WR STARS WITH RING NEBULAE

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ABSTRACT

It is shown that most of usually apparently single nitrogen WR stars with ring emission nebulae around them (WN + Neb) are a probable product of the evolution of a massive close binary with initial masses of components exceeding ~20 $M_{\odot}$.

These objects were indicated as a special class by Johnson and Hogg (1965) and Smith (1968). Parameters of nine objects of this type are displayed in the Table (Lozinskaya and Tutukov, 1981). Parameters of the Of-star HD 148937 with a similar nebula are taken according to Pismis (1974). Massevitch et al. (1976) supposed that these objects are products of massive close binary evolution after the common envelope stage. WR stars in the case should have the invisible relativistic satellites: neutron stars or black holes (Tutukov and Yungelson, 1973). Lozinskaya and Tutukov (1981), after the analysis of the main properties of WN + Neb, support the proposition by Massevitch et al. (1976). It was also proved that to explain the morphology and motion of some nebulae one needs to suppose a strong stellar wind of the central WR star. All WN + Neb stars are nitrogen stars although the number of nitrogen stars is comparable to that of carbon stars. The probability of the chance of such distribution over chemical composition is ~0.002. Young WR stars must be nitrogen ones according to the theory (Paczynski, 1967). The WN + Neb stars are really young (see the Table). Since the lifetime of WR stars is ~3-5.10^5 years, the relative number of WN + Neb stars should be about 10%, which agrees with the observed relative number.

It is remarkable that among central WN stars almost all subtypes except for the rare WN3 and WN4 are presented.

The gas of ring envelope with mass ~10 $M_{\odot}$ forms rather thin as a rule ellipsoidal shell that expands with the velocity of several tens of km/s. The mass of the envelope may increase by ~ $M_{\odot}$ during its lifetime due to stellar wind or gathering of the surrounding matter if

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the density of the latter is ~1 cm^{-3}. The stellar wind may increase the mass of the nebula only by one tenth of its value but as far as its velocity is about thirty times higher than the nebula velocity, the wind is important for the acceleration of nebula and for the generation of regular form. Three WN + Neb stars have high space velocities and four have large z-coordinates. Six WN + Neb stars have parameters that are typical for massive close binaries at late stages. Three WN + Neb stars have low mass close components: HD 96548 (Moffat and Isserstedt, 1980), HD 50896 (Firmani et al., 1980), and HD 192163 (Aslanov and Cherepashchuk, 1981). That is the direct evidence of their duplicity.

Two types of gas envelopes may arise around mass losing stars: from star matter and from interstellar gas. To estimate some parameters of envelopes we suppose that the relative thickness of the envelope is ~0.1, the minimal measure of emission is ~10^3 cm^{-6} pc, the initial velocity of the envelope is ~30 km/s, the velocity of the stellar wind is ~10^3 km/s. If the expanding envelope has the mass M_{Neb}, then it will be observed only if $t \lesssim 3.10^4\ (M_{Neb}/M_\odot)^{0.4}$ yrs. This estimation agrees with the average age of observed nebulae. If the nebula is the product of snow plow of the surrounding gas with density n, then such an envelope will be observed only for $t \gtrsim 10^9/n^{7/2}/\dot{M}_{-6}^{1/2}$ yrs ($\dot{M}_{-6}$ is the mass loss rate by the central star in 10^{-6} $M_\odot$/yr). As $\dot{M}_{-6} \simeq 10$ (Kornilov and Cherepashchuk, 1979), and the age of envelopes around WN stars is ~3.10^4 yrs, then observable nebulae can arise only if $n \gtrsim 14$ cm^{-3}. This value highly exceeds the average interstellar gas density. So the presence of about ten percent of all WR stars without OB companions (mostly of WN type) seems improbable. But sometimes WR stars including WC stars, WR + OB close binaries and OB stars with strong stellar wind may occur in clouds with the large density which is enough for the visible envelope formation, as it was proposed initially by Johnson and Hogg (1965). It is possible that ring nebulae around two WC stars (van der Hucht et al., 1980) and the nebula around the Of star HD 148937 (see the Table) arise in this way. The wind with $\dot{M} \simeq 10^{-5}$ $M_\odot$/yr, $v \simeq 10^3$ km/s and $n \gtrsim 10^2$ is enough to form this object.

The probability of the chance absence of WN + OB binaries among nuclei of WN + Neb stars is low (~0.002). This is also for the binary nature of WN + Neb objects. If a WR star has a relativistic component, it should have high space velocity. Now if the surrounding matter is dense enough, then the envelope will be gradually deaccelerated by it and lag behind the central star. For two WN stars HD 56925 and HD 192163 the relative shift of central WN stars along the small semiaxis of ellipsoidal envelopes of the order of 0.2 is evident. If the interstellar matter has the uniform density ρ_o, then in the frame of the snow plow model that relative shift must be

$$x \simeq \frac{1}{20} \frac{\frac{4\pi}{3} \rho_o R_{Neb}^3}{\frac{4\pi}{3} \rho_o R_{Neb}^3 + M_o} \cdot \frac{v_\star^2}{v_{Neb}^2}$$

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Table. The main parameters of nine WR stars and one Of star with nebulae

No	HD Sp	l b	m_V M_V	R z(pc)	Nebula	Size r(pc)	$M_{Neb}/M_{\odot}$ $n(cm^{-3})$	v_{exp} (km/s) r/v_{exp}(yrs)	v_{sp} (km/s)	P_{orb}(d) K(km/s)
1	50896 WN5	234° -10°1	6.9 -4.3	1600 -280	Ṡ 308	33' 7.7	3 100	23 3.10^5		3.76 K_1=35
2	56925 WN5	228° -0°1	11.7 -4.3	4000 -8	NGC2359	4' 2.3	9 100	30 8.10^4		
3	89358 WN5	284° -1°	11.2 -4.3	3600 -63	NGC3199	6' 3.1	160 240	30 10.10^4		
4	96548 WN8	292° -4°8	7.8 -6.2	4000 -340	RCW58	6'x9' 4	6 200			4.76 K_1=10
5	117688 WN6-C	308° 0°2	10.9 -4.8	4800 17	RCW78				90	
6	147419 WN6	333° -1°5	11.4 -4.8	4000 -104	RCW104	5' 3	650 190			
7	191765 WN8	50° 3°5	11.2 -6.2	4400 240	M1-67	1.5 1	4 260	60 3.10^4	106	
8	192163 WN6	75° 2°4	7.7 -4.8	1450 61	NGC6888	18'x12' 3	5 200	70 5.10^4	120	4.5 K_1=20
9	MR97 WN7	10° 1°7	12.3 -4.4	1000 31	G69.80 +1.74					
10	148937 06f		 -6.2	1500	NGC6164+ NGC6165	6'x3' 1		30 2.10^4		

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where R_{Neb} and v_{Neb} are the radius and the today velocity of the envelope, v_* is the space velocity of WN star, M_o is the initial envelope mass. If $v_* = 100$ km/s, $v_{Neb} = 30$ km/s, $R_{Neb} = 3$ pc, $M_o = 10\ M_\odot$, the shift may be explained if $n \gtrsim 2\ cm^{-3}$. Both of these objects are placed in rather dense regions of our Galaxy with low z-coordinate. The ratio of masses of the gathered matter to the initial envelope mass in these cases must be about 0.5. The shift occurs in the orbital plane of the central binary since in this plane the space velocity vector lies. Therefore the large semiaxis of nebulae coincides with polar directions of the orbital plane and probably with the rotation axis of components. It is possible that the ellipticity of envelopes is the result of near polar jets like jets of SS 433 which are also directed in the polar orbital space.

The exploration of fast WR stars with relativistic components is an effective way to study massive close binary evolution at the common envelope stage. The inevitability of this stage is proved by the low velocity of the nebulae expansion which is close to the run away velocity on the surface of red (super)giants. The high space velocity together with the relatively large orbital period of HD 192163 is possible only in the case when at the common envelope stage the large decreasing of distance between the helium core of the red supergiant and the relativistic star was absent. It means that merging of nuclei is not probable. Further theoretical investigation is necessary. The absence of stars with masses 2-20 $M_\odot$ in close binaries with WR components is remarkable. It means that initial masses of components in massive close binaries are almost equal as a rule.

The above arguments do not prove the duplicity of all WN+Neb. Some of them may be the products of evolution of single stars at the (infra) red supergiant stage (Bisnovatyi-Kogan, Nadyozhin, 1973), or the product of gathering of the dense interstellar gas by strong stellar wind (Johnson and Hogg, 1976).

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DISCUSSION FOLLOWING TUTUKOV

Chu: I have two comments : 1) There have been more WR ring nebulae identified and expansion velocities measured. The expansion velocity for the nice shells (or my W-type nebulae) is in the range of 15-80 km/s.
2) There are two WC stars that have nice W-type ring nebulae (HD 92809 in the Galaxy and HD 32402 in the LMC). For both cases, the ring nebulae are adjacent to big nebular complexes. This probably means WC stars can blow observable bubbles as long as there is enough interstellar gas in the vicinity.

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