The Wolf-Rayet Stars in 30 Doradus

Jorge Melnick
Universidad de Chile

1. Introduction: Giant HII regions as sites of massive star formation.

Giant HII regions are the brightest extragalactic emission line objects that can be studied in detail. With diameters of several hundreds of parsecs, these nebulae can be easily resolved out to distances of a few Mpc. Typically 100 or more O stars are required to account for the observed ionization of the nebular gas and this implies that the cores of giant HII regions contain populous young star clusters. The stars in these clusters have essentially the same age and chemical composition. Thus, giant HII region cores provide excellent sites where theories of the formation and evolution of massive stars and, in particular, of Wolf-Rayet (WR) stars can be tested.

The nearest optically visible giant HII region is NGC 3603 in our Galaxy. A recent photometric study (Melnick and Grøsbol, 1981) has shown that it's central cluster is not older than about 3 million years and that all, but the most massive, stars are still near the ZAMS. A low resolution spectrophotometric survey of the brightest stars in the cluster (Melnick 1978) led to the discovery of one WN star; thus with the central object of the cluster (most likely the unresolved Trapezium-like core of the cluster, Walborn, 1973) only two WR stars (both WN) are known in NGC 3603.

The second brightest giant HII region in the sky is the 30 Doradus nebula in the LMC. This gigantic nebula, several hundred parsecs across is visible to the naked eye despite its distance of more than 50kpc from the sun. 30 Doradus is ionized by a massive star cluster which contains more than 500 stars brighter than $M_V \sim -3$. This cluster contains many WR stars and may be one of the best objects where general ideas about the origin and evolution of WR stars can be tested.

2. The WR Stars in 30 Doradus.

The brightest stars in the central cluster of 30 Doradus can be studied optically, in the infra-red and in the UV with considerable detail. A major problem, however, is extinction; the dust is mixed with the nebular gas and the extinction varies significantly from star

C. W. H. de Loore and A. J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, 545–549.

to star. There is evidence that the ultraviolet (Borgman et al., 1978) and the visual (Melnick 1976) extinction laws in 30 Doradus differ considerably from the normal extinction law in the Galaxy. For the purposes of the present discussion the exact wavelength dependence of the reddening law in 30 Dor is not important and a uniform visual absorption of A_V = 1^{m}0 will be assumed for all the stars in the cluster (Melnick 1976). It is clear, however, that it is very important to accurately determine the extinction law in the nebula in order to adequately study the physics of the cluster stars.

Feast et al. (1960) and Melnick (1978) found a total of 12 WR stars in 30 Dor. In a recent study D'Odorico and Melnick (1981,DM) have identified 4 more WR candidates thus bringing to 16 the number of known WR stars in the cluster. Three stars previously classified as WN7 have been reclassified by Conti (1981) as Of stars. The relevant parameters of the 16 stars are summarized in Table 1. An identification chart is given by DM. The visual magnitudes given in the table were obtained from IDS scans for stars brighter than 13th magnitude (DM) and from the photometric study of the cluster stars by Melnick (1981) for stars fainter than this limit. For stars in common the two sets of magnitudes agree within 0^{m}1. The list includes as a single star the central object of 30 Dor R136, which is almost certainly the unresolved core of the cluster containing several WN and OB stars (Walborn 1973). The following statistics are obtained combining the data in Table 1 with electronographic photometry of all stars in the magnitude range 13<V<16 (Melnick, 1981).

There are 12 (counting R136 as one star) stars brighter than V∼13^{m}0 (M_V∼-6^{m}5). Out of these, 9 are WR stars, 2 are Of stars and 1, R138, was classified as Ao:I by Feast et al. (1960). The 9 WR stars belong to the N sequence. No correlation is found between WN subtype and absolute magnitude.

Of the 23 stars brighter V≈13^{m}7 (M_V∼-5^{m}8) at least 16 (there are 3 stars without classification) are WR or Of stars. The stars which do not show WR features rank among the faintest stars in the group with magnitudes close to V=13^{m}7. All stars brighter than 13^{m}7 within 30 arc-seconds (7.6 parsecs) of the cluster center (again with the exception of R138) are WR or Of stars.

The two stars with WC characteristics (R140 and MkE) show multiple images (see Fig. 1 of DM); R140 is composed of at least two stars and possibly three. Its WN+WC type, therefore, is most likely due to the superposition of a WN star and a WC star. Star E presents a remarkable structure; it is composed of two doubles of the same size, structure, orientation, magnitude and color! The separation of the two stars within each of these doubles is more than one arc-second (0.25pc) and it is unlikely that they are physical binaries. It is not known which of these stars is the WC but, given the similarities, both doubles may contain WC stars. Both E and R140 are two of the faintest WR stars known in 30 Dor.

3. Implications for Wolf-Rayet evolutionary theories

All stars in 30 Dor have essentially the same age and chemical com-

https://doi.org/10.1017/S007418090002934X Published online by Cambridge University Press

position. Thus, the most luminous stars must also correspond to the most massive. Although the bolometric corrections are not known, the following remarks can be safely made.

The brightest stars in the cluster are either WN or Of stars. Since Of and WN stars are generally believed to be evolved O stars, it may be concluded that these were the most massive stars formed in the cluster. This fits well with the evolutionary ideas for WN stars discussed by Chiosi (1981) and Firmany (1981). There, massive (50-100 $M_\odot$) O stars evolve first into Of stars and then into late WN stars to end their lives as early WN stars. The fact that most WR stars in 30 Dor are late (WN6 and WN7) stars indicates that the cluster must be very young.

The situation for the WC stars is less clear; WC stars are supposed to be more evolved than WN stars and this agrees well with the fact that most WR stars in 30 Dor are WN's. However, single WC stars are generally believed to be post red supergiants evolved from intermediate mass (20-30 $M_\odot$ according to Firmani; or 40-50 $M_\odot$ according to Chiosi) O stars. It is difficult to see how these stars may have evolved faster than the higher mass stars which became WN's. However, both WC's in 30 Dor are in multiple systems and the evolutionary ideas for single stars may not be appropriate here. It is premature to go into further detail until more data is available. This discussion clearly shows, however, that detailed optical, UV and IR studies of the central cluster of 30 Dor and other giant HII regions may greatly improve our understanding of the WR phenomenon.

Table 1

Basic Properties of WR Stars in 30 Doradus

Star	Type	V
R134	WN6	12.4
R135	WN7	13.2
R136	WN4.5	9.4
R137	WN	11.9
R139	WN7(Of)	11.9
R140	WN6+WC5	13.0+13.4
R142	WN	11.3
R145	WN6	12.2
MK A	WN7(Of)	13.0+13.2
MK C	WN4.5	13.1
MK D	WN	12.8
MK E	WC5	13.7+13.7
MK G	WN	12.8
MK H	WN7(Of)	13.0
MK I	WN6	13.1
MK J	WN6	13.4

Sources: Feast et al. (1960); Westerlund and Smith (1964); Melnick (1978); Conti (1981); D'Odorico and Melnick (1981) Phillips (1981).

References

Borgman, J., Danks, A.C. and Hartsuiker, J.W., 1978, A&A, 69, 309.
Chiosi, C., 1981, This volume.
Conti, P., 1981, This volume .
D'Odorico. S. and Melnick, J., 1981, preprint.
Feast, M., Thackeray, A. and Wesselink, A., 1960, M.N.R.A.S., 121, 337.
Firmani, C., 1981, This volume.
Melnick, J., 1976, Ph.D. thesis Caltech.
Melnick, J., 1978, Unpublished.
Melnick, J. and Grøsbol, P., 1981, A&A in press.
Melnick, J., 1981, Unpublished.
Phillips, M., 1981, preprint.
Walborn, N.R., 1973, Ap.J. (Letters) 182, L21.
Westerlund, B. and Smith, L.F., 1964, M.N.R.A.S. 128, 311.

DISCUSSION FOLLOWING MELNICK

Panagia: Before worrying about the problem of having many superluminous stars we must be sure that the 30 Dor nebula really belongs to the LMC and is not at an intermediate distance. Is there any compelling evidence for the association of 30 Dor to the LMC?

Melnick: That 30 Dor is not a foreground object with respect to LMC is proved by the kinematics of the associated nebulae. There is kinematic evidence (both in 21 cm and Hα) that indicate that 30 Dor is a member of the LMC.

Rosado: We think that H I and optical (Hα) radial velocities of 30 Dor are in good agreement with the radial velocities of the remaining H II regions of the LMC.

Cassinelli: There have been other studies that have concluded that the WR stars cannot account for the ionization of the 30 Dor nebula. Your comments primarily concern the brightness of the stars at visible wavelengths. A very hot luminous star may not seem especially bright at V because that wavelength band is in the Rayleigh-Jeans tail of the Planck distribution ($F_\lambda \sim T.R^2$). The crucial question is what is the radiation emerging from the central star in the extreme UV ($\lambda < 912$ Å)? A star with a temperature of "merely" 30000° may have V magnitude that is only 2 or 3 magnitudes fainter than a superluminous 60000° star, and it will even have a B-V color that is identical to the 60000 K star, yet its ionizing EUV radiation is negligible compared with that of the hotter star.

Melnick: At least in the ZAMS the brightest stars in V are also the hottest. The brightest stars in the core of 30 Doradus have intrinsic (B-V) colours brighter than -0.35 suggesting they are indeed very hot.

Tapia: Have you correlated your visual photometry with the results of the near-IR search of the 30 Dor region made by Hyland et al. with the Anglo Australian Telescope a few years ago? (A.J. 83, 20, 1978; Ap.J. 250, 116, 1981). This correlation would be interesting to see if the possible WR and Of stars in the cluster show IR properties similar to the galactic ones.

Melnick: Not yet.

Niemela: Are the WC stars fainter than the O stars in the 30 Dor cluster?

Melnick: No, the WC star (there is only one bonafide WC star) is the faintest (N=13.7) of the WR stars in the cluster. The other WC star (N=14.0) has a mixed type and is in a group of several stars but it appears to be rather faint (V=13.0).

Tenorio-Tagle: The nebula can also be ionized from the outside, the central cluster is certainly the major contributor. However the group from Marseille has found that stellar associations outside 30 Dor, like those sitting in the neighbouring super rings, provide it with a great deal of photons.

Melnick: There are no stars outside the nebula.

Tenorio-Tagle: Then Cassinelli's point is right, you should measure the photon output and see if really this can account for the ionization.

Smith: If the WC stars you refer to are R140+E observed by M. Philips the spectra are, in his opinion and in mine, intermediate WN-WC.

https://doi.org/10.1017/S007418090002934X Published online by Cambridge University Press