WOLF-RAYET STARS IN M31'S OB ASSOCIATIONS

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It is well-known that the massive star population exerts a disproportionately great influence on the environment within a galaxy, especially through the ejection of chemically enriched material and the input of energy into the interstellar medium. In order to more fully understand the structure and evolution of galaxies, it is important to determine how the massive star content of a galaxy changes with Hubble type, galaxian luminosity and metallicity. Conversely, if our goal is to understand the evolution of massive stars, it is helpful to observe them in a variety of environments, as stellar wind properties should depend on chemical abundances. We are involved in a long-term project to survey the massive star population in a diverse sample of nearby galaxies. Unfortunately, it is extremely difficult to isolate a sample of relatively unevolved massive stars in an external galaxy, since the colors and absolute visual magnitudes of a 20 $M_\odot$ and 100 $M_\odot$ star are nearly identical, and can be further confused by differential internal extinction. Wolf-Rayet (WR) stars, however, are relatively easy to detect due to their strong emission-line spectra and high luminosities. Since WR stars are known to have evolved from O stars and because their space distribution in the solar neighborhood is identical to that of the most massive O stars, we have decided to use WR stars as tracers of the massive star population in nearby galaxies.

When we began these studies, it was accepted that the surface density of WR stars decreased substantially from the Galaxy, to the LMC, to the SMC. Similarly, the ratio of WC to WN types fell fom 1:1 in the solar neighborhood, to 1:4.5 in the LMC, to 1:7 in the SMC. This behavior was widely attributed to the metallicity differences known to exist between these galaxies. Subsequently, Massey and Conti (1983) surveyed M33 and found that the WC to WN ratio in its central regions is about five times higher than that of the LMC, despite their similarity in chemical abundances. This pointed to some factor in addition to metallicity, the IMF for example, which controls the WR content. Furthermore, Armandroff and Massey's (1985) survey of the Magellanic-type Irregulars NGC 6822 and IC 1613 revealed that 6822 resembles the SMC in its WR surface density and WC to WN ratio, while 1613 is like the LMC. Since 6822 and the LMC appear to have similar

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abundances, while 1613 and the SMC are both more metal-poor, metallicity variations cannot account for the differences in WR content among these galaxies.

M31's prominence as the most massive and most metal-rich galaxy in the Local Group, and its morphological similarity to our galaxy made its inclusion in this survey essential. Unfortunately, M31's large inclination and substantial internal extinction have discouraged large-scale surveys, and its massive star content remains relatively unexplored. Recognizing these problems, we have decided to concentrate on individual OB associations (van den Bergh 1964), selecting the ones with the least amount of reddening and the ones apparently richest in massive stars, as evidenced by their Hα nebulosity. This procedure should not bias our conclusions since most of the WR stars identified in M33, NGC 6822 and IC 1613 are located within the boundaries of previously catalogued associations.

The observational technique used to survey M31 is nearly identical to that employed by Armandroff and Massey (1985) in their study of NGC 6822 and IC 1613. KPNO 4-m PFCCD exposures have been obtained of selected OB associations through UBV filters and three narrow-band interference filters. The interference filters were designed for the optimal detection of WR stars, and the unambiguous separation of these into WC and WN types. Consequently, two of the filters include strong WR emission features, while the third passes only continuum. WR stars can be detected by blinking either of the emission-line exposures with the continuum exposure, and stars can be classified as WC or WN by comparing their brightness in all three exposures. However, in order to be complete to small magnitude differences (e.g. weak-lined WN's) and in very crowded regions, it is necessary to go a step beyond blinking. Accordingly, a magnitude for every image on a set of exposures is determined using Peter Stetson's crowded-field photometry program, DAOPHOT. Magnitude differences between the emission-line and continuum frames are then calculated for each image, significant differences ($>2.5\sigma$) indicating a WR candidate. The UBV exposures are also reduced using DAOPHOT, and yield a color-magnitude diagram for each association.

Poor weather last Fall allowed us to search only nine associations (NGC 206, OB 8, 9, 10, 48, 54, 102, 136, 139) and limited us to UBV photometry of six (NGC 206, OB 8, 9, 10, 48, 102). Although we plan to obtain more observations this year, the data in hand are very suggestive. 30 WR candidates were detected in the regions surveyed, of which 17 are extremely probable ($>3.2\sigma$) WR stars. Of this extremely probable group, 11 are of WN type, yielding a WC to WN ratio of about 1:2.

The results outlined above are in sharp contradistinction with the photographic WR survey of Moffat and Shara (1983). In a survey covering two-thirds of M31's surface area, they identified 21 WR candidates. Subsequent spectroscopy indicated that 14 of these were WC stars, 3 were WN stars and the remaining 4 were non-WR, resulting in a WC to WN ratio of about 5:1. There are several reasons to suspect that the Moffat and Shara study suffers from substantial incompleteness. The root of the problem is that WC stars, on average, have much stronger lines than WN stars. The strongest line in WC stars, CIII λ4650, typically exceeds 1000A in equivalent width, while the strongest line

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in WN stars, HeII λ4686, ranges from 30A to 200A in equivalent width. Imaging surveys are complete to a given magnitude difference, which translates directly to a limiting equivalent width. If this completeness limit exceeds the typical equivalent width for WN stars, then primarily WC stars will be found. One of the OB associations which we surveyed falls within the search area of Moffat and Shara (1983). We detect both of their spectroscopically confirmed WR stars in this association, and both are very strong-lined. They, however, missed the additional WN stars that we have identified. Similarly, in NGC 6822, Moffat and Shara (1983) failed to detect any WR's, while Armandroff and Massey (1985) located 12 WR candidates, of which 7 are extremely probable (all of WN type). Moffat and Shara did not even detect the strong lined WN star in 6822 first discovered by Westerlund et al. (1983) using the grism technique. Based on the overlap between our two surveys, we estimate that the completeness limit of Moffat and Shara's (1985) survey is 150A, which explains the surprisingly low WR surface density and anomalously high WC to WN ratio that they find for M31.

The primary goal of this study is to use the observed WR content to deduce global measures of the massive star population in M31. Two quantities, the present-day star formation rate (SFR) and the initial mass function (IMF), can be used to parameterize this population. As has been discussed earlier, the hypothesis that metallicity controls the WR surface density and the WC to WN ratio fails to explain the results of recent WR surveys. Indeed M31, with a WC to WN ratio of 1:2 and a metallicity somewhat higher than that of the Galaxy, is inconsistent with this hypothesis. The simplest alternative explanation of the WR statistics is that the WC to WN ratio is telling us something about the IMF, given the evidence from binaries that WC stars evolve from more massive progenitors than WN's (Massey 1981). A low value of WC/WN would indicate a steeply sloping IMF, while a ratio near unity would correspond to a flatter IMF. The surface or mass density of WR stars, in this scenario, would be sensitive to the SFR, a higher WR density indicating a more vigorous SFR. M31, with a WC to WN ratio of about 1:2, therefore appears to have a more steeply sloping IMF than the Galaxy or the inner regions of M33. Two of the regions suveyed in M31, NGC 206 and OB 48, have a surface density of WR stars as high as any region in M33. For these two OB associations, the SFR must be comparable to that in the most active regions of M33. The regions in M31 that are actively forming massive stars appear to be as efficient as those in other galaxies, although there may be fewer of them. More OB associations need to be surveyed to answer this question.

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