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PG 1654+160: A NEW PULSATING DB WHITE DWARF

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ABSTRACT

We have found that the DB white dwarf PG 1654+160 is a pulsating variable star, and thereby the second member of the class of pulsating DB white dwarfs. The photometric properties of PG 1654+160 resemble those of the other variable in the class, GD 358: the light curve is at least quasi-periodic, with a typical pulse interval of about 560 s; the maximum amplitude reached is nearly 0.2 mag; and power spectra of its light curve show many periods between 148.5 s and 851 s. As with GD 358, the power is concentrated at low frequencies, in particular near 578 s and 851 s. PG 1654+160 was selected from DB white dwarfs in the Palomar-Green survey on the basis of the unusually strong and broad He I lines present in its optical spectrum. The success of this selection criterion strongly suggests that the variability of the pulsating DB white dwarfs is associated with the helium opacity maximum—as predicted by theory.

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

I. INTRODUCTION

Our theoretical studies of the pulsation properties of the pulsating DA white dwarfs suggested that hot DB white dwarfs should also pulsate as the result of driving from the helium partial ionization zone (Winget *et al.* 1982*b*; Winget 1981). This prediction led us to conduct a systematic photometric survey of 30 spectroscopically identified DB white dwarfs, which in turn led to the discovery of the variability of the DB white dwarf GD 358 (Winget *et al.* 1982*a*; Robinson and Winget 1983). The number of spectroscopically identified white dwarfs has recently doubled as a result of the Palomar-Green (PG) survey (R. Green and J. Liebert, private communication). We have begun to search for additional pulsators among the DB white dwarfs found in this survey.

The effective temperature of GD 358 is near 30,000 K (Winget *et al.* 1983; Koester, Weidemann, and Vauclair 1983). If we take this temperature as the center of the pulsation instability strip for DB white dwarfs, and if we assume the width of the instability strip is approximately 3000 K as given by the theoretical calculations of Winget *et al.* (1983), then only about one in 25 randomly sampled DB white dwarfs will be pulsators. The low probability of finding pulsators is in accord with the results from our first survey. To increase the probability of finding more pulsators, we have exploited our theoretical result that He I surface partial ionization zones are responsible for the instabilities. This implies that the He I opacities should be near maximum for these stars, and that the He I lines should be strong and broad. We therefore used the optical classification spectra of the PG stars, obtained by R. Green and J. Liebert, to select DB white dwarfs with extremely broad He I lines for high-speed photometric observation. There are roughly eight such objects in the PG sample. We report here the first positive result from this selective survey: PG 1654+160 is a pulsating variable star.

II. PHOTOMETRIC OBSERVATIONS AND ANALYSIS

PG 1654+160 was classified as a DB white dwarf on the basis of a low-resolution SIT spectrum obtained by Richard Green. We observed PG 1654+160 with a standard McDonald Observatory high-speed, two-star photometer (Nather 1973) on the 2.1 m telescope at McDonald Observatory. All observations were made in unfiltered light using a blue-sensitive RCA 8850 photomultiplier tube. The light curve of the comparison star observed in the second channel of the photometer was used to verify that the sky was photometric.

A summary of our observations is presented in Table 1. We obtained three runs on PG 1654+160 with durations of 1.4 hr, 2.7 hr, and 3.5 hr. A portion of the light curve of PG 1654+160 on the night of 1983 August 7 is shown in Figure 1. We have subtracted sky background and dark count from the data and then roughly removed the effects of extinction by dividing the data by a parabola fitted to the light curve. Thus, Figure 1 displays fractional intensity. The light curves consist of sharply peaked pulses with typical separations of about 560 s and typical amplitudes of 0.10 mag. The pulse amplitudes are variable and range from about 0.05 to about 0.18 mag full amplitude. The amplitudes of the pulses in the light curve of the previously discovered variable, GD 358, were also variable, and the variations were systematic, not random; the amplitudes were modulated at a period of 5400 s. We are unable to demonstrate the presence of any similar periodic modulation in the light curve of PG 1654+160. The amplitude of the pulses in PG 1654+160 varied on a time scale near 9,000 s on 1983 August 7, but our light curve is too short to prove that this variation is periodic.

We computed power spectra of all our light curves of PG 1654+160 to search for periodicities in its luminosity variations (Kepler *et al.* 1982). All the significant features in the spectra were confined to low frequencies; there were no periodicities with semiamplitudes greater than 2×10^{-3} between

TABLE 1

PHOTOMETRIC OBSERVATIONS OF PG 1654+160

Run Number	UT Date	UT Time of Run Start	Length of Run (hr)	Integration Time (s)
2817	1983 Aug 2	05:32:46	1.4	10.0
2821	1983 Aug 6	03:15:44	2.7	10.0
2822	1983 Aug 7	03:16:00	3.5	10.0

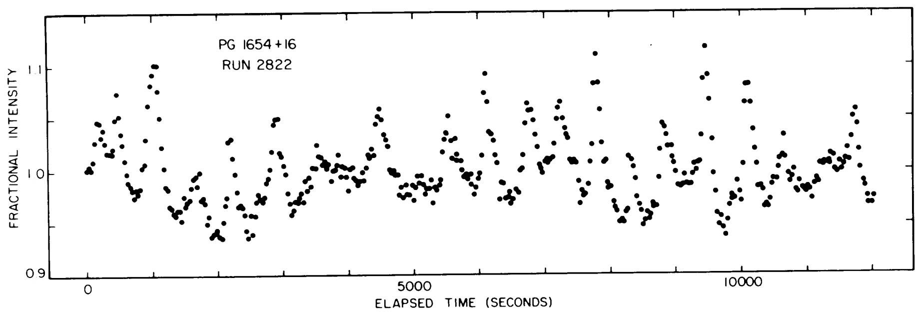

FIG. 1.—The light curve of PG 1654+160 on the night of 1983 August 7 (UT). Each data point is the mean of a 30 s integration in white light.

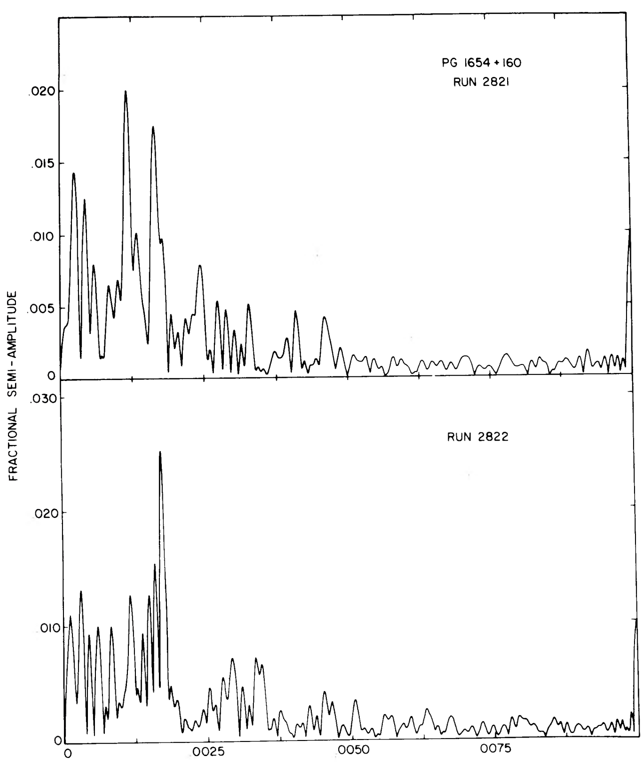

FIG. 2.—The amplitude spectra (the square root of the power spectra) of the light curves of PG 1654+160 on the nights of (*upper*) 1983 August 6, run 2821 (*lower*) 1983 August 7, run 2822. A tracer was introduced in both power spectra at 0.01 Hz and a fractional semiamplitude of 0.01. Most of the peaks between 0.001 Hz and 0.01 Hz are statistically significant.

20 and 148.5 s. The low-frequency portions of the amplitude spectra (the square root of the power spectra) of runs 2821 and 2822 are shown in Figure 2. The noise levels in the power spectra are sufficiently low that all the obvious features are significant.

There are large differences between the two spectra. It is possible that the differences reflect an intrinsic variability in the properties of the pulsations of PG 1654+160, but the amplitude spectra are exceedingly complex and dense in peaks, and they are probably underresolved. Most of the peaks in the spectra are severely contaminated by spectral leakage from power at nearby frequencies, so their frequencies and amplitudes are not given reliably by the spectra. Therefore, it is also possible that the properties of the pulsations are constant, and the differences between the two spectra are caused solely by measurement errors introduced by spectral leakage. Despite the measurement uncertainties, both spectra show power that increases toward low frequencies, and both have stronger peaks near 851 s and 578 s. We can safely conclude, therefore, that the pulsations have long periods and are at least quasi-periodic.

III. DISCUSSION

The discovery of pulsations in PG 1654+160 is important for two reasons:

1. We now know two pulsating DB white dwarfs, and we are confident we will be able to find others. We propose that the pulsating DB white dwarf stars are indeed a new class of variable stars, and that their pulsations provide new opportunities to probe their internal structure.

2. The presence of strong, broad He I lines in absorption is a good selection criterion, implying that the pulsations are driven by the helium ionization zone.

The photometric properties of PG 1654+160 and GD 358, the two known pulsating DB white dwarfs, are strikingly similar. The light curves of both stars are characterized by large-amplitude nonsinusoidal pulses with typical intervals of the order of 600 s; the amplitude spectra are complex, with periods in the range from 100 s to 1000 s; and the periods with the largest amplitude are the longest periods. One significant difference in the photometric properties of the two stars lies in the long-term modulation of the amplitude of their pulsations. The amplitudes of the pulses of GD 358 are modulated at a period of 5400 s, and this modulation produces groups of pulsation periods in the amplitude spectrum of its light curve with adjacent members of the groups separated by 1/5400 Hz. This behavior is consistent with g-mode pulsations that have been split by rotation of the white dwarf; the inferred rotation period is 5400 s (Winget *et al.* 1982*a*). There is no modulation of the pulse amplitudes of PG 1654+160 that is clearly periodic, and there are no obvious groups of evenly spaced pulsations in its amplitude spectrum. Either the rotational modulation of the pulse amplitudes is small, or the period of the rotation is too long (> 2 hours) to be easily distinguished in our data. The 9,000 s modulation in our longest run on PG 1654+160 may well be the result of rotation, but our data are not extensive enough to prove it.

PG 1654+160 is one of the eight DB white dwarfs we selected out of the entire sample of DB white dwarfs found in the PG survey, based on their unusually strong and broad He I lines. It is the only one of the newly selected DB white dwarfs we have observed so far, although PG 0112+102, a star in our previous survey that also meets our current selection criterion, did not vary in brightness by more than 0.003 mag (Robinson and Winget 1983). Nonetheless, the criterion appears to be successful, and its success argues strongly that the pulsations are caused by a helium opacity effect, as theory predicts (Winget 1981; Winget *et al.* 1983). We plan to observe the remaining stars from the selected set as weather and telescope access permit.

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