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An 8.15 hour modulation in the light curve of LMC X-2*

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Abstract. We present the results of an extensive optical monitoring campaign of LMC X-2 from both ESO and SAAO. The previously suggested 6.4 h period is not present in our data: the data instead provide evidence for an 8.15 h periodicity. We discuss the implications of such an orbital period for the evolutionary status of LMC X-2.

Key words: stars: binary – X-rays: binaries

1. Introduction

One of the major difficulties in the study of the galactic Low Mass X-ray Binaries (LMXBs) is the large uncertainty in the distance to these objects, which renders it very difficult to determine accurate X-ray and optical luminosities. Although in principle the LXMBs in globular clusters should not suffer from this problem, in practice optical identification of these LMXBs has proved extremely difficult in the crowded cluster cores. The study of LMXBs in the LMC, however does not suffer from this problem (e.g. Pakull et al. 1988).

In fact there are 3 known LMXBs in the LMC: LMC X-2, CAL 83 and CAL 87 (Johnston et al. 1979; Cowley et al. 1984; Pakull et al. 1988). Here we report the results of an optical study of the most luminous of all LMXB at X-ray energies, LMC X-2, which we performed in a concerted effort to determine the orbital period of the system.

The optical counterpart of this X-ray source is a variable, $V \sim 18.8$ blue star (Johnston et al. 1979). The X-ray luminosity (L_X) varies between 0.6–3 10^{38} erg s^{-1}, and the X-ray spectrum can be modelled either with a Componized thermal model with $kT \sim 3$ keV, or a combination of a thermal bremsstrahlung ($kT \sim 5$ keV) and a blackbody component ($kT_{BB} \sim 1.3$ keV; Bonnet-Bidaud et al. 1989). Because of its high X-ray luminosity, LMC X-2 might be expected to exhibit the canonical "Z" shape track in the X-ray colour-colour diagram (e.g. van der Klis 1989); however, it does not (although this may be due to poor statistics).

The optical spectrum is dominated by Hα, Hβ and He II λ4686 in emission. The characteristics of the optical spectrum, the relatively soft X-ray spectrum, and the high value of the ratio of X-ray to optical luminosity ($L_X/L_{opt} \sim 600$), imply that LMC X-2 is similar to the LMXBs in the galaxy (e.g. van Paradijs 1983). Bonnet-Bidaud et al. (1989) found evidence for a 6.38 h orbital period for LMC X-2, which is near the peak of the distribution of known orbital periods of galactic LMXBs (see e.g. Mason 1986).

2. Observations

We observed LMC X-2 using the ESO 1.5 m Danish telescope at La Silla and the SAAO 1 m telescope between January 12–19, 1988 and January 20–26, 1988, respectively. Detectors on both telesopes were RCA CCDs, with plate scales of 0.″47 and 0.″39 pixel^{-1}, respectively. Most of the exposures were taken through a Johnson V filter, with considerable B coverage being obtained from SAAO. Such was the seeing during the ESO observations that the use of relatively simple aperture photometry software was sufficient to perform the photometry with acceptable accuracy. The SAAO observations, however, were taken in seeing of ~ 2–$3''$, which required DAOPHOT profile fitting (Stetson 1987) in order to deconvolve the optical counterpart from its contaminators (Johnson et al. 1979). The data of the best statistical quality come from ESO: the error of individual differential magnitudes (relative to nearby comparison stars on the same frame) derived from these observations was ≤ 0.03 mag, compared to ≤ 0.1 mag for the SSAO data.

The zero point of the differential photometry was determined from CCD frames of Cousins standards (Cousins 1976). We find that the mean V magnitude of LMC X-2 during our observations was 18.5 ± 0.05 mag, with a mean $B-V$ during the SAAO observations of ~ -0.1. We plot in Fig. 1 the ESO light curve of LMC X-2. LMC X-2 exhibited ~ 0.1 mag flickering on time scales of ≤ 0.5 h, as well as longer term ~ 0.3 mag variations on ~ 4 h time scales. A Fourier analysis of this "raw" dataset did not reveal evidence for a unique periodic modulation: in particular, no evidence was found for the previously reported 6.38 h period.

We show in Fig. 2 the power spectrum of the detrended data produced using a one-dimensional version of a CLEAN deconvolution algorithm (Roberts et al. 1987). This type of analysis is well suited to unevenly sampled data. There is a clear peak at 8.15 h,

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* Based partly on data collected at the European Southern Observatory, La Silla, Chile

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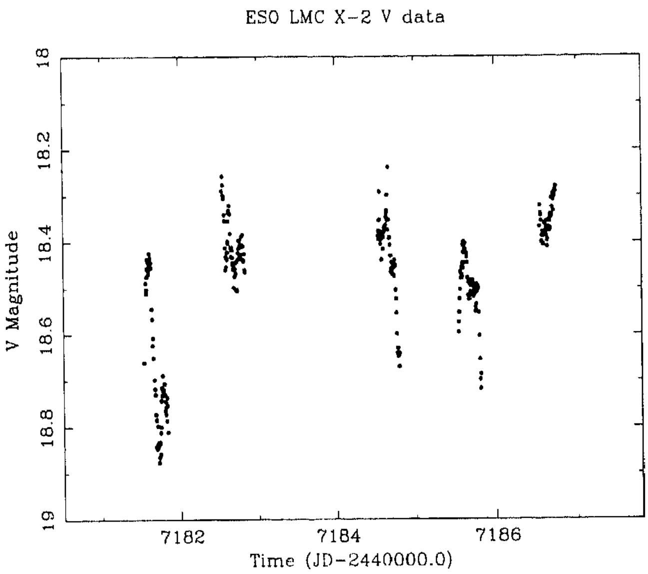

Fig. 1. The ESO V light curve of LMC X-2. The integration times are 400 s

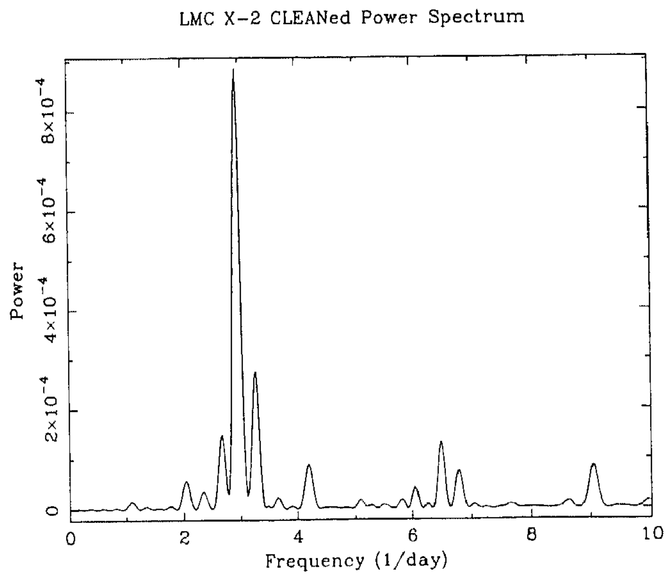

Fig. 2. The CLEANed power spectrum of the combined ESO and SAAO LMC X-2 data set. There is a clear peak at 8.15 h

with a peak-to-peak modulation depth of ~0.15 mag. This is a small modulation superimposed on large aperiodic variability. We note that this period is displaced ~2.5σ from the 8.74 ($\pm$0.2) h alias of Bonnet-Bidaud et al. The significance of this peak is not affected by the method of detrending the data (e.g. the use of a 3rd order spline fit, or the subtraction of the nightly mean). We have estimated the significance of this peak by studying ~500 simulated data sets generated with white noise characteristics, and with a sampling similar to our optical data. We then determined the probability of a peak of a given strength occurring by chance (see Lehto 1990 for further details). From these simulations we place a conservative upper limit on the probability of a peak of the observed amplitude occurring in our dataset purely by chance of 2 10^{-5}.

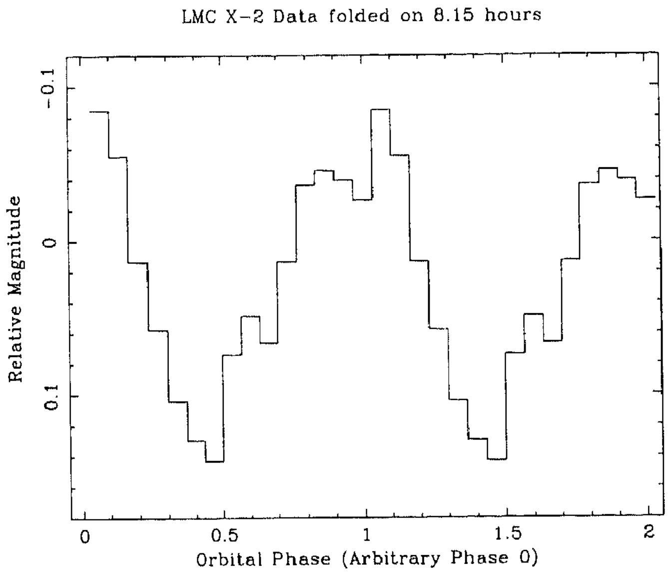

Fig. 3. The ESO and SAAO data folded on the 8.15 h period. The data have been rebinned. Phase zero is arbitrary, and the data have been repeated for clarity

The best fit sine-wave has a period of 0.340($\pm$0.001 day). The folded SAAO and ESO V light curves (after detrending) averaged in discrete phase bins is shown in Fig. 3. This folded light curve is rather smooth and sinusoidal, without evidence for a flat maximum.

3. Discussion

As has been previously pointed out (e.g. Callanan & Charles 1989), it is remarkable that although only three LMXBs are known in the LMC, we find amongst them the brightest LMXB both at optical (CAL 83), and at X-ray (LMC X-2) energies. A similar situation exists for massive X-ray binaries, whose X-ray luminosity function in the LMC and SMC appears to be shifted towards higher luminosities; this may be attributable to the low metallicity of the LMC (Clark et al. 1978). Apart from its very high X-ray luminosity, LMC X-2 has all the other traits of a "standard" LMXB – except for the absence in the optical spectrum of the Bowen blend, probably also due to the lower metallicity of the LMC as compared to the Galaxy (Motch & Pakull 1989).

Our data indicate an 8.15 h periodicity in the light curve of LMC X-2. In view of the known orbital period distribution this may be the orbital period. If this were true, then the shape of the folded light curve indicates that there is a significant contribution from a heated secondary or outer disk bulge, at least at maximum light. The mass transfer in such a system would be driven by magnetic braking of the secondary and/or the nuclear evolution of a subgiant companion (Pylyser & Savonije 1988; Webbink et al. 1983).

In an independent study of LMC X-2 Crampton et al. (1990) do not see evidence for a 8.15 h modulation. This implies that the depth of the modulation we see is in itself variable on long timescales ($\gtrsim$10 days). They report a long term trend in their light curve which may be consistent with an orbital period ~10 days, and indeed we note that the ephemeris of Schmidtke et al. (1990) does predict a minimum at JD 2447180.3 (see Fig. 1). A longer period would be more consistent with the subgiant hypothesis, and would imply that the variability observed by Bonnet-Bidaud et al. and ourselves could be a long term optical quasi-periodic modulation. A long orbital period would make the system similar to Cyg X-2 or 0921 − 63 (e.g. Bradt & McClintock, 1983) – but in the spectra of these systems there is direct evidence for an evolved secondary. Thus, a strong indication of a long orbital period would be the direct detection of the secondary in the optical spectrum of LMC X-2. This has not yet been observed.

4. Conclusions

We have observed a modulation of the optical flux of LMC X-2 which is consistent with an 8.15 h orbital period for this system. We suggest that a period of such a time-scale may more consistent with the other known characteristics of this system. Distinghuishing between a short term (~ 8 h) and long term (~ 10 day) orbital period for LMC X-2 awaits either detection of the secondary in the optical spectrum, or the outcome of a monitoring campaign even more extensive than that reported here.

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