THE ASTROPHYSICAL JOURNAL, **262**:L11–L15, 1982 November 1

PHOTOMETRIC OBSERVATIONS OF GD 358: DB WHITE DWARFS DO PULSATE

DONALD E. WINGET, EDWARD L. ROBINSON, AND R. EDWARD NATHER
McDonald Observatory and Department of Astronomy, University of Texas at Austin

AND

GILLES FONTAINE
Département de Physique and Observatoire du Mont Megantic, Université de Montréal
Received 1982 June 14; accepted 1982 July 15

ABSTRACT

We have found that GD 358, a helium atmosphere (DB) white dwarf, is a pulsating variable star. The amplitude of its variations can range up to nearly 0.30 mag, and although the light curve does not repeat itself, there is a typical interval between its pulse maxima of 600–700 s. There are at least 28 pulsation modes simultaneously excited in GD 358 with periods ranging from 142.3 s to 952 s, most of which were present on both nights we observed the star. Many of the pulsations fall into groups of 4 or 5 modes that are equally spaced in frequency, suggesting that the pulsations are $l = 2$ g-modes that have been split by rotation. All the pulsating white dwarfs found heretofore have been hydrogen atmosphere (DA) white dwarfs. They are located in a narrow instability strip on the white dwarf cooling sequence at an effective temperature near 11,000 K and are known as ZZ Ceti stars. From our theoretical studies of these stars, we predicted that the DB white dwarfs should also pulsate, but that the pulsations should be driven by helium partial ionization rather than hydrogen partial ionization as they are in the ZZ Ceti stars, and their instability strip should occur at appreciably higher temperatures. The detection of pulsations in GD 358 confirms these predictions.

Subject headings: stars: pulsation — stars: white dwarfs

I. INTRODUCTION

All the pulsating white dwarfs found up to now have been hydrogen atmosphere (DA) white dwarfs. These variables, known as ZZ Ceti stars, have pulsation periods between 100 and 1200 s and pulsation amplitudes between 0.005 and 0.30 mag. The ZZ Ceti stars are all multiperiodic, with some stars having dozens of periods simultaneously present in their light curves (for a review of the observational properties of these stars, see Robinson 1979). As a result of theoretical studies by ourselves and others, we now know that most, and perhaps all, of the pulsations of the ZZ Ceti stars are nonradial g-mode pulsations and that the pulsations are driven by the hydrogen partial ionization zone in the outer envelopes of the stars (Winget 1981; Dolez and Vauclair 1981; Winget *et al.* 1982).

Our theoretical studies of the ZZ Ceti stars also led us to predict that the DB, or helium atmosphere white dwarfs should be pulsationally unstable at effective temperatures near 20,000 K. The pulsations would be g-mode pulsations with periods of several hundred seconds and would look similar to the pulsations of the ZZ Ceti stars. Thus, the only substantial *observational* differences between these new variables and the ZZ Ceti variables would be their DB spectral types and their bluer colors. The pulsations would, however, be driven by a helium partial ionization zone rather than a hydrogen partial ionization zone. Accordingly, we began a systematic photometric survey for pulsations in DB white dwarfs.

This *Letter* reports the first positive results of the survey: the white dwarf GD 358, a DB white dwarf (Greenstein 1969), is a pulsating variable star.

II. OBSERVATIONS AND SPECTRAL ANALYSIS OF LIGHT CURVES

Almost nothing is known about GD 358 (= WD 1645 + 323) except its spectral type. Bern and Wramdemark (1973) give $V = 13.65$, $B - V = -0.11$, and $U - B = -1.04$ for the star, and Wegner (1979) gives $b - y = -0.049$ and $u - b = 0.000$, but these measurements must be considered uncertain because they were made before the large and rapid luminosity variations of GD 358 were known.

Our observations of GD 358 were made on the 0.9 m telescope at McDonald Observatory using a standard McDonald high-speed, two-star photometer (Nather 1973), and in order to maximize the photon counting efficiency, the observations were made in unfiltered light using a blue-sensitive RCA 8850 photomultiplier tube. On the nights of 1982 May 26 and May 28 (UT), we used integration times of 5 s and accumulated light

TABLE 1

PHOTOMETRIC OBSERVATIONS OF GD 358[a]

Run Number	UT Date	UT Time of Run Start	Length Of Run (hr)	Integration Time (s)
2672	1982 May 26	06:13:19	3.57	5.0
2674	1982 May 27	09:34:12	0.25	0.1
2675	1982 May 28	06:19:33	4.13	5.0

[a]All observations were made on a 0.9 m telescope in unfiltered light with an RCA 8850 photomultiplier tube.

curves about 4 hr long; and on the night of May 27, we used an integration time of 0.1 s and accumulated a light curve about 15 minutes long. A summary of the details of the observations can be found in Table 1. Since we observed GD 358 when it was within about 2 hr of the zenith, the extinction variations were insignificant compared with the intrinsic variations of the star. Because of this, and because the observations were made without filters and are uncalibrated, we have not removed the effects of extinction from the light curves. We have, however, subtracted sky background and dark noise from the light curves.

The light curve of GD 358 on the night of May 28 is shown in Figure 1. The variations have a sharply peaked, nonsinusoidal shape with a full amplitude of nearly 0.30 mag and a typical interval between pulse maxima of 600–700 s. There is also a strong modulation of the amplitude of the variations, with three amplitude maxima spaced about 5400 s apart showing clearly in the light curve. The visual appearance of the light curve of GD 358 is remarkably similar to the appearance of the light curves of the large-amplitude ZZ Ceti stars (*e.g.*, G29–38). This similarity and a report by Greenstein (1969) that Hγ was present in the spectrum of GD 358, raised the possibility that the spectral type of GD 358 might be in error and that it might really be a ZZ Ceti star. A spectrogram of GD 358 kindly obtained for us by Dr. Derek Wills, using the image dissector scanner on the 2.7 m telescope at McDonald Observatory, confirmed that GD 358 is a DB white dwarf. The spectrum of the star is normal. There are no absorption lines of hydrogen or ionized helium with central depths greater than 5% of the continuum.

We have calculated power spectra of all the light curves in order to decompose the variations into their constituent pulsation modes. The method we used to calculate the power spectra was standard in every respect and has been described in detail in Kepler *et al.* (1982). There are no significant periodicities in the light curve of GD 358 with periods between 0.2 and 142 s. From the power spectrum of the light curve on May 27, we found the upper limits to the fractional semiamplitude of any such periodicities to be 7×10^{-3} for periods between 0.2 and 0.4 s, 6×10^{-3} for periods between 0.4 and 1.0 s, and 4×10^{-3} for periods between 1.0 and 10.0 s. The power spectra of the light curves on the nights of May 26 and May 28 showed that there were no periodicities present with fractional semiamplitudes greater than 1.5×10^{-3} between 10 and 140 s.

In contrast, the power spectra are rich with periods longer than 140 s. Table 2 lists 28 periods that can be unequivocally detected in the power spectra of the light curves on either May 26 or May 28. Table 2 also gives the nights on which the periodicities were present and shows that most of them were present on both nights. There are, however, differences in the apparent amplitudes of the periodicities on the two nights, although these differences are at the limit of the reliability of the power spectra and may not be real.[1] We have assumed that the power spectra from both nights are the same and have calculated the average of the two, but we also add the warning that additional data may prove this assumption to be incorrect.

The average amplitude spectrum (the square root of the average power spectrum) is given in Figure 2, in which we plot the logarithm of the amplitude rather than the amplitude itself to display the large range of amplitudes in the spectrum. Most of the peaks which reach above the line labeled "noise level" in Figure 2 are significant. The amplitudes of these peaks are given in Table 2. There is a strong visual impression that the peaks tend to fall into several groups of four or five evenly spaced peaks. A more careful analysis confirms this behavior. There are at least four such groups, and the spacing, 1.86×10^{-4} Hz, is the same for each group and even within the groups to the limit of measurement. The four groups are bracketed in Table 2 and are shown by the joined tick marks in Figure 2. The evenly spaced periods give a beat period of 5380 s, which corresponds closely to the obvious beat period in the original light curve.

[1]The major source of uncertainty in the amplitudes is spectral leakage. The periodicities are so closely spaced in the power spectrum that their spectral windows overlap. As a result, the measured amplitude of a periodicity is altered by the presence of its neighboring periodicities. See Jenkins and Watts (1968) for a discussion of this effect.

1982ApJ...262L..11W

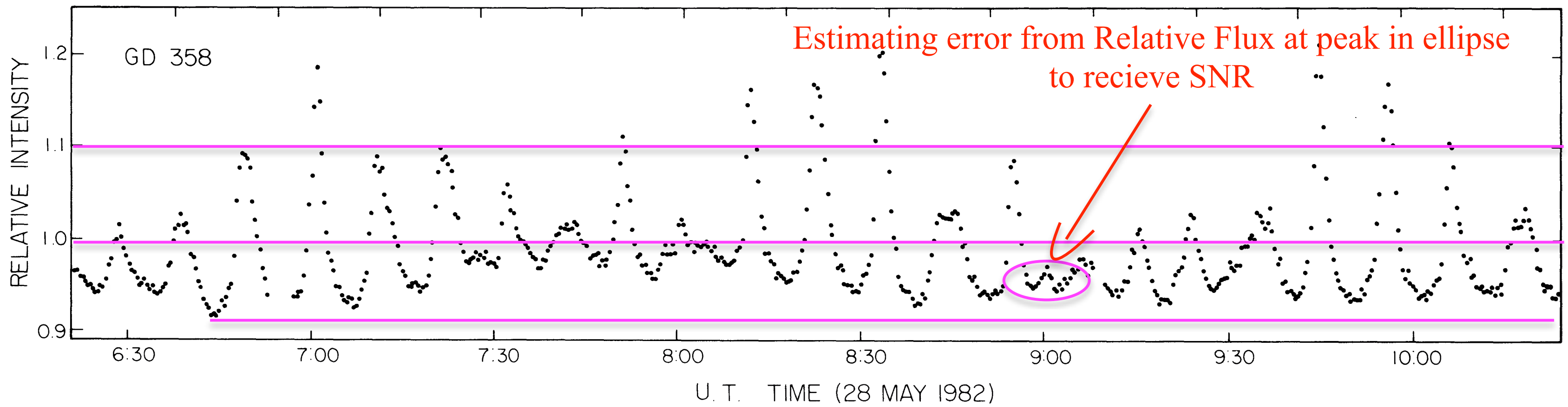

FIG. 1.—The light curve of GD 358 on the night of 1982 May 28 (UT). Each data point is the mean of a 25 s integration in white light

TABLE 2

THE PERIODS AND AMPLITUDES OF THE PULSATIONS OF GD 358

Group		Frequency[a] (10^{-3} Hz)	Period (s)	Mean Fractional Semi-Amplitude ($\times 10^{-3}$)	Present In Run 2672	Present In Run 2675
		1.050	952	12.1	×	×
	F3	1.246	803	21.2	×	×
1	F1	1.428	700	36.1	×	×
		1.619	618	38.8	×	×
		1.797	557	9.0	×	
		2.367	422	11.5	×	×
		2.525	396	7.3	×	
	F2	2.670	375	11.2	×	×
2	F5	2.861	349	10.2	×	×
		3.047	328	14.5	×	×
		3.230	310	11.9		×
		3.789	263.9	5.2	×	×
		3.973	251.7	5.8	×	×
	F4	4.105	243.6	5.8	×	
		4.287	233.3	4.6	×	×
3		4.473	223.6	3.8	×	
		4.660	214.6	6.5		×
		4.855	206.0	4.0		×
		5.057	197.8	2.3	×	
		5.225	191.4	3.5	×	×
4		5.406	185.0	3.3	×	×
		5.572	179.5	2.8	×	×
		5.768	173.4	2.2	×	
		6.289	159.0	3.0		×
		6.494	154.0	2.3	×	×
		6.613	151.2	1.9	×	
		6.756	148.0	1.5	×	
		7.027	142.3	2.2	×	×

[a] The error in the frequency measurement is $\pm 0.005 \times 10^{-3}$ Hz.

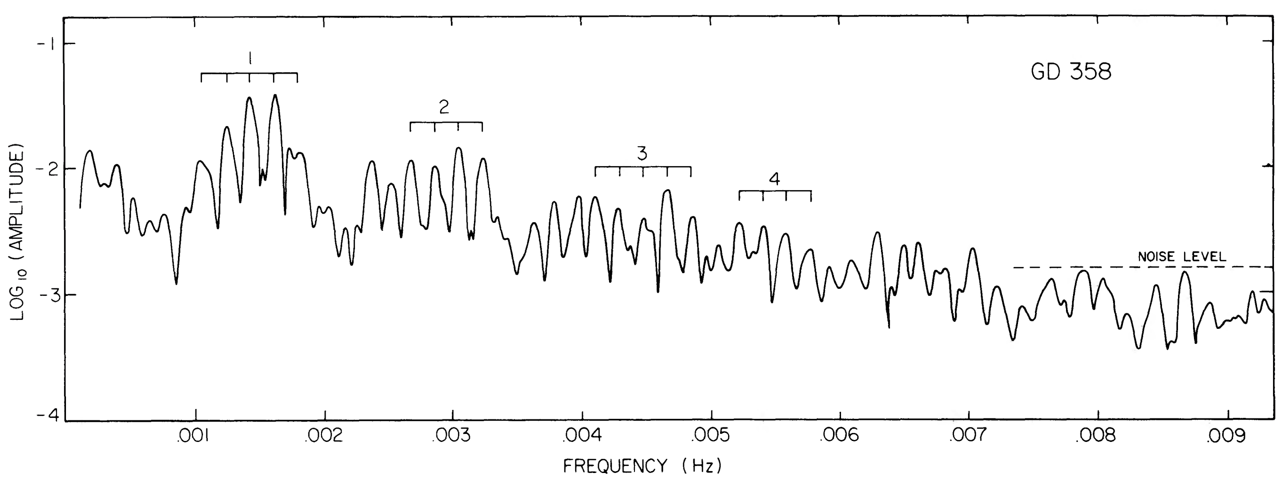

FIG. 2.—The amplitude spectrum (the square root of the power spectrum) of the light curve of GD 358. This spectrum is the average of the amplitude spectra from the nights of 1982 May 26 and May 28. The spectral window is symmetric and has side lobes less than 0.2 times the amplitude of the single central peak. The spectrum has been plotted on a logarithmic scale to show the low-amplitude, high-frequency periodicities. Most of the peaks between 0.001 Hz and 0.007 Hz are statistically significant. Groups of periodicities that are evenly spaced in frequency are marked with the joined tick marks. The numbers attached to each group correspond to the group numbers given in Table 2.

Taken together, the four groups of evenly spaced periods account for 18 of the 28 periodicities listed in Table 2. Many, although not all, of the remaining 10 periodicities are harmonics of the periodicities in the groups, and reflect the sharply peaked, nonsinusoidal shape in the light curve. Thus, much of the complexity of the power spectrum is more apparent than real.

III. DISCUSSION

We believe that the variations of GD 358 are the result of nonradial *g*-mode pulsations for four reasons. (1) The periods are between 140 s and 950 s—far too long for radial pulsations but well within the range appropriate to nonradial *g*-modes. (2) The richness of the observed power spectrum is consistent with the dense nonradial *g*-mode period spectrum. (3) The grouping of the periods into four or five modes equally spaced in frequency is consistent with $l = 2$ *g*-modes split by rotation; if the regular mode spacing of 1.86×10^{-4} Hz is interpreted as rotational splitting, then a rotation period of 5400 s is implied (Hansen, Cox, and Van Horn 1977). (4) The nonradial *g*-modes were predicted to be unstable for DB white dwarfs prior to the observational discovery of the pulsations.

The first three reasons for identifying the pulsation modes in GD 358 as nonradial *g*-modes are identical with those used to identify the pulsations of the ZZ Ceti stars. Here, however, the similarities with the ZZ Ceti stars end. As demonstrated by its DB classification, GD 358 has a surface composition dominated by helium rather than hydrogen, which argues that the driving mechanisms responsible for the observed pulsations are the κ and γ mechanisms operating in the surface helium partial ionization zone. Thus, GD 358 is the prototype and first example of a completely new class of variable stars: the variable DB white dwarfs. In the future, it will be possible to use the pulsations of this new class of variables to probe the interiors of DB white dwarfs, which should help resolve such questions as whether DA and DB white dwarfs have separate origins (*cf.* Liebert 1980). For the present, this discovery provides direct confirmation of our theoretical understanding of the pulsation and equilibrium properties of the white dwarf stars.

This research was supported in part by NSF grant AST 8108691, and by the Natural Sciences and Engineering Research Council. We thank C. J. Hansen, M. Tassoul, and particularly H. M. van Horn for invaluable contributions to this project.

REFERENCES

Bern, K., and Wramdemark, S. 1973, *Lowell Obs. Bull.*, No. 161.
Dolez, D., and Vauclair, G. 1981, *Astr. Ap.*, **102**, 375.
Greenstein, J. L. 1969, *Ap. J.*, **158**, 281.
Hansen, C. J., Cox, J. P., and Van Horn, H. M. 1977, *Ap. J.*, **217**, 151.
Jenkins, G. M., and Watts, D. G. 1968, *Spectral Analysis and Its Applications* (San Francisco: Holden-Day).
Kepler, S. O., Robinson, E. L., Nather, R. E., and McGraw, J. T. 1982, *Ap. J.*, **254**, 676.
Liebert, J. 1980, *Ann. Rev. Astr. Ap.*, **18**, 363.
Nather, R. E. 1973, *Vistas Astr.*, **15**, 524.
Robinson, E. L. 1979, in *IAU Colloquium 53, White Dwarfs and Variable Degenerate Stars* (Rochester, New York: University of Rochester), p. 343.
Wegner, G. 1979, in *IAU Colloquium 53, White Dwarfs and Variable Degenerate Stars* (Rochester, New York: University of Rochester), p. 250.
Winget, D. E. 1981, Ph.D. thesis, University of Rochester.
Winget, D. E., Van Horn, H. M., Tassoul, M., Hansen, C. J., Fontaine, G., and Carroll, B. W. 1982, *Ap. J.* (*Letters*), **251**, L65.

G. Fontaine: Département de Physique, Université de Montréal, P.O. Box 6128, Succ. A, Montreal, PQ H3C 3J7, Canada

R. E. Nather, E. L. Robinson, and D. E. Winget: Department of Astronomy, University of Texas, Austin, TX 78712