X-RAY ABSORPTION BY IONIZED GAS IN EXOSAT SPECTRA FROM THE BINARY SYSTEM 4U1700-37/HD153919

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ABSTRACT. We observed the 3.41 day eclipsing, massive binary system 4U1700-37/HD153919 with EXOSAT for more than one complete binary period to investigate the spectral variations during the orbital cycle of the neutron star. The spectra show a low energy excess below $\sim$ 3 keV when modelled by a powerlaw spectrum attenuated by photoelectric absorption by neutral gas, suggesting partial ionization of the absorbing gas. The column density derived from spectra above 3 keV shows an asymmetric distribution around orbital phase 0.5 with higher absorption before eclipse ingress. We approximated the with distance to the X-ray source gradually decreasing ionization of the wind by two zones. One of higher ionized wind around the X-ray source for which X-ray opacities of a gas in photoionization equilibrium were used and a zone of neutral gas further away from the X-ray source. We find that our spectra below 3 keV can be well fitted by a powerlaw which is attenuated first by photoelectric absorption of ionized gas and then by neutral gas. Since around phase 0.5 the major contribution of the wind column density along the line of sight arises from the ionized part we found that the total column density can be higher up to a factor of about 4 taking ionization into account.

1. INTRODUCTION

An accreting compact object orbiting an OB supergiant can be used to investigate the properties of the wind from the OB star. The X-ray emission from the compact object will suffer photo-electric absorption by the stellar wind and X-ray spectroscopy can be used to investigate the density and ionization structure of the wind. The driving force behind the mass loss from the OB star is the transfer of momentum from the supergiant's radiation field to the wind by scattering of radiation in UV spectral lines (see e.g. Lucy and Solomon 1970). X-ray photo-ionization of the wind will reduce the X-ray absorption and also can inhibit or enhance the velocity of the flow by changing the UV line transitions available to accelerate the wind (MacGregor and Vitello 1982). The X-ray spectra of the massive X-ray binaries (MXRB's) show variable absorption with increases in absorption around the times of eclipse ingress and egress, caused by the neutron star passing behind the dense innermost regions of the wind near to the supergiant (e.g. Branduardi, Mason and Sanford 1978, hereafter BMS). Strong photoelectric absorption is evident in the X-ray spectra of 4U1700-37 at lower energies with an equivalent hydrogen column density (n_H) varying between $1 \cdot 10^{22} - 4 \cdot 10^{23}$ H cm^{-2}. (Jones *et al.* 1973; Mason, Branduardi, and Sanford 1976; BMS; White, Kallman, and Swank 1983, hereafter WKS). An increase in photoelectric absorption is evident at orbital phases greater than 0.5 as well as close to eclipse (see e.g. BMS). Possible explanations are a slow moving wind trailing the X-ray source due to X-ray ionization disrupting the radial acceleration of the wind (Fransson and Fabian 1980, MacGregor and Vitello 1982), a dense gas stream from the primary that trails behind the X-ray source (Fahlman and Walker 1980), or a bow shock in the wind caused by the supersonic passage of the neutron star (Jackson 1975).

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2. RESULTS

2.1 The Observation

The EXOSAT observation of 4U1700-37 reported here began on 1985 April 4 at 04.30 UT and ended at 01.00 UT on 1985 April 8 with the only major interruption on April 4 between 09.00 and 20.00 UT by the perigee passage of EXOSAT. The principle instrument used in this study is the medium energy proportional counter array (ME, Turner, Smith, and Zimmermann 1981). The background subtracted X-ray light curve from the ME in the 2-10 keV band is shown in Figure 1 (upper panel) with a time resolution of ~8 min. The X-ray eclipse starts at ~10.00 UT on April 5 and ends at ~06.14 UT on April 6. The source undergoes constant flaring activity on time scales of minutes to hours with intensity variations up to a factor of 100 with several extended low states of exceptionally low intensity.

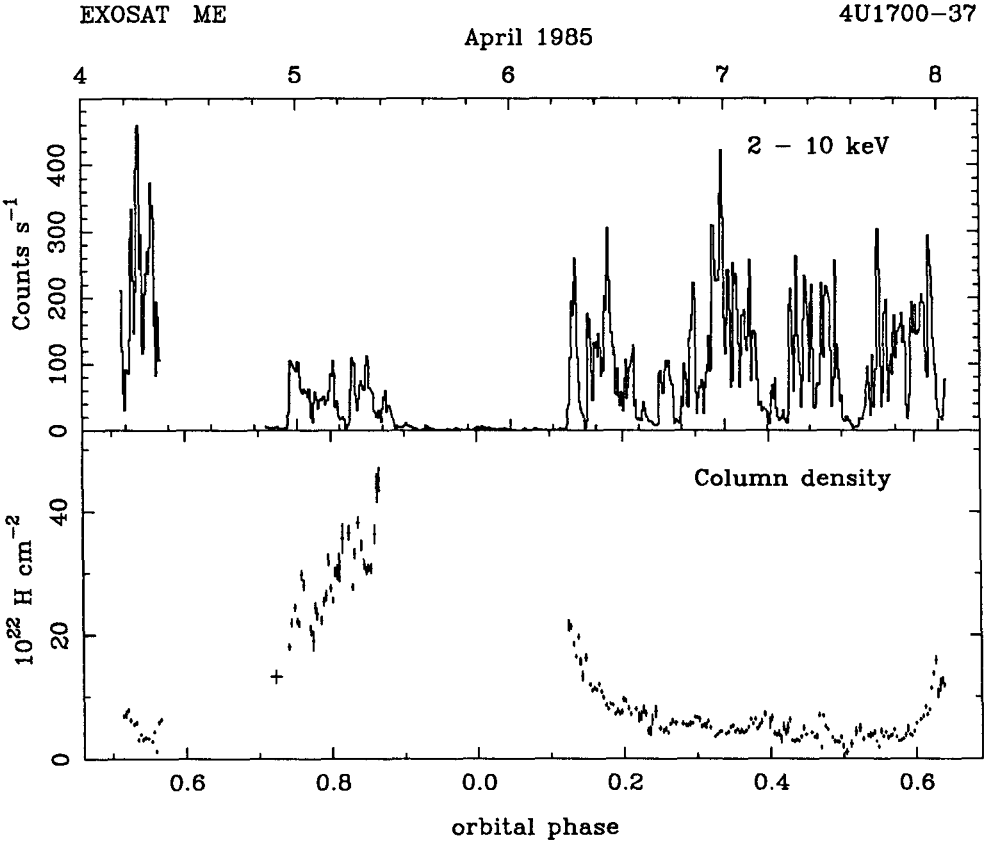

Figure 1. The background subtracted 2 - 10 keV light curve of 4U1700-37 obtained from the ME on 1985 April 4 to 8 (upper panel), with only one major interuption from about phase 0.6 to 0.7 caused by a perigee passage of EXOSAT. The count rate is in units of counts per second per half detector array with a time resolution of about 8 min. The lower panel shows the equivalent hydrogen column density versus orbital phase, derived from ME spectra above 3 keV using opacities for neutral gas.

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2.2 The Spectra above 3 keV

Pulse height analysed, PHA, spectra were obtained from the argon chamber of the ME in the energy range 1-20 keV. The spectra have been background subtracted and summed into ~15 min intervals. In the 3-20 keV band the spectra are well represented by a powerlaw with a high energy cutoff of the form $\exp[(E_c - E)/E_f]$ above a break energy E_c, with photoelectric absorption by cold material as predicted for a cosmic abundance by Morrison and McCammon (1983) and a narrow iron emission line around 6.4 keV. The best determination of the unabsorbed continuum parameters was obtained by taking a spectrum from the ME over a 4.4 hr interval around phase 0.4 starting at 22.00 on April 6 where the absorption was lowest. This gives an energy index α of 0.13 ± 0.10, E_c of 6.6 ± 0.7 keV and E_f of $21.1\ ^{+4.3}_{-3.3}$ with a χ^2_r of 0.5. All given errors indicate the 90% confidence region. To better constrain n_H the parameters E_c and E_f were fixed at 6.6 and 21.1 keV. The column density as a function of orbital phase derived from fitting to the 3-20 keV spectra is shown in the lower half of Figure 1. Apart from the expected increase in n_H around the time of eclipse ingress and egress, a sharp rise in n_H around binary phase 1.6 is visible, which also occurs on the previous cycle (between phase 0.74 and eclipse ingress) where it causes an additional absorption of $\sim 20{\cdot}10^{22}$ H cm^{-2} compared to eclipse egress.

2.3 An Excess In The Spectrum Below 3 keV

In the first spectral fitting we excluded energies below 3 keV because the spectra show an excess over the model prediction in this energy range. This excess increases with higher X-ray intensity and varies with orbital phase.

The increasing deviation in the energy spectrum from the model using opacities for neutral gas with increasing source intensity is most noticable in three ME spectra taken across an intensive flare that occured on April 4 around binary phase ~0.54. In Figure 2 a, b, and c the fits to the PHA spectra accumulated respectively before the flare, during the flare rise and at the flare maximum are shown. The average count rate during each is 46 cts s^{-1}, 381 cts s^{-1} and 605 cts s^{-1} respectively. The spectrum at the lowest intensity gives a good fit to the model used in paragraph 2.2 with χ^2_r of 1.1, but with increasing intensity the fit becomes progressively worse with e.g. for the highest intensity spectrum a χ^2_r of 5.5. This poor fit is caused by a deficiency in the observed spectrum around 3.5 keV and a low energy excess below 2.5 keV. This effect is most obvious around superior conjunction of the X-ray source and is less detectable in spectra taken close to eclipse egress. Excluding data below 3 keV gives acceptable χ^2_r between 1.0 and 1.2 for the three spectra.

We fitted our spectra to a "two zone model" where a powerlaw is attenuated by two different absorbing media in series, one with the opacities for a gas in photoionization equilibrium (Krolik and Kallman 1984) and one with opacities for neutral gas. This two zone model is an approximation for the wind near the X-ray source where the gas is ionized and far away from the X-ray source where the gas is neutral. The ionization parameter and column density in the ionized zone and the column density in the neutral zone are free parameters. The total absorption is given by the sum of the two column densities. In reality the degree of ionization around the X-ray source will decrease smoothly with distance, but a two zone approximation is good enough for this data. The powerlaw index was fixed at the value 0.13 obtained from the fits that excluded the data below 3 keV. The two zone model gives good fits to the flare spectra with χ^2_r between 1.0 and 1.2. The ionization parameter increases from $\log(\xi)$ of 1.56 to 1.65 during the flare which is still within the errors of typically 0.1. For the neutral column density only an upper limit of $2.5{\cdot}10^{22}$ H cm^{-2} is obtained while the ionized column density lies at $18{\pm}3{\cdot}10^{22}$ H cm^{-2}. Both column densities are constant within the errors and give a total of $\sim 20{\cdot}10^{22}$ H cm^{-2} while the fits with only neutral absorption give $\sim 5{\cdot}10^{22}$ H cm^{-2}.

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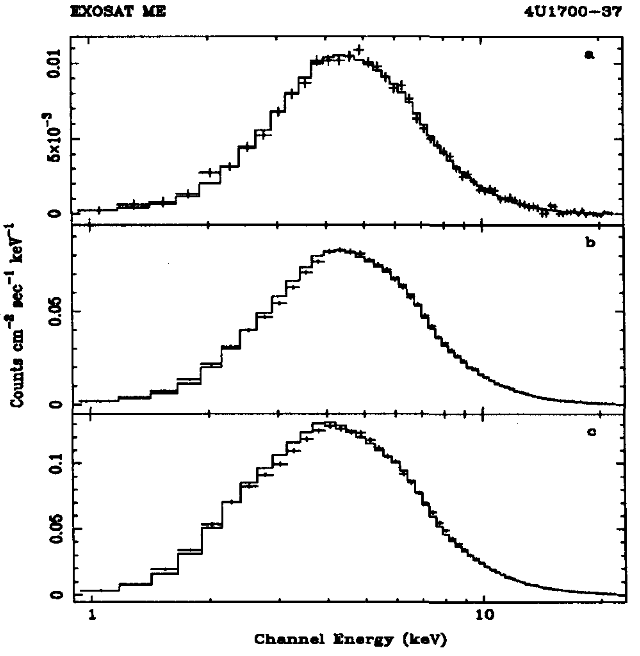

Figure 2.
Three ME spectra obtained during a flare on 1985 April 4. The spectrum on panel (a) was obtained before the flare, (b) during flare rise and (c) during flare maximum. Deviations from a powerlaw attenuated by neutral gas absorption (plotted as histogram) increase with source intensity.

3. DISCUSSION

The spectra during flare rise deviate more from a powerlaw attenuated by neutral gas absorption the higher the X-ray intensity was. One possible explanation is that X-rays change the ionization state of the wind in the vicinity of the X-ray source. The highly ionized gas has lower absorption cross sections for low energetic X-rays which leads to an excess in the spectra at low energies compared to spectra which are attenuated by absorption from neutral gas. Fits to flare spectra using a model in which a zone of ionized gas and a zone of neutral gas in series absorb the X-rays, gave acceptable χ^2. Due to the lower opacities of ionized gas the total column density is increased. This effect is most important around phase 0.5 where the line of sight does not go through the dense nearly neutral regions near the primary star. Hence it can change the column density profile and one has to be careful in modelling the wind using the column densities.

REFERENCES

Branduardi, G., Mason, K.O., and Sanford, P.W. 1978, *M.N.R.A.S.*, **185**, 137.
Fahlman, G.G.and Walker, G.A.H. 1980, *Ap.J.*, **240**, 169.
Fransson, C., and Fabian, A.A. 1980, *Astr. Ap.*, **87**, 102.
Jackson, J.C. 1975, *M.N.R.A.S.*, **172**, 483.
Jones, C., Forman, W., Tananbaum, H., Schreier, E., Gursky, H., Kellog, E., and Giacconi, R. 1973, *Ap.J.(Letters)*, **181**, L43.
Krolik, J.H. and Kallman, T.R. 1984, *Ap.J.*, **286**, 366.
Lucy, L.B. and Solomon,,P. 1970, *Ap.J.*, **159**, 879.
MacGregor, K.B., and Vitello, P.A.J. 1982, *Ap.J.*, **259**, 267.
Mason, K.O., Branduardi, G., and Sanford, P.W. 1976, *Ap.J.(Letters)*, **203**, L29.
Turner, M.J.L., Smith, A., and Zimmermann, H.U. 1981, *Space Sci. Rev.*, **30**, 513.
White, N.E., Kallman, T.R., and Swank,J.H. 1983a, *Ap.J.*, **269**, 264.

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