The Nearest Star of spectral type O3: A Component of the Multiple System HD 150136

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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 days. 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 18M⊙. The neutral He absorptions apparently do not follow the orbital motion of any of the binary components, thus they must probably arise in a third star in the system.

Key words: stars: binaries, spectroscopic— stars: individual (HD 150136)— stars: O–type—

1 INTRODUCTION
HD 150136 (α(2000)=16h41m24s; δ(2000)=−48°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 et al. 1980), with a period of 2.7 days 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 days.

HD 150136 is also the brightest star of a visual multiple system with 6 components within a radius of about 20 arcseconds. The closest component to HD 150136 is a 9th magnitude star (component B of the system) at 1.6 arcseconds (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 arcseconds from HD 150136.

In this paper, we report the first double-lined orbital solution for HD 150136 based on medium resolution digital high 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 1300pc (cf. Herbst & Havlen 1977), this star then becomes the nearest star of this early spectral type.

2 OBSERVATIONS
We have obtained 19 digital spectral images of HD 150136 with the REOSC Cassegrain spectrograph attached to the 2.1m reflector at the Complejo Astronomico El Leoncito (CASLEO1) in San Juan, Argentina. The spectra were observed in May and June 2004. A TEK 1024 × 1024 pixels CCD was used as detector. The reciprocal dispersion of the spectra is 1.8Å / pixel. Exposure times were between 1.5 and 5 minutes, resulting in spectra of signal-to-noise ratio between 100 and 150. The wavelength range covered in our spectral images is from 3800 to 5500Å . Comparison lamp spectra of CuAr were observed immediately after or before at the same telescope position as the stellar images. Flatfield and bias frames were also observed each night. Oneedi-
3 RESULTS AND THEIR DISCUSSION

3.1 The spectrum of HD 150136

Along with the characteristics of the previously determined spectral type of O5III:n(f), i.e. strong absorption lines of H and HeII, fainter absorptions of HeI, and NIII emission at 4634-40\AA\ our spectra of HD 150136 show also absorption lines of N\textsc{v} 4603-19 \AA\ and N\textsc{iv} 5203 \AA\ as well as the emission line of N\textsc{iv} 4058 \AA. These lines are the distinctive ones observed in earlier O2-3 type spectra, (cf. Walborn et al. 2002; Gamen & Niemela 2002). One of our spectra of HD 150136 is illustrated in figure 1. The simultaneous presence of HeI and N\textsc{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. HeII 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 HeII lines were determined using the debending routine of SPLOT. The absorption lines of N\textsc{v} and N\textsc{iv}, as well as the N\textsc{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 (\(\phi=0.21\) and \(\phi=0.71\)) are depicted in Figure 2, where the lines of both components can be appreciated.

We introduced the values of N\textsc{v} and N\textsc{iv} radial velocities in the period search routine of Lafser & Kimmann (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 days. The best period we found was 2.65 days, almost identical to the values found previously, indicating a binary period of a few days. We therefore searched for radial velocities from our spectra show large variations in the period search routine of Lafler & Kinmann (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. 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 velocities of N\textsc{v} 4603-19\AA\ and N\textsc{iv} 5203 \AA\ absorptions and the N\textsc{iv} 4058\AA\ 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 HeII 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 \pm 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 Figure 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 degrees would result in masses of about 60M\odot\ and 40M\odot\ for the O3 and O6 components, respectively.

The radial velocities of HeI 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 HeI absorptions mainly originate in a third star in the system, and thus HD 150136 is a multiple star similar to Sk-67deg18 in the Large Magellanic Cloud (Niemela, Seggewiss & Moffat, 2000). This fact is also supported by the lower amplitude of the radial velocity variations of the HeII absorptions of the primary component (138km s\(^{-1}\)), as compared with the radial velocity variations of N\textsc{v} and N\textsc{iv} lines (217km s\(^{-1}\)).

The middle panel and the lower panel in Figure 3 illustrate the radial velocity variations of the stronger components of HeII and of HeI absorptions, respectively, phased with the binary period.

A lower amplitude of HeII absorption radial velocity variations probably arises because of 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 HeI 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 HeII absorptions. We have tried to correct for pair-blending of HeII absorptions in our spectra of HD 150136.

\(^2\) available upon request from [ftp://llnen.fcaglp.unlp.edu.ar/pub/fede/gbart-0.1-41.tar.gz](ftp://llnen.fcaglp.unlp.edu.ar/pub/fede/gbart-0.1-41.tar.gz)

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Table 2. Preliminary Circular Orbital Parameters for HD 150136.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Primary (N\textsc{v}, N\textsc{iv})</th>
<th>Secondary</th>
<th>Primary (HeII)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a \sin \text{i} [R\odot])</td>
<td>11(\pm)2</td>
<td>17(\pm)2</td>
<td></td>
</tr>
<tr>
<td>(K [\text{km s}^{-1}])</td>
<td>217(\pm4)</td>
<td>322(\pm5)</td>
<td>138(\pm5)</td>
</tr>
<tr>
<td>(V_0 [\text{km s}^{-1}])</td>
<td>-18(\pm3)</td>
<td>-18(\pm4)</td>
<td>-30(\pm5)</td>
</tr>
<tr>
<td>(M \sin^3 \text{i} [M\odot])</td>
<td>27(\pm2)</td>
<td>18(\pm2)</td>
<td></td>
</tr>
<tr>
<td>(T_{RV\max} [\text{HJD}])</td>
<td>2430.000+3170.5(\pm)0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(P [\text{days}])</td>
<td>2.662(\pm)0.002</td>
<td></td>
<td></td>
</tr>
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</table>
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\textsc{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 semiamplitudes 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 et al. 2002).

3.3 The spectral types of the binary components

As noted in section 3.1, the presence of high ionization N\textsc{v} and N\textsc{iv} lines in the spectrum of the primary component points to an early O2-3 spectral type. The emission and absorption complex of N\textsc{iii} and He\textsc{ii} at 4634–4690 Å changes its shape with orbital phase. Emission of He\textsc{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\textsc{iv} emission at 4058 Å with the N\textsc{iii} emission at 4634–40 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\textsc{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 II* 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\textsc{i} and He\textsc{ii} 4471/4541 Å.
Table 1. Journal of spectral observations of HD 150136

<table>
<thead>
<tr>
<th>HJD</th>
<th>Phase</th>
<th>Primary (N v, iv)</th>
<th>Primary (He ii)</th>
<th>Secondary</th>
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</thead>
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<tr>
<td>3146.856</td>
<td>0.87</td>
<td>152</td>
<td>71</td>
<td>242</td>
</tr>
<tr>
<td>3150.849</td>
<td>0.37</td>
<td>-211</td>
<td>-158</td>
<td>236</td>
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<tr>
<td>3151.769</td>
<td>0.71</td>
<td>216</td>
<td>101</td>
<td>-345</td>
</tr>
<tr>
<td>3153.809</td>
<td>0.48</td>
<td>-65</td>
<td>-64</td>
<td></td>
</tr>
<tr>
<td>3154.769</td>
<td>0.84</td>
<td>156</td>
<td>106</td>
<td>-281</td>
</tr>
<tr>
<td>3155.761</td>
<td>0.21</td>
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<tr>
<td>3156.707</td>
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<td>3169.640</td>
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<td>3169.804</td>
<td>0.49</td>
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<td>-62</td>
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<tr>
<td>3170.501</td>
<td>0.75</td>
<td>212</td>
<td>101</td>
<td>-358</td>
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<tr>
<td>3170.505</td>
<td>0.75</td>
<td>205</td>
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<td>3170.548</td>
<td>0.77</td>
<td>181</td>
<td>120</td>
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<tr>
<td>3171.510</td>
<td>0.13</td>
<td>-165</td>
<td>-82</td>
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</tr>
<tr>
<td>3171.614</td>
<td>0.17</td>
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<td>-156</td>
<td>232</td>
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<tr>
<td>3171.705</td>
<td>0.20</td>
<td>-214</td>
<td>-151</td>
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<tr>
<td>3171.850</td>
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<td>-161</td>
<td>324</td>
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<tr>
<td>3171.873</td>
<td>0.27</td>
<td>-215</td>
<td>-144</td>
<td>304</td>
</tr>
<tr>
<td>3172.666</td>
<td>0.56</td>
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<td>5</td>
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</tr>
<tr>
<td>3172.824</td>
<td>0.62</td>
<td>143</td>
<td>34</td>
<td></td>
</tr>
</tbody>
</table>

HJD = Heliocentric Julian Date − 2450000 d
Phases were calculated according to $T_0 = 2453171.2+2.662E$

in our spectra when the secondary component has its maximum positive radial velocity. This is illustrated in Figure 4, where these lines corresponding to the secondary are denoted with dotted vertical lines. In this Figure we note that the He ii 4541Å line corresponding to the secondary is somewhat stronger than He i 4471Å, indicating a spectral type earlier than O7, where the relation of these lines becomes unity. Together with the fact that He ii 4686Å 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 days 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 He ii, 217±4 km s$^{-1}$ vs. 138±5 km s$^{-1}$, respectively.

(iii) The radial velocities of the main components of He ii 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 day 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 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 (3.62d) binary and a fainter O9 V component (Albacete Colombo et al. 2002); and the latter system similarly of a short-period (2.15d) 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 (3.32d) 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. Notorious examples of these are θ Mus (= HD 113904) and HD 5980. θ Mus consists of a WC+(O?) short period (18d) 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 (19d) and a line of sight O type companion (cf. Niemela et al. 1999).
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.

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.

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REFERENCES

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

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 4471Å and He II 4541Å in the secondary component, denoted with vertical dotted lines.