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SOUTHERN HEMISPHERE ZZ CETI STARS: THE NEW VARIABLE L19-2 AND BPM 30551

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ABSTRACT

We announce the discovery of a new ZZ Ceti star, L19-2, and discuss the photometric properties of this star and another star in this class, BPM 30551. By comparison with similar ZZ Ceti stars, the light curves and nonstationary power spectra of the light curves of these two stars are explained in terms of multiple *g*-mode nonradial pulsations. It is suggested that the nonstationarity of the power spectra observed in virtually all ZZ Ceti stars is a result of modulation by closely spaced pulsational frequencies. Null results from the southern hemisphere extension of our survey for ZZ Ceti stars are reported.

Subject headings: stars: variables — stars: white dwarfs

I. INTRODUCTION

Recently we have been conducting a systematic survey for luminosity variations in white dwarfs. The survey has shown that there exists an entirely new, homogeneous, and well defined class of variable stars, the ZZ Ceti variables, the primary characteristics of which are a DA spectral type and a $B - V$ color near $+0.20$. Thus far 10 such variables have been discovered. In general, the light curves and power spectra of the light curves of stars in this class show the luminosity variations to be multiply periodic or pseudoperiodic with the major periodicities occurring in the range 200–1000 s. The mechanism generating the luminosity variations is statistically nonstationary in that peaks in the power spectra are variable both in frequency and amplitude (McGraw and Robinson 1975 [Paper I]; McGraw and Robinson 1976 [Paper II]). The amplitudes of the luminosity variations range from a few thousandths to a few tenths of a magnitude, with those stars exhibiting lower-amplitude variations tending to show shorter periods and a simpler and more stable period structure (Robinson and McGraw 1976 [Paper III]).

The observed periodicities are more than two orders of magnitude longer than those predicted for radial oscillations of a white dwarf, but agree closely with periods and period ratios predicted for low-order nonradial oscillations (Osaki and Hansen 1973; Brickhill 1975). Survey results and additional observational support for an interpretation of the variability of the ZZ Ceti stars in terms of nonradial oscillations are given in Papers I–III, McGraw (1976 [Paper IV]), and Robinson, Nather, and McGraw (1976).

In this *Letter* we show that the white dwarf L19-2 may be added to the list of ZZ Ceti stars. We also discuss the luminosity variations of BPM 30551, first discovered by Hesser, Lasker, and Neupert (1976 [HLN]) in the course of their variable white dwarf survey. A second set of null results from the extension of our survey into the southern hemisphere is also presented.

II. OBSERVATIONS

All observations were obtained with either the 0.76 m or 1.02 m reflectors at the Sutherland observing station of the South African Astronomical Observatory. For all survey observations a computer controlled, two-star, pulse counting photometer (Nather 1973) was operated with an integration time of 10 s. The observing techniques are described in detail in Paper III.

Table 1 lists 28 white dwarfs found to be constant in luminosity, along with their $B - V$ colors and spectral types (when known) and a reference for these data. Each star was observed for approximately 1 hour. At the time of observation these stars did not vary by more than about 0.01 mag on time scales from 20 s to about 30 minutes. Included in the table are two C_2 degenerates and one DF star with $B - V$ near $+0.2$, one DB star, and one magnetic DA star (Wegner 1977), none of which showed detectable luminosity variations.

One DA star, L19-2 (BPM 784, LTT 5712) with colors $B - V = +0.25$ and $U - B = -0.53$ (Eggen 1969), was found to be a low-amplitude variable. BPM 30551, a DA star with $B - V = +0.29$ and $U - B = -0.58$ (Wegner 1973), was confirmed to be a large-amplitude variable with a strong beat pattern present in its light curve. The Journal of Observations for these two stars are given in Table 2, and portions of their light curves are shown in Figure 1. The light curve of L19-2 shows a primary periodicity near 190 s with a peak-to-peak amplitude of about 0.025 mag. When the variations are present, the light curve of BPM 30551 has an unstable periodicity near 825 s with an amplitude which may be in excess of 0.13 mag. The mean pulse shape of BPM 30551 appears decidedly nonsinusoidal. The mean light levels for these stars are virtually constant, with mean count rates, after back-

TABLE 1

CONSTANT-LUMINOSITY WHITE DWARFS

Name	(B−V)	Sp.	Ref.
PHL 627	...	DA?	1
BPM 16115	+0.17	DAwk	3,2
G161-36	+0.15	...	4
BPM 5639	+0.175	...	3
BPM 19738	+0.20	DA	3,5
GD 110	+0.25	...	4
GD 127	+0.14	...	4
BPM 7108	+0.18	C_2	5
GD 165	+0.14	...	4
GD 176	+0.23	...	4
LTT 6143	+0.14	...	9
G137-24	+0.24	...	4
BPM 890	+0.22	...	3
G19-20	+0.13	DA	4
BPM 24754	+0.27	...	3
BPM 24866	−0.04	DB	3,5
BPM 25114	−0.09	DAP	3,8
LTT 7219	...	DA?	1
G155-19	+0.14	DA	4
G21-16	+0.24	DAs	4
BPM 11668	+0.11	...	3
GD 215	+0.25	DAss	6
GD 216	+0.14	...	4
BPM 1266	+0.24	DA	3,5
BPM 27606	+0.16	C_2	3,5
BPM 14525	+0.16	DAwk	3,2
BPM 14703	+0.135	DF	3,5
LTT 9774	+0.15	DA	7

REFERENCES.—(1) Strömgren photometry (Kilkenny 1976). (2) Wegner 1975. (3) Eggen 1969. (4) Eggen 1968. (5) Wegner 1973. (6) Greenstein 1969. (7) Eggen and Greenstein 1965. (8) Wegner 1977. (9) Eggen 1968.

TABLE 2

JOURNAL OF OBSERVATIONS OF L19-2 AND BPM 30551

Run No.	Starting Time ($JD_{\odot}$ 2,442,920.+)	Integration Time (seconds)	No. of Integrations
	L19-2		
S2385	0.471896	10	254
S2457	44.337181	10	444
S2459	45.237115	5	1231
S2460	67.256582	10	591
S2466	68.232055	5	1431
S2470	69.231520	5	1433
S2475	70.225545	5	1464
S2479	71.221340	10	420
S2480	72.221903	10	735
S2484	73.232511	10	703
	BPM 30551		
S2478	70.565482	10	901
S2483	72.537814	10	1175
S2487	73.489613	10	1563

ground and extinction corrections, of about 3700 and 550 counts per second for L19-2 and BPM 30551, respectively.

In the bandpass from about 1.0×10^{-2} Hz to the Nyquist frequency the power spectra of the light curves of L19-2 are flat, showing no features with an amplitude greater than 0.002 mag. The low-frequency power spectrum of L19-2 from run S2470 is shown in Figure 2. Low-frequency power spectra show two persistent features near 5.20×10^{-3} Hz and 8.80×10^{-3} Hz, which correspond to periods of 192.4 s and 113.6 s, respectively. These features are variable in amplitude from run to run and within each run by at least 60% and 70%, respectively; in frequency each feature is variable by at least 4×10^{-5} Hz. There is no evidence for harmonics or nonlinearly coupled frequencies as found in the large-amplitude ZZ Ceti stars (Papers I–III). The peak at 8.4×10^{-3} Hz is the result of a 2 minute periodic drive error which appears when the 0.76 m telescope is used at large zenith distances.

The power spectra of the light curves of BPM 30551 show no features with amplitude greater than 0.003 mag in the bandpass from about 3×10^{-3} Hz to the Nyquist frequency. When BPM 30551 is active, its low-frequency power spectra show a complex, nonstationary group of peaks near 1.2×10^{-3} Hz: that for run S2487 is shown in Figure 2. The frequency of the primary peak is always near 1.215×10^{-3} Hz, corresponding to a period of 822.9 s, but is variable by at least 1×10^{-5} Hz. The secondary peaks in the group appear to be slightly more variable in frequency. Although the mean pulse shape of the light curve is nonsinusoidal, there is no evidence in the spectrum for any harmonics or nonlinear coupling among the peaks which are present. The power spectra of quiescent portions of the light curve differ drastically from power spectra of active portions. During quiescent portions the spectra are virtually that of noise—the maximum power may be down by more than a factor 50, and spectral "features" do not correlate at all with features in spectra of active portions of the light curve.

III. DISCUSSION

The discovery that L19-2 is a ZZ Ceti star raises the number of members of this class of variables to 11. BPM 30551 is confirmed to be a member of the class. The colors and spectra of these two stars are consistent with those of normal DA stars. For neither of these stars do we have enough observational data to unambiguously propose a definitive model, but by comparison with other similar ZZ Ceti stars we may investigate some probabilities. In particular, we suggest that both L19-2 and BPM 30551 are consistent with the model proposed in Papers I–III and in Robinson, Nather, and McGraw (1976) wherein the complex light curves of ZZ Ceti stars are interpreted in terms of rotationally split nonradial *g*-mode pulsations.

In its period structure, L19-2 appears to be only slightly more complex than the "simple," slightly longer period ZZ Ceti star, R548. Robinson, Nather, and McGraw (1976) analyzed an extensive series of observations of R548 which showed that the light curve could be very accurately predicted, in both amplitude and time, by assuming that the observed phase and amplitude modulations arise from beating of two pairs of

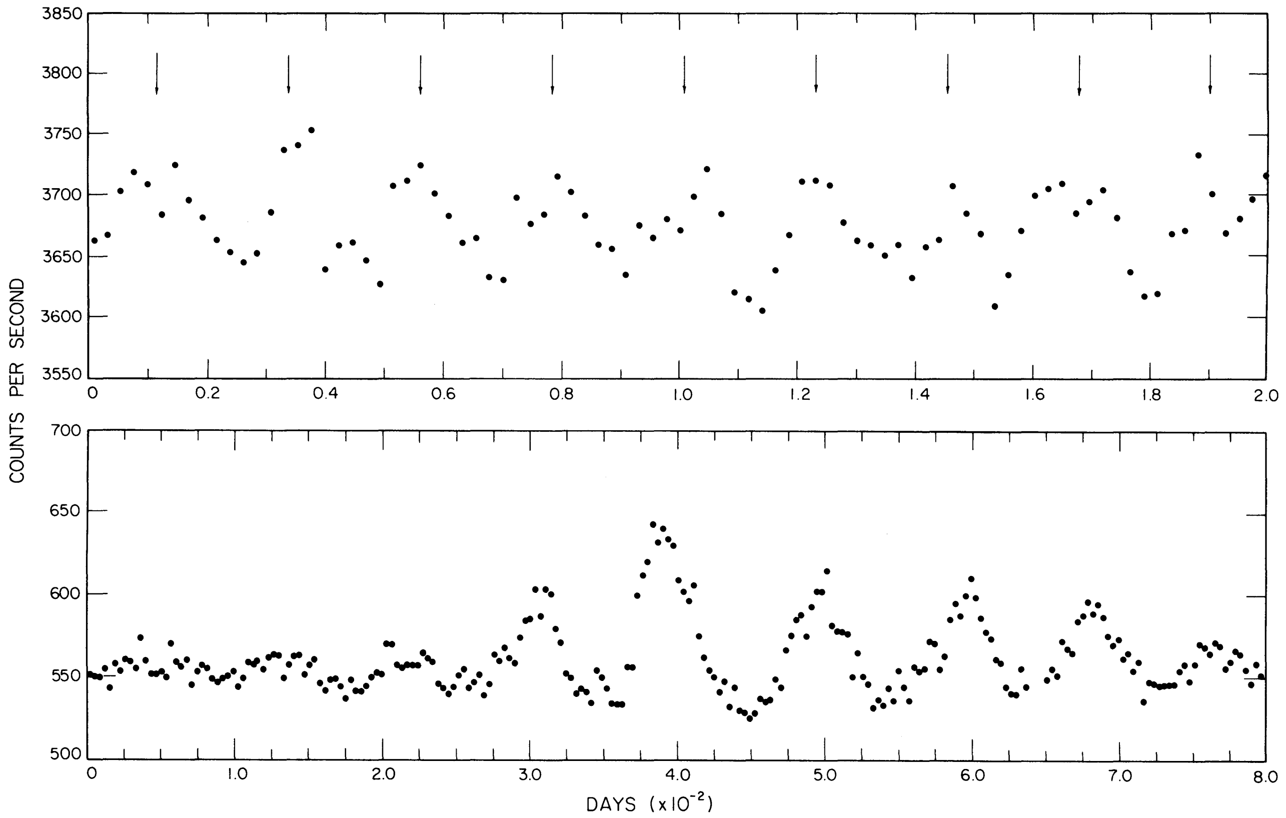

FIG. 1.—Segments of light curves of L19-2, run S2460 (*upper*) and BPM 30551, runs S2478 (*lower*) expressed in counts per second outside the atmosphere. For L19-2 each plotted point is the average of two 10 s integrations, and a constant period of 192.4 s is indicated. Each plotted point in the light curve of BPM 30551 is the average of three 10 s integrations.

pulsations closely spaced in frequency. Rotational splitting of the degenerate m modes of a nonradial g-mode pulsation of order $l = 2$ provided an accurate and consistent explanation for the two closely spaced pulsations. In the case of L19-2, the observations indicate that a similar mechanism may be operating. On the seven consecutive nights on which the star was observed, the half-amplitude of the primary periodicity smoothly changed from about 2.3×10^{-3} mag through a minimum of about 0.9×10^{-3} mag and back to about 2.8×10^{-3} mag, which, by analogy with R548, could indicate that the star was observed through about one-half of an amplitude modulation cycle, or some near alias thereof. Because the modulation period for both frequency and amplitude must be the same, intrarun frequency changes place a lower limit of about 30 minutes on the modulation period. As an example, a set of possible amplitude modulation periods for which we may have observed an alias is about $(20.6/N)$ hours, $N = 1, 2, 3, \ldots, 40$.

BPM 30551 appears to be unique in several respects. When it is active, its variations have realatively large amplitude and the mean pulse shape appears nonsinusoidal. The absence of harmonics or nonlinear coupling in the power spectrum indicates, however, that the light curve is simply a superposition of linear, sinusoidal frequency components. When it is inactive, the variations disappear almost totally. The simplest interpretation consistent with the power spectra is that interference of closely spaced pairs of frequencies causes the variations to disappear. Assuming two interfering frequencies in BPM 30551, examination of the light curves sets a lower limit to the beat period of 7.2 hours. Light curves of at least this duration must be obtained to resolve the interfering frequencies in the power spectrum. If more than two frequencies are interfering to cause the variations to disappear, much longer light curves may be necessary to resolve them.

In their discussion of BPM 30551, HLN isolate what they feel to be stable peaks in the power spectrum at periods near 606.8 s, 679.6 s, 752.4 s, and 825.2 s. They identify these with periods, P_{Kl} (cf. Brickhill 1975), of nonradial oscillations of order P_{61} through P_{91}, respectively, where K specifies the radial overtone. We agree with HLN that the luminosity variations of BPM 30551 are caused by nonradial g-mode pulsations, but we offer an alternative model which avoids preferential excitation of modes of unacceptably high order. G29-38 (Paper I) and G207-9 (Paper III) are large-amplitude ZZ Ceti stars which exhibit spectral behavior similar to BPM 30551. In these cases rotational splitting of g-mode oscillations of order $l = 2$, as in the case of the

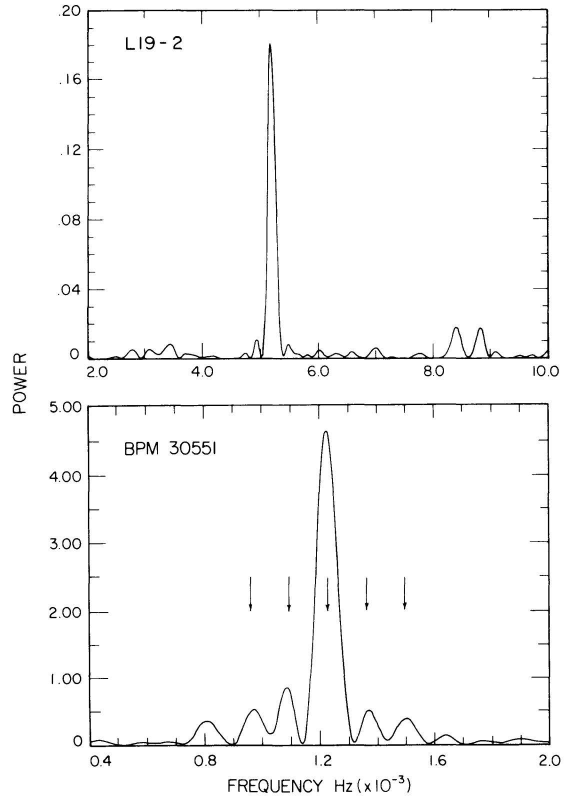

FIG. 2.—Power spectra of the light curves of L19-2 (run S2460) and BPM 30551 (run S2487). For BPM 30551, frequency spacings of 1.32×10^{-4} Hz centered on 1.215×10^{-3} Hz are indicated. One half the peak-to-peak amplitude in magnitudes, Δm, of a strictly periodic signal in the light curve is related to the amplitude of a spectral peak $P(f)$, at frequency f by $\Delta m = 2.5 \log \{1 + [2P(f)/N\Delta t]^{1/2}\}$, where $N = 4096$ is the number of points in the transform and $\Delta t = 20$ s and 30 s for L19-2 and BPM 30551, respectively.

"simple" variable R548, were again invoked to explain the appearance of a cluster of equally spaced frequencies. Though the observations presented here are not sufficiently long to unequivocally resolve the equally spaced peaks involved in this mechanism, the general appearance of the power spectra is the same as in the previous cases. From the power spectrum of the longest run, S2487, a mean frequency spacing of about 1.32×10^{-4} Hz may be estimated. In terms of rotationally split g-mode pulsations, this implies a rotation period for BPM 30551 of about 2.1 hours, a value consistent with rotational periods inferred from other ZZ Ceti stars (Papers I and III; Robinson, Nather, and McGraw 1976) and for other white dwarfs by means of spectroscopic (Greenstein and Peterson 1973) and polarization (Angel, Illing, and Landstreet 1972) observations.

BPM 30551 may, then, have two processes operating: (1) multiple g-mode nonradial pulsations with periods near 825 s which cause the beat phenomena, and (2) slow rotation with a period of about 2 hours. Thus, by recourse to phenomena previously observed in ZZ Ceti stars we may offer a reasonable alternative explanation for the light curve of BPM 30551.

In addition, statistical nonstationarity of the power spectra is easily explained by this model. In the power-spectrum representation of a light curve, by definition, all phase information is discarded. This means that any phase modulation present in the process generating the light curve, such as that caused by the interference of closely spaced pulsational frequencies, will give rise to a nonstationary spectrum. Since all of the ZZ Ceti stars except G117–B15A have nonstationary spectra, it is possible that virtually all of the variables in this class are strictly periodic and that the presence of closely spaced, interfering frequencies is responsible for their apparent photometric nonstationarity.

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