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PG 1456+103: A NEW PULSATING DB WHITE DWARF

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ABSTRACT

High-speed photometry presented in this paper demonstrates that the helium-rich white dwarf PG 1456 + 103 is a pulsating star. The three or four major periodicities present in its light curves range from 423 to 854 s, with amplitudes between 8.5 and 21 millimag. Upper amplitude limits for periods outside of this range (60–2000 s) are calculated to be on the order of 4 millimag from the data. PG 1456 + 103 is the fifth member of the DBV class of variable white dwarfs. It has been shown based on the *IUE* energy distribution to have a temperature (approximately 24 000 K) consistent with the temperature range for members of this group.

I. INTRODUCTION

The discovery that GD 358, a white dwarf of spectral class DB, pulsates marked a significant occasion in astronomy where theory predicted the existence of a new type of variable star before one was actually observed (Winget *et al.* 1982; Winget 1981). Since that time, PG 1654 + 160, PG 1351 + 489, and PG 1115 + 158 have also been found to pulsate (Winget *et al.* 1984,1987). Hill's (1986) detailed analysis of time-series photometry of these four stars is consistent with theoretical calculations which indicate that nonradial *g* mode pulsations are the source of the photometric variations. This new class of variables is commonly designated as the DBV stars (Sion *et al.* 1983, or Winget 1986).

Theoretical calculations of Winget *et al.* (1983) suggested an instability strip, approximately 3000 K wide, for helium white dwarfs with temperatures near 30 000 K. However, the null results of Robinson and Winget (1983) indicate a low probability of finding pulsators among a random selection of DB white dwarfs, most of which have much cooler temperatures. Optical observations of GD 358 compared with model-atmosphere calculations yielded estimates of $T_{\rm eff} = 24\,000 \pm 1000$ K and $\log g = 8.0 \pm 0.3$ (Koester *et al.* 1985), though the ultraviolet (*IUE*) temperature estimate is somewhat higher (Liebert *et al.* 1986).

The theoretical and observational results on the DBV stars indicated a need to identify more hot DB stars, and it was clear that the Palomar Green survey (Green, Schmidt, and Liebert 1986) provided several good candidates. Given that the He I lines saturate at $T_{\rm eff} > 18\,000$ K, and optical colors above this value are insensitive to temperature, Liebert *et al.* (1986) obtained ultraviolet (*IUE*) energy distributions for all hot DBV candidates from the PG survey, as well as those for the known pulsators. The goals were (1) to delineate the empirical temperature range of the DBV stars, and (2) to identify stars close to these temperatures. PG 1456 + 103 was assigned $T_{\rm eff} = 24\,000 \pm 3000$ K, a temperature that placed it near or within the DBV instability strip, and hence made it a prime target for time-series photometric observations. An optical spectrum obtained with the Steward Observatory 2.3 m telescope, Cassegrain spectrograph, and intensified photon-counting Reticon detector features strong, broad He I absorption lines similar to other hot DB stars.

In this paper, we report our discovery that PG 1456 + 103 is a pulsating variable. This brings to five the number of known DBV pulsating white dwarfs. This object has 1950 coordinates of $14^{\rm h}56^{\rm m}07.4^{\rm s}$ and $+10°20'15''$.

II. TIME-SERIES PHOTOMETRY OF PG 1456 + 103

The photometric observations of PG 1456 + 103 were made with the 1.3 m reflector at KPNO and the 1.5 m telescope of the University of Arizona located on Mount Bigelow, using the two-star photometer of the University of Arkansas at Little Rock. The data acquisition and reduction techniques described by Grauer and Bond (1981) were employed in each case to obtain the intensity of the object as a function of time. PG 1456 + 103 and a comparison star located 206″ west and 402″ south of it were observed simultaneously with two separate photomultipliers. No filters were used with the blue-sensitive (3200–6500 Å) bialkali photocathodes in order to increase photomultiplier count rates. The effective wavelength of the photomultiplier-tube–atmosphere combination is slightly bluer than Johnson *B* with a peak response occurring between 3700 and 4000 Å. Division of the sky-subtracted PG 1456 + 103 data stream by the smoothed sky-subtracted comparison-star data removed any effects of atmospheric extinction or transparency variations. An observing log is given in Table I. The star was observed to pulsate on all five nights; however, only the three longest runs were useful in extracting periods from the light

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TABLE I. Observing log for PG 1456 + 103.

UT date (1987)	Telescope		Starting UT	Run duration (hr)	Integration time (s)
Apr. 25	KPNO	1.3 m	07:08:48	2.3	5
Apr. 27	KPNO	1.3 m	08:46:05	1.8	6
May 17	UAO	1.5 m	05:30:42	1.2	5
May 18	UAO	1.5 m	03.48.29	4.1	5
May 22	UAO	1.5 m	04:16:59	4.8	10

curves. The nights of May 18 and 22 were of photometric quality. Transparency variations of a few percent (which divided out readily) were noted on the other nights. The time base used in the data-collection process was calibrated by comparisons between it and the WWV standard time signals during the course of each observing session.

III. LIGHT CURVES AND POWER SPECTRA

The light curves for the three longest time-series runs are presented in Fig. 1. The general character of the photometric variations observed is similar to the other known DBV stars (Winget *et al.* 1982,1984,1987). The light curves do not repeat on the timescales covered by our observations, and many of the pulses are sharply peaked.

Power spectra calculated for each of the light curves of Fig. 1 are presented in Fig. 2. Figure 3 is a plot of a power spectrum calculated from the combined data taken on 18 and 22 May 1987. A standard procedure was used to calculate a power spectrum for each night and for the pair of nights. For each night, the original integrations were summed into 30 s bins, the light curves were normalized to zero mean counts, and the first and last 10% of each data set was tapered with a cosine function to zero. This tapering process reduces the calculated amplitude of each component in the light curve by 10%. A Fourier transform of the data from each night and for the pair of nights prepared in this way was then calculated using the method of Deeming (1975). For each night and the pair of nights, the transform of a 600 s sine wave sampled and tapered like the real data (the spectral window) was compared with the transform of the corresponding PG 1456 + 103 light curve. For single nights, the window period was recovered to within 2 s for the 25 April 1987 light curve and within 0.5 s for the 18 and 22 May 1987 data. The time-series observations of PG 1456 + 103 are noisy and its light curve is not a sine wave. Consequently, a period determined for this star from a single night's data is probably accurate to within 10 s. A stable period measured from a pair of nights' observations is most likely to be within several seconds of the actual value.

Table II lists the periods found from the transforms of the individual nights. The amplitude given in millimagnitudes for each peak has been corrected for the effect of tapering. The frequency and amplitude of each of the peaks varied from night to night. Thus the value of a period determined from a single night of our data is really a measure of some blend of unresolved peaks within a closely spaced band of frequencies.

A Fourier transform of the combined light curves for the two longest runs obtained on May 18 and 22, along with the transform of a sine wave that has been sampled and tapered like the real data, is presented in Fig. 3. A band structure containing at least four groups of periods is evident. As can be seen from the window function, the signature of a single peak is complicated due to the large time gap between the two data sets. The center of the alias pattern for the 600 s window function is at 599.7 s, while those from the PG 1456 + 103 data are located at 854, 793, 659, and 423 s.

Table III presents upper amplitude limits, which we derived for those periods between 60 and 2000 s, which are outside the range of frequencies plotted in Fig. 2. The ampli-

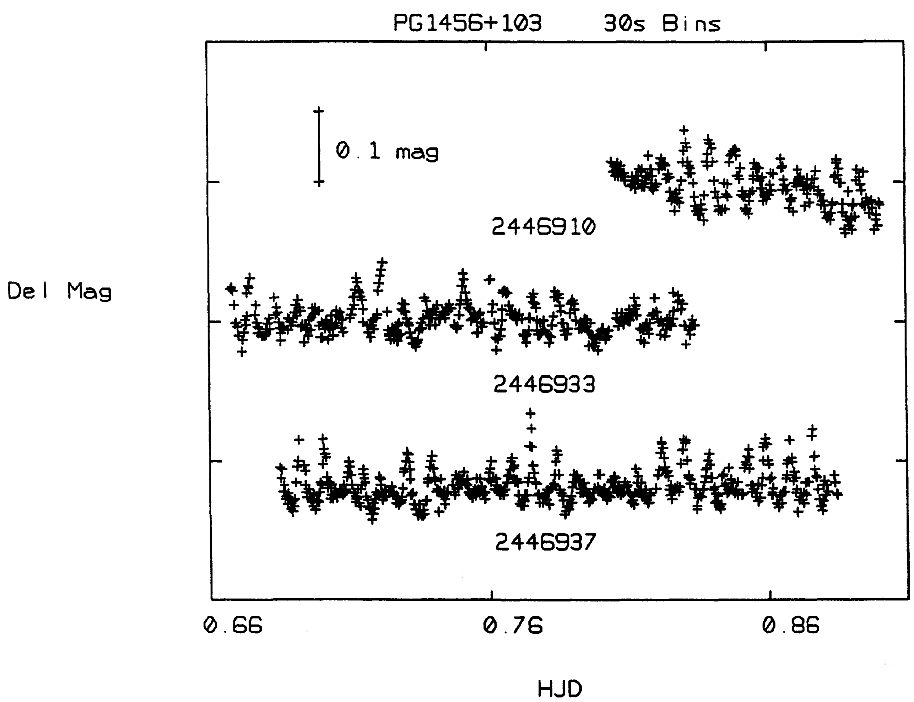

FIG. 1. The light curves of PG 1456 + 103 obtained on the nights of April 25 (2446910), May 18 (2446933), and May 22 (2446937) of 1987. The original integrations have been summed into 30 s bins. The difference in magnitude between PG 1456 + 103 and the comparison star is plotted against the heliocentric Julian date. Peak-to-peak variations in excess of 0.15 mag exhibit the sharp peaks characteristic of the other DBV pulsators.

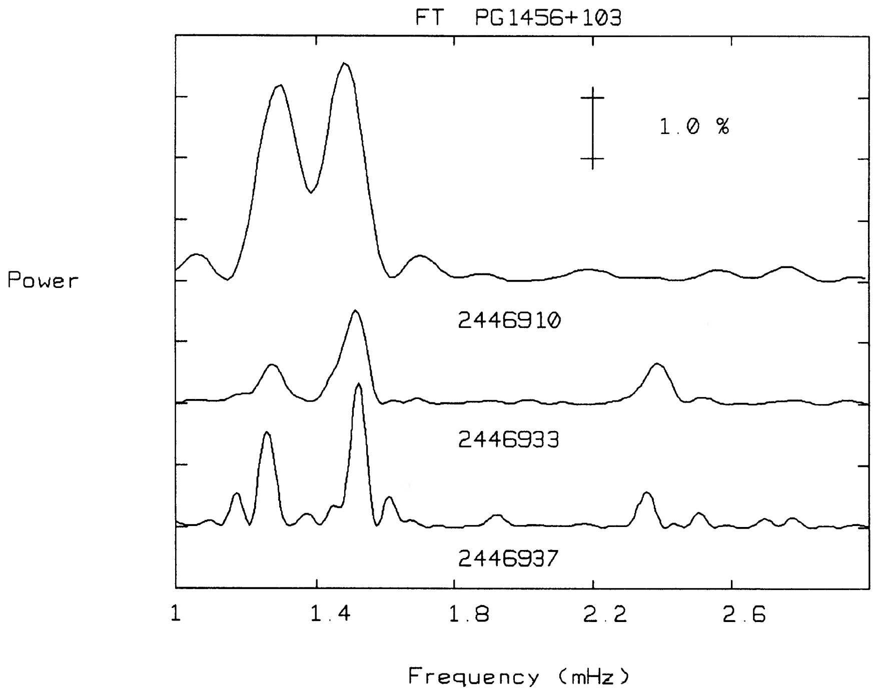

FIG. 2. Power spectra of the light curves of Fig. 1. The power (square of the fractional semiamplitude) in percent is plotted against frequency in mHz. The Fourier transforms of all three nights are plotted with the same scales. The night-to-night amplitude and frequency variations observed indicate that many periods must be present.

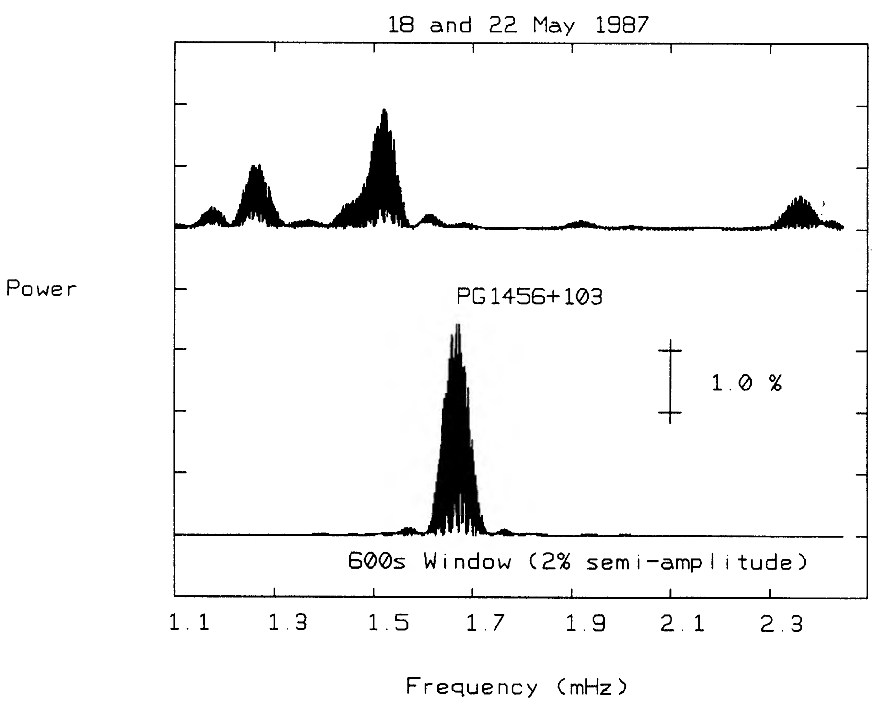

FIG. 3. The power spectrum of the combined data from the nights of 18 and 22 May 1987 indicates at least four bands of periods near 854, 793, 659, and 423 s. The power (square of the fractional semiamplitude) in percent is plotted against the frequency in mHz. The transform of a 600 s, 2% semiamplitude sine wave sampled and tapered like the PG 1456 + 103 data is plotted below the transform of the star's data. The same scales are used for both plots. The plotted amplitudes are 10% lower than their actual values because of the cosine tapering employed.

TABLE II. Periods present in PG 1456 + 103's light curves.

UT date (1987)	Periods (s)	Semiamplitude (millimag)
Apr. 25	774	19.9
	673	21.0
May 18	785	8.9
	661	13.7
	419	9.1
May 22	849	8.3
	793	13.9
	657	17.0
	425	8.5

TABLE III. Periods not found in PG 1456 + 103's light curves.

UT date (1987)	Period range (s)	Semiamplitude limit (millimag)
Apr. 25	60–360	3.1
	1000–2000	3.9
May 18	60–360	3.3
	1000–2000	6.0
May 22	60–360	3.1
	1000–2000	3.2

tude limits were taken to be the height of the largest noise peak in the transform for the period range given. None of these highest noise spikes were found at the same frequency on different nights. Thus, all significant peaks found in our data are located between 360 and 1000 s (the period range plotted in Fig. 2).

IV. SUMMARY

The time-series data presented here clearly demonstrate that PG 1456 + 103 is a pulsating star. There are now five known DBV white dwarfs.

This discovery tends to support the tentative instability strip for hot, helium-rich white dwarfs within the temperature range of Liebert *et al.* (1986).

Like the ZZ Ceti stars, the variable DBs display a range of period structure ranging from the "simple" case of PG 1351 + 489 to complex examples like this star. The apparently rich period structure of PG 1456 + 103 is in keeping with the initial theoretical models of Winget *et al.* (1983). A fully resolved power spectrum will be obtained observationally only by combining data from sites of different longitudes. These extended-coverage light curves should yield clues as to the masses, internal structure, rotation periods, and rates of evolution of these most interesting stars.

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