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DISCOVERY OF TWO NEW PULSATING DA (ZZ CETI) WHITE DWARFS[1]

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ABSTRACT

We report the detection of multiperiodic luminosity variations in the light curves of the two DA white dwarfs GD 244 and KUV 02464+3239. We selected these objects as candidate ZZ Ceti stars on the basis of our analysis of their optical spectra, which revealed that their atmospheric parameters place them inside the empirical instability strip in the log g-$T_{\rm eff}$ plane. We find that GD 244 is an intermediate-amplitude pulsator with at least four excited modes with periods in the range 203–307 s, which is consistent with its position in the middle of the ZZ Ceti instability strip at $T_{\rm eff} = 11{,}680$ K and log $g = 8.08$. We compare the properties of GD 244 with those of GD 66, a previously known ZZ Ceti star that appears to be a photometric clone of the former. We also find that KUV 02464+3239 is a large-amplitude, long-period variable, which is again consistent with its position at $T_{\rm eff} = 11{,}290$ K and log $g = 8.08$ in the log g-$T_{\rm eff}$ diagram, near the red edge of the empirical instability strip. The light curve of KUV 02464+3239 is dominated by a quasi-period of ∼ 832 s and resembles that of its photometric twin GD 154. Our findings bring to 31 the number of known gravity-mode ZZ Ceti pulsators.

Subject headings: stars: interiors — stars: oscillations — white dwarfs

1. INTRODUCTION AND HISTORICAL BACKGROUND

The first known pulsating white dwarf, HL Tau 76, was discovered accidentally by Landolt (1968) during the course of a large photometric program devoted to other scientific goals. Landolt (1968) gathered *UBV* light curves and reported on complex multiperiodic luminosity variations with a dominant quasi-period of ∼750 s and a peak-to-peak amplitude of ∼0.2 mag (in the *V* filter). A large-scale survey to search specifically for high-frequency oscillations in white dwarfs was subsequently initiated by Hesser, Ostriker, & Lawrence (1969). This survey was based on the then newly developed technique of fast photometry in integrated light. With little else to use but the apparent brightness of the candidates as a selection criterion for picking target stars, this general survey had a low yield, leading to the discovery of only one variable star. Luminosity variations with relatively low amplitudes (∼0.01 mag) and short periods (213 and 273 s) were thus found in the light curve of R548 (Lasker & Hesser 1971). In an independent effort, Schulov & Kopatskaya (1973) reported the discovery of luminosity variations in the light curve of G29−38, with characteristics rather similar to those found in HL Tau 76.

In the light of these findings, it became clear that the first luminosity variable white dwarfs had properties in common: Along with the fact that they were all multiply periodic, the three of them were also hydrogen-atmosphere (DA) white dwarfs, and they bunched together in a $U-B$, $B-V$ diagram, with comparable time-averaged Johnson colors. In particular, their similar values of $B-V$ indicated similar values of their effective temperatures. In the hope of increasing the success rate, these characteristics were exploited in follow-up efforts to uncover additional rapidly variable white dwarfs. Hence, the next observational searches focussed on DA white dwarfs with a color index near $B-V \sim 0.20$, the approximate value found in the first three luminosity variable white dwarfs.

On the basis of these selection criteria, a search carried out by Richer & Ulrych (1974) led to the discovery of the variability of G117−B15A. A similar result was obtained by Hesser, Lasker, & Neupert (1976) in the case of the southern object BPM 30551. However, the most complete and systematic survey using these criteria was that carried out by McGraw (1977a) as part of his Ph.D. thesis. McGraw (1977a) observed a relatively large sample of bright DA white dwarfs (from both the northern and southern hemispheres) with a color index in the range $0.15 \lesssim B-V \lesssim 0.25$. His successful search led to the discovery of seven new variable stars: G38−29 (McGraw & Robinson 1975), R808 (McGraw & Robinson 1976), GD 99 (McGraw & Robinson 1976), G207−9 (Robinson & McGraw 1976), BPM 31594 (McGraw 1976), L19−2 (McGraw 1977b), and GD 154 (Robinson et al. 1978). A total of 99 other targets were found to be constant, leading to a net yield of ∼7%. We note that, over the years, the use of the criterion $B-V \sim 0.20$ has continued to be useful in the quest for new luminosity variable DA white dwarfs. Thus, on this basis, variability was established in EC 23487−2424 (Stobie et al. 1993), EC 14012−1446 (Stobie et al. 1995), KUV 08368+4026 (Vauclair et al. 1997), KUV 11370+4222 (Vauclair et al. 1997), and BPM 24754 (Giovannini et al. 1998). However, we do not know the actual success rates of these various searches because the

[1] Based on observations gathered at the Canada–France–Hawaii Telescope, operated by the National Research Council of Canada, the Centre National de la Recherche Scientifique de France, and by the University of Hawaii.

authors have not provided the appropriate information. Presumably, the yields must have been comparable to that of McGraw (1977a).

It was first pointed out by Fontaine et al. (1980) that the success rate for discovering new luminosity variable DA white dwarfs could be significantly increased by using a temperature indicator more discriminating than the $B-V$ color index. By then, it had been well established that the luminosity variations in these stars were caused by gravity-mode pulsational instabilities that naturally arise in the evolution of a DA white dwarf as it cools across a narrow effective temperature range centered around $T_{\rm eff} \sim$ 11,000–12,000 K—the pulsating DA or ZZ Ceti instability strip (McGraw 1979; Robinson 1979). It was also well known that Strömgren colors or, even better, the multichannel colors obtained by Greenstein (1976) were vastly superior to Johnson colors for inferring the atmospheric parameters of broad-lined stars such as the ZZ Ceti stars.

Fontaine et al. (1982) used the $G-R$ multichannel color index (Greenstein 1976) to map more accurately the temperature distribution of DA stars across the instability strip. In sharp contrast to the more fuzzy empirical instability strip based on Johnson colors and suggesting that only $\sim$25% of the stars in the strip were actually variable, Fontaine et al. (1982) found no constant star in a pure instability strip delimited by $-0.45 \leq G-R \leq -0.38$, corresponding to a width of about 2000 K in effective temperature. It is not surprising then that the use of a selection criterion based on the value $G-R \sim -0.42$ has brought great success to further searches for new ZZ Ceti stars. Even though the bank of stars for which multichannel colors were available was relatively small (and limited to the northern hemisphere), the use of the $G-R$ criterion led to the discovery of eight additional pulsating DA white dwarfs: GD 385 (Fontaine et al. 1980), G255−2 (Vauclair et al. 1981), G185−32 (McGraw et al. 1981), G191−16 (McGraw et al. 1981), G226−29 (Fontaine et al. 1982), GD 66 (Dolez, Vauclair, & Chevreton 1983), G238−53 (Fontaine & Wesemael 1984), and PG 2303+243 (Vauclair, Chevreton, & Dolez 1987). Taking into account the observations of constant stars immediately near both the blue and red edges, the yield for this method was $\sim$25%, substantially higher than those for surveys based on the Johnson colors.[2]

Another avenue was pioneered by Bergeron & McGraw (1990) who exploited the significant progress made at that time in our ability to model accurately the emergent flux of the convectively unstable atmospheres of cool ($T_{\rm eff} \lesssim 15{,}000$ K) DA white dwarfs. Indeed, by combining high-quality optical spectra with improved model atmosphere calculations, Bergeron et al. (1990) had, among other things, started mapping the empirical ZZ Ceti strip in the log g-$T_{\rm eff}$ plane. Their results suggested that the DA white dwarf GD 165 had atmospheric parameters very similar to those of known ZZ Ceti stars in their sample. Even though GD 165 had previously been observed for variability and declared constant (McGraw 1977a), Bergeron & McGraw (1990) felt confident enough in the new spectroscopic results of Bergeron et al. (1990) to reexamine the possibility that it might still be a pulsator. In contrast to the more qualitative search criteria used in previous surveys (e.g., observations of DA stars with $B-V \sim 0.20$ or $G-R \sim -0.42$), the approach of Bergeron & McGraw (1990) constituted a true quantitative prediction for a specific object. GD 165 was found to be a low-amplitude ZZ Ceti star.

The approach of Bergeron & McGraw (1990) has opened the way to further searches for new pulsating DA white dwarfs which promise to be very successful. Their approach has been firmly consolidated in the follow-up work of Bergeron et al. (1995b) who have presented the most complete, systematic, and homogeneous study of the time-averaged atmospheric properties of the ZZ Ceti stars that has been published so far. Bergeron et al. (1995b) considered the full sample of 22 ZZ Ceti stars known at the time and demonstrated that optical spectroscopy, when properly handled and modeled, can be used to derive accurate and reliable values of the atmospheric parameters of ZZ Ceti and neighboring stars in the log g-$T_{\rm eff}$ diagram. In particular, ZZ Ceti pulsators cover a region in that diagram, the instability strip, where no constant stars are found.[3] Hence, optical spectroscopy can be used with confidence to derive the surface gravity and the effective temperature of a candidate variable star. Depending on these values with respect to the position of the empirical ZZ Ceti instability strip in the log g-$T_{\rm eff}$ plane, a minimum-risk search for luminosity variations might be warranted.

In this context, we note that Jordan et al. (1998) followed very closely the prescription of Bergeron et al. (1995b) to estimate the atmospheric parameters of HS 0507+04334A using optical spectroscopy. They found the star to be inside the empirical instability strip of Bergeron et al. (1995b). On this basis, they decided to search for luminosity variations and discovered yet another ZZ Ceti pulsator. More recently, Vauclair et al. (2000) analyzed, in a similar way, another DA white dwarf found originally in the Palomar-Green Survey, but rediscovered in the Hamburg Quasar Survey. The object, PG 1541+650, is another ZZ Ceti star. While there are other candidates in the Hambourg Quasar Survey with atmospheric parameters close to those of variable stars found in the empirical instability strip (and, thus, merit observations), only HS 0507+04334A and PG 1541+650 in that sample apparently have parameters that place them squarely *inside* that region according to Vauclair (2000, private communication). With the two new discoveries reported in this paper, we point out that the optical spectroscopy approach of Bergeron & McGraw (1990) has now led to the uncovering of five additional pulsating DA white dwarfs. The yield of the method has been 100% so far.

2. OBSERVATIONS AND ANALYSIS

2.1. *Spectroscopic Observations*

Over the years, through his own efforts and through collaborations, one of us (P. B.) has assembled a large bank of high-quality optical spectroscopic measurements of white dwarf stars. During the course of such a recent collaboration project, Bergeron has analyzed the optical spectra obtained by Chris Moran (Univ. Southhampton) for a sample of DA stars. While the scientific goals of that project as well as the details of the observational procedure are to be described elsewhere and by others than us, two of the

[2] To be complete, let us mention that another ZZ Ceti star, BPM 37093, was discovered on the basis of an estimate of its effective temperature using Strömgren colors and *IUE* energy distributions (Kanaan et al. 1992).

[3] Note that the empirical instability "strip" uncovered by Bergeron et al. (1995b) in the log g-$T_{\rm eff}$ plane is not a simple band in effective temperature, but a triangular-shaped region with a blue edge showing a strong dependence on the surface gravity.

objects drew our attention as candidate ZZ Ceti stars. Indeed, the analysis revealed that the derived atmospheric parameters of GD 244 and KUV 02464+3239 place them inside the empirical ZZ Ceti instability strip uncovered by Bergeron et al. (1995b).

Figure 1 shows our best (in a least-square sense) fits to the available hydrogen Balmer lines (Hβ through H9) in the optical spectra of GD 244 and KUV 02464+3239. The fitting procedure is the same as that used by Bergeron et al. (1995b; see also Bergeron, Saffer, & Liebert 1992), and we refer the reader to those papers for details. The input physics used in our model atmospheres and synthetic spectra is that described in Bergeron, Saumon, & Wesemael (1995a), but also incorporates the improvements discussed in Bergeron et al. (1995b). Following these latter authors, we have adopted the ML2/$\alpha = 0.6$ parameterization of the mixing-length theory to describe convection.

The derived atmospheric parameters for GD 244 are $T_{\rm eff} = 11{,}680$ K and $\log g = 8.08$, while those for KUV 02464+3239 are $T_{\rm eff} = 11{,}290$ K and $\log g = 8.08$. The formal 1 σ errors associated with our fitting procedure are the same in both cases and are quite small (55 K and 0.03 dex for $T_{\rm eff}$ and $\log g$, respectively). However, as discussed in Bergeron et al. (1995b), those represent only the ability of the model spectra to match the data. Taking into account external sources of errors (actually dominated by uncertainties of the flux calibration), Bergeron et al. (1995b) conservatively estimated typical uncertainties of $\sim$350 K and $\sim$0.05 dex for the atmospheric parameters derived from their optical spectroscopy approach. Since we use exactly the same technique in this paper, we adopt these values as more realistic estimates of the uncertainties on the atmospheric parameters of our two target stars.

We point out that, in Bergeron et al. (1995b), the 22 spectra that were analyzed had exposure times set long enough to cover several pulsation cycles in order to obtain appropriate time-averaged data. Of course, this safeguard procedure could not be carried out here since, at the outset, we did not know if GD 244 or KUV 02464+3239 were actual pulsators. Nevertheless, assuming that the optical spectra that are available to us are meaningful time-averaged values and are not too much perturbed by pulsations (if any), our above values of the atmospheric parameters place GD 244 right in the middle of the empirical ZZ Ceti instability strip of Bergeron et al. (1995b) and, likewise, place KUV 02464+3239 inside the strip, although much closer to the red edge than GD 244. And indeed, at $\log g \simeq 8.08$, the blue edge of the strip is located near $T_{\rm eff} \simeq$ 12,200 K, while the red edge is found near $T_{\rm eff} \simeq 11{,}160$ K.

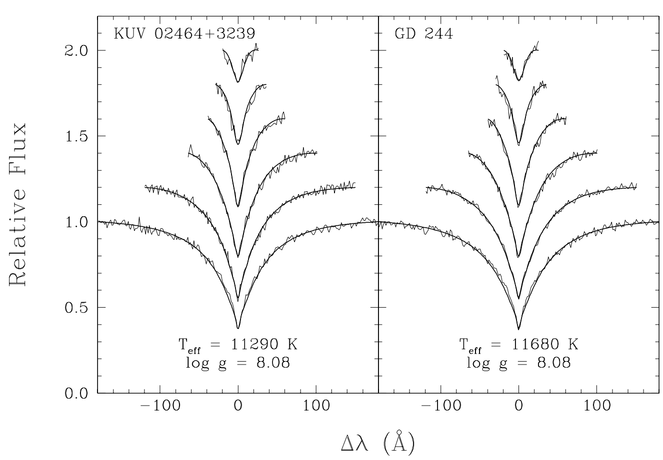

FIG. 1.—Model fits to the available hydrogen Balmer lines in our optical spectra of KUV 02464+3239 and GD 244. The lines range from Hβ (*bottom*) to H9 (*top*), each offset vertically by a factor of 0.2.

Given the success of the optical spectroscopy approach of Bergeron & McGraw (1990), we felt strongly that GD 244 and KUV 02464+3239 were excellent candidate ZZ Ceti stars and should be searched for rapid luminosity variations as soon as an opportunity would arise. With a somewhat reduced confidence, depending on the true accuracy of our derived atmospheric parameters, we also felt that relatively large amplitudes and long periods should be expected in KUV 02464+3239 since its position in the $\log g$-$T_{\rm eff}$ plane is close to the empirical red edge of the instability strip. Using the same arguments based on the amplitude-effective temperature and period-effective temperature relations observed in ZZ Ceti pulsators (see, e.g., Winget & Fontaine 1982), GD 244 would be expected, a priori, to show a more "normal" behavior, with amplitudes and periods that are neither small (as observed in stars at the blue edge) or large (as observed in stars at the red edge).

2.2. *Integrated Light Photometry of GD 244*

The opportunity to observe our two candidate ZZ Ceti stars arose in the course of a five-night observing run at the Canada-France-Hawaii Telescope (CFHT) in 1999 August. This run was dedicated to follow-up observations of the pulsating sdB stars KPD 1930+2752 and PG 0014+067. Our aim was simply (and hopefully!) to establish the variability of both DA stars without perturbing in any significant way the main science goals of the mission. Thus, we looked at GD 244 once in the middle of the first night, between the observations of our two main target sdB stars. Likewise, we "squeezed" a single short observation of KUV 02464+3239 at the end of the second night. The observing conditions were superb throughout the entire run.

GD 244 (WD 2254+126, LP 521−049, EG 231, $B_{\rm ph} \simeq$ 16.0) was observed in integrated (white light) "fast" photometric mode during 10,800 s on the night of 1999 August 13. The photometric observations were gathered with LAPOUNE, the portable Montréal three-channel photometer. We refer the interested reader to Billères et al. (1997) for details on our standard observational procedure. Figure 2 shows the full sky-subtracted, extinction-corrected light curve of GD 244. It is expressed in terms of the residual amplitude relative to the mean intensity of the star, and each plotted point corresponds to a sampling time of 10 s. Very clearly, GD 244 is multiperiodic, luminosity variable; another ZZ Ceti star. Interestingly, the amplitudes, periods, and degree of complexity of its light curve are consistent with the position of GD 244 in the $\log g$-$T_{\rm eff}$ plane as inferred above from optical spectroscopy.

A standard Fourier analysis of the light curve reveals more quantitatively its detailed structure. This is illustrated in Figure 3, which shows the Fourier (amplitude) spectrum of the light curve in the 0–20 mHz bandpass. The spectrum in the region from 20 mHz out to the Nyquist frequency (50 mHz) is entirely consistent with noise and is not shown. Figure 3 reveals at least four significant frequency components corresponding to periods of 307.0, 294.6, 256.3, and 203.3 s. Those can be associated with independent gravity-

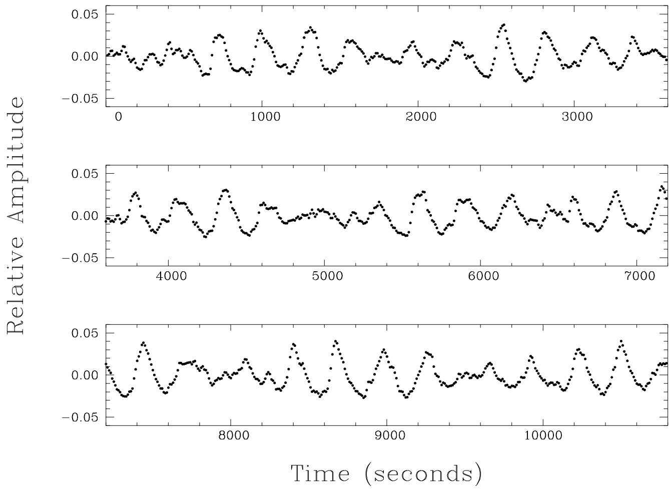

FIG. 2.—"White light" light curve of GD 244, observed on 1999 August 13 with LAPOUNE attached to the CFHT (run cfh-083). The light curve is expressed in terms of residual amplitude relative to the mean brightness of the star. It is continuous, starting at the upper left, and each point represents a sampling time of 10 s.

mode pulsations. There are other significant peaks in the Fourier spectrum, particularly those in the 6.5–7.5 mHz bandwidth, but they are most likely associated with nonlinear structure in the light curve (harmonics and cross-frequencies of the main peaks) and probably do not represent additional pulsation modes. For instance, the peak at 6.515 mHz (153.5 s) with an amplitude of ~0.23% is most likely the first harmonic of the dominant peak at 3.257 mHz (307.0 s). Likewise, the nearby peak at 6.643 mHz (150.5 s) with an amplitude of ~0.20% corresponds—within the run resolution of 0.09 mHz—to the sum of the frequencies of two of the main oscillations: 3.257 mHz (307.0 s) + 3.394 mHz (294.6 s) = 6.651 mHz (150.4 s). Also, the relatively large peak (~0.40%) at 7.155 mHz (139.8 s) corresponds, within the resolution, to the sum of the frequencies of the two largest amplitude oscillations: 3.257 mHz (307.0 s) + 3.902 mHz (256.3 s) = 7.159 mHz (139.7 s).

It is appropriate to point out that, as a ZZ Ceti star, GD 244 does not show any exceptional behavior. In fact, a quick search in the current zoo of ZZ Ceti pulsators reveals that GD 244 has a "photometric twin": GD 66 ($V = 15.56$). Although GD 66 is formally hotter than GD 244 at $T_{\rm eff} =$ 11,980 K and has a lower surface gravity at $\log g = 8.05$ (Bergeron et al. 1995b), the two stars are nearly identical from a spectroscopic point of view, given the uncertainties on the atmospheric parameters. However, if we take at face value the suggestion that GD 66 might be slightly hotter and less massive than GD 244, we recall that there is a compensating effect on the periods. Indeed, as is well known, the period of a gravity-mode in a ZZ Ceti star model decreases with increasing effective temperature but increases with decreasing surface gravity (see, e.g., Brassard et al. 1992). Both stars have, in fact, very similar light curves and period structures.

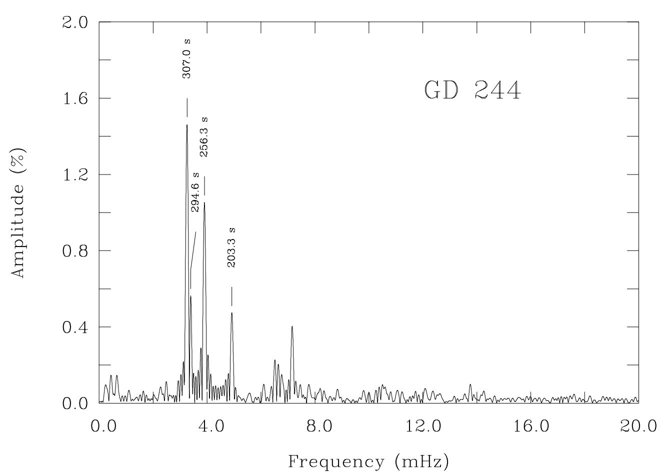

FIG. 3.—Fourier (amplitude) spectrum of the light curve of GD 244 (run cfh-083) in the 0–20 mHz bandpass. The amplitude axis is expressed in terms of the percentage variations about the mean brightness of the star. Four periodicities are clearly seen. Other peaks are also significant, but are associated with nonlinear features in the light curve (harmonics and cross-frequencies).

This is illustrated in Figure 4 which shows the light curve of GD 66 that we obtained on the night of 1995 January 25 using the same setup (CFHT/LAPOUNE) that we used later for GD 244. Except for the facts that the sampling time is 20 s and that the observing window is shorter (6920 s long), the figure clearly reveals striking similarities between the light curve of GD 66 and that of GD 244 (Fig. 2). In particular, the amplitudes, the quasi-periods, and the presence of patterns of constructive and destructive interference between pulsation modes are quite comparable. Not surprisingly then, Figure 5 reveals a Fourier amplitude spectrum of the light curve of GD 66 which is remarkably similar to that of GD 244 (Fig. 3). Here we isolate again four components which are likely four independent pulsation modes, while other significant peaks (around ~7–8 mHz, in particular) are probably nonlinear features. The periods of the pulsation modes detected in GD 66 are 304.5, 271.1, 256.5, and 197.8 s, again remarkably comparable to those found above in GD 244. The next two largest peaks in the Fourier spectrum have frequencies (6.948 and 8.126 mHz) that nearly fall, within the run resolution of 0.14 mHz, on sums of two frequencies of the main modes.

2.3. *Integrated Light Photometry of KUV 02464+3239*

KUV 02464+3239 (WD 0246+326, $V = 15.8$) was observed during 2900 s at the end of the night of 1999 August 14. Although quite short, this run was more than sufficient to establish the variability of KUV 02464+3239. And indeed, only a few minutes of observing in real time were enough to convince us that we had discovered yet another ZZ Ceti pulsator. Interestingly, KUV 02464+3239 is a long-period, large-amplitude pulsator, in perfect agreement with our initial expectations based on the position of

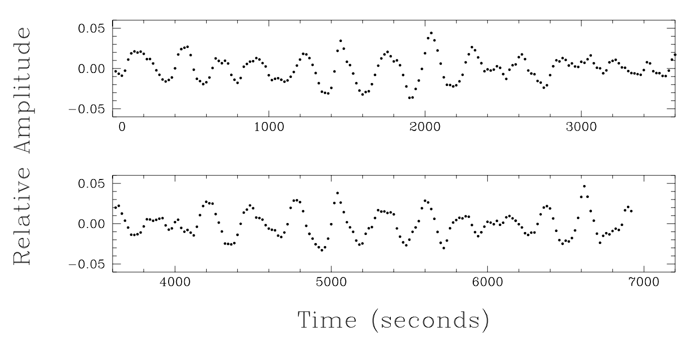

FIG. 4.—"White light" light curve of GD 66, observed on 1995 January 25 with LAPOUNE attached to the CFHT (run cfh-025). The format is similar to that of Figure 2, but note that the sampling time is 20 s here instead of 10 s. GD 66 is a photometric twin of GD 244.

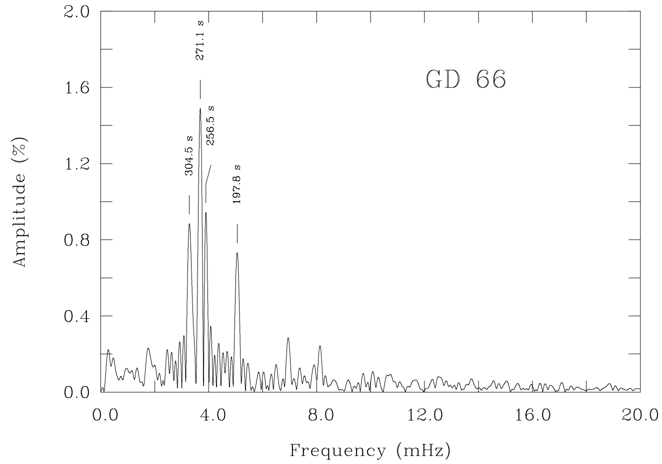

FIG. 5.—Fourier (amplitude) spectrum of the light curve of GD 66 (run cfh-025) in the 0–20 mHz bandpass. The format is similar to that of Figure 3. Again, four periodicities are clearly seen, and other nonlinear peaks are present.

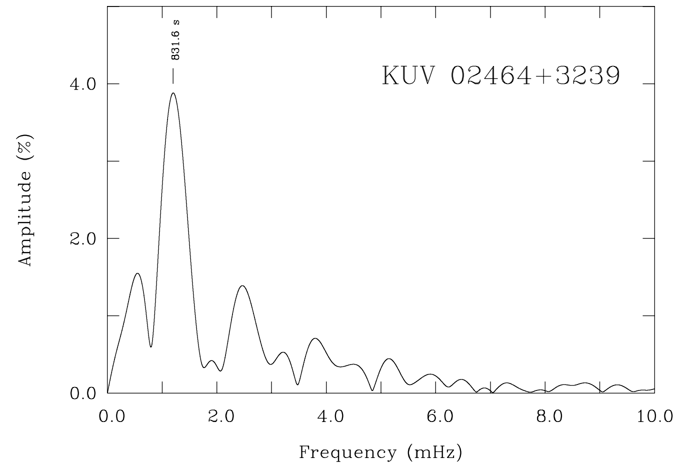

FIG. 7.—Fourier (amplitude) spectrum of the light curve of KUV 02464+3239 (run cfh-088) in the 0–10 mHz bandpass. The amplitude axis is expressed in terms of the percentage variations about the mean brightness of the star. The (low-resolution) spectrum is dominated by a large peak corresponding to a period of ∼832 s. The other peaks are very likely nonlinear features, and not independent pulsation modes.

the star near the red edge of the instability strip in the log g-$T_{\rm eff}$ diagram.

Figure 6 shows the sky-subtracted, extinction-corrected light curve of KUV 02464+3239. This light curve is characteristic of the cooler ZZ Ceti pulsators. Because of the low temporal resolution achieved here, it may appear, at least at first sight, that not much additional information can be gained by calculating the Fourier transform of this rather short light curve. Nevertheless, it is still instructive to consider Figure 7, which shows the Fourier (amplitude) spectrum of the light curve of KUV 02464+3239 in the 0–10 mHz bandpass. The rest of the spectrum, in the 10–50 mHz frequency interval, is entirely consistent with noise and is not shown. Figure 7 reveals a Fourier spectrum dominated by a large-amplitude peak (with a period of ∼832 s) accompanied by at least three higher-frequency peaks of decreasing amplitudes which appear to be the harmonics of the main peak.

Although higher resolution data are obviously needed to decipher the period structure of KUV 02464+3239, some insight may be gained by examining the properties of GD 154, another ZZ Ceti star residing near the red edge of the instability strip (see Bergeron et al. 1995b) and a photometric look-alike of the former. GD 154 ($V = 15.33$) was observed previously at the CFHT by three of us (G.F., P.B., and P.B.) during the course of a multisite campaign (see Pfeiffer et al. 1996). Our best light curve was gathered on the night of 1991 May 24, and is 20,900 s long. Figure 8 illustrates a 3000 s long segment of that light curve of GD 154. A comparison with Figure 6 underlines the obvious similarities between the light curve of GD 154 and that of KUV 02464+3239, although the dominant quasi-period in the former case is significantly longer.

The dotted curve in Figure 9 shows the Fourier spectrum of the 3000 s long light curve segment of GD 154 illustrated in the previous figure. In comparison with the spectrum shown in Figure 7, it too shows a structure dominated by a large-amplitude peak (this time, with a period of ∼1158 s) accompanied by a series of higher-frequency peaks of decreasing amplitudes which are associated with nonlinear features in the light curve. A much higher resolution Fourier spectrum is obtained by considering the full 20,900 s long light curve of GD 154, and this is illustrated by the solid curve in Figure 9. A detailed study of that complex spectrum as well as those obtained on adjacent nights reveals that only three independent pulsation modes have

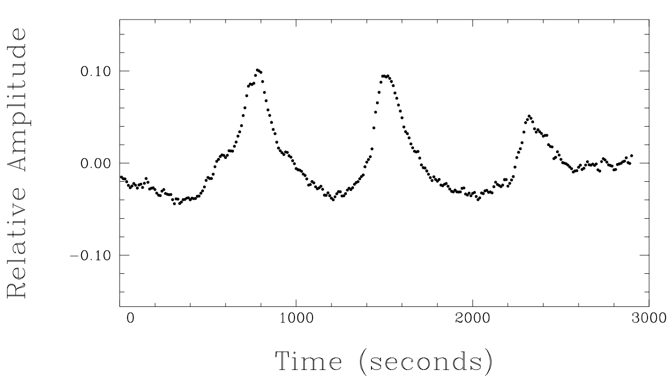

FIG. 6.—"White light" light curve of KUV 02464+3239, observed on 1999 August 14 with LAPOUNE attached to the CFHT (run cfh-088). The light curve is expressed in terms of residual amplitude relative to the mean brightness of the star. Each plotted point represents a sampling time of 10 s.

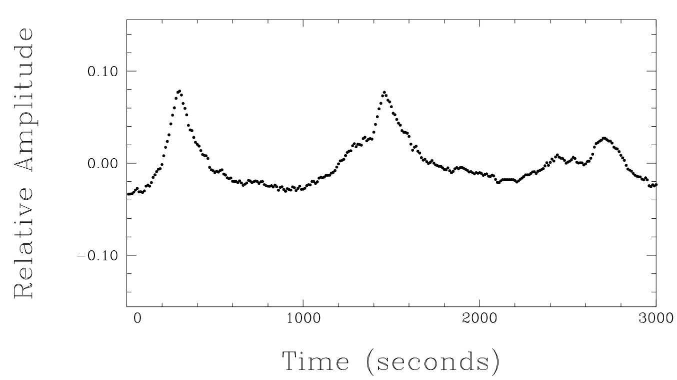

FIG. 8.—Portion of the "white light" light curve of GD 154, observed on 1991 May 24 with LAPOUNE attached to the CFHT (run cfh-008). Each plotted point represents a sampling time of 10 s. In order to compare directly with Figure 6, the segment shown here has a length of 3000 s, but the full light curve is 20,900 s long. GD 154 is a photometric twin of KUV 02464+3239.

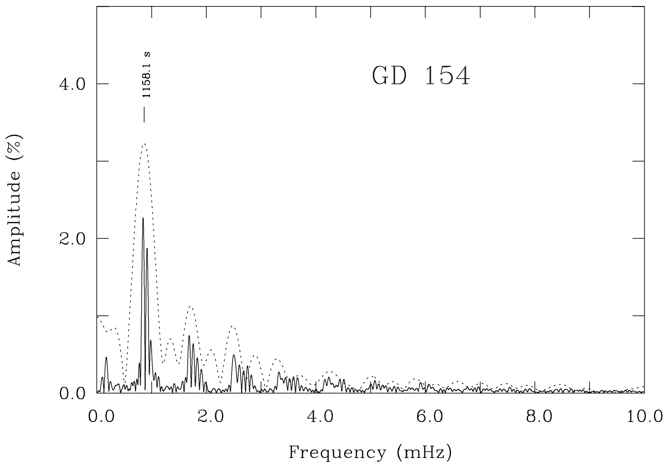

FIG. 9.—Fourier (amplitude) spectrum of the light curve of GD 154 (run cfh-008) in the 0–10 mHz bandpass. The format is similar to that of Figure 7. The dotted curve shows the (low-resolution) spectrum of the 3000 s long light curve segment shown in Figure 8. The curve is qualitatively very similar to the Fourier spectrum shown above for KUV 02464 + 3239, with a large peak, this time of period ∼1158 s, which again dominates. The solid curve, corresponding to the Fourier spectrum of the full light curve (20,900 s long), shows a rather complex structure that cannot be revealed at low temporal resolution.

been detected in the light curve of GD 154 (Pfeiffer et al. 1996). Two of those, with periods 1186.5 and 1088.6 s, belong to the unresolved 1158 s peak in Figure 9, while the other, with a period of 402.6 s, belongs to the unresolved second harmonic peak. Remarkably, the rest of the complex Fourier spectrum of GD 154 can be understood in terms of rotational splitting and nonlinear effects (harmonics and linear combinations of the independent rotationally split modes). We suggest that KUV 02464 + 3239 is likely to have a similar period structure, but this will have to be verified through more extensive observations.

3. CONCLUSION

In this paper, we reported the discovery of two new ZZ Ceti stars, thus bringing to 31 the number of known objects belonging to this family of gravity-mode pulsators. GD 244 and KUV 02464 + 3239 were selected as candidate ZZ Ceti stars on the basis of the optical spectroscopy approach pioneered by Bergeron & McGraw (1990) and further developed by Bergeron et al. (1995b). During the course of an independent study of the optical spectra of a sample of DA white dwarfs, these two objects stood out from the rest of the sample in that their derived atmospheric parameters put them inside the empirical instability strip described by Bergeron et al. (1995b) in the log g-$T_{\rm eff}$ plane. Hence, they became obvious candidates for rapid luminosity variations, and we took the first opportunity during a recent observing run at the CFHT to look at them.

Our success at predicting the variability of GD 244 and KUV 02464 + 3239 is an additional proof of the basic validity of the optical spectroscopy method of Bergeron & McGraw (1990). We point out that this method, used so far in five cases, has had a yield of 100%. Furthermore, from their positions in the log g-$T_{\rm eff}$ diagram, we expected that GD 244 should show intermediate-amplitude luminosity variations, while KUV 02464 + 3239, being much closer to the red edge of the instability strip, should show large-amplitude, long-period luminosity modulations. Remarkably, these expectations were well borne out by our observations, adding immensely to our confidence in the reliability of the derived values of the atmospheric parameters for these stars. Finally, we wish to point out that, contrary to rumors that have come up from time to time, the old claim of Fontaine et al. (1982) concerning the purity of the ZZ Ceti instability strip is still very much pertinent: The region occupied by ZZ Ceti stars in the log g-$T_{\rm eff}$ plane discussed by Bergeron et al. (1995b), and enriched since by additional discoveries such as those reported in this paper, *still* contains only variable stars.

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