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The X-Ray Spectrum of the X-Ray Binary 4U 1728-34, observed with *Suzaku*

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Abstract. This poster reported our spectroscopy of the neutron-star X-ray binary 4U 1728-34, observed with *Suzaku* in 2010 October. It is classified as an atoll source. Its continuous X-ray spectrum can be fitted by a combination of a multicolour accretion-disk model for the soft energy, plus a power-law model for the hard energy. A broad emission line at 6–7 keV can be fitted well using a simple Gaussian component with an equivalent width of ∼322 eV. However, for this object the presence of that feature is disputed, even though our results from *Suzaku* do suggest the presence of a broad Fe emission line that is consistent with results from *XMM-Newton*. Nevertheless, the parameters of the line (the line centroid and the equivalent width) are a little different, but that could be due to a difference in modelling the continuum.

Keywords. X-ray binaries, accretion, accretion disks

1. Introduction

Low-mass X-ray binaries (LMXBs) that contain a neutron star (NS) as the primary can be divided into two subclasses (atoll sources and Z sources), according to the patterns that they trace out in X-ray colour-colour diagrams, or hardness versus intensity diagrams (Hasinger & van der Klis 1989; van der Klis 2006). It is suggested that atoll sources have lower luminosities ($\sim 0.001-0.5\ L_{Edd}$) than Z sources. There are two distinct X-ray states for atoll sources: low hard states (in which the energy spectra are roughly flat), and high soft states (in which the energy spectra follow an exponential decrease above ∼10 keV). The transition between these two is named a 'transitional' state. The movement of an atoll source from a hard to a soft state is accompanied by an increasing luminosity, which usually denotes an increasing accretion rate.

Two competing models have been employed to explore the spectral properties of NS LMXBs: the Eastern model (Mitsuda *et al.* 1989) and the Western model (White *et al.* 1988); they have different choices of the thermal and Comptonised components. In the Eastern model, the spectra are described by the thermal (multicolour disk blackbody, MCD) and Comptonised components (weakly Comptonised blackbody) (e.g., Agrawal & Sreekumar 2003). In the Western model, the thermal component is described by a single-temperature blackbody (BB) describing the boundary layer, while Comptonised emission is from the disk (e.g., Church & Balucinska-Church 1995). However, the two models do not perform well in the soft state. Lin *et al.* (2007) therefore suggested a hybrid model for atoll sources, which incorporates a BB plus a broken power law (BPL) for the hard state, two thermal components (MCD and BB), plus a constrained BPL for the soft state.

4U 1728-34 is an atoll source. Type I X-ray bursts are detected, implying that the primary is a NS (Hoffman *et al.* 1976). The distance is estimated as $4.4-5.1$ kpc according to the detection of Eddington-limited bursts (van Paradijs 1978; Basinska *et al.* 1984; Kaminker *et al.* 1989). Studies of its X-ray spectra have been carried out in the past years

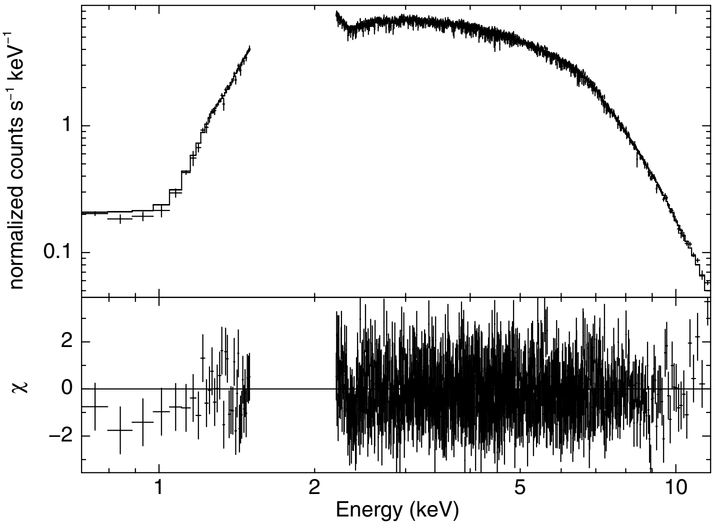

Figure 1. *Suzaku* spectrum of 4U 1728-34 fitted with the hybrid model.

with observations from different satellites. Although there has been a general agreement about the modelling of the continuum emission, the nature of local features, especially a broad Gaussian line at 6.2–6.7 keV, is still disputed. 4U 1728-34 is one of the few atoll sources detected in the radio band, which is often detected in black-hole binaries and Z sources (Marti *et al.* 1998). In this work, we study its X-ray spectrum with an observation from XIS/*Suzaku* during 2015 October.

2. Observation

Suzaku carries on board two types of instruments: an X-ray imaging spectrometer (XIS), and a hard X-ray detector (HXD). Our observation was made with XIS. The XIS has a focal-plane X-ray CCD camera, and covers the energy range 0.2–12 keV. There are four XIS detectors (XIS0, XIS1, XIS2, XIS3), but XIS2 was damaged in 2006 November. 4U 1728-34 was observed from 2015 October 4–6 (Obs. ID:405048010). We adopted a burst option of a 1-s exposure per frame, and a one-fourth window mode during the observation in order to limit the effects of photon pile-up; in consequence, the photon pile-up of all XIS spectra of 4U 1728-34 could be neglected.

We analysed the XIS spectra of 4U 1728-34 in the energy range 0.7–12.0 keV. (The 1.5–2.2 keV energy range was ignored in order to avoid systematic errors arising from calibration uncertainties). A systematic error of 0.5% was applied to each XIS spectrum. The resulting spectrum is shown in Fig. 1.

A series of models was fitted simultaneously to the spectrum of 4U 1728-34. The results show that the best-fitting model was one which included the multicolour disk model (*diskbb* in XSPEC) plus a power law (*powerlaw* in XSPEC). Adding the emission line in the range from 5–8 keV significantly improved the quality of the fit. The model therefore includes a Gaussian component whose parameters are a centroid line-energy $E_{Gaussian}$, the width of the line $\sigma_{Gaussian}$, and the normalisation $N_{Gaussian}$ to fit the data in the $6-8$ keV range. The interstellar absorption can be modified by the *wabs* model in XSPEC with a column density N_H. The associated χ^2/d.o.f. obtained for this fit is 1255/1158.

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Table 1. Results deduced from modelling the spectrum

kT_{diskbb}(keV)	N_{diskbb}	$E_{Gaussian}$(keV)	$EW_{Gaussian}$(eV)	Γ_{PL}	N_{PL}
$0.34^{+0.03}_{-0.02}$	6146^{+5953}_{-3730}	$6.35^{+0.08}_{-0.08}$	322^{+44}_{-37}	$2.01^{+0.02}_{-0.02}$	$0.96^{+0.03}_{-0.03}$

3. Results

We fitted the spectrum of 4U 1608-52 with XIS/*Suzaku* data using the model of wabs∗(diskbb + Gaussian + powerlaw), which gave the best fit. The spectrum can be fitted well with that model (Fig. 1); we attribute that as a confirmation that the observation corresponds to the source being in the hard state. Those model results for this observation show that the multicolour disk blackbody has a temperature of $0.34^{+0.03}_{-0.02}$ keV, the photon power-law index is $2.01^{+0.02}_{-0.02}$ and the normalisation is $0.96^{+0.03}_{-0.03}$. The photo-electrical absorption is demonstrated by an equivalent hydrogen column of $N_H = 3.51^{+0.12}_{-0.12} \times 10^{22}\ cm^{-2}$. The broad Fe emission line with its central energy of $E_{Gaussian}$ $\sim 6.35^{+0.08}_{-0.08}$ keV is detected in the spectrum; its equivalent width is 322^{+44}_{-37} eV. More details of the results are shown Table 1.

4. Conclusions and Discussion

We have analysed the spectral properties of the NS X-ray binary 4U 1728-34 observed in X-rays using an observation from XIS/*Suzaku*. The model of a multicolour disk plus a power-law component constitutes the best model to fit the continuum spectrum.

The broad Fe emission line which is commonly seen in X-ray binaries is also detected in the *Suzaku* spectrum of 4U 1728-34. Nevertheless, there is still a dispute about that broad Fe emission line in 4U 1728-34.

An analysis of a simultaneous *Chandra* and *RXTE* observation of 4U 1728-34 by D'Aí *et al.* (2006) found no evidence of broad emission lines at 6–7 keV; large residuals at 6–10 keV can be fitted by a broad Gaussian emission line with *FWHM* ∼2 keV, or by two absorption edges associated with lowly-ionised Fe. However, recent analysis of high-resolution *XMM-Newton* spectra of 4U 1728-34 showed that residuals at 6–7 keV are clearly revealed with different spectral models, thus supporting the identity of the feature as a broad Fe emission line (Ng *et al.* 2010). Moreover, a broad Fe line at 6–7 keV is also detected in spectra from *BeppoSAX* and *RXTE* (Seifina & Titarchuk 2011).

Instead of the Gaussian line profile, a combination of an Fe line and the corresponding absorption edge can also be fitted well for the feature at 6–7 keV (Ng *et al.* 2010). It can also be modelled well with a relativistically smeared line component, or a relativistically smeared reflection model component (Egron *et al.* 2011). Being able to fit satisfactorily the broad emission feature in 4U 1728-34 with a variety of line models demonstrates that an explanation of its origin in this source is complicated.

Fitting a simple Gaussian profile to that broad feature at 6–7 keV is consistent with the analysis of *XMM-Newton* spectra. However, the central energy obtained from *Suzaku* is lower than that of *XMM-Newton*, and the equivalent width is larger than that of *XMM-Newton*. The different parameters of the line may be due to differences in the models of the continuum spectra. Further study is needed to explore such differences.

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