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The massive Wolf-Rayet binary LSS 1964 (= WR 29)

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Abstract. We present a radial velocity study of LSS 1964 (= WR 29) based on digital spectral images obtained with the 2.15-m telescope at CASLEO, San Juan, Argentina, between 1997 and 2000. We find this star to be a double-lined WN + O binary with a period of 3.16415 days. The WN component appears to be more massive than the O type component. N IV absorption at $\sim \lambda$5203 Å is found to belong to the WN7 star.

Key words: stars: binaries: spectroscopic – stars: individual: WR 29 – stars: Wolf-Rayet

1. Introduction

LSS 1964 (Stephenson & Sanduleak, 1971) is one of the nine faint Wolf – Rayet (WR) stars discovered by MacConnell & Sanduleak (1970) (their star # 3) in the Carina region. This star was then included as star #29 in the Sixth Catalogue of Galactic Wolf-Rayet Stars (van der Hucht et al., 1981). WR 29 ($\alpha_{2000} 10h50m46\overset{s}{.}3$; $\delta_{2000} - 60°28'41\overset{''}{.}6$; v=12.65; b-v=0.64) was classified as WN7h+abs by Smith et al. (1996) (hereafter SSM96), which means that also absorption lines of unknown origin are seen in the otherwise emission line spectrum of WN type. These absorption lines could be either intrinsic to the WN star, i.e. blueshifted P Cyg absorptions, or come from an OB companion, or both. SSM96 also found WR 29 to display a diluted He II λ 5411 emission. They attributed this dilution effect (compared to the expected line strength) to the continuum light of a putative OB companion.

Because no further information about the binary status of WR 29 was found in the literature, we included this star in our spectroscopic observing list of candidate WR binary systems. In 1997, March, we obtained several spectra of WR 29 during consecutive nights finding it to be a short period binary (Niemela & Gamen, 1999).

In this paper we present the first orbital analysis of both components of WR 29 based on 54 digital spectra. Preliminary results based on part of this material have been shown by Niemela & Gamen (1999) and Niemela et al. (1999).

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2. Observations

We have obtained blue spectral images of WR 29 with the Cassegrain Boller & Chivens (B&C) and REOSC spectrographs attached to the 2.15-m telescope at Complejo Astronómico El Leoncito (CASLEO)[1] in San Juan, Argentina. A total of 54 spectra were obtained between 1997 and 2000, 28 of these were secured with the B&C spectrograph, in 1997, March, and 1998, February and May. A PM 512×512 pixels CCD, with pixel size of 20μm, was used as detector. The reciprocal dispersion was ~ 2.3 Å pixel^{-1}, and the wavelength region observed was about $\lambda\lambda$ 3900–4900 Å.

Twenty six spectra were obtained with the REOSC spectrograph, in 1999, January, May and December, and 2000, January and April. For the REOSC spectra a TEK 1024×1024 pixels CCD, with pixel size of 24 μm, was used as detector, the reciprocal dispersion was ~ 1.8 Å pixel^{-1}, and the observed wavelength region was $\lambda\lambda$ 3850–5450 Å.

We used a slit width of 2 arcsecs for all our spectra. Typical exposure times for the stellar images were between 30 and 40 minutes, resulting in spectra of signal-to-noise ratio S/N $\sim$ 50–100.

He-Ar (or Cu-Ar with REOSC spectrograph) comparison arc images were observed at the same telescope position as the stellar images inmediately after or before the stellar exposures. Also bias and flat-field frames were obtained each night, as well as flux and radial velocity standard stars.

All spectra were processed with IRAF routines at La Plata Observatory. Radial velocities were determined fitting Gaussian profiles to the spectral lines.

Radial velocities of Ca II K λ 3933 Å interstellar absorption line were also measured in the spectra of WR 29. For this line we find a mean velocity of 32 ± 3 km s^{-1}.

3. Results and their discussion

3.1. The spectrum of WR 29

Interstellar lines are prominent in the spectrum of this reddened WN star, nebular lines of Hβ and [O III] λ5006 and 4964 Å from the foreground Carina giant H II region are also faintly seen in the spectrum.

[1] Operated under agreement between CONICET, SeCyT, and the Universities of La Plata, Córdoba and San Juan, Argentina

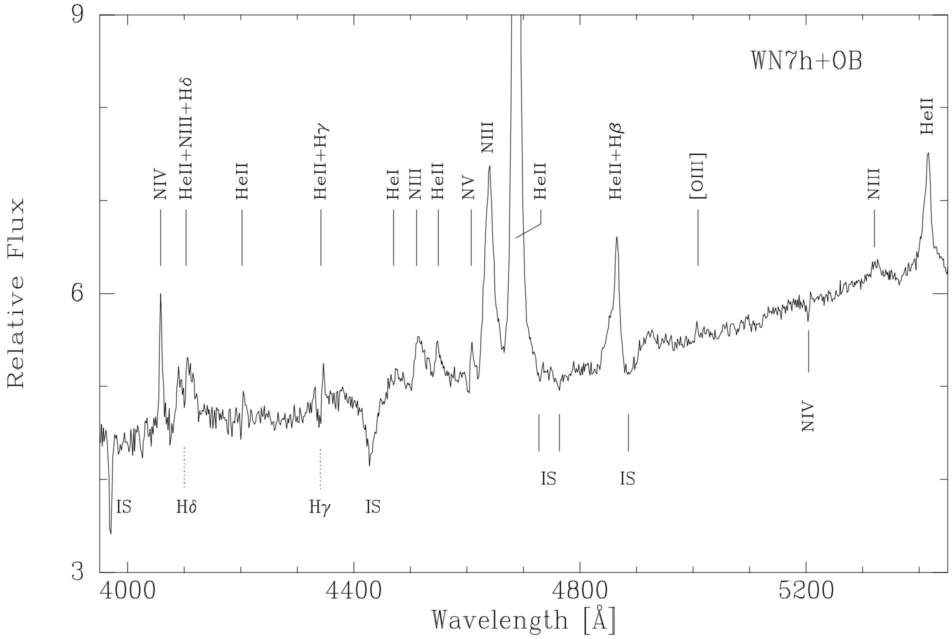

Fig. 1. Flux calibrated (in units of 10E-14 erg cm^{-2} sec^{-1} Å^{-1}) spectrum of WR 29 obtained at CASLEO in 2000, January.

3.1.1. The WN7 component

Our spectra of WR 29 show emission lines of N III, N IV and N V, as well as He II corresponding to a WN7 type spectrum. Faint He I emission is also present. P Cyg type profiles are observed in most lines of He and N V, but they are not apparent in the N IIIλ4634-40, nor in N IVλ4058 emission lines.

In Fig. 1, we show a flux calibrated spectrum of WR 29, where we notice that the overlapping H+He II Balmer and Pickering series emission lines exceed pure He II Pickering emissions only marginally. The spectrum shown in Fig. 1 confirms the classification of the WN type of WR 29 as WN7h. We also note that the determination of H/He ratio in a composite WR+OB spectrum as is WR 29 (see below) is uncertain due to the superimposed absorptions from the companion.

We identify a faint absorption line observed in the spectrum of WR 29 at $\sim$ λ 5203 Å as due to N IV. This line is observed as a faint emission in the spectra of several WN stars in the atlas of WN type spectra (Hamann et al., 1995). However, in the spectra of the Carina OB1 association WN stars, namely WR 22, WR 24 and WR 25 of spectral types WN7ha+O9, WN6ha and WN6ha, respectively (cf. SSM96), the line appears in absorption. This N IV line has also been observed as an absorption in the spectra of two O4f stars, namely HD 14947 (Underhill & Gilroy, 1990) and ζ Puppis (Baschek & Scholz, 1971). As shown below, the N IV absorption in the spectrum of WR 29 follows the same orbital motion as the emission lines, thus it originates in the atmosphere of the WN7 star. We do not observe in our spectra any emission component at $\sim$ λ5203 Å. We have used as rest wavelength of the N IV absorption in our spectra λ=5203.2 Å corresponding to the weighted mean wavelength of the N IV lines observed in laboratory (Striganov & Sventitskii, 1968).

3.1.2. The OB component

Upper Balmer absorption lines could be identified in some spectra, but due to the high reddening of WR 29 they appear noisy, and their origin as coming from the OB component is confused by blending with P Cyg absorptions of the WN emissions. Spectral lines of the OB component are best observed as rather wide Hδ and Hγ absorptions superimposed to the WN emissions. Absorption lines of He, other than the blueshifted P Cyg components in the spectrum of the WN7 star, are faintly detected in our spectra for He II at $\lambda\lambda$ 4200, 4541 and 5411 Å , and marginally for He I at λ 4471 Å. Thus the OB component certainly seems to be an O type star. Our spectra are not suitable for a more accurate classification of the OB component.

On the other hand, if the absolute visual magnitude of the WN7 component in the WR 29 binary system is similar to the WN7 stars in the η Car region, which have $M_v \sim -6.6$ (cf. van der Hucht et al. (1988)), the mere detection of the OB companion in the spectrum implies that it must have a luminosity of an O type star. Moreover, most WR binaries have companions of spectral type O, and WR 29 appears as another WN+O type system.

3.2. The radial velocity orbit

Radial velocities were determined for all observed lines in our spectra of WR 29 fitting Gaussian profiles. Absorption lines and NIV emission appear fairly gaussian in shape. We note that the HeII λ4686 Å emission sometimes appears with a shallow red wing, detected in the spectra with highest S/N. However, fittings of HeII emission with different functions give same results (within errors).

In Table 1 we list the heliocentric radial velocities of the least blended and best defined lines in the WN spectrum, namely N IVλ4058 Å and He IIλ4686 Å emission lines, and the

N V λ4604 Å P Cyg absorption line. The radial velocities of the N IV λ5203 Å absorption, when this line was observed, are also included in this table, although these values have rather large errors ($\sim$ 50 km s^{-1}) because the line appears faint and noisy in our spectra. In the last column of Table 1 we give also the mean of the radial velocities of Hγ and Hδ absorptions of the O type component observed in several spectra during the maximum separation of the spectral lines. The velocities are tabulated according the heliocentric julian dates (HJD) of observations.

As is evident from Table 1, the radial velocities of the emission lines in the spectrum of WR 29 show large variations from one night to the other, while radial velocities obtained during the same night do not show very large differences, implying a binary period of a few days. Two period search algorithms (Marraco & Muzzio, 1980; Cincotta et al., 1995) were applied independently to the radial velocities of each line separately. The results of both algorithms were coincident. We find periods of P=3.16414$\pm$0.00005 days for N IV λ4058 Å, P=3.16416$\pm$0.00004 for He II λ4686 Å, and P=3.1642$\pm$0.0005 days for N V λ4604 Å. As all these periods coincide within the errors, and no alias periods with similar probabilities were found, we have adopted as the most probable value of the orbital period of WR 29 P=3.16415$\pm$0.00005 days. In this period, the orbit of WR 29 appears essentially circular, as expected in a massive short period binary system. Therefore we have determined orbital parameters fitting a circular orbit to the radial velocity data of Table 1. All data were considered of equal weight.

Orbital elements found for different spectral lines are listed in Table 2 with their corresponding standard errors. The radial velocity orbits for different lines are illustrated in Fig. 2 It is evident, from this figure and Table 2, that the radial velocity variations of the emission lines and the P Cyg absorption of N V λ4604 Å as well as the N IV λ5203 Å absorption show an alike orbital motion, corresponding to the WN component of the binary. The amplitude of the orbital motion of the N IV absorption appears somewhat larger than the other lines of the WN spectrum.

The amplitudes of the orbital motion of the emission of N IV λ4058 Å and that of the P Cyg absorption of N V λ4604 Å are similar within the errors. However, the emission of He II λ4686 Å shows an orbital motion of reduced amplitude. This could be explained if this emission line is preferentially formed nearer the center of mass of the system, i.e. in the hemisphere of the WN component facing the O type component.

The mean of the radial velocities of the Hδ and Hγ absorptions observed on top of the respective emissions during quadrature phases exhibit an orbital motion which is antiphased with respect to the orbital motion of the spectral lines of the WN7 star, indicating that these absorptions belong to the O type component of the binary. We also notice, that the amplitude of the radial velocity variations of the O star absorptions appears to be considerably larger than that of the lines corresponding to the WN7 component, implying that the WN7 component is more massive than the O type component of the system. This is also the case for the WN7+O9 binary system WR 22 (=HD 92740) (e.g.

Table 1. Observed heliocentric radial velocities (in km s^{-1}) of WR 29

HJD 2 450 000+	Phase[1]	N IV em. λ_0 4057.76	N IV abs. λ_0 5203.21	N V abs. λ_0 4603.73	He II em. λ_0 4685.68	H abs.[2]
537.63	0.21	227		103	252	-258
538.63	0.53	4		-181	63	
539.71	0.87	-145		-228	-92	
540.53	0.13	160			162	
540.63	0.16	234		-49	202	-400
540.75	0.19	275			238	-328
541.51	0.44	106			114	
541.59	0.46	86		-146	98	
541.68	0.49	42		-219	86	
541.78	0.52	30		-196	71	
542.49	0.75	-204			-114	300
542.59	0.78	-223		-370	-102	238
542.70	0.81	-188		-442	-87	351
542.78	0.84	-152		-200	-69	334
854.65	0.40	67		0	146	
854.75	0.43	139		-58	162	
858.69	0.68	-210		-371	-107	147
858.83	0.72	-206		-335	-67	276
859.63	0.97	-47		-204	-27	
860.59	0.28	224		75	217	-342
860.87	0.37	234		24	206	
861.69	0.62	-163		-285	-61	
862.82	0.98	-18		-178	36	
868.67	0.83	-164		-357	-82	332
868.82	0.88	-107		-272	-33	
963.48	0.79	-225		-387	-89	284
964.46	0.10	161		-54	154	
965.47	0.42	164		-166	161	
1243.76	0.37	207	69	57	200	
1244.69	0.67		-234	-272	-76	275
1246.71	0.30	230	223	134	277	
1303.55	0.27	243	119		259	
1303.64	0.30	228	140	71	242	-330
1304.53	0.58	-95	-81	-274	13	
1304.68	0.63	-198		-389	-68	
1305.52	0.89	-121	-208	-254	-26	
1305.66	0.93	-80	-200	-190	-21	
1546.81	0.15	273	167	10	215	
1547.80	0.46	84	-114	-113	104	
1563.71	0.49	58	-110	-121	121	
1564.83	0.84	-155	-426	-274	-52	185
1566.83	0.47	75	-28	-98	122	
1567.83	0.79	-239	-391	-286	-88	311
1570.75	0.71	-204	-427	-311	-64	380
1571.80	0.04	90	-14	-17	136	
1572.83	0.37	193	72	-1	207	
1573.84	0.69	-210	-326	-380	-45	
1574.82	0.00	41	-30	-85	86	
1575.80	0.31	234	101	87	262	-372
1649.68	0.66	-209	-371	-354	-57	348
1653.56	0.88	-104	192	-361	-22	
1654.58	0.20	282	192	154	273	-184
1655.55	0.51	1	-42	-170	91	
1655.69	0.56	-76		-317	10	

[1] Phases were computed according to T_0 = 2,450,540.13 + 3.16415E
[2] Mean of Hδ and Hγ

Table 2. Circular orbital elements of WR 29

Parameter		N IV 4058 em.	N IV 5203 abs.	N V 4604 P Cyg abs.	He II 4686 em.	< Hδ + Hγ > abs.
V_0	[km s^{-1}]	24 ± 3	-91 ± 10	-145 ± 5	74 ± 2	-26 ± 30
K	[km s^{-1}]	240 ± 3	274 ± 13	229 ± 8	172 ± 3	326 ± 15
T_0	[HJD][1]	0.13 ± 0.03	0.14 ± 0.03	0.10 ± 0.03	0.16 ± 0.03	1.76 ± 0.06
$a \sin i$	[R$_\odot$]	15.0 ± 0.2	17.1 ± 0.8	14.3 ± 0.5	10.8 ± 0.2	20.6 ± 0.9
$\mathcal{M}_{WN}\ sin^3 i$	[$\mathcal{M}_\odot$]	36 ± 4	40 ± 6	34 ± 4	28 ± 3	
$\mathcal{M}_{OB}\ sin^3 i$	[$\mathcal{M}_\odot$]	26 ± 2	33 ± 5	24 ± 3	14 ± 2	
σ	[km s^{-1}]	15	41	33	15	29

[1] Time of conjunction when the WN star is in front of the system: HJD 2,450,540 +.

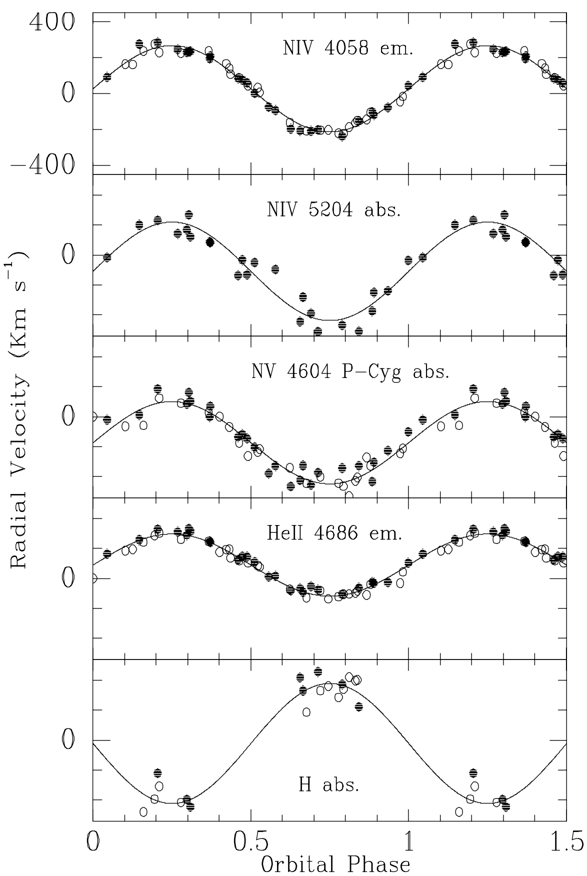

Fig. 2. Radial velocities of N IVλ4058 Å emission, N IVλ5203 Å absorption, N Vλ4604 Å P Cyg absorption, He IIλ4686 Å emission, and mean of Hδ and Hγ absorption lines in the spectrum of WR 29, phased with the period of 3.16415 days. Filled and empty circles represent radial velocities measured in spectra observed with the REOSC and B&C spectrographs, respectively. Continuous curves represent the orbital solutions from Table 2. Phase 0.0 corresponds to the time when the WN7 component is in front of the system.

Schweickhardt et al. (1999)). Indeed, the spectrum of WR 29 closely resembles that of WR 22.

Assuming that the radial velocity variations of N IVλ4058 Å emission represent the true orbital motion of the WN component, and the Hδ and Hγ absorptions that of the O type component, the minimum masses of the WN7 and O type components of WR 29 binary system would be $36M_\odot$ and $26M_\odot$, respectively. These seem to be rather high values, suggesting a high orbital inclination. Therefore light variations could be expected for the WR 29 binary system.

A mass ratio $q = M_{WN}/M_O = 1.4$ for the components of WR 29 is indicated from our orbital analysis. This is fairly lower than the mass ratio found for the WR 22 system by Schweickhardt et al. (1999), namely $q = M_{WN}/M_O = 2.7$, and indicates that the O type component in the WR 29 binary system may be of earlier spectral type than the one in WR 22.

The high mass of the WN7 component in the WR 29 binary system, as well as that of WR 22, implies that these components, which still show some hydrogen at their surface, are probably near the end, but still in the H-burning phase. The recent evolutionary models including rotation (Meynet & Maeder, 2000) indeed predict that stars initially more massive than about $40M_\odot$ and rotating at velocities over ~20% of the break-up velocity, will be overluminous with respect to their masses and have significant surface He- and N- enhancements at "early age". This is also consistent with the finding of WN6-7h/Of type spectra for the most luminous stars in the cores of massive young star clusters, such as e.g. the central cluster of 30 Dor in the Large Magellanic Cloud (Massey & Hunter, 1998), and NGC 3603 in our Galaxy (Drissen et al., 1995). WR 22 is one of the most luminous stars in Carina OB1. Also WR 29 may well be the most luminous star in a yet undetected galactic OB association, which a photometric and spectroscopic study of the surrounding stellar field could unveil.

4. Conclusions

A radial velocity study of the spectral lines of WR 29 shows that it is a WN7+O spectroscopic binary with an orbital period of 3.16415 days. The orbital motion of the O type component appears to be larger than that of the WN7 component of the binary, indicating that WR 29 probably is another massive binary system similar to WR 22, the WN7 component being the more massive one. Also, the minimum masses that we obtain for the binary components of WR 29 are high, $26M_\odot$ and $36M_\odot$ for the O type and WN7 components, respectively. These high values suggest a high orbital inclination, therefore a search for light variations for WR 29 seems indicated.

Higher resolution spectra with better S/N are needed to determine the spectral type and the orbital motion of the O type component in WR 29 binary more accurately.

We have also identified an intrinsic N IV λ5203 Å absorption line in the spectrum of the WN7 component of the binary. This absorption is also observed in the spectra of some Of stars and the WN stars in the great Carina nebula, enhancing the similarity between Of and WN7 type stars (Walborn, 1971).

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