ERRATIC VARIABILITY OF LMC X-1 IN THE 1.5-10 KEV RANGE. SPORADIC PRESENCE OF A QPO IN A BLACK HOLE CANDIDATE.

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ABSTRACT

We observed LMC X-1 on October 5-6 1997 with *BeppoSAX*. The analysis of erratic variability yielded a power–law red noise with frequency index α=0.86±0.05. Marginal evidence of a QPO centered at 0.075±0.007 Hz, with a power corresponding to 5±2.2% was found. These results are in good agreement with those from *GINGA* 1987 measurements (Ebisawa et al. 1989). Recently Schmidtke et al. (1999) failed to detect QPOs in 9 observations performed in 1996 with *RXTE*. The presence of QPOs in the power spectrum of LMC X-1 appears sporadic.

KEYWORDS: Stars: individual: LMC X-1; Stars: binaries; X-rays: stars

1. INTRODUCTION

LMC X–1 is, together with Cyg X–1 and LMC X–3, a persistent X–ray binary where the presence of a black hole is established by the accurate measurement of the mass function. After the identification of the optical counterpart (Cowley et al. 1995), an orbital period of 4.2 d was measured. The mass function $f(M) = 0.14M_\odot$ implies a mass of the compact star $M_\mathrm{X} \simeq 6M_\odot$, indicative of a black hole (e.g. Hutchings et al 1983).

The spectrum of LMC X–1 was studied in detail with *GINGA* (Ebisawa et al 1993) and was modeled using a superposition of a multicolour disk black body (DBB) and a power–law high energy tail (PL). Ebisawa, Mitsuda and Inoue (1989) detected in the 1.2-15.7 keV count rate from *GINGA* the presence of quasi–periodic oscillations (QPOs) with a centroid frequency of 0.0751±0.0009 Hz and an amplitude of 2.9±0.2%. In addition a red noise continuum component $P(f) \propto f^{-\alpha}$ appeared in the Power Spectral Density (PSD) with a slope $\alpha = 0.81 \pm 0.12$. The recent *RXTE* observations of Schmidtke, Ponder and Cowley (1999) failed to detect QPOs in nine observations from February 1996 to October 1996, while the prominent red noise was confirmed. The 3σ upper limits for QPOs were between 0.2 and

CP599, *X-Ray Astronomy*, edited by N. E. White et al.

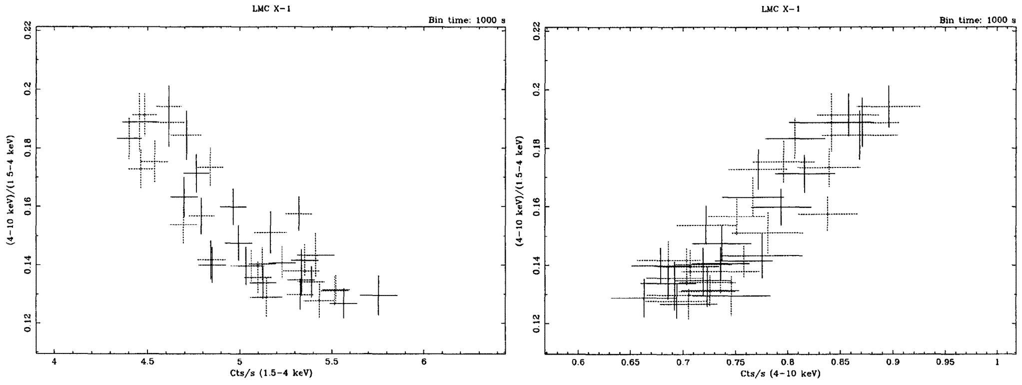

FIGURE 1. *Left panel:* hardness ratio versus 1.5–4 keV count rate. *Right panel:* hardness ratio versus 4–10 keV count rate (see text).

1.8%.

We report on temporal variability of LMC X–1 measured during a *BeppoSAX* observation performed on October 5/6, 1997. Preliminary results on the spectral analysis are reported in Treves et al. 1999. A complete presentation will be given in a forthcoming paper (Haardt et al. 1999 in preparation).

2. DATA ANALYSIS AND RESULTS

The MECS source count rate shows the known erratic variability of this source. In Figure 1 the colour versus intensity diagrams for two MECS energy bands (1.5–4 and 4–10 keV), binned on 1000s, show evidence of correlation. The spectral hardness correlates positively with the count rate in 4–10 keV and anti–correlates with the count rate in 1.5–4 keV. This differs from the behaviour observed by Schmidtke et al. (1999), where no correlation between colour and "soft" count rate was detected. A natural explanation of our observation is that the source spectrum is pivoting. Assuming a two–component spectral model this implies that the disk blackbody is anticorrelated with the power law component. We analyzed the temporal variations in the X–ray flux from LMC X–1 by calculating a Power Spectral Density (PSD) on the 1.5–10 keV count rate. 16 uninterrupted time intervals were selected, with a typical duration of 3000s. One PSD for each of these data run was calculated and the resulting spectra were averaged. The logarithmically rebinned averaged spectrum in coarse frequency bins is shown in Figure 2, left panel. The PSD is normalized to have its expected value for a purely white noise equal to 2 (Leahy et al. 1983), this holding when instrumental and dead time effects are negligible. In Figure 2 a fit with a power law plus constant is also shown. The value of the observed slope α is completely consistent with those obtained in previous measurements (Ebisawa et al 1989, Schmidtke et al. 1999).

In order to search for the presence of QPOs, we analysed the PSD using a linear rebinning, with an optimal choice to detect the QPOs at the expected frequency, if present. A visual inspection of this linearly rebinned PSD shows a possible power excess at a frequency compatible with the measure of Ebisawa et al. (near 7×10^{-2}

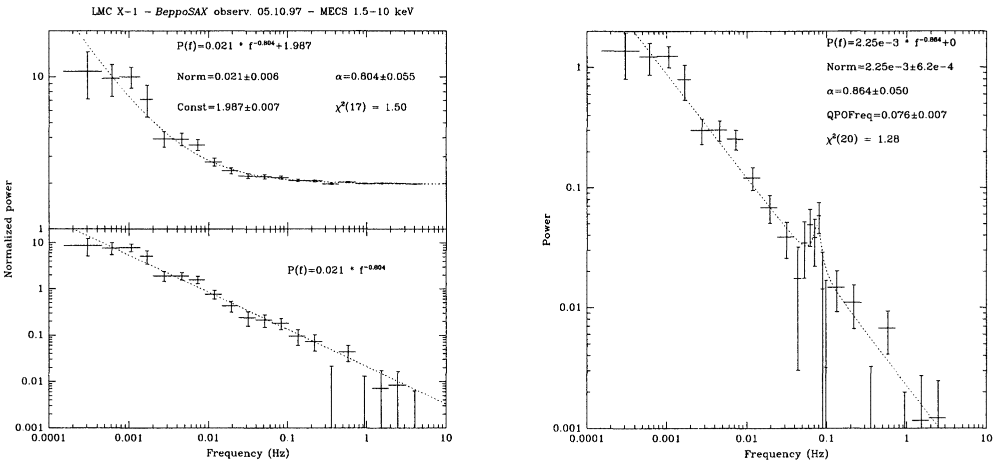

FIGURE 2. *Left panel:* Power Spectral Density of LMC X–1 in 1.5–10 keV from merged MECS2 and MECS3 events. A fit with a power law plus constant is also shown. Errors are 68% single parameter confidence level. *Right panel:* A finer frequency binning near the *GINGA* QPO frequence shows the presence of a marginal excess. A fit with a power law plus a Lorentzian (to model the QPO peak) is also shown.

Hz). The resulting broad–band PSD with fine binning in the vicinity of the expected QPO frequency is shown in Figure 2, right panel. The total significance of the excess power is rather low. It can be quantified adding a component to the spectral modeling and performing an F–test. We therefore compared a fit using a simple power law with a fit using a power law plus a Lorentzian. In the first case the minimum χ^2 is 31.1 for 23 degrees of freedom and in the second case the minimum χ^2 is 25.8 for 20 degrees of freedom. The F–test gives a probability of chance improvement adding the Lorentzian of 0.32. The total excess above the power law fit is 5±2.2% rms. This is close to the measured power by Ebisawa et al. (1989), but much higher than the observed upper limit by RXTE (~0.8%) and BBXRT (Schlegel et al. 1994 – ~1.6%).

3. DISCUSSION AND CONCLUSIONS

Low frequency QPO have been observed in a number of black hole candidates and in general their intensity is strongly variable (see van der Klis (1995) for a review and Nowak et al. (1999) at this conference). In these regards the case of LMC X-1 is not exceptional. The time lag between the QPO detection with Ginga and with BeppoSAX was 10 years, and the QPO frequency was reproduced within the uncertainties. In the same time interval negative searches were performed RXTE

TABLE 1: DISK LUMINOSITY

Experiment	L_{Disk} (erg/s)	QPO?
Ginga	$1.2 \times 10^{38} / \cos i$	Y
BBXRT	$1.0 \times 10^{38} / \cos i$	N
RXTE	$1.2 \times 10^{38} / \cos i$	N
BeppoSAX	$9.5 \times 10^{37} / \cos i$	Y

and BBXRT.

In order to understand the origin of the QPO and constrain physical models, it would be of interest to correlate the appearence of the QPOs with a spectral property, and an obvious parameter could be the X-ray intensity. This is summarized in Table 1. The presence of the QPO thererefore does not directly correlate with the intensity. However, as it was noted above, the X-ray spectral shape is rather complex. In particular it could be of interest to correlate the QPO presence with the power law component. Unfortunately present data are affected by too large uncertainties.

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