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HAS A 97 MINUTE PERIODICITY IN 4U 1700−37/HD 153919 REALLY BEEN DISCOVERED?

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ABSTRACT

The identification of a 97 minute modulation in the X-ray and optical intensities of 4U 1700−37/HD 153919 with an intrinsic periodicity of the source is subject, at present, to important uncertainties. By computer simulation we show the dominance of a spurious modulation with a similar period in a Fourier analysis of a smooth signal of $\sim 0^{d}.6$ variability (simulating the mean X-ray curve), viewed through the 94.5 and 101 minute and the "telemetry dropout" *SAS 3* windows. An analysis of a full night of new optical observations of HD 153919 around binary phase 0.5 also fails to show any such modulation.

Subject headings: stars: binaries — stars: early-type — stars: eclipsing binaries — stars: neutron — stars: Of-type — X-rays: binaries

I. INTRODUCTION

Matilsky, La Sala, and Jessen (1978, hereafter MLJ) have recently reported a possible 97 minute periodicity in the binary X-ray source 4U 1700−37. Following their report, Kruszewski (1978) examined optical data from HD 153919, taken 200 days earlier by van Paradijs, Hammerschlag-Hensberge, and Zuiderwijk (1978), and claims to have found a similar periodicity in the 0.44–0.59 binary phase range; moreover, he makes a tentative identification of a similar periodicity in data of van Genderen and Uiterwaal (1976), taken 400 days prior to the van Paradijs *et al.* data.

A discovery of an X-ray pulsar with such long periodicity, in particular if the period is also shown observationally to be slowly varying, will have a significant impact on current theoretical models for such systems. The purpose of this *Letter* is to point out uncertainties in both these X-ray and optical analyses which, in our view, render them, in their present form, inconclusive, and to encourage further observations of this source. We show, by numerical simulation, that in spite of the fact that the 97 minute period does not appear in X-ray counts from the reference tube of *SAS 3* (which shows only the 94.5 and 101 minute satellite periods), it can *still* be due merely to satellite artifacts, when combined with the $\lesssim 1^{d}$ variability of the 4U 1700−37 data. We also analyze further optical data of HD 153919 around binary phase 0.5, which were taken continuously in the course of one "windowless" observation night, and find no evidence for periodicity in them.

II. FOURIER ANALYSIS PROBLEM

The process of recovering periodicities from a given signal, by means of a time Fourier analysis, is not devoid of problems, especially when the data are broken in time into several trains. The case in question in this *Letter* is one important example for the rise of such a problem. Here, sets of "windows" in the X-ray data have Fourier frequencies which are separated by a frequency gap so small that it can be easily "bridged" by the range of frequencies of the signal. As a result, the signal smears out the window frequencies, while a "new," intermediate, frequency emerges. That new frequency, even though its appearance is due to the particular frequency content of the true signal, nevertheless is not part of this frequency content at all.

To be more specific, consider two window functions, $W_1(t)$ and $W_2(t)$, which are periodic in time t with respective periods T_1 and T_2, and which take on the value 1 during a time interval $t_i \equiv \eta_i T_i (\eta_i < 1;\ i = 1,2)$ in each cycle, and the value 0 elsewhere. In Fourier series, if we put, for simplicity, $t = 0$ at the middle of two of the $W_i(t) = 1$ intervals, we have

$$W_1 W_2 = 2\eta_1\eta_2\left[1/2 + \frac{\sin \pi\eta_2}{\pi\eta_2}\cos(2\pi t/T_2) + \frac{\sin \pi\eta_1}{\pi\eta_1}\cos(2\pi t/T_1) + \ldots\right]. \quad (1)$$

Thus W_1W_2 has frequency power in the fundamentals $(2\pi/T_1)$ and $(2\pi/T_2)$ of respective strengths proportional to $(\sin \pi\eta_1/\pi\eta_1)^2$ and $(\sin \pi\eta_2/\pi\eta_2)^2$.

Next, limit the data to some finite interval $-\frac{1}{2}T_3 \leq t \leq \frac{1}{2}T_3$, where $T_3 \gg T_{1,2}$. This is mathematically accomplished by multiplying W_1W_2 with a W_3, which has the value of unity in the T_3 interval and vanishes outside of it,

$$W_3(t) = \frac{T_3}{2\pi}\int_{-\infty}^{\infty} d\omega \frac{\sin(\frac{1}{2}\omega T_3)}{(\frac{1}{2}\omega T_3)}\exp(i\omega t).$$

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W_3 has a Fourier spectrum of width $\Delta\omega \sim (2\pi/T_3)$.

The Fourier spectrum of $W_1W_2W_3$, which is the convolution of that of W_1W_2 and that of W_3, will consist of a group of "spikes" of the form

$$\frac{\sin \frac{1}{2}T_3(\omega - \omega')}{\frac{1}{2}T_3(\omega - \omega')} ,$$

centered around each of the frequencies

$$\omega' \equiv \frac{2\pi n_1}{T_1} \pm \frac{2\pi n_2}{T_2}$$

of equation (1). Whenever $T_1 \approx T_2$, there will be in the $(2\pi/T_1)$ region two peaks, of width $\sim(2\pi/T_3)$, centered around $(2\pi/T_1)$ and $(2\pi/T_2)$.

With $W_1W_2W_3$ as a window function, consider a signal $F(t)$ of spectral width $\Delta\omega_s$, e.g.,

$$F \propto \exp\left[-\frac{(t-t_0)^2}{2\sigma^2}\right],$$

of which the Fourier spectrum is a Gaussian around $\omega = 0$, with half-width $\frac{1}{2}\Delta\omega_s = \sigma^{-1}$. The Fourier spectrum of $W_1W_2W_3F$ is the convolution of these of $W_1W_2W_3$ and F; hence each of the peaks around $(2\pi/T_1)$ is now further broadened by $\Delta\omega_s$. If

$$\Delta\omega_s > \frac{2\pi|T_1 - T_2|}{T_1T_2} ,$$

the resultant Fourier curve could now have a new peak; hence the data will have a "new" frequency, located between $(2\pi/T_1)$ and $(2\pi/T_2)$. This illustrates our basic argument.

In the following numerical simulations we introduce yet another window, W_4, to imitate "telemetry drop-outs" in the X-ray data. W_4 consists of three gaps and has power at low ($\sim 2\pi$ day^{-1}) frequencies; these combine with the main peak to introduce some side peaks of lower power.

III. THE X-RAY DATA

MLJ Fourier analyzed 1977 March 27 to 1977 March 31 ($T_3 \sim 3^d8$) data from the horizontal tube (HT) of *SAS 3*, which was pointing toward 4U 1700−37. Their analysis "yielded a normalized PDS amplitude of 7200 at a period of 96.8 minutes," while data from the inclined tube (IT), pointing to the background 6° away, "yield maximum normalized PDS amplitudes of 63 and 49 at 101 and 94 minutes." The latter two periodicities are the synodic (South Atlantic Anomaly) and sidereal (eclipse) periods of the satellite and hence represent T_2 and T_1.

The quoted evidence for the 97 minute period being intrinsic to the X-ray output of 4U 1700−37 and not being an artifact of the satellite orbital motion is, that if it were so, "one would expect this [the 97 minute period] to show up as a modulation in the IT data. None is observed." We now describe, after the previous section, how the 96.8 minute period might *not* be intrinsic to 4U 1700−37 at all.

A rough idea of what $F(t)$ may look like can be obtained from Figure 1 of MLJ: The data train has a characteristic width of $\sim 0^d6$ (between orbits nos. 523 and 535); hence $F(\omega)$, its Fourier amplitude, must have a width of $\sim(2\pi/0.6)$d^{-1}. This is larger than the frequency difference [of $(2\pi/1)$d^{-1}] between the 94 and 101 minute periods. The important outcome of that is that, in the Fourier transform of $F(t)W(t)$ [where $W(t)$ is the total window function, $W_1W_2W_3W_4$], *the 94 and 101 minute maxima will be replaced by a single wide peak somewhere between them*—possibly the 96.8 minute period of MLJ. That peak will appear to be rather well defined, because only one period in the range of the peak, to within ±1.7 minutes, will survive the $\sim 3^d8$ frequency grid.

One specific illustrative example of the way in which an intermediate period of 96.8 minutes appears is shown in Figures 1–7. In Figures 1–6, we have drawn simulated curves which correspond respectively to MLJ's Figures 1–6 (but note that, for simplicity, we have not included in Fig. 4 an additional 94.5

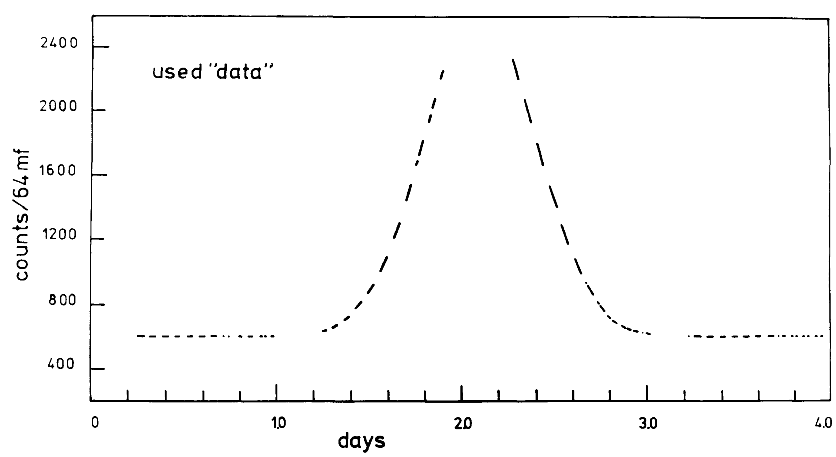

FIG. 1.—The simulated modfied "signal" $F(t)W(t)$. Figs. 1 through 6 are to be compared with same figure of MLJ. The vertical scales are different; in order to compare our "count" differences from the "zero" level of ~ 10 counts/mf with the MLF differences from that same "zero" value, one should multiply our differences by ~ 0.4.

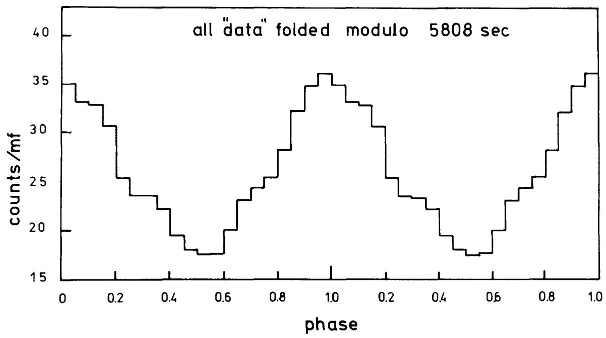

FIG. 2

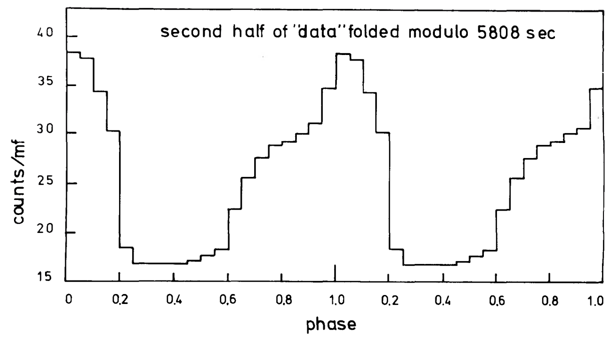

FIG. 3

FIG. 2.—Average 5808 s "pulse" profile, derived by folding all "data"

FIG. 3.—Same as Fig. 2, but folding only the second half of the "data"

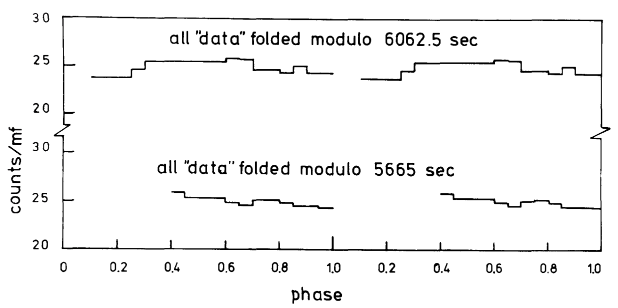

FIG. 4

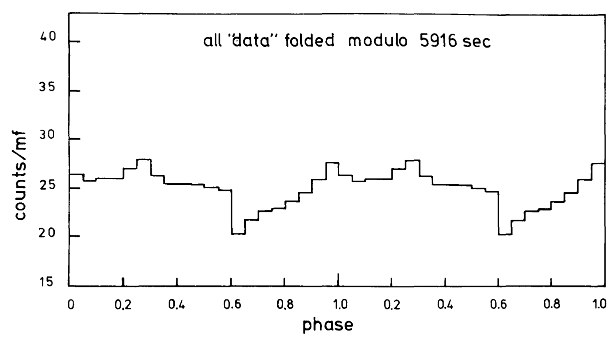

FIG. 5

FIG. 4.—Folding all "data" modulo the 5665 and 6062.5 s period windows

FIG. 5.—Folding all "data" modulo 5916 s (representative of a nonpeak periodicity)

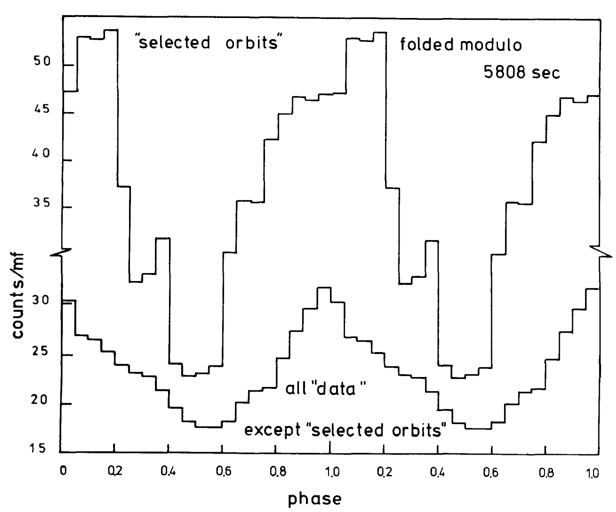

FIG. 6.—Folding modulo 5808 s of "data" corresponding to "satellite orbits" 524, 531, 532, 533, 538, 550, and 551.

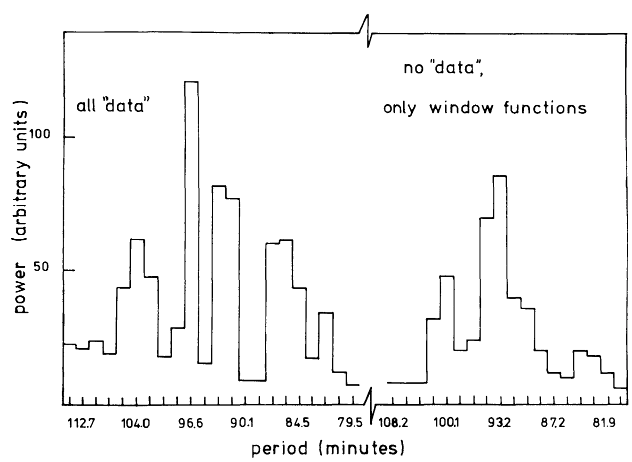

FIG. 7.—Fourier spectra. *Left*, of the "data" in Fig. 1; *right*, of the window function $W(t)$ alone. The vertical scales for left and right curves are not the same. The horizontal scale is linear with frequency but, for convenience, values (in minutes) of the corresponding periods are given.

minute effect to simulate the *SAS 3* atmospheric effects, i.e., the attenuation of X-rays through the atmosphere, just after emergence from Earth occultation; and that we also added to this figure a folding modulo 101 minutes). In addition, we give two Fourier power spectra, of $F(t)W(t)$ and of $W(t)$ (Fig. 7).

In the computer Fourier data analysis, we naturally use only the discrete set of frequencies $\omega_n \equiv (2\pi/T_3)n$. If $S(\omega)$ is the Fourier transform of $W_1W_2W_3W_4F$ as a function of angular frequency ω, then it is essentially "discretized" by replacing $S(\omega_n)$ with an average of $S(\omega)$ over an ω interval of $\pm(\pi/T_3)$ around ω_n. This has the effect of amplifying and narrowing some peaks in $S(\omega)$, and also causes an indeterminacy of $\pm(\pi/T_3)$ in their location.

We have used as an input a single Gaussian curve with a half-width of 0ᵈ3, which simulates the original, nonobscured, signal of MLJ's Figure 1 (note, however, that we "stretched" the peak above the "zero" level, of 600 counts/64 mf, by a factor ~2.5 over MLJ), and is centered at the 2ᵈ1 point of that figure (Fig. 1). We also used a 94.5 minute window function with 60% viewing time (Fig. 4) and a 101 minute window function with 90% viewing time (a value roughly consistent with Fig. 4 of MLJ and the reported total average viewing time of ~50 minutes per satellite orbit).

In addition, we put in three "telemetry dropout" windows, corresponding to the intervals 0ᵈ98–1ᵈ25, 1ᵈ9–2ᵈ25, and 3ᵈ02–3ᵈ23 of MLJ's Figure 1. These windows produce a Fourier grid of roughly 2π day^{-1} spacing; hence, by convolution with the (2π/94.5 minute) peak, enhance the (smaller) window peak near (2π/101 minute) over its value in (1) and so shift the "new" period more toward the 101 minutes than expected on the basis of the 94.5 and 101 minute windows alone. These "telemetry dropout" windows are also the source of the secondary peaks around 92 and 105 minutes, as mentioned in MLJ and in the previous section.

The actual total simulated stretch of "data" used was 3ᵈ76, consisting of 10,816 points. In view of the large similarity between our curves and those given by MLJ, we conclude that, on the basis of the latter alone, the reported 96.8 minute periodicity cannot be distinguished from an artifact of the satellite motion.

IV. THE OPTICAL DATA

Because the data of van Paradijs *et al.* of the 0.44–0.59 binary phase range are quite "broken" (into five nights, containing an average of less than two 97 minute intervals each), we expected difficulties in its analysis as well. Furthermore, upon reexamining the original van Paradijs *et al.* data and the proposed 97 minute pulse, at binary phase region 0.44–0.59, of Kruszewski, we find that the pulse amplitude, of ~0.02 mag, is biased by a small number of less reliable points in the data used.

To overcome these problems, we have now analyzed new measurements of HD 153919, taken in the Walraven system on the night of 1978 June 29–30. These measurements were taken continuously between UT 22ʰ19ᵐ21ˢ and UT 31ʰ37ᵐ28ˢ at the Leiden Observatory at Hartebeespoortdam, South Africa, at binary phase region around 0.5 of the source. We find an upper limit of 0.01 mag to a peak-to-peak possible variation in V and, within observational error, no evidence for any periodicity.

V. DISCUSSION

In order to avoid a spurious 97 minute periodicity in 4U 1700−37 with data from *SAS 3* (and perhaps also in order to avoid it in other observations of this satellite), it seems that one must select a data set with no appreciable variability on a time scale $\lesssim$1 day. In particular, the data train itself should extend over 1 day (note that if the time extension $\ll$1 day, the spurious intermediate peak conveniently becomes very wide, but then only very few segments of a possible real period occur in the data set for the period to be resolved). It seems that, due to telemetry windows and intrinsic source variability, no such partial data train exists in MLJ Figure 1. Alternatively, a random selection of a few short segments (as in MLJ Fig. 6) has the effect of introducing yet other windows, with similar time scales, hence similar problems (see our Fig. 6).

Naturally, it would be best if either the T_1 or T_2 period could have been avoided, or, at least, if no telemetry dropouts which amplify the 101 minute peak occurred. Only then could a new check on the existence of such an intrinsic period be made, using a carefully selected data train. It seems, at any rate, that one needs more observations. In view of the importance of finding some period in 4U 1700−37/HD 153919, we hope such observations will soon be under way.

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