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EVIDENCE FOR LONG-PERIOD SPORADIC PULSATIONS IN THE HARD X-RAY FLUX OF CYGNUS X-1

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ABSTRACT

Power spectral density estimates performed on the data of three balloon observations of Cyg X-1 show a peak at a frequency of 5.75×10^{-2} Hz. This is interpreted as evidence for the presence of strong correlations in the hard X-ray flux of the source. That peak, however, appears to be present, in the single observation, only for limited periods of time, outside which it tends to disappear or to be displaced. Pulsations of limited duration, about 1 hour, cannot be excluded as a possible cause of the detected phenomenon.

Subject headings: pulsation — X-ray sources

I. INTRODUCTION

Three balloon observations of Cyg X-1 have been analyzed with Fourier techniques to search for periodicities in the 30–200 keV intensity on the scale of a few seconds. We report here the results of this analysis which show evidence for the presence of strong correlations in the flux around 17 s delay.

The instrumentation used and the characteristics of the flights have already been described (Frontera, Fuligni, and Cavani 1974). We summarize here only the most important parameters. The detectors were always made up of NaI(Tl) crystals with semi active collimators giving a triangular response of 13° FWHM.

In the first observation, performed on 1971 September 20, two identical independent detectors were used, each having a useful area of 68 cm^2. By means of a stabilized platform pointing in a fixed azimuthal direction the transit of the source was observed from about 20^h30^m to 21^h30^m above 0.5 relative exposure.

In the second (1972 June 30) and third (1973 June 30) observations an improved version of the above detector was used, with an effective area of 280 cm^2. A programmed tracking system permitted monitoring of the source above 0.80 relative exposure for about 6000 s in both flights.

The outputs of two gyroscopes and of the magnetometer were transmitted in real time to obtain information on the motions of the gondola.

Data were transmitted in an analog way with a precision of 0.1 ms and recorded on magnetic tape which also contained the timing reference signal derived by a clock with a stability better than 1 part in 10^8.

II. DATA ANALYSIS AND RESULTS

For every flight, counts corresponding to the source in the detector field of view have been collected in time intervals of 2 s. In this way three discrete time series were obtained. Figure 1 shows a sample of count rate profiles for the three observations.

For each of these runs the autocorrelation function, with time lags of 200 s, was evaluated and then the Fourier transform with the use of the Hanning window computed.

Three power spectral density (PSD) estimates were so obtained, showing each a peak in the same frequency channel 23, corresponding to a period of $17^{s}3 \pm 0^{s}3$.

For the 1971, 1972, and 1973 estimates the probability of chance occurrence of the mentioned peak is $P_1 = 2 \times 10^{-2}$, $P_2 = 7 \times 10^{-3}$, $P_3 = 4 \times 10^{-3}$, respectively, as evaluated on the basis of a χ^2 distribution.

The random probability of our result—that is, the presence of a peak at the same channel in three independent groups of 100 data—is then $100P_1P_2P_3$, which means less than 6 parts in 10^5.

This figure is in agreement with the confidence level of the result obtained by the weighted sum of the three PSDs expressed in fractional units, i.e., calculated by dividing the single data, transformed to zero mean, by their average value $\langle N \rangle$.

As weights, the relative errors for each estimate have been used. This sum is shown in Figure 2.

A similar analysis performed for each flight on the background counts, when the source was outside the field of view, gave negative results. A typical PSD of background is shown in Figure 3*a*.

An attempt has been made to evaluate the power contained in the peak in the hypothesis of a periodic wave present during the periods of source observation.

By simulation with a triangular wave we obtain roughly for that power: 10 percent of the Cyg X-1 intensity in 1971 and 5 percent in 1972 and 1973.

Search for spurious causes of this effect has been performed. In particular, oscillations of the gondola could induce a modulation of the flux of the source due to the triangular response of the collimator. An amplitude of the oscillations of $0^{\circ}8$ around the axis of view could in fact produce an intensity modulation of the same order we measured in 1972 and 1973.

A much longer period has been detected by the magnetometer for the azimuthal oscillations and in any case with insufficient amplitude, so that their direct influence must be excluded.

Pendulum oscillations are more critical as the re-

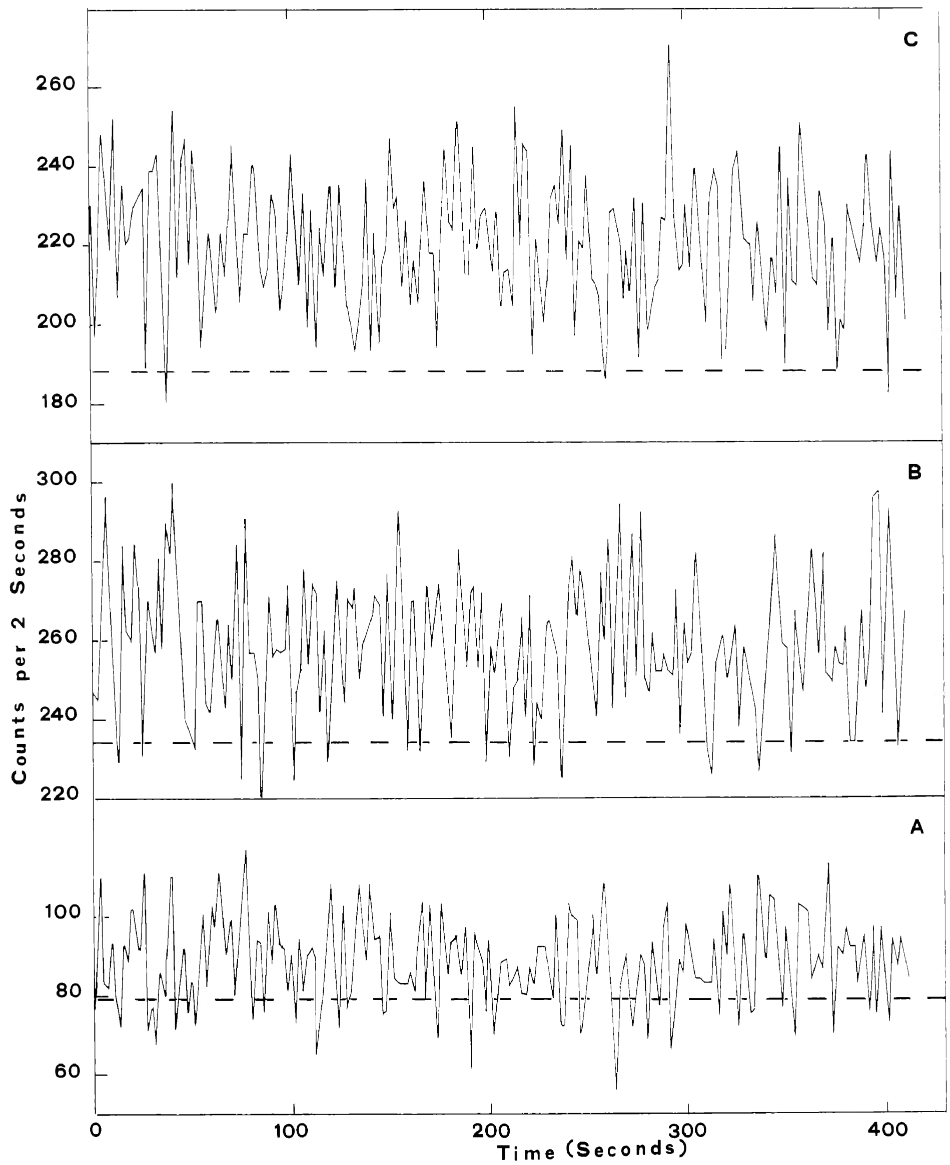

FIG. 1.—Samples of count rate profiles for the (*a*) 1971, (*b*) 1972, and (*c*) 1973 observations. Dashed lines represent the background levels.

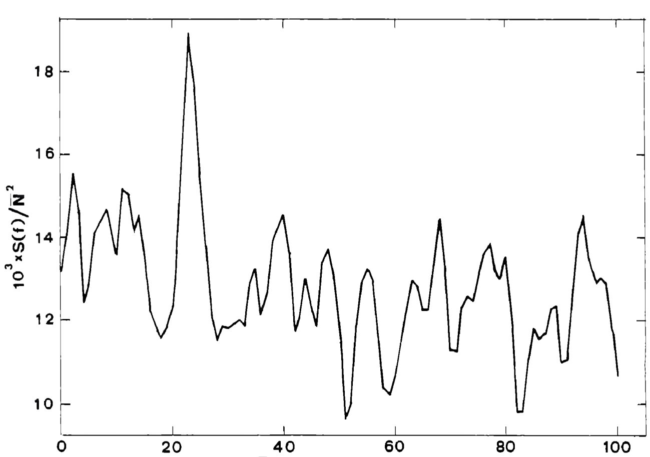

FIG. 2.—Power spectral density obtained as weighted sum (see text) of the power spectra evaluated over the whole Cyg X-1 observing time for the 1971, 1972, and 1973 flights.

quested amplitude is at the limits of sensitivity of the gyroscopes we used for long period oscillations. However precise, measurements of the amplitude of oscillations performed in other flights give a value less than 0°.1 (C. Peterson, private communication). On the other hand, in the two last flights balloons of different dimensions and different suspension lengths were used. We estimate that these differences would displace the period of possible oscillations of about 30 percent, which would imply an appreciable difference in the peak position in the two PSDs. We think, however, the best check for the correctness of these considerations is given by the analysis, performed with the same procedures, on the data of a previous observation of the Crab Nebula, in which an apparatus identical to that of the 1971 flight was used. This analysis has given negative results, which are shown in Figure 3*b*.

Two different digitizing procedures have also been used, both giving the same results.

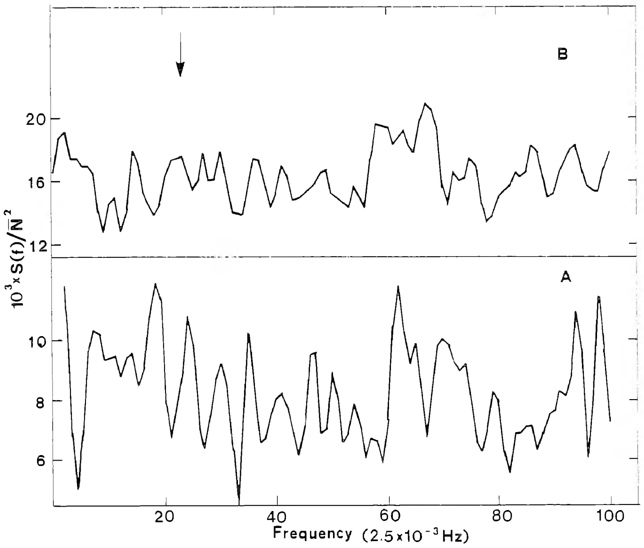

FIG. 3.—(*a*) Typical power spectral density of background with the source outside the field of view. (*b*) Power spectral density of Crab Nebula. The vertical arrow gives the position of the peak present in Fig. 1.

III. CONCLUSIONS

As no obvious instrumental or dynamical effect can be found to explain the presence of the aforementioned feature in the PSD, it seems natural to ascribe it to strong time correlations existing in the hard X-ray emission of Cyg X-1.

Search for details of this phenomenon has been attempted for the data of 1972 and 1973, which had better statistics, by performing the same kind of analysis over successive segments of 800 seconds.

The statistics and shortness of pieces do not allow to draw definite conclusions. We note, however, a number of indications, which alone have no great significance, suggesting that the feature is not stable during all the observation time, but rather concentrated in a period of about 1 hour. In both flights a number of successive segments, covering in fact this period, all show a peak at channel 23, whereas in the remaining elements this feature tends to disappear or to be displaced. In particular for the 1972 run, complete absence is found during the first 20 minutes of observation. At this time the source was particularly active: a flarelike event at

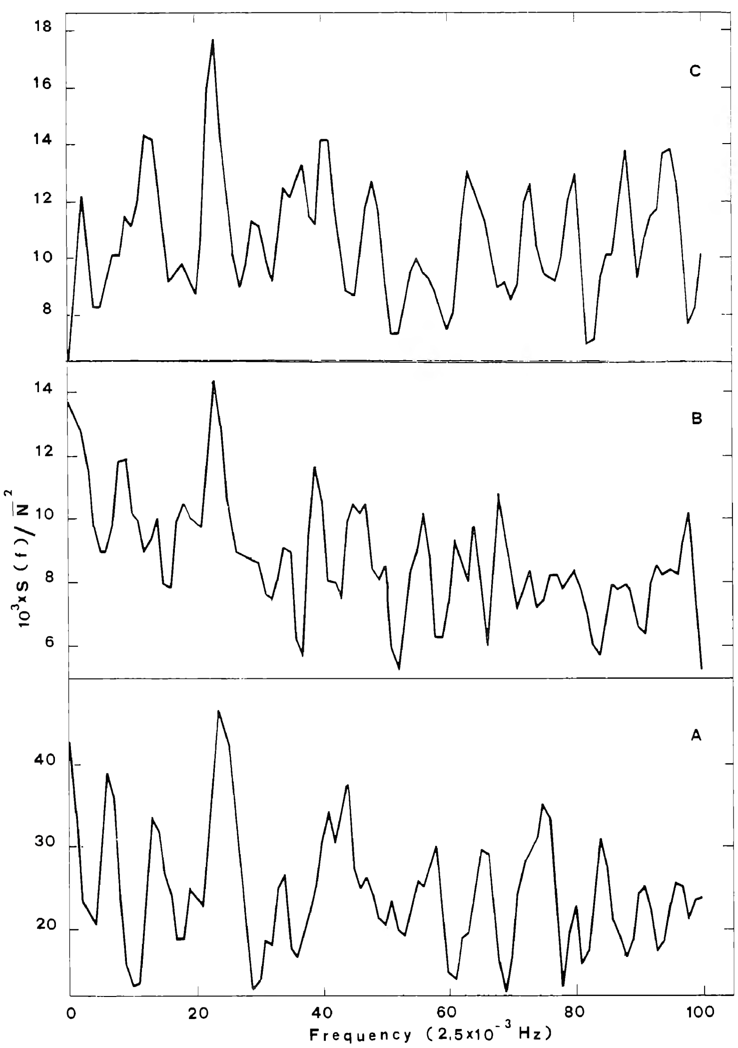

FIG. 4.—Power spectral density for (*b*) 1972 and (*c*) 1973 observations taken over 4200 seconds corresponding to the periods of relevance. (*a*) Power spectral density for 1971 observation during the time of maximum exposure of the source.

energies below 100 keV and a general decrease of the flux between 100 and 200 keV was in fact detected (Fuligni and Frontera 1973). Finally for both flights the significance of the peak does not increase by adding further data to the above mentioned periods. Figures 4*b* and 4*c* show the PSDs for the two flights during these periods of concentration. Also shown (Fig. 4*a*) is the PSD for the 1971 observation taken during the time of maximum exposed area.

In spite of the fact that the sum of the data covering all the observation time in the three years (Fig. 2) gives positive evidence for periodicity, we consider the above arguments to be indications that we are not in presence of a strictly periodic phenomenon.

Particularly "fortunate" fluctuations, similar in character to those suggested by Terrell (1972), could have caused the effect we detected.

If this interpretation is correct, these results give further support to the peculiar nature of this source, showing peculiar activity in all time scales in all energy ranges.

An alternative interpretation, which can be checked by other observations, is to ascribe the origin of the peak to periodic pulsations which are possibly powered ON and OFF, or, generally speaking, amplitude-modulated, on time scales of the order of 1 hour.

A period of the order of that corresponding to our feature as well as its possibly nonpersistent character could be accounted for by the oscillations of a white dwarf (e.g., see Warner and Robinson 1972). However, the presence of such an object in this intriguing system appears, on the grounds of optical observations (Brucato and Kristian 1973), rather untenable.

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