SEARCH FOR PERIODICITY IN OPTICAL LIGHT VARIATIONS OF CYG X-2*

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The x-ray source Cyg X-2 had been identified with a faint variable star, V 1341 Cyg, as long ago as 1967, but up to now there is no conclusive evidence that this is a binary system, notwithstanding a number of endeavors to find a binary period. The situation with this x-ray source resembles that of Sco X-1, for which the binary period was found after a large number (~ 1000) of optical observations had been averaged.[3] I believe that the same technique will prove to be fruitful for Cyg X-2 when a large enough number of observations is available.

In this communication I want to present some new results obtained by analysis of optical observations carried out by V. M. Lyutiy, V. P. Goransky, and S. Yu. Shugarov at the Crimean Observatory and at Moscow University in 1974–75.[2,5] These observations comprise 335 photoelectric UBV magnitudes and 509 photographic B magnitudes taken between J.D. 2442247 and 2442684. The ostensible optical brightness variations seem to be irregular with full amplitude $\sim 1^{m}$. If there is any regular component, its amplitude should be appreciably less than this value. To find such a regular component buried under large-amplitude chaotic variations, the computer program based on two independent algorithms was used.[1] In the first algorithm for each trial period the correlation coefficient with the sine wave was calculated and normalized so as to give the best sine-wave approximation to the observed magnitudes in the limit of the large number of observations. This coefficient is plotted along the ordinate axis in FIGURES 1 and 3. In the second algorithm the mean squared deviation from the average light curve (called "dispersion" in FIGURE 2) was found for each trial period. The basic property of both algorithms is that with the increasing number of observations the scatter in "amplitude" and "dispersion" (cf. FIGURES 1 and 2) for "false" trial periods decreases while the peaks corresponding to "true" periods of persisting regular components remain approximately the same.

In early spring of 1975, when about 200 individual photoelectric points had been obtained, the periodograms (similar to those in FIGURES 1–3) showed three distinct peaks corresponding to periods $P_1 = 5\overset{d}{.}9$, $P_2 = 1\overset{d}{.}203$ and $P_3 =$

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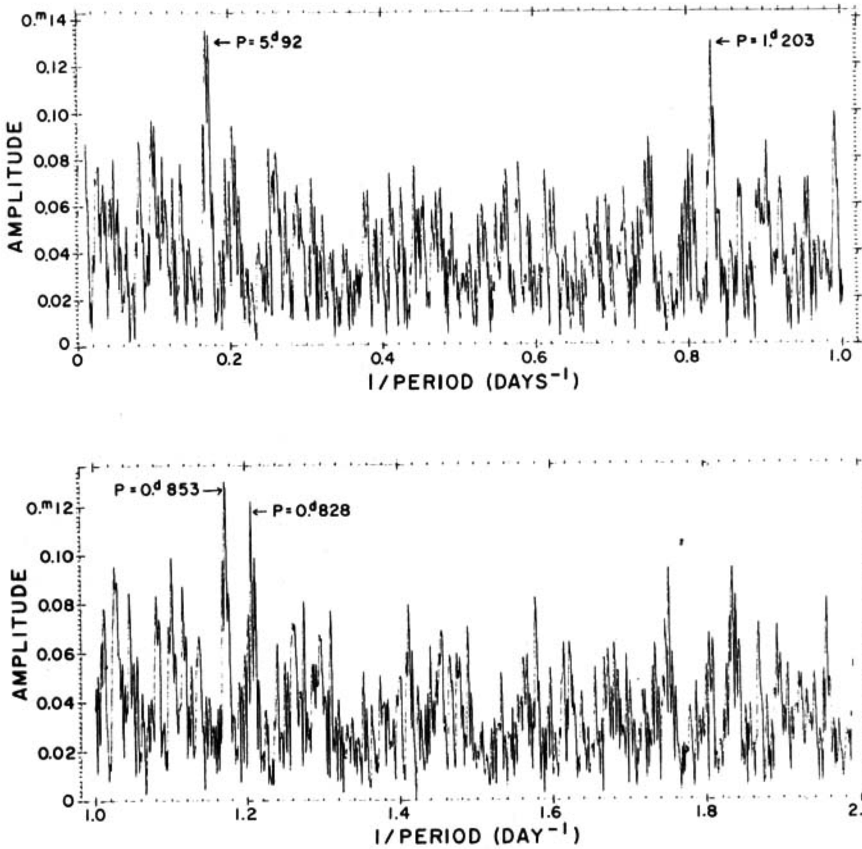

FIGURE 1. Periodogram of the photoelectric B-magnitudes of Cyg X-2 obtained between J.D. 2442247 (July 18, 1974) and 2442570 (June 6, 1975). The abscissae are the reciprocals of trial periods P in days. The ordinates are the correlation coefficients with the sine wave $\sin(2\pi t/P + \psi)$ normalized so as to give the semiamplitude of the regular component in brightness variation in the limit of the large number of observations.

$0\overset{\text{d}}{.}853$; and as more and more observations became available, these peaks became more and more pronounced. The periods P_1, P_2, and P_3 are aliases related through the equation

$$1/P_{2,3} = 1/1^{\text{d}} \mp 1/P_1 .$$

From our analysis we cannot favor any of those periods—all three seem to be equally good candidates for the binary period of Cyg X-2 (or probably half of it, if the actual light curve is a double-humped wave).

However, somewhere in April–May 1975 the situation drastically changed. The data obtained after May 1975 were steadily decreasing the confidence level of all three periods mentioned above, and this can be clearly seen when FIGURE 3 is compared with FIGURE 1. More informative is FIGURE 4, where all photoelectric (B-filter) and photographic data available are folded modulo period 0^{d}.8525. Comparing the light curve before J.D. 2442520 and after this date, one readily sees that the decrease in the amplitude of the regular component was accompanied by a decrease in the average magnitude of V 1341 Cyg.

When this analysis had been completed there were still no simultaneous x-ray observations of Cyg X-2 available. So our tentative suggestion was as follows: If one assumes that the regular component in the optical brightness variation of Cyg X-2 is due to the rotation of the normal star illuminated by x-rays from Cyg X-2, then the sudden decrease in the amplitude of this component in late

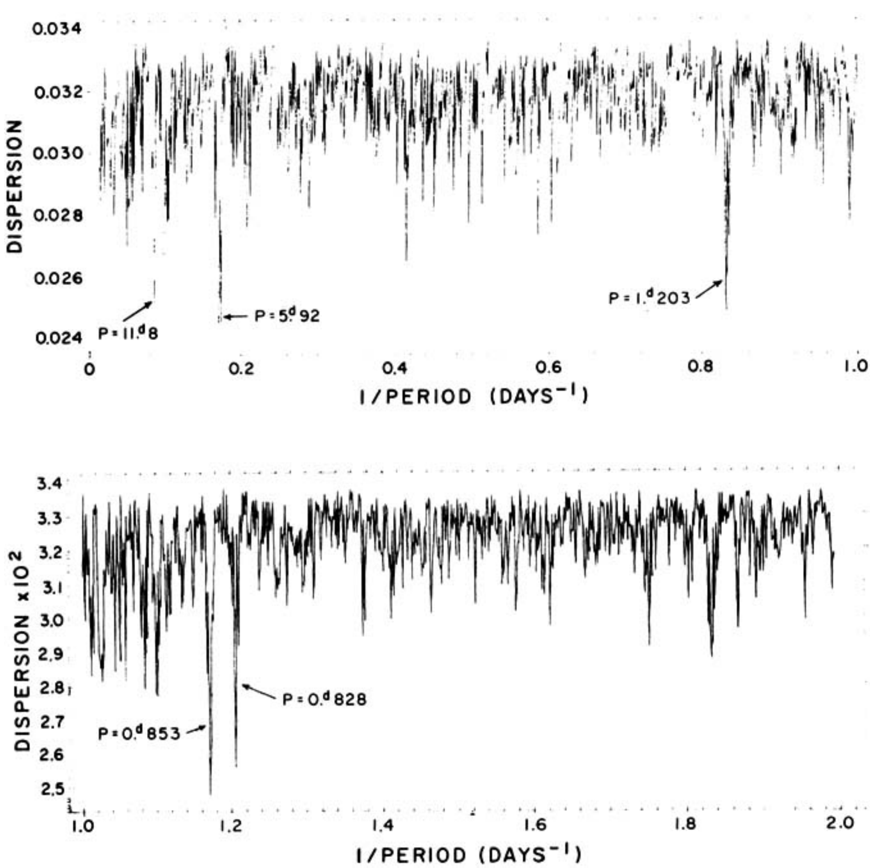

FIGURE 2. Periodogram of the same observational points as in FIGURE 1 calculated with the second algorithm. The ordinates are $N^{-1}\sum_{k=1}^{6}\sum_{i}(m_i - \langle m\rangle_k)^2$, calculated for each trial period P (P^{-1} are the abscissae), where k is the bin number, $\langle m\rangle_k$ is the average magnitude in k-bin, the inner sum includes all magnitudes m_i in k-bin, and N is the total number of observations.

spring of 1975 can be naturally explained by a sudden drop in the x-ray luminosity of Cyg X-2. And the recently published results of the x-ray observations of this source by Ariel-5 All-Sky Monitor[4] seem to confirm such an explanation. From FIGURE 1 of the paper by Holt *et al.*[4] one sees that somewhere at the end of May 1975 the x-ray source Cyg X-2 actually underwent a transition from the variable high-level active state to a quiet low-level state (the average luminosity dropped by at least a factor of 2). Now, the following prescription for determination of the binary period of Cyg X-2 is evident: One should combine and analyze those optical data which were obtained during active periods of Cyg X-2. For this, simultaneous optical and x-ray observations are highly desirable.

Having analyzed x-ray observations, Holt *et al.*[4] found evidence for $11^{d}.2$ day periodicity in the x-ray flux from Cyg X-2. This value is very close to $2P_1 = 11^{d}.8$ but does not coincide with it. The difference is at least as large as 5σ, and I have no idea how to reconcile these values. The confidence levels for both of these values

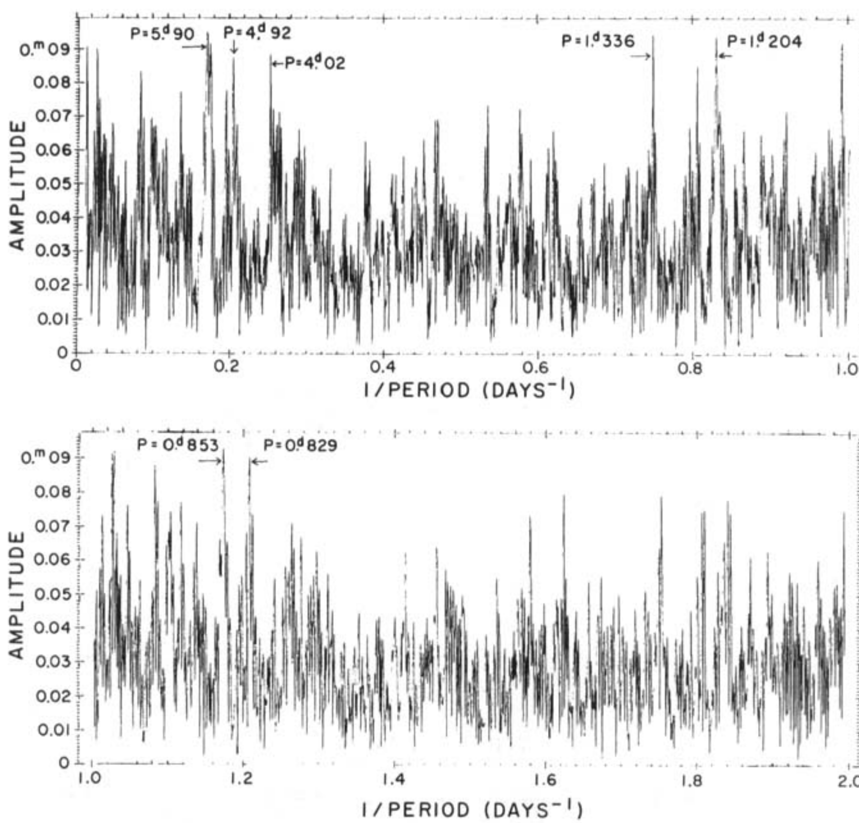

FIGURE 3. Periodogram of the same type as in FIGURE 1 for the time span of observations from J.D. 2442247 (July 18, 1974) to J.D. 2442684 (September 28, 1975).

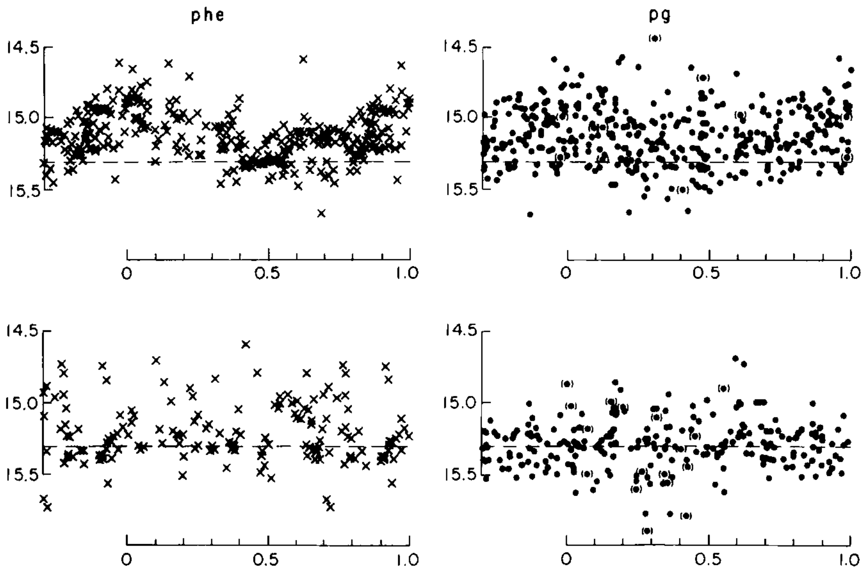

FIGURE 4. The photoelectric (crosses) and photographic (dots) observations folded modulo period $P_3 = 0^{\mathrm{d}}\!.8525$; the orbital phase 0 corresponds to J.D. 2442327.1. *Top:* the light curve before J.D. 2442520 (April 17, 1975); *bottom:* the light curve after J.D. 2442520.

seem to be comparable (compare FIGURE 2 of this communication and FIGURE 2 in the paper by Holt *et al.*[4]) and not very high.

So, the principal conclusion of our optical study of the x-ray source Cyg X-2 is as follows: We have found a regular component in brightness variation with period $P_1 = 5^{\mathrm{d}}\!.\ 92$ ● 0.05 (or $P_2 = 1^{\mathrm{d}}\!.203 \pm 0.002$, or $P_3 = 0^{\mathrm{d}}\!.8528 \pm 0.001$, or twice any of these three values) and with full amplitude $\sim 0^{\mathrm{m}}\!.25$ (B-filter), which persists only when the x-ray luminosity of Cyg X-2 is high enough. To reach an ultimate conclusion about binary period of Cyg X-2, more optical and x-ray observations are needed.

REFERENCES

1. BASKO, M. M. 1976. Peremennye Zvezdy (Soviet Variable Stars) Suppl. Ser. **2:** 337.
2. BASKO, M. V., V. P. GORANSKY, V. M. LYUTIY, L. L. RUSAN, R. A. SUNYAEV & S. YU. SHUGAROV. 1976. Lett. Sov. Astron. **2:** 539.
3. GOTTLIEB, E. W., E. L. WRIGHT & W. LILLER. 1975. Astrophys. J. Lett. **195:** L33.
4. HOLT, S. S., E. A. BOLDT, P. J. SERLEMITSOS & L. J. KALUZIENSKI. 1976. Astrophys J. Lett. **205:** L143.
5. LUYTIY, V. M. & R. A. SUNYAEV. 1976. Sov. Astron. **53:** 511.