THE ASTROPHYSICAL JOURNAL, 209:853–857, 1976 November 1

HIGH-FREQUENCY STELLAR OSCILLATIONS. XI. THE ZZ CETI STAR BPM 30551

JAMES E. HESSER AND BARRY M. LASKER
Cerro Tololo Inter-American Observatory*

AND

HERMANN E. NEUPERT
Cerro Tololo Inter-American Observatory,* and Observatorio Nacional de Cerro Calán
Received 1976 February 6; revised 1976 April 12

ABSTRACT

BPM 30551, which is a DA-type white dwarf located in the region of the *UBV* (2)-color plane favorable to variability, has been found to be a rather complex ZZ Ceti star with periods of 606.8, 682.7, 744.7, and 840.2 s and amplitudes ~ 0.01 mag.

Subject headings: stars: individual — stars: variable — stars: white dwarfs

I. INTRODUCTION

Systematic photometric searches for variability in white dwarfs (Hesser, Ostriker, and Lawrence 1969; Hesser and Lasker 1971*a*, *b*) have defined a preferred region of the $U - B$, $B - V$ plane in which the so-called ZZ Ceti variables (Kukarkin *et al.* 1971) lie. To date less than 10 of these stars have been identified (see, e.g., the review of Warner 1975). Consequently the properties of the group are rather ill-defined, the only obvious unifying characteristic being small-amplitude oscillations at a frequency too low to be a radial pulsation; a DA spectral type is conceivably another unifying feature.[1]

In an attempt to enhance our empirical knowledge of such stars and to obtain observational clues to the physical nature of the oscillations and the mechanism exciting them, we have continued the search for new variables. Recent emphasis has been especially directed to Wegner's (1973) list of southern white dwarfs, from which one of us[2] discovered (under marginal photometric conditions) on the night of 1974 August 25/26 that BPM 30551 ($\alpha = 1^h04^m.7$, $\delta = -46°26'$ [1950], $V = 15.26$, $B - V = 0.29$,[3] $U - B = -0.58$ [Eggen 1969], spectral type DA [Wegner 1973]) is a complex low-amplitude variable with periods in the order of 10^3 s (Hesser, Lasker, and Neupert 1975).

* Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

[1] McGraw and Robinson (1976) would require a DA spectral type for membership in this group, but the case of EG 72 (Lasker and Hesser 1969; Warner, Van Citters, and Nather 1970), which has a DC spectral type (Greenstein 1970), must be taken as a counterexample.

[2] H. E. Neupert, as part of a *Memoria* to be submitted to the University of Chile in partial fulfillment of the requirements for the degree of *Licenciado en Astronomía*.

[3] Wegner (1973) gives a bluer $B - V$, $+0.23$, which more nearly agrees with the colors of most other white dwarf variables (e.g., Warner 1975).

II. OBSERVATIONS AND ANALYSIS

A summary of the time-series observations, taken with our standard techniques (Hesser and Lasker 1971*b*), is presented in Table 1 together with certain results from the analysis. With the exception of file 2213, a single-channel S-20 photometer with no filter was used throughout, and typical count rates were about 500 s^{-1} above a usually dominant (moonlit) sky. Representative series of observations are presented in Figure 1. Some data sets, typified by file 2215, display clear oscillations during ~$1\frac{1}{2}$ hr-long bursts separated by relatively quiescent 2–3 hr intervals, rather suggestive of a beat phenomenon; others, like file 2216, are more erratic and contain segments in which the high-frequency variations are of very small amplitude; and still others, eg., file 2228, contain somewhat weak but more nearly harmonic activity.

The time-series data are supplemented by three spectroscopic results. The CTIO two-channel scanner was used with the 1.5 m telescope on the nights of 1974 December 2–4 to obtain an Hγ profile and the continuum fluxes. The full width at half-intensity for Hγ is ~40 Å, consistent with a degenerate object (Eggen and Greenstein 1965). The continuum fluxes (cf. Hesser, Lasker, and Osmer 1972, 1974) are represented by log $(F^{\nu}_{4255}/F^{\nu}_{7100}) \approx 0.19$ and log $(F^{\nu}_{3571}/F^{\nu}_{4255}) \approx -0.13$, which, on the bais of Shipman's (1971) models imply log $g \approx 8$ and $T_e \approx 1.3 \times 10^4$ K. Finally two 125 Å mm^{-1} image-tube spectra of the Hα region obtained on 1974 November 22 with the 1.5 m telescope show no evidence of emission lines. These observations confirm and extend Wegner's (1973) conclusion that BPM 30551 is a DA-type white dwarf with no evident spectroscopic peculiarities.

Our efforts to understand this photometrically complex object are oriented around the Fourier techniques previously used in this program (Hesser and Lasker 1971*b*). The data were examined for activity in the period range $4 \leq P \leq 300$ s by computing power spectra of 24 independent subsets of the observations. While curious peaks occasionally

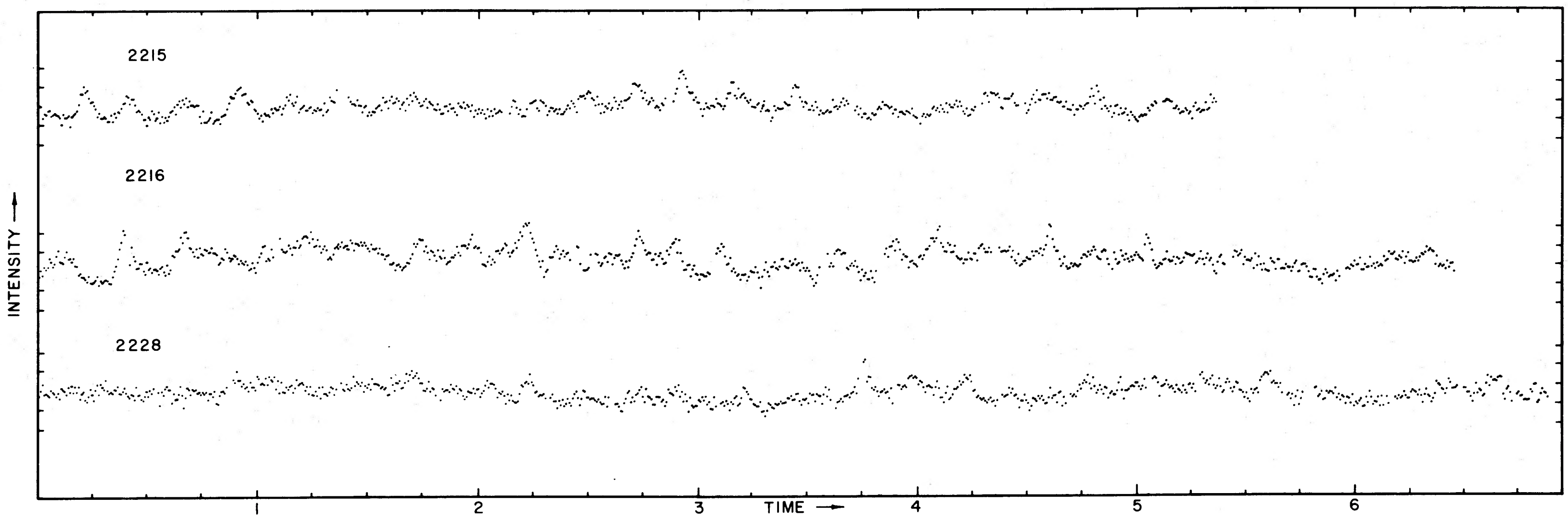

FIG. 1.—Representative time-series data for BPM 30551. The time-origins are as given in Table 1, the abscissa is in hours, and the ordinate is in units of 0.04 mag. Each point represents data integrated to 28 s.

TABLE 1

BPM 30551: The Observations and Some Results

File	Date (1974)	Time (UT)	N*	Q†	P_1‡	A_1‡	P_2	A_2	P_3	A_3	P_4	A_4	P_5	A_5	P_6	A_6	P_7	A_7
2213 § ‖	26 Aug	06:13:37	3549	0.031	688.4	20												
2214 #	13 Oct	04:03:33	4277	0.055	741.4	20	920.5	17	655.4	16	378.4	7	442.8	6	309.1	5	348.6	5
2215	14 Oct	02:44:33	9702	0.046	819.2	18	885.6	14	936.2	12	993.0	6	738.0	6	609.6	6	409.6	6
2216 §	15 Oct	01:07:55	11668	0.062	844.5	18	963.8	12	682.7	12	606.8	12	1938.9	10	1724.6	10	799.2	10
2221	26 Oct	04:24:53	6500	0.039	606.8	14	751.6	12	682.7	10	920.4	8	546.1	5	300.6	5	496.5	4
2222 **	27 Oct	00:43:46	12228	0.055	607.9	16	682.7	12	910.2	8	1916.3	6	862.3	6	731.4	6	344.9	6
2223 **	28 Oct	00:33:18	13923	0.075	744.7	17	606.8	15	1213.6	12	1129.9	10	2340.6	9	2048.0	9	1057.0	8
2227 ††**	29 Oct	00:57:27	12082	0.054	862.3	15	606.8	13	2340.6	8	1437.2	8	1137.8	8	958.1	7	744.7	7
2228 ††	30 Oct	00:46:07	12508	0.056	606.8	11	936.2	9	993.0	8	744.7	7	2259.9	6	712.3	6	1092.3	5
2230 **	04 Nov	01:09:54	13084	0.058	799.2	8	2259.9	7	1365.3	7	744.7	7	668.7	7	862.3	6	612.5	5

* The number of integrations in the data set; all integrations were 1.99 s with a spacing of 2 ± 10^{-8} s.

† The *quiescency* parameter, as defined in Hesser, Ostriker, and Lawrence (1969); typical values for nonvariable white dwarfs are ~0.011 (Hesser and Lasker 1971*a*).

‡ The P_i, A_i, $i = 1, 7$ are the periods in seconds and the amplitudes in units of 0.001 mag for the seven largest peaks in the power spectrum with $P \leq 0.2N$ s. As the discovery-night was photometrically unreliable, only the obvious 688 s period is listed.

§ Marginal photometric conditions.

‖ 1P21 Photomultiplier.

Note that lower resolution characterizes this rather short data set; e.g., at 655 s a change of one frequency element in the discrete Fourier transform gives a change in P of ~50 s, whereas in a data set like 2222 such uncertainties near 606 s are ~11 s.

** A 120 s signal due to an improperly focused Fabry lens admitting small systematic tracking errors is ignored.

†† 1.5 m telescope; all other data were taken with the 0.9 m.

occurred in the individual power spectra for $P \leq 120$ s, their irreproducible character among the various spectra lead us to dismiss them as noise; the combined power spectrum made from the 24 subsets is given in Figure 2 and shows no high-frequency activity $\gtrsim 0.003$ mag in the 4–120 s range.[4]

On the other hand, the lower frequency portions of Figure 2 show the activity that we anticipated from the time-domain data (e.g., Fig. 1). This activity is shown in greater detail in the power spectra, Figure 3, for the three representative data sets of Figure 1. Many of the available data sets are quite long and should produce statistically reliable power spectra for periods up to 40 min; thus the power spectra of Figure 3 and others (not shown) support the idea that the variations of BPM 30551 represent a complex, statistically *nonstationary* process. Two periodicities, at ~608 and ~748 s, appear in nearly all of the data sets of Table 1 with peak-to-peak amplitudes of $\sim 0.010 \pm 0.006$ mag. While a number of other periods are also given in Table 1, the individual power spectra contain more information that we can presently use; and the combined power spectrum, Figure 4, would seem a better basis for speculation.[5] There the prominent peaks lie at 606.8, 682.7, 744.7 and 840.2 s.

Attempts to use the maximum entropy technique (Richer and Ulrych 1974; Andersen 1974; Akaike 1970) to refine any of the above periods were unsuccessful, yielding uncertainties in the period of order ±2 s. Similar attempts to use the maximum entropy methods to follow slow frequency changes (such as those reported for G61–29 by Richer *et al.* 1973) were unsuccessful, yielding excessively high values for M_0, the chosen order of the autoregressive process, and periodicities unreasonably dependent on the exact data subset chosen for analysis.

[4] However, the tedious searching required to discover the 30 s oscillations in CD −42°14462 (Warner 1973; Hesser, Lasker, and Osmer 1974) compels us to treat this kind of statement cautiously.

[5] However, as this is a time-average over a nonstationary process, it must be regarded as a representation of the various possible oscillations and not as a description of a single oscillatory state of the star.

III. DISCUSSION

The obvious starting point for further investigation is the relationship among the four persistent periods in the combined low-frequency spectrum. In a mathematical sense they could be fitted well by the 11th–8th harmonics, respectively, of a 1.870 hour fundamental; but we have failed to find such a periodicity in the data. (Such a period, of course, would be reasonable for a binary system.)

Several authors (Chanmugan 1972; Warner and Robinson 1972; Harper and Rose 1970) have proposed that the mechanism of the ZZ Ceti variability is *g*-mode oscillations. Using Brickhill's (1975) models[6] for such oscillations, we see that taking a P_{61} to be 606.8 s gives $P_{k1} = 679.6$, 752.4, and 825.2 s for $k = 7$, 8, 9, respectively, in tantalizing agreement with the observations; and a model slightly less massive than

[6] Brickhill's equation (11) is a garble, which on the basis of the example in paragraph 4, p. 414 of Brickhill (1975), should read $P_{k+1,l} = P_{1l}(1 + k/h)$. Our use of this equation with $h = 3.317$ from the 0.6M13T(c) model is an extrapolation outside the k's of his Table 3 and must be regarded with caution.

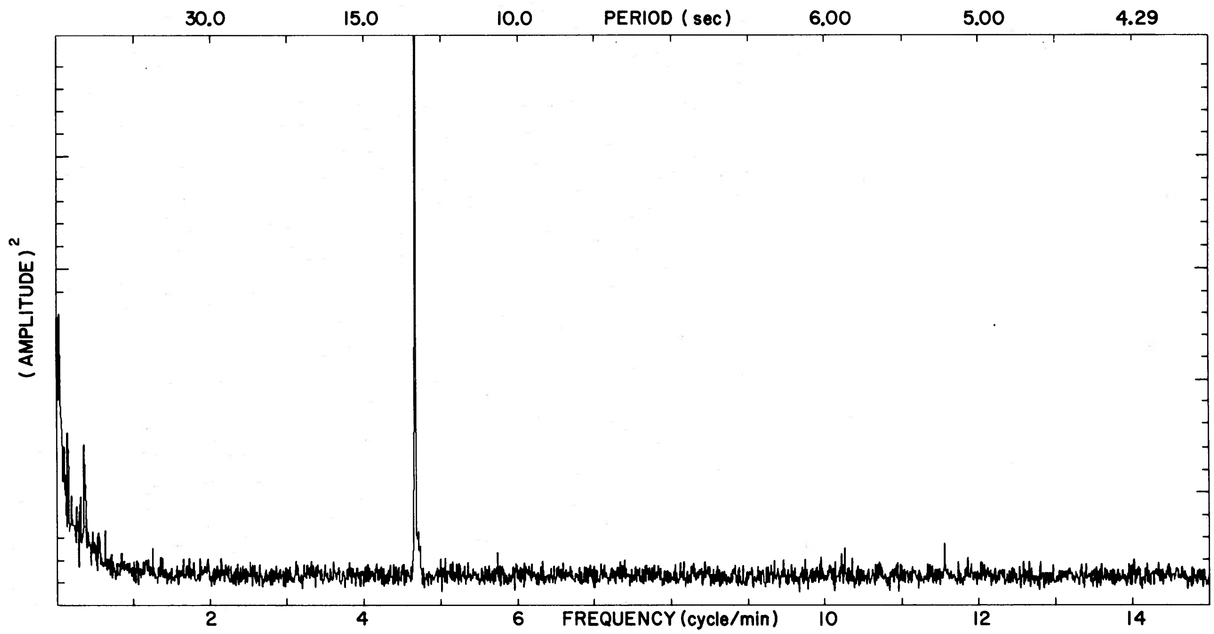

FIG. 2.—The combined power spectrum from 24 independent subsets of the time-series data. The large peak at 4.8 cycles min^{-1} is an artificial tracer with amplitude 0.025 mag.

Brickhill's 0.6M13T(c) should have the required P_{61} (cf. eq. [10] of Brickhill 1975). The difficulty lies in imagining a mechanism that would preferentially excite such high modes.

Compared with the other known luminosity-variable white dwarfs, BPM 30551 is a relatively complex object; however, this relative complexity may be observationally distorted since the star is one of the better observed and analyzed variables. In addition to further searches for new ZZ Ceti variables, there is ample justification for further monitoring of the known ones to see if the apparent simplicity of some is real; in this spirit we are currently analyzing data accumulated from 1970 to 1974 for R548.

In regard to BPM 30551 itself, we are uncertain of the significance of the numerical relations presented

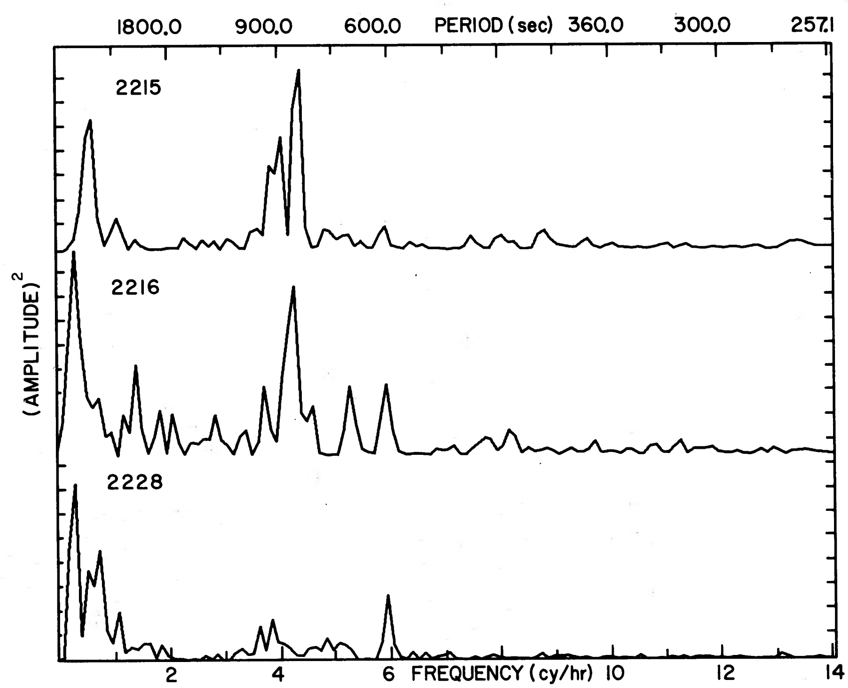

FIG. 3.—The low-frequency power spectra for the three data sets given in Fig. 1. The ordinates are obtainable from Table 1.

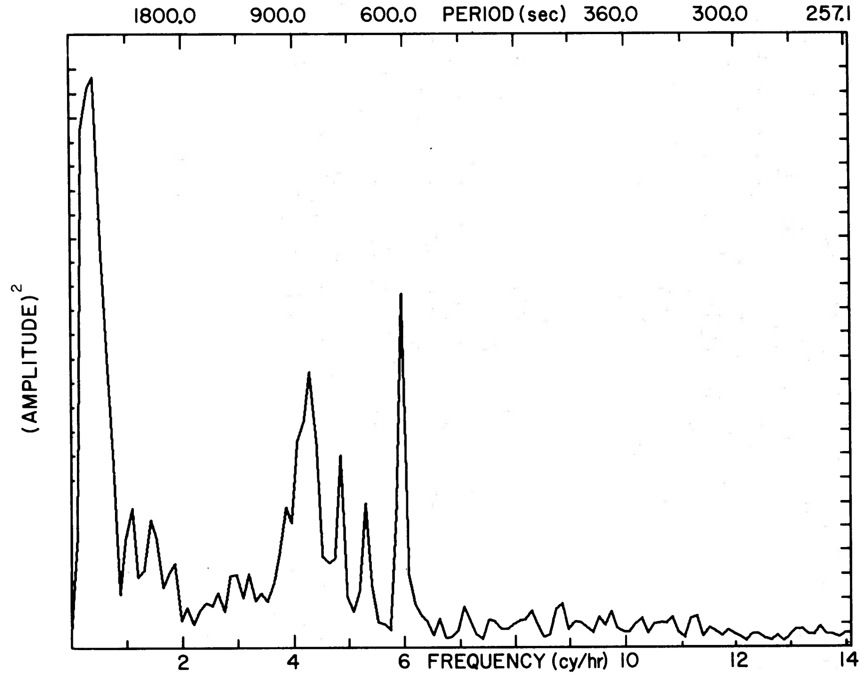

FIG. 4.—The low-frequency power spectrum made by combining files 2215, 2216, 2222, 2223, 2227, 2228 and 2230. The amplitude of the 608 s peak is ~0.012 mag in this figure.

above and feel that further observational insights into this star may be useful. In particular, the quality of our photometric data is insufficient to exclude a weak eclipse or small amounts of flickering; and the nonstationary properties of the variations, which are evident in Figure 3 and suppressed in Figure 4, require further attention.

The authors are indebted to H. B. Richer and T. J. Ulrych for assistance with the maximum-entropy algorithm and to their colleagues in La Serena for critical comments. H. E. Neupert wishes to thank the Cerro Tololo Inter-American Observatory for the facilities and financial support it has made available during the course of this investigation.

REFERENCES

Akaike, H. 1970, *Ann. Inst. Stat. Math.*, **22**, 203.
Andersen, N. 1974, *Geophysics*, **39**, 69.
Brickhill, A. J. 1975, *M.N.R.A.S.*, **170**, 405.
Chanmugan, G. 1972, *Nature*, **236**, 83.
Eggen, O. J. 1969, *Ap. J.*, **157**, 287.
Eggen, O. J., and Greenstein, J. L. 1965, *Ap. J.*, **141**, 83.
Greenstein, J. L. 1970, *Ap. J. (Letters)*, **162**, L55.
Harper, R. V. R., and Rose, W. K. 1970, *Ap. J.*, **162**, 963.
Hesser, J. E., and Lasker, B. M. 1971*a*, *Proc. IAU Symposium No. 42, White Dwarfs*, ed. W. J. Luyten (Dordrecht: Reidel), p. 41.
———. 1971*b*, *Proc. IAU Colloquium 15, New Directions and New Frontiers in Variable Star Research* (Veröffentlichungen der Remeis-Sternwarte Bamberg, **9**, 160).
Hesser, J. E., Lasker, B. M., and Neupert, H. E. 1975, *IAU Circ.*, No. 2876.
Hesser, J. E., Lasker, B. M., and Osmer, P. S. 1972, *Ap. J. (Letters)*, **176**, L31.
———. 1974, *Ap. J.*, **189**, 315.
Hesser, J. E., Ostriker, J. P., and Lawrence, G. M. 1969, *Ap. J.*, **155**, 919.
Kukarkin, B. V., Kholopov, P. N., Pskovsky, Yu. P., Efremov, Yu. N., Kukarina, N. P., Kurochkin, N. E., Medvedera, G. I., Perova, N. B., Fedorovich, V. P., and Frolov, M. S. 1971, *General Catalog of Variable Stars* (2d Suppl.; Moscow: Academy of Sciences of USSR Press).
Lasker, B. M., and Hesser, J. E. 1969, *Ap. J. (Letters)*, **158**, L171.
McGraw, J. T., and Robinson, E. L. 1976, preprint.
Richer, H. B., Auman, J. R., Isherwood, B. C., Steele, J. P., and Ulrych, T. J. 1973, *Ap. J.*, **180**, 107.
Richer, H. B., and Ulrych, T. J. 1974, *Ap. J.*, **192**, 719.
Shipman, H. L. 1971, *Ap. J.*, **166**, 587.
Warner, B. 1973, *M.N.R.A.S.*, **163**, 25P.
———. 1975, preprint.
Warner, B., and Robinson, E. L. 1972, *Nature*, **239**, 2.
Warner, B., Van Citters, G. W., and Nather, R. E. 1970, *Nature*, **226**, 67.
Wegner, G. 1973, *M.N.R.A.S.*, **163**, 381.

JAMES E. HESSER and BARRY M. LASKER: Cerro Tololo Inter-American Observatory, Casilla # 63-D, La Serena, Chile

HERMANN E. NEUPERT: Cerro Tololo Inter-American Observatory and Observatorio Nacional de Cerro Calán, Universidad de Chile, Casilla # 36-D, Santiago, Chile