THE ASTROPHYSICAL JOURNAL, 220:614–618, 1978 March 1

A NEW PULSATING WHITE DWARF: GD 154

EDWARD L. ROBINSON, RICHARD J. STOVER, R. E. NATHER, AND J. T. MCGRAW
McDonald Observatory and Department of Astronomy, University of Texas at Austin
Received 1977 July 18; accepted 1977 September 7

ABSTRACT

We report additional results of a survey of luminosity variations in white dwarfs. GD 154, a DA white dwarf with $B - V = +0.18$, is found to vary at either of two dominant periods, 1186 or 780 s. For nine nights the 1186 s period dominated and the light curve was strictly periodic, so that we could construct an ephemeris which predicted the time of arrival of pulse peaks to ± 30 s. On a 10th night the 780 s period dominated. The variations are probably caused by nonradial *g*-mode pulsations, but the extreme length of the 1186 s pulsation period forces us to suggest that the white dwarf is pulsating in a very high overtone ($k \approx 10$–30). We attribute the change in the period on the last night to transference of pulsation energy from the 1186 s pulsation mode to the 780 s pulsation mode.

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

I. INTRODUCTION

For the past several years we have been conducting a survey of luminosity variations in white dwarfs; as a result of our survey and a similar survey conducted by J. E. Hesser and B. M. Lasker at Cerro Tololo, a total of 11 variable white dwarfs are now known. A detailed summary of the properties of the variable white dwarfs may be found in the review by Robinson and McGraw (1976*b*), and in more recent updates by McGraw (1976, 1977) and by Hesser, Lasker, and Neupert (1976). In brief, the known variables have very similar properties. All of them are DA white dwarfs, with colors in a narrow range near $B - V = +0.20$; in all of them, the variations are multiply periodic, with periods in the range 100–1000 s. It is generally believed that the variations are caused by nonradial *g*-mode pulsations. The evidence for this belief is compelling for the low-amplitude, short-period variables such as R548 (Robinson, Nather, and McGraw 1976); but the very long periods observed in some of the variables, such as the 1023 s period in G38-29 (McGraw and Robinson 1975), are not, at first sight, easily explained by pulsations.

The present paper gives further results of our survey. We present an additional list of nonvariables we have observed, and we present data on a new variable white dwarf, GD 154. GD 154 is of particular interest, since, although it too is multiply periodic, its variations were dominated by just one large amplitude periodicity at 1186 s on all nights except one. The 1186 s period was sufficiently stable for us to count unambiguously the number of cycles of the variation which occurred over the entire observing interval; using this cycle count, we calculate an ephemeris which gives the time of arrival of the individual pulses in the light curve with a mean error of ± 30 s. The exceptional length of the 1186 s period requires a revision in our concept of which pulsation modes it is "reasonable" to expect to see in the variable white dwarfs.

II. THE OBSERVATIONS

Our observational technique has been described previously (Robinson and McGraw 1976*a*). We acquired the light curves with the 82 inch (2 m) telescope at McDonald Observatory using the McDonald high-speed photometer; the observations were made in unfiltered light with a blue-sensitive bi-alkali photomultiplier tube. Table 1 is a list of stars which did not vary in luminosity during our observations. The cautionary comments we made concerning our previous lists of null results also apply to this new list (see Robinson and McGraw 1976*a*).

The new variable is GD 154. A spectrogram of GD 154, kindly taken for us by A. P. Fairall and D. W. Weedman, confirms that GD 154 is a DA white dwarf; according to Eggen (1968), the magnitude and colors of GD 154 are $V = 15.33$, $B - V = +0.18$, and $U - B = -0.59$. We observed GD 154 on six nights in 1977 May and four nights in 1977 June. The properties of the light curve of GD 154 were very stable over the first nine nights of our observations, but on the last night, 1977 June 20 (UT), the properties of the light curve changed somewhat. We shall discuss first the nine stable nights and then the changes which took place on the last night.

TABLE 1
CONSTANT LUMINOSITY STARS

Star	$B - V$	Star	$B - V$
G116-16........	+0.24	GD 129........	+0.15
G152–B4B......	+0.09	GD 186........	+0.16
GD 27..........	+0.20	GD 226........	+0.15
GD 33..........	+0.19	GD 230........	+0.16
GD 47..........	+0.15	GD 279........	+0.17
GD 67..........	+0.17	GD 348........	+0.18
G115-9.........	+0.21	G226-29........	+0.19
GD 115.........	+0.19		

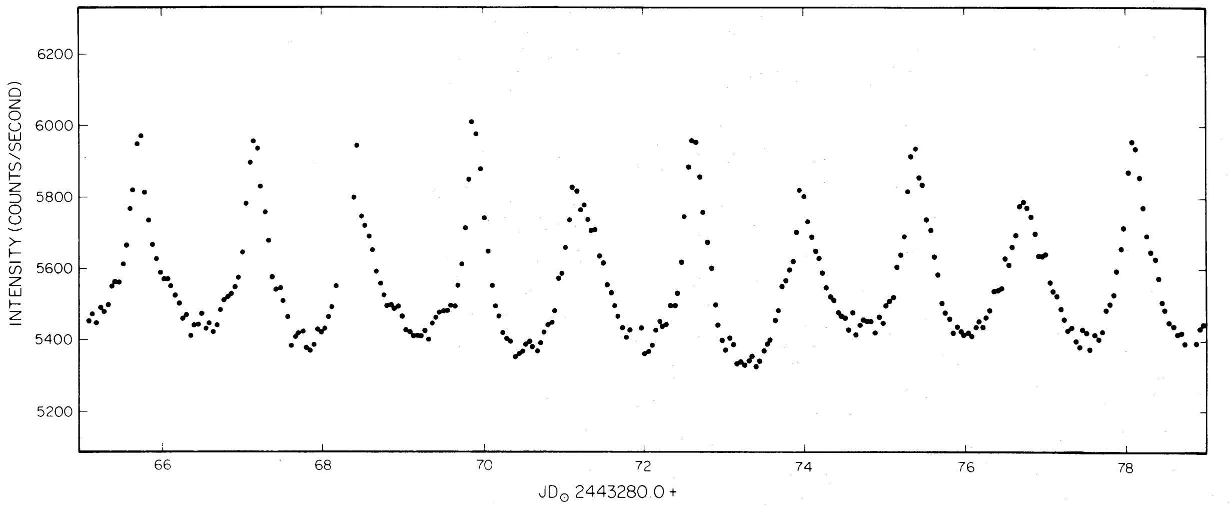

FIG. 1.—The light curve of GD 154 in unfiltered light on the night of 1977 May 17 (UT). The vertical axis is the number of detected photons s^{-1} reduced to outside the atmosphere. Each point in the light is the mean counting rate averaged over 40 s. The integration time in the original data was 10 s.

A portion of the light curve of GD 154 from the night of 1977 May 17 (UT) is displayed in Figure 1 and is typical of the first nine nights. The light curve consists of a series of evenly spaced pulses which recur every 20 minutes. The typical peak-to-peak amplitude of the pulses is about 0.09 mag, but the amplitudes of successive peaks tend to be alternately larger and smaller than the mean. The power spectrum of the light curve in Figure 1 is shown in Figure 2. The power spectra of GD 154 on the first nine nights were essentially identical. There were no measurable night-to-night changes in either the frequencies or the amplitudes of the periodicities in the power spectrum —not even simple changes of the kind seen in power spectra of R548 (Robinson *et al.*). Furthermore, the power spectrum is unusually intelligible. There is one large-amplitude fundamental period at 1186 s, which is denoted by the symbol F in Figure 2. This fundamental period is the interval between the pulses in the light curve. Four harmonics of the fundamental, denoted by 2F, 3F, 4F, and 5F, can be seen in Figure 2 and reflect the nonsinusoidal shape of the pulses.

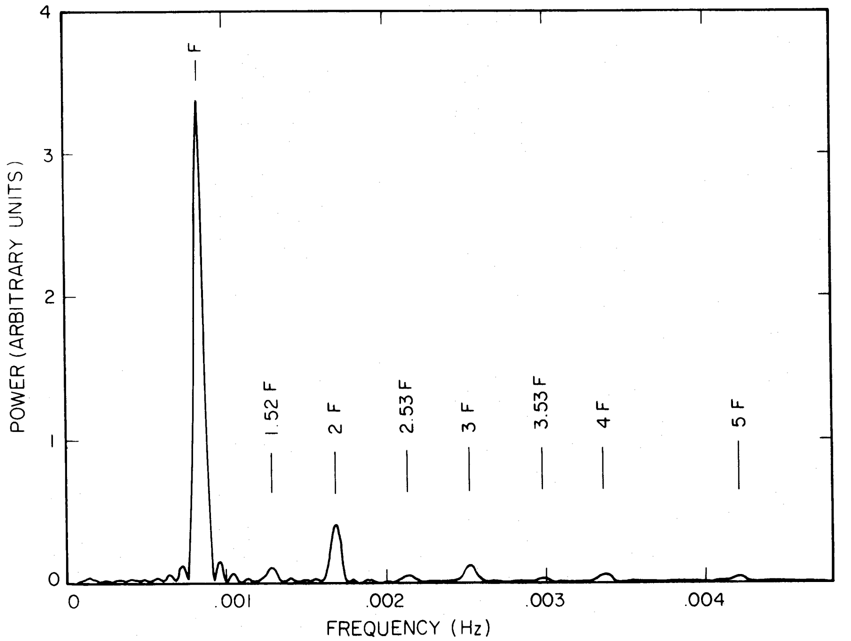

FIG. 2.—The power spectrum of the light curve of GD 154 on the night of 1977 May 17 (UT). The peak labeled F is the fundamental frequency of the light curve and corresponds to the period of the pulses in Fig. 1.

TABLE 2

PERIOD STRUCTURE OF GD 154

Period (s)	Frequency (Hz)	Label
1186.14.........	8.4307×10^{-4}	1F
780...........	1.282×10^{-3}	1.52F
593.6..........	1.685×10^{-3}	2F
469.5..........	2.130×10^{-3}	2.53F
396.7..........	2.521×10^{-3}	3F
336.4..........	2.973×10^{-3}	3.54F
296.8..........	3.369×10^{-3}	4F
237.45.........	4.211×10^{-3}	5F

In addition, there is a series of low-amplitude intermediate frequencies, denoted by 1.52F, 2.53F, and 3.53F, all differing by about 0.47F (±0.01F) from the next higher harmonic of the fundamental. These intermediate frequencies are responsible for the alternating amplitudes and slightly variable shapes of the pulses in the light curve. The exact frequencies and corresponding periods of the peaks in the power spectra are listed in Table 2.

Since the light curve of GD 154 on these nights was very stable, it was possible to predict accurately when the pulses would occur. Table 3 gives the heliocentric Julian date of the peaks of all the pulses we observed in GD 154 on the first nine nights. The times of the pulse peaks are fitted by the following ephemeris:

$$T = \mathrm{JD}_{\odot}2443278.69459 + 0^{\mathrm{d}}.01372812E\,, \quad \pm 6 \qquad \pm 5$$

where T is the predicted heliocentric Julian date of a pulse peak and E is the corresponding cycle number of the pulse. The cycle numbers of the pulses are also listed in Table 3. The mean error between the observed and the predicted times of the pulse peaks is 30 s, most of which can be attributed to the variations in the pulse profiles. The period of the pulses was constant to within the limits of measurement, and the upper limit on the rate of change of the period was $|\dot{P}| < 7 \times 10^{-8}$.

The light curve of GD 154 on the 10th and last night is shown in Figure 3. The light curve is less regular than on the earlier nights, but, more interestingly, the dominant pulse period has changed from 1186 to about 780 s. The power spectrum from this night is of poor quality since the light curve is short; but it shows that the 1186 s period is still present, although weakly, and that the period at 1.52F (780 s) has greatly increased in amplitude. Thus no new periods appeared in the light curve, but the relative amplitudes of the 1186 and 780 s periods reversed. Unfortunately,

TABLE 3

TIMES OF PULSE PEAKS IN GD 154

Julian Date	Cycle No.	Julian Date	Cycle No.	Julian Date	Cycle No.
Run 1857		Run 1863		Run 1873	
3278.69499.......	0	3281.63160.......	214	3308.67661.......	2184
.70778.......	1	.64613.......	215	.69050.......	2185
.72237.......	2	.65967.......	216	.70404.......	2186
.73504.......	3	.67402.......	217	.71770.......	2187
.74905.......	4	.68704.......	218	.73124.......	2188
.76311.......	5	.70128.......	219	.74536.......	2189
.77688.......	6	.71499.......	220	Run 1875	
.79031.......	7	.72848.......	221	3310.65396.......	2328
Run 1860		.74266.......	222	.66773.......	2329
3279.65515.......	70	.75637.......	223	.68150.......	2330
.66927.......	71	.76939.......	224	.69487.......	2331
Run 1862		.78403.......	225	.70894.......	2332
3280.64396.......	142	(.7975)*......	226	.72259.......	2333
.65767.......	143	.81094.......	227	Run 1878	
.67185.......	144	Run 1864		3312.67162.......	2475
(.6847)*......	145	3282.64874.......	288	.68446.......	2476
.69922.......	146	.66153.......	289	.69931.......	2477
.71190.......	147	.67628.......	290	.71311.......	2478
.72660.......	148	.68913.......	291	.72587.......	2479
.74002.......	149	.70360.......	292	.74071.......	2480
.75397.......	150	Run 1868			
.76774.......	151	(3283.6368)*......	360		
.78117.......	152	.65076......	361		
.79540.......	153	.66408......	362		
.80842.......	154	.67814......	363		
.82214.......	155	.69168......	364		

* Contaminated by clouds or bad seeing.

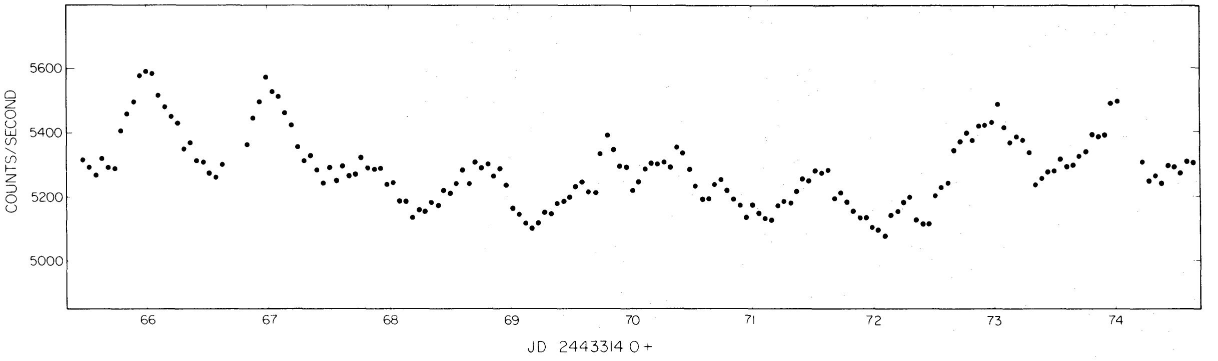

FIG. 3.—The light curve of GD 154 on the night of 1977 May 20 (UT). Each point in the light curve is the mean counting rate averaged over 45 s.

the change in the light curve of GD 154 occurred on the last night of our last observing run of the season, so we were unable to investigate the change in greater detail.

III. DISCUSSION

The colors, spectral type, length of period, and multiple periodicity of GD 154 are all similar to those of the previously known variable white dwarfs, and they leave no doubt that GD 154 is a legitimate member of the group. We believe that the luminosity variations of GD 154 are caused by nonradial *g*-mode pulsations: first, because it is difficult to account for the pulse profiles by any mechanism but pulsations; second, because pulsation modes other than the *g*-mode pulsations have periods which are far too short to account for the observed periods; and third, because the properties of GD 154 are very similar to those of R548 and other members of the group of variable white dwarfs, for which *g*-mode pulsations provide a satisfactory explanation (Robinson *et al.*). Even so, the pulsations of GD 154 present a problem, since the 1186 s pulsation is too long by an order of magnitude to be matched by the pulsation periods normally considered in the literature (e.g., Brickhill 1975). Although the 1186 s pulsation period of GD 154 presents this problem in an acute form, the problem is far from being unique to GD 154. All of the white dwarfs with pulsation periods longer than about 400–500 s—a group which includes more than half the known variables—present the same problem. The problem is sufficiently common, then, that it is worthwhile examining the ways by which it might be resolved.

We know of three ways for *g*-mode pulsations to have periods as long as 1186 s. The first way is to invoke an extremely low mass for the white dwarf. We reject low masses, because the colors of GD 154—and of all the other pulsating white dwarfs—are normal for a moderate- to high-mass white dwarf (Terashita and Matsushima 1969). A second, more interesting way is to invoke rotation of the white dwarf. If the pulsation mode is one of the traveling wave modes and if the wave is traveling opposite to the direction of rotation, the *apparent* pulsation period can be made arbitrarily long by making the difference between the rotation period and the true pulsation period arbitrarily small. We believe that this mechanism must be at work in some of the pulsating white dwarfs, since it is inherent to traveling wave pulsations; but the mechanism can be made to lengthen only one narrow range of pulsation periods at once, and even then, it will shorten rather than lengthen the periods if the pulsation wave travels in the wrong direction. Therefore, since more than half the pulsating white dwarfs have long periods, we cannot use this mechanism as the *sole* mechanism for lengthening the periods without simultaneously requiring a series of remarkable accidents, or an unknown and ad hoc physical mechanism to restrict the excited pulsation modes to the correct periods and directions.

The third way to make long-period *g*-mode pulsations is to invoke very high overtone pulsations: $k \approx 10$–30 in the notation of Brickhill (1975) or Dziembowski (1977). It is usually assumed that the nonradial pulsation modes most likely to be excited are those with small values of l and k, the angular and radial mode indices, respectively. Small values of l appear to be justified. Large values of l give periods which are too short to agree with the observed periods (*g*-mode pulsation periods decrease with increasing l); and large values of l dissect the surface of the star into many alternating bright and faint regions, thus making large-amplitude luminosity variations difficult to achieve. However, the argument for low values of k is very weak and, at best, is an argument by analogy: Radial pulsators such as the RR Lyrae stars pulsate only in the fundamental or first few overtone modes, and, therefore, the nonradial pulsators should also pulsate in these modes. Against this argument we have the fact that high-overtone pulsation modes can easily account for the observed periods. We suggest, then, that the *a priori* assumption that k must be small should be discarded, and that the possibility that pulsation modes with k in the range 10–30 are being excited should be seriously examined. We do not find attractive the possibility that high overtones are being excited, if for no other reason than that it allows a new host of pulsation modes to escape from this

Pandora's box. If our suggestion is correct, it will be exceedingly difficult, perhaps impossible, to identify correctly the exact pulsation modes which are being excited. Therefore, we point out that there is a weakness in our argument for large values of k. We have argued by elimination; thus, should new mechanisms for producing long-period pulsations be found, they too must be considered seriously.

The change in the pulsation period of GD 154 on our last night of observations is the second well-documented case of such a change, the first of which was BPM 31594 (McGraw 1976). In both stars, a single period dominates the light curve on all nights but one, and on the exceptional night a different period dominates. We suggested that the change in BPM 31594 was due to mode jumping or, more accurately, to a transference of pulsation energy from one pulsation mode to another. A possible competing mechanism is variation in the apparent amplitude of the pulsations due to simple beating of pairs or groups of pulsations with closely spaced periods such as we observed in R548 (Robinson *et al.*). This mechanism is inadequate as an explanation for GD 154, since its most important observational characteristic—continually varying pulsation amplitudes—is absent. Therefore, we believe that GD 154, like BPM 31594, also transferred part of its pulsation energy from one pulsation mode to another.

From the first 11 pulsating white dwarfs detected, it appeared that there was a correlation between the periods and amplitudes of their pulsations, in the sense that the low-amplitude variables had systematically shorter periods (Robinson and McGraw 1976*b*). The amplitudes of three of the pulsating white dwarfs, R548, G207-9, and G117–B15A, are less than the amplitude of GD 154, while the remaining eight variables have a greater amplitude. Thus GD 154 has a moderately low amplitude compared with the other variables, but its 1186 s pulsation period is the longest discovered so far. Therefore, GD 154 vitiates this correlation. Previous observations also suggested a second correlation: The low-amplitude variables have fewer periods in their light curves, and the power spectra of their light curves tend to be more stable. GD 154 has four independent periods in its light curve, of which only two have large amplitudes. The power spectrum of GD 154 is very stable, since it showed no detectable changes on the first nine nights, and the only change on the last night was in the relative amplitudes of the already existing periods. Therefore, GD 154 corroborates the second correlation. This second correlation is explicable in terms of the linearity of the pulsations. Low-amplitude pulsations will be more nearly linear. Then, because they are linear, the coupling among the various pulsation modes will be weaker, so that, if a pulsation mode is excited, it is less likely to transfer its energy and excite other modes. According to this explanation, GD 154 is a nonlinear pulsator, and the nonlinearity gives rise to the nonsinusoidal pulse profile and the transfer of energy from the 1186 s pulsation to the 780 s pulsation; but its amplitude is sufficiently low that the nonlinearity is very weak, so that the 1186 s pulsation could remain constant in amplitude for 1 month before finally losing energy to the 780 s pulsation.

This research was supported by NSF grant AST 75-15124.

REFERENCES

Brickhill, J. A. 1975, *M.N.R.A.S.*, **170**, 405.
Dziembowski, W. 1977, *Acta Astr.*, **27**, 1.
Eggen, O. J. 1968, *Ap. J. Suppl.*, **16**, 97.
Hesser, J. E., Lasker, B. M., and Neupert, H. E. 1976, *Ap. J.*, **209**, 853.
McGraw, J. T. 1976, *Ap. J.* (*Letters*), **210**, L35.
———. 1977, *Ap. J.* (*Letters*), **214**, L123.
McGraw, J. T., and Robinson, E. L. 1975, *Ap. J.* (*Letters*), **200**, L89.
Robinson, E. L., and McGraw, J. T. 1976*a*, *Ap. J.* (*Letters*), **207**, L37.
———. 1976*b*, *Proc. Los Alamos Conf. Solar Stellar Pulsations*, p. 98.
Robinson, E. L., Nather, R. E., and McGraw, J. T. 1976, *Ap. J.*, **210**, 211.
Terashita, Y., and Matsushima, S. 1969, *Ap. J.*, **156**, 203.

J. T. McGraw, R. E. Nather, Edward L. Robinson, and Richard J. Stover: Department of Astronomy, University of Texas at Austin, Austin, TX 78712