Cygnus X-1: shedding light on the spectral variability and polarization of black holes


We present an analysis of extensive recent monitoring observations of the black hole HMXB Cygnus X-1 obtained as part of the 2007 to 2011 Key Programme (KP) observations of the INTEGRAL mission. Cyg X-1 is one of only three supergiant black hole binaries in our galaxy that spend most of their time in the hard spectral state.

After spending 3 years in the hardest regime of its parameter space, the source displayed a softening and flaring episode in mid 2009, endured a soft state in early 2010 June and entered a transitional phase in April 2011. While the hard X-ray spectrum of Cyg X-1 is one of the best studied examples of its kind, e.g. through our monitoring campaign with RXTE and coordinated radio observations with AMI (formerly: flyte), the INTEGRAL monitoring allows us to study the spectral evolution from about half an hour over a few days to weeks, timelines that have been only sparsely sampled so far. The parameter ranges for the hard and soft states as well as the transitional phases are constrained. These measurements are of special importance for understanding the physics of the hot plasma in the jet base and to extend the X-ray timing analysis for Cyg X-1 to the soft state.

Abstract

The source spent the first three years of the KP in an extraordinarily hard state (see Nowak et al., 2011), interrupted only by a radio flaring episode in mid 2009, which was not seen in the BAT lightcurve. In June 2010 it entered the soft state (Grinberg et al., 2010), which continued until April 2011 (Grinberg et al., 2011). In the figure, the radio flare is indicated by a red star. The hard to soft state transition in blue and the soft state in red. Since December 2009 (revolution 877 and after) the Cyg X-1 KP is carried out with a random pattern, which is the standard for the soft state, and in the INTEGRAL revolution 0628, as the source is in the JEM-X field of view in every KP ScW, as well as in three artificial features (as visible as straight patterns between the mosaic in the previous box) during the image reconstruction for ISGRI.

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Cyg X-1 data from the whole mission have been used for the polarization studies conducted by Laurent et al. (2011), which led to the discovery of polarized gamma-ray emission from the source. Overall, 5 Ms observations of Cyg X-1 between 2003 and 2009, when the source was mostly in the hard state, yielded the standard INTEGRAL IBIS spectra presented in the text. Clearly shows a thermal Comptonization component as well as a high energy component of disputed origin which can be described with a power law with a photon index of 1.6 ± 0.2. Cadolle Bel et al. (2006) observed this component with the SPI instrument onboard INTEGRAL. The existence of two distinct components is consistent with the presence of different emission processes.

Spectral Models

We extracted ISGRI spectra for all ScWs during the Cyg X-1 KP using OSA 8. We added spectra for every revolution (~3 days) to achieve a better signal to noise ratio and used a 2% systematic error for fitting as recommended in the cookbook.

Good fits are achieved using both the spherical cuttoptl model (left panel) and the simple Comptonization model cutoptl (right panel). Both models have been used in the literature (see Cadolle Bel et al., 2006, for INTEGRAL data and Wilms et al., 2006, for RXTE data) and result in fits of comparable quality (leafpoint box). We expect the photon temperature to remain in the range of ~1 keV (e.g. Wilms et al., 2006), so it cannot be constrained in ISGRI spectra and has therefore been fixed to 1 keV.

Polarization

Using INTEGRAL/IBIS as a Compton polarimeter (e.g. Forot et al., 2007), the polarization signal of the two spectral components, i.e. the polarization signal in the 250–400 keV (middle panel) and the 400 keV to 2 MeV (right panel) band, can be measured.

The results obtained by Laurent et al. (2011) show that the emission in the 250–400 keV region is not significantly polarized with an upper limit of 20% for the polarization fraction, as expected for a Comptonization region. The emission in the 400 keV to 2 MeV is strongly polarized with a polarization fraction of 30% ± 5%. Such a high degree of polarization can only be achieved if the magnetic field is stable over a large fraction of the emission site, which in turn can be used to study the intrinsic polarized emission. The source is not yet able to do this, but it is still possible to observe the polarization signal of the gamma-ray emission in this energy range, consistent with recent studies of Cyg X-1 in the mid-infrared band.

Outlook

The low count rates in the soft state prevent us from constraining the spectral parameters in revolution-wise summed data well. We are therefore investigating the possibility of using the whole data set from a few to a few tens of thousands of revolutions to improve the constraint. The inclusion of the JEM-X field (with a better coverage due to the random pointing strategy) and SPI data will enable us to extend the analysis both to higher and lower energies and therefore to investigate the behaviour below the soft break at ~ 10 keV, which has been seen e.g. in RXTE and Suzaku data (Wilms et al., 2006; Nowak et al., 2011) and the hard tail.