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The orbital period of the optical/X-ray burster X1735−444 (V926 Sco)

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Summary. We present extensive CCD photometry of the optical counterpart of X1735−444 which reveals the orbital period of the system. It is periodically variable with a period of 4.654 hr and a full amplitude of 0.15 mag. The mean modulation is quasi-sinusoidal; there are, however, also significant intrinsic deviations from the mean light curve.

1 Introduction

The galactic X-ray source X1735−444 is a member of the class of X-ray bursters (Lewin & Joss 1983) and one of the few in which simultaneous X-ray and optical bursts have been observed. These objects are generally believed to consist of a weakly or non-magnetized neutron star accreting material from a Roche lobe filling late-type star. The optical counterpart of X1735−444 has been identified (McClintock *et al.* 1977) with a faint ($V{\sim}17$) blue emission-line star, V926 Sco. Previous attempts to determine the binary period, fundamental to an understanding of this system, have proved inconclusive. McClintock & Petro (1981) have suggested a ~4.3 hr period on the basis of one night's optical photometry whereas Hutchings, Cowley & Crampton (1983) obtained a 2.86 hr period from eight optical spectra. Smale *et al.* (1984), however, have obtained optical spectroscopy which tends to support a period longer than 4 hr.

2 Observations

Photometry of X1735−444 was obtained at two telescopes during 1985 August:

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(i) The South African Astronomical Observatory (SAAO) 1.0-m equipped with the UCL CCD system (Walker *et al.* 1984), between 1985 August 13 and 19.

(ii) The Cerro Tololo Inter-American Observatory (CTIO) 0.91-m using an RCA CCD system between 1985 August 15 and 21.

Exposures were made through filters approximating the Johnson *B* band and were typically 600 and 300 s in length at SAAO and CTIO respectively. A total of 521 useful exposures were obtained. Simultaneous X-ray data were obtained with *EXOSAT* in collaboration with Trümper *et al.* and will be presented in a later paper.

The CCD images were analysed using an automated computer reduction system similar to that described in Corbet *et al.* (1985). This system produces differential magnitudes with respect to several other stars in the field. The magnitudes presented in this paper are with respect to a star located 34 arcsec N and 155 arcsec W of X1735−444. A systematic offset was found between the magnitudes produced from the two telescopes which we attribute to small differences in the effective bandpasses of the two systems, which are exaggerated by the red colour of our comparison star. We have calibrated this effect using stars in the field with a wide range of colours and have corrected for the effect to an accuracy ~0.02 mag (systematic). Small air-mass corrections have also been applied to the resulting magnitudes. In Fig. 1 the results of the photometry are shown. From measurements of stars of similar brightness in the field we estimate the errors on the individual measurements of X1735−444 to be 0.02–0.03 mag.

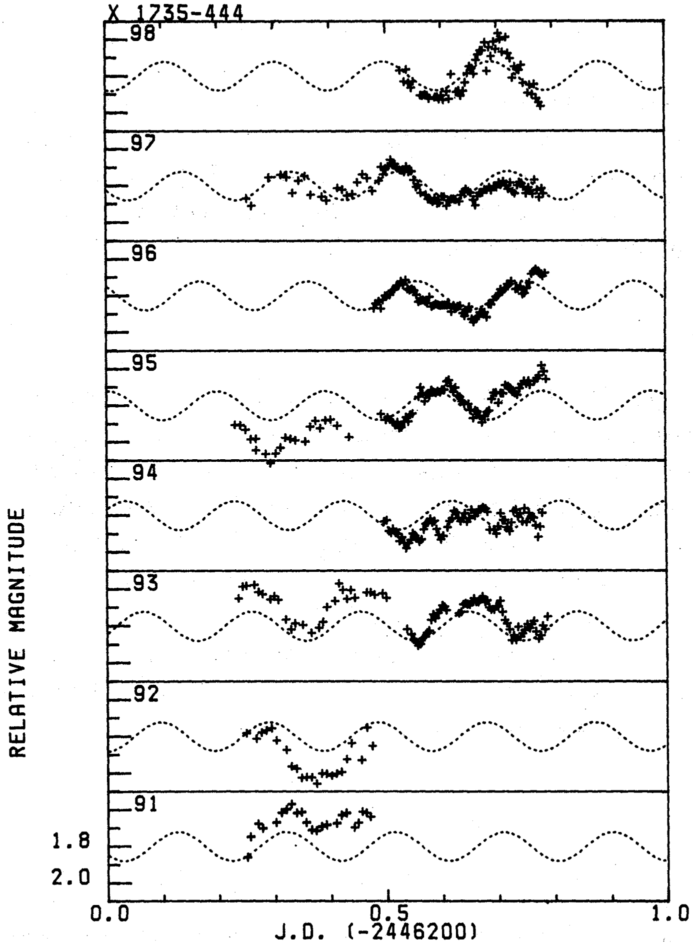

Figure 1. *B* band photometry of X1735−444. The dashed line is the best-fit sine wave. The number in the upper left of each panel is the Julian Day of each observation (−2446200).

3 Periodicities

A period search was performed on the photometric data using a Fourier transform routine. This search was made on the combined data set and also on the SAAO and CTIO data sets individually. Periods between the Nyquist period and half the length of the data set were searched. In all cases the strongest power was found to be at a period of ~4.6 hr (f~5.2 day^{-1}) with a full amplitude of ~0.15 mag. The standard deviation of the data about this sine wave is 0.08 mag. From the total data set we adopt a period of 4.654±0.005 hr. The probability of this period being due to chance is ~10^{-32}. The transform of the total data set is shown in Fig. 2 and the parameters of the best fitting sine wave to the photometry are given in Table 1. The Fourier transform, in fact, shows no significant power at the first or second harmonics of the 4.654 hr period, but there is power at some low-frequency periods. However, we consider these to be artefacts caused by small residual differences between the CTIO and SAAO data for the following reasons: (i) the transforms of the individual data sets show no significant power at low frequencies, (ii) the apparent power at low frequencies is increased if the colour-dependent offset between the two data sets is not applied, and (iii) these periods consist simply of 2.5 day, 1.5 day and harmonics thereof.

There is also substantial power at the low-frequency one-day alias of 4.654 hr (5.77 hr) but this period is far less likely and we consider it to be an artefact. We note that this is close to double the

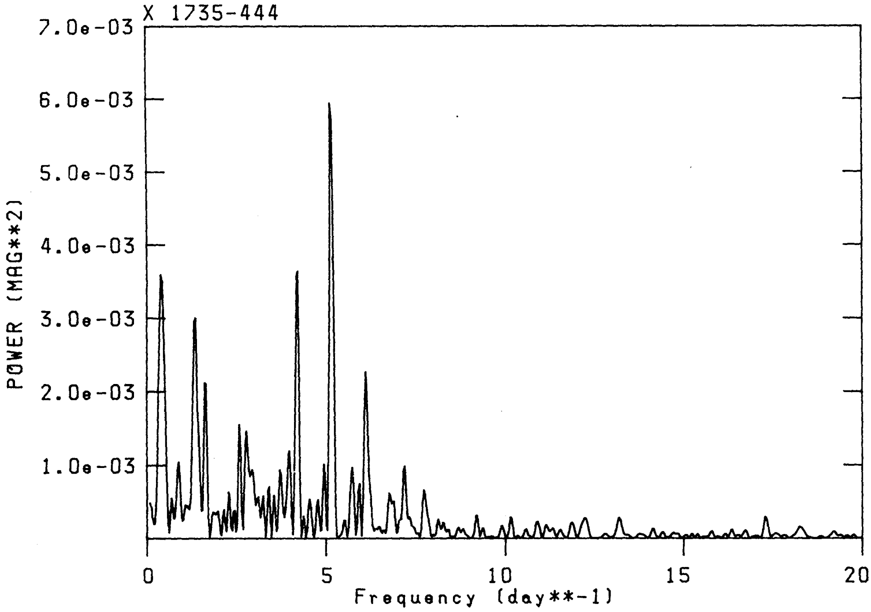

Figure 2. Power spectrum of optical photometry of X1735−444. The strongest peak is at a period of 4.654 hr (frequency=5.157 day^{-1}), one-day sampling aliases of this period are also present as well as spurious low-frequency periods (see text).

Table 1. Results of sine wave fit to photometry of X1735−444.

Period	4.654±0.005 hr
Semi-amplitude	0.079±0.005 mag
T0[1]	HJD 2 446 290.351±0.005
Mean magnitude[2]	1.798±0.004 mag

[1] Time of maximum light.

[2] Magnitude with respect to comparison star (see text) in CTIO instrumental system.

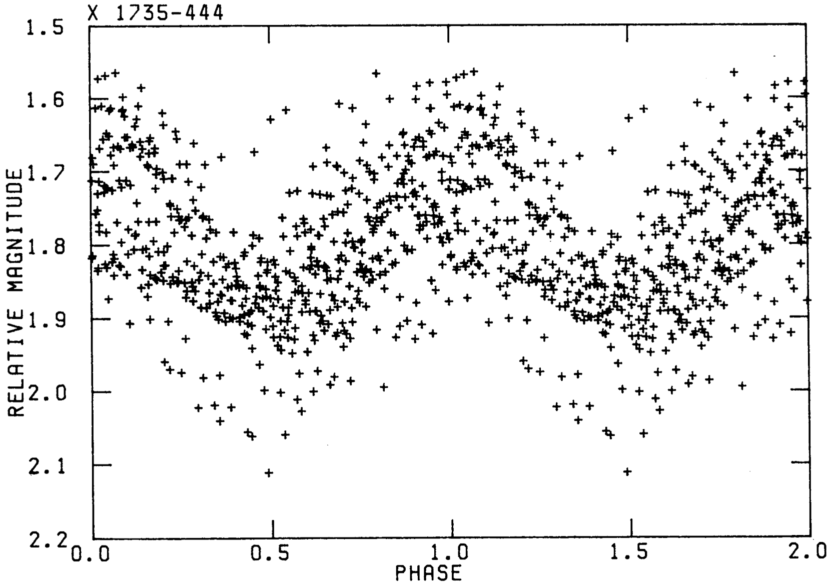

Figure 3. Photometry of X1735−444 folded on the 4.654 hr period. For clarity two cycles are shown.

spectroscopic period of 2.86 hr found by Hutchings *et al.* (1983). We have folded their data on our 4.654 hr period and find that they are also compatible with our period although their spectra were taken over four nights and do not fully cover all phases. Our photometry folded on the 4.654 hr period is shown in Fig. 3. Although periodic, the exact shape of the light curve does not repeat exactly from cycle to cycle and we find that this additional scatter is independent of phase. This can account for the slightly different period obtained by McClintock & Petro (1981) from a much smaller data set. The 4.654 hr period revealed by our extensive observations is thus consistent with the previous results which were based on small amounts of data.

Menzies & Mack (private communication) also obtained CCD photometry of X1735−444 on two nights on 1984 July. These data show evidence for periodic variability with a period of near either 4.7 or 5.8 hr, providing further evidence that the ~4.6 hr modulation is a constant feature of the light curve.

In order to search for other possible periodicities in X1735−444 we removed the best-fitting sine wave from our photometry and then subjected the modified data set to a Fourier transform. No additional periodicities were found.

4 Discussion

The 4.654 hr period is almost certainly the orbital period; its apparent stability argues for this. Also, Sco X-1 (V818 Sco) has a photometric modulation that appears similar to the one obtained here (Gottlieb, Wright & Liller 1975); its orbital period can be determined independently from radial velocity measurements, and is identical with the photometric period (La Sala & Thorstensen 1985; Crampton *et al.* 1976). A period of 4.6 hr is typical for other X-ray bursters (White 1986) and in particular very close to that of the low-mass X-ray binary X1755−338 (P=4.4 hr; Mason, Parmar & White 1985) with which we make some comparisons. Mason *et al.* suggest that the optical light curve of X1755−338 may be a symmetric with a gradual ingress to minimum followed by a more rapid egress. No such asymmetry is seen in the folded light curve of X1735−444. The gradient of our light curve shows no significant difference between ingress and egress. We therefore postulate that the apparent asymmetry in X1755−338 is spurious and caused by intrinsic non-periodic variability such as is present in X1735−444 (see Fig. 1).

The mean light curve is approximately sinusoidal, indicating that the main cause of the optical modulation may be the changing aspect of the X-ray heated non-degenerate component. Comparison with Sco X-1 again supports this interpretation; the phasing of the emission-line radial velocities indicates that the photometric modulation probably arises from the changing aspect of the X-ray heated face in that case (La Sala & Thorstensen 1985; Crampton *et al.* 1976). Other factors might also contribute to the optical modulation, namely (i) azimuthal asymmetries in the accretion disc and (ii) a partial eclipse of the accretion disc by the non-degenerate star (*cf.* discussion in Mason *et al.* 1985). These effects would lead to departures from a sinusoid. The relatively low amplitude of the modulation in X1735−444 (full amplitude ~0.15 mag B band) compared with, for example, X1755−338 (0.4 mag V band) suggests that the inclination angle of this system may be relatively low. If this is the case then the probability of seeing large-amplitude X-ray dips as observed in some other systems is likely to be low. If we assume that the mass donating star in the system is a Roche lobe filling main-sequence star, then our period implies that its mass is about 0.45 $M_\odot$, where we have used the semi-empirical expression derived by Patterson (1984); the implied spectral type is about M0 (Allen 1973).

Now that the orbital period of X1735−444 is known it is necessary to obtain optical radial velocity measurements so that the mass function and geometry of this system may be determined.

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