Mon. Not. R. Astron. Soc. **356,** 974–978 (2005) doi:10.1111/j.1365-2966.2004.08513.x

The nearest star of spectral type O3: a component of the multiple system HD 150136

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Accepted 2004 October 14. Received 2004 October 12; in original form 2004 September 6

ABSTRACT

From radial velocities determined in high signal-to-noise digital spectra, we report the discovery that the brightest component of the binary system HD 150136 is of spectral type O3. We also present the first double-lined orbital solution for this binary. Our radial velocities confirm the previously published spectroscopic orbital period of 2.6 d. He II absorptions appear double at quadratures, but single lines of N V and N IV visible in our spectra define a radial velocity orbit of higher semi-amplitude for the primary component than do the He II lines. From our orbital analysis, we obtain minimum masses for the binary components of 27 and 18 $M_{\odot}$. The neutral He absorptions apparently do not follow the orbital motion of any of the binary components, thus they most probably arise in a third star in the system.

Key words: binaries: spectroscopic – stars: individual: HD 150136.

1 INTRODUCTION

HD 150136 [$\alpha(2000) = 16^{\mathrm{h}}\, 41^{\mathrm{m}}\, 24^{\mathrm{s}}$; $\delta(2000) = -48^{\circ}\ 45'\, 47''$; $V = 5.5$], together with its close companion HD 150135, are the brightest stars of the open cluster NGC 6193 in the nucleus of the Ara OB1 association. Their spectra have been classified by Walborn (1972) as O5 III:n(f) and O6.5V((f)), respectively. HD 150136 appears as a double lined binary in the compilation of binary stars of spectral type O (Garmany, Conti & Massey 1980), with a period of 2.7 d and mass ratio of 1.8, but the orbit has not been published yet. Arnal et al. (1988), in their search for short-period binaries in the open cluster NGC 6193, published a single-lined orbit with a period of 2.6 d.

HD 150136 is also the brightest star of a visual multiple system with six components within a radius of about 20 arcsec. The closest component to HD 150136 is a 9-mag star (component B of the system) at 1.6 arcsec (cf. Mason et al. 1998). HD 150135 ($V = 6.7$, component C) is the second brightest star in this group at a separation of 9.6 arcsec from HD 150136.

In this paper, we report the first double-lined orbital solution for HD 150136 based on medium-resolution digital high signal-to-noise ratio (S/N) spectral images. Furthermore, our spectra and radial velocities suggest that the primary star has a very early spectral type O3. At the distance of AraOB1, about 1300 pc (cf. Herbst & Havlen 1977), this star then becomes the nearest star of this early spectral type.

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2 OBSERVATIONS

We have obtained 19 digital spectral images of HD 150136 with the REOSC Cassegrain spectrograph attached to the 2.1-m reflector at the Complejo Astronomico El Leoncito (CASLEO[1]) in San Juan, Argentina. The spectra were observed in 2004 May and June. A TEK 1024 × 1024 pixel CCD was used as detector. The reciprocal dispersion of the spectra is 1.8 Å pixel^{-1}. Exposure times were between 1.5 and 5 min, resulting in spectra of signal-to-noise ratio between 100 and 150. The wavelength range covered in our spectral images is from 3800 to 5500 Å. Comparison lamp spectra of CuAr were observed immediately after or before at the same telescope position as the stellar images. Flat-field and bias frames were also observed each night. One-dimensional spectra were extracted from the two-dimensional spectral images using IRAF routines.

3 RESULTS AND THEIR DISCUSSION

3.1 The spectrum of HD 150136

Along with the characteristics of the previously determined spectral type of O5 III:n(f), i.e. strong absorption lines of H and He II, fainter absorptions of He I, and N III emission at 4634–4640 Å, our spectra of HD 150136 show also absorption lines of N V 4603, 4619 Å and N IV 5203 Å as well as the emission line of N IV 4058 Å. These lines are the distinctive ones observed in earlier O2–3 type spectra (cf. Gamen & Niemela 2002; Walborn et al. 2002). One of our spectra of HD 150136 is illustrated in Fig. 1. The simultaneous presence

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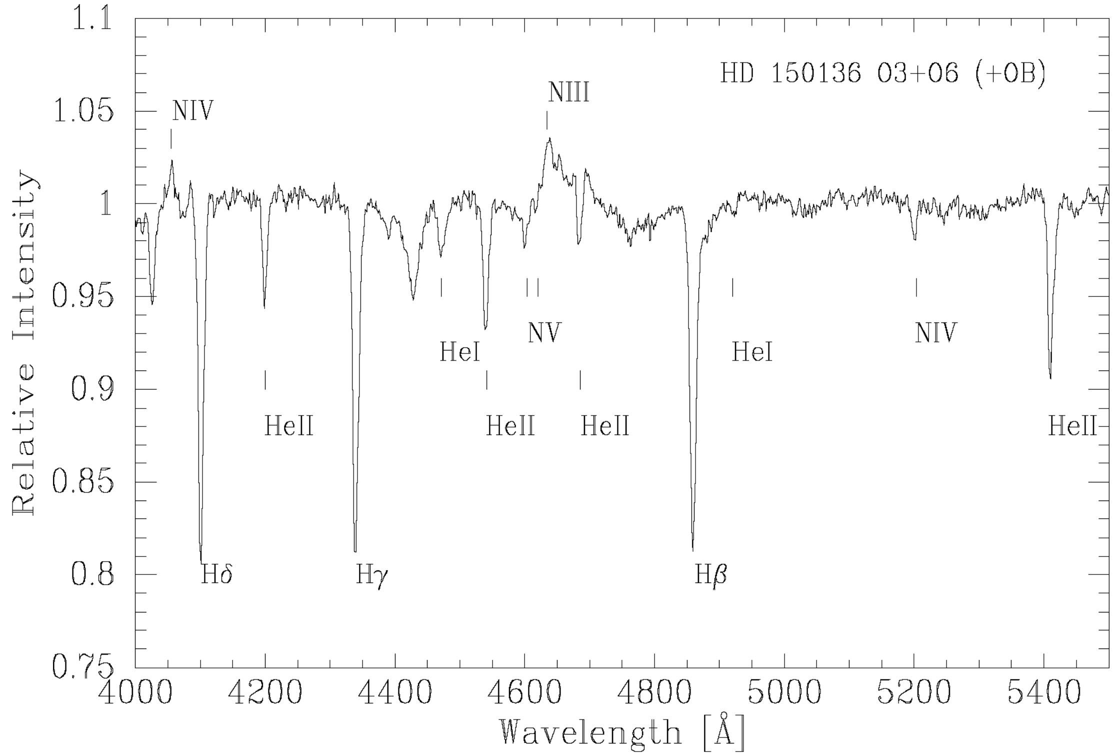

Figure 1. Continuum rectified spectrum of HD 150136 obtained at CASLEO in 2004 May. Absorption lines identified below the continuum are Hδ λ4102, Hγ λ4340, Hβ λ4862, He II $\lambda\lambda$ 4200, 4541, 4686, 5411, He I $\lambda\lambda$4471, 4922, N V $\lambda\lambda$4604, 4620, and N IV λ5203. The emission lines identified above the continuum are N IV λ4058 and N III $\lambda\lambda$4634–4640–4642.

of He I and N V absorptions in the spectrum clearly pointed to a composite spectrum and to the possibility that the brighter binary component is of earlier spectral type than O5. We therefore decided to study the radial velocities of the lines in the spectrum of HD 150136.

3.2 The radial velocity orbit

Radial velocities were determined fitting Gaussian profiles to the spectral lines within the IRAF routine SPLOT. He II absorptions, and to a lesser extent also those of hydrogen Balmer lines, have the appearance of double lines of unequal components in several of our spectra. We did not use the H absorption lines in our radial velocity study. Radial velocities for He II lines were determined using the deblending routine of SPLOT. The absorption lines of N V and N IV, as well as the N IV emission, appear single in all of our spectra, and we used the radial velocities of these lines to determine an approximate orbital period. The journal of our radial velocity observations is presented in Table 1, and spectra corresponding to approximately opposite orbital phases (ϕ = 0.21 and ϕ = 0.71) are depicted in Fig. 2, where the lines of both components can be appreciated.

We introduced the values of N V and N IV radial velocities in the period search routine of Lafler & Kinmann (1965). As can be seen from the values listed in Table 1, the radial velocities from our spectra show large variations from one night to another, but smaller variations between observations obtained during the same night, thus indicating a binary period of a few days. We therefore searched for periods between 1 and 5 d. The best period we found was 2.65 d, almost identical to the values found previously, namely 2.7 d and 2.6 d (cf. Garmany et al. 1980; Arnal et al. 1988).

The value of the period we found was then introduced as an initial value to the routine for defining the orbital elements of the binary.

Table 1. Journal of spectral observations of HD 150136.

HJD	Phase	Heliocentric radial velocity (km s^{-1}) Primary (N V, IV)	Primary (He II)	Secondary
3146.856	0.87	152	71	242
3150.849	0.37	−211	−158	236
3151.769	0.71	216	101	−345
3153.809	0.48	−65	−64	
3154.769	0.84	156	106	−281
3155.761	0.21	−235	−186	316
3156.707	0.57	19	−17	
3169.640	0.43	−133	−109	
3169.804	0.49	−57	−62	
3170.501	0.75	212	101	−358
3170.505	0.75	205	114	−345
3170.548	0.77	181	120	−353
3171.510	0.13	−165	−82	
3171.614	0.17	−176	−156	232
3171.705	0.20	−214	−151	246
3171.850	0.26	−237	−161	324
3171.873	0.27	−215	−144	304
3172.666	0.56	37	5	
3172.824	0.62	143	34	

HJD = Heliocentric Julian Date −2450 000 d.
Phases were calculated according to $T_0 = 2453\,171.2 + 2.662\,E$.

To this end we used an improved version [2] of the program originally published by Bertiau & Grobben (1969). The radial velocity orbit of the primary star was derived using the mean of the radial

[2] Available upon request from ftp://lilen.fcaglp.unlp.edu.ar/pub/fede/gbart-0.1-41.tar.gz

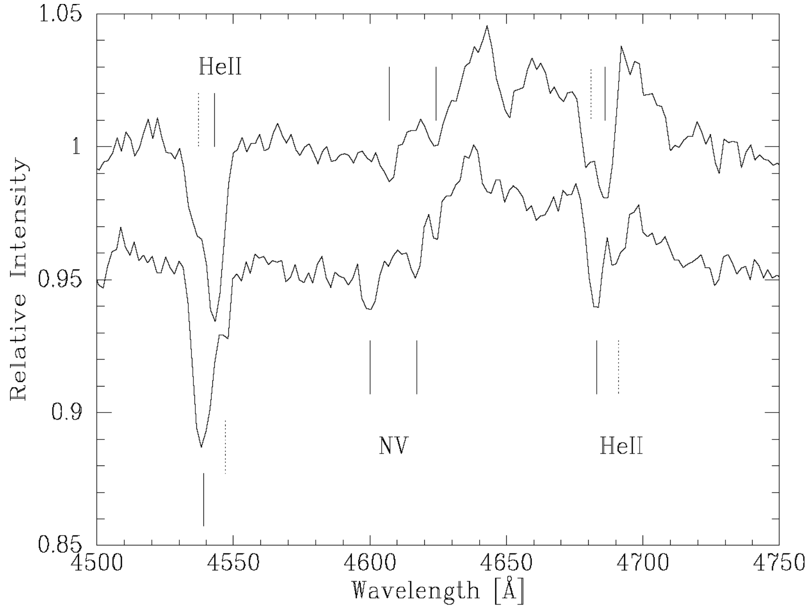

Figure 2. Spectra of HD 150136 during opposite orbital phases ($\phi = 0.21$ and $\phi = 0.71$) are depicted showing the spectral lines of the two components. Lines of the primary are denoted with vertical solid lines and those of the secondary component with dotted lines.

Table 2. Preliminary circular orbital parameters for HD 150136.

	Primary (N V, IV)	Secondary	Primary (He II)
$a \sin i$ [$R_\odot$]	11 ± 2	17 ± 2	
K [km s^{-1}]	217 ± 4	322 ± 5	138 ± 5
V_0[km s^{-1}]	-18 ± 3	-18 ± 4	-30 ± 5
$M \sin^3 i$ [$M_\odot$]	27 ± 2	18 ± 2	
$T_{\rm RVmax}$ [HJD] 2450 000+	3170.5 ± 0.2		
P [days]	2.662 ± 0.002		

velocities of N V 4603, 4619 Å and N IV 5203 Å absorptions and the N IV 4058 Å emission line, since these lines likely originate only in the brighter component. The orbit of the secondary component was determined from the radial velocities of the He II absorptions observed when the components appeared most separated. To a first approximation, the radial velocity orbit appears to be circular, as we obtained an orbital eccentricity of 0.03 ± 0.02. Therefore we have fitted circular orbits to our radial velocity observations. The orbital elements are listed in Table 2. These orbital elements should be considered as preliminary values, because due to the rather limited wavelength resolution of our spectra, the separation of the spectral lines of the secondary component may not be adequate. The upper panel in Fig. 2 illustrates the double-lined radial velocity orbit of HD 150136.

The minimum masses that we find for the binary components are moderately high (cf. Table 2). However, HD 150136 is not known as an eclipsing binary, and from *Hipparcos* photometry Marchenko et al. (1998) find a dispersion of 0.03 mag, with no trace of periodicity. Thus we may expect the orbital inclination to be rather low. An inclination of 50° would result in masses of about 60 $M_\odot$ and 40 $M_\odot$ for the O3 and O6 components, respectively.

The radial velocities of He I absorption lines apparently do not follow the orbital motion of any of the binary components. However, in a few of our spectra, these absorptions show a fainter component to the red when the secondary of the binary system has its maximum positive velocity. We therefore assume that the He I absorptions mainly originate in a third star in the system, and thus HD 150136 is a multiple star similar to Sk-67°18 in the Large Magellanic Cloud (Niemela, Seggewiss & Moffat 2001). This fact is also supported by the lower amplitude of the radial velocity variations of the He II absorptions of the primary component (138 km s^{-1}), as compared with the radial velocity variations of the N V and N IV lines (217 km s^{-1}).

The middle panel and the lower panel in Fig. 3 illustrate the radial velocity variations of the stronger components of He II and of He I absorptions, respectively, phased with the binary period.

A lower amplitude of He II absorption radial velocity variations probably arises because despite the possible line-blending effects, these lines are also blended with those of the third star in the system. As noted by Andersen (1975) for the diffuse He I lines, pair-blending effects are appreciable on lines which show extensive wings, even if their cores appear well defined and resolved. This effect probably also affects the He II absorptions. We have tried to correct for pair-blending of He II absorptions in our spectra of HD 150136 using the multiple profile deblending routines within IRAF, which fit Gaussian, Lorentzian or Voigt line profiles with a linear background. Obviously, to verify the success of this procedure in separating the lines of the secondary component, as well as to ascertain the contribution of the third star to the stronger components of the He II absorptions, an improved orbital solution based on high-resolution observations is needed. However, the high masses of the binary components for an assumed orbital inclination of 50° together with the lack of photometric variations (see above) suggest that our preliminary values of the semi-amplitudes of the radial velocity variations in the HD 150136 binary system may not be very far from the true values, unless the masses of the binary components are much higher than those determined for other stars of similar spectral types (e.g. Massey, Penny & Vucovich 2002).

3.3 The spectral types of the binary components

As noted in Section 3.1, the presence of high-ionization N V and N IV lines in the spectrum of the primary component points to an

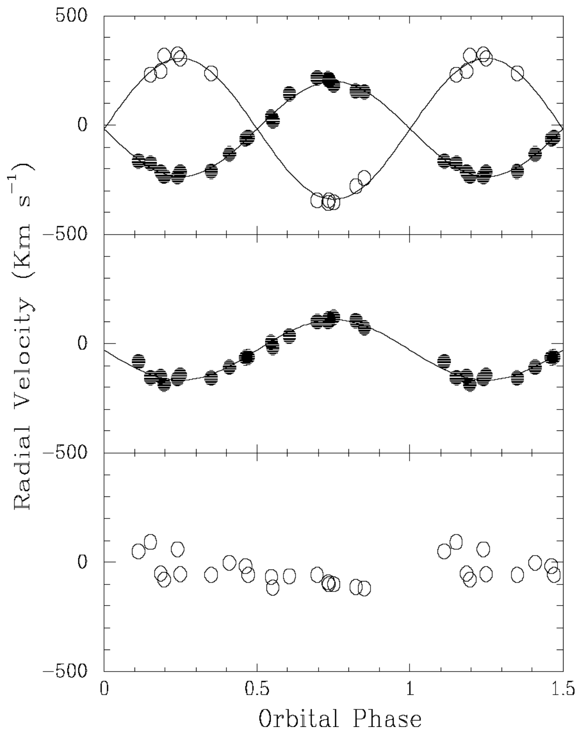

Figure 3. Upper panel: radial velocity variations of the primary component (filled circles) from the N V and N IV lines, and of the secondary component from He II absorptions observed during maximum separation of the lines (open circles) in the HD 150136 binary system, phased with the period of 2.662 d. Continuous curves represent the orbital solutions from Table 2. Middle and lower panels: radial velocity variations of the stronger components of the He II absorptions (filled circles), and of the He I absorptions (open circles) in the spectrum of HD 150136, respectively. All data have been phased with the same ephemeris.

early O2–3 spectral type. The emission and absorption complex of N III and He II at ∼ 4634–4690 Å changes its shape with orbital phase. Emission of He II 4686 Å is apparent when the primary is in front of the system. The spectral classification criteria for O2–4 stars put forward by Walborn et al. (2002) compare the N IV emission at 4058 Å with the N III emission at 4634–4640 Å. In our spectra of HD 150136 this criterion would indicate a spectral type O3.5. The luminosity class is difficult to infer, but assuming that the He II 4686 Å PCyg type profile observed when the primary is in front of the system arises in this component, the primary would appear to be an O3.5 If* type star.

We have estimated the spectral type of the secondary component in the HD 150136 binary system from a comparison of the spectral lines of He I and He II 4471/4541 Å in our spectra when the secondary component has its maximum positive radial velocity. This is illustrated in Fig. 4, where these lines corresponding to the secondary are denoted with dotted vertical lines. In this figure we note that the He II 4541 Å line corresponding to the secondary is somewhat stronger than He I 4471 Å, indicating a spectral type earlier than O7, where the relation of these lines becomes unity. Together with the fact that the He II 4686 Å line, which is a luminosity indicator in O type stars, appears in absorption (cf. Fig. 2), the spectral type of the secondary component appears to be O6 V.

4 SUMMARY AND CONCLUSIONS

From an analysis of recent high signal-to-noise spectra of HD 150136 we find the following.

(i) Radial velocity variations of spectral lines with a period of 2.662 d are present in our spectra of HD 150136, confirming the previously found values of the binary period (Garmany et al. 1980; Arnal et al. 1988).

(ii) Radial velocity variations of the highest ionization lines, namely N V and N IV, define an orbital motion of rather higher amplitude for the primary star than the absorptions of HeII, 217 ± 4 km s^{-1} versus 138 ± 5 km s^{-1}, respectively.

(iii) The radial velocities of the main components of He I absorptions do not follow the orbital motion of any of the binary components. Therefore HD 150136 appears to harbour at least another luminous OB type component, in addition to the 2.6-d binary system.

(iv) The primary component of this binary system is of spectral type O3, noticeably earlier than the spectral classification found in the literature, namely O5 III:n(f), which obviously referred to the

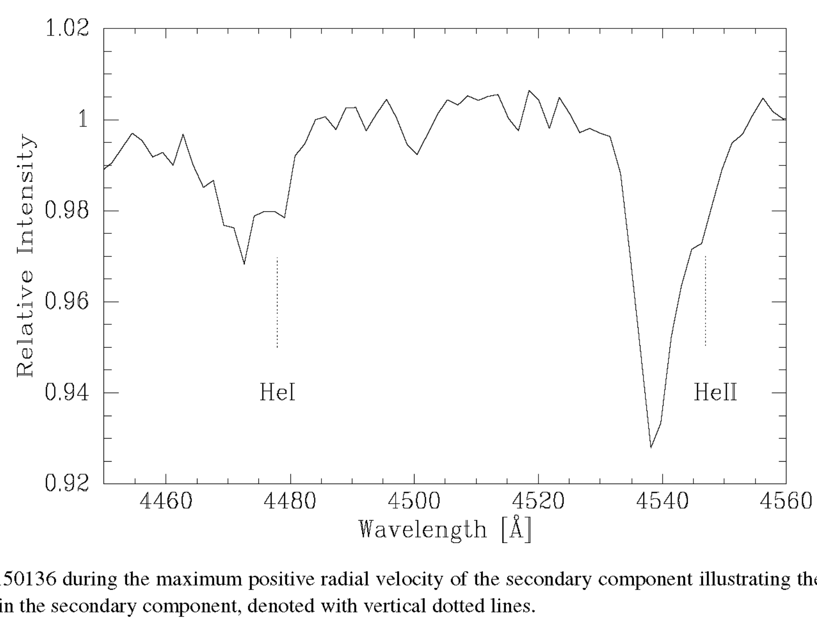

Figure 4. Spectrum of HD 150136 during the maximum positive radial velocity of the secondary component illustrating the relation of absorption lines of He I 4471 Å and He II 4541 Å in the secondary component, denoted with vertical dotted lines.

composite of all three spectra present, at a single phase. We estimate a spectral type for the secondary component as O6 V.

(v) Previously reported small light variations do not show periodicity, thus the orbital inclination is probably low. An inclination of 50° would produce masses of 60 and 40 $M_{\odot}$ for the O3 and O6 components, respectively.

HD 150136 is one more example of the increasing number of O stars discovered to belong to tight multiple star systems, such as, e.g. CPD −59°2636 and CPD −59°2603 in the open cluster Trumpler 16 in the Carina Nebula. The former system consists of an O7 V+O8 V short-period (3.62 d) binary and a fainter O9 V component (Albacete Colombo et al. 2002); and the latter system similarly of a short-period (2.15 d) eclipsing O7 V+O9.5 V binary bound to a B0.2 IV star (Rauw et al. 2001). Another relevant example is HD 167971, a triple system with a short-period (3.32 d) eclipsing binary and a more distant star of spectral type O8 Ib, which is the most luminous component of this triple system (Leitherer et al. 1987).

Close triple stars are also found among the Wolf–Rayet stars, thought to be evolved descendants of O type stars. Notable examples of these are θ Mus (= HD 113904) and HD 5980. θ Mus consists of a WC+(O?) short-period (18 d) binary with a wider component which is a more luminous late O type supergiant (cf. Moffat & Seggewiss 1977). HD 5980 resides in the brightest H II region of the Small Magellanic Cloud, and contains a Luminous Blue Variable (LBV) which erupted in 1994 (Barbá et al. 1995). The system consists of two emission-line stars in an eclipsing binary of short period (19 d) and a line-of-sight O type companion (cf. Niemela, Barbá & Morrell 1999).

Mason et al. (1998), in their astrometric/spectroscopic survey of O stars brighter than $V \sim 8$, find a large fraction of primary components in close visual systems to be short-period spectroscopic binaries. These 'hard' binaries in close triple and multiple systems are clues to our understanding of massive star formation processes, as well as the formation of runaway stars by gravitational encounters.

ACKNOWLEDGMENTS

We thank the director and staff of CASLEO for the use of their facilities. We also acknowledge the use at CASLEO of the CCD and data acquisition system partly financed by US NSF grant AST-90-15827 to R. M. Rich. We are grateful to the referee, Dr Nolan Walborn, for very helpful comments which improved the presentation of this paper. We are indebted to Federico Bareilles for the improved version of the Bertiau & Grobben program. This research has received financial support from IALP, CONICET, Argentina.

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