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Constraints on the Binarity of the WN3/O3 Class of Wolf–Rayet Stars

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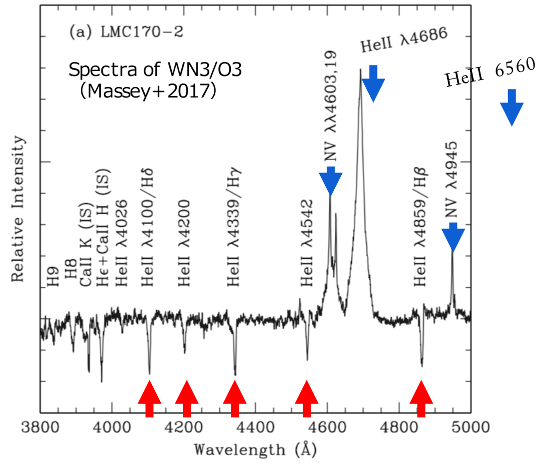
Abstract

- The WN3/O3 Wolf–Rayet (WR) stars were discovered as part of WRs survey in the Magellanic Clouds.
- Their place in the evolution of massive stars remains unclear.
- Although these are not WN3+O3V binaries, they could still harbor unseen companions.

→ multiyear radial velocity study of 6 known WN3/O3s over 3–5 yr period.
→ no evidence of statistically significant radial velocity variations
→ short-lived stage in the evolution of massive stars



emission-line from **WN3** star
(strong Nv, but no Niv)
+
absorption-line from **O3** star
(Balmer + HeII, but no HeI)

Observation

- **Spectroscopic observation**
  - Las Campanas Magellan Echellette (MagE) spectrograph w/ Clay & Baade 6.5 m Magellan telescope
    : 1″ slit
    : R~4100 = 73km/s
    → measurement of radial velocity

Evaluation

- **Radial velocity**
  - cross-correlation techniques using emission / absorption lines
    : Nv : λ4946
    : Nv + HeII : λ4946
    : Hδ / HeII : λ4100
    : Nγ / HeII : λ4339

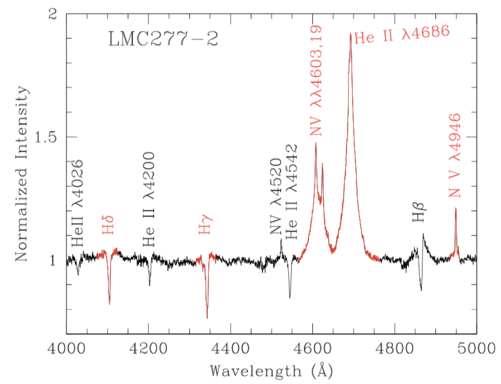


Figure 1. Section of one of our highest-S/N spectra. The regions used in our cross-correlations are shown in red.

Table 1
WN3/O3 Stars in This Radial Velocity Study

Star	α_{2000}	δ_{2000}	V	$B-V$	M_V	No. of Observations	No. of S/N>100
LMC079-1	05 07 13.33	−70 33 33.9	16.31	−0.25	−2.6	13	9
LMC170-2	05 29 18.19	−69 19 43.2	16.13	−0.17	−2.8	10	6
LMC172-1	05 35 00.90	−69 21 20.2	15.95	−0.12	−3.0	12	8
LMC199-1	05 28 27.12	−69 06 36.2	16.65	−0.22	−2.3	10	8
LMC277-2	05 04 32.64	−68 00 59.4	15.83	−0.16	−3.1	9	8
LMCe159-1	05 24 56.87	−66 26 44.4	16.34	−0.23	−2.6	9	8

multi observation

Date	HJD	Exp. Time (s)	S/N[a]	Designation
LMC079-1				
2013 Oct 18	2,456,583.869	1 × 600	50	…
2013 Dec 14	2,456,640.671	1 × 600	60	…
2015 Jan 9	2,457,031.668	1 × 1200	80	…
2017 Feb 7	2,457,791.675	3 × 500	60	…
2017 Feb 8	2,457,792.606	3 × 550	100	A
2017 Dec 31	2,458,118.659	3 × 900	130	B
2018 Jan 1	2,458,119.675	3 × 900	120	C
2018 Jan 6	2,458,124.661	3 × 900	100	D
2018 Feb 5	2,458,154.678	3 × 900	130	E
2018 Nov 25	2,458,447.765	3 × 900	140	F
2020 Nov 26	2,459,179.684	3 × 900	170	G
2021 Dec 21	2,459,569.789	3 × 900	130	H
2022 Oct 2	2,459,854.738	3 × 900	175	I

Cross pair of radial velocity for each line

Table 3
Radial Velocity Measurements

Cross Pair[a]	Radial Velocities (km s^{-1}) N V λ4946	N V+He II λ4603-4686	Hδ/He II λ4100	Hγ/He II λ4339	Mean (regions)	Std. Dev. (regions)
LMC079-1						
A–B	9.9	9.8	11.5	18.4	12.4	4.0
A–C	12.6	11.1	4.6	8.6	9.2	3.5
A–D	16.8	5.1	11.3	11.2	11.1	4.8
A–E	13.0	1.5	0.3	14.4	7.3	7.4
A–F	11.5	−13.8	1.1	11.8	2.7	12.1
A–G	6.2	2.1	8.6	5.5	5.6	2.7
A–H	16.5	19.6	2.6	−15.8	5.7	16.1
A–I	13.8	−4.1	15.7	11.6	9.3	9.1
B–C	2.9	−0.4	−8.5	−17.5	−5.9	9.1
B–D	6.5	−3.4	0.8	−12.3	−2.1	7.9
B–E	1.9	−7.7	−13.5	−6.9	−6.6	6.4
…	…	…	…	…	…	…
σ_{pairs}	6.4	13.2	8.4	13.8	5.7	…

Table 4
Statistics of Radial Velocity Measurements

Star	σ_{pairs} km s^{-1}	I km s^{-1}	N	E/I	F	p
LMC079-1	5.72	9.76	8	1.17	1.07	0.39
LMC170-2	3.20	13.66	6	0.47	0.17	1.00
LMC172-1	8.82	13.96	8	1.26	1.43	0.11
LMC199-1	6.39	13.45	8	0.95	0.72	0.83
LMC277-2	7.07	11.63	8	1.22	1.11	0.34
LMCe159-1	6.33	9.94	8	1.27	1.42	0.12

Cross pair of radial velocity for each line

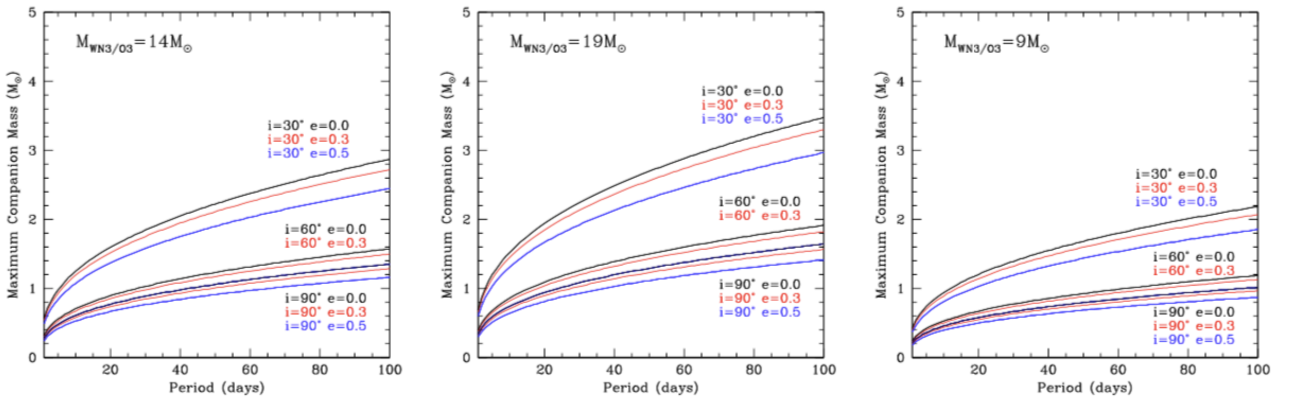


Figure 2. Maximum allowable mass for any companion shown as a function of period based upon the maximum orbital semi-amplitude allowed by our data ($K < 10$ km s^{-1}). The three panels cover the range of masses determined for the WN3/O3 stars in our sample by the analysis of Neugent et al. (2017). For each panel, we have computed nine curves, corresponding to orbital inclinations i of 90° (edge-on), 60°, and 30°, and eccentricities e of 0.0 (circular orbit, shown in black), 0.3 (shown in red), and 0.5 (shown in blue). The $i = 60°$, $e = 0.5$ curve is coincident with the $i = 90°$, $e = 0.0$ curve.

- Mass of main star ~ 14M⊙
- Period of binary system
- Orbital inclination of binary system
- Eccentricity
- K = 10 km/s

→ mass of companion

→ ~2M for 100days
→ ~1M for 10days

→ **Not O stars**

Summary and Discussion

・ no evidence of radial velocity variations
: Any binary motion would have to have an orbital semi-amplitude of K < 10 km/s to remain undetected in data.
: the mass of any unseen companion would likely be less than 2M⊙ for periods of 100 days or less, and less than 1M⊙ for periods of 10 days or less.

・ compact companion of solar mass ?
→ The formation time for a solar-mass star is many times the age of a WR star
→ T Tauri ?

・ lack of X-ray emissions
→ the possibility of a neutron star companion in a wide orbit.

・ non-binary WRs may have been stripped by companions that have since merged.
→ no rapid rotation
→ rotation rates are 120–150 km/s (=typical of normal O-type dwarfs)

・ the companions in most of the known WR systems are luminous O-type stars
→ Such a companion would dominate the spectral energy distribution, swamping intrinsic absorption from the WN3/O3 component.

no companion & short-lived transitional phase in the evolution of massive stars
: still hydrogen exist & mass-loss rate is low

→ look for other examples of this new class of WRs　　今後、もっと観測しましょう