Rotational velocities of the giants in symbiotic stars – I. D′-type symbiotics[★]

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ABSTRACT

We have measured the rotational velocities ($v \sin i$) of the mass donors in a number of D′-type symbiotic stars (SSs), using the cross-correlation function method. Four out of five D′ SSs with known $v \sin i$ appeared to be very fast rotators compared with the catalogues of $v \sin i$ for the corresponding spectral types. At least three of these stars rotate at a substantial fraction ($\gtrsim$0.5) of the critical velocity. This means that at least in D′-type SSs the cool components rotate faster than isolated giants. If these binary stars are synchronized, their orbital periods should be relatively short (4–60 d). We also briefly discuss the possible origin of the rapid rotation and its connection with mass loss and dust formation.

Key words: binaries: symbiotic – stars: late-type – stars: rotation.

1 INTRODUCTION

Symbiotic stars (SSs) – thought to comprise a white dwarf (WD) accreting from a cool giant or Mira – represent the extremum of the interacting binary star classification. They offer a unique and exciting laboratory in which to study such important processes as (i) mass loss from cool giants and the formation of planetary nebulae, (ii) accretion on to compact objects, (iii) photoionization and radiative transfer in gaseous nebulae, and (iv) non-relativistic jets and bipolar outflows (e.g. Kenyon 1986; Corradi, Mikołajewska & Mahoney 2003).

Soker (2002) has shown theoretically that the cool companions in symbiotic systems are likely to rotate much faster than isolated cool giants or those in wide binary systems. However, there are no systematic investigations of $v \sin i$ of the mass donors in SSs.

On the basis of their infrared (IR) properties, SSs have been classified into stellar continuum (S) and dusty (D or D′) types. The D-type systems contain Mira variables as mass donors. The D′ types are characterized by an earlier spectral type (F–K) of the cool component and lower dust temperatures. Among 188 objects in the latest catalogue of SSs (Belczyński et al. 2000), there are only seven that are classified as D′ type: Wray15-157, AS 201, V417 Cen, HD 330036, AS 269, StHα 190 and Hen 3-1591 (although Hen 3-1591 can be classified as S or D′). Three of these have been studied using model atmospheres and all display rapid rotation and s-process elemental overabundances (see Pereira, Smith & Cunha 2005).

Our aims here are as follows: (i) to measure the projected rotational velocities ($v \sin i$) and the rotational periods ($P_{\rm rot}$) of the giants in D′ SSs, using a cross-correlation function (CCF) approach; (ii) to test the theoretical predictions that the mass donors in SSs are faster rotators than the isolated giants or those in wide binary systems; (iii) to provide pointers to the determination of binary periods (assuming corotation). This is the first of a series of papers exploring the rotation velocities of the mass donating (cool) components of SSs.

2 OBSERVATIONS

The observations were performed with FEROS at the 2.2-m telescope [European Southern Observatory (ESO), La Silla]. FEROS is a fibre-fed echelle spectrograph, providing a high resolution of $\lambda/\Delta\lambda = 48\,000$, a wide wavelength coverage from about 4000 to 8000 Å in one exposure and a high overall efficiency (Kaufer et al. 1999). The 39 orders of the echelle spectrum are registered on a 2k × 4k EEV CCD. All spectra were reduced using the dedicated FEROS data reduction software implemented in the ESO-MIDAS system.

3 $v \sin i$ MEASUREMENT TECHNIQUE

Radial velocities and projected rotational velocities have been derived by cross-correlating the observed spectra with a K0-type

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Table 1. Journal of observations and projected rotational velocities of D′-type SSs (note that value for AS 201 is from the literature). The spectral types of the giants are from different papers (see Section 4.1), $(B–V)_0$ is the intrinsic colour for the corresponding spectral type. $v \sin i$ is the rotational velocity measured in this paper. The last column gives other measurements of $v \sin i$ (if available).

Object	Date-obs	MJD	Exp. time	Cool star spectrum	$(B–V)_0$	$v \sin i$ (km s^{-1})	Other (km s^{-1})
HD 330036	2004-05-22	53147.212	2×10 min	F8III	0.90	107.0 ± 10	100 ± 10[a]
Hen 3-1591	2004-07-19	53205.222	2×20 min	K1III	1.09	23.71 ± 1.5	
StHα 190	2004-06-03	53159.397	2×10 min	G4III/IV	0.88	105.0 ± 10	100 ± 10[b]
V417 Cen	2004-04-14	53109.280	2×10 min	G9Ib–II	0.98	75.0 ± 7.5	
AS 201	–	–	–	F9III	0.58	–	25 ± 5[a]

[a]Pereira et al. (2005). [b]Smith et al. (2001).

numerical mask, yielding a CCF whose centre gives the radial velocity and whose width is related to the broadening mechanisms affecting the whole spectra, such as stellar rotation and turbulence. Details of the cross-correlation procedure are given in Melo, Pasquini & De Medeiros (2001).

In order to use the width (σ) of the CCF as an estimate of $v \sin i$, it is necessary to subtract the amount of broadening contributing to σ unrelated to stellar rotation (e.g. convection, instrumental profile, etc.), i.e. σ_0. Melo et al. (2001) calibrated σ_0 as a function of $(B–V)$ for FEROS spectra of stars with $0.6 < (B–V) < 1.2$. The $v \sin i$ measured from our CCFs for a set of standard stars within this $B–V$ range are in good agreement with the literature values. Therefore, for all four giants in Table 1, the Melo et al. (2001) calibration has been adopted.

For $v \sin i$ greater than about 30 km s^{-1}, the shape of the CCF becomes gradually closer to the Gray rotational profile (Gray 1976). Therefore, in order to correctly fit the CCF, a different approach is needed as described in Melo (2003). The CCF is then fitted by a family of functions $CCF_{V \sin i} = C - D[g_0 \otimes G(V \sin i)]$, which is the result of the convolution of the CCF of a non-rotating star g_0. This can be fairly approximated by a Gaussian, and the Gray (Gray 1976) rotational profile computed for several rotational velocities $G(V \sin i)$. For each function $CCF_{V \sin i}$ we found the radial velocity V_r, the depth D and the continuum C for minimizing the quantity $\chi^2_{V \sin i}$ which is the traditional χ^2 function with $\sigma_i = 1$, where σ_i is the measurement error (see fig. 1 of Melo 2003, for an example of the procedure). The CCFs of our objects are plotted in Fig. 1.

For $v \sin i > 30$ km s^{-1} the typical error of our $v \sin i$ measurements is 10 per cent. For $10 < v \sin i \leqslant 30$ km s^{-1} the error is about 1.5 km s^{-1}. Our measurements are given in Table 1.

4 ROTATION OF THE MASS DONORS

4.1 Individual objects

HD 330036. Pereira et al. (2005) obtained $L = 650\ L_\odot$ for the cool component (with possible uncertainties $160 < L < 3000\ L_\odot$), $T_{\rm eff} = 6200 \pm 150$ K, $\log g = 2.4 \pm 0.7$. This implies $R_{\rm g} = 22\ R_\odot$ (using $L = 4\pi\, \sigma_{\rm SB}\, R_{\rm g}^2\, T_{\rm eff}^4$), $M_{\rm g} = 4.46\ M_\odot$ (using $R_{\rm g}$ and $\log g$) and $P_{\rm rot} \lesssim 10.4 \pm 2.4$ d (using $P_{\rm rot}\ v \sin i \leqslant 2\pi R_{\rm g}$).

Hen 3-1591. Medina Tanco & Steiner (1995) give spectral type K1 for the cool component. We assume that it is luminosity class III. The average radius of a K1III star is $23.9 \pm 3\ R_\odot$ and the average $T_{\rm eff} = 4280 \pm 200$ K (van Belle et al. 1999). A K1III star would have a mass of $3.9 \pm 0.3\ M_\odot$ (Allen 1973). The uncertainties correspond to ±0.5 spectral types. This will result in $L = 172\ L_\odot$ (±20 per cent) and $P_{\rm rot} \lesssim 51.0 \pm 11.3$ d.

StHα 190. The cool component is of type G4 III/IV with $T_{\rm eff} = 5300 \pm 150$ K, $\log g = 3.0 \pm 0.5$ and $L = 45\ L_\odot$ (Smith, Pereira & Cunha 2001). This implies $R_{\rm g} = 7.9 \pm 0.4\ R_\odot$ and $P_{\rm rot} \lesssim 3.8 \pm 1.2$ d (upper limit calculated for $R_{\rm g} = 8.3\ R_\odot$ and $\sin i = 1.0$). The upper limit for $P_{\rm rot}$ is considerably shorter than the supposed orbital periods of 171 d (Munari et al. 2001) or 38 d (Smith et al. 2001).

V417 Cen. Van Winckel et al. (1994) detected a photometric period of 245 d. For the cool component they obtained G9 Ib–II, $\log L/L_\odot = 3.5$, $T_{\rm eff} = 5000$ K, $\log g = 1.5 \pm 0.5$. This implies $R_{\rm g} = 75\ R_\odot$ and $P_{\rm rot} \lesssim 50.6 \pm 10.2$ d. $P_{\rm rot}$ is considerably shorter than the period obtained from photometry. However, the photometric period is not confirmed with radial velocity measurements and we do not know whether this is the orbital period.

AS 201. Following Pereira et al. (2005), the cool component is of type F9III with $T_{\rm eff} = 6000 \pm 100$ K, $L = 700\ L_\odot$ (with possible uncertainties $300 < L < 1200\ L_\odot$) and $\log g = 2.3 \pm 0.3$. This implies $R_{\rm g} = 24.5\ R_\odot$ and $P_{\rm rot} \lesssim 49.5 \pm 11.0$ d.

4.2 Projected rotational velocities $v \sin i$: comparison with catalogues

There are no systematic investigations of the rotation of the mass donors in SSs. The rotational velocities of 13 S-type systems listed in Fekel, Hinkle & Joyce (2003) are between $v \sin i = 3.6$–10.4 km s^{-1}. All D′-type systems so far observed (see Table 2) rotate with $v \sin i > 20$ km s^{-1}.

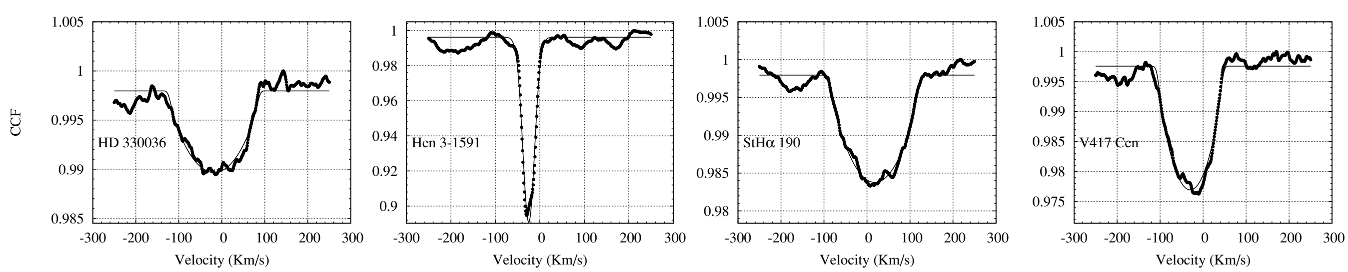

Figure 1. CCF relative intensity (heavy line) and the fit versus radial velocity for SSs observed in this paper.

Table 2. Parameters of D′-type SSs. IR types are from the catalogue of Belczyński et al. (2000), $v \sin i$ is the rotational velocity of the mass donors (as adopted here), and R_g and M_g are the radius and the mass of the giant, respectively (see Section 4.1). τ_{syn} is the synchronization time of the binary adopting $P_{orb} = P_{rot}$, τ_{syn} (100) is the synchronization time of the binary adopting $P_{orb} = 100$ d, v_{crit} is the critical rotational velocity of the giant, P_{rot} is the rotational period of the giant, and a is the semimajor axis of the system calculated supposing synchronized rotation ($P_{orb} = P_{rot}$). The values in brackets for P_{rot} and a are the upper limits, supposing 10 per cent uncertainty in $v \sin i$ and R_g.

Object	IR type	Cool star spectrum	$v \sin i$ (km s^{-1})	v_{crit} (km s^{-1})	R_g (R$_\odot$)	M_g (M$_\odot$)	τ_{syn} (yr)	τ_{syn} (100) (yr)	P_{rot} (d)	a (R$_\odot$)
HD 330036	D′	F8III	107.0	160	22.1	4.46	25	2.1×10^5	<10.4 (12.8)	35(40)
Hen 3-1591	S, D′	K1III	23.7	144	23.9	3.9	8680	1.3×10^5	<51.0 (62.3)	98(112)
StHα 190	D′	G4III/IV	105.0	191	7.88	2.25	27	1.3×10^7	<3.78 (4.64)	15(17)
V417 Cen	D′	G9Ib–II	75.0	105	75.0	6.45	36	553	<50.6 (61.8)	112(128)
AS 201	D′	F9III	25.0	150	24.5	4.35	6423	1.1×10^5	<49.5 (60.5)	99(113)

The catalogue of de Medeiros et al. (2002) of $v \sin i$ of Ib supergiant stars contains 16 objects from spectral type G8–K0 Ib–II. These all have $v \sin i$ in the range 1–20 km s^{-1}. This means that V417 Cen is an extreme case of very fast rotation for this spectral class.

The catalogue of rotational velocities for evolved stars (de Medeiros & Mayor 1999) lists ~100 K1III stars, and 90 per cent of them rotate with $v \sin i < 8$ km s^{-1}. There are only five with $v \sin i > 20$ km s^{-1}. This means that Hen 3-1591 is a very fast rotator (in the top 5 per cent). The same catalogue contains five objects from spectral type F8III–F9III. They rotate with $v \sin i$ of 10–35 km s^{-1}. AS 201 is well within this range. However, HD 330036 is an extremely fast rotator. The same catalogue lists 60 objects from spectral type G3, G4, G5 III–IV. They all rotate with $v \sin i < 24$ km s^{-1}. Again, this means that StHα 190 is an extremely fast rotator.

Thus, overall, four out of five D′-type SSs in our survey are very fast rotators.

4.3 Critical speed of rotation

There is a natural upper limit for rotation speeds, where the centripetal acceleration balances that due to gravitational attraction, often called the 'critical speed', where $v_{crit} = \sqrt{GM/1.5R} = 357\sqrt{M/R}$km s^{-1} (the factor of 1.5 appears from the assumption that at critical rotation speeds the equatorial radius is 1.5 times the polar radius, R). The calculated v_{crit} is included in Table 2. No star can rotate faster than its critical speed; however, we can see that at least three D′-type SSs are rotating at a substantial fraction of their critical speeds: $(v \sin i)/(v_{crit}) \sim 0.67$ (HD 330036), ~0.54 (StHα 190), ~0.71 (V417 Cen). It is probable that for these three SSs the orbital inclination is high $i \geqslant 50°$. For the remaining two objects we cannot exclude the possibility that they also rotate very fast but are observed at low inclination ($i \lesssim 30°$).

5 SYNCHRONIZATION AND BINARY PERIODS

5.1 Synchronization in symbiotic stars

The physics of tidal synchronization for stars with convective envelopes has been analysed several times (e.g. Zahn 1977, and also the discussion in chapter 8 of Tassoul 2000). There are some differences in the analysis of different authors, leading to varying synchronization time-scales. Here, we use the estimate from Zahn (1977, 1989). The synchronization time-scale in terms of the period is

$$\tau_{syn} \approx 800 \left(\frac{M_g R_g}{L_g}\right)^{1/3} \frac{M_g^2[(M_g/M_{WD}) + 1]^2}{R_g^6} P_{orb}^4 \text{ yr}, \qquad (1)$$

where M_g and M_{WD} are the masses of the giant and WD, respectively, and R_g and L_g are the radius and luminosity of the giant (all in solar units). The orbital period P is measured in days.

The S-type SSs are very likely synchronized (Schmutz et al. 1994; Schild et al. 2001). Another proof of this supposition is that most of the SSs with derived orbital parameters (see Mikołajewska 2003) have orbital eccentricity $e \approx 0$. Because the circularization time of the orbits is ~10 times longer than the synchronization time (Schmutz et al. 1994, and references therein), if the orbit of an SS is circularized, it will very likely be synchronized too.

A typical D′-type SS would have $R_g \sim 20$ R$_\odot$, $L_g \sim 500$ L$_\odot$, $M_g \sim 3$ M$_\odot$, and WD mass $M_{WD} \sim 1$ M$_\odot$. For a period of 100 d for a typical D′-type SS, we find $\tau_{syn} \sim 9 \times 10^4$ yr.

For the individual systems, we calculated the synchronization time (τ_{syn}) for two cases: τ_{syn} is derived assuming $P_{orb} = P_{rot}$, and τ_{syn} (100) assuming $P_{orb} = 100$ d. These are given in Table 2. Depending on the individual parameters, the synchronization time can be from <100 yr up to > 10^7 yr. This means that it is possible for a D′-type SS to be synchronized if the orbital period is short ($P_{orb} \approx P_{rot}$).

5.2 Evolutionary status of the mass donors

The masses of the mass donors in S-type SSs with known parameters are in the range 0.6–3.2 M$_\odot$ (Mikołajewska 2003). The calculated masses of the mass donors in D′-type SSs are larger. As can be seen in Table 2, they range from 2.2 up to 6.5 M$_\odot$.

Masses of 8 M$_\odot$ are generally considered the upper limit for evolution to planetary nebula nuclei and WDs, after heavy mass loss, especially during their asymptotic giant branch (AGB) phases. Following our calculations for the mass of the giants (Table 2) and assuming $M_{WD} \leqslant 1.4$ M$_\odot$, the total mass of the binary is about $(M_g + M_{WD}) \sim 3.5$–8.0 M$_\odot$, in agreement with the above upper limit of 8 M$_\odot$ for the WD progenitor.

The position of the mass donors on the Hertzsprung–Russell (H–R) diagram is presented in Fig. 2, assuming near solar chemical composition and stellar parameters as given in Section 4.1 (see also Pereira et al. 2005). The evolutionary tracks of Schaller et al. (1992) have been used. The donors appeared in a wide mass interval, from 2.5 to 7 M$_\odot$. The derived evolutionary masses are in good agreement with those obtained from R_g and log g. Three of these appeared to be crossing the Hertzsprung gap (HD 330036, V417 Cen and AS 201), StHα 190 is situated near the base of the red giant branch, and He 3-1591 is already evolving on the red giant branch.

The relevant time for a 5-M$_\odot$ star to cross the Hertzsprung gap is $\approx 8 \times 10^5$ yr and its lifetime on the red giant branch is $\approx 5 \times 10^5$ yr

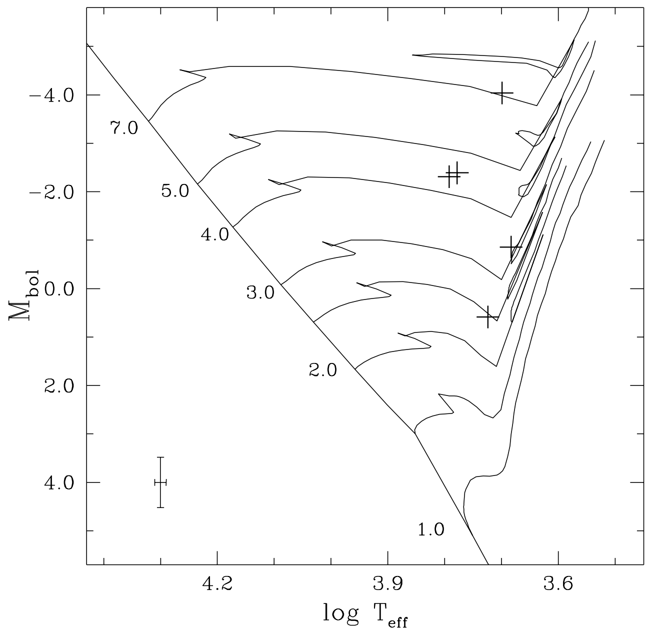

Figure 2. The position of the mass donors on the H–R diagram (see Section 5.2). From top to bottom, the objects are V417 Cen, AS 201, HD 330036, Hen 3-1591 and StHα 190. The typical error is plotted in the bottom-left corner.

(Iben 1991). For a 1.5-M$_\odot$, star, these times are 1.5×10^8 yr and 1.57×10^8 yr (Iben 1991). These lifetimes are longer than the calculated $\tau_{\rm syn}$ and comparable with $\tau_{\rm syn}$ (100). This means that the rotation of the mass donors in D′-type SSs could be synchronized for these lifetimes.

5.3 Clues regarding the orbital periods

Because the orbital periods of the majority of SSs are unknown, an indirect method to obtain $P_{\rm orb}$ is to measure $v \sin i$. If the mass donors in SSs are corotating ($P_{\rm rot} = P_{\rm orb}$), we can find clues for the orbital periods via the simple relation $P_{\rm orb}\, v_{\rm rot} = 2\pi R_{\rm g}$, where $P_{\rm orb}$ is the orbital period, and $v_{\rm rot}$ and $R_{\rm g}$ are the rotational velocity and radius of the giant, respectively. This is very useful in the case of eclipsing binaries, where $\sin i \approx 1$ and $v \sin i \approx v_{\rm rot}$. If the inclination is unknown, we can only obtain an upper limit for $P_{\rm orb}$.

Using Kepler's third law $[4\pi a^3 = G(M_{\rm g} + M_{\rm WD})P^2]$, we can calculate the semimajor axis of the systems. These are given in Table 2. The values in the brackets (for $P_{\rm rot}$ and a) correspond to the estimation of the upper limit of these parameters, assuming 10 per cent errors in $v \sin i$ and $R_{\rm g}$.

Up to now, from 188 SSs, the orbital elements and binary periods are well known for ∼40 objects only (and they are all S-type). The orbital periods are in the range 200–2000 d (Mikołajewska 2003). As can be seen in Table 2, if D′-type SSs are synchronized, their orbital periods would be relatively short (4–60 d) and the distance between the WD and the mass donor would be 2–5$R_{\rm g}$.

6 DISCUSSION

The observation of fast rotation of D′-type SSs raises two further questions. First, what is the evolutionary history of these stars which has produced such high rotation? Secondly, what does the effect of high rotation have on their mass loss and subsequent dust formation?

We see three possible reasons for the fast rotation of mass donors in D′-type SSs.

(i) The rotation is synchronized with the binary period ($P_{\rm rot} = P_{\rm orb}$). In this case, their orbital periods should be short $\lesssim$50 d.

However, it could also be that they are not synchronously rotating. There is the possibility that $P_{\rm rot} > P_{\rm orb}$ has to be excluded because the orbital separations would be unreasonably small, and the synchronization time would be extremely short (they will be synchronized in 30–9000 yr; see $\tau_{\rm syn}$ in Table 2). If $P_{\rm rot} < P_{\rm orb}$, the reasons for their fast rotation could be the following.

(ii) The current giants have been spun up from the transfer of angular momentum. Jeffries & Stevens (1996) proposed a mechanism in which the accretion of a slow massive wind from the AGB progenitor of the current WD can transfer sufficient angular momentum. This also explains the chemical enrichment in s-process elements in D′-type SSs that were present in the AGB wind (see also Pereira et al. 2005). Mass transfer via L_1, when the current WD was the mass donor, can also spin up the companion, as in millisecond radio pulsars (van den Heuvel 1984).

(iii) Planet swallowing to spin up the giant. A rough estimation gives angular momentum transfer during a collision of a planet with mass $m_{\rm p}$ and velocity $v_{\rm p}$ to a giant of mass $M_{\rm g}$, of the order of $\Delta\, \Gamma = m_{\rm p}\, v_{\rm p}\, R_{\rm g}$. This causes a change in the giant's rotational velocity $\Delta v_{\rm g}^{\rm rot} = m_{\rm p}\, v_{\rm p}/{\rm const.}\, M_{\rm g}$, where const. $= J_{\rm g}/M_{\rm g}\, R_{\rm g}^2$ depends on the internal structure of the giant (const. = 0.4 for a solid uniform density sphere, and less for a star-like centrally condensed sphere). Assuming a centrally condensed star (giant) such that const. $=$ 0.01, $v_{\rm p} = \sqrt{GM_{\rm g}/R} \sim$ 10–100 km s^{-1}, $M_g = $ 2–10$M_\odot$ and $m_{\rm p} = 0.01$ M$_\odot$ we estimate $\Delta v_{\rm g}^{\rm rot} \sim$ 1–50 km s^{-1}, showing that, in the right circumstances, the planet could spin up the giant to the rotational velocities observed in D′-type SSs.

Fast rotation (i.e. $v_{\rm rot} \geqslant 0.5\, v_{\rm crit}$) may change a spherical star with a spherical wind into an equatorially flattened system, with both the radius of the star and stellar wind parameters depending on the stellar latitude. Such stars will have an equatorial radius significantly larger than the polar one, and equatorially enhanced mass loss (see Lamers 2004 and references therein).

Because it seems that the majority of the giants in D′-type SSs are rapid rotators (Section 4.3), we expect that (i) they have a larger mass-loss rate than the slower rotating giants, (ii) their mass loss is enhanced in the equatorial regions, and (iii) they could be even equatorially flattened.

It is possible that the dusty environment in D′-type SSs is connected with rapid rotation of the mass donors. Intense mass loss in the equatorial regions can lead to the formation of an excretion disc in which the higher gas density enhances dust formation and growth. The broad IR excess in D′-type SSs can then be a result of the temperature gradient in the dust from such an excretion disc (Van Winckel et al. 1994). Other possible explanations for the presence of dust can be that it is left over from the formation of a planetary system, or it is a relic from a strong dusty mass loss when the present-day WD was on the AGB. However, we consider it is more likely that it originates in the current outflow and that this is enhanced in the equatorial regions by rapid rotation.

7 CONCLUSIONS

Our main results are as follows.

(i) We have measured the rotational velocities of the mass donors in D′-type SSs, using the CCF approach.

(ii) Four of the five objects appeared to be very fast rotators compared with the catalogues of $v \sin i$ for the corresponding spectral types. At least three of them rotate at a substantial fraction ($\gtrsim$0.5) of the critical velocity. This means that at least in D′-type SSs, the cool components rotate faster than isolated giants (as predicted by Soker 2002).

(iii) If they are tidally locked, the orbital periods should be as short as $\lesssim$10–50 d.

(iv) As a result of the rapid rotation, they must have larger mass-loss rates than the more slowly rotating giants, and their mass loss is probably enhanced in the equatorial regions.

To understand these objects better, we need their binary periods to be derived from radial velocity measurements and the inclination determined. In subsequent papers, we plan to explore the projected rotational velocity of the cool giants in other types of SSs and to compare their rotational velocities with that of the isolated giants with similar mass and evolutionary stage.

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REFERENCES

Allen C. W., 1973, Astrophysical Quantities, 3rd edn. Athlone Press, London
Belczyński K., Mikołajewska J., Munari U., Ivison R. J., Friedjung M., 2000, A&AS, 146, 407
Corradi R. L. M., Mikołajewska J., Mahoney T. J., eds, 2003, ASP Conf. Ser. Vol. 303, Symbiotic Stars Probing Stellar Evolution. Astron. Soc. Pac., San Francisco
de Medeiros J. R., Mayor M., 1999, A&AS, 139, 433
de Medeiros J. R., Udry S., Burki G., Mayor M., 2002, A&A, 395, 97
Fekel F. C., Hinkle K. H., Joyce R. R., 2003, in Corradi R. L. M., Mikołajewska J., Mahoney T. J., eds, ASP Conf. Ser. Vol. 303, Symbiotic Stars Probing Stellar Evolution. Astron. Soc. Pac., San Francisco, p. 113
Gray D. F., 1976, The Observation and Analysis of Stellar Photospheres, Wiley-Interscience, New York, p. 484
Iben I. J., 1991, ApJS, 76, 55
Jeffries R. D., Stevens I. R., 1996, MNRAS, 279, 180
Kaufer A., Stahl O., Tubbesing S., Norregaard P., Avila G., Francois P., Pasquini L., Pizzella A., 1999, The Messenger, 95, 8
Kenyon S. J., 1986, The Symbiotic Stars. Cambridge Univ. Press, Cambridge, p. 295
Lamers H. J. G. L. M., 2004, in Maeder A., Eenens P., eds, Proc. IAU Symp. 215, Stellar Rotation. Astron. Soc. Pac., San Francisco, p. 479
Medina Tanco G. A., Steiner J. E., 1995, AJ, 109, 1770
Melo C. H. F., 2003, A&A, 410, 269
Melo C. H. F., Pasquini L., De Medeiros J. R., 2001, A&A, 375, 851
Mikołajewska J., 2003, in Corradi R. L. M., Mikołajewska J., Mahoney T. J., eds, ASP Conf. Ser. Vol. 303, Symbiotic Stars Probing Stellar Evolution. Astron. Soc. Pac., San Francisco, p. 9
Munari U. et al., 2001, A&A, 369, L1
Pereira C. B., Smith V. V., Cunha K., 2005, A&A, 429, 993
Schaller G., Schaerer D., Meynet G., Maeder A., 1992, A&AS, 96, 269
Schild H., Dumm T., Mürset U., Nussbaumer H., Schmid H. M., Schmutz W., 2001, A&A, 366, 972
Schmutz W., Schild H., Muerset U., Schmid H. M., 1994, A&A, 288, 819
Smith V. V., Pereira C. B., Cunha K., 2001, ApJ, 556, L55
Soker N., 2002, MNRAS, 337, 1038
Tassoul J., 2000, Stellar Rotation. Cambridge Univ. Press, Cambridge, p. 36
van Belle G. T. et al., 1999, AJ, 117, 521
van den Heuvel E. P. J., 1984, J. Astrophys. Astron., 5, 209
Van Winckel H., Schwarz H. E., Duerbeck H. W., Fuhrmann B., 1994, A&A, 285, 241
Zahn J.-P., 1977, A&A, 57, 383
Zahn J.-P., 1989, A&A, 220, 112