G238−53: A NEW PULSATING DA WHITE DWARF

G. FONTAINE[a] AND F. WESEMAEL[a]
Département de Physique and Observatoire du Mont Mégantic, Université de Montréal, Montréal, Québec H3C 3J7, Canada
Received 21 June 1984; revised 30 August 1984

ABSTRACT

High-speed photometric observations of the DA white dwarf G238 − 53 show that it is another star of the ZZ Ceti type. Its colors place it within the instability strip. Fourier analysis of three independent light curves of G238 − 53 reveals that it is a very low-amplitude variable ($\Delta m \simeq 0.009$ mag) with a quasiperiod of about 206 s. Only one peak with significant power is seen in the Fourier spectrum, but the data suggest that this peak could be made up of at least two unresolved frequency components. G238 − 53 is likely to be a stable, linear pulsator.

I. INTRODUCTION

Over the past few years, we have been conducting a survey for variability in DA white dwarfs. The aims of this program are (1) to discover new variables of the ZZ Ceti type and (2) to determine what fraction of DA stars become pulsationally unstable as they evolve through the instability strip. A progress report on our survey has been presented by Fontaine *et al.* (1982). To date, the most significant result has been the recognition that most, and possibly all, of the DA white dwarfs become variable in a narrow color range corresponding to an effective temperature interval between ~13 000 K and ~11 000 K. Coupled with recent theoretical investigations of the pulsational properties of DA white dwarfs, this result—confirmed independently by Greenstein (1982)—has important implications for our understanding of the evolution and internal structure of these stars. We refer the reader to the review of Winget and Fontaine (1982) for more details.

The candidate stars of our survey have been selected on the basis of their DA spectral type and their colors on the multichannel scanner system (Greenstein 1976, 1984). Only stars in a relatively narrow range of colors near $(G-R)_{69} \simeq -0.40$—where all of the known DA variables are located—were considered. Here, $(G-R)_{69}$ is a temperature-sensitive color index calibrated on the so-called AB69 scale. Such selection criteria have led to the discovery of six new ZZ Ceti stars. Our survey has been responsible for the identification of four of those: GD385 (Fontaine *et al.* 1980), G185 − 32 and G191 − 16 (McGraw *et al.* 1981), and G226 − 29 (McGraw *et al.* 1984); Vauclair and his collaborators, using essentially the same selection criteria, have independently reported the variability of G255 − 2 (Vauclair, Dolez, and Chevreton 1981) and GD66 (Dolez, Vauclair, and Chevreton 1983).

In this paper, we present evidence showing that G238 − 53 is yet another variable of the ZZ Ceti class, a result that brings the sample of firmly established pulsating DA white dwarfs to a total of 19.

II. PHOTOMETRIC OBSERVATIONS AND ANALYSIS

With a color index $(G-R)_{69} = -0.42$ (Greenstein 1980), G238 − 53 (Gr538, LP66 − 262, WD1350 + 656, $\alpha(1950) = 13\ 50\ 47$ and $\delta\ (1950) = 65\ 39.7$) falls within the instability strip and was, consequently, included early on our list of candidate stars. However, its relative faintness ($V = 15.5$) and position in the sky have made that object difficult to study. Indeed, because of its large northern declination, G238 − 53 is inaccessible from the 2.5-m Hooker telescope, where part of our survey is being carried out.

Several attempts to detect luminosity variations in G238 − 53 were made at the Mont Mégantic 1.6-m telescope. Generally, these observations would rule out variations with semiamplitudes larger than $\Delta m \simeq 0.03$ mag, indicating that, at least, G238 − 53 is not a large-amplitude variable in the period range characteristic of ZZ Ceti stars. To search for possible low-amplitude variations, we have only retained the light curve obtained under the best conditions at Mont Mégantic; furthermore, we have obtained two additional data strings at Kitt Peak National Observatory (KPNO). The details of these runs are given in Table I. In each case, the light curve consists of a string of equally spaced data points obtained with no filters to maximize the photon-counting rate. Single-channel photometers and S-20 photomultipliers were used. The KPNO observations were secured with the automated Mark II photometer attached to the 1.3-m telescope; this particular setup has the advantage of incorporating TV guiding and sky subtraction. With an 18″ aperture, the S/N ratio was equal to about 2 for our observations.

A visual inspection of the light curves—corrected for extinction—revealed rather noisy structures with no obvious periodicities. However, the power spectra of these light curves all have one common characteristic: the presence of an unresolved frequency peak around ~4.85 mHz with an amplitude slightly larger than the noise level. For example, Fig. 1 shows the Fourier spectrum (up to the Nyquist frequency) of the light curve for run 3. The largest peak at 8.93 mHz is an artificial 1% tracer inserted in the data string to calibrate the vertical axis. The next largest peak is at 4.91 mHz and is obviously made up of at least two unresolved frequency components as revealed by its asymmetry. Were it not for the presence of a similar asymmetric peak in the power spectra of the other two light curves, it would be impossible to conclude that G238 − 53 is a variable star. Table I gives the value of the frequency of the dominant peak for each run. There are slight variations in the shape, location, and amplitude of the dominant peak from run to run. For example, the asymmetry is on the left-hand side for run 3 (see Fig. 1), whereas it appears on the opposite side for run 2. However, within the present measurement errors, these dif-

[a] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE I. High-speed photometric observations of G238 − 53.

Run number	Date (UT)	Telescope (m)	Sampling time (s)	Total number of data points	Dominant peak (mHz)	Resolution (mHz)
1	1982, March 18	MM, 1.6	20	200	4.87	0.25
2	1984, March 6	KPNO, 1.3	28	139	4.76	0.26
3	1984, April 8	KPNO, 1.3	28	144	4.91	0.25

ferences from run to run can not be considered significant. Hence, in all cases considered, there is an unresolved dominant peak at ~4.85 mHz (the average of the 3 measurements) with a semiamplitude of $\lesssim$0.009 mag (or ~0.8% of the mean intensity of the star). We take this as strong evidence that G238 − 53 is a very low-amplitude ZZ Ceti star.

In order to increase the S/N ratio, we have averaged together the three individual power spectra. This can readily be done because the temporal resolution is essentially the same for each run. The results of this operation are illustrated in Fig. 2. First, in panel a, we show the low-frequency part (0–10 mHz) of the Fourier spectrum for run 3. This is basically a subset of Fig. 1, except that the 1% tracer has been removed and the dominant peak is normalized to one. Panel b next shows the average power spectrum for runs 3 and 2. Notice how the noise level has decreased as compared to the previous case. Finally, panel c illustrates the average power spectrum for the three runs. The peak at ~4.85 mHz now clearly stands out above the noise level. This leaves little doubt as to the reality of low-amplitude luminosity variations in G238 − 53.

To our knowledge, this is the first instance where the power of Fourier analysis is required to demonstrate the variability of a ZZ Ceti star. In all other cases, a casual inspection of

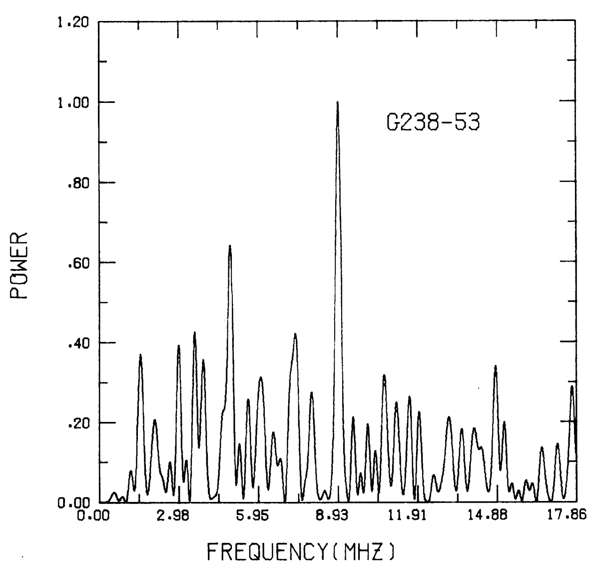


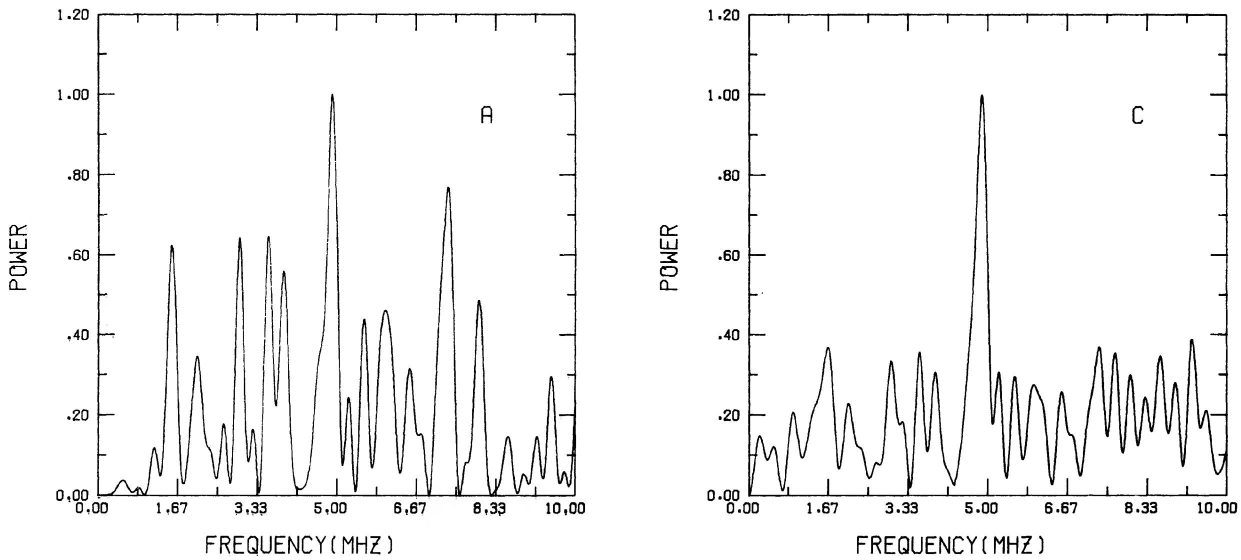
FIG. 1. Power spectrum of G238 − 53 for run 3. The largest peak at 8.93 mHz is an artificial tracer with an amplitude of 1% of the mean intensity of the star. Note the unresolved components of the peak at 4.91 mHz.

the light curve has proved sufficient to reveal luminosity variations, although, of course, Fourier techniques were needed for quantitative studies because of the multiperiodic character of the ZZ Ceti stars. In the present case, the small amplitude of the variations and the faintness of the target star explain the noise in our light curves. Some qualitative information can, however, be obtained by folding the light curves. This is possible because there is only a single—if unresolved—peak with significant power in the Fourier spectra. We have thus interpolated the original light curves (in magnitudes) to generate new time series such that ten data points would cover exactly the period of the variation indicated by the Fourier analysis (cf. Table I). We then folded consecutive groups of ten data points to obtain a mean pulse shape. We finally subtracted the DC component and displayed the results as a function of phase. Figure 3 illustrates the amplitude variation (expressed in terms of percentage of the mean intensity of the star) as a function of phase for run 1 (closed circles), run 2 (open circles), and run 3 (open squares). As a guide to the eye, we have also plotted a sine wave with a 0.8% amplitude; note that this curve does *not* represent a least-square fit to the data. The phases of the individual runs have been adjusted to that of the sine wave by simple visual inspection. The folded light curve for run 1 agrees surprisingly well—considering the noise in the original data—with a sinusoidal variation. The results from the other two runs deviate somewhat more from the sine wave, but remain consistent with it. In any case, Fig. 3 leads us again to conclude the reality of low-amplitude luminosity variations in G238 − 53.

III. CONCLUDING REMARKS

Our ongoing survey has led to the discovery of another nonradial pulsator of the ZZ Ceti type. The analysis presented in this paper demonstrates that G238 − 53 is a low-amplitude variable ($\Delta m \lesssim 0.009$ mag) with a dominant period around 206 s. Yet the data suggest that there could be at least two (unresolved) frequency components responsible for the luminosity variations. This is in line with the fact that all ZZ Ceti stars are known to be multiperiodic. In addition, G238 − 53 satisfies the period-amplitude correlation which is generally observed in pulsating DA white dwarfs. The sense of the correlation is that small-amplitude variables usually have shorter periods. This suggests that G238 − 53 is an intrinsic low-amplitude variable.

The observations presented in this paper establish the variable character of G238 − 53, but more extensive studies are badly needed to better understand its quantitative behavior. Such studies are difficult and will require large telescopes and much longer light curves than those we have obtained. This is because the amplitude of variations is small



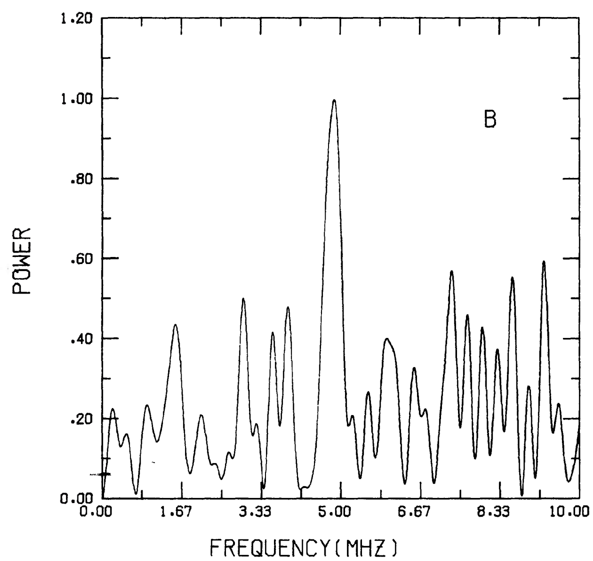


FIG. 2. Low-frequency (0–10 mHz) part of the power spectrum of G238 − 53. Panel a shows the power spectrum for run 3. Panel b gives the average spectrum for runs 2 and 3, and panel c illustrates the average power spectrum for the three runs. Note how the noise level has decreased by this averaging process. The unresolved peak at ~4.85 mHz corresponds to a true luminosity variation.

while the star is relatively faint. For instance, next to G226 − 29—for which the light curve has been deciphered by Kepler *et al.* (1983)—G238 − 53 is the smallest-amplitude ZZ Ceti star currently known. However, it is roughly 20 times fainter than G226 − 29, and the S/N ratio is correspondingly worsened. Further observations of G238 − 53 should, however, be rewarding because it is a likely addition to the subgroup of ZZ Ceti stars which consists of stable, linear pulsators [e.g., R548 (Stover *et al.* 1980), L19 − 2 (O'Donoghue and Warner 1982), G117 − B15A (Kepler *et al.* 1982), GD385 (Kepler 1984), and G226 − 29 (Kepler *et al.* 1983)] for which $\dot{P}$ measurements may eventually lead to estimates of the cooling age (e.g., Robinson and Kepler 1980).

Finally, we emphasize the fact that the multichannel color index of G238 − 53 [$(G-R)_{69} = -0.42$] places it within the instability strip defined by $-0.45 \leqslant (G-R)_{69} \leqslant -0.38$. To date, all of the ZZ Ceti stars for which multichannel colors are available (13 out of 19) fall within that color range,

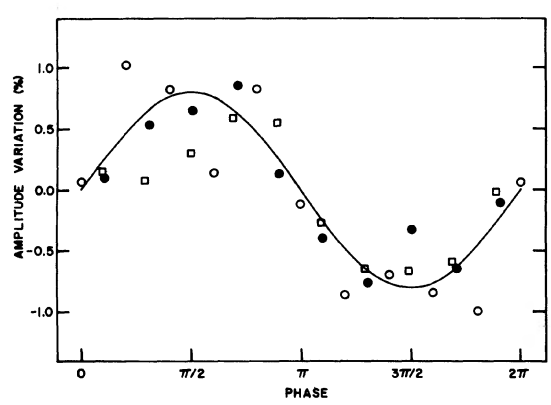


FIG. 3. Folded light curves for run 1 (closed circles), run 2 (open circles), and run 3 (open squares) expressed as fractional amplitude variation as a function of phase. The amplitude variation is given in percentage of the mean intensity of the star. A sine wave with an amplitude of 0.8% has been drawn to assist the eye. It is *not* least-square fitted to the actual data.

and no constant star has yet been found in that interval. The apparent counterexample to that assertion offered by the bright DA star Wolf 485A has recently been dismissed by Wesemael and Fontaine (1985). Thus the present results further reinforce the conclusions of the statistical analysis of ZZ Ceti stars of Fontaine *et al.* (1982).

We thank S. O. Kepler, P. Lacombe, J. T. McGraw, and D. E. Winget for their interest in this work. Thanks are also due to the Director of KPNO for a grant of observing time, and to the KPNO staff for its help with the observations. This research has been supported in part by the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

Dolez, N., Vauclair, G., and Chevreton, M. (1983). Astron. Astrophys. **121**, L23.

Fontaine, G., McGraw, J. T., Coleman, L., Lacombe, P., Patterson, J., and Vauclair, G. (1980). Astrophys. J. **239**, 893.

Fontaine, G., McGraw, J. T., Dearborn, D. S. P., Gustafson, J., and Lacombe, P. (1982). Astrophys. J. **258**, 651.

Greenstein, J. L. (1976). Astron. J. **81**, 823.

Greenstein, J. L. (1980). Private communication.

Greenstein, J. L. (1982). Astrophys. J. **258**, 661.

Greenstein, J. L. (1984). Astrophys. J. **276**, 602.

Kepler, S. O. (1984). Astrophys. J. **278**, 754.

Kepler, S. O., Robinson, E. L., Nather, R. E., and McGraw, J. T. (1982). Astrophys. J. **254**, 676.

Kepler, S. O., Robinson, E. L., and Nather, R. E. (1983). Astrophys. J. **271**, 744.

McGraw, J. T., Fontaine, G., Dearborn, D. S. P., Gustafson, J., Lacombe, P., and Starrfield, S. G. (1981). Astrophys. J. **250**, 349.

McGraw, J. T., Fontaine, G., Dearborn, D. S. P., Gustafson, J., and Lacombe, P. (1984). In preparation.

O'Donoghue, D. E., and Warner, B. (1982). Mon. Not. R. Astron. Soc. **200**, 563.

Robinson, E. L., and Kepler, S. O. (1980). Space Sci. Rev. **27**, 613.

Stover, R. J., Hesser, J. E., Lasker, B. M., Nather, R. E., and Robinson, E. L. (1980). Astrophys. J. **246**, 947.

Vauclair, G., Dolez, N., and Chevreton, M. (1981). Astron. Astrophys. **103**, L17.

Wesemael, F., and Fontaine, G. (1985). Astrophys. J. (in press).

Winget, D. E., and Fontaine, G. (1982). In *Pulsations in Classical and Cataclysmic Variables*, edited by J. P. Cox and C. J. Hansen (University of Colorado, Boulder), p. 142.