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RXTE Monitoring of LMC X-3: Recurrent Hard States

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Abstract. The black hole candidate LMC X-3 varies by a factor of four in the soft X-rays on a timescale of 200 or 100 days (Cowley et al., 1991). We have monitored LMC X-3 with RXTE in three to four week intervals starting in December 1996, obtaining a large observational database that sheds light on the nature of the long term X-ray variability in this source. In this paper we present the results of this monitoring campaign, focusing on evidence of recurring hard states in this canonical soft state black hole candidate.

INTRODUCTION

Long-term X-ray variability on timescales of months to years is seen in many galactic black hole candidates. In analogy to the 35 d cycle of Her X-1, this variability has been identified with the precession of a warped accretion disk in some objects. Possible driving mechanisms include radiation pressure (Maloney, Begelman & Nowak, 1998; Wijers & Pringle, 1999) or accretion disk winds (Schandl, 1996). In this paper we present a spectral and temporal analysis of the long term variability of the canonical soft state black hole candidate LMC X-3. Together with LMC X-1, this source is the only persistent black hole candidate which so far has only been observed in the soft state. While LMC X-1 does not exhibit any long term variability, LMC X-3 was known to be variable on a ~ 100 d timescale (Cowley et al., 1991, 1994). Detailed results of our campaign are presented elsewhere (Wilms et al., 1999b).

LONG TERM VARIABILITY

Our analysis of the long-term RXTE All Sky Monitor light curve (Fig. 1, top) indicates a complex long term behavior. Analysis with the Lomb (1976)-Scargle (1982) Periodogram indicates that the variation is dominated by epochs of low luminosity, which are recurring on the ~ 100 d timescale found previously (Cowley et al., 1994). In addition, a long term periodicity is apparent in the data. Contrary to the 100 d timescale, the long term periodicity is not stable: Depending on what time interval of the ASM light curve is studied, the long term period varies between 200 and 300 d. This periodicity is caused by the times of average to high luminosity seen in the light curve and manifests itself by a broad peak at ~ 250 d in the Lomb Scargle PSD.

SPECTRAL VARIABILITY

We have analyzed the RXTE data using the newest RXTE `ftools`, as well as `XSPEC`, Version 10.00ab. The spectral model used for the data analysis was the standard multi-temperature disk blackbody (Mitsuda et al., 1984; Makishima et al., 1986), plus a power-law component. Adding a Gaussian iron line resulted in upper limits for the line equivalent width only. Typical reduced χ^2 values were $\chi^2_{\text{red}} < 2.5$ for 41 degrees of freedom, with the residuals being fully consistent with the uncertainty of the detector calibration (Wilms et al., 1999a,b).

In Fig. 1 we present the variation of the spectral parameters found during the analysis as a function of time. During episodes of high ASM flux, the source behaves like any other source in the classical soft state: The accretion disk temperature, kT_{in} varies freely to accommodate the variable luminosity of the source, while the the normalization of the multi-temperature disk black body is constant. At the same time, the photon index Γ varies independently of kT_{in} . See, e.g., Tanaka & Lewin (1995) for similar examples in other soft state black hole candidates.

On the other hand, for times of low ASM count rate, the disk temperature decreases to $kT_{\text{in}} \ll 1$ keV from its usual value of ~ 1 keV, while at the same time the photon index changes dramatically from ~ 4 to ~ 1.7 . We interpret these changes as evidence for transitions to the hard state in LMC X-3.

HARD STATES IN LMC X-3

Fig. 2 displays the spectral evolution of LMC X-3 from 1998 June through August. In Obs28 the source had the lowest flux of all monitoring observations. No evidence for a soft spectral component is present in the data, the spectrum is consistent with a pure power-law spectrum with photon-index 1.8. After Obs28, the soft component slowly emerged until the standard soft state spectrum is reached.

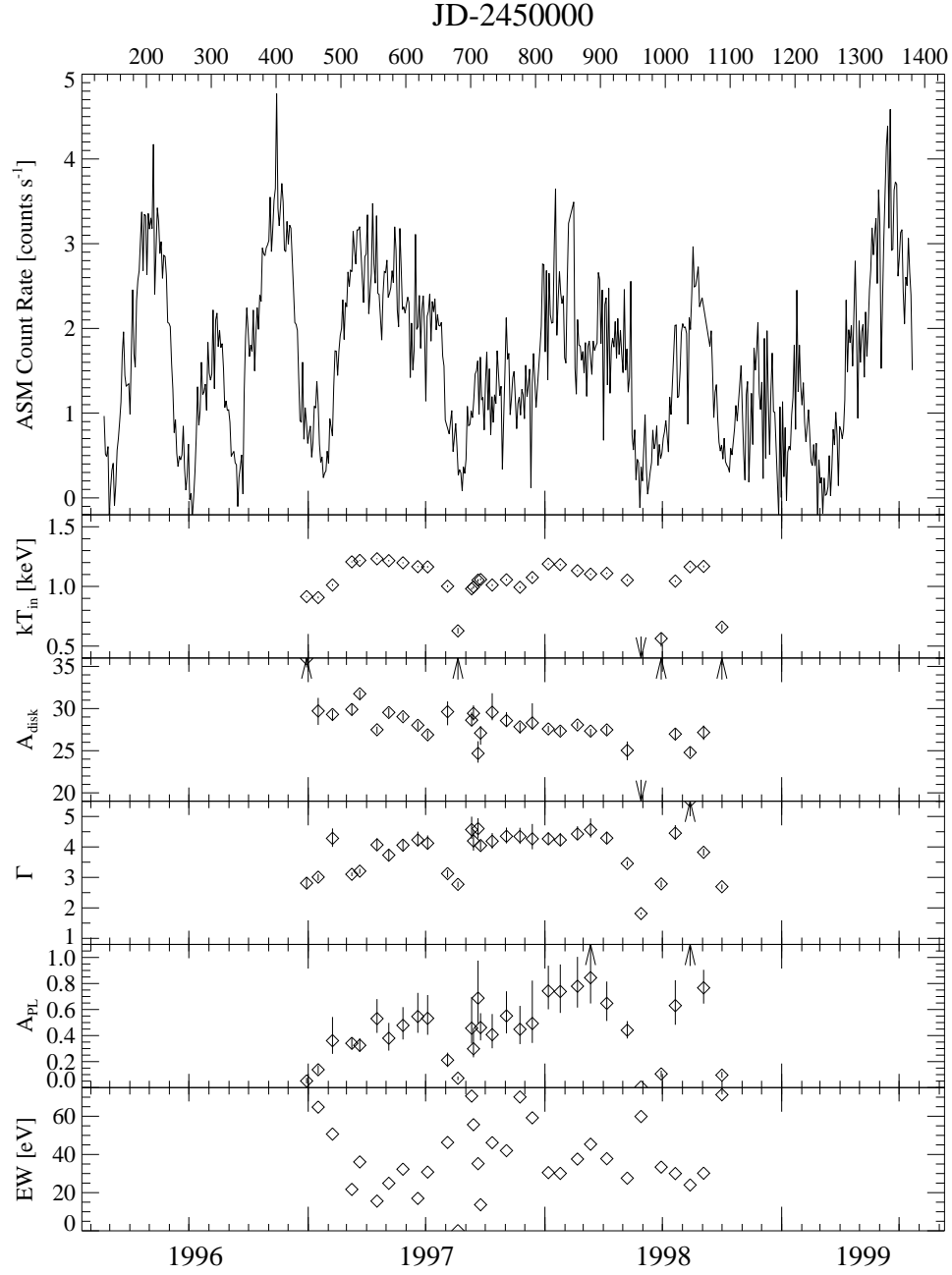


FIGURE 1. Temporal variability of the spectral parameters of LMC X-3. Note that the power law is harder and the inner disk temperature is smaller during the recurring episodes of low source luminosity.

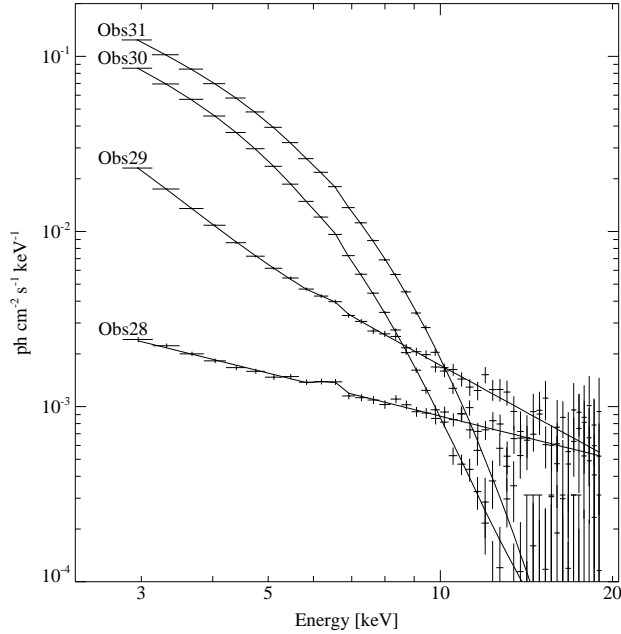


FIGURE 2. Spectral evolution from the hard state of 1998 May 29 (JD=2450962; Obs28) to the normal soft state spectrum in 1998 July and August (Obs30 and Obs31). Shown are the unfolded photon spectra, the lines denote the best fit model.

DISCUSSION AND CONCLUSIONS

We have presented the results from the first two years of our RXTE campaign on LMC X-3. This is the first campaign where a systematic study of a soft state black hole candidate with monthly coverage was possible (earlier campaigns, such as those of Cowley et al., 1991; Ebisawa et al., 1993, suffered from the inflexible pointing constraints of the earlier satellites). We have found that the long-term luminosity variations are due to changes in the spectral shape of the source, for large luminosity these changes are due to a variation of the characteristic disk temperature, kT_{in} , while for small luminosity the source undergoes a spectral hardening. We have presented the first clear case for a soft to hard state transition in this canonical soft state black hole candidate.

Our results are a challenge to models in which the long term variability of sources such as LMC X-3 is explained in the context of warped accretion disk models. In these models, no clear spectral evolution with source intensity is expected, with the exception of possible changes in N_{H} due to covering effects. In black hole candidates such as Cyg X-1, the hard- to soft-state transitions are attributed to changes in the accretion disk geometry, e.g., the (non-) existence of a hot and Comptonizing electron cloud in the center of the source. These changes are typically attributed to a varying mass accretion rate, \dot{M} . Our result makes such a geometry also probable for LMC X-3. A possible cause for the quasi-periodicity of the soft to

hard transitions, therefore, might be periodic changes in \dot{M} .

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