Short term X-ray rms variability of Cyg X-1

T. Gleissner¹, J. Wilms¹, K. Pottschmidt²,³, P. Uttley⁴, M.A. Nowak⁵ and R. Staubert¹
¹ Universität Tübingen, IAAT – Abt. Astronomie, Sand 1, 72076 Tübingen, Germany
² Max-Planck-Institut für extraterr. Physik, Postfach 1312, 85748 Garching, Germany
³ INTEGRAL Science Data Center, 16, Chemin d’Écogia, 1290 Versoix, Switzerland
⁴ Department of Physics and Astronomy, University of Southampton, Southampton S017 1BJ, UK
⁵ MIT-CXC, NE80-6077, 77 Massachusetts Ave., Cambridge, MA 02139, USA

Abstract. A linear dependence of the amplitude of broadband noise variability on flux for GBHC and AGN has been recently shown by Uttley & McHardy [1]. We present the long term evolution of this rms-flux-relation for Cyg X-1 as monitored from 1998–2002 with RXTE. We confirm the linear relationship in the hard state and analyze the evolution of the correlation for the period of 1996–2002. In the intermediate and the soft state, we find considerable deviations from the otherwise linear relationship. A possible explanation for the rms-flux-relation is a superposition of local mass accretion rate variations.

1. Data Analysis

The Cyg X-1 data presented here were obtained by the PCA onboard RXTE, mostly gained through our monitoring campaign 1998–2002 (for a description of the data see [2]). We split each light curve into segments of 1s length and determine the mean flux of each segment. The segments are binned into 41 equally segmented flux bins, for each of which we calculate the power spectral density (PSD) of all contained light curve segments via the DFT (see, e.g., [3, 4]). From all periodograms of each flux bin the mean PSD is determined using standard methods. For better statistics we chose to take into account only flux bins containing at least 20 periodograms. Integrating the Poisson noise corrected PSD over the range $\nu = 1–32$ Hz, we arrive at the squared fractional rms variability. In a next step we multiply the fractional rms variability by the mean flux of the bin, to obtain the absolute rms variability $\sigma$.

2. rms-flux-Relation

For all bins of each observation we plot $\sigma$ over flux $F$ and fit a linear function in two different representations. By fitting $\sigma = kF + a$, two characterizing values are determined: slope $k$ and intercept $a$ on the $\sigma$ axis. The gradient of the $\sigma$-F-trend $k$ is equivalent to the fractional rms variability of the light curve.

Alternatively to intercept $a$, it was proposed to determine the physically meaningful intercept $C$ on the $F$ axis by fitting $\sigma = k(F - C)$ [1]. If $k$ is interpreted as the variable component of the lightcurve, then $C$ represents a second component
of it which does not follow the linear $\sigma$-$F$-trend. In deriving results, it should be kept in mind that $C$, which is identical to $-a/k$, and $k$ are not independent values for the characterization of the rms-flux-relation. Generally, there is a good linear relationship between $\sigma$ and $F$ in the hard state, which is reflected by the stable Pearson correlation coefficient in Fig. 1. We also notice coincidence of the change of the general long term behavior of Cyg X-1 from a “quiet hard state” to a “flaring hard state” in 1998 May [2] with a shift in the values of slope $k$ and the intercepts.

3. **In the Soft State and during “Failed State Transitions”**

The shape of the rms-flux-relation in the soft states of 1996 and 2001/2002 changes continuously between waviness and approximate linearity (see Fig. 2).

During “failed state transitions” (FST), i.e., during times when the source reached its intermediate state [2, 5], the linear rms-flux relation breaks down. We examined four FST: 1998 July 15, 1999 Dec 05, 2000 Nov 03, and 2001 Jan 29 (indicated in Fig. 1 by dotted lines). Comparing these events with the neighboring hard state observations, we notice that the rms-flux-relations of 1999 December 05 and 2000 November 03 – being strictly linear before and after – change to an arch-
4. Discussion and Conclusions

An explanation of the rms-flux-relation seems to be the modification of a theory which explains the PSD of GBHC by the superposition of accretion disk (AD) instabilities occurring at several radii in the AD that are propagated towards the innermost region of the disk \[6,7\]. Local ˙\(M\) variations, which are caused by short term changes of the disk viscosity and whose time scale is dependent on radius, are superimposed on long term ˙\(M\) modulations. If the fractional amplitude of the ˙\(M\) variations is independent of the long term ˙\(M\), a linear flux-rms relation will be observed \[1\]. The rms-flux-relation will break down if the corona is severely disturbed. This seems to be the case during the intermediate state of Cyg X-1, in agreement with earlier results for the behavior of X-ray time lags \[8\]. Here, the observed X-ray time lag is much larger than during the normal hard state, which could indicate changes in the geometry of the AD corona, possibly related to the observed radio emitting outflow.

References

1. Uttley, P., & McHardy, I. M., 2001, MNRAS, 323, L26
2. Pottschmidt, K., Wilms, J., Nowak, M. A., et al., 2002, A&A, submitted (astro-ph/0202258)
3. Nowak, M. A., Vaughan, B. A., Wilms, J., et al., 1999, ApJ, 510, 874
4. Nowak, M. A., 2000, MNRAS, 318, 361
5. Belloni, T., Mendez, M., van der Klis, M., et al., 1996, ApJ, 472, L107
6. Lyubarskii, Y. E., 1997, MNRAS, 292, 679
7. Churazov, E., Gilfanov, M., & Revnivtsev, M., 2001, MNRAS, 321, 759
8. Pottschmidt, K., Wilms, J., Nowak, M. A., et al., 2000, A&A, 357, L17