THE FIRST DETECTION OF WOLF-RAYET STARS IN M31

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Abstract

A search to continuum magnitude B $\sim$ 21.5 ($M_B \sim -3$) using a narrow band filter at λ4670Å and a wide B-band filter has revealed 21 Wolf-Rayet star candidates in about half the giant Sb galaxy M31. Some weak-line WR stars, particularly WN subtypes, may have escaped detection. These numbers are compatible with the total number of luminous (i.e. massive) stars in M31. Eighteen of twenty confirmed candidate stars in M31 lie in the direction of OB associations in the ring of prominent star formation 5-16 kpc from the center.

Introduction

A comprehensive search for Wolf-Rayet (WR) stars in galaxies is potentially important not only to learn more about the nature of WR stars, their role in stellar evolution and their relation to their environment, but also about the galaxies in which they lie.

Specifically, one would like to detect and investigate WR stars in external galaxies for the following reasons: (1) the total number of WR stars in a galaxy can be expected to tell us something about the present efficiency of star formation at the massive end of the initial mass function, since WR stars are believed to be a common but relatively short phase in the post main sequence evolution of massive O-stars (cf. Conti 1976). (2) WR stars are believed to be immediate precursors of type II supernovae (cf. van den Heuvel and Heise 1972). Thus, with typical lifetimes of $\sim 2 \times 10^5$ years (vanbeveren and Packet 1979) for the WR phase as massive He- burning stars (plus short post He-burning phases) there is a good chance that one WR-star from a total sample of 5000 will explode in the next 40 years.
(3) By comparing the number of WR stars with the number of red supergiants, it seems that one has an extremely sensitive indicator of metallicity. Maeder, Lequeux and Azzopardi (1980) find the number ratio MI/WR to increase by two orders of magnitude in the Galaxy from R $\gtrsim$ 8 to 12 kpc from the center. The ratio for the LMC corresponds to

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the outer regions of the Galaxy, while the SMC has an even larger ratio, in line with the decreasing trend in abundance of heavy elements in passing from the Galactic disc to the SMC.
(4) With spectral information, one can expect statistically to be able to probe the metal content within as well as among spiral and irregular galaxies, where star formation is still proceeding.

Search Method

The approach we use to detect Wolf-Rayet stars in relatively large fields involves narrow band photography with an interference filter whose central wavelength coincides with the most intense emission feature in the easily accessible optical range. This occurs at $\lambda \sim 4670$Å where strong lines of CIII/IV $\sim$ 4650 in WC, NIII $\sim$ 4640 in WN, and HeII 4686 in both, dominate. By blinking or photometric scanning techniques, such a narrow-band plate can be compared with either a narrow-band, off-line filter (cf. Wray and Corso 1972) or a wide-band filter centered on the same wavelength. In either case, WR stars should appear brighter on the 4670 plate, except when the emission lines are too weak to be detected above the noise ($\sim$ 0.2 mag on photographic plates). The plate pairs must be taken in immediate succession, in order to diminish the probability of picking up variable stars, and to match the seeing (for ease in blinking).

Our 4670 plates were blinked with a wide band B-plate (central wavelength $\sim$ 4500Å for IIaO emulsion + Schott filter GG 385). Since the broad-band plates are not exactly centered at λ 4670 (IIIaJ + GG 385 would be better but more time consuming since one would have to use IIIaJ with the 4670 filter too), very red stars will appear up to $\sim$ 0.3 mag brighter on the 4670 plate and must be eliminated by blinking B-V plate pairs. Compared with the off-line filter method, one gains significantly in observing time, because the narrow-band filters are generally $\gtrsim$ 10 times slower than the B-filter.

Observations of M31

The Sb giant galaxy M31 was photographed using the 3.6m CFH telescope. Two 37' fields have been studied so far, one centered on the nucleus, the other about 40' SW of the nucleus along the major axis. The baked IIaO plates were exposed 3h at λ4670 and 18 min in B, reaching B $\simeq$ 21.5 in the continuum.

From blinking the 4670-B plate pairs, we found $\sim$ 200 candidate WR stars in M31. We have rated them from probability 1 (4670 much brighter than B) through 2 to 3 (marginal magnitude difference). Blinking B-V pairs lead to the elimination of most of the probability 3 stars as red objects. We retained 21 candidates with a reasonable to excellent chance of being WR stars. Fig. 1 shows an enlargement of one of the 4670 and B discovery plates.

Spectrophotometry of the twenty-one candidates done with the Multi-Mirror Telescope shows that twenty are, indeed, Wolf-Rayet stars; the lone exception is a red foreground dwarf. Seventeen of the twenty WR stars are WC subtypes, (WC4 to WC8) and three are WN stars. This further reinforces our belief that we are probably not detecting the weakest lined WN stars. Spectra and finding charts of all the WR stars in M31 are in preparation and will be published elsewhere; we show in Figure 2 sample spectra of two WC stars in M31.

Discussion

(a) Total number of WR stars

The observed number of WR stars in M31 is probably fairly complete in the areas surveyed (about half of the actively star-forming regions of M31: cf. van den Bergh 1964). Some weak-line WR stars ($W_e \lesssim 30$Å) may have been missed and may be better found using objective spectroscopic techniques (cf. Conti and Massey 1981).

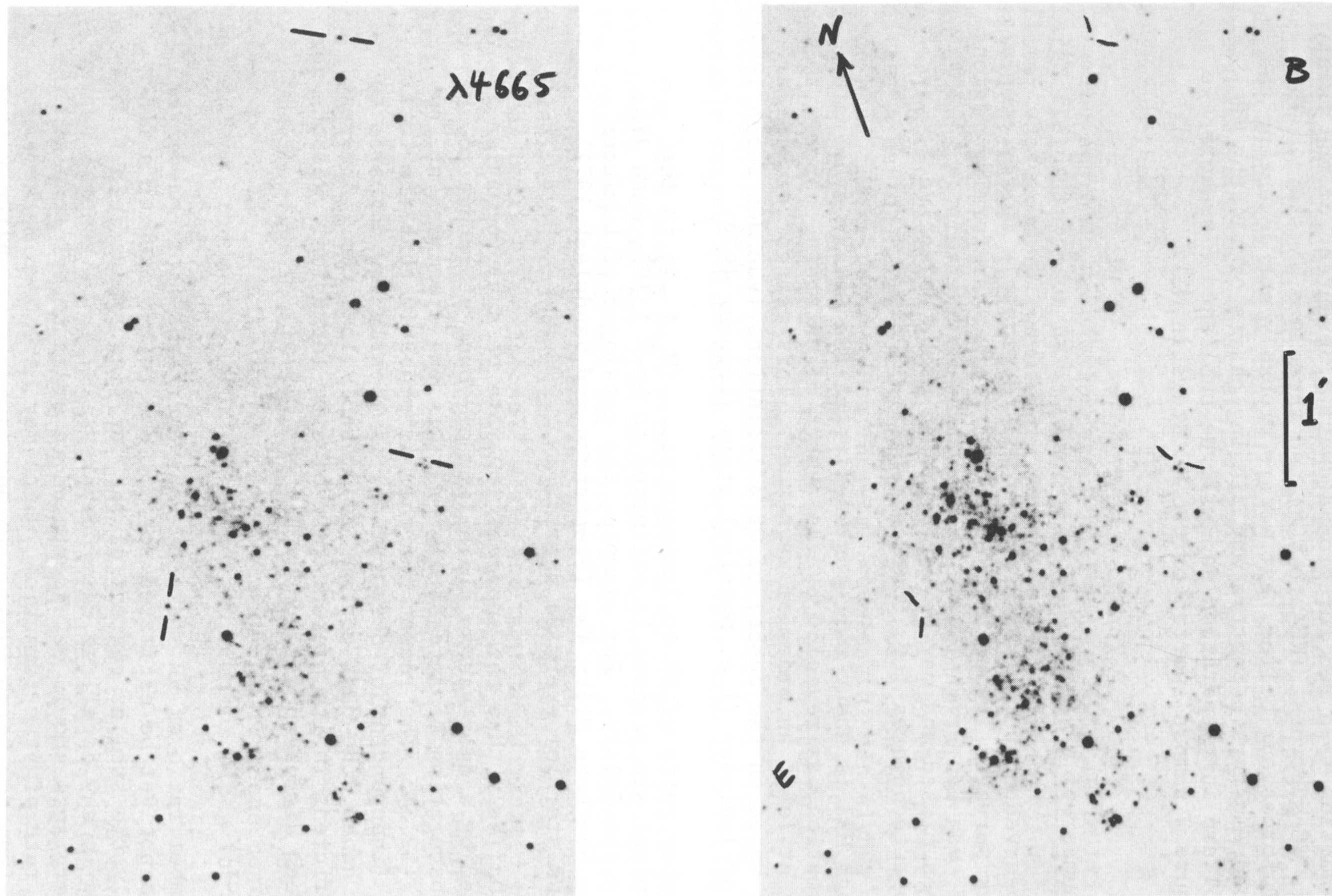
Although M31 is about twice as massive as the Galaxy, the rate of star formation, as revealed by the number of WR stars, appears to be lower by at least an order of magnitude. This reinforces similar conclusions based on the number of OB associations (van den Bergh 1964) and counts of luminous (i.e. massive) stars (Lequeux 1979).

The number ratio of WR to luminous stars ($M_V \lesssim -3$) in the prominent spiral arm regions is estimated to be $\sim$ 1:100, much like the ratio in the Galaxy. For example, the catalogue of Luminous Stars in the Southern Milky Way (Stephenson and Sanduleak 1971) contains 1 WR star for every 54 stars.

It is unlikely that the apparent low rate of star formation in M31 is caused by a decrease in visibility of young stars due to the increased obscuration of interstellar dust in the disc seen at low inclination (12°3). The reason for this is probably that the total gas content (independent of obscuration) is clearly low compared to the Galaxy; hence, the dust content is probably low, too. Apparently, M31 is inefficient in its present rate of star formation. Reasons for this have been discussed already by Lequeux (1979).

(b) Metallicity

The number ratio of WR stars to red supergiants (cf. Maeder et al. 1980) cannot yet be estimated for M31 due to the lack of a red survey. Only the stellar content of the outlying Baade field IV has been studied in any detail so far (Humphreys 1979). A general survey for red supergiants should be undertaken in order to help explain the present low rate of star formation, which may have been much larger in the past (van den Bergh 1964). In any case, it is unlikely that the mean metallicity is lower than in the Galaxy, since the number ratio of WR to luminous stars is similar in both galaxies.



Enlargement of a section of a CFHT plate pair (IIa O) around the large OB association 45' SW of the nucleus of M31. Three WR candidates are differentially brighter on the 4665 Å narrow filter plate than the wide-band B plate. Figure 1.

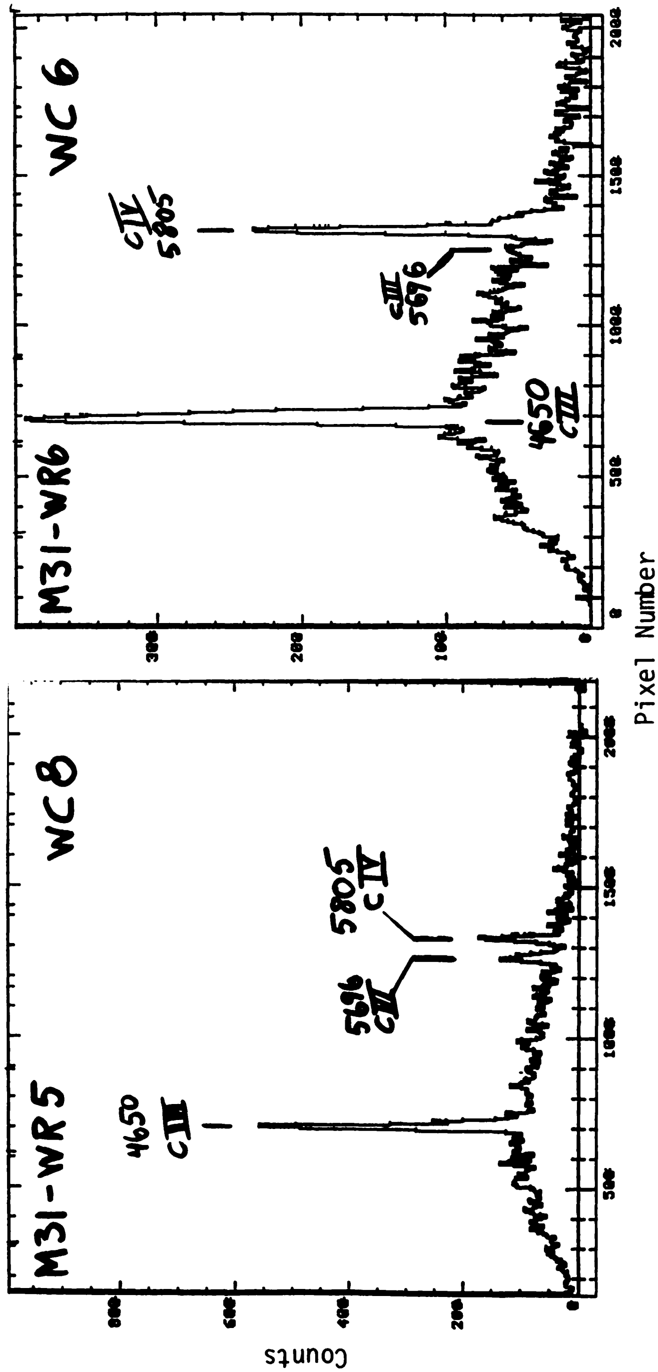


Figure 2: Raw spectra of two of the brighter Wolf-Rayet stars in M31. The relative strengths of the CIII 5696-CIV 5805 line pair determines the indicated spectral type.

(c) Distribution in M31

All but two of the 20 WR stars lie in the direction of OB associations (van den Bergh 1964). Their assumed membership implies ages of $\lesssim 20.10^6$ y. Thus, WR stars are young, but evolved massive stars.

In the central field of M31, (van den Bergh 1964) more (factor ∿ 3) associations are located on the NE side than the SW; the same trend is evident among the WR stars. Further from the nucleus, the largest and densest OB associations are located ∿ 40' from the nucleus towards the SW, where we also find the most WR candidates. Beyond this surveyed area, it remains to be seen whether the number density of WR stars drops rapidly as does the projected radial density of OB associations. The latter remains superior to half the peak density at ∿ 5-16 kpc from the center. This ring-like structure is also evident in the distribution of neutral hydrogen and synchrotion radiation (cf. Beck and Wielibinski 1981) somewhat like our own Galaxy (Gordon and Burton 1976). The fact that we see more WR stars in the SW region than the central area is probably the result of the low projection angle ($12^{\circ}.3$); in the outer parts, we are looking nearly tangentially down the ring.

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DISCUSSION FOLLOWING SHARA AND MOFFAT

Henize: Nearly all the stars for which you took spectra are WC stars. What is the significance of this?

Moffat: With the present method we only detect stars with emission line equivalent widths $\gtrsim$ 30 Å falling in our λ4670 filter. This will probably exclude many WN stars and WR+OB binaries in which the lines are often weaker than this limit, at least judging from galactic WR stars.

Massey: The same thing happened with the 25 Wray and Corso WR stars in M33 - these were also picked out by narrow band interference photographs, and with two exceptions were all WC's. When Peter Conti and I began looking in the M33 H II regions we began finding the WN's. So the statistics are dominated by selection effects.

Smith: It is nice to see the WR stars in M31 looking similar to galactic stars. There is still a problem with the WC stars in M33, despite improved spectra by Boksenberg et al. (1978, MNRAS 180, 15p), which have narrower lines than WC stars in the Galaxy of the same excitation class.

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