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IS CYGNUS X–3 A LOW-MASS X-RAY BINARY?

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ABSTRACT

We present examples of the quasi-periodic variations in the X-ray flux of Cyg X-3 which we have recently found during observations of this source with EXOSAT. Amplitudes and periods of the variations range from 5% to 20% of the total flux and from 50 to 1500 s, respectively. Our tentative interpretation of these quasi-periodicities, the occurrence of quasi-periodic phenomena in an accretion disk which partially occults the X-ray source, points towards an analogy of Cyg X-3 with certain 'dipping' low-mass X-ray binaries such as 4U 1822-37, as suggested /1/ previously. We point out, however, that there are also fundamental differences between Cyg X-3 and this type of low-mass X-ray binary.

INTRODUCTION

Cygnus X-3 is a famous bright X-ray source, which occasionally shows very large radio outbursts /2/, and which may be emitting γ-rays in the 10^8 /3/, 10^{12} /4/ and 10^{16} /5/ eV bands. The source has an intrinsic X-ray luminosity which sometimes exceeds 10^{38} erg/s, and always shows a smooth, large-amplitude X-ray modulation with a period of 4.8 hr /6/. This period is probably the orbital period of a binary system, in which the X-rays are generated by either accretion onto a compact object or by a young, Crab-like pulsar /7/. In most models proposed, the smoothness of the X-ray modulation is explained in terms of scattering material surrounding the X-ray source, with various geometries being invoked for the distribution of this material /8/,/9/,/10/,/11/,/1/. The X-ray light curve varies strongly from one 4.8 hr cycle to the next /12/ but in the long run these variations average out, giving an average light curve which is very constant in shape, but not in amplitude /13/. On the basis of a statistical analysis of a large amount of low-sensitivity X-ray data, the cycle-to-cycle variability of Cyg X-3 was estimated to occur mainly on time scales below 3000 s, with an amplitude of 5-10% of the amplitude of the 4.8 hr modulation, i.e., 7.5-15% of the total flux /12/. In this paper we show examples of the transient, quasi-periodic oscillations which we have found to be a component of the cycle-to-cycle variability of Cyg X-3, and consider some possible consequences of this behaviour.

OBSERVATIONAL RESULTS

Cyg X-3 was observed on 5 occasions between October 1983 and January 1984 with the EXOSAT Medium Energy instrument. During four of these observations, which each lasted between 0.6 and 1.4 10^4 s, a total of six different quasi-oscillations were seen. The oscillations covered a range in period of 50-1500 s and had amplitudes between 5% and 20% of the total flux. They always occurred in the phase interval 0.0 to 0.75 (with phase 0.0 at light curve minimum). Examples are given in Fig. 1. A particularly interesting case is illustrated in Fig. 2, where a 25% intensity drop on a 100 s time scale is preceded by two simultaneous quasi-oscillations, with periods of $\sim$ 500 s and $\sim$ 70 s, respectively. Insets show the enhancements caused by the quasi-oscillations in the power spectra of the data. Notice that the oscillations are in some cases quite coherent (only a few bins in the power spectrum) and in other cases cover a considerable range in frequency.

DISCUSSION

The observed time scales of the quasi-oscillations correspond to the dynamical time scale of matter well inside the Roche lobe of the X-ray source. For a 1.4 $M_\odot$ neutron star, they correspond to the rotation- and vertical oscillation time scale in an accretion disk at radii between 5% and 50% of the average Roche-lobe radius. It is possible, therefore, that the quasi-oscillations are due to partial occultations of the X-ray source by matter at different radii in the disk, the periodicities arising either by oscillations in the z-direction or by blobs of matter being carried around by the rotation in the disk. The latter mechanism seems

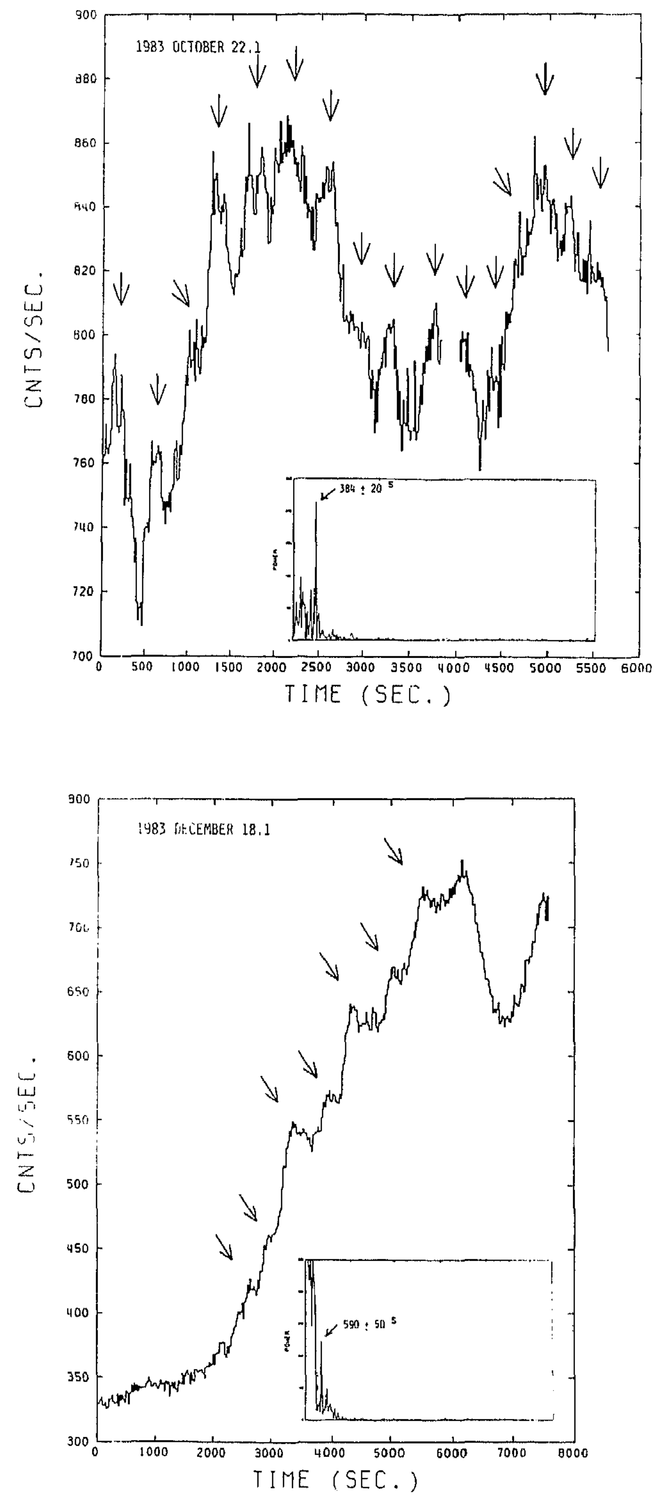

Fig. 1. 1-10 keV counting rate as measured with the full 1500 cm^2 array of proportional counters in the EXOSAT ME experiment. Start times of the observations (TIME = 0.0) are indicated in the figure. Insets show power spectra of the data, detrended by subtracting a low-order polynomial to remove low-frequency components. The peaks of the quasi-oscillations which correspond to the enhancements in the power spectra are indicated with arrows.

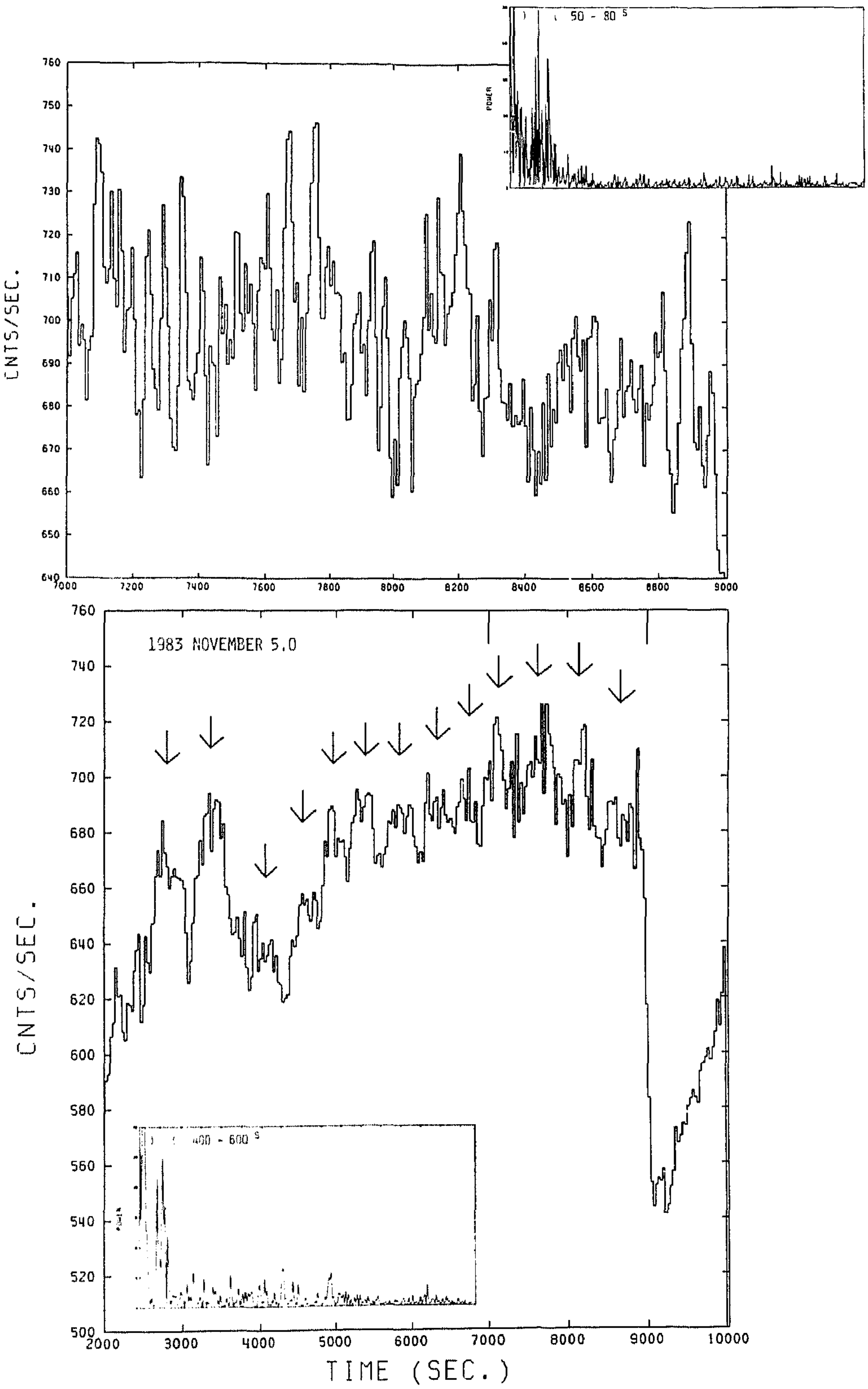

Fig. 2. As Fig. 1. The upper frame contains a more detailed blow-up of part of the data in the lower frame, showing a series of flares with a typical recurrence time of 50-80 s which are superposed on the slower ~ 500 s quasi-oscillations highlighted in the lower frame.

to be more in accordance with the non-sinusoidal character which frequently characterizes the quasi-oscilllations.

This interpretation is in accordance with the accretion-disk corona model which was applied by White and Holt /1/ to Cyg X-3 as well as to the low-mass X-ray binaries 4U 1822-37 and 4U 2129+47, which show periodic X-ray dips. Similar explanations have been proposed for a 10^3 s quasi-periodicity observed in the pulsating source 4U 1626-67 /14/, and recently for fluctuations seen /15/ in 4U 1755-33 /16/ and 4U 1705-44 /17/. These sources are all low-mass X-ray binaries believed to be powered by the Roche-lobe overflow of a red-dwarf companion to the X-ray source. The mechanism which is causing the red dwarf to overflow its Roche lobe in these systems is not yet clear. Gravitational radiation /18/ and magnetic braking /19/ have been proposed to take care of the necessary loss of angular momentum from the system. Independent of the precise nature of the angular momentum sink, we can calculate what the orbital evolution of the system must be if it is powered by the Roche lobe overflow of a main-sequence red dwarf.

Adopting the approximate mass-radius relation of main-sequence stars for the red dwarf: $M_{rd}/M_{\odot} = R_{rd}/R_{\odot}$, and using the expression for the Roche-lobe radius of the least-massive binary component (in this case the red dwarf) /20/, $R_{RL}/a = 0.46(M_{rd}/M)^{1/3}$, where M is the total mass of the system, and a the binary separation, one finds, with Keplers law, that the condition that the red dwarf fills its Roche lobe (i.e., $R_{RL} = R_{rd}$) implies: $(\dot{P}/P)_{orb} = (\dot{M}/M)_{rd}$, where P_{orb} is the orbital period. This result implies that all low-mass X-ray binaries in which a main-sequence red dwarf is transferring matter to a neutron star more massive than itself by Roche-lobe overflow, the period must be decreasing (and the orbit must be shrinking). The rate of period decrease depends on the mass-transfer rate and could be as high as $-(\dot{P}/P)_{orb} = 10^{-8}$/yr. This result has not, as yet, been verified for any of the 'canonical' low-mass X-ray binaries.

In Cyg X-3, however, the orbital period is increasing /21/ at a rate of $\sim 10^{-9}$/yr, which shows that the source can not be powered by Roche-lobe overflow of a main-sequence red dwarf. Therefore, we must conclude that (even ignoring the unique radio-, γ-ray and IR properties of the source) Cyg X-3 does not fit in with the 'standard' model for low-mass X-ray binaries. The discovery of quasi-periodic fluctuations in the X-ray flux of the source does strengthen the suspicion, on the other hand, that there is a similarity between the way in which the X-ray modulation is produced in Cyg X-3 and in certain 'dipping' low-mass X-ray binaries with a similar orbital period.

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