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HIGH-FREQUENCY STELLAR OSCILLATIONS. VI. R548, A PERIODICALLY VARIABLE WHITE DWARF

BARRY M. LASKER AND JAMES E. HESSER
Observatorio Interamericano de Cerro Tololo, La Serena, Chile
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ABSTRACT

The white dwarf R548 is a periodic variable with a dominant period of 212.864 ± 0.031 sec and a secondary period of 273.0 ± 0.6 sec. The amplitude of the former is 0.01 mag, while that of the latter fluctuates between 0.001 and 0.01 mag on a time scale of $\lesssim$24 hours. Light curves are given for both variations.

This star and the other confirmed periodically variable white dwarfs, HL Tau 76 and G44−32, lie near the lower junction of the DA boundary and the blackbody line in the $[(U - B), (B - V)]$-diagram, but other stars in this region of the two-color plane appear quiescent. The variations of these white dwarfs cannot be readily interpreted as pulsations, and the need for other physical models is discussed.

I. OBSERVATIONS

The harmonically variable white dwarf R548 (Lasker and Hesser 1970), which is number 10 in the list of Eggen and Greenstein (1965; hereafter referenced as EG) has been observed on 6 nights with the 36-inch telescope of the Cerro Tololo Inter-American Observatory. Figure 1 shows a selected data sample from the discovery night (1970 October 31–November 1); the dominant 213-second oscillation is obvious.

Photometry in the V-band on two separate nights confirms the time-averaged value, $V = 14.10$, given by EG. Table 1 summarizes the time-series observations taken with the Cerro Tololo data system (Lasker 1970), a conventional offset-guiding photometer without filters, and a refrigerated photomultiplier (FW-130 or 1P-21). The table format follows that of Hesser, Ostriker, and Lawrence (1969; hereafter referenced as HOL).

The data have been analyzed by conventional Fourier techniques (Blackman and Tukey 1958), the details of which are given elsewhere (HOL; Hesser and Lasker 1970 [Paper IV]; and Lasker and Hesser 1971 [Paper V]). The numerical procedures used on our IBM 1130 computer follow those of Singleton (1967). The programs were checked by reanalyzing time-series data of nova DQ Her (Walker 1954) acquired at the Kitt Peak National Observatory for use as a control during the initial observations of short-period variability in G44−32 (Lasker and Hesser 1969 [Paper II]), and by analyzing data for quiescent white dwarfs observed at the same time as R548.

A portion of the power spectrum from the data of November 23/24 is given in Figure 2, where the peak corresponds to a period of 213.12 ± 0.33 sec. On certain other nights a strong secondary peak appears at 273.0 ± 0.6 sec. The amplitude [$\frac{1}{2}$(peak − trough)] of the principal peak, A_{213}, and the relative strength of the secondary peak, A_{273}/A_{213}, are given in Table 1. When the secondary peak is strongly present, the light variability is extremely complex in the time domain and can be easily mistaken for simply noisy data. The much stronger variation in amplitude for the 273-sec peak (Table 1) on adjacent nights is not correlated with the change in spectral response between 1P-21 and FW-130 photomultipliers. The sharpness of the peaks in the power spectra suggests periodic activity, and the lack of overtones in the power spectra implies at least approximately sinusoidal variations, as opposed to the double sine wave encountered in HZ 29 (Ostriker and Hesser 1968). Finally, we note that in our 27 hours of observing, no dramatic flare activity occurred, such as that found in G44−32 (Warner, van Citters, and Nather 1970).

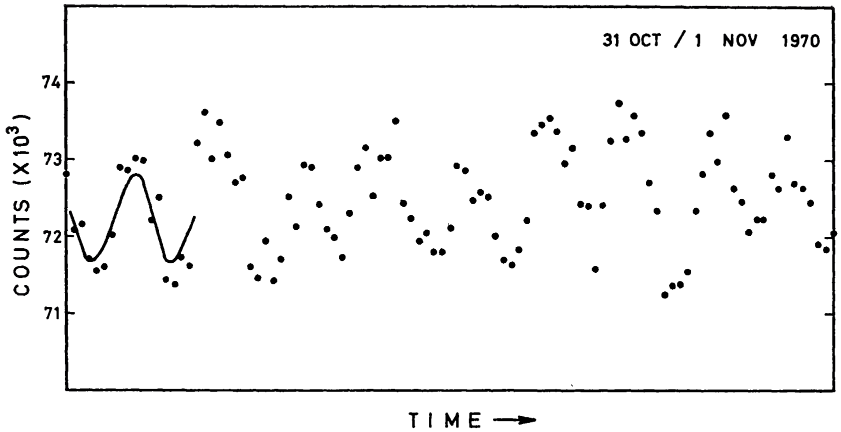

FIG. 1.—A data sample of consecutive 20-sec integrations in white light from the night of 1970 October 31–November 1, which shows the 213-sec variation clearly. For the first 1.5 cycles, an approximate light curve for $T = 213$ sec is sketched. The sky level, which has not been subtracted, was at about 10^4 counts per integration.

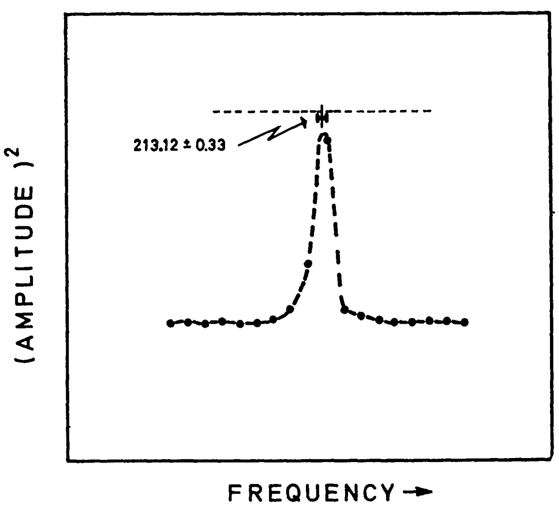

FIG. 2

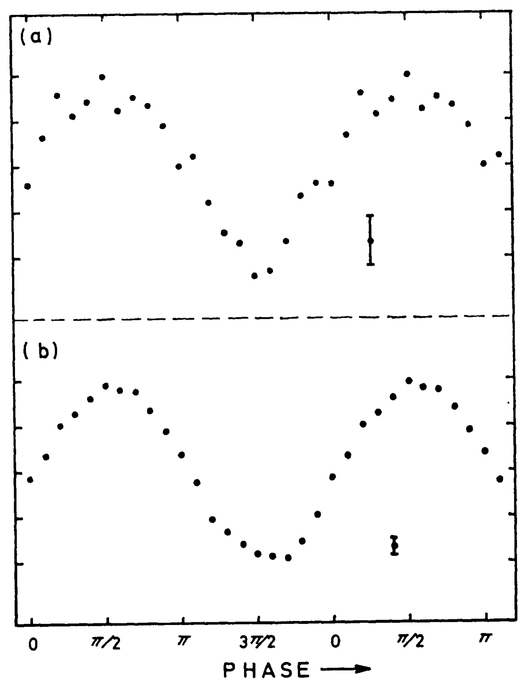

FIG. 3

FIG. 2.—Power spectrum in the vicinity of 213 sec for data from 1970 November 23/24. Dotted line corresponds to the power associated with a 0.01-mag peak variation in light. When present with strength the appearance of the 273-sec peak is similar to that displayed here for the 213-sec variation.

FIG. 3.—(*a*) Light curve for the 273-sec periodicity, generated from the November 1/2 data. (*b*) Light curve for the 213-sec variation generated from the November 23/24 data. Errors shown are 1 σ in each direction, and the amplitudes are given in Table 1.

TABLE 1

SUMMARY OF TOLOLO 36-INCH OBSERVATIONS ON R548

Date (1970)	Time (UT)	N	τ (sec)*	A_{213} (mag)	A_{273}/A_{213}	Q	Comments
October 31–November 1	03:03:45	8457	1.990	0.0103	0.37	0.0100	FW-130
November 1–2........	01:35:25	21749	0.990	0.0043	0.99	0.0062	FW-130
November 13–14†.....	01:49:50	3199	1.990	0.0021	0.27	0.0056	1P-21
November 14–15......	00:49:04	12003	0.990	0.0096	0.92	0.0191	1P-21
November 22–23......	00:37:28	6153	1.990	0.0070	0.93	0.0103	1P-21
November 23–24......	00:15:46	14163	1.990	0.0093	0.16	0.0108	FW-130

† Since the data were taken very near full Moon, the A's are rather uncertain.

The cross-correlation function of two subsets of data from the night of November 23/24 was used to refine the principal period to 212.94 ± 0.15 sec. This is sufficiently accurate to work with cross-correlations of adjacent nights; the three such possible combinations from the data of Table 1 yield a period of 212.864 ± 0.031 sec. (Extending this procedure to data sets with greater separation gives a tentative heliocentric period of 212.865 ± 0.006 sec, but we feel that the phase uncertainty over this longer interval is such that more data, currently being obtained, are needed with about a 5-night spacing.) Figures 3*a* and 3*b* give light curves for the two periods, each constructed from unfiltered data selected to display the respective variation clearly.

II. DISCUSSION

The properties of R548 may be summarized as follows:

i) The star is a DA-type white dwarf with $B - V = +0.20$, $U - B = -0.54$, and $V = +14.10$ (EG), and the current mean value of V is identical to that measured ~5 years ago by EG.

ii) The light varies with a period of 212.864 ± 0.031 sec, and has a relatively constant amplitude, 0.01 mag (Table 1). The light curve is not significantly different from a sine wave, and double-sine-wave behavior is definitely excluded.

iii) An additional periodicity of 273.0 ± 0.6 sec exists and is highly amplitude-modulated with a time scale of $\lesssim$24 hours. The light curve associated with this variation may contain some harmonics (Fig. 3*a*); but, again, a double sine wave is excluded.

iv) Except for the peaks at 213 and 273 sec, the power spectra are very quiet ($A_{max} \leq 0.0013$ mag), and the Q-values are quite small (cf. Paper II, IV, or V). Thus there is no activity on the high-frequency range 2 sec $\leq T <$ 212 sec. Furthermore, no conspicuous flares exist in our time-series data.

v) Except for DQ Her (Walker 1954) and the pulsars, R548 appears to be the shortest-period variable star with a well-defined light curve.

Parameters of the EG white dwarfs which are known to vary are given in Table 2. (Because of its controversial nature, HZ 29 [Ostriker and Hesser 1968] is excluded from the present discussion.) The remaining variable stars are all type DA or DC (EG; Greenstein 1969, 1970), and all lie near the lower junction of the DA boundary and the blackbody line in the two-color diagram (Fig. 4). However, the other stars near the region of the variables in Figure 4 (EG 2, 6, 11, 54, 82, and 162) are quiescent to within certain limits (HOL; Paper IV; and unpublished data) and demonstrate that occupancy of this part of the two-color diagram is an insufficient condition for short-period variability.

TABLE 2

PARAMETERS FOR KNOWN VARIABLES FROM THE LIST OF EGGEN AND GREENSTEIN

Name	EG	V	$B-V$	$U-B$	Spectrum	Period (sec)	References*
R548.......	10	14.1	+0.20	−0.54	DA	212.864±0.031 273.0 ±0.6	
G44−32....	72	16.6	+0.29	−0.58	DC	1638 822 600	Lasker and Hesser (1969) Spectrum: Greenstein (1970)
HZ 29.......	91	14.2	−0.23	−1.01	DBp	1051.118±0.015	Period: Ostriker and Hesser (1968); Smak (1967)
HL Tau 76..	265	15.2	+0.20	−0.50	DA†	750	Period: Landolt (1968); Spectrum: Landolt (1968)

* Spectral classification and *UBV* photometry from Eggen and Greenstein (1965) except as noted.

† Landolt's spectrum variation not confirmed by Greenstein (1969, 1970).

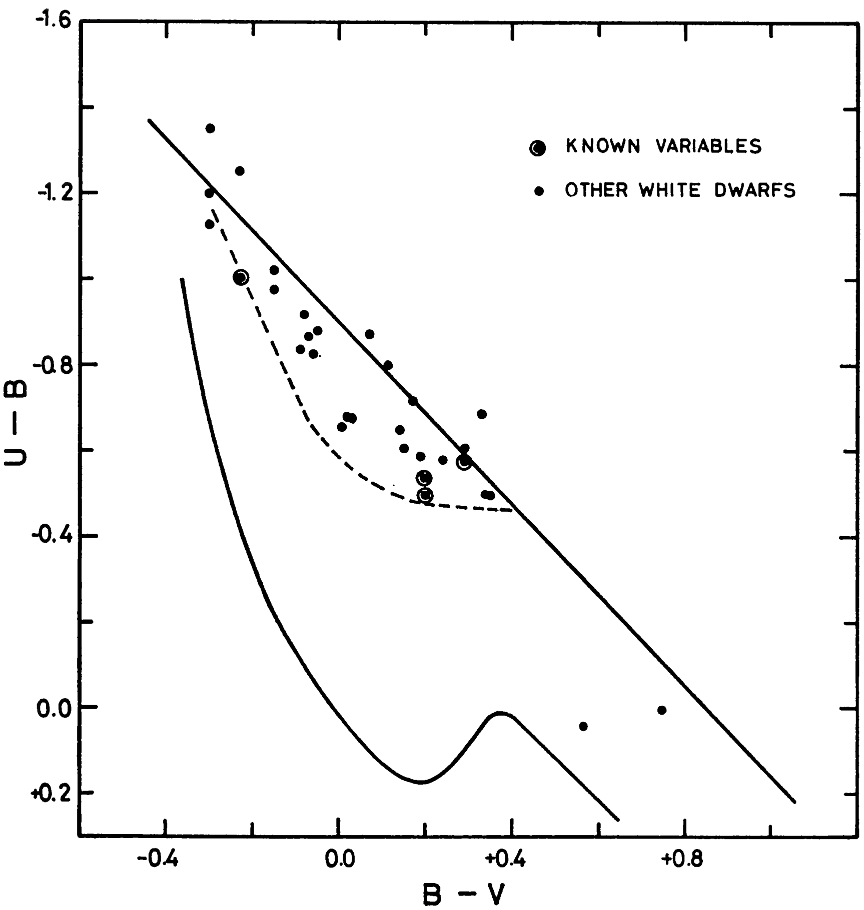

FIG. 4.—Two-color diagram for white dwarfs according to Greenstein (1969), in which we plot all white dwarfs that have been observed to be quiescent in the Princeton-Tololo searches for low-amplitude, periodic-variability stars (*dots*) as well as the four known variables (*circled dots*).

A possible spectroscopic distinction is that the two DA stars, HL Tau and R548, have relatively stable light curves, while G44−32, a DC type, has more erratic photometric behavior (Paper II; also Warner *et al.* 1970). For the latter two stars, the period ratios 273/213 and 13.7/10.0 are remarkably similar. Clearly we are working with a new group of variable stars in the process of delineation, and further work is needed to define its characteristics.

The physical interpretation of these variables is a puzzle. The observed periods are 100 times longer than are expected for pulsating white dwarfs (e.g., Faulkner and Gribbin 1968; Ostriker and Tassoul 1968), but all of these variables are spectroscopically and photometrically confirmed white dwarfs. Van Horn's (1970) observations that these stars may photometrically lie near the boundary of a convective zone where atmospheric material can be mixed with the degenerate core is probably of no help here, for such mixing would lead to nuclear reactions (Van Horn 1970) that would excite oscillations at the pulsation frequency ($\sim$ 1 sec), which, at least for $T \geq 2$ sec, are excluded by the present observations.

Possible physical models might involve two white dwarfs in a binary system, but it is difficult to see how the (apparently) common period ratios, 273/213 and 13.7/10.0 for R548 and G44−32, respectively, can be compatible with the random distribution of orbital parameters to be expected among binary systems.

A similar dilemma for the pulsars (neutron stars) appears to have been resolved by the identification of the oscillation mechanisms with oblique magnetic rotators (e.g., Ostriker and Gunn 1969; Gunn and Ostriker 1970; Hewish 1970). If the pulsar periods are scaled from neutron-star to white-dwarf densities by $\rho^{-1/2}$, then periods in the order of 10^2 sec result, making the possible analogy to white dwarfs clear. In order to explain the multiple periodicity with such a model, coupling of the rotation to two modes of some kind of oscillation would be needed.

Clearly many questions remain unanswered after this initial examination of our data, and additional experiments come readily to mind. We strongly believe that further studies of white-dwarf variable stars will lead to new insights into the final stages of stellar evolution.

One of us (J. E. H.) particularly wishes to thank the participants of IAU Symposium No. 42, especially Drs. J. P. Ostriker and H. Van Horn, for their many encouraging comments and stimulating queries, which had a direct bearing upon the continuation of this work and the subsequent discovery of R548. In addition, we are very grateful to Dr. Ostriker and Dr. J. W. Brault for considerable mathematical aid over the last two years and to Dr. W. K. Rose for a critical discussion of the present results. We also wish to acknowledge the assistance of Srs. O. Saá and A. Gómez at the telescope, of Sr. L. Pastén in data reduction, and of Mrs. B. Hesser in all phases of the program.

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