WOLF-RAYET STARS IN NEARBY GALAXIES

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I have recently reviewed the reasons for studying the Wolf-Rayet (WR) content of nearby galaxies, and what these findings seem to be telling us (Massey 1985). The only data which has become available since that review is discussed elsewhere in this volume by Armandroff et al. Here I will only outline the salient points.

Unless metallicity plays a dominant role in the evolution of massive stars (and it may), the number density of WR stars in a galaxy should be proportional to the number of massive star progenitors. In any event, the relative numbers of WR stars in galaxies of similar metallicity should provide a direct comparison of the relative numbers of massive stars. Detecting WR stars is far more reliable than attempting to determine the unevolved massive star population, given the degeneracy in broad-band colors for very hot stars. By using CCD photometry with "optimized" WR filters, and crowded field photometry algorithms, reasonable completeness can be achieved.

So far, this is what is known:

(1) The LMC and SMC differ significantly in the number density of WR stars, with the LMC richer than the SMC by a factor of three or four over that expected on the basis of either mass or surveyed area (Azzopardi and Breysacher 1979). The LMC and SMC both have a considerably higher WN:WC ratio (5 or 6 : 1) than that found within a few kiloparsecs of the sun. Most of the WR stars in the Clouds are of high excitation type (WN3, WN4, WC4), although a few lower-excitation WN types are found in the 30 Doradus region of the LMC. In the vicinity of the sun, roughly equal numbers of high and low excitation stars are found.

(2) The Sc galaxy M33 has a number density of WR stars in its inner region considerably greater than that found in the solar neighborhood. The number density falls off with increasing radius; presumably this principally reflects the general decline of the star formation rate with galactocentric distance. In addition, the there is a conspicuous absence of WR stars in the northern arm, in accord with the study of Boulesteix et al. (1981), who suggested a lack of very massive stars in that region, based upon the scarcity of HII regions there. Most of the WR stars are found within the OB associations catalogued by Humphreys and Sandage (1980), although a few fall well away from obvious star-forming complexes. The ratio of WC to WN types is a strong function of galactocentric distance, falling from 2:1 near the center to 1:5 at the Holmberg radius. However, at the radius at which the oxygen abundance is similar to that of the LMC, the ratio of WC to WN types is roughly a factor of 5 higher than that found in the LMC. This suggests that metallicity alone does not control the relative numbers of WC and WN types, as had been inferred from comparing the Magellanic Clouds with the solar neighborhood. The details of the M33 study, including references to earlier work, can be found in Massey and Conti (1983). Further analysis by Humphreys et al. (1985) found that WR stars and red supergiants (RSG) were usually not found in the

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same OB associations in M33, which is to be expected if most RSG's come from lower mass progenitors than do WR stars.

(3) Armandroff and Massey (1985) have recently completed a study of the Magellanic-type irregulars IC 1613 and NGC 6822. They found that the surface density of WR stars in NGC 6822 was low, similar to that of the SMC, while the number density of WR stars in IC 1613 was as high as that of the LMC. Since the metallicity of NGC 6822 is like that of the LMC, while that of IC 1613 is like that of the SMC, this **must** mean that NGC 6822 is poorer in massive stars than the LMC, while IC 1613 is considerably richer in massive stars than the SMC, no matter what role metallicity plays in the evolution of massive stars. Furthermore, all of the WR stars in NGC 6822 are of WN type, which again suggests that this ratio is not simply correlated with galaxian metallicity. The authors speculate that the ratio of WC to WN type may reflect differences in the IMF of recently formed massive stars, but the effects of small numbers could easily dominate the statistics at this point.

(4) In this symposium, Armandroff et al. present the results of a survey of several OB associations in M31. In two of the regions, NGC206, and OB48, the number density of WR stars is as large, or larger, than that of any area of M33. Thus there are regions in M31 which are extremely active in forming massive stars. Their data are too scarce, as yet, to comment on the global ratio of WC to WN types, or to search for gradients, but in the four well-studied regions, WN types clearly dominate.

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Discussion : MASSEY

MELNICK :

I think you should be very cautious about quoting WN/WC ratios until you have slit spectra of all your candidates. Also the WN/WC ratio in 30 Dor is different from that of the LMC as a whole so when you look at M31 you may be seing local "snapshots" of the real M31 ratio.

MAEDER :

The differences in the population of massive stars in galaxies may result from several facts : star formation rate (SFR) - initial mass function (IMF) - effects of metallicity Z on stellar structure - effects of Z on mass loss rates, etc. It is thus very difficult to exclude metallicity effects, since the other causes should be kept constant. It seems that one of the best ways to see whether Z-effects are present is to compare the galactic gradient of WR stars with the galactic gradient of their O-type precursors of initial mass larger than 40 Mo. As mentionned by Peter Conti, the gradient of WR stars is steeper than the gradient of O-type stars initially more massive than 40 Mo. Since neither the SFR nor the IMF can be advocated here, metallicity effects are a likely candidate for explaining the differences of these galactic distributions.

SHARA :

Though you didn't state it explicitely in your talk, your results imply that the WN/WC number ratio in M31 (or at least in its OB associations) is about 5. It is crucial that you obtain and publish spectra of your candidate stars to support or disprove this high WN/WC ratio. The fact that you are finding few new WC stars implies that our global survey of M31 is quite complete for WC's, and that there are only 30-40 WC's in all of M31. Even if WN/WC is about 5 in stars in total in M31 the Galaxy probably contains > 1,000 WR stars, and has only half the mass of M31. Thus M31 is much quieter at present, than the Galaxy. Your abstract rejected this "conventional wisdom", could you explain why?

MASSEY :

We have surveyed only a few regions in M31, and we selected the ones likely to be the most active. Interestingly, we found that these regions were very active in forming massive stars. Your statement that the total WC population in M31 has been identified is probably wrong by factors of 10-1000, as you have ignored (Moffat and Shara Ap.J. 273, 533 and your poster paper) differential reddening. While there may be some

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controversy as to whether M33 has different reddening from one region to another, nobody else here is likely to claim that for M31. We selected regions likely to be unreddened; even so, the B-V color of the blue supergiant plume in OB48 is .2 mag redder than in NGC 206. Furthermore, we found WC stars which you missed.

ROSA :

a) by going back to HII regions like NGC 604, do you detect the WR stars spectroscopically with your technique?
b) you might be missing a large fraction of the WR population in your statistics.

MASSEY :

We found a number of the Conti and Massey objects in NGC 588 (Ap.J. 249,471) in our "test" M33 field (Armandroff and Massey, Ap.J. 291, 685). We didn't try NGC 604, but we would probably have found them, given their high luminosity (good S/N). The HII regions matter only a little since we do local sky determinations. However, it is not the optimum way of detecting them.

ROSA :

a) can you find with your technique the W/C stars in giant HII regions - i.e. have you tried to reobserve NGC 604 to find the ones known already? b) the point of my question is, that you may be missing a substantial fraction of a galaxy's WR population. c) with an EQW of only 5-20 for the blue WR band the detection is very much hindered in such regions - may it be due to the dilution by OB star continua or the intrinsic low EQW of peculiar objects.

ZINNECKER :

You want to extend your WR star search. What is your strategy, what questions do you want to answer? It would perhaps be interesting to find WR stars outside OB associations. Whether very massive stars form in OB associations only, or in the field as well, would be an important question to answer.

MASSEY :

We answered that, I think, in our study of M33 (Massey and Conti : Ap.J. 273, 576) : while most WR stars were found in OB associations, a few of them are out in the boon-docks, and must have been formed there.

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