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Letter to the Editor

Attenuation of dipping at low energies in the LMXB source X 1755-338

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Abstract. We report spectral fitting results for *Rosat PSPC* observations of the dipping source X 1755-338. These results are consistent with the two-component model that we previously proposed consisting of a blackbody point source plus an extended power law component. Remarkably, the low energy cut-off of the spectrum does not change appreciably in dips, and it can be seen that dipping takes place in the higher part of the PSPC band where the blackbody contributes to the spectrum. Thus dipping consists primarily of absorption of this component, whereas the low energy cut-off is determined by the power law. Thus, above 0.5 keV, the dipping is approximately independent of energy as seen in *Exosat* and 10 ± 0.4% deep. Below 0.5 keV, there may be a small residual dipping effect of up to 3%; however dipping is certainly substantially reduced compared with the 20% seen by *Exosat*, and this is the first time that the effective cessation of dipping at low energies in such sources has been seen.

Key words: X rays: stars – stars: individual: X 1755-338 – binaries: close – accretion: accretion discs

1. Introduction

X 1755-338 is one of the most interesting members of the class of $\sim$ 10 Low Mass X-ray Binary (LMXB) sources which show periodic dips in X-ray intensity at the orbital period. It is generally accepted that the dips are due to absorption in the bulge in the outer accretion disc caused by the impact of the accretion flow from the companion (White & Swank 1982). The evolution of the X-ray spectra during dips varies considerably between dipping sources and it is not the case that the sources in general show an increase in low energy absorption leading to a hardening of the spectrum as expected for photoelectric absorption in the relatively cool material of the outer disc. In particular cases there may be a hardening or a softening or no change in hardness. X 1755-338 is very unusual in this respect since the high quality *Exosat ME* spectra showed that within error, the dipping was energy independent in the band 1 - 10 keV (White et al. 1984), because of which it has been called the energy-independent dipper. Various explanations of this effect have been proposed, notably that the metallicity of the absorber is substantially reduced from solar values (White et al. 1984). Other possibilities include absorption in a region closer to the central compact object where there will be stronger photoionization (Frank, King & Lasota 1987), or partial covering of an extended source (Frank & Sztajno 1984). More recently we have suggested an explanation based on a two-component model of the source (Church & Bałucińska-Church 1993) in which the total emission consists of a blackbody point source originating in the neighbourhood of the compact object plus an extended power law component probably due to Comptonisation in an Accretion Disc Corona. Dipping is seen to be primarily due to absorption of the blackbody.

We have found that the same two-component model can also explain the dipping in X 1624-490 in which the spectral evolution is complex, consisting of a hardening in shallow dipping, followed by a softening in deeper dipping (Church & Bałucińska-Church 1995a). It can also explain dipping in the very different source XB 1916-053 in which dipping can reach 100% (Church et al. 1997), and we have proposed that the two-component model may explain all of the dipping sources (Church & Bałucińska-Church 1995b). It is important to determine which explanation of the energy-independence is correct, and one way to do this is to examine the spectrum at energies both lower and higher than the *Exosat ME* band. If the two-component model is correct, at photon energies much lower and higher than kT_{bb} for the blackbody (0.9 keV) there should be very little dipping since the blackbody contribution to the spectrum will be negligible.

In the present paper we examine the spectrum of the source in the PSPC band 0.1 - 2.0 keV. We find that the two-component

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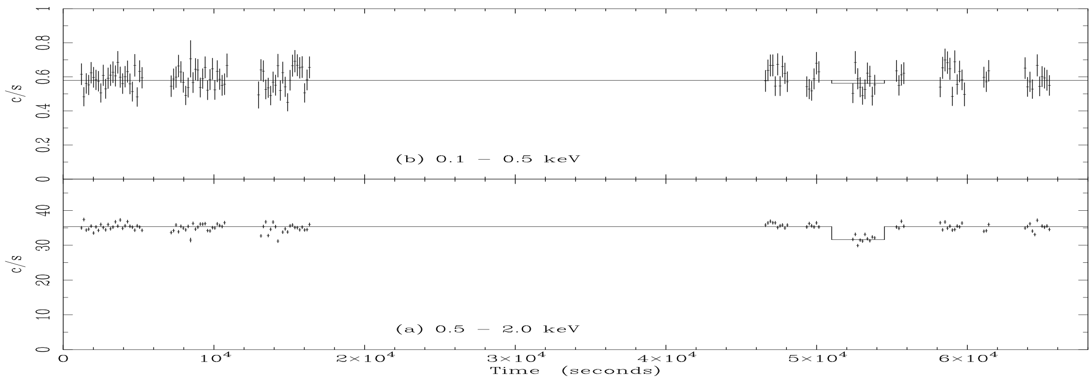

Fig. 1. X-ray light curves for the complete 18 h *Rosat* observation in two energy bands: 0.5 - 2.0 keV and 0.1 - 0.5 keV with 160 s timebins.

model is a good representation of the spectra. Dipping is less obvious in the PSPC band than in the ME, but it can be seen that it is due to increases of N_H for the blackbody, and that at the lowest energies below 0.5 keV, the extent of dipping is substantially reduced.

2. Data analysis

Three observations have been made of X 1755-338 with the *Rosat PSPC*. In two of these there is little or no sign of dipping. We present results for the other longer observation made on 1993 March 29, lasting 18 h. Source data were extracted from a circle of radius 2 arcmin, taking into account the dust scattered X-ray halo of the source discussed by Predehl and Schmitt (1995). Photons scattered in the halo are not expected to show dipping because of the variable time delays introduced which smear out time-variability. From the figure given by Predehl and Schmitt, it can be estimated that a radius of 2 arcmin includes 96% of the unscattered source counts, but excludes 97% of the halo, which should contribute about 3 c/s in the total PSPC band. For source extraction from a 2 arcmin region, background subtraction is not very important in this bright source, normally less than 0.1% of the total count rate, except for the subtraction of sharply rising background at the ends of each of the first 3 sections of data in Fig. 1 which in fact caused the switch-off of the detectors in the following data gaps. We obtained background data from an annulus between 0.22° and 0.28°, excluding point sources outside this region, and excluding most of the halo which Predehl and Schmitt show is becoming small at 0.22°. It is important for spectral fitting that background subtraction is made from a region with sufficiently high background count, and this region is the best for this requirement.

The light curve of the source in the band 0.5 - 2.0 keV is shown in Fig. 1a with 160 s timebins. Ideally, longer binning would be better, but the shortness of some of the data sections do not allow this. Consequently, it is still possible to see the effects in the light curves of the wobbling of the telescope to prevent occultation of sources behind the wires, and this effect dominates over Poisson noise in the light curves. A section of data can be seen with count rate reduced by $\sim$ 10% , which, allowing for data gaps, lasts between 25 and 68 m. The duration is consistent with the duration of dipping seen in the *Exosat ME* of 40 m. The depth of dipping in the ME was typically $\sim$ 20% (1 - 10 keV), although one dip at 12% was seen. Thus there is an indication that the depth of dipping is less in the 0.1 - 2.0 keV band. The lack of other dips is consistent with the orbital period of about 4.4 h which predicts that other dips would occur during the data gaps (although there is a possibility that the first section of data in the light curve is contaminated at the end by the onset of dipping). Finally, our spectral fitting results are fully consistent with this low intensity period being a dip.

We extracted spectra for each of the non-dip sections of data in the light curve lasting more than 1500 s, and also dip data (1700 s). These were corrected by subtracting the background and correcting for deadtime and vignetting. The spectra were rebinned into 24 channels (after excluding channels below 0.1 keV and above 2.0 keV), and a systematic error of 2% was added conservatively to each spectral channel. The results were completely consistent with those obtained fitting the spectra in primitive channels without rebinning. We present results below obtained using the January 1993 instrument response as appropriate to this observation in the later part of the *Rosat* mission (see Fiore et al. 1994). However to assess systematic errors, the data were also analysed using the alternative March 1992 response. It was found that parameters derived from spectral fitting changed by only 1.5% to 5%, giving confidence in the results.

3. Results

Firstly, we consider simple models. In the case of the PSPC non-dip spectra of X 1755-338, a simple absorbed power law model gives an acceptable fit, with however a value of Γ = 1.9$\pm$0.1. In our previous work on the *Exosat ME* data, we found that a two-component model was necessary to describe the source, consisting of a blackbody with kT_{bb} of 0.88 keV, and a power law with photon index Γ of 2.67. Having re-examined the ME data we find that a value of 1.9 can be rejected for a single spectrum with certainty greater than 93%, and in our *Exosat* work, we were able to fit the complete observation divided into a sequence of 314 spectra with Γ values between 2.6 and 2.8. Thus the simple power law fit is not acceptable. It can however be used to test whether the low energy cut-off (LECO) of the spectrum changed between non-dip and dip data (minimising model dependency). There was *no detectable change in* N_H, but dipping could be seen as a decrease in the spectral flux in the higher part of the PSPC band (0.5 - 2 keV).

Use of a two-component model is clearly indicated. It is shown below (see Fig. 2) that the LECO is determined by the power law, and so the blackbody can not have a smaller N_H than the power law, and a model of the form $AB \cdot (AB \cdot BB + PL)$ (where AB, BB and PL are the absorption, blackbody and power law terms) should be used. Very good fits were obtained for both non-dip and dip data using this model, showing that the PSPC data are fully consistent with the two-component model. If Γ and kT_{bb} are allowed to be free, low values of Γ are again obtained $\sim$ 1.5, inconsistent with the values we obtained from the ME data. The *Rosat PSPC* is not able to constrain power law index well in the presence of a second component, or kT_{bb} for a blackbody peaking above the PSPC band. However the PSPC data can be used in conjunction with parameter values already established for a source to determine the lower energy part of the spectrum. It is clearly more sensible to fix both Γ and kT_{bb} at the ME values.

Results are shown in Fig. 2 (plotted with primitive channels, see below). In Fig. 3, the spectra analysed with 24 channels are shown, plotted together with typical *Exosat ME* spectra. Again, there was little or no change in the LECO between non-dip and dip spectra. The energy range of the *Rosat* PSPC is ideal for accurate determination of the cut-off, and N_H for the power law, which can be seen to determine the cut-off, did not change within the errors. The lack of change in the LECO is model-independent and is primary proof that dipping is absent at low energies, since the non-dip and dip spectra have to converge towards the cut-off. Moreover, it is clear from Fig. 2 that dipping occurs preferentially at higher energies in the PSPC band, and is seen to be due to increased absorption of the blackbody. At $\sim$1 keV the non-dip and dip spectra exhibit the energy-independence well known from *Exosat*. The blackbody contribution (dashed line) shows large changes in N_H indicating that dipping is primarily due to absorption of this component. Thus below 0.5 keV, the contribution of the blackbody is very small and so the extent of dipping is markedly reduced compared with the 0.5 - 2.0 keV band.

Typical spectral fitting results for non-dip data have N_H for the power law = $5.29 \pm 0.22 \cdot 10^{21}$ H atom cm^{-2}, normalisation I (at 1 keV) = 0.58 ± 0.05 photons cm^{-2} s^{-1}, N_H for the blackbody = $5.4^{+5.6}_{-0.2} \cdot 10^{21}$ H atom cm^{-2} and I = 0.12 ± 0.02 photons cm^{-2} s^{-1} (90% confidence errors). There was very good consistency of the results from different sections of data with only small variations of parameter values, eg I_{PL} varied by about 0.016 photons cm^{-2} s^{-1}. The corresponding blackbody normalisation was non-zero at the 8σ level, showing clearly the necessity for this component in fitting the spectra of this source. The additional absorption term for the blackbody was in all cases close to zero, showing that that during persistent emission both spectral components are subject to the same absorption. The dip data were fitted by the same model with the normalisations fixed at non-dip values. Allowing the dips to be modelled by normalisation changes would be to assume that some change in the emission processes takes place in the source coincident with the absorption during dipping, which can be discounted as unphysical. For dip data, the total N_H for the blackbody increased to $10.4^{+5.6}_{-1.3} \cdot 10^{21}$ H atom cm^{-2}, with N_H for the power law equal to $5.37 \pm 0.22 \cdot 10^{21}$ H atom cm^{-2}.

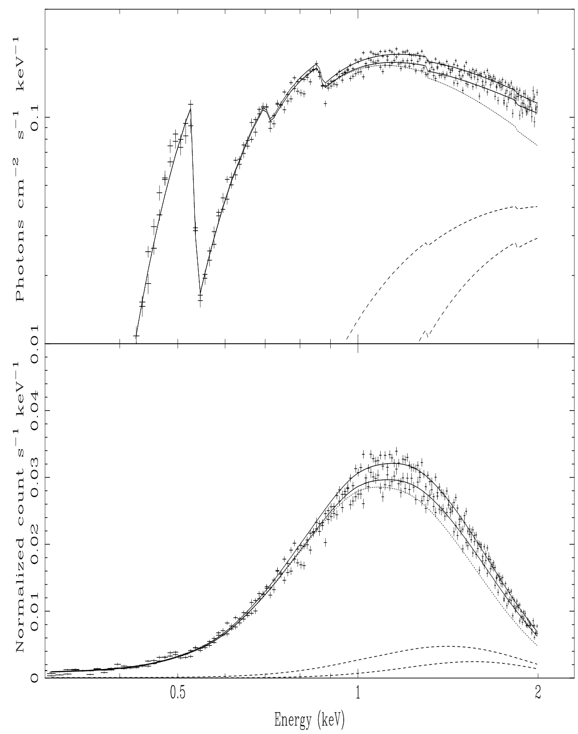

Fig. 2. Spectral fits to non-dip and to dip emission. The solid lines show the total fit, and the dotted line and dashed lines show the power law and blackbody components respectively.

Fig. 2 shows that below $\sim$0.5 keV the blackbody is very small and so implies that below 0.5 keV dipping should be effectively absent since in this source, it appears that absorption of the power law in dipping is very small. To demonstrate this we have obtained the light curve in the band 0.1 - 0.5 keV shown in Fig. 1b. Although the count rate is of course low in this band, there is little or no sign of dipping, and this is confirmed by examining the mean count rates in all of the sections of data in this figure. In the band 0.5 to 2.0 keV, the decrease is 3.6 c/s, ie 10 ± 0.4% which in terms of the standard deviation of the mean of non-dip means 0.49 c/s is 7.2σ, and so is highly significant. N_H for the power law did not change in dipping within the errors of fitting, and we estimate possible residual dipping in the band 0.1 - 0.5 keV as 3^{+1}_{-2}% in count rate, as indicated by the bar in Fig. 1b at the position of dipping (which is 3% deep). There may be residual dipping at a low level; however the data of Fig. 1b do not constitute a significant detection of this.

From the results, absorbed photon fluxes of the spectral components were calculated. In the band 0.1 - 2.0 keV, the blackbody comprises 17% of the total, whereas in the band 1.0 - 10.0 keV it is 38% of the total. This is in good agreement with a typical blackbody percentage of 39% taken from our previous *Exosat ME* work. The lower percentage in the PSPC band corresponds to a blackbody contribution to the count rate of 16% in the band 0.1 - 2.0 keV. Thus since the depth of dipping in the *Exosat* observation indicated only partial absorption of the blackbody, a level of dipping $\sim$ 10% in the PSPC band might be expected, as is seen.

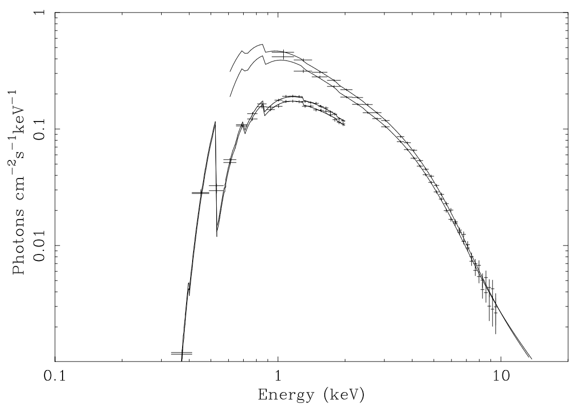

Fig. 3. Comparison of the *Rosat PSPC* spectra with typical *Exosat ME* results for non-dip and dip data.

4. Discussion

We previously found that a two-component model provides a good explanation of the energy-independent dipping in the *Exosat ME* band for X 1755-338, and proposed that this model may be able to explain all of the dipping sources. We now find that this model gives good fits to the *Rosat PSPC* data and allows the observed features of the PSPC data to be understood.

Firstly there is no significant change in the LECO of the data between non-dip and dip data. The LECO is determined by the power law component and the spectral fitting results show there is no significant change in N_H, This lack of change would be quite unexpected in terms of photoelectric absorption of a single emission component which should show a large change in LECO if the absorber has normal abundances. Thus two emission regions at least *have* to be present. The two-component model gives a good explanation of the lack of change in the LECO, since the blackbody is responsible for dips but does not determine the spectrum below 0.5 keV.

Secondly, the light curves show a clear decrease of count rate of 10% in the band 0.5 - 2.0 keV; in the lower band 0.1 - 0.5 keV there is little evidence for dipping but a small residual level of dipping of 3^{+1}_{-2}% may persist. Thus dipping is substantially reduced especially when compared with the typical 20% dipping seen in the *Exosat ME* band. Spectral fitting shows that dipping is caused primarily by absorption of the blackbody. It is interesting that in this source there appears to be little absorption of the extended power law component. Comparison of the *Rosat PSPC* results with the previous *Exosat ME* results shows that the brightness of the source was $\sim$ 1.7 times less during the *Rosat* observation.

The blackbody plus power law model was found to be a good fit to *TTM* data on X 1755-338 by Pan et al. (1995). However they were not able to find a best fit model, and several models fitted equally well including the above model and a multi-temperature disc plus power law. The latter model would allow the source to be a black hole candidate. Thus, the conclusion of Pan et al. that their results strongly support the black hole nature of the source does not seem to be justified.

It is clear that the *Rosat PSPC* results support the two-component model of the dippers. This model predicts that as dipping is due to absorption of the blackbody it can not extend indefinitely to energies much less than kT_{bb}. This is supported by our results which show for the first time a marked reduction in the extent of dipping at low energies in a LMXB dipping source.

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