PROCEEDINGS OF SCIENCE

Testing reflection features in 4U 1705–44 with *XMM-Newton*, *BeppoSAX*, and *RXTE* in the hard and soft states

Elise Egron[*†]
Università di Cagliari - Italy
E-mail:
emailelise.egron@dsf.unica.it

Tiziana Di Salvo
Università di Palermo - Italy
E-mail: disalvo@fisica.unipa.it

Sara Motta
INAF-Osservatorio Astronomico di Brera - Italy
E-mail: sara.motta@brera.inaf.it

Luciano Burderi
Università di Cagliari - Italy
E-mail: burderi@dsf.unica.it

We perform a self-consistent study of the reflection component in the bright atoll source 4U 1705–44 using the data from *XMM-Newton*, *BeppoSAX*, and *RXTE*, both in the hard and in the soft state. Although the data selected are not simultaneous, the spectral decomposition is shown to be consistent among the different observations, when the source flux is similar. We have therefore selected observations performed at similar flux levels in the hard and soft states to study the spectral shape in these two states in a broad-band (0.1–200 keV) energy range, with good energy resolution, and using self-consistent reflection models. These reflection models provide a good fit for the X-ray spectrum both in the hard and in the soft state in the whole spectral range. We discuss the differences in the main spectral parameters we find in both states, providing evidence that the inner radius of the optically thick disk slightly recedes in the hard state.

"An INTEGRAL view of the high-energy sky (the first 10 years)" 9th INTEGRAL Workshop and celebration of the 10th anniversary of the launch,
October 15-19, 2012
Bibliotheque Nationale de France, Paris, France

[*]Speaker.
[†]This work was supported by the Initial Training Network ITN 215212: Black Hole Universe funded by the European Community.

PoS(INTEGRAL 2012)049

1. Introduction

The low-mass X-ray binary system 4U 1705–44 contains a weakly magnetized neutron star, which allows the accretion disk to extend down to the neutron star surface. This implies a similar configuration with respect to the one envisaged for accreting black holes, since the radius of the neutron star is close to the size of the innermost stable circular orbit (ISCO) of matter around a black hole. Similarities have been observed between these systems (7), suggesting common physical processes producing X-ray emission and similar properties of the accretion flow around the compact object.

Here we present the spectral analysis of the bright and persistent source 4U 1705–44 using data from *XMM-Newton*, *BeppoSAX*, and *RXTE* when the source was both in the hard state and in the soft state. Using the same spectral models to describe the source spectrum in both states, we aim at highlighting the differences in the spectral parameters.

2. Selection of the data

The light curve produced from the All-Sky Monitor onboard *RXTE* allow us to follow the evolution of the source flux for a period of ~ 16 years. 4U 1705–44 shows clear spectral transitions, from the hard (3 counts/s) to the soft state (25 counts/s). The source was observed by *XMM-Newton* on 2006 August 26 for an effective exposure of 34.7 ks, when the source was in the hard state. The corresponding RXTE/ASM count rate was 1 c/s. The second time, 4U 1705–44 was observed during the soft state (target of opportunity), on 2008 August 24 for a total on-source observing time of 45.2 ks. The RXTE/ASM was 19 c/s during this observation. Moreover, *BeppoSAX* performed observations of 4U 1705–44 in August and October 2000, for total on-source observing times of 43.5 ks and 47 ks, respectively. The count rates registered by the RXTE/ASM associated to these observations were 18 c/s and 3 c/s, respectively.

Since there was no simultaneous observation performed by *RXTE* during the *XMM-Newton* and *BeppoSAX* observations, we produced a color-color diagram (CD) from all the *RXTE* observations and a time-resolved CD from the two *XMM-Newton* observations using the same energy bands for the two instruments. We selected the *RXTE* observations that matched the *XMM-Newton* observations, both in the hard and soft states, as shown in Fig.1. In this way, the joint spectra from the three satellites cover the full $0.1 - 200$ keV energy range. The detail of the all the observations selected is given in (5).

3. The models applied

We performed a broad-band ($0.4 - 200$ keV) and moderately high-energy resolution spectral analysis of the X-ray burster 4U 1705–44 both in the soft and in the hard states using data from *XMM-Newton*, *BeppoSAX*, and *RXTE* observatories. This source is particularly interesting since it shows several reflection features observed at a high signal-to-noise ratio. In the *XMM-Newton* spectrum corresponding to the soft state, a strong Fe line has been detected at ~ 6.7 keV, in addition to other emission lines at 2.6, 3.31, and 3.90 keV associated with S XVI, Ar XVIII, and Ca XIX, respectively. We fitted these features with several models, from the simplest ones (e.g. Gaussian,

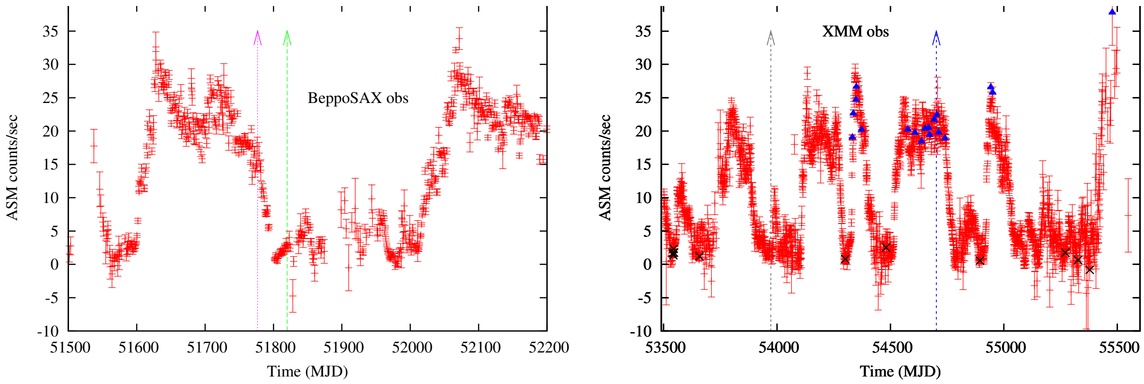

Figure 1: RXTE/ASM light curves of 4U 1705-44 from November 1999 to October 2001, and from May 2005 to November 2010. Left panel: The two arrows show the observations performed by *BeppoSAX* in August and October 2000. Right panel: The arrows mark the two *XMM-Newton* observations performed in August 2006 and 2008. The black crosses and the blue triangles represent the *RXTE* observations selected in the hard and soft state, respectively.

DISKLINE) to the most complex ones, such as self-consistent reflection models, in order to test the common origin of all these features. The aim is to see if they are all compatible with being produced by reflection of the primary Comptonization spectrum on the inner accretion disk. Here, we present the results obtained with the REFLIONX model, which gives the best $\chi^2_{\rm red}$. However, we applied other models such as XILLVER and PEXRIV to the whole dataset, which give also good results, in agreement with those obtained with REFLIONX (see (5)).

4. From the hard to the soft state

The main differences between the spectral parameters obtained from the soft and the hard states concern the electron temperature and the seed photon temperature of the Comptonized component, the inner radius of the disk as derived from the smearing of the reflection component, and the ionization of the reflection component.

We observe a clear difference in the spectral parameters from the soft to the hard state. The electron temperature increases from $kT_{\rm e} = 2-3$ keV in the soft state to $\sim 20-24$ keV in the hard state, whereas the power-law photon index and the temperature of the seed photons decrease from $\Gamma = 2.2-2.8$ to $\Gamma = 1.8$ and from $kT_{\rm seed} = 1.1-1.4$ keV to $0.7-0.8$ keV, respectively.

In the following, we discuss more in details the differences observed from one state to the other one as regards the iron line profile, the geometry of the accretion disk and the ionization parameter.

4.1 The iron line

In the soft state, the Fe line at 6.7 keV is associated with highly ionized Fe XXV, which is a triplet consisting of the following components: at $r = 6.700$ keV, $i_2 = 6.682$ keV, $i_1 = 6.668$ keV, and $f = 6.637$ keV. We also included a GAUSSIAN to consider the H-like Fe XXVI contribution of the Lyα transitions at $Ly\alpha_1 = 6.973$ keV and $Ly\alpha_2 = 6.952$ keV. Unfortunately, the resolution of *XMM-Newton* and *BeppoSAX* does not allow us to resolve the structure of the resulting line,

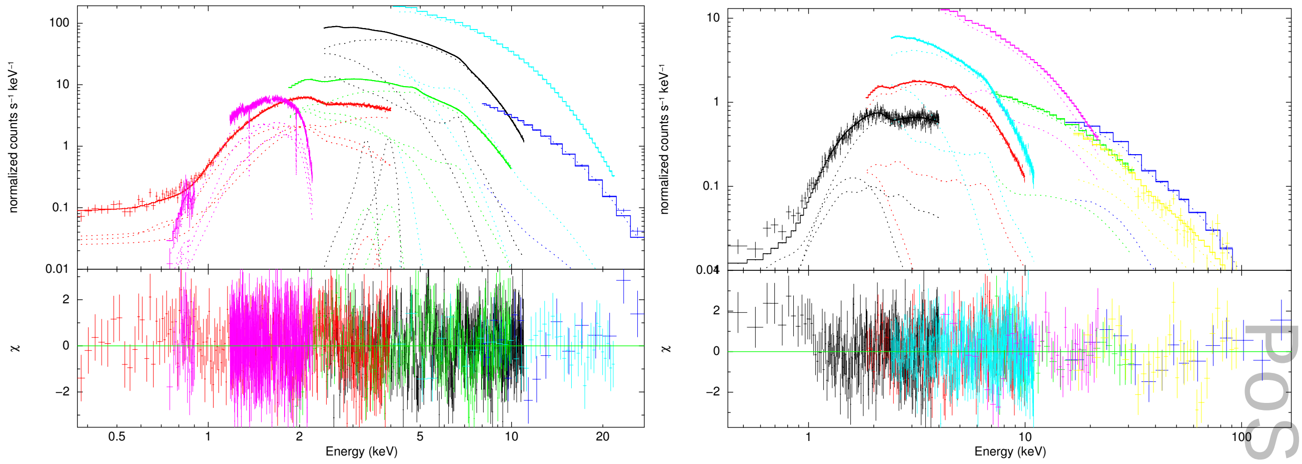

Figure 2: Spectra of 4U 1705–44 obtained with *XMM-Newton*, *BeppoSAX*, and *RXTE* in the soft and hard state. The bottom panels show the residuals (data-model) in unit of σ when the REFLIONX model is applied. Left panel: XMM/EPIC-pn (black), BeppoSAX/LECS (red), BeppoSAX/MECS (green), BeppoSAX/HPGSPC (blue), RXTE/PCA (cyan), XMM/RGS1 (magenta) data points in the range 0.3−30 keV, when 4U 1705–44 was in the soft state. Right panel: BeppoSAX/LECS (black), BeppoSAX/MECS (red), BeppoSAX/HPGSPC (green), BeppoSAX/PDS (blue), XMM/EPIC-pn (cyan), RXTE/PCA (magenta), RXTE/HXTE (yellow) data points in the range 0.4−200 keV, corresponding to the hard state.

which appears to be dominated by the intercombination line of the triplet, and this is why a single GAUSSIAN or a DISKLINE has been used to take all these components into account. It should be noted, however, that these lines are all included in the reflection models we used in our spectral analysis, and a further smearing was required to properly fit the line complex. Consequently, the iron line is consistent with being produced in the inner part of the accretion disk where the line profile is distorted by Doppler and by mildly relativistic effects relatively close to the compact object. At the inner disk radii we find, $R_{\rm in} \sim 10-17\,R_g$, the Keplerian velocities become mildly relativistic, and the Doppler boosting effect yields the blue-shifted horn (produced by matter coming in our direction) brighter than the red-shifted one (produced by receding matter).

In the hard state, the Fe emission line at $6.4-6.6$ keV is related to a low ionized Fe fluorescence line. The line does not present clear asymmetry anymore and is equally well fit by a GAUSSIAN or with the DISKLINE model. The apparent symmetry of the line may be due to the relativistic effects becoming less important farther from the compact object and/or to the lower statistics in the hard state. In both states, the broadening of the line is not as extreme as in the case of some black hole X-ray binaries or AGNs (11; 6). The Compton hump of the reflection component, however, is required with a very high confidence level to get a good fit of the data in the hard state.

4.2 Geometry of the accretion disk

In all the models, the RDBLUR component was needed to improve the fit. The mildly relativistic blurring was applied to the entire reflection spectrum, confirming the common origin of the reflection features in the inner part of the accretion disk, where strong relativistic effects broaden emission and absorption features. This component gives us information on the inner radius of the accretion disk, $R_{\rm in} = 10-16\ R_{\rm g}$ in the soft state, and $R_{\rm in} = 19-59\ R_{\rm g}$ ($R_{\rm in} = 26-65\ R_{\rm g}$ for the inclination fixed at 39°) in the hard state, so we have an indication that the accretion disk is close to the neutron star surface in the soft state and truncated farther from the compact object in the hard state. This agrees with (1) and (9), who interpret the transitions from one state to the other in this source with different truncation radii of the accretion disk. This is also a possible interpretation for black hole binaries that show clearer transitions from the soft to the hard state and vice versa (3).

The spectral state transitions are also associated with variations in the overall X-ray luminosity. We calculated the accretion rate in both states using the typical value of the accretion efficiency $\eta = 0.2$, corresponding to a neutron star ($M_{\rm NS} = 1.4\ M_\odot$ and $R_{\rm NS} = 10$ km), and to the bolometric luminosities inferred by our spectral modeling. In the soft state, $\dot{M}_{\rm SS} = 1.6\times10^{-8}\ M_\odot\ yr^{-1}$, while in the hard state the accretion rate decreases, $\dot{M}_{\rm HS} = 2\times10^{-9}\ M_\odot\ yr^{-1}$. This difference in the accretion rate is consistent with changes in the flow geometry, hence with a different inner radius of the accretion disk. The evaporation of the inner part of the accretion disk may lead to a truncated disk at low-mass accretion rates (8) .

We therefore infer a similar geometry to what has been proposed for black hole binaries where the accretion disk is truncated at low luminosity (2; 4); however, some differences should be observed between these systems, especially in the soft state, because of the boundary layer in the case of the neutron star binaries. And in fact we find that the disk is truncated in 4U 1705–44 relatively far from the compact object (at more than 10 R_g both in the soft and in the hard state) as is inferred by the fact that the observed distortion of the iron line profile is never extreme.

4.3 The ionization parameter

Reflection models give an indication of the ionization state of the matter in the inner part of the accretion disk: $\xi = 4\pi F_{\rm X}/n_{\rm H}$, where $F_{\rm X}$ is the total illuminating flux (erg cm^{-2} s^{-1}) and $n_{\rm H}$ is the hydrogen number density. We note that the matter is much more ionized in the soft state, $\xi = 3600$ erg cm s^{-1}, in comparison with $\xi = 210$ erg cm s^{-1} in the hard state. This again agrees with the disk-reflection scenario for a truncated disk and with a lower illuminating flux in the hard state. When the accretion rate is high, the disk penetrates the hot flow, favoring the interactions between the inner disk and the illuminating flux and resulting in a high ionization and of the matter in the disk and, possibly, in a high reflection amplitude (10). In contrast, when the accretion rate is low, the disk is truncated farther from the compact object, disk matter is less ionized, and the amount of reflection is intrinsically low (2). This is consistent with the observed energy of the iron line found in the soft state, $E_{\rm Fe} = 6.6-6.7$ keV, and in the hard state, $E_{\rm Fe} = 6.4-6.5$ keV.

5. Conclusions

From our analysis, we inferred the main parameters of the inner accretion disk. In particular, we found (i) the inclination of the system with respect to the line of sight that is constrained in the range $35-41°$, (ii) the inner radius of the disk that increases from $10-16\ R_{\rm g}$ in the soft state up to $26-65\ R_{\rm g}$ in the hard state, and (iii) the ionization parameter that decreases from ~ 3600 erg cm s^{-1} in the soft state to 210 erg cm s^{-1} in the hard state. We also find an indication of an iron overabundance by a factor 2–3 with respect to its solar abundance. All these results appear

PoS(INTEGRAL 2012)049

to be strong against the particular reflection model used to fit these features and against possible distortion caused by photon pile-up in the XMM-Newton/EPIC-pn CCDs.

We have also discussed the differences in the spectral parameters between the soft and the hard states. The results found are consistent with the following scenario. At low luminosity, the accretion disk is truncated farther from the neutron star, so the interaction efficiency of the disk photons with the hot electrons of the corona is lower. The rate of photons coming from the disk is also lower because of the cooler temperature of the disk. This results in a hard spectrum and a low-ionization reflection. At higher luminosity, the mass accretion rate increases and the inner radius of the disk moves closer to the compact object. The soft photons from the disk are much more efficient at cooling the corona, resulting in a softer spectrum. In addition to this, reflection increases due to a stronger irradiation of the disk, and the matter becomes more ionized. Moreover, the emission lines are broadened by stronger Doppler effects as the disk approaches the compact object.

This scenario is generally well supported by the timing analysis through power density spectra where correlations are observed between the characteristic frequencies of the fast time variability and the position of the source in the CD or in its spectral state (9), with characteristic frequencies increasing when increasing the inferred mass accretion rate.

References

[1] Barret D. & Olive J. F. 2002, ApJ, 576, 391

[2] Barrio F. E., Done C., Nayakshin S. 2003, MNRAS, 342, 557

[3] Done C., Gierlinski M., Kubota A. 2007, A&A Reviews, 15, 1

[4] Done C. & Diaz Trigo M. 2010, MNRAS, 407, 2287

[5] Egron E., Di Salvo T., Motta S. et al. 2012, arXiv:1211.2933, to appear in A&A

[6] Fabian A. C., Zoghbi A., Ross R. R. et al. 2009, Nature, 459, 540

[7] Maccarone T. J. 2012, arXiv:1204.3154

[8] Meyer F., Liu B. F., Meyer-Hofmeister E. 2000, A&A, 361, 175

[9] Olive J. F., Barret D., Gierlinski M. 2003, ApJ, 583, 416

[10] Poutanen J., Krolik J. H., Ryde F. 1997, MNRAS, 292, 21

[11] Reis R. C., Fabian A. C., Ross R. R. et al. 2009, MNRAS, 395, 1257

PoS(INTEGRAL 2012)049