The low mass X–ray binary system 4U 1735–44

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Introduction

A low mass X-ray binary system consists of a compact object (e.g. a neutron star) and a main-sequence companion star with a mass around one solar mass. The compact object accretes matter via Roche lobe overflow and an accretion disc is formed around it. Close to the surface of the neutron star relativistic effects can be observed in the accretion disc. Such extreme conditions have an influence on both the spectral and the timing behaviour of a source. The most prominent spectral feature is a broad fluorescence iron line. Due to relativistic effects, like the relativistic doppler effect and the gravitational redshift, the line has a characteristic shape. The shape depends on the inner radius of the disc which can be used to constrain the radius of the neutron star to an upper limit. With the help of the kilohertz quasi–periodic oscillations (kHz QPO) also conclusions on the mass of a neutron star can be drawn. The frequencies of these QPOs can be related to the spin of the neutron star and the frequency of the keplerian orbit at the inner radius of the disc (e.g. Miller et al., 1998). The keplerian frequency depends on the radius and the mass of the compact object.

4U 1735–44 is a low mass X-ray binary with a neutron star. The companion star has a mass of $0.53 \pm 0.44\,M_{\odot}$ (Casares et al., 2006), the distance is 8.5 kpc (Galloway et al., 2008) and the orbital period was determined to 4.654 hr (Corbet et al., 1986). It was classified as an Atoll Source by Hasinger & van der Klis (1989). An iron line was reported by Ng et al. (2010) with an equivalent width of 46 eV. Two kHz QPOs were discovered by Wijnands et al. (1998) and Ford et al. (1998).

In the following we present the results of the timing and spectral analysis of several observations performed by BeppoSax, RXTE and XMM–Newton. Simultaneous observations with these satellites offer a detailed study of both the broad iron line and the kHz QPOs.

Used X–ray satellites: BeppoSax, XMM, XTE

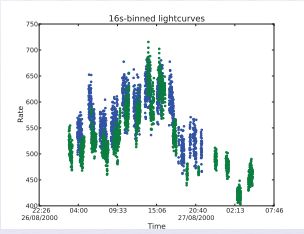
BeppoSax was an Italian–Dutch mission (1996–2002) which allowed to study the broad band spectrum from 0.1–300 keV with an effective area of 150 cm^2 at 6 keV and a spectral resolution of 8% FWHM (Boella et al., 1997). This broad energy coverage is provided by four instruments (LECS, MECS, HPGSPC, PDS). Four observations were performed in the year 2000 with a total exposure time of ∼115 ks (MECS).

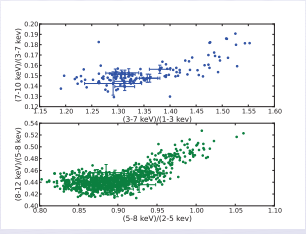
XMM–Newton (Mason et al., 2001) consists of three imaging X-ray telescopes, each with an effectiv area of 1500 cm^2 at 1 keV. A spatial resolution of 6″ is achieved. The three detectors, two EPIC–MOS cameras (0.1–10 keV) and one EPIC–PN camera (0.1–15 keV), provide a spectral resolution of E/ΔE of ∼50. We will present the results of the analysis of a 20 ks observation performed in 2001.

The Proportional Counter Array (PCA) aboard the NASA RXTE mission (1995–present) is able to perform observations with a time resolution of 1 μs in an energy range from 2–60 keV (Jahoda et al., 1996).

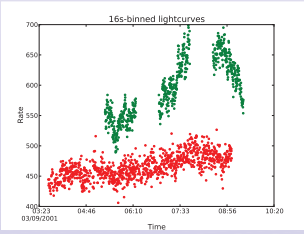
A 35 ks observation was performed simultaneously with one of the BeppoSax observations and another 25 ks observation covered the same period as the introduced XMM–Newton observation.

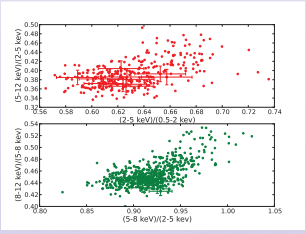
Observations





The lightcurves of BeppoSax (blue) and RXTE (green) are shown above on the left side. To illustrate the overlap and the variability, the BeppoSax count rate was multiplied by a factor of 10. The time binning for both lightcurves is 16 seconds. On the right side the Color – Color diagrams for both the BeppoSax (blue) and the RXTE (green) observation are shown. For BeppoSax one point represents 400 seconds and for RXTE one point is 16 seconds of observation time. To illustrate the error some errorbars are shown. The diagrams show that the source was in the so-called banana state of an Atoll source.



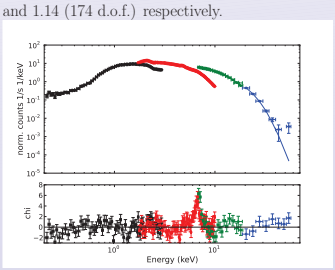


On the left side the lightcurves of the simultaneous observations of XMM–Newton (red) and RXTE (green) are shown. The XMM data was checked for pile up with the SAS tool EPATPLOT. The observation shows effects of pile up. To deal with this the inner three columns of the boresight were excluded for the extraction of the lightcurve. The time binning for both lightcurves is again 16 seconds. The Color – Color diagrams for XMM (red) and RXTE (green) are shown on the right side. One point for the RXTE observation represents again 16 seconds and for the XMM observation 64 seconds. The diagram shows that also during this observation the source was in the banana state.

Analysis

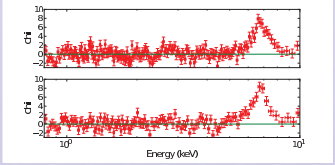
We analysed the first BeppoSax observation (performed in March 2000) with an exposure time of 39 ks (MECS). Data of all four instruments aboard of BeppoSax were fitted with the X-ray spectral analysis package XSPEC (Arnaud, 1996).

The spectrum was fitted with a combination of a blackbody from a multicolor disk (DISKBB in XSPEC, see Mitsuda et al., 1984) and a comptonization model by Titarchuk (COMPTT). The photo-electric absorption was modelled with WABS and a constant was introduced to take into account the different normalizations of the instruments (MECS is 1). A Gaussian line at 1.08 keV was also included to fit line-like residuals which can originate from Fe XVII or Fe XVIII. The iron fluorescence line was fitted by a GAUSSIAN with an equivalent width of 53 eV. The line was also fitted with a relativistic accretion disk model (DISKLINE, Fabian et al., 1989). Additionally, a systematic uncertainty of 0.5 % was applied to the model. The best-fit results are reported in the table below. The reduced χ^2 was 1.16 (188 d.o.f.) and 1.14 (174 d.o.f.) respectively.



Continuum		Iron Line	
nH (10^{22}cm^{-2})	0.27	GAUSSIAN	
DISKBB		LineE (keV)	6.70
T_{in} (keV)	0.92	Sigma (keV)	0.333
norm	172	norm	0.0023
COMPTT		DISKLINE	
T0 (keV)	1.33	LineE (keV)	6.61
kT (keV)	2.99	R_{in} (GM/c^2)	6.00
taup	12.9	Incl	64°
norm	0.238	norm	0.0034

The BeppoSax data give no significant evidence for a Gaussian or a relativistic broadened iron line. We also performed a spectral analysis of the introduced XMM observation. Since the observation was piled up we first removed the inner three columns of the boresight and performed then the analysis. To verify that there are no pile-up effects we also removed the inner five columns. The residuals are shown in the plot below (upper plot 3 columns, lower 5 columns removed). We can see that the shape of the line changes depending on the number of lines removed.



Parameter	3 columns	5 columns
GAUSSIAN		
LineE (keV)	6.70	6.65
Sigma (keV)	0.547	0.544
norm	0.0046	0.0493
DISKLINE		
LineE (keV)	6.68	6.67
R_{in} (GM/c^2)	6.00	6.07
Incl	56°	51°
norm	0.0042	0.0034

Conclusions & Outlook

We have shown that in the low mass X-ray binary system 4U 1735–44 a broad iron line is present. Whether this line is relativistically broadened cannot be excluded or confirmed with the help of the BeppoSax data. Also the XMM results show no significant evidence if the line is relativistic broadened or not (which was shown by Ng et al., 2010). A more detailed study of pile-up and its effects will be performed.

In the Color-Color diagrams as well as the presented lightcurves a good overlap of the BeppoSax and the RXTE as well as the XMM and the RXTE observations is confirmed. We have shown that the source was during all observations in the banana state of an Atoll source. The spectral changes along the path of the Color-Color diagram will be investigated for the BeppoSax and the XMM data.

A detailed timing analysis of the RXTE data will be performed to check for kHz QPOs and the timing behaviour in general. If kHz QPOs will be found a simultaneous study of the broad iron line and the kHz QPOs will be possible.

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