WOLF-RAYET STARS ASSOCIATED TO GIANT REGIONS OF STAR FORMATION

Sandro D'Odorico[1] and Michael Rosa[2]
1: European Southern Observatory, Garching bei München, FRG
2: Landessternwarte Koenigstuhl, Heidelberg, FRG

ABSTRACT
Data on Wolf-Rayet(WR) stars in extragalactic H II regions and emission line galaxies are presented and discussed. The sample is still limited and inhomogeneous but two important points appear to be already established: a) The WR stars are more numerous than the blue supergiants at least in same phase of the evolution of the stellar clusters which ionize the giant H II regions, b) when the WR stars are detected, two cases are apparently observed, one in which only WN, the other in which both WN and WC, are present.

I. INTRODUCTION

It is generally accepted that the ratio of WR stars to blue supergiants within a few kiloparsec from the Sun is close to 0.1. This fact, among other considerations, led to the suggestion that WR stars mights be He-burning stars in a post-red supergiants phase. The stars in the sample, in particular the blue supergiants, are mainly located in young clusters and associations. The number of massive stars in these systems is very small as compared to the number in the stellar clusters which ionize the giant H II regions in irregular and spiral galaxies and even more so for the emission line galaxies. As an example, the brightest H II region in M 33, NGC 604, requires the equivalent of 33 05 stars to keep the observed mass of ionized gas. Star formation occurs in these systems at a very high rate and we cannot take for granted that the initial mass function is the same as for the solar neighbourhood. In view of these differences, it is not entirely surprising that in these systems the ratio WR/blue supergiants, a number correlated to the evolution of massive stars, is sometimes found to be more than 10 times the accepted value for the solar vicinity. This fact, when fully understood, will certainly affect our ideas on stellar evolution and star formation. In section II we review the new results of the WR stars in giant H II regions, and in section III we draw some preliminary conclusions.

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II. OBSERVATIONS OF WR STARS IN GIANT REGIONS OF STAR FORMATION

In Table 1, we have collected all of the data which we know, on the observations of WR stars in giant regions of star formation. The sample is limited and inhomogeneous because the stellar continuum in H II regions has not been studied systematically. The intensity of the WR features is, in a first approximation, proportional to the continuum and in most of the past observations of giant H II regions interest has been centred on the intensities of the emission lines from the ionized gas for abundance determinations.

In Table 1, we give only the equivalent widths (EQW) of a blue and a red band. The first, from 4600 to 4720 Å, includes the well known N III, N IV and He II bands as well as the C IV in WC stars. The second, from 5750 to 5870 Å, includes the N IV and C IV bands. The observed fluxes, uncorrected for absorption with the exception of NGC 5461, have been normalized to the distance of the LMC.

Table 1. Emission bands of WR stars in giant H II regions

Object	Dist. (Mpc)	Type	EQW+ BB	EQW+ RB	Obsvd Flux* BB	Obsvd Flux* RB	Aperture ($pc^2.10^{-2}$)	Reference
LMC								
30Dor cluster	0.056	WN+WC	11	6	22	10	8.0	1
R136	0.056	WN	11	nd	8	nd	---	1
Mk E	0.056	WC	60	60	3	1.5	---	1
M 33								
NGC 604	0.72	WN+WC	27	20	24	13	2.2	2
NGC 604 sw	0.72	WC	25	no	13	no	2.7	3
NGC 604 nw	0.72	WN	16	no	15	no	2.7	3
NGC 604 ne	0.72	WN	6	no	3	no	2.7	3
IC 1613/3	0.77	WN+WC	300	>200	2:	2:	1.3	4
NGC 5461	5.0	WN	5:	nd	74	nd	280	5
NGC 5128/13	5.5	WN+WC	2:	3:	45:	34:	107	6
He 2-10	10.0	WN	3:	nd	>100	nd	?	7
Tol 3	12.5	WN	8	nd	370	nd	72	8

+ : EQW in Å ; *: Flux in ergs $cm^{-2}s^{-1} \times 10^{12}$; nd: not detected; no: relevant spectral range not observed.
References: (1) D'Odorico & Melnick 1981; (2) D'Odorico and Rosa 1981a; (3) Conti and Massey 1981; (4) D'Odorico and Rosa 1981b; (5) Rayo et al. 1981; (6) Moellenhoff 1981; (7) Allen at al. 1976; (8) Kunth and Sargent 1981. Conti and Massey (1981) report observations of WN stars in the giant H II regions NGC 588,592 and 595 in M33 as well.

LMC It has been known for many years that many WR stars are present in the stellar cluster in the centre of the 30 Dor nebula, but lack of accurate photometry and spectroscopy had prevented people from realizing that most of the brightest stars are indeed WR. Since 30 Dor is the only giant H II region where we can resolve the individual stars, it can be used as a tool to understand the integral spectrum of other objects farther away. In Table 1, we give the WR characteristics of the cluster at the centre of 30 Dor, as derived by the photometry of all stars by Melnick (1981) and the observations of the WR stars by D'Odorico and Melnick (1981). Stars within 1 arc min from the centre have been considered. Values for the WR bands of R136, central object of the cluster, and of Mk E, one of the two WC stars in the cluster, are also given.

NGC 604 The brightest H II region in the Local Group galaxy M 33 is very similar to the 30 Dor nebula but for the larger distance. Both the observations by D'Odorico and Rosa (1981a) and by Conti and Massey (1981) indicate the presence of both WN and WC stars. In view of the distance of the object, and its similarity to the 30 Dor nebula, it seems premature to accept the Conti and Massey hypothesis that they have possibly detected superluminous WR stars while observing individual knots in NGC 604.

IC1613/3 In contrast to NGC 604 and 30 Dor, this is a relatively small H II region (110x33 pc) even if it is ranked third in size in the dwarf irregular galaxy which it belongs to. The galaxy is interesting because of its low metal content (about 1/10 of the solar value). The H II region appears to be ionized by a single or a few WR stars with both WC and WN features of extremely high EQW.

NGC 5461 and Tol. 3 The WN features in this giant H II region in M 101 and in the dwarf emission line galaxy Tol 3 are discussed at length in the respective papers.

NGC 5128/13 This H II region in Cen A is characterized by strong WR features and by a strong UV continuum. The values for the WR bands are rough estimates based on the published tracing of the spectrum.

He 2-10 This is an emission line dwarf galaxy with a strong non-thermal continuum and infrared emission. Allen at al. (1976) remarked on the rich WR population implied by the strength of the WR bands.

III. CONCLUSIONS

The data of Table 1 are of different accuracy so that a detailed comparison is premature. It is however possible to derive at least two important results. First, we can conclude on the basis of the observations of 30 Dor and NGC 604 that there is a phase in the evolution of giant H II regions when the WR stars will outnumber the blue supergiants.

The possibility, suggested by Conti and Massey (1981), that giant H II regions are populated by a previously unrecognized class of superluminous WR stars does not invalidate this assertion. 30 Dor may have a superluminous object with WR features at its centre, but it still has many other, fainter, WR stars whose presence must be explained. In the other cases, we observe a range of WR emission line EQW and absolute fluxes which indicate that the relative importance of the WR stars varies from object to object. A trend is difficult to determine at present. However, let us assume for a moment that the high number of WR stars is the result of many massive, He-burning stars entering the WR phase at the same time, as suggested by D'Odorico and Rosa (1981) and Kunth and Sargent (1981). In this "short burst" hypothesis, we would expect less than 1/10 of the H II regions to show WR characteristics, according to the short duration of this phenomenon in the lifetime of a massive star. The present data, however limited, suggest that the frequency of intense WR activity is high in giant H II regions. If this observation is confirmed, we must either assume that the WR features can appear in massive stars which are still in the He-burning phase or that distinct bursts of star formation occur at intervals which are short compared to the lifetime of these massive stars. This would increase the probability of finding a cluster in the WR phase. The co-existence of clusters of different age would also explain the range in the equivalent width of the WR lines in the integral spectrum of distant giant H II regions.

A second interesting result concerns the number ratio WN/WC. In 30 Dor, while only two WC are observed, the absolute strengths of their emission bands is so great that the WC contribution to the integral spectrum is far from negligible. In NGC 604 some of the observed knots show WC characteristics and WC features are probably present in NGC 5128/13. In the other system listed in Table 1, including the other giant H II regions in M 33 studied by Conti and Massey (1981), WC features were not detected. This cannot be a chemical composition effect because in NGC 604 both WN and WN+WC knots are observed. More likely, the WC stars appear only in a certain stage of the evolution of the cluster of the ionizing stars, progenitors having either already gone through the WN phase or having a different initial mass function.

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DISCUSSION FOLLOWING D'ODORICO AND ROSA

Nussbaumer: An essential property of WR stars are their peculiar abundances and not their wide emission lines. Have abundance determinations been done for these WR stars in the extragalactic H^+ regions?

D'Odorico: Abundance determinations should be possible for the WR in the LMC and I think a number of people are working in this direction. For the other cases, the problem is complicated by the fact that we do not resolve individual stars in our observations due to the distance of these systems.

Panagia: In the cases in which you quote no detection in the red band what is the actual upper limit to the flux?

D'Odorico: Upper limits vary from object to object depending on the quality of the original data.

Underhill: Giant H II regions are considered to be young objects, I believe. Your demonstration that WR stars are associated with them indicates that some WR stars are in early stages of evolution. The fact that some central stars of planetary nebulae show WR spectra indicates that a WR spectrum can also be generated at late stages of evolution. I must conclude that the fact that a Wolf-Rayet spectrum is seen is an ambiguous indication of the stage of stellar evolution.

D'Odorico: I agree on this remark as for the WC stars, which are found both as nuclei of PN and even if in very small number, in young H II regions.

Lundström: There is a survey of M33 by Corso in his 1975 thesis that would give some idea about the distribution of the brightest WR stars.

Moffat: It is interesting and worthwhile to take spectra of the most luminous compact H II regions but to get an unbiased and complete idea of the WR connection with massive stars, one will have to survey these galaxies for WR stars.

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D'Odorico: I agree completely, especially if one wants to compare the results with the solar neighbourhood. However, extragalactic giant H II regions appear the best place one can think of to study a young population of massive stars, and the WR/OB stars ratio as related also to chemical abundances.

Massey: I agree with you that it's difficult to tell if these WR objects in NGC 604, etc are single, superluminous beasties or tight clusters. However, if they are clusters the dominant number must be O stars, since the WR emission features are weak. If you look with IUE at low dispersion you should be able to tell if you're looking at a bunch of O9 stars or at another R136.

D'Odorico: The WR emission features in NGC 604 seem to be of the same strength than in the 30 Dor integral spectrum (within 1' from R136), so it seems quite possible that WR stars in NGC 604 are as numerous as in 30 Dor. The IUE data on NGC 604 have been discussed in the paper by D'Odorico et al. (1980), as for what concerns the presence of WR stars. To fully interpret the data we need more observations with an accurate positioning of the slit in the HII region.

Smith: From the spectra I saw in your preprint on NGC 604 I would classify the WC part WC5 or 6 from the dominance and width of the C IV 5810 line.