When the meeting was finally through
I asked "did you learn something new?"
After thought (at the bar)
He said that the star
Is γ Velorum not ².

SESSION 8

EVOLUTIONARY SCENARIO AND THE WR CONNECTION

Chairman: J.M. VREUX
Introductory Speaker: P.S. CONTI

1. A.F.J. MOFFAT and W. SEGGEWISS: The galactic WN7/WN8 stars as massive O stars in advanced stages of evolution.

2. A.J. WILLIS and R. WILSON: The chemical nature and evolutionary status of the Wolf-Rayet stars.

3. E.M. LEEP: Of-WN evolution: spectral types and effective temperatures.

4. V.S. NIEMELA: Observations of velocity fields in WN and Of stars.

5. B. BOHANNAN: BE 381: WN9 or O8 Iafpe?

6. D. VANBEVEREN, J.P. DE GREVE, C. DE LOORE and E.L. VAN DESSEL: Conservative and non-conservative evolutionary computations in connection with Wolf-Rayet binaries.

Summary of Conference: E.P.J. VAN DEN HEUVEL

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EVOLUTION OF O STARS AND THE WR CONNECTION

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ABSTRACT

The stellar wind mass loss rates of at least some single Of type stars appear to be sufficient to remove much if not all of the hydrogen-rich envelope such that nuclear processed material is observed at the surface. This highly evolved state can then be naturally associated with classic Population I WR stars that have properties of high luminosity for their mass, helium enriched composition, and nitrogen or carbon enhanced abundances. If stellar wind mass loss is the dominant process involved in this evolutionary scenario, then stars with properties intermediate between Of and WR types should exist. The stellar parameters of luminosity, temperature, mass and composition are briefly reviewed for both types. All late WN stars so far observed are relatively luminous like Of stars, and also contain hydrogen. All early WN stars, and WC stars, are relatively faint and contain little or no hydrogen. The late WN stars seem to have the intermediate properties required if a stellar wind is the dominant mass loss mechanism that transforms an Of star to a WR type.

INTRODUCTION

It is with some irony that my talk today concerns mostly the status of WR stars, whereas, as we are all aware, the Symposium that has brought us all here is entitled "Mass Loss and Evolution of O-Type Stars." In defense of this apparent disregard for the plans of the Scientific Organizing Committee may I offer the following: At the IAU Symposium #49 on "WR and High Temperature Stars" (Bappu and Sahade 1973) my paper concerned Of stars; and at IAU Symposium #70 on "Be and Shell Stars" (Slettebak 1976) my contribution with Stewart Frost discussed Oe stars. Since we finally now have a Symposium devoted entirely to O-type stars it then seems only fair to discuss WR stars.

It appears certain now that WR stars are the highly evolved remnants of the O stars that have evolved with mass loss of some kind.

P. S. Conti and C. W. H. de Loore (eds.), Mass Loss and Evolution of O-Type Stars, 431–445.

The populations and lifetimes (some 10^5 yrs) are consistent with the concept that all O stars more massive than 25 $M_\odot$ become WR stars (Smith 1973). I will first briefly review the status of O and Of stars. I will then consider what similar information we have about WR stars, and will emphasize the lack of quantitative data on these objects. Some preliminary highly suggestive results of newly acquired spectra of WN stars in the LMC will also be discussed.

Of TYPE STELLAR PARAMETERS

In an HR diagram the input parameters are luminosity and temperature, due essentially to various combinations of mass and composition. I will not discuss the composition in detail except to say it has been assumed to be "solar" for normal O-type stars. A few abundance analyses on main-sequence O types show this to be correct within a factor two. This is probably essentially correct for Of stars also. However, I have often worried that the H/He ratio could be different by factors of two or three from solar (e.g., enhanced helium) and we wouldn't know it from the spectra given the complications of line emission in these stars.

Masses can come directly only from those stars that are in binary systems; although it is possible to extract such information from independent measures of radius and surface gravity (spectroscopically) I do not think this method can ever be more promising than a factor two at best. Presently approximately 40 O-type binary systems are known, including the three involved with collapsed companions as X-ray sources (Conti 1978a). The O6.5III companion to the X-ray pulsar Cen X-3 has a very well determined mass of 18 $M_\odot$. In the other 37 systems masses can be determined exactly only for those few double-lined eclipsing systems. As Conti and Burnichon (1975) have pointed out, masses derived for those main sequence systems meeting these stringent observational criteria agree reasonably well with theoretical tracks.

So far, analyses have been completed for only five double-lined Of systems. The data are contained in Table 1. Only two of these systems eclipse so the values for the masses are lower limits in the other cases. The important fact about this table is the range in masses, from 9 $M_\odot$ to 58 $M_\odot$ for a similar spectral type: O7f. Clearly mass loss and evolutionary status are important parameters in these binary systems.

The luminosity-temperature relation for O and Of stars was extensively discussed by Conti and Burnichon (1975); a more recent diagram, which has been reproduced elsewhere in this Symposium, was constructed by Conti (1976). The O-type stars nicely fall into the expected region in the HR diagram compared to evolutionary tracks. The Of stars are invariably the more luminous stars and populate the upper portions of the diagram, being classified as late OB supergiants when their temperatures are sufficiently low that emission lines are not observed in the

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Table 1. Stellar masses -- Of types

Star	Types	$M \sin^3 i$	M_s/M_p	ΔM	Ref.
HD47129	O7If O7	58 64	1.1	$1\overset{m}{.}2$	1
29 CMa* UW CMa	O8.5If OB	20 24	1.2	$1\overset{m}{.}1$	2
HD149404	O8.5I O7III(f)	1.6 2.7	1.7	$\sim 0\overset{m}{.}5$	3
BD+40°4220* V729 Cyg	O7f O6f	31 9	0.29	$\sim 0^m$	4,5
HDE228766	O7.5 O5.5f	34 23	0.68	$\lesssim 0\overset{m}{.}5$	5

*Eclipsing system

References: 1. Hutchings and Cowley (1976); 2. Struve et al. (1958); 3. Massey and Conti (1979 -- this Symposium); 4. Bohannan and Conti (1976); 5. Massey and Conti (1977)

blue region of the spectrum. The computational step in going from the observed spectrum to temperature, and from the observed M_v to the luminosity are in reasonably good shape for O and Of stars.

Finally, what of the mass loss rates themselves? Extensive data exist on only one Of star, ζ Pup. The four independent methods of UV line analysis, Hα emission strength, IR free free measures and the radio detection give a number of the order of $7 \times 10^{-6}\ M_\odot\ yr^{-1}$ (Conti 1978b). I should remind all of you that it is believed that mass loss rate scales with the Hα emission line strength: ζ Pup has one of the weaker Hα profiles. As reported by Conti and Frost (1977) 6 out of 20 early type O stars have Hα emission, and mass loss rates, of this order or larger. Unfortunately, mass loss rates for O-type stars are not yet available. It is expected, given the absence of emission lines in their optical spectrum, that their rates will be below that of ζ Pup. However, it is known (e.g., Snow 1979 -- this Symposium) that all of these stars have stellar winds. The actual values for the rates of mass loss in O-type stars is a very needed parameter for understanding their evolution, as the proceedings of this Symposium have stressed.

WR TYPE STELLAR PARAMETERS

As you all are aware, WR stars are believed to be helium burning objects, in which the hydrogen rich envelope has been removed by an extensive mass loss process, either due to mass exchange in a binary

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(Paczynski 1973) or loss from a stellar wind (Conti 1976), or both. The WN and WC subtypes are believed to be characterized by the presence of enhanced nitrogen (WN) due to CNO cycle material being brought to the surface, or enhanced carbon (WC) where the products of helium burning are exposed (Paczynski 1973). A recent abundance analysis of nine WR stars by Willis and Wilson (1978) supports this general picture.

Stellar masses have been estimated from those eight double-lined binary systems that are listed in Table 2. One problem is that invariably the radial velocity study concerns exclusively the emission lines in the WR star and the absorption lines in the OB type. Although this introduces an additional uncertainty in the values of K and the masses, it cannot have a drastic effect. For the systems listed, the WR star is probably always the fainter, based on eye estimates of line intensities. The WR star would normally be called the secondary were it not for its extraordinary spectrum. All WR stars in Table 2 are less massive than their companions. Only three systems eclipse, so the

Table 2. Stellar masses -- WR types

Star	Types	$M \sin^3 i$	M_{WR}/M_{OB}	Ref.
γ Vel	WC8 O9I	17 32	0.53	1
HD90657	WN5 O6	6.76 13.6	0.50	2
HD152270	WC7 O8	1.85 6.85	0.27	3
HD168206* CV Ser	WC8 O	8.1 35.2	0.23	4
HD186943	WN4 B	3.36 7.94	0.42	5
HD190918	WN4 O9I	0.21 0.78	0.27	5
HD193576* V444 Cyg	WN5 O6	8.4 19.5	0.43	6
HD211853*	WN6 O6I	11.5 33	0.35	7

*Eclipsing system

References: 1. Niemela and Sahade (1979 -- this Symposium); 2. Niemela (1976); 3. Seggewiss (1974); 4. Cowley et al. (1971); 5. Bracher (1967); 6. Ganesh et al. (1967); 7. Stempien (1970).

masses are otherwise minimum values. Note that the WC8 companion to γ Vel has a minimum mass of 17, nearly twice that of the Of secondary in BD+40°4220 (Table 1). Considering the paucity of data in Tables 1 and 2 it would appear that an extensive observational program on more systems would greatly improve our knowledge of their masses and light ratios.

As for the luminosity and temperature of WR stars, these parameters are not as well known. What is reasonably well established is the M_V for a number of stars, mostly those in the LMC (Smith 1968b) where the distance modulus has been established from other objects. Three cluster associations in our galaxy that contain WR stars -- Carina, Sco OB1, and TR 27 (Moffat, Fitzgerald and Jackson 1977) have well-established distances. The single WR stars, classified by Smith (1968a,b), which have distances from LMC or this cluster/association membership, are plotted in Figure 1. This diagram represents what I believe are the most reliable M_V data for single WR stars. I did not use any stars with kinematic distances as discussed by Crampton (1971), or any of the WR "pairs" of Smith (1968b), since I feel these determinations are not as accurate as the galactic cluster moduli. I did not plot any stars with companions (i.e., absorption lines visible in their spectra) on the assumption that they are

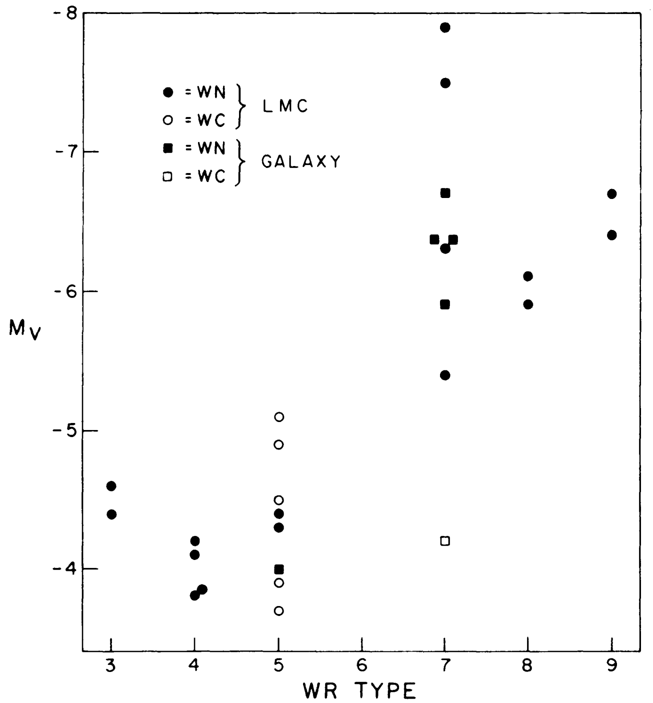

Figure 1. M_V for Wolf-Rayet stars. The values are for those individual stars in the LMC, Carina, Sco OB1, or TR 27 which have well-determined distances. See text.

binaries. I did plot those late WN types (Niemela 1979 -- this Symposium) in which absorption lines are identified in the WR star itself. The two LMC WN stars plotted at type WN9 also have absorption lines. Bruce Bohannan (1979) will discuss one of these two stars, BE 381, later in this session.

The present M_V data on WR stars are admittedly sparse. There are no WN6 stars identified in the LMC using Smith's classification, although by Walborn's (1974) criteria three WN7 stars in Figure 1 would be of this type. Three of the cluster WN7 stars are "transition" types (Conti 1976). The WC star shown at type WC7 is a composite type WC7-N6 and needs to be investigated further. There are no late WC stars in the LMC, for reasons that are not understood. Breysacher and Azzopardi (1979 -- this Symposium) have also pointed out that all WR stars so far identified in the SMC are early WN type. This is also not understood.

From Figure 1 the following statements can be made about the absolute visual magnitudes of WR stars (Underhill 1968; Smith 1973): The WC stars all have an average M_V about -4.3, with a spread of about $1\overset{m}{.}2$. The early WN stars also have M_V near this value, with a smaller range among them. The late WN types are appreciably brighter with M_V averaging about $-6\overset{m}{.}4$ and with a range in values of $2\overset{m}{.}5$. This large difference in M_V among the late WN stars requires comment. It would be nice if there were some spectroscopic distinction for luminosity but a preliminary examination of image tube spectrograms of all of these stars shows nothing clearcut. I frankly do not understand this large range in M_V but it must be related to some combination of the mass and composition, i.e., how much of the star has been peeled away and from what initial mass.

In Figure 1, the abscissa has been labeled with spectral type. These have been adopted exclusively from Smith (1968a,b) who has done the most extensive classification of WR stars in both hemispheres and in the LMC. The WR star classification depends mostly, but not exclusively, on N III, N IV, and N V emission line ratios for WN stars and C III, C IV emission line ratios for WC stars. This has been done only qualitatively by eye estimates. Other classification schemes (e.g., Beals 1938; Hiltner and Schild 1966; Walborn 1974) have also generally used line ionization criteria. A very disturbing feature of this entire classification problem is the lack of agreement among the different observers as to the types of identical stars.

What are the effective temperatures of WR stars? Clearly the classification scheme itself describes an ionization and/or excitation temperature (see, e.g., Bappu and Ganesh 1968). It is by no means certain that this envelope temperature is directly related to the effective temperature as Anne Underhill has stressed many times (Underhill 1968, 1973). Without an envelope model, I believe that fitting continua measurements is also fraught with difficulties. The reddening problem at least appears to be in hand (Smith and Kuhi 1970) when relatively narrow emission-line-free photometry is used.

Willis and Wilson (1978,1979 -- this Symposium), from a study of the UV lines and continua of nine WR stars, have evidence that they all have effective temperatures near 30,000°K. On the other hand, Ms. Leep (1979 -- this Symposium) has noted that those several late WN stars with absorption lines all could be consistently classified as early O type -- with effective temperatures near 45,000°K. If these authors are correct (no stars are in common) then it might be that early WN stars, and WC stars are cooler than later WN stars (i.e., there is no relation between the ionization/excitation value and the effective temperature -- Underhill 1973).

One other method has been used to determine effective temperatures of WN stars. This uses the Zanstra principle, extensively discussed by Morton (1969,1973) wherein the total flux in the H II region surrounding a single star can be estimated and the effective temperature inferred. This method alone avoids problems with the stellar envelope (to first order) but is, of course, not without its own difficulties. Following Smith (1973) and Morton (1973) I have adopted this scheme here but point out that only a few types have been measured: WN5, WN6, and WN8. No H II regions surrounding WC stars have yet been measured so no temperatures are available for them with this method.

I must now discuss the bolometric corrections (b.c.). As a zeroth order approximation it is probably reasonable to assume that the b.c. depends on the effective temperature alone. This seems to work reasonably well for O stars (Conti 1976) and probably Of stars also, but we have no independent confirmation of this for WR stars. There may well be drastic modifications to this simple assumption for WR stars with their extensive stellar winds. For mass loss rates as large as 10^{-4} $M_\odot$ yr^{-1}, the kinetic energy in the wind can be an appreciable fraction of the WR luminosity and adopting a b.c. from the effective temperature might well be an overestimate of the real value. In any case, for the purposes of discussion, I have assumed that the b.c. depends on the effective temperature only, adopting the values listed by Morton (1969) for OB stars.

Mass loss rates for WR stars seem to be typically a factor 10 larger than for Of stars, e.g., between 10^{-5} and 10^{-4} $M_\odot$ yr^{-1} (Conti 1978b; Willis and Wilson 1979), although only a few numbers are as yet available in the literature. Several have been detected as IR sources and as radio point sources due to emission from the surrounding envelope. If WR stars are burning helium in the core and have lifetimes on the order of a few 10^5 years (Smith 1973), then mass loss rates near the upper end of the above limits will be significant during their evolution.

EVOLUTIONARY STATUS

Figure 2 shows a theoretical HR diagram for Of and WN stars, with the location of the companions to the X-ray sources also indicated (from Conti 1978a). The Of stars are the same as discussed by Conti (1976).

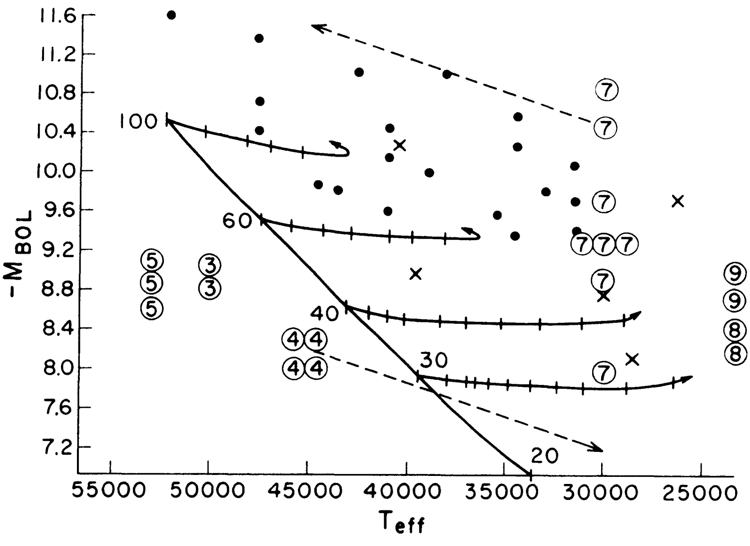

Figure 2. Theoretical HR diagram for evolution of massive stars. The solid lines are for masses, as indicated, with mass loss parameter N=300 (de Loore et al. 1978). The tic marks on these tracks are every 5×10^5 yrs. The solid circles are the positions of Of stars (Conti 1976); the open circles represent WN stars with an interior number showing the type. The × represent the positions of binary companions to X-ray sources (Conti 1978a). The dashed lines represent different positions for the WN stars if alternative effective temperatures are chosen. See text.

The M_{bol} for the WN stars come from those with M_V in Figure 1, and the b.c. given from the T_{eff} values tabulated for the various types by Smith (1973) and Morton (1973). The "WN9" stars are assumed to be similar to WN8 stars for want of better information. The evolution tracks in this figure are from de Loore et al. (1978) for various stellar masses with a mass loss parameter N=300 to the end of core hydrogen burning. With this parameter the endpoint masses are typically half the initial values. Such a mass loss rate is probably an overestimate of the real value for single stars with initial masses of ~40 $M_\odot$ or less but may not be too bad for binary systems or more massive objects. The companions to the X-ray sources are all undermassive for their luminosities, consistent with this rate.

The dashed lines in Figure 2 give the changes in the positions of the WN7, 8, 9, stars if they have effective temperatures near 45,000°K, following Leep (1979), or the positions of the WN3, 4, 5 stars if they are at 30,000°K, following Willis and Wilson (1978). One may conclude that the WN star effective temperatures are uncertain to 50%, a not very satisfactory state of affairs.

A number of Of stars are appreciably brighter than theoretical tracks for 100 $M_{\odot}$ with mass loss. They may well be evolved from higher mass objects, or there may be some parameter amiss in the observations or the theoretical tracks. In the former case the weakest link is the bolometric correction: if this had been overestimated by up to a magnitude, then the brighter Of stars would fall lower in this diagram. A number of simplifying assumptions have been made in the calculations, but it is not obvious that any of these drastically affect the luminosity of the evolving stars (complete mixing might do it, but this is highly speculative).

The early and late WN stars form distinct groupings: fainter (and hotter?) and brighter (and cooler?), respectively. (The lack of WN6 stars with known M_V is a real problem in their interpretation.) Interestingly enough, there is one other crucial distinction between the early and late WN stars. The former have little or no evidence of hydrogen present in their spectra (Smith 1973), whereas the late types all do. I have recently obtained image tube spectrograms of all the WR stars in the LMC with M_V (the stars in Figure 1). Without exception, all the WN7, 8, and 9 stars have evidence of hydrogen in their emission line spectra. Figure 3 shows a preliminary reduction of a portion of the blue region of the spectra of five late WN stars in the LMC. The classification, it will be recalled, comes from the N III/N IV emission line ratio (not shown). All stars have the Balmer lines appreciably stronger than the alternating He II Pickering lines, hence some hydrogen

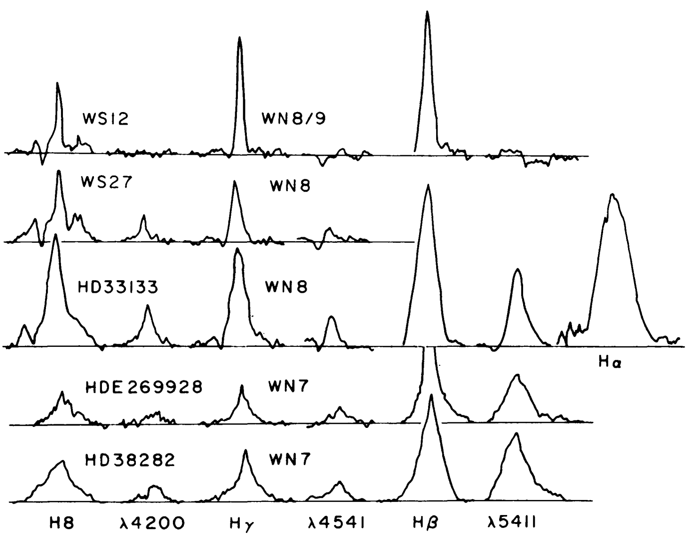

Figure 3. Selected emission line profiles of five stars in the LMC. Without exception, all show evidence of hydrogen as shown by the strength of the Balmer series with respect to the Pickering series.

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must be present, irrespective of the He I/He II ionization state. In nearly all early-type WN stars, the Balmer and Pickering lines have similar strength, indicating that He II dominates the blended lines (Smith 1973).

It is probably no coincidence that it is these same late WN stars, still containing hydrogen (on the surface at least), that appear to have luminosities near those of Of objects, whereas the early WN stars, without appreciable hydrogen and burning helium in the core, are considerably fainter. What is the relation between these late WN stars, and Of stars (Underhill 1968)? As I have mentioned, a few of the former have Balmer lines in absorption; but all have hydrogen and similar luminosities to Of stars. The only spectroscopic distinction is emission line width, which presumably means that the wind density is higher and the mass loss rate is larger. Masses for late WN stars are unknown at present (cf. Table 2) but at least one Of star has a mass that is typical of WR stars (cf. Table 1). Could it be that these late WN stars are also burning hydrogen in the core (or in a shell) and their status is near the end of this phase of stellar evolution? I know of no evidence specifically to the contrary for these WR stars. The actual numbers of identified stars are few but Moffat and Seggewiss (1979 -- this Symposium) will indicate later that the statistics are consistent with their being descendants of initially massive Of stars. It must also be recalled that the effective temperatures are sufficiently uncertain that they cannot be used pro or con this argument.

There are no numbers for mass loss rates of late WN stars as yet but values appreciably larger than 10^{-5} $M_{\odot}$ yr^{-1} would not be surprising given the Hα and λ4686 emission line strengths. Late WN stars could well evolve to more extreme WR types (e.g., those without hydrogen) in their remaining lifetimes if they are near the end of core hydrogen burning (or shell burning) or even if they are helium burning as other WR stars are supposed to be.

DISCUSSION

Given that WR stars are the direct descendants of O and Of stars that have suffered substantial mass loss, I now return to the question of how they got there. In the (now) classical explanation this has occurred by mass exchange in a close binary (Paczynski 1973). This hypothesis requires all WR stars to be close binaries, a conclusion which is becoming increasingly at odds with discovery of apparently single stars (Castor and Van Blerkom 1970; Moffat and Seggewiss 1978; Seggewiss and Moffat 1978; Conti, Niemela and Walborn 1979). Furthermore, if the mass loss process is an exchange, then not only must the other star accept a great deal of material from the initial primary, now the WR star, but the transfer process must be relatively rapid (on the Kelvin-Helmholtz timescale, about ~3×10^4 yr for a 30 $M_{\odot}$ MS star -- Paczynski 1971). I know of no evidence that any companion of a WR binary has accepted mass from its evolved companion; a most favorable case for detection would be γ Vel, with an 09 supergiant star and a WC companion. If the former star has accepted appreciable material from the WC star, one would expect its composition to be anomalous (e.g., nitrogen and helium rich). There is no evidence for this in the spectrum of the supergiant. If mass exchange occurs, it must be on a thermal time scale, and one would not expect to see any WR stars with intermediate properties (e.g., hydrogen present) since evolution occurs relatively rapidly. As I have emphasized during this talk, all late WN stars have such properties. The late WN stars may therefore be a link in the evolution of O and Of stars to all WR types, or they may be endpoints in themselves. If many other WR type stars are found to be single, the former possibility seems more reasonable.

I should stress that discarding the concept of mass exchange as a process in the evolution of WR stars is not equivalent to saying the close binary nature of many WR stars has played no role. On the contrary, if one admits the possibility that such an interaction enhances the mass loss rate from the system via a stellar wind, and realizes that this process is a long-term one, on the time scale of the evolving star, stars with intermediate properties will be observed in binary systems also. BD+40°4220 (Bohannan and Conti 1976) would seem to be one such system but more work on known WN binaries (e.g., CQ Cep) would also prove useful. The present evidence concerning mass flow in early-type close binary systems (e.g., UW CMa, McClusky and Kondo 1976) suggests appreciable mass is leaving the system. Finally, in the case of those OB stars with X-ray companions, the present primary star is under-massive for its luminosity by about a factor two (Conti 1978a). For these four systems containing neutron stars, we are sure that the mass that has somehow been lost by the OB star had not been exchanged to the X-ray companion. These observations are suggestive that mass exchange in early-type systems is not important in their evolution, although mass loss certainly appears to be. It is suspected that mass loss phenomena are more important in stars that are members of close binary systems than in single stars of similar mass (Hutchings 1976). For the most luminous single stars, the stellar wind will control the evolution.

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DISCUSSION FOLLOWING CONTI

de Loore: Can you comment on the bolometric magnitudes? How were they determined?

Conti: These were taken from Morton (Ap.J. 158, 629, 1969) and we make the assumption that the BC is dependent on T_{eff} only, which is clearly a very serious limitation for WR stars. The BC is probably allright for O and Of stars, but may be highly suspect for WR stars.

Underhill: Placing the WR stars in the HR diagram is a somewhat uncertain process and I am extremely sceptical that the effective temperatures are as high as you have indicated. They may all be of the order of 30 000 K or less, as an interpretation of spectrophotometric data on the visible continuum suggests. The uncertainty in M_{bol} is probably of the order of $0^m.5$, for it is well known (Lindsey Smith, Crampton) that the WN7 and WN8 stars lie in the range -6 to -7 for M_v, while all the other WR subtypes lie in the range -4 to -5 for M_v. The bolometric correction is a function of T_{eff}. Its value is not particularly uncertain if you know T_{eff}, for model atmospheres of all types, from black bodies to complex NLTE atmospheres, produce about the same relation between BC and T_{eff} once T_{eff} > 25 000 K. The real problem is to relate the electron temperature in the emission-line forming region to the formal effective temperature, T_{eff}, which describes the total flux of radiation flowing through the atmosphere. From the pattern of emission-line intensities, one assigns a spectral type; one also may estimate an electron temperature, T_e, by some type of spectroscopic diagnosis. From consideration of the physics of flowing ionized gases one infers that T_e is a function not only of the radiative flux flowing through the atmosphere but also of the input of mechanical and/or magnetic energy which is injected. R.N. Thomas has emphasized how necessary it is to use diagnostic techniques to infer the mechanical/magnetic heating as well as radiative heating before relating spectral type to T_{eff}. I suspect that the perturbation caused by mechanical/magnetic heating is large in the case of WR stars and that it far exceeds the perturbation which I told you of on Monday for the B-type supergiants. In addition, it is possible that Zanstra temperatures found by comparing radio emission with visible continuum emission are also in error, for the electron temperature in the gas where the radio emission originates may be determined by the flux of mechanical/magnetic energy while the visible continuum reflects the flux of radiative energy only. Use of the Zanstra method implies that the electron temperatures in both regions are determined by the radiation field only. I doubt that this is true for WR stars. Consequently I think your estimates of T_{eff} for the Wolf-Rayet stars may be seriously overestimated. Lower T_{eff} would resolve most of your problems.

Hearn: If you take a typical Wolf-Rayet star with mass 10 M_o and radius 10 R_o with a mass loss of a few $10^{-5} M_o yr^{-1}$, then the optical depth of the matter streaming out of the star is greater than 1. This means that we are not seeing the surface of the star. The radius of the star could be much less than the radius derived from optical depth 1 through electron scattering. For a given radiative flux from the star, the effective temperature depends on the radius of the star ascribed. Thus the effective temperatures of Wolf-Rayet stars could be much higher than the currently accepted values.

Morton: Electron scattering increases the radius of the star but leaves the fluxes unchanged. Since the Zanstra temperature was determined by the ratio of visual flux to Lyman continuum flux, which was estimated from the free-free emission of the surrounding nebula, the temperature should not depend on whether electron scattering is present.

Carrasco: I would like to make a remark, the luminosities for WR stars would not be in such a large disagreement if the adopted mass loss rate is reduced, and another theoretical track is plotted.
What is the base of your luminosity calibration for stars not in the Magellanic Clouds?

Conti: Membership in Sco OB1, Carina or TR 27 (see text).

Leung: I am in support of Ann Underhill's suggestion. In the system of V729 Cyg (O7fEa + OfIa) the lines strength are similar between the components if we interprete that the two components may have similar luminosities (Bohannan and Conti) from the lines strength. This lead to two difficulties: 1) the low mass component having radius much larger than the Roche radius, and 2) the luminosity of the same component exceeds the Eddington limit. If we accept the alternative interpretation (Leung and Schneider), the low mass does not encounter the above problem, but one new difficulty arised. The luminosity of this component becomes too low to be detached in the spectra. Thus, it leads to suggest that the spectral lines detached are not formed in normal stellar atmosphere but from a very rarely atmosphere. Under such circumstance line intensity may not reflect the luminosity of the star.

Chiosi: I have the impression that you cannot account for the location of Of stars in your sample only because you have compared it with theoretical models suffering a too heavy mass loss during the core H burning phase, as it is in the case of the N=300 set of de Loore et al. (1977). Conversely if we use slightly smaller mass loss rates as involved in the α=0.90 or α=0.83 sets of Chiosi et al. (1978) the position of Of stars can be easily included in the core H-burning band.