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Radial velocity study of the pulsating subdwarf B star and possible Type Ia supernova progenitor KPD 1930+2752

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ABSTRACT

We report the results of a high-time-resolution radial velocity study of the subdwarf B star and possible Type Ia supernova progenitor KPD 1930+2752. There were no significant peaks in the power spectrum of the velocity curve above our detection limit, about 4 km s^{-1}, at the frequencies where peaks due to pulsation were present in the photometric data of previous researchers. We report an orbital velocity amplitude, 348.5 ± 1 km s^{-1}, in agreement with that reported by previous investigators. We find an orbital period of $P = 0.09509308 \pm 0.00000015$ d based on our data and the ephemeris of Maxted et al. (2000).

Key words: stars: individual: KPD 1930+2752, subdwarfs, binaries: spectroscopic, stars: variables: other

1 INTRODUCTION

Subdwarf B (sdB) stars are a class of evolved hot stars with physical properties that place them between the main sequence and the white dwarf track in a colour-magnitude diagram. Since the discovery that the sdB star EC 14026−2647 pulsates (Kilkenny et al. 1997), the number of known pulsating sdB stars (EC 14026 or sdBV stars) with published data has increased to 19 (O'Donoghue et al. 1999; Piccioni et al. 2000; Billères et al. 2000; Silvotti et al. 2000; Østensen et al. 2001).

KPD 1930+2752 is a subdwarf B star (Downes 1986). It was identified as a pulsating sdB (EC 14026 or sdBV) star which varies at multiple frequencies by Billères et al. (2000). They also found that the largest amplitude photometric frequency is best explained as ellipsoidal variations caused by a close binary orbit ($P = 8217.8$ s). This was confirmed by Maxted et al. (2000), who found a spectroscopic orbit with the same period as the ellipsoidal variation. The large orbital velocity and a typical sdB mass imply a minimum total binary mass of $1.47 \pm 0.01\mathrm{M}_{\odot}$. An orbital inclination smaller than 90° would imply a larger mass. Maxted et al. suggest that the characteristics of the binary make it a good candidate to become a Type Ia supernova. In a recent report, Ergma, Fedorova, & Yungelson (2001) say that their evolution models indicate that the most likely result of the eventual merger will be a high mass white dwarf, but with a mass below the Chandrasekhar mass.

In previous work it has been possible to measure the velocity variations of sdBV stars due to pulsation (Jeffery & Pollacco 2000; O'Toole et al. 2000; Woolf et al. 2002). The measured velocity and brightness variations will be useful in identifying the pulsation modes so that asteroseismology can be used to make accurate determinations of the stellar parameters. The photometric amplitudes of KPD 1930+2752 pulsations are similar to those seen in other sdBV stars for which radial velocity variations were measured, so it seemed likely that similar velocity measurements would be possible for this star.

2 OBSERVATIONS AND REDUCTION

We obtained spectra of KPD 1930+2752 at a high time resolution (12.1-s repetition) using the 4.2-m William Herschel Telescope (WHT) on the nights of 2000 June 20 and 21. We used the blue arm of the ISIS spectrograph with the R1200B grating. The charge-coupled device (CCD) was read out in drift mode (Rutten et al. 1997). Observations were made over a period of 7.2 h starting at HJD = 2451716.43394 and a period of 5.2 h starting at HJD = 2451717.42469, with short breaks for CuAr arc calibration spectra. Spectral resolution was $\lambda/\Delta\lambda = 5000$ and the spectral range was $4020 < \lambda < 4430$Å. The exposure timings come from the clock of the CCD controller, which is synchronized daily with the GPS-calibrated time service of the observatory. The clock normally drifts by up to 1 s during the night.

The data were reduced using scripted standard IRAF routines to make the bias, flat-field, and sky corrections, extract the one dimensional spectra, and to apply the wavelength calibration from CuAr arc spectra.

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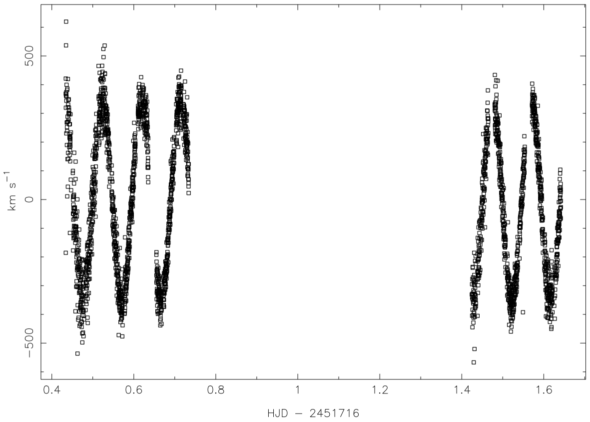

Figure 1. Radial velocities measured for KPD 1930+2752.

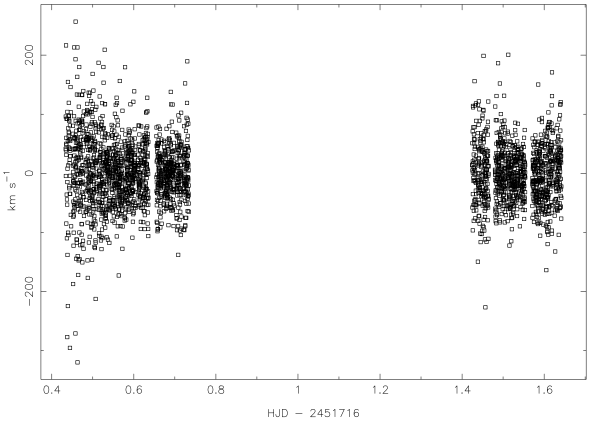

Figure 2. Radial velocities with orbital motion removed.

3 ANALYSIS AND RESULTS

Our first attempt to determine radial velocities from the spectra and search for periods in the velocity variations followed the method outlined by Jeffery & Pollacco (2000) using IDL programs. The large velocity variations due to orbital motion introduced problems with the normally straightforward determination of the velocity shifts from cross-correlation peaks. For the small-amplitude velocity variations present with other sdBV stars we defined a fitting window of about 10 pixels (about 280 km s^{-1}). The velocity variations of KPD 1930+2752 move the cross-correlation peak outside of this window. Simply using a much larger window does not solve the problem because fits to the peak become much less precise when they are affected by points far from the peak centre. We found best results by shifting a 35-pixel window to follow the approximate velocity shifts and ran several iterations until the velocity amplitude found for the orbital motions matched the amplitude introduced in the fitting window. Using this method, we found a projected orbital velocity amplitude of 359 ± 8 km s^{-1}.

Because of worries about the automatic fitting routine, we used the IRAF routine FXCOR to do the cross correlation 'manually'. We applied the velocity corrections found with the automatic routine to the individual spectra and co-added them to use as the cross correlation template. Using FXCOR allowed us to eliminate bad pixels more reliably and discard spectra where the cross correlation function peak looked especially bad. The radial velocities thus found are shown in Fig. 1. A sine wave was fitted to the velocity curve thus produced using the downhill simplex program AMOEBA (Press et al. 1992) to minimize the χ^2 difference. Using this method we found a projected orbital velocity amplitude of 348 ± 1 km s^{-1}. We believe this amplitude is more reliable than the one found using our automatic fitting routine. The velocity curve with the orbital velocity fit subtracted is shown in Fig. 2.

Because of the noise in our data, we cannot improve upon the orbital period determined by Billères et al. (2000) using our data alone. However, by including the T_0 found by Maxted et al. (2000) an improvement in accuracy is possible. We fitted a sine wave to our (FXCOR-derived) data assuming the period from Billères et al. We then determined the period using the phasing we found and $T_0 = 2451651.6466$ from Maxted et al. ($P = \Delta t n^{-1}$ where n is the number of orbits during the time Δt). We then fitted a sine wave to our data assuming the period found in the first iteration. After four iterations the input and output periods matched. We find $P = 0.09509308 \pm 0.00000015$ d with $T_{681} = 2451716.404990$ (zero phase when the binary primary is closest to the observer).

Our orbital period estimate is 1.7 s shorter than that found by Billères et al. (2000), 0.095113 d. The 1.7-s difference translates to a 108 s phasing difference over the 6 d covered by the data of Billères et al. The difference is probably the result of the improved precision possible with the longer time baseline, more than 64 d (>680 orbits), rather than a change in orbital period.

The orbit of the stars should be decaying due to gravitational radiation at a rate predicted by

$$\dot{P} = -\frac{96}{5}\frac{PG^3}{c^5}\frac{M^2\mu}{a^4} = -1.7 \times 10^{-10}\,\frac{\mathrm{d}}{\mathrm{y}}$$

where M is the total mass of the binary, μ is the reduced mass, and a is the separation of the centres of mass of the stars (i.e. the sum of their distances from the centre of mass of the system) (Shapiro & Teukolsky 1983), and we use $M_1 = 0.5M_\odot$, $M_2 = 0.96M_\odot$, and $a = a_1 + a_2 = 6.92 \times 10^5$ km. It should be possible to measure the effect of the period change on cycle timings after a few decades: a 1-minute cycle arrival timing difference due to orbital decay should be present after about 46 y. The period uncertainty will need to be reduced by a factor of 100 for such a measurement to be possible. Other effects, e.g. magnetic fields, will also probably affect the orbit.

The Fourier transform power spectrum of the velocity data with the orbital motion removed (Fig. 2) is shown in Fig. 3. We did not unambiguously detect peaks in the power spectrum above our detection limit, about 4 km s^{-1}, with frequencies at which Billères et al. (2000) reported photometric variations due to stellar pulsation. KPD 1930+2752 is fainter ($B = 13.75$) than the sdBV stars for which high-speed spectroscopy using 4-m telescopes was able to detect velocity variations due to pulsation: PG 1605+072 ($B = 13.01$), KPD 2109+4401 ($B = 13.17$), and PB 8783 ($B = 12.5$) (Woolf et al. 2002; Jeffery & Pollacco 2000). The

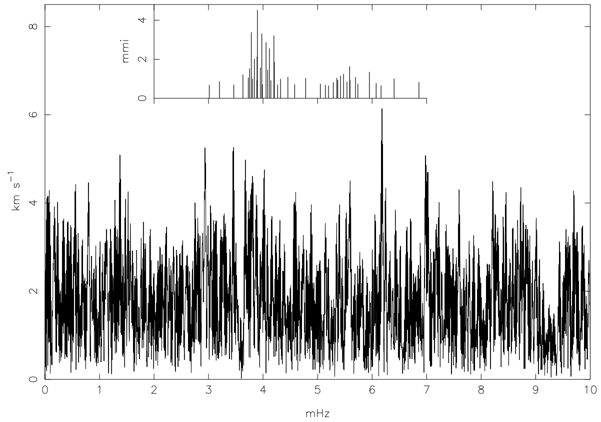

Figure 3. KPD 1930+2752 power spectrum with photometric frequencies and amplitudes from Billères et al. (2000) indicated in the inset.

non-detection is probably due to higher observational noise, not smaller pulsation amplitudes: comparing the photometric amplitudes due to pulsation in KPD 1930+2752 with the photometric and velocity amplitudes of KPD 2109+4401 and PB 8783, stars with comparable T and $\log g$, indicates that we should expect maximum pulsational velocity amplitudes in KPD 1930+2752 between 2 and 3 km s^{-1}. However, since period and amplitude changes are often observed for pulsations of sdBV stars and we do not have simultaneous photometric observations, we cannot rule out the possibility that during our observations the pulsation amplitudes had greatly decreased from those present when earlier photometric measurements were made. Such temporal changes in amplitude have been observed or suspected in sdBV stars on both time scales of days, e.g. Feige 48 (Koen et al. 1998), and timescales of months to years, e.g. PG 1605+072 (Woolf et al. 2002).

The largest photometric amplitude observed for KPD 1930+2752 is caused by ellipsoidal variations due to its close binary orbit. It should be possible to measure gravity and temperature variations through the orbit as well, although the signal to noise ratios of our spectra are not high enough to do so.

4 CONCLUSIONS

The primary reason for this project was to measure the radial velocity variations due to stellar pulsation in the sdBV star KPD 1930+2752. We find that our observations, 2 nights of high time resolution (12.1 s) spectra from the 4.2-m WHT, are insufficient to allow us to resolve the velocity peaks in the power spectrum. Longer, more continuous time coverage or spectra from a larger telescope will be required to resolve the peaks.

The orbital velocity amplitude we determine for KPD 1930+2752, 348 ± 1 km s^{-1}, is in good agreement with that found by Maxted et al. (2000), 349.3 ± 2.7 km s^{-1}. Our orbital period estimate, $P = 0.09509308 \pm 0.00000015$ d, is 1.7 s shorter than that found by Billères et al. (2000), 0.095113 d.

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