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KUV 05134+2605: A NEW PULSATING DB WHITE DWARF

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ABSTRACT

We report time-series photometry that shows that KUV 05134 + 2605 is a pulsating DB white dwarf. The light curve shows sharply peaked pulses with a complicated mode structure including periods between 350 and 900 s. The optical spectrum appears to be that of a star near the hot end of the DB sequence, consistent with theoretical predictions and the temperature range estimated empirically for previously known DBV stars.

I. INTRODUCTION

The ZZ Ceti stars, also called the DAVs, were the initial class of pulsating white dwarfs to be discovered. The first such object found was HL Tau-76 (Landolt 1968); however, its nature remained elusive for some time. The DAV's have hydrogen atmospheres and effective temperatures between 11 000 and 13 000 K. A detailed theoretical analysis indicates that the partial ionization of hydrogen in the outer atmospheric envelope drives *g* mode pulsations in these stars. Furthermore, analysis predicted that a second class of pulsators should exist among those white dwarfs with helium-rich atmospheres (Winget 1981). These new variable stars were expected to have a driving mechanism based on the partial ionization of He I and, thus, be found at a higher surface temperature than the DAV stars. This prediction was confirmed when GD 358, a white dwarf of spectral class DB was found to pulsate (Winget *et al.* 1982). Since that time several more variable helium white dwarfs have been found. This new class of pulsators is commonly designated as the DBV stars (Sion *et al.* 1983 or Winget 1986).

The light curves of the DBV stars feature sharply peaked pulses approximately 500–700 s apart with peak-to-peak amplitudes between 0.1 and 0.3 mag. The light curve of GD 358 has a typical pulse interval of 600–700 s with a peak-to-peak amplitude of approximately 0.3 mag. Its transform indicates at least 28 periods between 140 and 1000 s. In some ways, GD 358's light variations are similar to the much cooler DAV star G29-38 (Winget *et al.* 1982). PG 1654 + 160 has a light curve with a typical pulse interval of 560 s and peak-to-peak amplitude of 0.18 mag. The main peaks in its power spectra are near 851 and 578 s (Winget *et al.* 1984). PG 1115 + 158 has a complex mixture of periods and a light curve that does not appear to repeat itself (Winget *et al.* 1987). The unique DBV star PG 1351 + 489 has a light curve that is totally dominated by a single period and its harmonics (Winget *et al.* 1987). Fourier transforms of PG 1456 + 103's light curves have many peaks between 400 and 900 s (Grauer *et al.* 1988). Initial observations of CBS 114 show that it has a light curve with a complex mixture of periods between 277 and 670 s (Winget and Claver 1988a,b). It has a typical pulse period of 650 s with an amplitude of 0.3 magnitudes. The generally rich mixture of periods found for these stars is in keeping with the expected filter mechanisms for *g* mode pulsations.

When no selection criteria are applied to a pool of DB white dwarfs there is a low probability of finding variables (Robinson and Winget 1983). However, a combination of theoretical guidance and spectroscopic information can be used to identify new pulsators with an approximately 50% success rate.

The prototype DBV star GD 358, has a spectrum that features strong He I lines in absorption. Spectroscopic observations of this star when compared with model atmosphere calculations yield estimates of $T_{\rm eff} = 24\,000 \pm 1000$ K and $\log g = 8.0 \pm 0.3$ (Koester *et al.* 1985). However, the ultraviolet (*IUE*) temperature of $28\,000 \pm 2\,000$ K obtained by Liebert *et al.* (1986) is somewhat higher.

More detailed calculations by Winget *et al.* (1983) and Cox *et al.* (1987) predict an instability region for helium white dwarfs with temperatures between 25 000 and 30 000 K. These values are near the hot end of the known sequence of DB white dwarfs. Indeed, there is growing evidence that the pulsators are among the hottest DB stars. Theory indicates that the DBV stars should have surface He I ionization zones with opacities near their maximum values (Winget *et al.* 1984). Unfortunately, the temperatures of hot DB stars are not accurately determined at $T_{\rm eff} > 20\,000$ K at which the He I lines are very broad and saturated in strength. Thus, it is difficult to identify candidates that might fall into the correct $T_{\rm eff}$ range for pulsational instability, and this range is not determined accurately from observations. Despite these difficulties, it is important to identify new candidates to define the temperature boundaries of this new instability strip, study the pulsational mode properties, and find objects with simple frequency spectra suitable for evolutionary cooling measurements.

The strong He I lines in the spectrum of KUV

05134 + 2605 (Wegner *et al.* 1987) led to its classification as a hot DB star with an effective temperature greater than 20 000 K. This observation prompted us to obtain time-series data on it.

We report here our discovery that KUV 05134 + 2605 is a DBV pulsating white dwarf. Time series photometric data and new spectroscopic observations can be found in subsequent sections of this paper. This object has 1950 coordinates of $05^h\ 13^m\ 22^s$, $+26^d\ 05'\ 21''$. A finding map is given by Kondo *et al.* (1984).

II. TIME-SERIES PHOTOMETRIC OBSERVATIONS

The photometric observations of KUV 05134 + 2605 were made with two of Steward Observatory's telescopes, the 1.5 m located on Mount Bigelow (61 in.) and the 1.5 m situated on Mount Lemmon (60 in.). The two-star photometer of the University of Arkansas at Little Rock was used. Data acquisition and reduction techniques similar to those described by Grauer and Bond (1981) were employed in each case to obtain the intensity of the object as a function of time. KUV 05134 + 2605 and a comparison star were observed simultaneously with two separate photomultipliers. Since the star is rather faint (V approximately 17), 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.

Ten second integrations were employed for all of the time-series runs. All three nights were of photometric quality. 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. At the 61 in. the comparison star used is located 489″ east and 46″ north of the variable. Due to a smaller plate scale of the 60 in. a comparison star 283″ east and 74″ south of KUV 05134 + 2605 was employed at this telescope. Division of the sky-subtracted KUV 05134 + 2605 data stream by a parabola obtained from a least-squares fit to the data completely removed any effects of atmospheric extinction. An observing log is given in Table I.

TABLE I. Photometric observing log for KUV 05134 + 2605.

UT date (1988)	Telescope	Run Starting UT	Run duration (hr)
12 October	UAO 1.5 m Mount Bigelow	09:37:20	2.0
14 October	UAO 1.5 m Mount Bigelow	10:19:20	1.9
16 October	UAO 1.5 m Mount Lemmon	09:45:10	2.5

III. LIGHT CURVES AND POWER SPECTRA

Light curves obtained on three different nights are presented in Fig. 1. The general character of the photometric variations observed is similar to the other known DBV stars. 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. They were obtained using the method of Deeming (1975) applied to the stream of 10 s integrations after a sky-subtraction and a parabolic extinction correction had been performed. The time-series observations of KUV 05134 + 2605 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.

Table II lists the periods found using the transforms of the individual nights. The amplitude is given in millimagnitudes for each peak. The frequency and amplitude of each of the

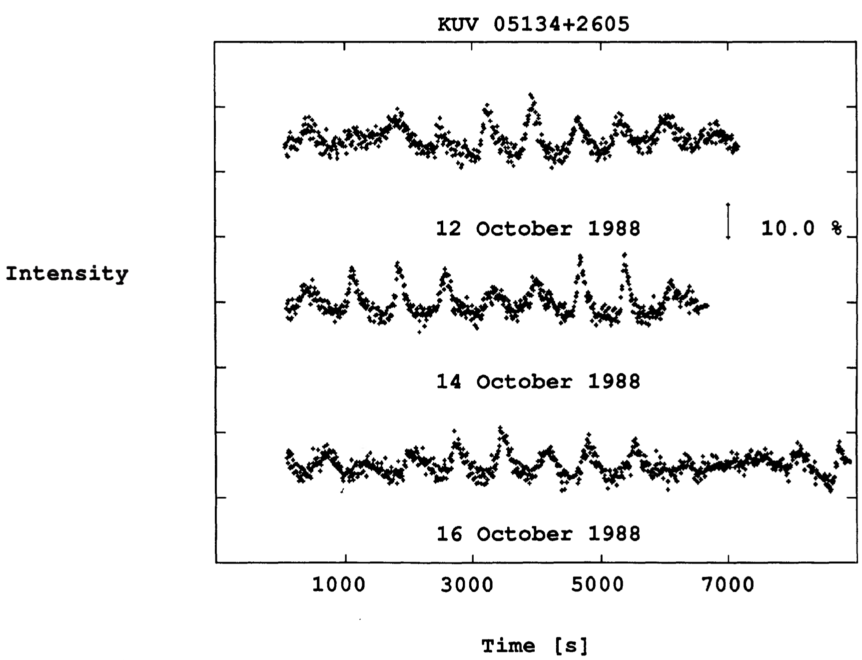

FIG. 1. The light curves of KUV 05134 + 2605 obtained on the nights of 12, 14, and 16 October 1988. The original 10 s integrations are presented unsummed. Fractional intensity is plotted against the time in seconds from the run start time of Table I. Peak-to-peak variations in excess of 20% exhibit the sharp peaks characteristic of the other DBV pulsators.

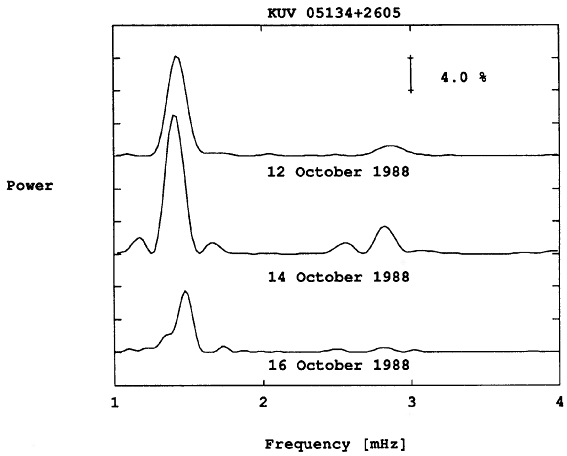

FIG. 2. Power spectra of the light curves of Fig. 1. The power (square of the fractional semiamplitude) in percent is plotted against frequency in mHz. The Fourier transforms of all three nights are plotted with the same scales. The night-to-night amplitude and frequency variations observed indicate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

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 periods within a closely spaced band of components. This behavior is similar to that of most of the other known DBV stars.

Table III presents upper amplitude limits, which we derived for those periods between 60 and 1500 s, which are outside the range of frequencies plotted in Fig. 2. The amplitude 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 250 and 1000 s (the period range plotted in Fig. 2).

KUV 05134 + 2605 has been found to have periods between 350 and 900 s and a light curve with sharply peaked pulses. Most of the power is found in the lower frequency modes within this range. An indication of the presence of many unresolved modes can be found in the fact that the power appears to be concentrated in bands whose amplitude and frequency vary on a night-to-night basis. Comparison of these results with the brief summary of the properties of the other DBVs given in the introductory section of this paper shows that KUV 05134 + 2605 is a typical member of this class of variable stars.

IV. SPECTROSCOPIC OBSERVATIONS

Figure 3 shows a spectral scan of the star obtained on 14 October 1988 using the 2.4 m Hiltner telescope on Kitt Peak and the Mark III spectrograph employing a 300 lines/mm grism and 2 arcsec slit, with which an RCA CCD as the detector yields a resolution of 13.2 Å. Data reductions were done using the program IRAF, whereby this spectrum was corrected for atmospheric extinction and the instrumental response using the standard star W1346 (Oke 1974) and assuming mean extinction values for Kitt Peak. The accuracy of the calibration is suspect for wavelengths shorter than 4200 Å due to the strong drop of the instrumental sensitivity there. The spectroscopic observations were obtained

TABLE II. Periods present in KUV 05134 + 2605's light curves.

UT date (1988)	Periods (s)	Semiamplitude (millimag)
12 October	699.4	34.9
	,349.0	11.2
14 October	861.4	14.3
	709.6	41.2
	603.0	11.7
	391.3	11.7
	355.0	18.6
16 October	678.5	27.4
	579.1	8.6
	356.7	7.6

TABLE III. Periods not found in KUV 05134 + 2605's light curves.

UT date (1988)	Period range (s)	Semiamplitude limit (millimag)
12 October	60–250	4.3
	1000–1500	7.6
14 October	60–250	8.9
	1000–1500	5.3
16 October	60–250	3.1
	1000–1500	5.8

through clouds, so an absolute flux calibration could not be obtained from these data.

The new spectrum of KUV 05134 + 2605 covering the wavelength interval 3950–7200 Å confirms its strong-lined nature. Inspection of Fig. 3 indicates that there are no lines of any element other than He I to within the signal-to-noise which we estimate to be about ± 3% of the continuum at

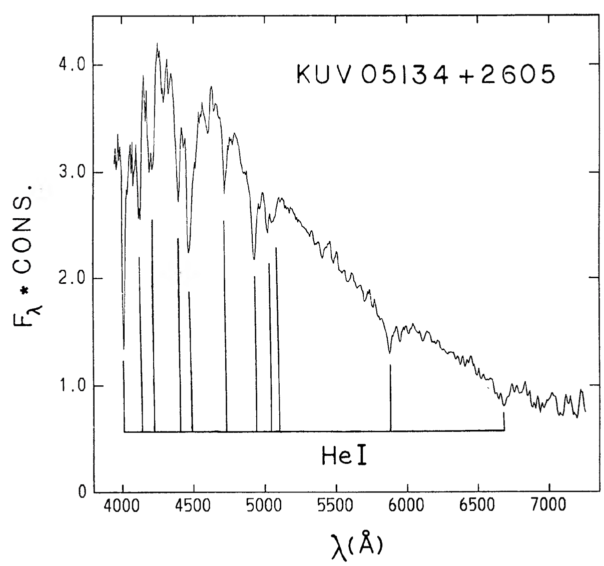

FIG. 3. Spectral scan of KUV 05134 + 2605 obtained with the Hiltner 2.4 m telescope. The data have been corrected for the atmospheric and instrumental response functions. Positions of some of the strongest He I lines are marked.

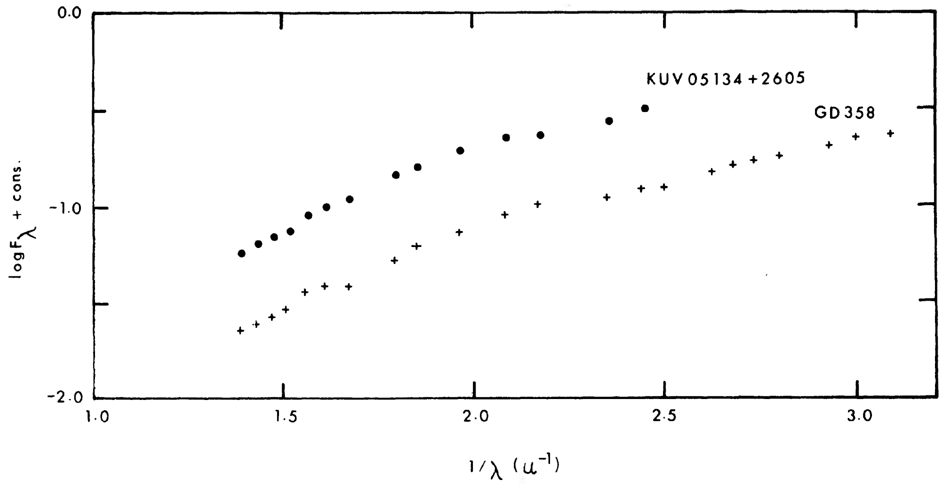

FIG. 4. Comparison of the continuum energy distributions of KUV 05134 + 2605, as measured with the 1.3 m (Wegner *et al.* 1987) and 2.4 m telescopes and GD 358 (Oke *et al.* 1984). These data indicate that the slopes of the continua of the two stars are nearly identical.

5500 Å. Comparison of this spectral scan with the high-quality spectrum of GD 358 published in Koester *et al.* (1985) shows that the relative strengths and widths of the He lines are similar in the spectra of these two stars.

Some idea of the effective temperature of KUV 05134 + 2605 can be obtained from Fig. 4 which compares continuum points of the star's spectral energy distribution obtained from the 1.3 and 2.4 m spectra with those of GD 358 from Palomar MCSP scan (Oke *et al.* 1984). The energy distributions are identical to within the errors of each measurement.

V. SUMMARY

The time-series photometric and spectroscopic data presented here clearly demonstrate that KUV 05134 + 2605 is a pulsating star similar to the prototype DBV, GD 358. There are now seven known variable white dwarfs of this type. They all appear to lie within the instability strip for hot helium-rich white dwarfs suggested by the temperature range of Liebert *et al.* (1986).

This star displays a complex frequency spectrum like the majority of the variable DB stars. It is likely that a fully resolved power spectrum for KUV 05134 + 2605 may be obtained only by combining data from sites of different longitudes. Such 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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