Spectral variability of Cyg X-1 using INTEGRAL data

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The studies of the spectral states are an important diagnostic tool of the black hole binary systems and Cyg X-1 is one of the most well analyzed objects in this aspect. We present a novel approach, using the 13-years INTEGRAL data of Cyg X-1 for the spectral identification based on the hard X-ray emission, which results in a more unambiguous selection between the hard and soft spectral states. Based on this classification, the INTEGRAL/ISGRI data were split into 12 groups (substates) with a similar total exposure time. The ISGRI spectra of each substate were analyzed together with contemporary INTEGRAL/JEM-X spectra using two advanced Comptonization models. The spectral analysis allowed us to find a correspondence between the physical model parameters of the system and the phenomenological classification based on the ISGRI count rates. In particular, we investigated the evolution of the thermal and non-thermal plasma properties on the hard X-ray hardness ratio.

1 Introduction

Cyg X-1 is a prototype of the high-mass X-ray binaries, because of its high X-ray brightness and close proximity to us. The spectra of this system are separated into three main spectral states: *hard*, *soft* and *intermediate* (Tananbaum et al., 1972), connected to different geometries of the accretion disk. The study of its spectral variability and their classification can give us insights about the plasma's physical properties and the system's geometry.

The aim of our work is to perform spectral analysis of the Cyg X-1 INTEGRAL/ISGRI (INTEGRAL Soft Gamma-Ray Imager) and INTEGRAL/JEMX (The Join European X-ray Monitor) data using thermal and hybrid Comptonization models. Such an analysis will provide insights into the physical processes taking place at each spectral state. Such a study will also monitor the evolution of the plasma's physical parameters, e.g. the hardness ratio defined as the count rate ratio in the [40,100] keV band over the [22,40] keV band.

2 Data

The available INTEGRAL/ISGRI data span a period of 13 years with a total exposure time of 15 Ms. In Fig. 1 left panel, we present the light curve in the $22-100$ keV band using all the good quality data. Usually Cyg X-1 is monitored with INTEGRAL twice a year with campaigns lasting several months. Cyg X-1 is known to be a persistent source, spending most of the time in the hard spectral state. The periods with a low count rate around 2011 and between $2012-2015$ correspond to

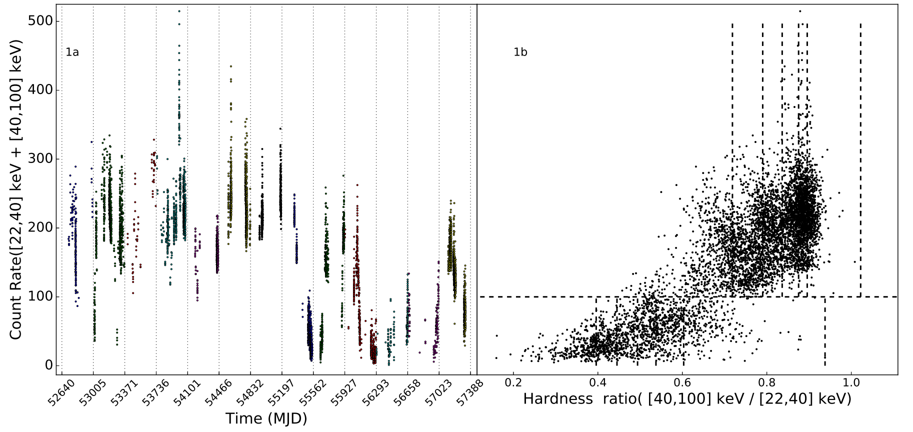

Fig. 1: Left panel: The [22,100] keV light curve of Cyg X-1 over the 13 years of INTEGRAL/ISGRI observations. Each verical lines marks the beginning of a year. Right panel: The hardness intensity diagram of Cyg X-1 using the same data as for left panel.

the soft spectral state. The diamond shaped points in the above figure correspond to the flare observed between MJD 54002-54005 (Malzac et al., 2008).

3 Spectral state classification

We have chosen a simple criterion of 100 cps (counts per second) to disentangle the hard and soft states of the INTEGRAL/ISGRI 22 – 100 keV data (Fig. 1 right panel). It was set that the hard state points are those with higher than 100 cps, otherwise they belong to the soft state. The hardness ratio was defined as the [40,100] keV/[22,40] keV count rate ratio. To study the spectral evolution within a given state, each state was split into six substates with similar total exposure times. Hybrid Comptonization models implemented in the XSPEC (Arnaud, 1996) package were fitted to the summed spectrum of each substate (Fig. 2 left panel). This figure also illustrates the selection power of the classification based on the hard X-ray bands. The region between the red lines corresponds to the soft X-ray RXTE/ASM band between 1.5 – 12 keV, used in some classifications of the Cyg X-1 spectral states. The blue lines mark the 22 – 100 keV hard X-ray INTEGRAL/ISGRI region, used in our work.

The choice of thishard X-ray energy range and these physical models, provides a more distinct separation between the two main spectral states (soft, hard) compared to earlier classifications (red lines in Fig. 2 left panel, based on soft X-ray RXTE/ASM data at 1.5 – 12 keV (Zdziarski et al., 2002), (Grinberg et al., 2013) or on MAXI data at 2 –10 keV (Grinberg et al., 2013).

4 Spectral analysis

The summed spectrum of each substate was fitted with the thermal COMPPS (Poutanen & Svensson, 1996) and hybrid EQPAIR (Coppi, 1999) models. This

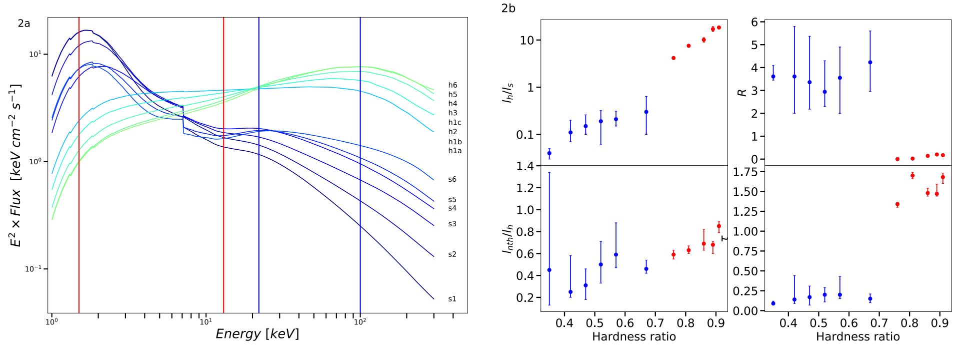

Fig. 2: Left panel: As described in the text, the red/blue lines mark the ASM the INTEGRAL/ISGRI energy range respectively, used for classification. Right panels: The evolution of some selected EQPAIR physical parameters as hardness increases. The blue/red points correspond to the soft/hard state respectively.

part of our study, helped us to investigate the evolution of the physical parameters of the system. In Fig. 2 right panels, we present the evolution of several EQPAIR parameters, such as the ratio of the hard to soft compactness ($l_{\rm h}/l_{\rm s}$), the fraction of the power that accelerates non-thermal particles ($l_{\rm nth}$), the plasma optical depth (τ) and the Compton reflection amplitude (R).

5 Conclusions

We found that the phenomenological classification of the Cyg X-1 spectral states based on the hard X-ray count rates allows for a more decisive identification of the states than the ones based on the soft X-rays. In addition, a thorough spectral modeling shows that the hard X-ray categorization unambiguously corresponds to distinct physical parameters values of the Cyg X-1 spectra determined for different states. Our analysis is still in progress. Single pointing spectra are being analyzed and we expect the results will add more information about the physical properties of the system corresponding to each state. Furthermore, we are working on a method to convert the INTEGRAL/ISGRI parameters into SWIFT/BAT parameters for the state classification. We are also testing an alternative version of the above mentioned models with an additional soft excess component.

Acknowledgments

AF and PL have been supported by the Polish National Science Center (NCN) grant UMO-2014/13/B/ST9/00570. AAZ has been supported by the Polish NCN grant 2015/18/A/ST9/00746.

References

Arnaud, K. A., in G. H. Jacoby, J. Barnes (eds.) Astronomical Data Analysis Software and Systems V, *Astronomical Society of the Pacific Conference Series*, volume 101, 17 (1996)

Coppi, P. S., in J. Poutanen, R. Svensson (eds.) High Energy Processes in Accreting Black Holes, *Astronomical Society of the Pacific Conference Series*, volume 161, 375 (1999)

Grinberg, V., et al., *A&A* **554**, A88 (2013)

Malzac, J., et al., *A&A* **492**, 527 (2008)

Poutanen, J., Svensson, R., *ApJ* **470**, 249 (1996)

Tananbaum, H., et al., *ApJL* **177**, L5 (1972)

Zdziarski, A. A., Poutanen, J., Paciesas, W. S., Wen, L., *ApJ* **578**, 357 (2002)