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ABSTRACT

We report here a search for a 78.4-day modulation in the high-energy X-ray flux observed with OSO-8 and in the U-band optical polarisation observed by Dolan, with negative results. We suggest that if such modulation does exist, it is more likely to be related to the rotation of the free modes of oscillation of the primary than to the existence of a third body in the system.

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THE 78.4-DAY PERIOD OF CYGNUS XR-1

Cygnus XR-1/HDE 226868 is a multiple star system in which the secondary is the best astronomical candidate for a black hole. The existence of a third body in the system could affect the mass derived for the secondary from the analysis of spectroscopic radial velocity curves.[1] Hence, the presence of a periodicity in the system other than that of the 5.6-day binary orbit bears strongly upon the identification of the secondary with a black hole, especially if such a periodicity can be related to the orbital period of a third body. The existence of a 78.4 (or 39.2) day periodicity in the optical and low-energy x-ray wavelength region of the emission from this system has been reported by Kemp *et al.*[2,3] The existence of a 39.2-day modulation in the optical and low-energy x-ray luminosities has been questioned by Walker *et al.*[4] We report here a search for a 78.4-day modulation in the high-energy x-ray flux observed with OSO-8 and in the U-band optical polarisation observed by Dolan[5], with similar negative results. We suggest, however, that if such modulation does exist, it is more likely to be related to the rotation of the free modes of oscillation of the primary than to the existence of a third body in the system.

Analysis of the power spectrum of the U-band polarisation of HDE 226868 on 225 nights during the years from 1974 through 1977 led to the original detection by Kemp *et al.*[2] of a 39.2-day modulation in the magnitude of polarisation with peak-to-peak amplitude of 0.25% (or 0.0054 mag.). A modulation with a 78.4-day period was detected by Kemp *et al.*[3] in the power spectrum analysis of the U-band photometry of the system taken during 43 nights in 1974 and 84 nights in 1977. The peak-to-peak modulation was approximately 0.015 magnitudes. A reanalysis of the ultraviolet-filter photometry at the 78.4-day period produced a double-peaked modulation; the 0.0054 magnitude modulation in the polarisation was equivalent to a peak-to-peak amplitude of approximately 8% of the mean polarisation. In a similar analysis of the power spectrum of the x-ray flux in the energy range 3 to 6 keV from Cyg XR-1 observed between October 1974 and December 1977 with the All-Sky Monitor on Ariel V, Kemp *et al.*[3] detected a 78.4-day modu-

lation with peak-to-peak amplitude of approximately 15% of the mean flux. The modulation appears to be in phase with the U-band photometric modulation. This periodic modulation was detected only when the x-ray source was in an intensity "low state."

Cygnus XR-1 was observed with the high energy x-ray spectrometer[6] on OSO-8 during periods of 10 to 20 days in each of the years from 1975 to 1977 (ref. 7). The source exhibited a transition from the intensity "low state" to the intensity "high state" during the observation in 1975 (ref. 8). Consequently, only the data obtained in 1976 and 1977, when the source was continuously in a low state, were analysed for a 78.4-day modulation. The counting rates from the source between 23 and 153 keV, binned in intervals of one-tenth the 5.5995-day binary period, were folded modulo the 78.4-day period with zero phase as given by Kemp *et al.*[3] (Fig. 1a). The weighted mean counting rate over intervals of 0.1 in phase are shown in Fig. 1b for direct comparison with the 3 to 6 keV x-ray data of Kemp *et al.* (Fig. 1c). The modulation observed by Kemp *et al.* at lower energies is not immediately apparent in our data. The variations evident in Fig. 1b have a peak-to-peak range of 19% of the mean flux between 23 and 153 keV. If any 78.4 day modulation exists in the high-energy x-ray flux from Cyg XR-1, it must be at an amplitude significantly lower than this. Because of the irregular spacing of the data and the fact that all observing runs were short compared to the 78.4-day period, no more stringent limits could be placed on the existence of a 78.4-day modulation by the use of power spectrum analysis.

Observations of the polarisation of HDE 226868 in the U-band were obtained over 23 nights in 1973, 1974 and 1975 by Dolan.[5] The observations were folded modulo the 78.4-day period with the same zero phase as above. The weighted mean polarisation, in intervals of 0.1 in phase, is shown in Fig. 2a. The modulation detected by Kemp *et al.*[3] is shown for comparison in Fig. 2b. The peak-to-peak amplitude of the variations we see is 34% of the mean polarisation. Variations typically of this magnitude were ascribed by Dolan[5] to Rayleigh scattering of light from inter-component gas streams known to exist in the system. A chi-squared test shows that the data points making up the polarisation light curve are consistent with a random distribution about either a non-varying polarisation or the polarisation curve fitted to their data by Kemp *et al.*[3] normalised to our

mean value. Once again, the irregular spacing and greatly varying statistical weights of the individual observations preclude the use of a power spectrum analysis to set more stringent limits on any periodic modulation.

Kemp *et al.*[3] propose a physical interpretation of a 78.4-day period in terms of either a ternary system, the precession of an accretion disk, or some kind of pulsation. These authors discuss at some length the three body possibility, although they point out that their analysis of spectroscopic radial velocity observations of the visible primary limits any third body in the system with a 78.4-day period to a mass of less than $(0.8 \pm 0.6)\ M_{\odot}$. We believe that a more likely interpretation of a 78.4-day periodicity in the system, if confirmed, is related to the funcamental rotation properties of the free modes of oscillation of the primary. The non-degenerate star is believed to be pulsating in a broad array of gravitational modes (g-modes), global in scale and lacking spherical symmetry (cf. ref. 9). Under slow rotation and sufficient non-linear coupling, the g-modes can combine to form a much smaller set of non-linear modes departing from azimuthal symmetry. As the main anti-nodes of these non-linear modes rotate past each other, the oscillatory power density at these locations is temporarily enhanced. The occurrence of transitions between intensity states of the x-ray source is ascribed by Dolan *et al.*[7] to sudden changes in the amount of mass transferred whenever the main anti-nodes are aligned with the sub-secondary point on the surface of the primary. In this picture, the 78.4-day period would be the time between effective alignments of certain g-modes.

As noted by Kemp *et al.*[3], excess mass transfer between the binary components modulated with a 78.4-day period could explain all the modulation they see in the x-ray and UV emission. The continued existence of this period over a duration of three years implies that some forcing function may be maintaining it. The 78.4-day period is an exact integral multiple of the 5.6-day orbital period of the secondary [2,3]; tidal forces occurring every periastron passage may provide such a forcing function. Continued observations are necessary to determine whether the 78.4-day modulation can be confirmed, and whether it can be related to the rotation properties of the primary's free modes of oscillation.

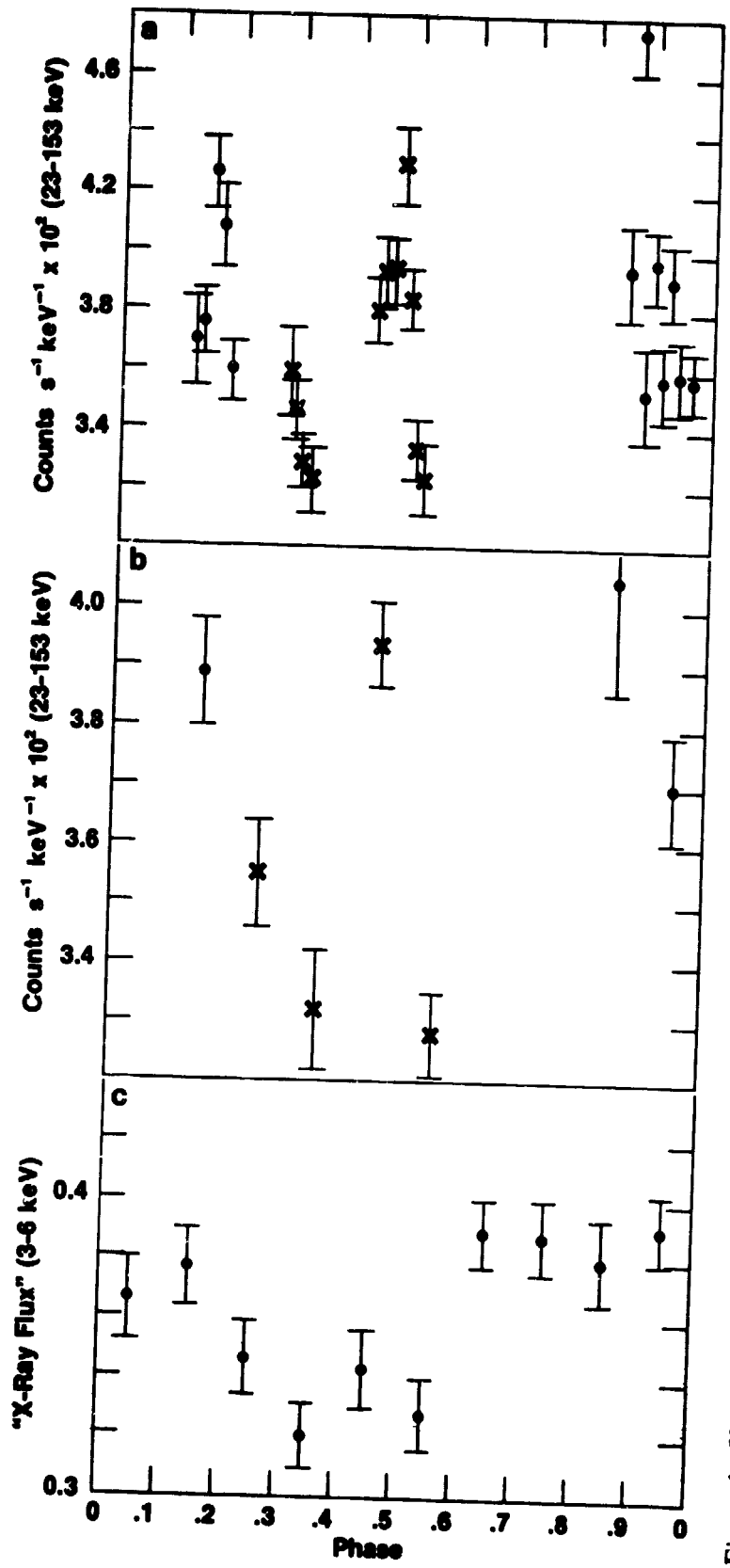

Figure 1. X-ray count rates observed from Cyg XR-1 plotted modulo the 78.4-day period of Kemp *et al.*[3] (a) Individual observations of the 23 to 153 keV count rates taken in 1976 (crosses) and 1977 (circles). (b) Weighted mean count rate of the observations in (a) over intervals of 0.1 in phase. (c) The 3 to 6 keV flux observed by Kemp *et al.*[3]

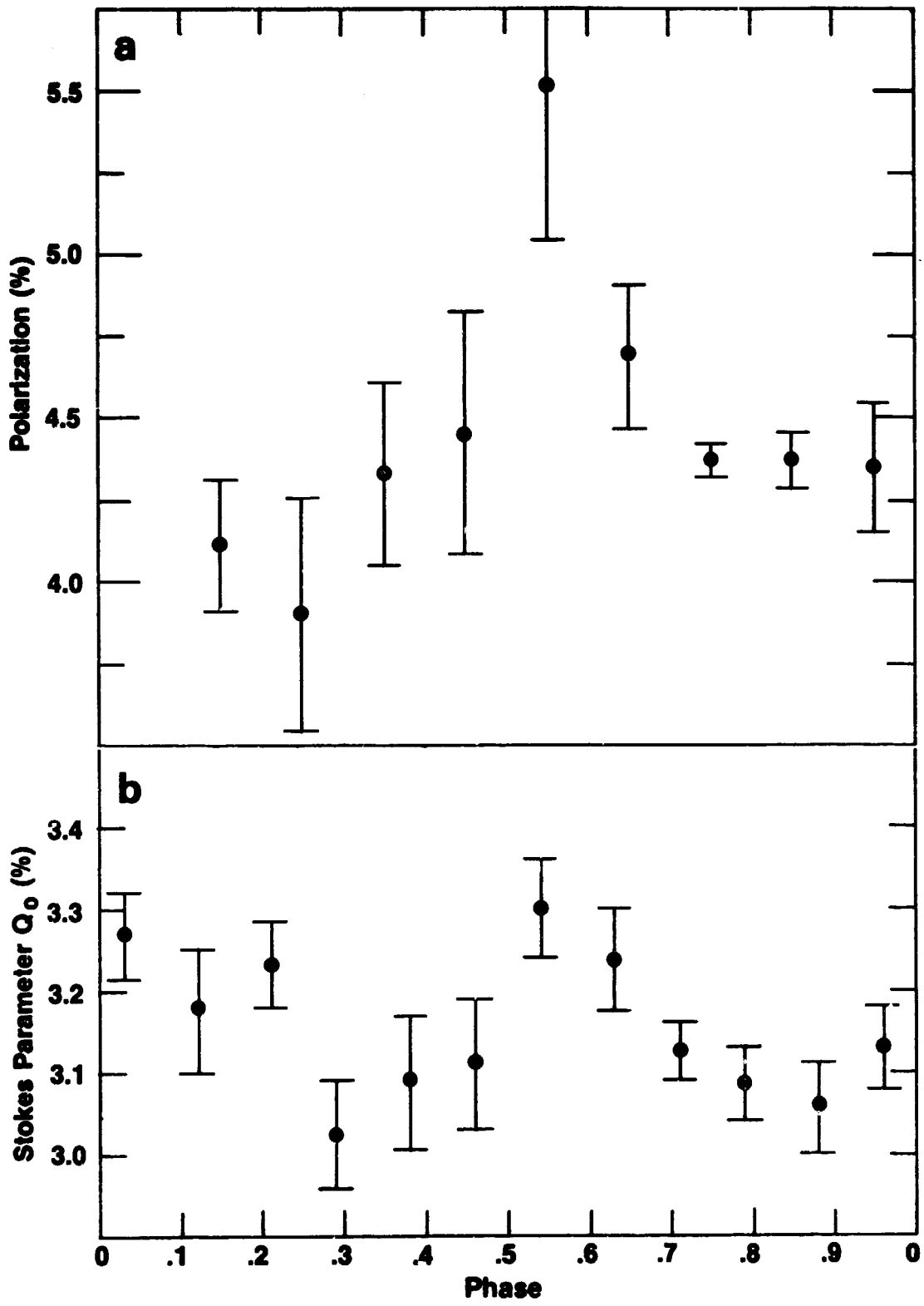

Figure 2. The polarisation of HDE 226868 observed in the U-band filter folded modulo the 78.4-day period of Kemp *et al.*[3] (a) The weighted means of the polarisation observed 1973 to 1975 by Dolan[5] binned in intervals of 0.1 in phase. (b) Modulation in the Stokes parameter Q_O in the U-band observed by Kemp *et al.*[3]

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