THE ASTROPHYSICAL JOURNAL, Vol. 153, September 1968

ULTRASHORT-PERIOD STELLAR OSCILLATIONS. II. THE PERIOD AND LIGHT CURVE OF HZ 29

JEREMIAH P. OSTRIKER AND JAMES E. HESSER*
Princeton University Observatory, Princeton, New Jersey
Received July 17, 1968

ABSTRACT

The periodic variability, discovered by Smak, of the fourteenth-magnitude object HZ 29 has been reinvestigated, using extensive new photoelectric data and modern autocorrelation analytical techniques. The variations, which have maintained a constant phase over at least a quarter of a year, allow us to determine the period to high accuracy: 1051.118 ± 0.015 sec. Combining the observations using this period, we find a mean light curve having an amplitude of about 0.01 mag and the character of a double wave. These observations confirm this star as the shortest-period variable star for which a light curve is available. Although the nature of HZ 29 remains unclear, it seems increasingly unlikely that it is, as suggested by Burbidge, Burbidge, and Hoyle, a quasi-stellar object with large redshift.

I. INTRODUCTION

The blue object HZ 29, originally listed by Malmquist (1936) and subsequently by Humason and Zwicky (1947), is of considerable current interest because of its peculiar spectral characteristics (Greenstein and Matthews 1957) and its suspected variable luminosity (Smak 1967). A low-luminosity object, HZ 29 lies in the north galactic polar region, is characterized by $V = 14.18$, $B - V = -0.23$, $U - B = -1.01$ (Harris, unpublished; see Greenstein 1958), $\mu_\alpha = +0''.017$, $\mu_\delta = +0''.033$ (Luyten and Miller 1951), and was originally classified as a DBp (strong He I lines, no hydrogen lines) white dwarf with very shallow, possibly double He I lines (Greenstein and Matthews 1957; Eggen and Greenstein 1965). According to Greenstein and Matthews, there are no large shifts in the He I lines on plates taken either at short intervals or on successive nights, although the diffuseness of the He I lines makes quantitative velocity measurements impossible. The spectrum was reinterpreted by Burbidge, Burbidge, and Hoyle (1967), who noted a number of coincidences between wavelengths of absorption features in HZ 29 and absorption lines in two quasi-stellar sources, 3C 191 and PKS 0237−23, and suggested that perhaps HZ 29 is a quasi-stellar object with redshift $z = 1.95$. After studying photoelectric scanner spectra of HZ 29, Wampler (1967) has commented that HZ 29 appears, in spite of some peculiarities in its spectra, to be a hot star with He I absorption lines rather than a quasi-stellar object; he has also noted that the apparent double nature of the absorption lines could be caused by pressure-broadening with $T = 2 \times 10^4\,^\circ$K and $N_e \sim 1.5 \times 10^{17}$ cm^{-3}.

Variability was discovered in HZ 29 by Smak (1967), who published analyses by autocorrelation techniques of observations made in 1962 indicating that the star shows low-amplitude oscillations with a period of either about 9 or 18 minutes. He has consequently suggested that it may be a binary system. At this time the nature of HZ 29 is uncertain, but confirmation of the variability found by Smak would be crucial to any picture of this unusual object. It is for this reason that we have attempted to confirm Smak's discovery with new photoelectric observations of HZ 29, made using the Princeton 36-inch telescope and employing modern power-spectrum techniques to search the data for the suspected variability.

* Present address: Observatorio Interamericano de Cerro Tololo, La Serena, Chile.

II. OBSERVATIONAL DATA AND ANALYTICAL TECHNIQUES

Our techniques have been briefly described in an earlier communication (Lawrence, Ostriker, and Hesser 1967; hereinafter referred to as "Paper I") and will be described in detail elsewhere (Hesser, Ostriker, and Lawrence 1968; hereinafter referred to as "Paper III"). In brief, the data are obtained by use of a single-channel, 1P21, *UBV*, pulse-counting photometer on the Princeton 36-inch Cassegrain telescope. They are recorded in digital form at the time of observation with 2-sec counting intervals. In Table 1 we list the relevant information concerning the observing runs; the time listed in Table 1 is the starting time of the run. The analysis to follow is based upon a total of ~21 hours of observations.

Our analysis of the data consists of basically three parts. (1) A power spectrum is derived using the conventional techniques described by Blackman and Tukey (1958); a detailed description of this portion of the analysis will be given in Paper III. Periodic

TABLE 1

OBSERVATIONS OF HZ 29 AT PRINCETON

Date (1968)	Time (E.S.T.)	Record Length (sec)	Filter
January 6	03:43:11	3136	None
February 21	22:42:12	14432	None
February 23	01:09:50	11040	None
February 23	22:52:18	13600	None
April 1	20:24:32	4072	None
April 1	21:33:51	10944	None
April 6	20:02:16	17792	None

signals that are very small compared to fluctuations in the noise level are easily isolated, and for $P \sim 500$ sec an accuracy of $\delta P/P < 1$ per cent can be obtained from records as long as those in Table 1. (2) An autocovariance analysis is then made to determine the period more accurately. In this analysis, pairs of observing runs with increasing time lags between them are combined by shifting one record with respect to the other in order to determine which delays give maximum overlap of the two records. There is an intrinsic uncertainty introduced here due to a possible error in the integral number of periods between observing runs (see Fig. 1). (3) In the final step the best period averaged from the results of stage 2 is used to derive the mean light curve; one may also vary the period slightly at this stage in order to minimize collectively the probable errors of the individual points on the light curves. In stages 2 and 3 heliocentric times were used. The details of the second and third steps will be given in subsequent papers.

III. RESULTS

Initial estimates of the period of variability have been obtained from three "coarse" analyses of the available data. (*a*) Smak's autocovariance analysis of half of his available 1962 data indicated that the longer period, P_1, was ~1054 sec. (*b*) We reduced all Smak's data from his Tables 1 and 2 to digital form and processed them with our power-spectrum programs. This is equivalent to Smak's treatment, since the power spectrum is just the Fourier transform of the autocovariance. (*c*) Finally, we have determined the period from the average power spectrum derived from the observations listed in Table 1. The results of these three analyses, with *formal* probable errors, are (*a*) Smak's analysis of his data: $P = 1054 \pm 9$ sec; (*b*) our analysis of Smak's data: $P = 1049 \pm 8$ sec; (*c*) our analysis of our data: $P = 1047 \pm 4$ sec.

In the power spectra derived from our data, only two reproducible peaks were found, those corresponding to the ~525-sec and the ~1050-sec variations. The ratio of the powers at these two frequencies in the mean spectrum was $A^2(525)/A^2(1050) = 1.45$.

We then use the period ~1050 sec in the first stage of fine analysis, where we calculated the autocovariance of the signal from eight pairs of observing runs, as indicated in Table 2. This function of time lag peaks at integral multiples of the period. By dividing the time lag, at a peak, by the integral number of periods, we derive an improved estimate for the period. Other peaks give additional estimates that can be combined to give a mean period with associated probable error. Figures 1 and 2 show the results of this analysis applied to the ~525-sec variation. Using more and more widely separated

TABLE 2

PAIRS OF OBSERVING RUNS USED IN AUTOCOVARIANCE ANALYSIS

Designation	Run Pair*	Approximate No. 500-Sec Periods
I........	April 1 (1)–April 1 (2)	16
II.......	February 23 (1)–February 23 (2)	150
III......	February 21–February 23 (1)	175
IV.......	February 21–February 23 (2)	322
V.......	April 1 (2)–April 6	810
VI.......	February 23 (2)–April 1 (2)	6240
VII......	February 21–April 1 (1)	6545
VIII.....	February 21–April 6	7380

* (1) or (2) after the date indicates that the first or second run (see Table 1) of that date was used.

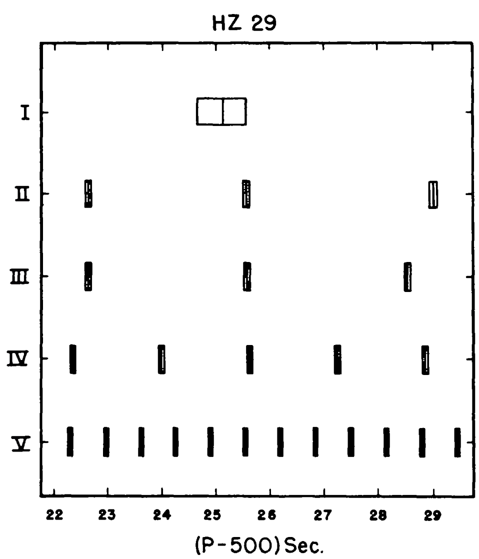

FIG. 1.—Estimates of the ~525-sec period of HZ 29 derived from various pairs of observing runs. Each horizontal row of rectangles represents a specific pair of runs, as identified in Table 2. Each rectangular box represents an estimate of the period, the width of box being twice the formal probable error of estimate. Ambiguity of period mentioned in text is indicated by multiplicity of boxes in each horizontal row; examination of Fig. 1, however, shows that only the 525.5-sec alternative is possible.

observing runs, we find the period converging to $P_0 = 525.53 \pm 0.03$ sec and $P_1 = 1051.06 \pm 0.06$ sec.

Adopting the latter period, we construct mean light curves from each run, which we then combine to find the grand average; the resulting light curve is shown in Figure 3. In this last step we further refine the period by choosing that P_1 which minimizes the dispersion about the resulting grand-average light curve. The final adopted period is $P_1 = 1051.118 \pm 0.015$ sec.

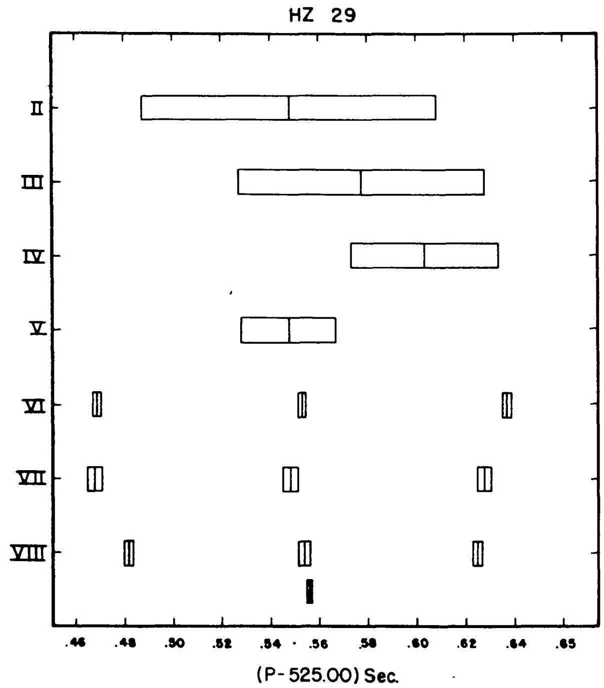

Fig. 2.—Same as Fig. 1, except that more widely separated pairs are used to define the period to higher accuracy. Final entry, below row VIII, is period derived from construction of final light curve, as described in text.

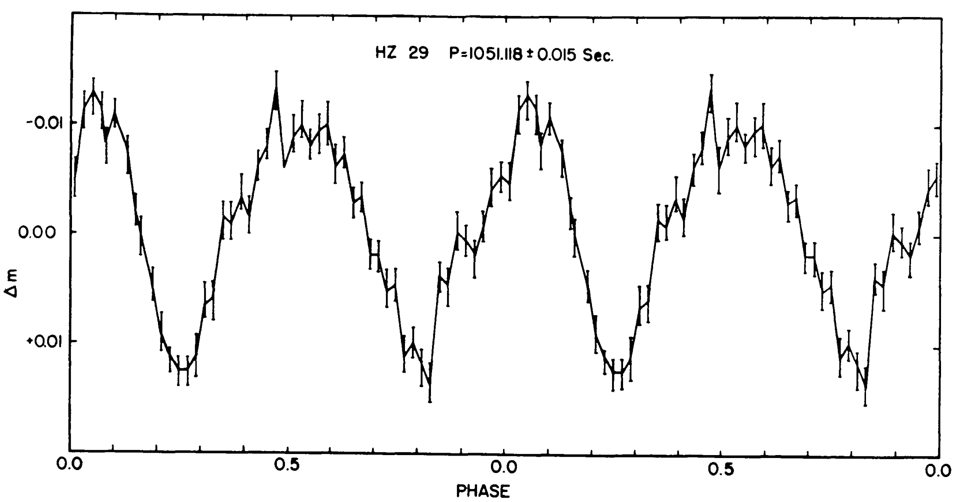

Fig. 3.—Light curve of HZ 29 constructed using indicated period. Two cycles are shown for convenience. Error bars indicate formal probable error of the mean of the approximately 1500 observations included in each point. Zero phase is defined to occur at 2439000.000 J.D.⊙.

When this period is used, the phase at, say, minimum light, shows no shift between runs greater than that due to statistical fluctuations. Each point in Figure 3 represents $\sim$1500 individual observations. The amplitude [(peak − trough)/2] of the curve is only $\sim$4 photoelectrons per sec compared to a total (sky + star) count level of $\sim$900 sec^{-1}, where the total count level has intrinsic fluctuations of at least $(900)^{1/2} = 30$ counts sec^{-1}. Thus, by looking in a narrow frequency band and combining large numbers of observations, we are able to detect a signal at a ratio of $\lesssim$0.2 of the noise level and measure its variation to an accuracy (see probable-error bars in Fig. 3) corresponding to a ratio of $\lesssim$0.02. For the 20-sec equivalent integration times used in Figure 3, these ratios should be multiplied by $\sim$4.5. While the fine details of the light curve are certainly not reliable, we can safely characterize it as being generally of the "double wave" type. Alternating maxima are of nearly the same height and minima of the same depth. The maxima are somewhat flatter than the minima, and alternating maxima are broader.

IV. INTERPRETATIONS

As pointed out in § 1, Wampler (1967) has discounted, on the basis of his studies of the optical continuum, the suggestion by Burbidge, Burbidge, and Hoyle (1967) that HZ 29 is a quasi-stellar object with $z = 1.95$. Wills (1968), finding a low radio luminosity for HZ 29, has similarly cast doubt on the suggestion, noting that the ratio of radio to optical luminosity of HZ 29 is much lower than that for known quasi-stellar objects. And, finally, the confirmation of the very short-period variability and the appearance of a distinct light curve would seem to be inconsistent with any of the present models of quasi-stellar objects.

A binary-system interpretation also seems unlikely, since maximum light occurs only during a small fraction of the total light curve. Also, the object is not on the main sequence, and, if it were instead a pair of eclipsing white dwarfs, the mass would have to be very low in order to have a close pair with a period as long as 10^3 sec. However, the period is not impossible for a pair of hot subdwarfs, even though the very low amplitude of the observed variation greatly reduces, on a purely statistical basis, the plausibility of an eclipsing system.

The observed period is too long for a radial pulsation in a white dwarf with $M \geq 0.03\, M_\odot$ (Ostriker and Tassoul 1968), but the period is compatible with pulsations that might exist in a hot subdwarf; for instance, Rose (1967) has computed that a helium-shell-burning star with $M = 0.75\, M_\odot$ could have fundamental modes with $P \sim 280$ sec, and it would be easy to increase this value either by reducing the mass or by adding hydrogen to the envelope. If pulsations *were* taking place, the velocity in the atmosphere would be of the order of a few km sec^{-1} and consequently undetectable.

A fourth possibility may merit some future attention. It is known that magnetic A stars are intrinsically slow rotators for their type (for a recent review see van den Heuvel 1968), and they often show low-amplitude, double-wave patterns in integrated-light photometry. Contraction, with mass loss, to the white-dwarf stage of such a star would leave a white dwarf with a rotation period of $\sim 10^3$ sec and, for a field that is frozen in, $H_{\mathrm{surface}} \sim 10^7$ gauss. The amplitude of the variations in brightness would be expected to be preserved after contraction to the white-dwarf stage, because the magnetic energy scales as the gravitational energy, and the resulting star might resemble HZ 29.

Detailed interpretation of the observational data accumulated in recent years for HZ 29 awaits further attention, but at this time the most tenable suggestions are that HZ 29 is either a hot subdwarf star undergoing radial pulsations or a magnetic variable. We believe that this is the shortest-period variable star for which a light curve is available. The combination of very short period and very low amplitude may indicate that perhaps we are seeing a typical member of some new class of variable star rather than an extremely eccentric member of one of the classical categories.

We have benefited from numerous discussions with colleagues and particularly wish to thank Drs. G. W. Preston, G. M. Lawrence, and M. Schwarzschild. Mr. J. Born continues to offer significant aid in the observational work. We have made extensive use of data-recording equipment belonging to the Spectroscopy Laboratory of the Princeton University Observatory, which is supported by NASA grant NsG-414. This work has been supported by NSF grant GP-6927, as part of the research program with the Princeton 36-inch telescope, while the computer facilities have been supported, in part, by NSF grant GP-579.

REFERENCES

Blackman, R. B., and Tukey, J. W. 1958, *Measurement of Power Spectra* (New York: Dover Publications).
Burbidge, G., Burbidge, M., and Hoyle, F. 1967, *Ap. J.*, **147,** 1219.
Eggen, O. J., and Greenstein, J. L. 1965, *Ap. J.*, **141,** 83.
Greenstein, J. L. 1958, *Encyclopedia of Physics* (Berlin: Springer-Verlag), **50,** 161.
Greenstein, J. L., and Matthews, M. S. 1957, *Ap. J.*, **126,** 14.
Hesser, J. E., Ostriker, J. P., and Lawrence, G. M. 1968, *Ap. J.* (Paper III, in press).
Heuvel, E. P. J. van den. 1968, *B.A.N.*, **19,** 309.
Humason, M. L., and Zwicky, F. 1947, *Ap. J.*, **105,** 85.
Lawrence, G. M., Ostriker, J. P., and Hesser, J. E. 1967, *Ap. J.* (*Letters*), **148,** L161 (Paper I).
Luyten, W. J., and Miller, W. C. 1951, *Ap. J.*, **114,** 488.
Malmquist, K. G. 1936, *Stockholm Ann.*, Vol. **12,** Part 7.
Ostriker, J. P., and Tassoul, J. L. 1968 (in preparation).
Rose, W. K. 1967, *Ap. J.*, **150,** 193.
Smak, J. 1967, *Acta Astr.*, **17,** 255.
Wampler, E. J. 1967, *Ap. J.* (*Letters*), **149,** L101.
Wills, D. 1968, *Observatory*, **88,** 61.