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Detection of an increasing orbital period in the subdwarf B eclipsing system NSVS 14256825

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ABSTRACT

New timings of eclipses made in 2010 and 2011 are presented for the hot subdwarf B (sdB) eclipsing binary NSVS 14256825. Composed of an sdB star and a much cooler companion, with a period near 0.1104 days, this system is very similar to the prototype sdB eclipsing binary HW Vir. The new observations show that the binary period of NSVS 14256825 is rapidly increasing at a rate of about 12×10^{-12} days orbit^{-1}.

Key words: binaries: eclipsing – stars: individual: NSVS 14256825.

1 INTRODUCTION

Close binary stars have long been useful for the determination of fundamental stellar parameters such as mass and radius. Double-lined spectroscopic binaries enable the mass ratio of the binary components to be determined, and if the inclination of the binary orbit can be measured or reasonably constrained – as in the case of an eclipsing system – then the absolute masses can be found. In addition, the light curve of an eclipsing system allows relative stellar radii to be found and the absolute radii if the system is a double-lined binary. Detailed fitting of theoretical models to observed binary light curves allows constraints to be put on the stellar temperatures, albedos and limb-darkening coefficients, for example.

Evaluating, or even constraining such parameters is especially important for hot subdwarf stars in binary systems because of the uncertainties in understanding the evolutionary processes which have led to the formation of these extreme horizontal branch stars. In particular, it is not clear how almost all of the hydrogen can be lost from the star at the same time that the helium core starts helium burning at around 0.5 $M_{\odot}$. Many binary subdwarf B (sdB) stars have quite short orbital periods – down to 0.073 days (For et al. 2010) – with the components in such systems being separated by only $\sim$1 $R_{\odot}$. In these cases, the system must have undergone a common envelope phase with the possibility of extensive mass loss from the system or mass transfer between the components (see e.g. Han et al. 2002, 2003). Such systems provide excellent opportunities to study the products of common-envelope evolutionary processes. Additionally, the post-horizontal-branch evolution of sdB stars in binaries is of considerable interest; Maxted, Marsh & North (2000) have shown that KPD 1930+2752 is probably a Type Ia supernova progenitor, and Schenker (2005) has suggested that cataclysmic variables below the period gap might all have arisen from post-sdB binary evolution.

In the past few years, it has become clear that continuous orbital period change is not uncommon in HW Vir type systems – very close binaries which have hot subdwarf primaries and which show eclipses, a substantial reflection effect and have typical parameters $R_1 \sim R_2 \sim 0.2\,R_{\odot}$, stellar separations $\sim$1 $R_{\odot}$ and periods $\sim$0.1 days. The prototype system, HW Vir itself, was first shown by Kilkenny, Harrop-Allin & Marang (1991) to have a decreasing orbital period. Subsequent observations showed the period change to be quite complex, leading to the suggestion that the system could contain a substellar companion (Kilkenny, Marang & Menzies 1994; Kilkenny et al. 2000; Kilkenny, van Wyk & Marang 2003a). Most recently, Lee et al. (2009) have interpreted the (O − C) diagram of HW Vir in terms of a secular quadratic term, ascribed to angular momentum loss from the system, plus two cyclic terms attributed to reflex motions caused by planets with masses around 10–20 times the mass of Jupiter.

The HW Vir system, HS 0705+6700, was discovered to be eclipsing by Drechsel et al. (2001). Qian et al. (2009) have presented evidence for a cyclic term in the (O − C) diagram and have interpreted it as due to a brown dwarf companion with an orbital period of about 7 years.

The exotic system NY Vir (PG 1336−018) is also an HW Vir type close binary, but the sdB primary is a rapid pulsator with many small-amplitude p mode pulsations (Kilkenny et al. 1998, 2003b). Although the pulsations make accurate timing of eclipse minima more difficult, Kilkenny (2011) has very recently shown that this system has a decreasing period (-11.2×10^{-13} days orbit^{-1}) possibly due to a magnetic wind braking mechanism (Lee et al. 2009). Experience with HW Vir itself motivates caution in the early interpretation of results, but Qian et al. (2012) have already claimed a cyclic effect with period $\sim$8 years and an amplitude of only 6 seconds.

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The above examples show that these very close binary systems with very short orbital periods (∼0.1 days) provide potentially valuable probes of different mechanisms. Apart from the relevance of such close binaries to evolutionary processes, the short, well-defined eclipses provide an accurate clock to measure the effects of orbital mechanics – mass loss, for example, and even the possibility of future detection of gravitational radiation (Kilkenny 2011) – and to detect the presence of other bodies in the system – bodies which could be small enough to be brown dwarf stars or even planets. In this paper, we present new eclipse timings of the sdB binary system, NSVS 14256825, which show it to have an increasing orbital period.

2 NSVS 14256825

NSVS 14256825 was detected as a variable in the Northern Sky Variability Survey (NSVS; Wozniak et al. 2004) and discovered to be an eclipsing binary with an sdB primary by Wils, Di Scala & Otero (2007). These authors were able to obtain V, B and I_C light curves including 21 primary eclipses spread over 3 months and used these, combined with 'single data points showing the star in eclipse' from the NSVS and ASAS3 (Pojmanski 2002) surveys to determine an ephemeris:

$$\mathrm{HJD} = 245\,1288.9198(5) + 0.110\,374\,10(2)\,E,$$

where the numbers in parentheses are the errors in the last digit of each element of the ephemeris.

Wils et al. (2007) used the Wilson & Devinney (1971) code to determine photometric parameters for the system. By assuming $T_1 \sim 35\,000$ K and $T_2 \sim 3500$ K, they obtained reasonable fits to the observed light curves, but they were forced to make the albedos of both stars unity to obtain good fits to the secondary eclipses. They also derived parameters $M_1 = 0.46\,\mathrm{M}_{\odot}, M_2 = 0.21\,\mathrm{M}_{\odot}, R_1 = 0.20\,\mathrm{R}_{\odot}, R_2 = 0.16\,\mathrm{R}_{\odot}$ and $\log g_1 = 5.50 \pm 0.02$, which are consonant with an HW Vir type eclipsing system.

Unpublished spectroscopic results yield $T_1 = 35\,250 \pm 250$ K, $\log g_1 = 5.49 \pm 0.07$ and $\log(\mathrm{He/H}) = 2.7 \pm 0.2$ (Østensen, in preparation), in good agreement with the Wils et al. (2007) light curve results. This temperature places it in the regime where p mode pulsations can be found.

Wils et al. (2007) found that their data ruled out any rapid variation as large as 0.01 mag and – whilst most of our data are closely restricted around primary eclipses and unsuitable for a pulsation search – we do have one complete light curve of good quality. Cutting out the eclipses themselves and removing the reflection effect with low-frequency sinusoids, we find no significant rapid variations as large as 0.002 mag; the largest peak we find in the p mode region is about 0.0015 mag and is barely above the general noise level. From such a short set of observations, we cannot rule out longer period, g mode variations, but the high temperature of the primary makes these unlikely.

3 NEW OBSERVATIONS

The observations reported here were almost all made with the University of Cape Town CCD photometer (UCTCCD) on the 1-m telescope at the Sutherland site of the South African Astronomical Observatory, although in one case the STE4 CCD camera was used on the 1.9-m telescope at the same site. The UCTCCD has been described briefly by O'Donoghue, Koen & Kilkenny (1996) and operates in frame-transfer mode, so that there is no time lost between integrations (15 or 20 seconds, in this case) for read-out of the CCD. The STE4 was operated in conventional mode and, even with 2 × 2 pre-binning, has a read-out time of about 20 seconds to add to the integration time.

All the UCTCCD measurements were made in white light – that is, with no filter in the beam – but with the STE4 camera, a Johnson *R* filter was used. (The *R* filter also reduces the magnitude difference between the target and comparison stars.) Colour equations were not employed in the data reduction; each set of flat-fielded observations was corrected only for sky background and mean atmospheric extinction, since the aim of the observations was simply to establish an accurate mid-point of each eclipse.

In the field of the UCTCCD, there are only three stars suitable for differentially correcting the photometry – and these are all fainter than NSVS 14256825 (by perhaps 1–1.5 mag in white light) and consequently tend to introduce noise to the differentially corrected target star data. We have therefore measured the eclipses from uncorrected data on photometric nights but used corrected data when there was any indication of sky transparency variations. In the first case, the aperture photometry (Ap) gives rather better results – in the sense of cleaner light curves – but as soon as any differential correction is applied, the profile-fitted (PF) magnitudes are somewhat better; the difference is not great. Details of the eclipse photometry are listed in Table 1 and a light curve ('typical' in the sense of being typical of the best we have) is illustrated in Fig. 1.

Eclipse minima were measured by the bisected chords method – essentially measuring the mid-points of a number of chords joining eclipse ingress and egress curves and running parallel to the time axis in a magnitude/time plot. These mid-points always lie very close to a line perpendicular to the time axis, indicating eclipse symmetry, and the errors in the eclipse timings in Table 1 indicate the scatter (standard deviation) in these measurements.

4 THE EPHEMERIS

To determine the ephemeris of NSVS 14256825, we have followed the recommendations of Eastman, Siverd & Gaudi (2010) in using Barycentric Julian Date, based on Terrestrial Time (BJD-TT), rather than Heliocentric Julian Date, based on coordinated universal time (HJD-UTC), as the former corrects to the Solar system barycentre and also avoids the unnecessary and undesirable leap seconds.

Table 2 lists the Table 1 SAAO eclipses as well as the Wils et al. (2007) eclipses converted to BJD-TT. The use of BJD-TT rather than HJD-UTC makes no real difference to what follows, because the short time span covered by the observations under consideration entails only one leap-second addition and the barycentric correction – dominated by Jupiter – has an amplitude of about 4 seconds

Table 1. New eclipse timings for NSVS 14256825. Numbers in parentheses are the errors in the last digit of the eclipse timing which is given in BJD-TT). '*t*' is the integration time, which includes read-out time for the STE4 CCD.

Year	Eclipse number	BJD-TT (245 0000 +)	Phot	*t* (seconds)	Mag
2010	10646	5449.25176 (5)	UCT	15	PF
	10647	5449.36215 (2)	UCT	15	PF
	10673	5452.23189 (2)	UCT	15	Ap
2011	13077	5717.57146 (1)	STE4	30	PF
	14062	5826.29008 (2)	UCT	20	PF
	14089	5829.27017 (2)	UCT	20	PF
	14379	5861.27873 (2)	UCT	20	Ap
	14397	5863.26542 (3)	UCT	20	Ap
	14406	5864.25879 (3)	UCT	20	PF

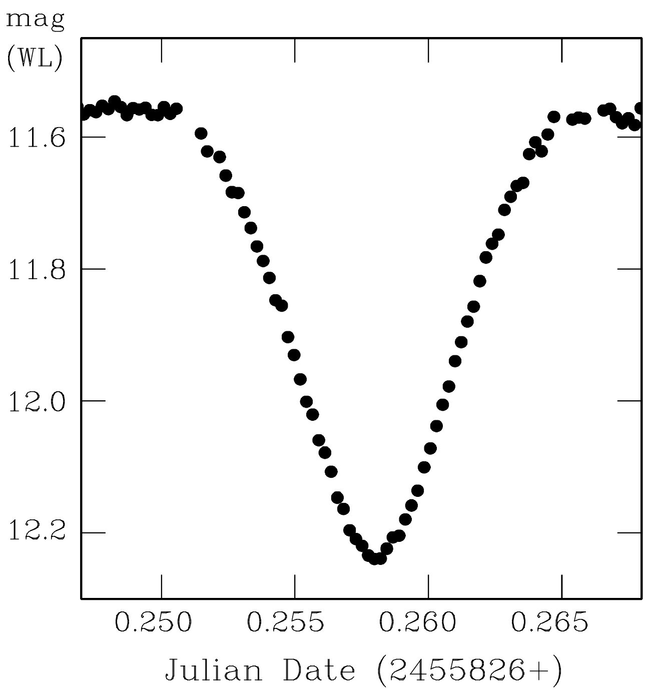

Figure 1. Primary eclipse of NSVS 14256825. The zero-point of the magnitude scale is arbitrary. [The *V* magnitude just outside primary eclipse is about 13.3; Wils et al. (2007).] The abscissa is HJD.

Table 2. Eclipses of NSVS 14256825 in BJD, together with residuals from the linear and quadratic ephemerides.

Eclipse number	BJD-TT (245 0000 +)	Residuals (linear)	Residuals (quadratic)
0	4274.2088	0.000 00	−0.000 03
72	4282.1559	0.000 17	0.000 14
73	4282.2661	−0.000 01	−0.000 03
108	4286.1291	−0.000 10	−0.000 12
172	4293.1932	0.000 05	0.000 04
180	4294.0762	0.000 06	0.000 04
181	4294.1866	0.000 08	0.000 07
190	4295.1799	0.000 02	0.000 00
316	4309.0870	−0.000 02	−0.000 03
317	4309.1973	−0.000 10	−0.000 10
325	4310.0804	0.000 01	0.000 00
362	4314.1642	−0.000 03	−0.000 04
380	4316.1509	−0.000 07	−0.000 07
397	4318.0274	0.000 07	0.000 07
406	4319.0206	−0.000 10	−0.000 09
407	4319.1312	0.000 13	0.000 13
443	4323.1045	−0.000 04	−0.000 04
452	4324.0979	−0.000 01	0.000 00
832	4366.0401	0.000 02	0.000 05
10 646	5449.251 76	−0.000 18	−0.000 02
10 647	5449.362 15	−0.000 17	0.000 00
10 673	5452.231 89	−0.000 15	0.000 01
13 077	5717.571 46	−0.000 02	0.000 00
14 062	5826.290 08	0.000 07	0.000 01
14 089	5829.270 17	0.000 06	0.000 00
14 379	5861.278 73	0.000 12	0.000 03
14 397	5863.265 42	0.000 07	−0.000 02
14 406	5864.258 79	0.000 08	−0.000 02

over ~11 years for a star in the ecliptic. However, using BJD-TT will hopefully ensure homogeneity with future observations (see Eastman et al. 2010, for a full and excellent discussion).

A linear least-squares solution (based on a program by Bevington 1969) for all the Table 2 measurements gives the following:

$$T_0 = 2454\,274.208\,79\ (2)\ \text{days},$$
$$P = 0.110\,374\,144\ (3)\ \text{days},$$

for an ephemeris of the form $T_{\rm min} = T_0 + nP$ and where the numbers in parentheses are the formal least-squares errors in the last digit of each ephemeris element.

The upper panel of Fig. 2 shows the (O − C) diagram for this solution, and it is evident that a linear ephemeris is not sufficient. Note that the scatter in the points at any epoch is compatible with (generally better than) the error values quoted in both Table 1 and by Wils et al. (2007).

A quadratic fit to the eclipse timings using the same eclipse numbers (*n*) as in the linear fit gives the following:

$$T_0 = 2454\,274.208\,82\ (2)\ \text{days},$$
$$P = 0.110\,374\,065\ (15)\ \text{days},$$
$$k_1 = (+5.8 \pm 1.1) \times 10^{-12}\ \text{days},$$

for an ephemeris of the form $T_{\rm min} = T_0 + nP + n^2k_1$. The quadratic term is clearly significant, both in the formal least-squares error and the residuals illustrated in Fig. 2. The k_1 term is equivalent to a period increase of $dP/dn = 11.6 \times 10^{-12}$ days orbit^{-1}.

5 DISCUSSION

We have shown that the eclipsing sdB binary, NSVS 14256825, has an orbital period which is increasing at about $dP/dn = 11.6 \times 10^{-12}$ days orbit^{-1}, based on the currently available data spanning roughly 4 years (2007–11).

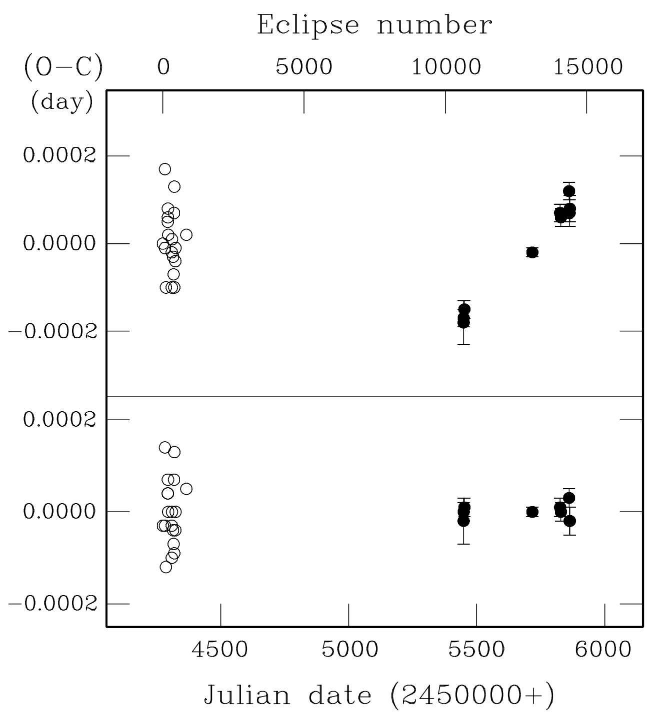

Figure 2. (O − C) diagrams for NSVS 14256825 for linear (upper panel) and quadratic (lower panel) ephemerides. Filled circles are the Table 1 eclipse timings; error bars represent the standard deviations listed in Table 1. Open circles are timings from Wils et al. (2007).

Remarkably, of five well-studied close eclipsing binaries with hot subdwarf primaries, four have variable periods.

(i) The prototype system, HW Vir, studied for over 25 years, shows deviations from a linear ephemeris of the order of 100 seconds (Kilkenny et al. 2003a). These are complex and were interpreted by Lee et al. (2009) as being resolved into a secular term due to angular momentum loss and two cyclic terms attributed to planets orbiting the binary.

(ii) HS 0705+6700 has been shown by Qian et al. (2009) to have a variation from a linear ephemeris of about 90 seconds and a period of around 7 years, attributed by these authors to a brown dwarf tertiary. (We note that the baseline of the observations is not much greater than 7 years, so it would not be surprising to see greater complexity develop – as it did with HW Vir.)

(iii) NY Vir has been recently shown by Kilkenny (2011) to have a decreasing period ($\mathrm{d}P/\mathrm{d}n = -11.2 \times 10^{-13}$ days orbit^{-1}), and Qian et al. (2012) have claimed a cyclic effect with period ∼8 years and an amplitude of 6 seconds. Again, it would be unsurprising to see more complexity in future.

(iv) The current work shows that NSVS 14256825 has an increasing period, but it is too early to see if this is cyclic. We can rule out angular momentum loss via magnetic braking (e.g. Patterson 1984) and conservative mass transfer as these would lead to a period decrease. Non-conservative mass transfer can result in a period increase and a third body in the system or the Applegate (1992) mechanism (gravitational coupling of the orbit to changes in oblateness of a magnetically active star during magnetic cycles) will have cyclic effects which could appear as a period increase at some epochs. Hopefully, time will tell – and perhaps fairly quickly, as the period change rate in NSVS 14256825 is about 10 times larger than that for NY Vir and a few times larger than in HW Vir.

Even from this small sample, it is clear that the HW Vir close binary systems are sources of quantitative information on perhaps several different mechanisms and their rates of operation – light travel time effects in triple systems (or binaries plus brown dwarfs/planets), mass loss and mass exchange and, eventually, the effects of gravitational radiation. It is also clear that interpreting these effects might not be simple and that substantial baselines in time could well be required to get even close to the correct solutions; we are, after all, seeing snapshots over a few decades of processes that can take millions of years. In this context, we note that it is usually assumed that any period changes can conveniently be described by low-order polynomials or sinusoids. However, there is no guarantee that real life will necessarily be so obliging. It is possible, for example, that systematic deterministic processes (such as evolutionary period changes) might show short-term deviations from well-established trends or even that intrinsically random processes could be involved (see the review by Koen 2005). Finally, we note that the best observed close subdwarf binary, AA Dor (sdOB primary; $P \sim 0.25$ days), with a baseline of observation of ∼35 years (Kilkenny 2011), might well be highly unusual in that it shows no detectable period change – as yet.

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