

We also show the variation in equivalent width of the iron emission line with the source flux in 3-20 keV energy range (see figure 2). Our results suggest that the EW is high at low luminosity and low at high luminosity. Inoue (1985) and Makishima (1986) estimated the equivalent widths of the fluorescence iron line emission from neutral matter in a sphere surrounding the X-ray source using a power law type incident spectrum. In accretion powered X-ray pulsars, the iron line equivalent width can be higher if the compact object is hidden from direct view and only X-rays scattered into the line of sight by an accretion disk corona or wind are visible. This may explain the higher value of iron equivalent width during low luminosity of 4U 1538-52 and is consistent with the X-ray coming from a spherical plasma surrounding the neutron star rather than from an accretion disk.

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