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EVOLVED MASSIVE STARS IN THE LOCAL GROUP. II. A NEW SURVEY FOR WOLF-RAYET STARS IN M33 AND ITS IMPLICATIONS FOR MASSIVE STAR EVOLUTION: EVIDENCE OF THE "CONTI SCENARIO" IN ACTION[1]

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ABSTRACT

We expect the evolution of massive stars to be strongly influenced by mass loss and hence to be sensitive to metallicity. It should be possible to test this "Conti scenario" be comparing the populations of evolved massive stars among the Local Group galaxies, but such investigations have been hampered by incompleteness. In a previous paper, we presented results of a new survey for red supergiants (RSGs) in selected regions of the Local Group galaxies M33, M31, and NGC 6822. In the present paper, we survey eight fields in M33 for Wolf-Rayet stars (WRs), using interference-filter imaging with a CCD to select candidates. Follow-up spectroscopy is used to confirm 22 newly found WR stars, 21 of WN type. We establish that our survey would readily detect WRs as weak-lined as any known, and we conclude that our survey is essentially complete. This survey confirms suspicions that the previous photographic surveys were only 50% complete for WN-type WRs and allows us to combine the data with equally complete samples on other Local Group galaxies. We find that the relative number of WC- and WN-type WRs correlates extremely well with metallicity, varying by a factor of 3 with galactocentric distance within the plane of M33, and continuing the trend to lower and higher metallicity galaxies. The WC/WN ratio within 3 kpc of the sun is slightly above this trend, and we argue that WN stars are underrepresented in this sample. The WC/WN ratio is anomalously high in IC 10, given its low metallicity, and we demonstrate that this is not because of selection effects but is likely caused by IC 10's current status as a starburst system. We examine the spectral properties of WC stars within these galaxies, confirming the previously reported trends that the spectral lines are stronger and broader in regions of lower metallicity. We suggest that the different WC spectral subclasses do not primarily indicate different physical properties for these stars but rather are simply a reflection of the effect that the initial metal abundances has had on the stellar wind structure. Finally, we compare the luminous RSGs with WRs in these galaxies. We find that there is a very strong correlation of the relative numbers of RSGs and WRs with metallicity, in the sense predicted by Maeder, Lequeux, & Azzopardi: at lower metallicities the fraction of luminous ($M_{\rm bol} < -7$) RSGs is higher, with a factor of 6 change within the disk of M33 [Δ log (O/H) = 0.35 dex], and a factor of $\sim$10 change from M31 (or the inner portions of M33) to NGC 6822 [Δ log (O/H) = 0.5 dex]. This is easily explained by the Conti scenario in terms of massive stars spending proportionately less of their He-burning lifetimes as RSGs rather than WRs at higher metallicities and hence higher mass-loss rates. Finally, we note that the presence of luminous RSGs and WRs stars is extremely well correlated for the OB associations in M31 and M33: where one finds one, one finds the other. To the extent that an association is strictly coeval, this argues that some stars of 15 $M_\odot$ and above indeed do go through both RSG and WR stages. The presence of WR stars of both WN and WC types in the same associations as luminous RSGs further suggests that some WCs, at least, have gone through the RSG phase. We include an Appendix providing a complete catalog of confirmed WR stars in Local Group galaxies beyond the Magellanic Clouds.

Subject headings: galaxies: stellar content — Local Group — stars: evolution — supergiants — stars: Wolf-Rayet

1. INTRODUCTION

As a very massive star evolves, it loses matter via radiation-driven stellar winds. Conti (1976) first proposed that this mass loss could explain the existence of Wolf-Rayet stars (WRs), whose spectra showed strong, broad emission lines of exposed nuclear-processed material. Our

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modern picture of massive evolution, with its emphasis on the importance of mass loss, has become known as the "Conti scenario," and updated versions may be found in the reviews by Maeder & Conti (1994) and Maeder (1996). As we currently understand the process, a star of 85 $M_\odot$ is born as spectral-type O3 V with $T_{\rm eff} = 50{,}000$ K and burns hydrogen in its core for about 2.8 Myr. During this time, it evolves to somewhat cooler temperatures ($T_{\rm eff} = 28{,}000$ K) at fairly constant bolometric luminosity ($M_{\rm bol} = -10.3$ to -10.6). During this time, the mass-loss rate is $\sim 10^{-5}$ $M_\odot$ yr^{-1}, and by the end of core H burning the star will have lost 30% of its original mass. (These numbers all come from the $z = 0.02$ metallicity evolutionary tracks of Schaller et al. 1992). Because the star has increased in radius and decreased in mass, its surface gravity will have lessened to the point that the star is very near its Eddington limit, with radiation pressure delicately balanced with gravity. Some poorly understood instability then occurs (Humphreys & Davidson 1994; Maeder & Conti 1994), and the star enters its luminous blue variable (LBV) phase. Although this phase is very, very short (10^4 yr?), a significant amount of additional material (10 $M_\odot$?) is lost during episodic outbursts. Once the outer layers are lost, the star becomes stable again, with processed nuclear material now present at the star's surface and a mass-loss rate that is ~ 10 times what it had been on the main sequence (Willis 1996). This phase is identified as a WN-type Wolf-Rayet star. Further mass loss results in revealing the He-burning products at the star's surface, and a WC-type Wolf-Rayet star results.

The models predict that stars of even higher mass (> 120 $M_\odot$) will have sufficient mass loss and mixing to enter the WN phase during their core H-burning lifetime. Indeed, the most luminous stars in the R136 cluster in the LMC are believed to be such objects, with masses of 120–150 $M_\odot$ and spectra that appear to be those of H-rich WN5–6 stars despite their 1–2 Myr age (Massey & Hunter 1998).

For stars of somewhat lower mass (~ 60 $M_\odot$?), the WR phase may be preceded by a red supergiant (RSG) phase, possibly replacing the LBV phase. Below some mass limit (40 $M_\odot$?), there will not be sufficient mass loss to lead to the WC stage, and the star will end its He-burning life while still in the WN stage. Even lower mass stars (20 $M_\odot$?), with corresponding smaller luminosities and lower mass-loss rates, will never reach the WR stage at all but will remain RSGs, or possibly "blue loop" B supergiants, similar to the precursor of SN 1987A.

There are many unanswered questions in our picture of massive star evolution. Some of these reflect the broad, qualitative uncertainties that remain, such as when in a star's life it goes through an LBV phase, and whether or not any WR stars have gone through an RSG phase. There are also quantitative questions that we wish to answer in order to provide the basis for critical assessments of the theoretical models, such as determining what mass ranges become WC and WN stars. For a recent description of these and other problems, see Maeder (1996).

This paper is the second in a series providing the observational basis for answering how massive star evolution depends upon metallicity. In the first (Massey 1998b), we developed a technique for identifying red supergiants in nearby galaxies and developed a catalog of RSGs in selected regions of NGC 6822, M31, and M33. The NGC 6822 and M31 fields were chosen to be coincident with locations that had previously been surveyed for Wolf-Rayet stars. In the present paper, we present the results of a new survey for WR stars in M33 fields, selected for being coincident with the RSG survey. These data, combined with what we know for the Magellanic Clouds and Milky Way, then allow us to begin to answer some of these fundamental questions of how massive stars evolve as a function of metallicity.

If the Conti scenario has any validity, we expect to see large differences in the evolved massive star populations in galaxies of differing metallicity, and indeed such differences were noted early on in the recognition that mass loss played an important effect in the evolution of massive stars. Since mass loss is driven by radiation pressure through highly ionized metal lines, we expect that the mass-loss rates are thus dependent on metallicity ($\dot{M} \sim L^{0.7} \times z^{0.5}$: Garmany & Conti 1984; de Jager, Nieuwenhuijzen, & van der Hucht 1988; Kudritzki, Pauldrach, & Puls 1987). This implies that the mass limit for becoming a WR star should be higher in a lower metallicity environment, and that in such an environment there should thus be fractionally fewer WC-type WR stars compared to the number of WN stars. Indeed, what little was known of the WR population as a function of metallicity in the early 1980s suggested that this might be the case. In the SMC ($z = 0.002$), the ratio of WC to WN stars was known to be 1:7 (Azzopardi & Breysacher 1979); in the LMC ($z = 0.008$), the number ratio was known to be 1:4.5 (Breysacher 1981); and in the 2.5 kpc region around the sun ($z = 0.02$), the number ratio was roughly 1:1 (Conti et al. 1983). Additionally, we knew that all of the late-type WC stars (WC8–9 subclasses) were found inward of the solar circle, and that none of this class were found in either the LMC or SMC. However, at the time there was an attractive alternative explanation that could also explain these observations, namely that we were seeing the results of different initial mass functions in these three systems, with proportionately fewer of the high-mass stars found in the lower metallicity systems, a suggestion backed by the apparent "gradient" in the IMF slope found in the Milky Way by Garmany, Conti, & Chiosi (1982). Massey & Conti (1983) undertook a spectroscopic survey of WR candidates found in the Local Group galaxy M33 by visually blinking photographs obtained through an interference filter that included the strongest lines in WN (He II λ4686) and WC (C III λ4650) stars against a broadband *B* exposure (Massey et al. 1987b), similar to the technique employed by Wray & Corso (1972) in their first detection of WR stars in M33. And indeed, Massey & Conti (1983) found that the relative number of WC and WN stars changed by a factor of 4 or 5 with galactocentric distance in M33, the only problem being that the absolute value was not in accord with the metallicity when compared to that of the Magellanic Clouds, suggesting that a second parameter, such as a changing IMF, was, in fact, at work.

However, there is mounting evidence that the massive-star IMF is constant in these galaxies (Massey, Johnson, & DeGioia-Eastwood 1995b; Massey et al. 1995c; Massey 1998a). One possible problem with the Massey & Conti (1983) result on M33 was the selection bias against WN stars. Figure 1 shows the equivalent widths of WN and WC stars in the Milky Way and LMC, and it is clear from this that the *median line strength is a factor of 4 higher for WCs than for WNs*. Although the size of this effect wasn't known quantitatively to Massey & Conti (1983), they did discuss the problem that WN stars have considerably weaker lines than do WC stars, and hence that there is a problem in

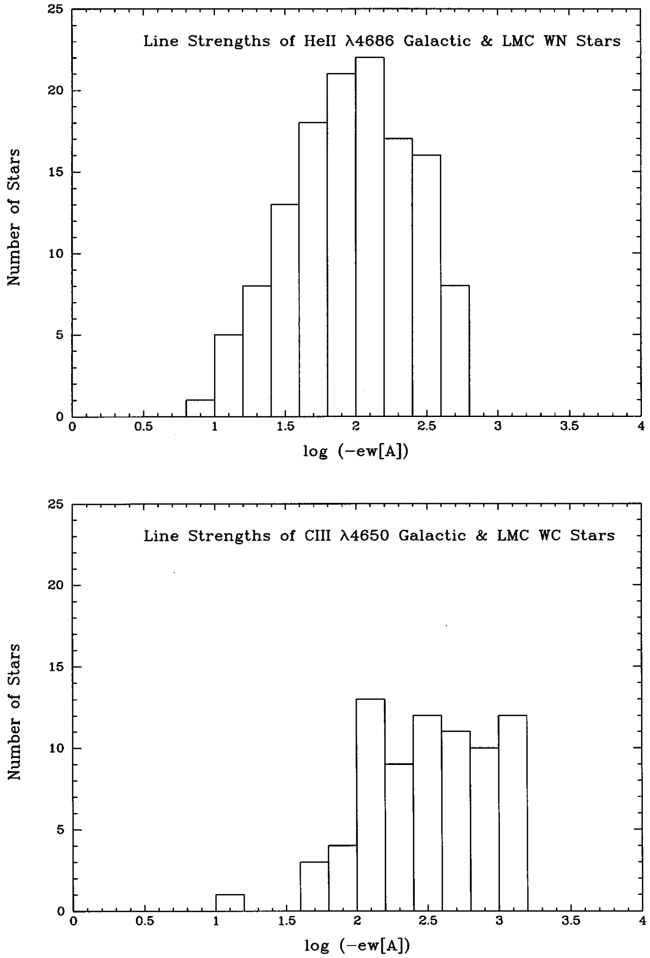

FIG. 1.—Equivalent widths (EWs) of WN stars are compared to those of WC stars. The data are for Galactic and LMC Wolf-Rayet stars from Conti & Massey (1989).

determining good absolute numbers. The size of the problem was hinted at by the extension of this work by Armandroff & Massey (1985; hereafter AM85) who conducted a survey for WR stars in the Local Group galaxies IC 1613 and NGC 6822. Using CCD imaging through three filters—one centered on C III λ4650, one on He II λ4686, and one on neighboring continuum—they were able to photometrically detect, and classify as WC or WN type, far weaker lined stars than had hitherto been possible. Their two "test fields" of M33 revealed most of the previously known WRs, plus a host of additional ones, which follow-up spectroscopy confirmed were primarily WN type (Massey, Conti, & Armandroff 1987a, hereafter MCA87; Armandroff & Massey 1991, hereafter AM91). Thus accurate knowledge of the WC to WN ratio requires more completeness than could be achieved photographically. (A similar example is M31, where the photographic study by Moffat & Shara 1983 had detected WC stars but few WNs. The CCD study by Massey, Armandroff, & Conti 1986 detected many additional WC and WN stars, with the vast majority of additional stars being WN type.)

Until now, however, no follow-up study has been made to explore the global WR content of M33 and to reexamine whether the WC/WN gradient exists. We present such a study here, and these new data, combined with what was previously known about other Local Group galaxies, allow us to make three observational tests of the Conti scenario: (1) the connection between metallicity and WC/WN ratios, (2) the connection between line widths of WC stars and metallicity, and (3) the connection between RSG content, WR content, and metallicity.

2. THE NEW SURVEY OF M33

Eight 5′.2 × 5′.2 fields were imaged in M33 using the KPNO 2.1 m and a Tektronix 1024 × 1024 device with 24 μm pixels. The resulting image scale was 0″.305 pixel^{-1}. In Figure 2 we show the locations of our fields, and we list them in Table 1. The data were obtained through three filters: a λ4650 filter (referred to as the "*WC*" filter), a λ4686 filter ("*WN*"), and a λ4752 filter ("*CT*"). The full-widths at half-maximum (FWHMs) were 50 Å, and the peak transmissions were ∼70%. These three filters were made to be as similar as possible to the filter set designed by AM85, but with the central wavelengths designed for the relatively slow f/7.5 beam of the 2.1 m rather than the f/2.8 beam of the Cerro Tololo Inter-American Observatory (CTIO) 4 m used by AM85. The filters were made by the Andover Corporation, produced excellent image quality, and were well blocked into the IR.

The data were obtained during five photometric nights, 1993 September 18–22, with seeing conditions 0″.9–1″.3. The exposure times were 900 s in each filter, except for the central region ("M33-X"), where the times were shortened to 600 s because of impending twilight. Six of the eight fields were imaged twice through each filter, usually on different nights; only one set of exposures was obtained for the fields M33-C and M33-F. As we shall see, the use of two independent sets of frames for most fields gave us a powerful tool for evaluating the reality of the candidates for which we did not obtain spectra.

TABLE 1

SURVEY FIELDS

	POSITION (2000)			
FIELD	α	δ	OB ASSOCIATION[a]	COMMENT
M33-A	01 35 01.3	+30 41 48	OB 88, 89	RSG survey
M33-B	01 33 51.3	+30 45 14	OB 65-68	RSG survey
M33-C	01 33 32.1	+30 40 50	OB 55-58, 61-63	NGC 595; contains AM 85 field 2
M33-D	01 32 55.6	+30 35 30	OB 20-22, 24	RSG survey
M33-E	01 33 10.9	+30 29 50	OB 17, 115, 127, 128	RSG survey
M33-F	01 33 40.3	+30 20 44	OB 110, 112	RSG survey
M33-G	01 33 44.5	+30 33 22	OB 3, 6–14, 49–51	RSG survey; slight overlap with AM 85 field 1
M33-X	01 33 56.8	+30 38 25	OB 96, 142, 143	Includes nucleus

[a] OB associations are from Humphreys & Sandage 1980.

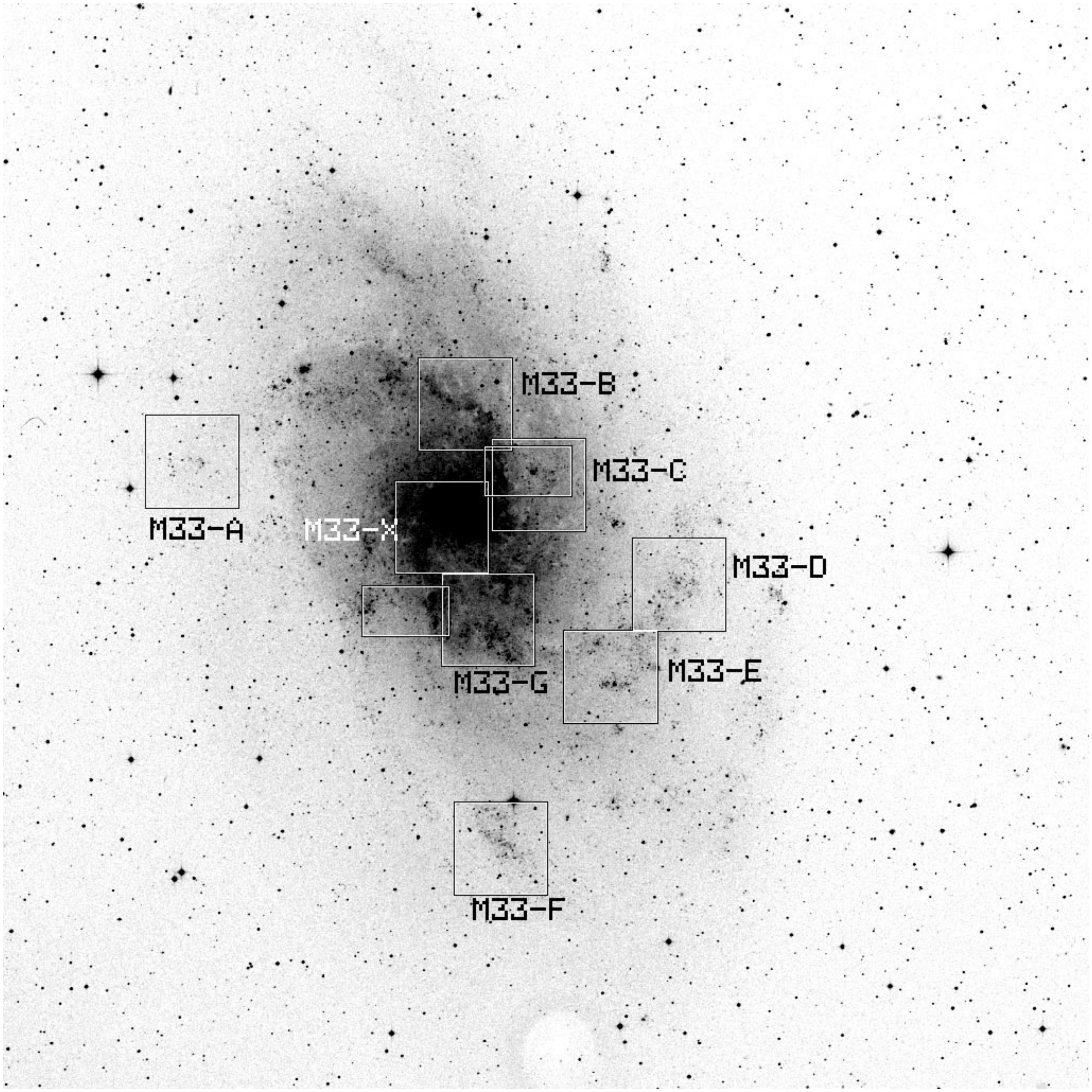

FIG. 2.—Locations of the eight 5'.2 × 5'.2 survey fields are shown. The two rectangles show the survey fields of Armandroff & Massey (1985)

The data were analyzed using the crowded-field photometry program DAOPHOT (Stetson 1987) using the ALLSTAR routine as implemented under IRAF. In total, we analyzed ∼67,500 stellar images on 42 CCD frames, or ∼22,500 stars in each of the three filters. The most sparsely populated field (M33-A) contained only ∼400 stars, while our most crowded field (M33-G) contained ∼4,000 stars; typically a field would contain 1,500 stars.

Following AM85, we selected WR candidates based upon the photometry, looking for statistically significant differences between the on-line (*WC* and/or *WN*) exposures and the continuum exposure (*CT*). For each set of three frames, we determined the average instrumental magnitude differences between the *WC* and *CT* exposures, and between the *WN* and *CT* exposures, and next compared the differences of individual stars from these averages. Since the statistical uncertainties are known (from the number of counts and the detector properties) for each star, we can then judge whether magnitude differences are significant or not. Stars that had been found on the *WC* or *WN* frame, but not on the *CT* frame, were manually inserted into the coordinate list for the *CT* frame, and ALLSTAR was rerun. Stars that remained unmeasurable on the *CT* frame, but were present on either or both of the *WC* and *WN* frames, were checked by eye for reality; one previously known WR star, MC 51, was recovered in this manner. When we were satisfied with the reductions, we then checked the instrumental magnitudes to see if a star was "significantly" brighter in either the *WC* or *WN* exposures compared to the continuum exposure. Stars with magnitude differences $WC - CT$ or

$WN - CT < -0.25$ with a significance level of 3 σ or greater were considered WR candidates. Stars with smaller magnitude differences ($-0.10 \geq WC - CT \geq -0.25$ or $-0.10 \geq WN - CT \geq -0.25$) were considered candidates only if the significance level was 5 σ or greater; these stars are explicitly noted in Table 2 via the comment "small Δm." The cut-off in magnitude was needed both to eliminate spurious candidates and to reduce the number of "Of" stars in the sample. ("Of" stars have N III λ4634, 4642, and He II λ4686 emission, but at weaker strength than WR stars.) The images of all potential WR candidates were then examined to see if the candidate was legitimate. For most candidates of moderate or low significance, blinking the frames would not actually show if the star was "really" brighter in one frame or another but provided a useful check on other problems, such as mismatches or cosmic rays.

Each of the two sets of three frames was treated independently. The continuum magnitude CT zero point was determined using observations of spectrophotometric standard stars; i.e., the CT magnitudes are equivalent to "AB" magnitudes at λ4650; we expect that these values are good to 0.1 mag. We give our table of candidates in Table 2.

In classifying the stars photometrically ("WC" type vs. "WN" type), we relied on Figure 2 of AM85. Generally, stars with $WC - WN < 0$ will be WC stars, and stars with $WC - WN > 0$ are expected to be WN stars. However, some late-type WN stars will have slightly negative values of $WC - WN$ because of the presence of N III λ4634, 4642 in the WC filter. These can usually be distinguished from true WC stars, thanks to the fact that C III λ4650 is a much stronger line in WC stars than the N III line is in WN stars. For stars with slightly negative $WC - WN$ values ($-0.5 < WC - WN < 0$), we will call the star a WC only if $WC - CT < -0.7$ mag. Stars with $WC - WN < -0.5$ were all considered WCs, and stars with $WC - WN > 0$ were all considered WNs.

We have identified 145 WR candidates in Table 2. (The star AM 11 appears twice in Table 2, as it was identified in the region of overlap of fields M33-B and M33-C. No other star occurs in the regions of overlap.) How many of these are new? To answer this, we carefully recomputed the coordinates for all the previously known Wolf-Rayet stars in M33 (see the Appendix). Of the 145 WR candidates in Table 2, 58 had been previously spectroscopically confirmed as WRs (Massey & Conti 1983; AM85; MCA87; AM91; Massey et al. 1995a, 1996), and one (OB 88-7) as an extreme Of star. The remaining 86 stars are new WR candidates. In the table, previously known WRs are given using their original designations; stars new to this survey are identified with the field name and an arbitrary number (i.e., "X9").

How complete is this sample? We will address the sensitivity issue in § 2.1, but here we can address one aspect of this question by examining how many of the known WR stars we detected, and at what significance level. Prior to this study, 67 WR stars were known in our eight fields (counting AM 11 twice); we successfully recovered 59 of these (88%) as follows. We recovered all 12 of the known WRs stars in fields A, D, E, and F. In field B, we found eight of the known WRs but missed two others: OB 66F-61 (WN6), and UIT 154 (B0.5 Ia + WNE). In field C, we successfully found 15 of the known WR stars, including all 12 of the spectroscopically confirmed AM85 stars in the field, but we missed three others: MCA 4 (WN), MC 30 (Of? or WNL?), and MC 31 (WNL). In field G we found 16 of the known WRs, but missed one: UIT 177 (WN4.5 + O6–9). Finally, in field X, we found eight known WRs but missed two: UIT 289 (WN4) and UIT 213 (B1 Ia + WN). Unsurprisingly, our efforts were more successful for WC stars (25 out of 25, or 100%) than for WN stars (34 out of 42, or 81%).

What were the causes of our failures? These are due to crowding rather than lack of sensitivity. Consider the three missing stars in field C. Field C is an extreme case, as one set of exposures was available; thus it was not possible to recover on one set candidates missed on another. All three of the missing stars (MC 30, MC 31, and MCA 4) were also within the survey field of AM85, who also failed to detect them. Two of them, MC 30 and MC 31, occur in the very crowded core of NGC 595. MC 30 was called an Of star by Conti & Massey (1981), but even the small He II λ4686 emission that is typical of an Of star is now in doubt (see Appendix). Inspection of our photometry reveals that MC 30 was not detected, but that MC 31 was listed as a "possible" candidate but rejected because of mismatching between the three exposures due to the extreme crowding. MCA 4 was detected as a possible candidate but was rejected as a cosmic ray happened to be superposed on the WC image.

It is instructive to consider *how strongly* we detected the WR stars that were previously known. Of the 58 (individual) previously known WRs that we detected, one was undetected on our continuum exposure (MC 51); of the rest, all but four were found at the ≥ 8 σ level. (Thirteen had detections that were 30 σ or greater.) For the 41 previously known WR stars that occurred in regions that were imaged twice, all but four were found twice. The exceptions are all crowded, again arguing that our survey is more affected by crowding than sensitivity. Not only did we detect all of the AM85 stars, we detected them at far greater significance levels than in the AM85 survey. For instance, the star AM 11 that was found at the 18.1 σ level in field B and at the 13.4 σ level in field C had originally been detected by AM85 at only the 3.0 σ level. However, since all of our lack of detections were of WN stars, we might expect that sensitivity plays some role in our detections—crowded WC stars would not be rejected during our check of potential candidates simply because it was readily apparent by blinking frames by eye that the candidate was real.

Finally, we note that our survey detected many new WR candidates with moderate and high significance levels, many of which are now confirmed spectroscopically.

2.1. *Spectroscopic Follow-up*

2.1.1. *New Spectra*

We obtained new spectroscopy for 30 stars in Table 2 in order to understand the fraction of our new candidates that are bona fide Wolf-Rayet stars as a function of significance level. We were able to confirm 22 previously unknown WR stars, and rule out emission for nine; a tenth non-WR star was previously known to be an extreme Of star with very strong He II and N III emission. This spectroscopy also allowed us to identify stars with particularly interesting spectra. Two of these are among the Ofpe/WN9 stars found as part of the present survey and were previously discussed by Massey et al. (1996).

Observations were obtained mainly with the KPNO 4 m telescope and RC spectrograph, often with the spectrograph

TABLE 2

WR CANDIDATES

Star[a]	No.[b]	Position (2000) α	δ	ρ[c]	WC−CT Difference	σ	WN−CT Difference	σ	WC−WN Difference	σ	CT	Spectral Type Predicted	Actual[d]	Comments[e]
Field M33-A														
MC 78	2	01:34:58.90	+30:41:29.1	1.01	−2.3	20.0	−1.7	14.3	−0.3	−14.5	21.3	WC	WC4	Comp 1″.5 S
MC 79	2	01:35:05.38	+30:41:14.9	1.11	−2.1	84.9	−1.4	52.2	−0.3	−57.9	19.1	WC	WC4–5	Isolated
A3	1	01:35:03.92	+30:43:18.9	1.06	−0.3	2.7	−0.4	3.1	0.1	0.5	21.1	WN		
A4	1	01:35:01.01	+30:43:48.0	1.01	0.0	−0.3	−0.4	4.1	0.5	5.6	21.0	WN		
A5	2	01:35:00.26	+30:41:51.0	1.02	−0.2	6.5	0.0	0.4	−0.2	−5.3	19.4	WN		Small Δm
A6	2	01:35:07.06	+30:41:43.7	1.13	−0.1	5.2	0.0	1.6	−0.1	−3.2	18.4	WN		Small Δm
A7	1	01:34:58.90	+30:40:27.0	1.03	−0.1	4.1	−0.1	5.7	0.0	1.5	18.2	WN		HS-anon; small Δm
OB 88-7	2	01:34:59.36	+30:42:01.3	1.01	−0.1	5.8	−0.1	3.7	0.0	−2.0	18.0	WN	O8Iaf	Small Δm
A9	2	01:35:00.27	+30:43:06.2	1.01	−0.1	6.5	−0.1	6.0	0.0	0.1	18.2	WN		Red colors; small Δm
Field M33-B														
AM 11	2	01:33:40.67	+30:42:53.8	0.24	−0.7	9.1	−1.2	18.1	0.3	11.2	20.5	WN	WN	Also in field M33-C
MCA 12	2	01:33:52.40	+30:43:51.7	0.17	−0.6	23.7	−0.5	17.0	−0.1	−4.9	19.0	WN	WNL	Isolated
MC 57	2	01:33:52.67	+30:45:02.0	0.23	−1.6	20.0	−0.9	10.1	−0.4	−12.9	20.8	WC	WC	
B4	2	01:33:52.72	+30:44:44.4	0.21	−1.0	12.5	−1.3	17.6	0.2	6.2	20.7	WN	WN+neb	
MC 58	2	01:33:52.78	+30:43:47.8	0.17	−0.8	9.5	−1.1	13.9	0.1	4.7	20.3	WN	WNE	Isolated
MC 59	2	01:33:53.21	+30:44:13.6	0.19	−2.0	37.7	−1.8	34.8	0.0	−3.4	20.4	WC?	WC	
B7	1	01:33:55.26	+30:45:42.9	0.25	−0.4	3.5	−0.2	1.4	−0.2	−1.7	20.8	WN	Non-WR?	
B8	2	01:33:55.68	+30:45:01.2	0.22	−0.4	19.7	−0.4	21.6	0.0	2.3	18.4	WN	WN7	UIT 245 = HS B337
MCA 8	2	01:33:43.30	+30:44:50.7	0.29	−1.0	9.6	−1.6	16.5	0.3	9.3	21.1	WN	WN	Isolated
B10	1	01:33:45.02	+30:44:47.7	0.27	−0.3	2.8	−0.4	3.5	0.1	0.8	20.2	WN		Brt comp 1″E
MC 51	1	01:33:47.93	+30:45:06.7	0.26	...	...	...	...	0.5	8.3	...	WN	WN	Comp 2″E
B12	2	01:34:00.09	+30:46:15.0	0.27	−0.2	2.4	−0.4	9.0	0.2	2.6	18.1	WN	Non-WR (B8 I)	Close double
B13	2	01:33:40.30	+30:46:01.0	0.37	−1.2	4.9	−1.5	6.8	0.4	5.0	22.1	WN	WR?	
B14	1	01:33:46.73	+30:46:16.0	0.32	−2.4	15.0	−0.1	0.4	−2.4	−16.4	21.3	WC	Non-WR?	V. odd colors; brt comp
B15	1	01:33:45.20	+30:47:19.1	0.38	−0.3	3.0	−0.2	2.8	0.0	−0.4	20.9	WN		
B16	1	01:33:53.33	+30:47:43.0	0.34	−0.9	10.2	−1.5	19.2	0.6	9.6	20.9	WN		
B17	1	01:33:55.60	+30:45:34.7	0.24	−0.6	5.0	−0.8	7.1	0.2	1.7	21.0	WN	WN	
B18	1	01:33:55.62	+30:45:25.5	0.24	−0.2	1.4	−0.5	3.1	0.2	1.4	21.0	WN	UIT 244?	
B19	2	01:33:49.22	+30:46:58.0	0.33	−0.1	2.3	−0.1	6.2	0.1	3.3	18.4	WN		Red colors; small Δm
OB 66-25	1	01:33:44.65	+30:44:36.8	0.26	−0.2	5.2	−0.2	5.4	0.0	0.0	18.4	WN	WN8	Small Δm
Field M33-C														
AM 9	1[f]	01:33:40.05	+30:42:38.8	0.24	−2.0	37.9	−0.9	15.7	−1.1	−33.0	20.0	WC	WC4–5	
AM 11	1[f]	01:33:40.68	+30:42:54.0	0.24	−0.8	8.2	−1.2	13.4	0.4	7.3	20.6	WN	WN	Also field M33-B
C3	1[f]	01:33:41.63	+30:38:55.3	0.12	−0.6	9.2	−0.9	14.1	0.3	6.7	20.2	WN	WN	
C4	1[f]	01:33:43.19	+30:39:00.5	0.10	−0.4	17.1	−0.1	4.6	−0.3	−10.8	18.6	WN?	WC	
C5	1[f]	01:33:24.09	+30:41:36.1	0.43	−0.2	1.2	−0.5	3.2	0.3	2.1	21.3	WN		
AM 1	1[f]	01:33:26.64	+30:40:40.5	0.37	−3.4	17.6	−2.1	10.7	−1.3	−32.6	21.8	WC	WC5–6	
C7	1[f]	01:33:27.23	+30:39:09.2	0.34	−0.3	24.4	−0.3	18.2	−0.1	−5.7	17.8	WN	Ofpe/WN9	UIT 104
AM 2	1[f]	01:33:32.61	+30:41:27.4	0.30	−0.7	28.7	−0.8	35.5	0.2	9.2	19.0	WN	WNL	
AM 3	1[f]	01:33:32.80	+30:41:46.2	0.31	−0.6	36.3	−0.8	32.9	0.2	7.8	18.1	WN	WNL	UIT 118
AM 4	1[f]	01:33:32.95	+30:41:36.2	0.30	−0.6	32.8	−0.8	38.6	0.1	8.8	18.0	WN	WNL	UIT 119
AM 5	1[f]	01:33:33.28	+30:41:29.8	0.28	−1.7	22.4	−0.8	9.5	−0.9	−22.1	19.7	WC	WC	
AM 7	1[f]	01:33:34.28	+30:41:30.5	0.28	−0.5	7.2	−0.5	8.1	0.0	0.6	19.8	WN	WNL	
AM 8	1[f]	01:33:35.45	+30:42:20.4	0.29	−2.1	34.9	−1.3	20.0	−0.8	−24.1	20.4	WC	WC	

TABLE 2—*Continued*

Star[a]	No.[b]	Position (2000) α	Position (2000) δ	ρ[c]	$WC-CT$ Difference	$WC-CT$ σ	$WN-CT$ Difference	$WN-CT$ σ	$WC-WN$ Difference	$WC-WN$ σ	CT	Spectral Type Predicted	Spectral Type Actual[d]	Comments[e]
C14	1[f]	01:33:36.71	+30:38:31.6	0.19	−0.3	3.4	−0.1	0.5	−0.3	−3.2	20.5	WN?		
MC 38.........	1[f]	01:33:40.21	+30:41:02.1	0.18	−0.5	5.7	−1.0	13.0	0.5	7.6	20.8	WN	WN	
AM 10.........	1[f]	01:33:40.26	+30:40:53.6	0.18	−3.6	13.2	−2.5	9.1	−1.1	−32.3	22.0	WC	WC	
AM 13.........	1[f]	01:33:41.81	+30:41:55.0	0.19	−2.3	23.8	−1.1	11.5	−1.1	−27.8	20.6	WC	WC6–7	
MCA 7	1[f]	01:33:41.89	+30:42:02.9	0.19	−0.5	5.6	−0.7	8.7	0.2	3.8	20.3	WN	WN	
C19	1[f]	01:33:42.88	+30:42:17.5	0.19	−0.4	3.5	−0.2	1.7	−0.2	−2.1	21.0	WN		
AM 6	1[f]	01:33:34.22	+30:41:38.1	0.29	−0.6	24.8	−0.6	24.6	0.1	2.5	18.1	WN	WNL	UIT 126
C21	1[f]	01:33:38.39	+30:43:02.1	0.27	0.4	−5.2	−1.2	18.7	1.6	22.5	19.7	WN		V. odd colors
C22	1[f]	01:33:33.55	+30:42:19.4	0.32	−0.2	10.6	−0.1	6.9	−0.1	−4.0	18.1	WN		UIT 121
W91-129	1[f]	01:33:43.17	+30:39:06.3	0.10	−0.1	8.7	−0.2	10.7	0.1	3.4	16.6	WN	WN7+abs	
C24	1[f]	01:33:43.61	+30:39:10.2	0.09	−0.2	5.7	−0.1	3.9	−0.1	−2.1	19.1	WN		UIT 178; small Δm
							Field M33-D							
D1	1	01:32:54.41	+30:37:59.4	0.82	−0.6	3.5	−0.4	2.6	−0.2	−1.1	21.7	WN		
D2	1	01:32:58.70	+30:33:54.5	0.72	−0.3	3.4	−0.2	1.4	−0.2	−1.6	21.1	WN		
D3	1	01:32:56.88	+30:35:35.6	0.76	−0.3	3.1	−0.2	1.6	−0.2	−2.1	20.6	WN	Non-WR?	Comp 1″E
D4	1	01:32:58.26	+30:33:35.4	0.73	−0.3	3.0	−0.2	2.1	−0.1	−1.1	20.9	WN		
MC 10.........	2	01:33:03.21	+30:34:08.7	0.66	−0.7	8.2	−1.0	12.8	0.3	4.5	20.6	WN	WNL	
D6	1	01:32:57.76	+30:35:15.3	0.74	−0.5	3.2	−0.2	0.9	−0.4	−2.5	21.6	WN?	Isolated	
MC 6	2	01:32:57.87	+30:35:49.9	0.74	−1.0	23.7	−0.6	13.7	−0.4	−11.7	19.5	WC	WC4–5	UIT 023(?), SE mem of 3
D8	1	01:32:48.79	+30:34:30.9	0.87	−0.3	2.9	−0.3	3.0	0.0	0.0	21.3	WN		
D9	1	01:32:50.49	+30:36:56.4	0.86	−0.6	3.2	−0.4	1.8	−0.2	−1.3	21.9	WN		
D10	1	01:32:51.79	+30:35:26.8	0.83	−0.3	3.6	−0.1	1.4	−0.2	−2.0	20.7	WN	Brt comp 1″W	
D11	1	01:33:00.60	+30:34:19.7	0.70	−0.6	3.8	−0.6	4.3	0.0	0.2	21.6	WN		Comp 1″NW; v. brt comp 3″S
OB 21-65......	1	01:32:56.33	+30:35:35.4	0.77	−0.3	4.3	−0.3	7.8	0.1	3.9	18.4	WN	WN6+abs	Double ≪0.3″
D13	1	01:33:02.37	+30:34:48.2	0.67	−0.1	0.7	−0.3	3.2	0.3	2.4	20.7	WN	OB 21-115; brt comp 1″S	
D14	1	01:33:01.67	+30:32:57.8	0.68	−0.6	5.0	−0.5	3.4	0.2	3.6	21.2	WN	Non-WR	
D15	1	01:33:01.13	+30:35:07.9	0.69	−0.2	5.8	−0.1	3.0	−0.1	−1.8	19.6	WN	OB 21-110; small Δm	
D16	1	01:32:51.06	+30:35:34.9	0.84	−0.2	6.0	−0.2	5.7	0.0	−0.5	19.1	WN	OB 21-23; small Δm	
							Field M33-E							
E1..............	2	01:33:00.20	+30:30:15.2	0.72	−0.4	19.0	−0.6	24.2	0.1	6.3	18.7	WN	WN8	
MC 7	2	01:33:02.67	+30:31:20.2	0.67	−1.2	11.8	−1.9	19.0	0.7	22.5	20.5	WN	WNE	
MC 13.........	2	01:33:05.64	+30:28:57.5	0.67	−1.3	17.7	−1.9	27.5	0.7	21.3	20.6	WN	WNE	
E5..............	2	01:33:12.15	+30:27:40.4	0.63	−0.6	4.7	−1.0	8.1	0.4	6.8	21.1	WN	WN	
E6..............	2	01:33:14.30	+30:29:55.3	0.56	−0.4	6.1	−0.7	10.9	0.3	6.5	20.0	WN	WN	Comp 1″SW (OB 127-47)
MC 12.........	2	01:33:04.98	+30:32:00.0	0.64	−1.9	7.1	−2.5	9.5	0.6	10.3	22.1	WN	WNE	
MC 15.........	2	01:33:07.77	+30:29:51.1	0.63	−1.2	11.9	−2.0	20.4	0.8	22.0	20.9	WN	WNE	
MC 16.........	2	01:33:08.52	+30:28:05.5	0.56	−0.9	10.6	−1.5	19.0	0.6	16.6	20.5	WN	WNE	
E16	2	01:33:10.71	+30:27:34.1	0.64	−0.8	6.5	−1.4	12.3	0.6	12.0	21.0	WN		
MCA 3	2	01:33:16.47	+30:32:21.5	0.49	−0.6	4.8	−0.8	6.4	0.2	5.1	20.2	WN	WNL	
E30	1	01:33:00.55	+30:30:55.0	0.71	−0.3	4.6	−0.3	4.7	0.0	0.2	20.0	WN	Non-WR	
E32	1	01:33:20.09	+30:27:18.2	0.57	−0.5	3.0	−0.4	2.7	−0.1	−0.7	21.5	WN		
E33	2	01:33:22.30	+30:30:14.3	0.48	−0.4	4.6	−0.1	0.7	−0.4	−2.8	18.7	WN?	Non-WR (A I)	
E34	2	01:33:11.28	+30:31:47.1	0.56	−0.1	3.5	−0.1	5.9	0.1	2.6	18.4	WN		UIT 051; small Δm
							Field M33-F							
F1..............	1[f]	01:33:46.55	+30:22:30.2	0.76	−0.5	3.0	−0.2	0.7	−0.3	−1.5	21.1	WN?		
F2..............	1[f]	01:33:34.73	+30:20:19.8	0.82	−0.5	3.1	−0.1	0.6	−0.4	−2.3	21.1	WN?		
MCA 6	1[f]	01:33:39.69	+30:21:01.9	0.80	−0.7	8.0	−1.2	13.9	0.5	8.1	20.2	WN	WNE	Middle of 3 < 1″

TABLE 2—*Continued*

Star[a]	No.[b]	Position (2000) α	Position (2000) δ	ρ[c]	$WC-CT$ Difference	$WC-CT$ σ	$WN-CT$ Difference	$WN-CT$ σ	$WC-WN$ Difference	$WC-WN$ σ	CT	Spectral Type Predicted	Spectral Type Actual[d]	Comments[e]
							Field M33-G							
G1	2	01:33:33.19	+30:33:43.4	0.30	−0.3	8.1	0.0	−0.8	−0.3	−9.3	19.3	WN		
MC 36	1[f]	01:33:39.27	+30:35:54.9	0.19	−0.6	13.6	−1.1	25.2	0.5	14.2	19.6	WN	WN	Comp 4″NE
G3	2	01:33:40.01	+30:31:21.3	0.35	−0.4	11.3	−0.9	27.5	0.5	18.6	19.4	WN	WN	
MC 40	1[f]	01:33:40.18	+30:35:51.8	0.18	−1.2	40.7	−0.6	17.5	−0.6	−30.4	19.1	WC	WC	
G5	1	01:33:44.76	+30:31:19.3	0.36	−0.4	3.2	−0.3	1.8	−0.2	−1.1	21.3	WN		
MCA 10	2	01:33:45.56	+30:34:51.9	0.20	−0.6	9.0	−1.0	14.9	0.4	7.2	20.4	WN	WNL	
MC 48	2	01:33:46.77	+30:33:34.4	0.26	−1.5	34.5	−1.6	38.5	0.2	5.7	20.1	WN	WN/CE	
G8	2	01:33:47.81	+30:33:38.0	0.27	−0.3	7.4	−0.5	11.2	0.2	5.0	19.6	WN	WN	
G9	2	01:33:50.18	+30:33:42.4	0.27	−1.3	5.2	−1.9	7.7	0.6	5.9	22.3	WN	WN+neb	
AM 14	2	01:33:54.40	+30:34:53.0	0.25	−2.9	18.6	−1.6	9.8	−1.3	−27.5	21.6	WC	WC	Isolated
G11	1	01:33:54.55	+30:33:02.5	0.33	−0.6	3.5	0.0	0.0	−0.6	−3.6	21.4	WC?		
G12	1	01:33:56.34	+30:31:51.1	0.40	0.0	−0.2	−0.4	3.4	0.5	3.2	21.4	WN		
G13	2	01:33:34.24	+30:33:47.5	0.29	−0.6	6.3	−1.4	16.3	0.8	10.9	20.7	WN	WN	
G14	1	01:33:37.05	+30:35:00.9	0.23	−0.3	1.6	−0.8	5.2	0.5	3.9	21.4	WN		
MCA 5	2	01:33:37.30	+30:35:27.2	0.22	−0.9	8.5	−1.6	15.2	0.6	10.8	20.9	WN	WN	
MC 35	2	01:33:38.16	+30:31:12.6	0.36	−3.2	29.0	−1.9	17.5	−1.2	−45.7	21.0	WC	WC	
MC 42	2	01:33:40.16	+30:31:34.5	0.34	−1.9	44.3	−1.2	27.8	−0.6	−30.4	19.7	WC	WC4–5	Fnt comp 1.3″N
G18	1	01:33:43.59	+30:33:08.5	0.28	−0.4	2.6	−0.6	3.3	0.2	1.0	21.6	WN		
MCA 11	2	01:33:46.17	+30:34:36.4	0.22	−0.8	6.7	−1.3	11.8	0.5	7.8	21.1	WN	WNE	
G20	1	01:33:47.04	+30:35:20.8	0.19	−0.2	1.5	−0.4	3.2	0.2	1.4	21.5	WN		
MC 55	2	01:33:51.82	+30:33:28.3	0.29	−2.4	24.9	−1.3	12.5	−1.1	−24.5	21.1	WC	WC	
AM 15	2	01:33:55.92	+30:34:07.7	0.30	−2.2	8.1	−1.0	3.5	−1.2	−10.8	20.2	WC	WC4–5	Several comps < 1″
AM 16	2	01:33:56.21	+30:32:41.5	0.36	−3.1	22.7	−1.9	13.7	−1.2	−41.6	21.3	WC	WC	
AM 17	2	01:33:56.36	+30:34:55.5	0.27	−3.0	39.8	−1.8	22.8	−1.2	−34.1	20.9	WC	WC	
G25	1	01:33:35.66	+30:31:08.8	0.37	−0.4	4.3	−0.4	3.3	−0.1	−0.5	20.6	WN		Brt comp 1″NE
MC 44	2	01:33:42.50	+30:33:14.6	0.27	−0.8	25.1	−0.3	8.1	−0.5	−14.3	18.7	WC	WC4–5	
MC 37	2	01:33:39.92	+30:31:38.4	0.34	−1.0	33.8	−1.4	49.1	0.4	20.9	19.1	WN	WN	
G28	1	01:33:40.25	+30:35:19.2	0.20	−0.6	3.0	0.1	−0.3	−0.7	−3.1	20.7	WC?		
G29	1	01:33:38.67	+30:35:20.5	0.21	−0.4	2.9	−0.6	4.3	0.2	1.4	21.2	WN		
G30	1	01:33:47.33	+30:31:57.9	0.34	0.0	−0.1	−0.3	3.5	0.3	2.9	20.6	WN		
G31	1	01:33:55.57	+30:33:09.9	0.34	−0.1	1.3	−0.3	3.2	0.2	1.8	20.9	WN		Coords OK?
G32	1	01:33:37.04	+30:34:26.4	0.25	−0.4	2.1	−0.6	3.5	0.2	1.2	21.7	WN		
G33	1	01:33:41.88	+30:32:31.8	0.30	−0.2	1.4	−0.4	3.8	0.3	2.5	20.9	WN		Red!; comp 1.2″E
G34	1	01:33:53.79	+30:35:28.9	0.22	−0.5	8.4	−0.7	14.2	0.3	5.7	18.5	WN	WNE	Comp < 1″(OB 3-12)
G35	1	01:33:33.19	+30:33:43.3	0.30	−0.3	5.9	−0.1	1.3	−0.2	−4.5	19.3	WN		Small Δm
OB 6-5	2	01:33:54.83	+30:32:22.7	0.37	−0.2	10.3	−0.2	8.5	0.0	−2.1	17.9	WN	WN8	Small Δm
							Field M33-X							
MC 46	2	01:33:45.98	+30:36:02.4	0.16	−1.3	17.4	−1.8	24.3	0.5	14.4	20.1	WN	WN	
MC 47	2	01:33:46.54	+30:37:00.3	0.12	−2.7	25.0	−1.8	15.9	−0.9	−29.3	20.9	WC	WC	
MC 49	2	01:33:47.14	+30:37:02.5	0.12	−3.0	22.0	−2.0	14.1	−1.0	−24.3	21.0	WC	WC	
X4	2	01:33:48.82	+30:39:49.4	0.02	−0.3	2.7	−0.4	4.2	0.1	1.1	19.5	WN	WN	
MC 52	2	01:33:50.06	+30:38:56.2	0.04	−2.7	34.6	−1.8	22.1	−0.9	−33.9	20.1	WC	WC	
X6	2	01:33:50.06	+30:38:18.8	0.07	−0.2	5.3	−0.3	10.2	0.1	4.9	18.3	WN	WN+O8–9	
MC 50	2	01:33:52.69	+30:39:07.3	0.06	−1.9	6.2	−2.5	8.1	0.6	8.7	21.4	WN	WNE	Extreme colors
X8	2	01:34:00.88	+30:39:18.0	0.17	−0.7	7.5	−1.1	12.1	0.4	5.3	20.0	WN	WN5	
X9	2	01:34:01.74	+30:36:19.8	0.27	−1.2	30.0	−0.9	21.9	−0.3	−11.6	19.0	WC	WNL?+abs	UIT 286
X10	1	01:34:01.63	+30:39:05.6	0.19	−0.5	2.6	−0.9	4.7	0.3	2.2	21.4	WN		
X11	1	01:34:04.21	+30:37:42.6	0.26	−0.2	1.5	−0.4	3.0	0.2	1.4	20.7	WN		

TABLE 2—*Continued*

Star[a]	No.[b]	Position (2000) α	Position (2000) δ	ρ[c]	$WC-CT$ Difference	$WC-CT$ σ	$WN-CT$ Difference	$WN-CT$ σ	$WC-WN$ Difference	$WC-WN$ σ	CT	Spectral Type Predicted	Spectral Type Actual[d]	Comments[e]
MCA 9......	2	01:33:45.21	+30:38:41.1	0.07	−0.7	7.5	−0.9	9.8	0.2	3.8	20.1	WN	WN	Multiple
X13..........	1	01:33:50.88	+30:38:27.2	0.06	−0.4	3.2	−0.1	0.8	−0.3	−1.8	20.7	WN?	Non-WR	
MC 56......	2	01:33:51.99	+30:40:23.5	0.03	−2.4	9.6	−1.4	5.7	−0.9	−13.1	21.4	WC	WC	
X15..........	2	01:33:53.58	+30:38:51.5	0.08	−0.3	13.2	−0.2	9.9	−0.1	−3.9	17.8	WN	Ofpe/WN9	UIT 236
X16..........	2	01:34:00.55	+30:38:09.1	0.20	−0.4	3.9	−0.4	5.0	0.1	0.9	20.1	WN	WN+neb	
X17..........	1	01:34:05.46	+30:39:39.3	0.23	−0.3	0.8	−0.8	3.0	0.5	1.9	21.8	WN		
X18..........	1	01:34:05.13	+30:39:43.4	0.23	−0.4	2.0	−0.6	3.0	0.2	1.2	21.3	WN		
X19..........	1	01:34:01.29	+30:40:04.3	0.16	−0.6	8.7	−0.2	2.5	−0.4	−5.0	17.9	WN?	WCL	UIT 281
X20..........	1	01:34:01.51	+30:38:59.0	0.19	−0.3	3.0	−0.3	2.4	−0.1	−0.9	20.1	WN		
X21..........	1	01:33:58.94	+30:39:12.4	0.14	−0.2	1.0	−0.4	3.5	0.3	2.2	20.5	WN	Non-WR?	
X22..........	1	01:34:03.88	+30:36:02.0	0.31	−0.4	2.6	−0.5	3.5	0.1	1.2	20.7	WN		
MC 54......	1	01:33:51.27	+30:38:11.7	0.08	−1.0	16.2	−0.4	4.6	−0.6	−7.4	18.5	WC	WCE	NE of brter star
X24..........	2	01:34:01.91	+30:38:19.0	0.21	−0.2	14.4	−0.1	8.0	−0.1	−6.3	17.5	WN		UIT 288 (Hα source); small Δm

[a] "AM" designations are from Armandroff & Massey 1985, "MC" from Conti & Massey 1983, "MCA" from MCA87, and all others are new from the present study.

[b] "No." denotes whether the star was identified as a WR candidate from a single set of images ("1") or from two sets ("2").

[c] ρ is the distance from the nucleus within the plane of M33. We have assumed $\alpha_{center}(1950) = 01:31:01.2$, $\delta_{center}(1950) = +30:24:27$, an inclination of 57°, and position of the major axis of 20°, and normalized the distance to a Holmberg radius of 25′, following Kwitter & Aller 1981.

[d] Spectral types for previously known WR stars are from Massey & Conti 1983, MAC87, or Armandroff & Massey 1991.

[e] "Isolated" means no stars within 1″as judged from *HST* WFPC2 images; "comp" = companion; "brt" = bright; "fnt" = faint; "v." = very; "UIT" = UV-bright source identified by Massey et al. 1996; "HS" = blue star designation from Humphreys & Sandage 1980; "ob" denotes blue star identified by Massey et al. 1995a.

[f] Star is within field of view of only one set of images.

rotated to place two candidates placed along the slit simultaneously. Spectra were obtained on 1995 August 7–8 and 1996 October 8–9 with a 632 line mm^{-1} grating used in second order with a BG-38 or BG-39 blocking filter for coverage from 3900 to 4900 Å with 1.8 Å resolution. A few spectra were obtained with multislit masks used with the 4 m and RC spectrograph (1995 September 17–18) with the same setup. Some spectra were obtained with the Wisconsin-Indiana-Yale-NOAO (WIYN) 3.5 m and the Hydra fiber positioner (1995 October 19) using the same grating, the blue fiber cable (3″fibers), and the Simmons camera to provide very similar wavelength coverage and resolution. Several lower dispersion spectra were obtained with the KPNO 4 m and RC spectrograph using a 632 line mm^{-1} grating in first order on 1997 September 9; these covered the wavelength region 3700–6700 Å at 3.5 Å resolution. Similar spectra were obtained with the Multiple Mirror Telescope (MMT) on 1997 October 24 with a 500 line mm^{-1} grating (3.6 Å resolution, wavelength coverage 3700–7300 Å).

The spectral types are included in Table 2, and for the 22 newly confirmed WR stars, we also give equivalent width (EW) measurements in Table 3. We include there the EW measurements for five previously known WRs in our survey but without previous EW information, and, for comparison, that of the extreme Of star OB 88-7, which also showed up as a WR candidate. As discussed by MCA87, only the strongest emission-line features are typically identifiable at the sort of signal-to-noise ratio (S/N) levels commonly obtained on these distant stars. Either He II λ4686 or C III λ4650 was always visible, allowing us to classify the star as either WN or WC. The continuum was not always present, making EW measurements impossible. However, in many instances we were also able to establish if a star was "early" or "late." For WN stars, the subclasses depend upon the relative strengths of N III λ4634, 4642, N IV λ4058, and N V λ4603. Often we could detect none of these lines, and we simply called the star a WN. However, we know that these stars are earlier than WN8, as N III should be as strong as He II λ4686, which of course is seen if we call the star a WN. If N III is present and dominant over neighboring N V, we call the star "WNL," which corresponds to type WN6 and later. If N V dominates, we call the star "WNE," corresponding to type WN4.5 and earlier. For the WC stars, the classification depends upon the relative strengths of C IV λ5812, C III λ5696, and O V λ5592. However, only a few spectra go sufficiently far in the red to include these lines, and generally all we know is that the star is a WC.

We illustrate the spectra of most of our newly found candidates in Figure 3. Stars B4 and B13 were too weakly exposed to be normalized meaningfully; the spectra of our beautiful Ofpe/WN9 stars C7 and X15 were illustrated and discussed by Massey et al. (1996), under the names UIT 104 and UIT 236, respectively. Figure 3*a* shows several spectra extending into the red; note the presence of C III λ5696 in X19, which led to its WCL classification. Similarly N V is clearly present in G34, leading to its WNE classification. In the other three, only the strongest features (C III λ4650 in WC stars, He II λ 4686) can be identified with certainty, although star C3 does show He II λ5400 and *may* show N V λ4603, 4619, which would make it a WNE. In Figure 3*b*, we see two late-type WN stars, B8 and E1, which we classify as WN7 and WN8, respectively. E1 clearly shows H in its spectrum, as the even-*n* Pickering He II lines (coincident with the Balmer lines) are stronger than the odd-*n* Pickering lines, which are essentially invisible and are not marked.

TABLE 3

SPECTROPHOTOMETRY

Star	Spectral Type	C III λ4650 and He II λ4686: log (−EW [Å])	C III λ4650 and He II λ4686: FWHM (Å)	Other Lines, Comments
B4	WN+neb	…	…	Nebular contamination He II λ4686
B8	WN7	1.2	9	N III 0.9
B13	WR?	…	…	Faint He II λ 4686?; no continuum detected.
B17	WN	0.7	19	
C3	WN	1.6	18	Strong He II lines
C4	WC	1.3	50	C IV 1.3 (FWHM = 42 Å), no C III or O V
C7	Ofpe/WN9	0.7	5	N III 0.9; illustrated in Massey et al. 1996
E1	WN8	1.4	12	N III 1.3; H-rich, He I λ4471 P Cygni
E5	WN	1.8	23	
E6	WN	1.3	…	Poor signal
G3	WN	1.8	21	
G8	WN	1.6	27	
G9	WN+neb	1.9	60	
G13	WN	1.9	27	
G34	WNE	1.4	27	N V 0.7
X4	WN	1.1	21	
X6	WN+O8–9	1.2	26	Nice absorption spectrum present
X8	WN5	1.5	22	N III, N IV, and N V all present
X9	WNL?+abs	1.7	80	He II λ4686 blended with either C III or N III
X15	Ofpe/WN9	0.8	6	N III 0.9; illustrated in Massey et al. 1996
X16	WN+neb	0.7	20	Very strong nebulosity
X19	WCL	1.6	48	C IV 1.5 (FWHM = 46 Å); C III λ5696 0.8
MC 50	WNE	2.2	40	N V 1.4
OB 6-5	WN8	0.4	13	N III 0.2
OB 21-65	WN6+abs	1.1	14	N III, N IV present
OB 66-25	WN8	0.2	6	N III 0.6; emission very weak. Of?
W91-129	WN7+abs	0.7	13	N III
OB 88-7	O8Iaf	−0.2	3	N III −0.2

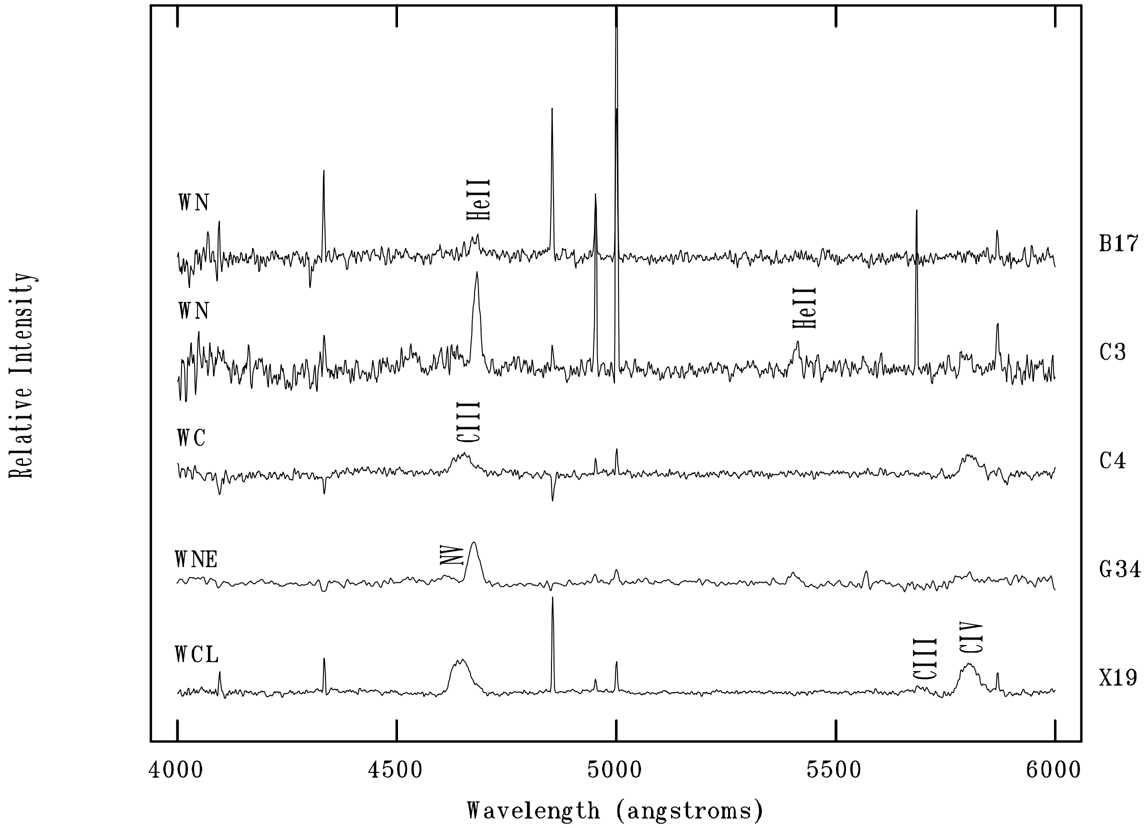

FIG. 3*a*

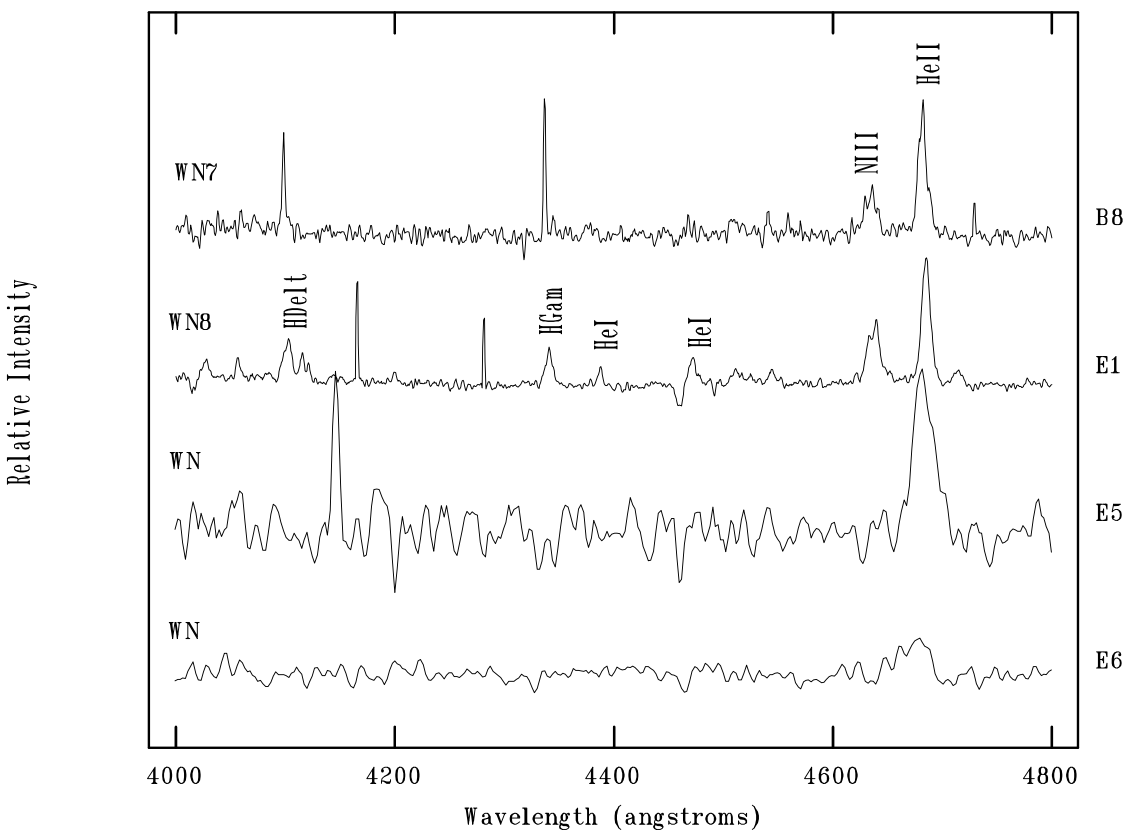

FIG. 3*b*

FIG. 3.—Spectra of 17 of the newly discovered WR stars are shown normalized to the continua. (*a*) Spectra of five stars in the wavelength range 4000–6000 Å. The lines identified are N V $\lambda\lambda$ 4603, 4619, C III λ4650, He II λ4686, He II λ 5400, C III λ 5696, and C IV λ5812. (*b*–*d*) Spectra of the remaining stars in the wavelength region 4000–4800 Å. (*b*) Lines identified include the Balmer lines Hδ and Hγ, He I λ4387, He I λ4471, N III $\lambda\lambda$4634,42, and He II λ4686. (*c*) The He II λ4686 feature is identified. (*d*) The He II λ4686 feature is marked. Note that the star X9 either contains unresolved N III 4634, 4642, or else is a WC star with the broad feature a blend of C III 4650 and He II λ4686.

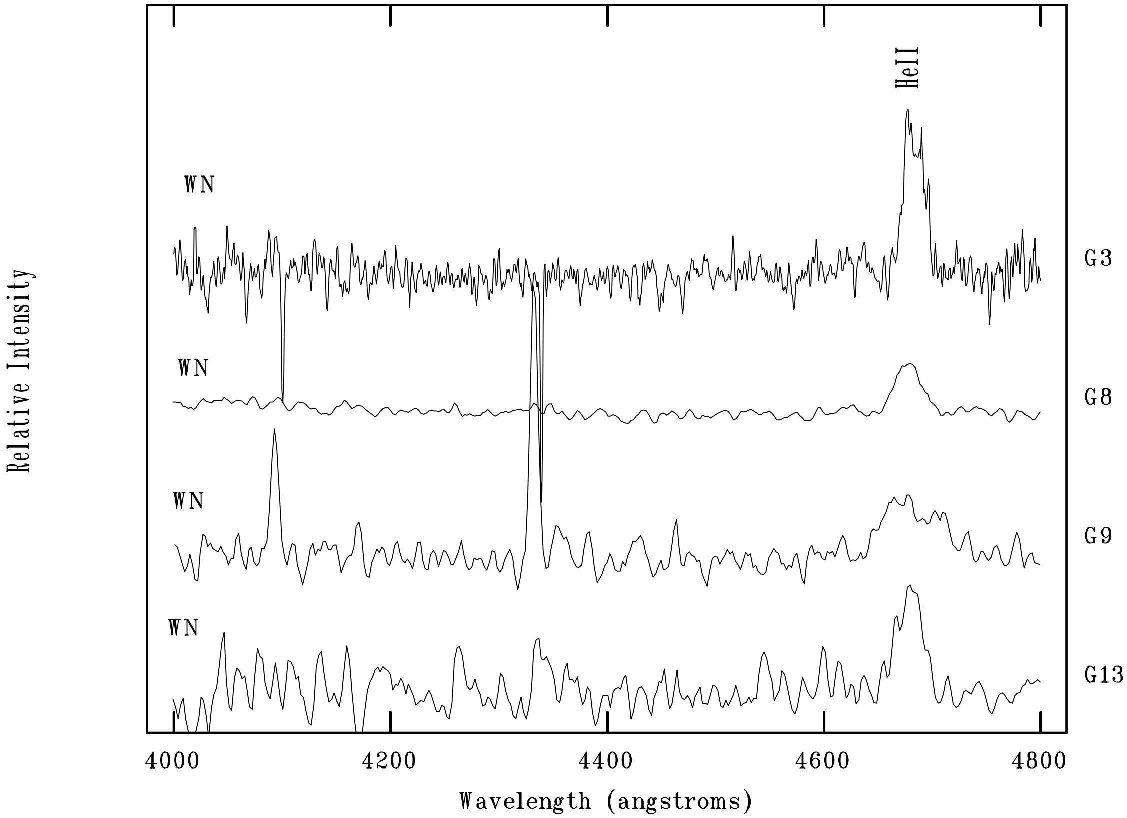
HeII
WN
G3
WN
G8
WN
G9
WN
G13
Relative Intensity
4000
4200
4400
4600
4800
Wavelength (angstroms)

FIG. 3*c*

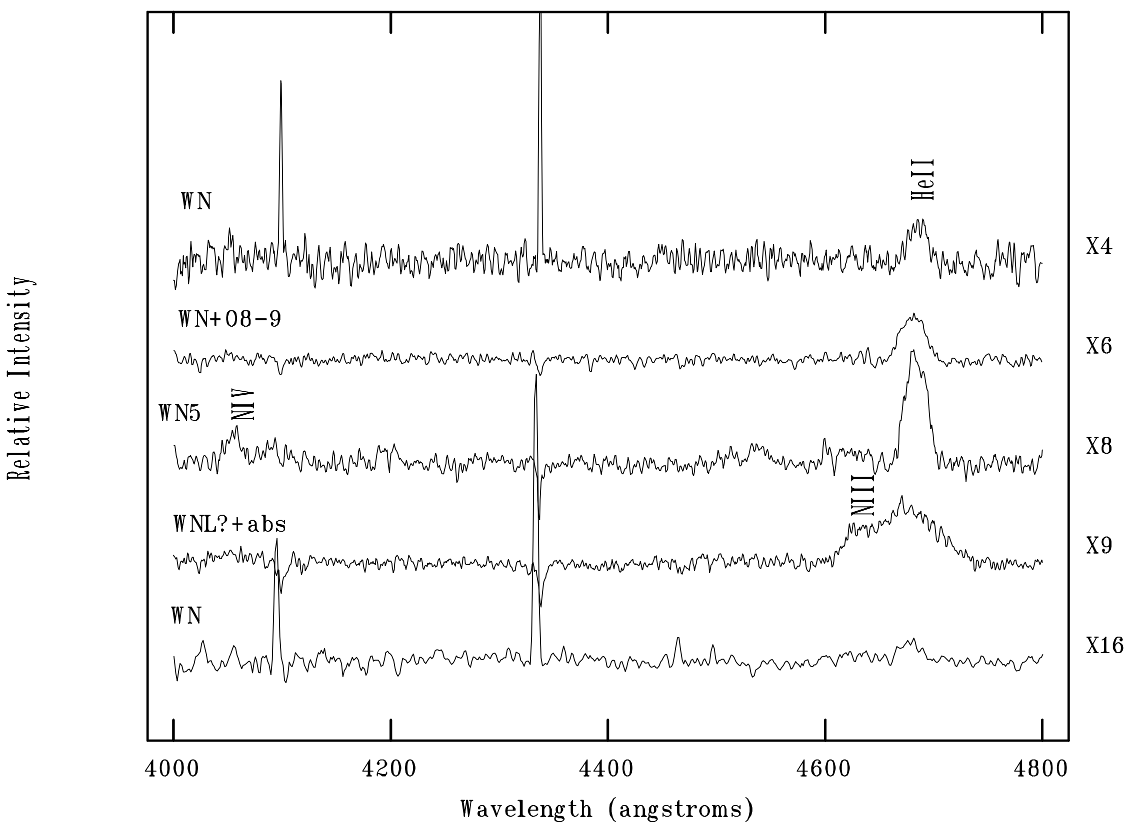
WN
HeII
X4
WN+O8-9
X6
WN5
NIV
X8
NIII
WNL?+abs
X9
WN
X16
Relative Intensity
4000
4200
4400
4600
4800
Wavelength (angstroms)

FIG. 3*d*

Little can be said about E5, other than that strong He II λ4686 is present. In Figure 3*c* we again see three generic WN stars; we can be sure that these stars are not as late as WN7 (or else N III would be present), but at these S/Ns, little else can be said. In Figure 3*d* we see the spectra of five more WN stars. Careful inspection of the spectrum of X6 shows the presence of absorption lines; we classify the companion star as O8-9. (An "Of" classification for this star can be ruled out based upon the lack of N III emission and the broadness of the He II feature.) The star X8 shows N IV λ4058 stronger than either N III λ4634, 4642 or N V λ4602, 4619, which are missing at our S/N. The spectrum of X9 is very peculiar, with a double-peaked emission feature. Our initial impression of this spectrum was that it had to be a WC star, with strong C III λ4650 blended with He II λ4686 as is common in WC stars. However, a careful inspection of the wavelengths indicates that the blue peak more likely corresponds to N III λ4634, 4642. This would make the star a late-type WN star, although narrow lines are a feature of WNL stars. A second spectrum obtained of this star did nothing to clarify this mystery. The star X16 is a good example of a weak-lined WN star; the measured EW is comparable to strong-lined Of stars. A better spectrum of the star might possibly show absorption lines.

Determining for certain that a candidate was not a WR star was harder: particularly in the case of faint stars with weak emission, it was necessary to use an objective measure of whether the S/N was good enough to rule out the amount of emission expected based upon the $WC - CT$ or $WN - CT$ measurements. We used the procedure described in detail by AM91. In brief, we convolved our observed spectrum with the filter bandpasses, and compared the counts in the WC or WN bandpasses to that in the neighboring continuum. We then used the measured rms of our spectrum to ask how much emission could be hidden within 3 σ of the noise. If there was a 0.2 mag or greater discrepancy between this number and the amount of excess expected from our photometry, we then declared the candidate a non-WR star.

2.1.2. *Detection Limits*

We now return to the question of our detection sensitivity. We can ask the question: would we have detected WR stars as weak lined as those found in the Milky Way or Magellanic Clouds? In Figure 4 we show the equivalent width measures versus the magnitude differences $WN - CT$ or $WC - CT$ for the spectroscopically confirmed stars in our survey. Some of the scatter in this figure is doubtless due to measuring uncertainties in the line strengths, particularly in the case of weak continuum; we estimate that our uncertainty is typically 0.2 dex. The scatter is also attributable to the fact that the widths are greater than the 50 Å bandpass of our interference filters; i.e., not all of the line will be contained within the filter.

One of the stars with a small magnitude difference that did show up in our survey was the extreme Of star OB 88-7. Massey et al. (1995a) classified the star as an O8 Iaf, with the "a" denoting strong emission for an Of star, and hence high luminosity. It has long been known that the line strength of He II λ4686 of the most extreme Of stars approaches that found in the weakest lined WN stars. For instance, the extreme Of stars HD 14947, HD 15570, and HD 16691 have EWs of −3 to −7 Å (Conti & Frost 1977); i.e., log (−EW [Å]) = 0.5–0.8. As discussed below, the

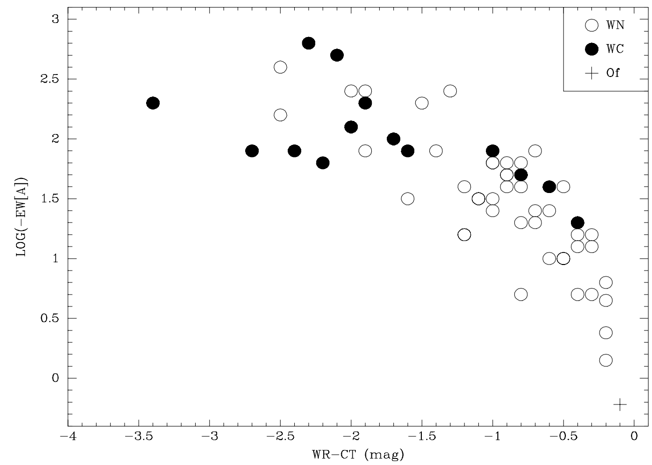

FIG. 4.—Equivalent widths (EW) of the He II λ4686 line (WN stars) and the C III λ4650 line (WC stars) are shown plotted as a function of the magnitude difference ($WN - CT$ or $WC - CT$). The data for the equivalent widths are from Table 3 from the current work, from MCA87, and from AM91.

weakest lined WN star in the SMC has log (−EW [Å]) = 0.8. There are actually six stars among our WNs in Table 3 with EWs weaker than this, in addition to the O8 Iaf star OB 88-7. In some of these cases (such as OB 66-25), it may be that the star simply is an Of star, and at our S/N and resolution we were unable to discern the absorption spectrum.

However, a survey such as ours is actually flux limited in terms of its detection. An interesting consequence is that stars with lines whose EWs are low because of a companion star will nevertheless have the same line flux and hence should have a similar "significance level." Although the equivalent widths will be weaker, and hence the magnitude difference will be smaller, the errors on the magnitudes will also be smaller because the star is brighter because of its companion.

Let us consider some examples. The weakest lined WN stars (in the sense of equivalent widths) known in the Milky Way and the LMC are the WN9 stars, where the EW of He II λ4686 becomes comparable to that of Of stars, approximately −10 Å; i.e., log (−EW [Å]) = 1.0. (See Figs. 4 and 5 of MCA87.) However, the late WN stars (WN7–9) also are the more luminous, and hence even a small magnitude difference may be quite significant. In fact the Ofpe/WN9 stars turn out to be among the UV-brightest population in M33, and spectroscopy of *UIT* sources revealed six such stars (Massey et al. 1996). Two of these were actually first discovered as part of the present survey (C7 and X15) with very small magnitude differences (−0.2 to −0.3 mag) but very high significance levels (24.4 and 13.2 σ).

The SMC WN stars are early in type but have extremely weak emission lines compared to those of Milky Way or LMC stars, either because of putative binary companions or because of weak stellar winds, according to Conti, Garmany, & Massey (1989), who list the weakest lined star as AB6, with log (—EW [Å]) = 0.86, and $M_v = -7.1$. Even if such a star were located in the most heavily reddened OB association in our sample (Massey et al. 1995a), with $E(B-V) = 0.3$ and $A_V = 1.0$ mag, its continuum magnitude would be 18.5. Inspection of Table 2 suggests that the expected magnitude difference of −0.2 to −0.3 mag would be evident at >10 σ.

More typical examples are fainter in absolute magnitude but have stronger equivalent widths. In Figure 5 we show the line fluxes of the He II λ4686 line as a function of absolute magnitude. We have approximated the line fluxes by simply taking the measured EWs (Conti & Massey 1989; Conti et al. 1989) and multiplying by $10^{-M_V/2.5}$ for easy comparison with the M33 data. We see that there actually is a trend (as discussed by Conti & Massey 1989); the stars with the fainter absolute (visual) magnitudes really do have lines with smaller fluxes in the line and thus are the hardest to detect.

We can see immediately from this figure that we obtained spectroscopic confirmation for stars as difficult to detect as nearly any stars in the LMC or SMC. The three faintest stars in our sample, G9, MC 12, and MC 50, were found with significance levels of 7.7, 9.5, and 8.1 σ, respectively, well above the 3.0 σ cut-off we imposed in our selection of WR candidates. The three stars with the smallest line fluxes are B17, X16, and OB 88-7. The latter is the O8 Iaf star previously discussed. The first two were found with significance levels of 7.1 and 5.0 σ, again well beyond the 3.0 σ cut-off. Of course, at either of these extremes, our sample of spectroscopically confirmed stars will be biased toward the easiest to detect sample (i.e., at faint magnitudes we will favor the detection of the stronger lined stars). However, the comparison with the distribution of the Magellanic Cloud sample is reassuring.

We can go one step further in addressing this, by plotting the significance level as a function of line flux for our spectroscopically confirmed sample (Fig. 6). In this figure, we emphasize the location of the 3 and 5 σ detection levels as dashed lines. We will discuss our detection success rate as a function of significance level in the following section, but here we note that we spectroscopically confirmed only two WR stars with significance levels below 5 σ, although to some extent this was due to the considerable greater effort involved in detecting the weaker lined stars spectroscopically. While this sample may be incomplete at lower significance (<5 σ) levels in that spectroscopy wasn't obtained, the distribution of stars above 5 σ, and certainly above 10 σ, should be nearly complete. A least-squares fit to this later subsample suggests that on average a 5 σ detection should find stars that are as weak or weaker than any Magellanic Cloud WN star (Fig. 5). We expect that even given the scatter in this diagram we should have successfully detected the vast majority of bona fide WN stars with a significance level of 5 σ or greater.

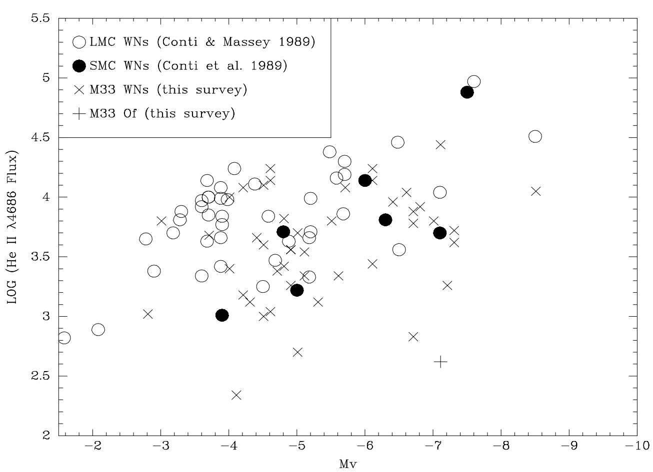

FIG. 5.—Emission-line flux of the He II λ4686 line is approximated by taking the measured EWs and multiplying by $10^{-M_V/2.5}$. The EWs for the LMC stars come from Conti & Massey (1989); those for the SMC from Conti et al. (1989); and those for M33 from the present study. The absolute magnitudes for the LMC stars were taken from Vacca & Torres-Dodgen (1990) if available; otherwise, we adopted a constant reddening $E(B-V) = 0.12$ and a distance modulus of 18.3. The absolute magnitudes for the SMC WN stars come from Conti et al. (1989a, 1989b). The absolute magnitudes for the M33 stars were approximated by using the CT magnitudes in Table 2, an average reddening $E(B-V) = 0.16$ (Massey et al. 1995a), and a distance modulus of 24.63 (Madore & Freedman 1991).

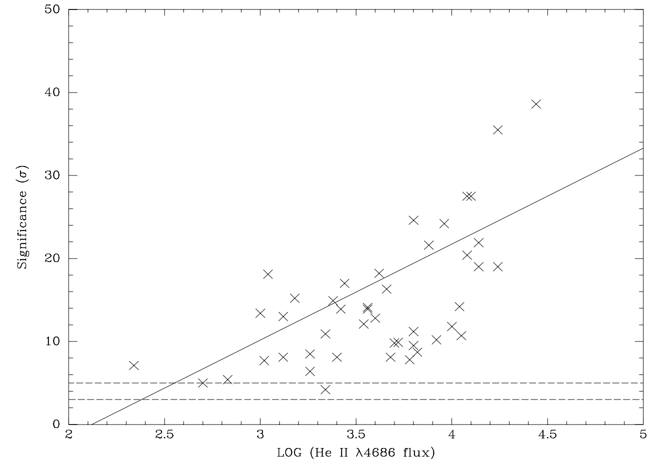

FIG. 6.—Significance level $WN-CT$ is shown as a function of the He II λ4686 line flux for the spectroscopically confirmed WN stars in our sample. The two dashed lines at the bottom correspond to 3 and 5 σ. The solid line is a least-squares linear fit to the data with >10 σ, which should be complete.

Of course, we do run the risk of including some Of stars in our sample by being as sensitive to weak emission as we are. We have already discussed the O8 Iaf star OB 88-7. We have included magnitude differences as small as 0.1 mag among our candidates, although only if the significance level was 5 σ or greater. Buried among these we might expect to find additional Of stars.

What about the WC stars? Since the absolute magnitudes of WCs and WNs are very similar (Vacca & Torres-Dodgen 1990) but the weakest equivalent widths are still considerably stronger than those of the weakest WN stars (Fig. 1), at most we may miss the occasional star through misfortune in crowded regions.

2.1.3. *Success as a Function of Significance Level*

Since we lack sufficient spectroscopy to be certain whether each WR candidate is a bona fide WR star or not, we must use the spectroscopic sampling we did obtain to determine our success rate as a function of significance level. These data are summarized in Table 4A. We see that our success rate is excellent (>90%) for our highest significance

TABLE 4A

SUCCESS RATE

	NUMBER OF CANDIDATES			
SIGNIFICANCE	Confirmed	Non-WR (?)	Unknown	SUCCESS (percent)
>10 σ	62	1	5	98
>7.5–10.0 σ......	12	1	1	92
>5.0–7.5 σ	4	1	11	80
3.0–5.0 σ..........	2	7	36	22

($>10\ \sigma$) candidates and falls as we go do down in significance level.

We have the occasional failure at high significance level: the faint star B14 was found at a 15 σ significance level on a single set of images and appears to be a non-WR star. The star B12 was found on two sets of images, at a 9 σ significance level, and yet its spectrum is clearly that of a B8 I star. Examination of these images reveals that both stars are extremely crowded: B 12 is a blend of two equally bright stars separated by only 2.5 pixels (2.5 pixels is typically the fitting radius used for the point-spread function [PSF]); star B14 is one PSF radius (11 pixels) from a star 5 mag brighter. The B14 also has a *CT* mag approximately 1.5 mag fainter than the *V*-band photometry described by Massey et al. (1996); it is possible that the star is variable and that this variability led to its false detection.

Unsurprisingly, we have the lowest success rate, and greatest number of unknowns, for our low-significance (3.0–5.0 σ) candidates. How many of these do we expect to be real? Based upon the scant spectroscopy in this group, we expect only a 22% success rate, or about eight stars out of the 38 unknowns to be real.

However, there is a bias in this spectroscopy—most of the stars we observed spectroscopically with small significance levels were the ones that were detected independently on two sets of frames. We can make use of the additional datum of whether or not a star that was present on two sets of images was found on both or only singularly. In Table 4B, we have separated our stars into those that were detected twice and those that were detected only once. We see from this table that the number of detections provides valuable information in predicting whether a candidate is real or not. Of the confirmed WR stars that were found with low significance levels, both were found on two sets of frames. Of the seven non-WRs in this group, all but one were single detections. Of the remaining 36 candidates, 33 are within the field of view (FOV) of two sets of frames but were found on only one. (The remaining three were only within the FOV of one frame.) We believe we can safely ignore these stars as unlikely to be real.

TABLE 4B

SUCCESS RATE AND NUMBER OF MULTIPLE DETECTIONS

	Number of Candidates			
Significance	Total	Only 1 FOV	2 FOVs, 1 Detection	2 FOVs, 2 Detections
	Confirmed WRs			
$>10\ \sigma$	62	18	2	42
>7.5–$10.0\ \sigma$	12	2	3	7
>5.0–$7.5\ \sigma$	4	0	2	2
3.0–5.0 σ	2	0	0	2
	Non-WRs (?)			
$>10\ \sigma$	1	0	1	0
>7.5–$10.0\ \sigma$	1	0	0	1
>5.0–$7.5\ \sigma$	1	0	0	1
3.0–5.0 σ	7	0	6	1
	Unknowns			
$>10\ \sigma$	5	2	1	2
>7.5–$10.0\ \sigma$	1	0	0	1
>5.0–$7.5\ \sigma$	11	1	5	5
3.0–5.0 σ	36	3	33	0

Should we be surprised at the number of false detections we are assuming in the 3–5 σ range? Not really. In doing this survey, we obtained photometry of over 22,500 stars; i.e., 67,500 photometric data were analyzed in all three filters). A star that is 3 σ brighter in either the *WC* or *WN* exposure relative to that of the *CT* exposure will be considered a WR candidate (if it were 0.25 mag or more brighter). In a Gaussian distribution of data, 99.730% will lie within $\pm 3.0\ \sigma$ of the mean. Of the expected number of data lying outside this range, only half will have positive differences, but we would call an outlier a candidate if *either* the $WC - CT$ or $WN - CT$ index were significant. Thus if we had imposed no magnitude difference constraint, we would expect something like 0.270% of 22,500 stars, or 61 stars, to be spurious detections. Considering the distribution of errors in our photometry, we expect 46% to have errors ≤ 0.083 mag ($3\ \sigma = 0.25$) and 20% to have errors ≤ 0.050 mag ($5\ \sigma = 0.25$). Thus the actual number of spurious detections in the 3–5 σ range should be 54%–80% of 61, or 33–49. Our adopted number of 43 (36 assumed plus 7 known non-WRs) is thus quite consistent with the number of spurious detections we expect on purely statistical grounds.

We can invoke one additional piece of information in eliminating spurious detections: the broadband colors. Massey et al. (1996) describe a catalog of *UBV* photometry of $\sim$4300 stars covering the face of M33. The fainter WR candidates are too faint for inclusion in this, but the brighter stars ($V < 20$) are likely to be included. There are three stars in Table 2 whose colors are not those of a hot object. B14 (described above) had $U-B = 0.20$ and $B-V = 0.17$, and hence a reddening-free index $Q = +0.08$. Spectroscopy demonstrated this star is a non-WR star. Both A9 and B19 have colors suggesting that they are very red objects. (A9 has $U-B = 2.12$ and $B-V = 1.24$; B19 has $U-B = 1.91$ and $B-V = 1.49$.) Both of these also have very small magnitude differences between the emission-line filters and the *CT* filter, only marginally large enough to be included in our list. We will assume that neither of these stars are real WRs, despite having been detected independently on two sets of frames. Both of these have significance levels in the >5–$7.5\ \sigma$ category.

For the remaining candidates with "Unknown" status in Table 4, we will assume that all of the candidates of $>7.5\ \sigma$ are real, that the other three >5–$7.5\ \sigma$ candidates that were detected twice are real, and that none of the 3–5 σ candidates are real.

Throughout this analysis we have assumed that the interstellar extinction within the disk of M33 is constant—that our detection limits will not be overly affected by differential reddening within M33. Massey et al. (1995a) gives $E(B-V)$ values for OB stars covering the same areas as discussed here, except for the central region. The range in $E(B-V)$ is small (0.09–0.33) and should not affect our results. While we do not have comparable data on the inner region (field M33-X), photometry has been published on the *UIT* sources in this field, including three confirmed WR stars and one high-significance WR candidate (Table 2). The $B-V$ values of these stars range from -0.11 to -0.23, suggesting that the reddening is not appreciably higher for these stars.

Finally we turn to the question of how successful we were in *classifying* the stars photometrically. Comparison of the predicted and actual spectral types in Table 2 shows that we were correct in 77 out of 80 cases (96%). Of the other three, two were classified as uncertain WNs (WN?) and are in fact WC, while the third one (X9) was classified photometrically as "WC" and the spectrum itself is ambiguous—either that of a peculiar WNL star or that of a WC (§ 2.1). We will therefore adopt the photometric spectral subtypes for the "unknown" stars that we are assuming are bona fide WRs.

3. RESULTS: THREE TESTS OF THE CONTI SCENARIO

We are now ready to proceed with combining these new data on the WR content of M33 with what is known from other Local Group galaxies. The data on these other galaxies is summarized by AM91 and Massey & Armandroff (1995). Here we will simply reiterate that NGC 6822, IC 1613, and IC 10 have been exhaustively searched for WR stars via this same CCD technique, with extensive follow-up spectroscopy; the confirmed WR stars given by AM91 and Massey & Armandroff (1995) are taken as a complete census.

Eight fields in M31 have been similarly surveyed; we count the 24 confirmed WR stars of AM91 plus assume that three of the four remaining high-significance candidates are real. The Magellanic Cloud data comes primarily from objective prism surveys and is relatively complete, although a few WR stars were subsequently detected by spectroscopy in the LMC and/or reclassified (Breysacher 1981; Conti & Massey 1989; Crowther & Smith 1997). The SMC census is likewise considered complete, and an unpublished CCD survey for WR stars in the SMC's OB associations failed to detect any additional candidates (Massey 1996). WR stars in the Milky Way come primarily from the HD catalog with a few subsequent additions, with distances and spectral types from Conti & Vacca (1990); we will return to this point below.

3.1. *The WC/WN Ratio and The Relationship with Metallicity*

One of the first implications of the Conti scenario to be recognized (§ 1) was that the relative number of WC and WN stars in a mixed age population should depend upon the metallicity, as this will control the mass-loss rate for a given stellar luminosity. The metallicity of the young stellar component of a galaxy is assumed to be that of the gas, measurable from the nebular emission-line spectra of H II regions. It is the oxygen abundance that is most reliably measured, which is highly fortuitous as it is oxygen (along with carbon and nitrogen) that is the primary accelerator of the stellar wind at the high effective temperatures appropriate to O-type stars (Abbott 1982). Although these elements do not always track each other, particularly in galaxies of low metallicity (see, e.g., Garnett 1995), we will stay with the standard assumption that a galaxy's metallicity Z is proportional to the oxygen abundance (Lequeux et al. 1979).

We thus expect to find a galactocentric gradient of the WC to WN ratio in M33, as the presence of a strong oxygen abundance gradient is well established (Searle 1971; Kwitter & Aller 1981; Vilchez et al. 1988; Zaritsky, Elston, & Hill 1989; Garnett et al. 1997). Massey & Conti (1983) indeed found such a gradient in the WC/WN number ratio, finding that it changed from ~ 2 in the inner regions to ~ 0.5 in the outer. They believed that, although the absolute numbers may have been too high (because of the under-representation of the harder-to-find WN stars), the gradient itself was real, with WN stars equally unrepresented at all galactocentric distances. However, it is not clear if this is really true in the central region, an area where the detection of WN stars might be selectively harder with photographic material. Let us reexamine this question with the new data.

In Figure 7 we show the WC/WN ratio of galactocentric distance within M33, and compare this to that found by Massey & Conti (1983). We have subdivided the galaxy into three bins; this coarse division is necessary as we must be sure that we are including stars of different ages. (At a given metallicity, the WC/WN ratio of a coeval group will reflect only the age, as described in the introduction.) The quantity ρ is the galactocentric distance within the plane of M33, normalized to the Holmberg radius using the assumptions in Table 2; for the Madore & Freedman (1991) Cepheid distance modulus $(m-M)_o = 24.63$ (843 kpc), $\rho = 1.00$ corresponds to 6.13 kpc.

We see that the gradient with galactocentric distance is quite real and is in fact similar in magnitude to that suggested by Massey & Conti (1983): we find a change of a factor of 3 from the center to the outer portions (Table 5). The fears voiced by Massey & Conti (1983) that the absolute WC/WN number ratio was overinflated because of a selective incompleteness for WN stars are also confirmed. The galaxy-wide average WC/WN in Massey & Conti (1983)'s data was 0.88; that of the survey here is 0.39, indicating a factor of over 2 incompleteness for WN stars in the photographic study, in accord with estimate given by AM91.

Let us now use these new data in conjunction with data on WC/WN ratio and abundances in other Local Group galaxies. We have summarized these data in Table 5, updated from Massey & Armandroff (1995). In addition, we have taken advantage of the improved knowledge of the metallicity abundances where appropriate. We show the corresponding plot of WC/WN ratio with oxygen abundance in Figure 8, using the values tabulated in Table 5.

The new data on M33 have had a profound effect on this relation: we find now a very good relationship between the WC/WN number ratio and metallicity, with the notable exception of IC 10. Prior to this study, the M33 data argued that we were seeing very different WC/WN ratios for galaxies of the same metallicity (see discussion in Massey &

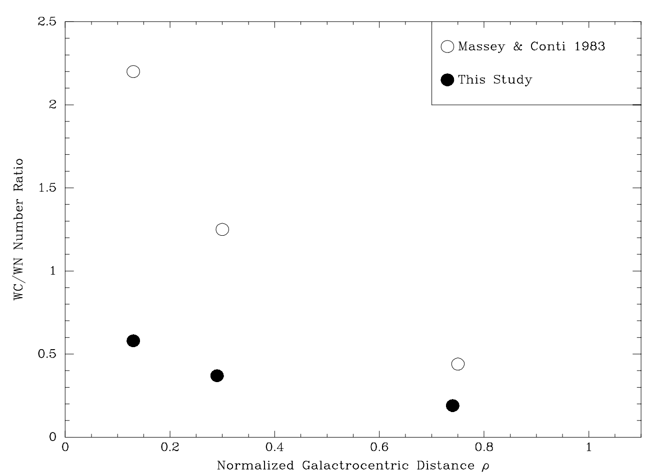

FIG. 7.—WC/WN ratio determined from the present study is compared to that found from by Massey & Conti (1983). Although the absolute WC/WN ratio has been substantially reduced because of the inclusion of many WN stars that were undetected on the older photographic study, there is still a clear gradient with galactocentric distance.

TABLE 5

WC/WN IN THE LOCAL GROUP

Galaxy	WRs	WC/WN	WRs kpc^{-2}	Abundance 12 + log (O/H)	Reference
M33 (8 CCD fields)............	97	0.39	4.1	...	
$0.0 < \rho \leq 0.2$ ($\bar{\rho} = 0.13$)......	30	0.58	...	8.75	1
$0.2 < \rho \leq 0.4$ ($\bar{\rho} = 0.29$)......	48	0.37	...	8.65	1
$\rho > 0.4$ ($\bar{\rho} = 0.74$)	19	0.19	...	8.30	1
IC 10	15	2.0	5.1	8.25	2
IC 1613	1	(1 WC)	0.7	7.85	3
NGC 6822	4	0.0	0.6	8.25	4
SMC	8	0.1	0.9	8.13	5
LMC	108	0.19	2.1	8.37	5
Milky Way ($d < 3$ kpc).........	64	0.88	2.4	8.70	6
M31 (8 CCD fields)............	27	0.9	0.7	9.00	7

REFERENCES.—(1) Garnett et al. 1997; (2) Garnett 1990; (3) Talent 1980; (4) Pagel, Edmunds, & Smith 1980; (5) Russell& Dopita 1990; (6) Esteban & Peimbert 1995; (7) Zaritsky et al. 1994.

Conti 1983 and Massey & Armandroff 1995), but the relative completeness of the present study results in a clearer and cleaner picture emerging: the relationship is actual quite good. We have not included error bars on this figure, but the typical uncertainty in the metallicity determination is 0.1 dex. In some cases the actually *range* of oxygen abundances is greater than that; for instance, for the ± 3 kpc difference in galactocentric distance in the Milky Way, the Esteban & Peimbert (1995) gradient would predict that the oxygen abundance would range from 8.5 to 9.1. We have also included the total number of WR stars used for each galaxy in Table 5; we see that the small number for NGC 6822 (four) and for the SMC (seven) renders these points less certain than the others, just from a timing issue: observed at another time, we would expect that these galaxies might show ratios that were numerically quite different. We have chosen not to include IC 1613 on this graph given that it contains only one WR star (of WC type).

Given these uncertainties, the correlation of the WC/WN number ratio with metallicity in Figure 8 is excellent, with the exception of IC 10, which we discuss below. It is interesting that the Milky Way point is high compared to the general relation. We have used the data from the Conti & Vacca (1990) compilation and included only those WR stars

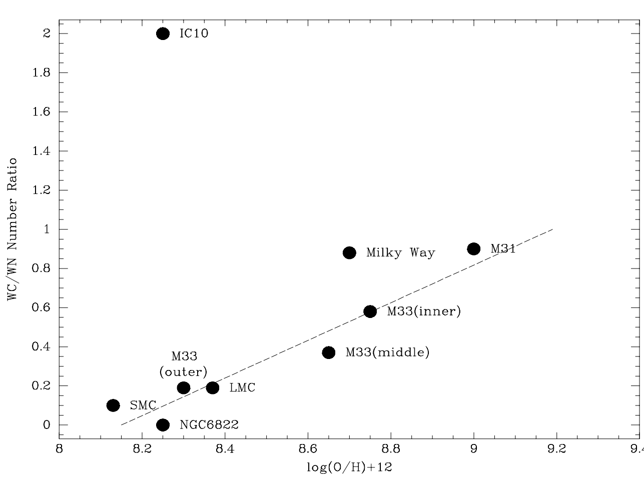

FIG. 8.—WC/WN ratio for Local Group galaxies is shown plotted against the oxygen abundance. The data comes from Table 5. The dashed line is the least-squares fit, ignoring the data points for IC 10 and the Milky Way, for the reasons discussed in the text.

within 3 kpc of the sun, as it was thought by Conti et al. (1983) that this sample was probably complete. But, given what we have found in our new survey of M33, it is worth reexamining this claim. Most, although not all, of the WR stars in the Milky Way sample were discovered as part of the Henry Draper catalog. The typical absolute magnitude of an early-type WN star is -3.8 (Conti & Vacca 1990). With no extinction, such a star would have $V = 8.5$ at a distance of 3.0 kpc, within the probable completeness limit for the HD survey. However, the *average* extinction found for 10 Galactic OB associations studied by Massey et al. (1995b) at similar distances is $A_V = 2.3$ mag. Thus, a typical WNE star at 3 kpc will have $V = 10.8$, and its inclusion in the HD catalog will be problematic. Thus, the WC/WN for the solar neighborhood really must be taken as an upper limit, again for the reason that WC stars near the limit are far more likely to be discovered in objective prism surveys than WN stars.

What, then, about IC 10? Massey & Armandroff (1995) argue that the anomalously high WC to WN ratio is real and suggest that it is somehow connected with IC 10 being a classic "starburst," with galaxy-wide star formation proceeding at a prodigious rate. Indeed, if we compare the number of WR stars per square kiloparsec tabulated in Table 5, we find that the galaxy-wide average is greater than that of the 8 CCD fields we chose for M33—despite the fact that we purposefully chose regions that were centered on the most active OB associations. There are two possibilities that we consider likely. (1) The high star formation rate in IC 10 has biased the IMF toward higher mass stars. This is the view espoused by Massey & Armandroff (1995) and is in accord with the suggestion by Larson (1985, 1986) that fragment mass should be related to gas temperature. However, since that time, Massey & Hunter (1998) have investigated the IMF of the extreme object R136, a "supercluster" at the heart of 30 Dor in the LMC, and find that the IMF of the massive stars is perfectly "normal", i.e., Salpeter, and as such is indistinguishable from those of OB associations that are 200–1000 times as sparse. (2) Daniel Schaerer has argued (see discussion following Massey 1996) that models of starbursts predict that 30% of WR-rich galaxies will be dominated by WC stars, even at low metallicity. Basically this is simply saying that the "mixed age" argument does not apply for a starburst galaxy: if the massive star population (of the entire galaxy!) is coeval, then the relative number of WC and WN stars will simply reflect the time since the burst occurred. However, that would require that the duration of the burst to have been incredibly short, comparable to the life of the WC stage, perhaps 0.5 Myr. (For further discussion, see Schaerer & Vacca 1998.) While it is clear that most of the massive stars in OB associations have formed over a short time (less than or equal to 1 Myr, according to Massey et al. 1995b), such an explanation for a high percentage of WC stars in a starburst would require coevality over a scale of a kiloparsec (rather than a few parsecs) of a high order. Still, the high ratio in IC 10 does require some explanation.

A third possibility, which we need to consider here, is that the survey of IC 10 was less complete for WN stars than supposed by Massey & Armandroff (1995). They argue that they had detected stars with as small EWs as known in the Magellanic Clouds, but they did not actually consider the issue from the perspective of line fluxes. Using the $(m-M)_o = 24.57$ Cepheid distance of Wilson et al. (1996), the reddenings found by Massey & Armandroff (1995), and the *CT* fluxes of Massey, Armandroff, & Conti (1992), we have computed the absolute magnitudes and intrinsic emission-line fluxes for the five WN stars in IC 10 as we did for the Magellanic Cloud and M33 WN stars in § 2.1.2. We list these in Table 6. Comparing these values to those shown in Figure 5, we find ourselves in accord with the Massey & Armandroff conclusion: stars as weak lined as even the SMC stars were detected in IC 10. We do note that two of the IC 10 WN candidates (IC 10 WR 3 and WR 16) lacked sufficient spectroscopy to show whether or not they were WR stars. One of these was detected twice; the other once. If these both proved to be bona fide WR stars, the WC/WN ratio would be decreased to 1.4, still highly anomalous in Figure 8.

We have computed a least-squares linear fit to the data in Figure 8 simply as a guide to which models may be compared; excluding the IC 10 and Milky Way points (for the reasons given above) leads to

$$\mathrm{WC/WN} = 0.96 \times [12 + \log(\mathrm{O/H})] - 7.82 .$$

We illustrate this fit in Figure 8. The scatter about this curve is 0.08 in the WC/WN ratio. The fact that this relationship is so tight (despite the uncertainty in the abundances, and the effect of small-number statistics for the SMC and NGC 6822) provides extremely strong support for the implication that massive star evolution is strongly influenced by the effects of metallicity acting through mass loss, the fundamental tenet of the Conti scenario (Maeder & Meynet 1994).

3.2. *Wolf-Rayet Spectral Properties: Metallicity Effects?*

It has long been known that the relative proportions of various Wolf-Rayet spectral subtypes were different in the Magellanic Clouds than in the Milky Way (Smith 1968). For instance, no late-type WC (WC7–9) stars are found in the LMC or SMC, and nearly all the ones known in the Milky Way occur inward of the solar circle. Similarly, few late-type WC stars have been found in M33, although the higher metallicity M31 does contain some stars of type WC7 and possibly later. The fact that late-type WC are generally not found in regions of lower metallicity has suggested some linkage between metallicity and spectral subtype.

Schild, Smith, & Willis (1990) observed several of the known M33 WC stars and found a very interesting result: there appeared to be a correlation of the line widths of early WC4–5 stars with galactocentric distance within the galaxy. This effect was further quantified by AM91, who included EWs in their comparisons and showed that the same effect was present not only in M33 but also in the Milky Way—but was lacking in M31. Here we update this discussion using all the data available.

In Figure 9*a* we show the spectral subtypes for the Milky Way WC stars as a function of emission-line strength [log (−EW [Å])] and line width (FWHM). The stars follow the "inverted hockey stick" pattern described by MCA87, with the weaker lined stars having small line widths and the broadest lined stars all having large line widths. We note

TABLE 6

IC 10 WN Stars

Name	Type	M_V	log (He II flux)
IC 10 WR 5	WNE	−5.6	4.4
IC 10 WR 9	WN	−4.3	3.1
IC 10 WR 17......	WN	−5.3	3.2
IC 10 WR 19......	WNE	−3.6	3.3
IC 10 WR 21......	WN	−3.3	3.8

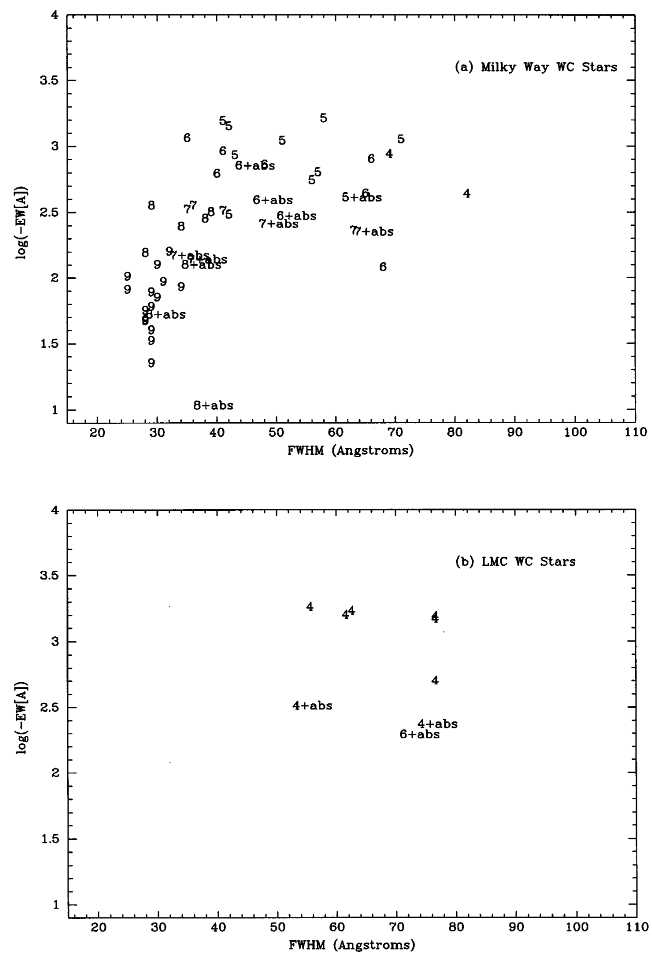

Fig. 9.—Emission line strength is plotted against line width for the unblended C IV λ5812 line for WC stars (*a*) in the Milky Way and (*b*) in the LMC. The numbers in the figures refer to the spectral subtype (i.e., "9" = WC9). We have excluded the WO stars from this figure. The data come from Conti & Massey (1989) and AM91.

that binaries or stars with line-of-sight companions ("+abs") behave as expected: the emission-line strengths are diluted by the continuum of the companion, but the line widths are not changed substantially, and hence these stars will fall low relative to the other stars. In Figure 9*b* we see that the LMC stars extend the base of the "hockey stick" to broader lined stars, and that there is little overlap between the two figures—the LMC, with its relatively low metallicity, has only early-type WC stars with broad, strong lines, while the Milky Way, with its relatively high metallicity, has a mixture of types. The difference in average metallicity represented by the two figures is Δ log (O/H) $= -0.3$ dex, with average metallicities of $12 + \log$ (O/H) $= 8.7$ and 8.4 (see Table 5).

In Figure 10 we divide the Milky Way data into those stars with Galactocentric distances less than and greater than 8 kpc. In going from the higher metallicity inner region of the Milky Way to the lower metallicity outer region, we see the same trend as in Figure 9 in going from the Milky Way to the LMC. The stars in the lower metallicity regions tend to have stronger, broader lines and are of earlier type. Using the median galactic distance of each of the two sets, and the Galactic abundance gradient of Figure 1 of Esteban & Peimbert (1995), we expect a metallicity difference similar to that between the Milky Way and the LMC, i.e., Δ log (O/H) $= -0.3$ dex, with values for the two bins of $12 + \log$ (O/H) $= 9.0$ and 8.7.

For M33, we divide the data similarly; we show the results in Figure 11. Here the distinction is equally dramatic. One must keep in mind that the S/N of the data for M33 (and M31) is not, in general, good enough to show the presence of absorption lines; hence, points that are low in these diagrams are likely due to the presence of a companion star. The median galactocentric distances of the two samples are $\rho = 0.30$ (1.8 kpc) and $\rho = 0.78$ (4.8 kpc); using the oxygen abundance gradient of Garnett et al. (1977), we expect a metallicity difference similar to those of the two previous examples, with Δ log (O/H) $= -0.4$ dex, and $12 + \log$ (O/H) $= 8.7$ and 8.3 for the two bins.

Finally, for M31, we show the difference in the line strength versus line width for the inner and outer regions in Figure 12. Here little or no difference is seen! AM91 explain this by citing that M31 has a much smaller metallicity gradient than either M33 or the Milky Way. The two samples were divided into two galactocentric distances, $\rho < 0.6$ and $\rho > 0.6$. (Note that we have normalized ρ to 77'.44 following Zaritsky, Kennicutt, & Huchra 1994, rather than the somewhat larger value used by AM91 in their Table 2.) The

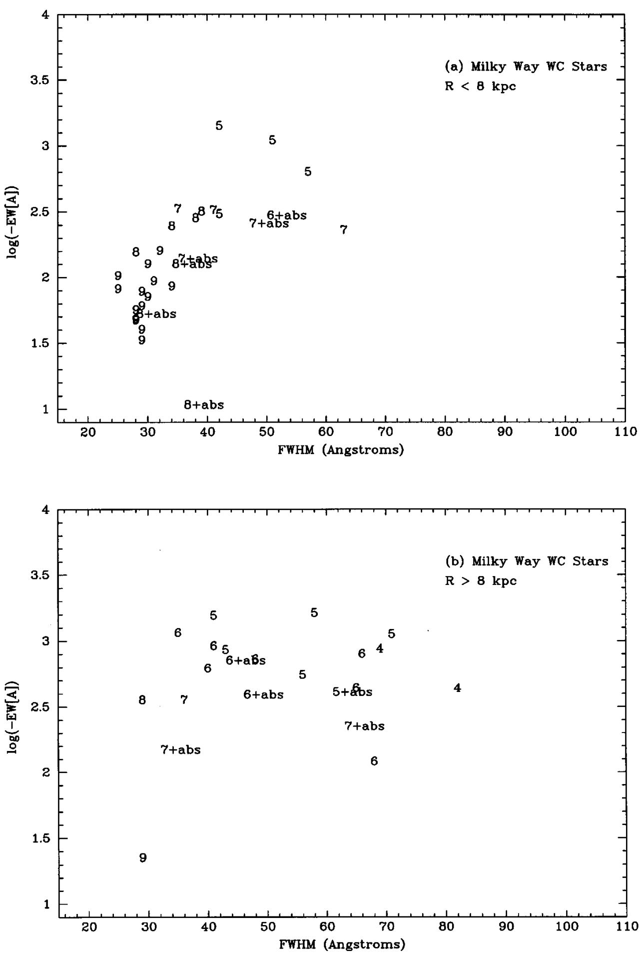

FIG. 10.—Data for the Milky Way WC stars shown in the previous figure are now shown separately for (*a*) the stars with Galactocentric distances less than 8 kpc and (*b*) stars with Galactocentric distances greater than 8 kpc. The Galactocentric distances are taken from Conti & Vacca (1990).

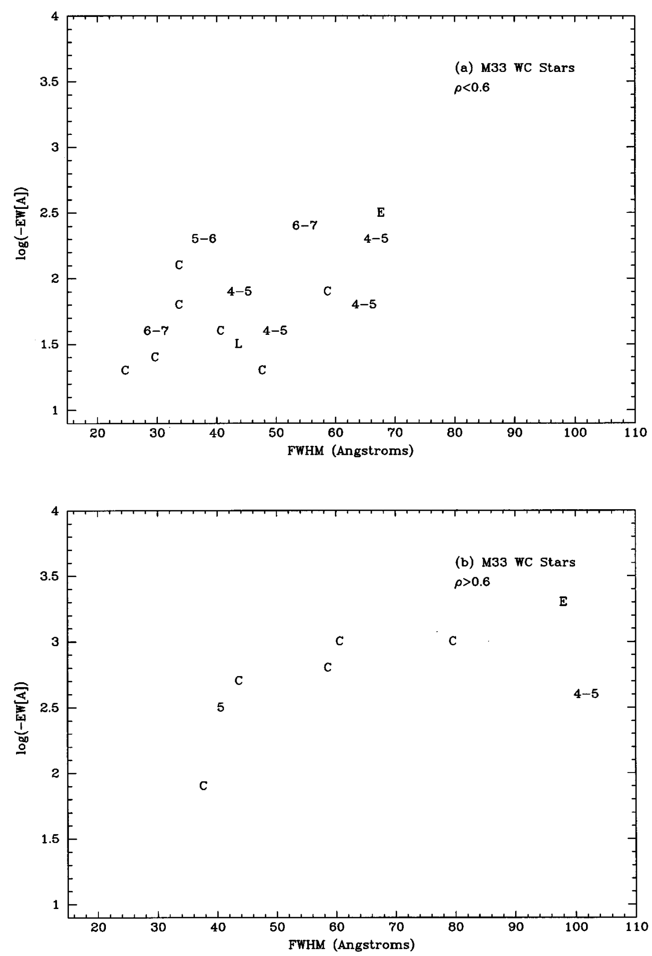

FIG. 11.—Data for the M33 WC stars are shown for stars (*a*) in the inner portion and (*b*) in the outer portion. "E" stands for "WCE," "L" stands for "WCL," and the stars for which no subtype information is available are simply denoted "C." The data come from MCA87, Schild et al. (1990), AM91, Willis et al. (1992), and from Table 3 of the present paper. As discussed earlier, $\rho = 1.00$ corresponds to 6.1 kpc within the plane of M33.

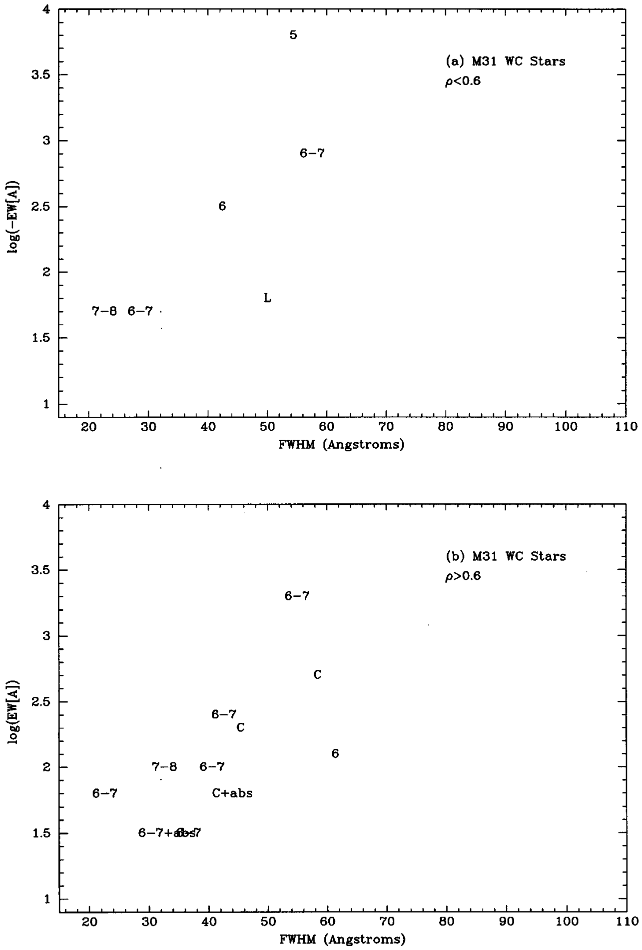

FIG. 12.—Data for the M31 WC stars are shown for stars (*a*) in the inner portion and (*b*) in the outer portion. The data come from Schild et al. (1990), AM91, and Willis et al. (1992). In computing the normalized distance ρ within the plane of M31, we have adopted the coordinates of the center, the inclination, and the position angle given by Hodge (1981) and references therein, and a Holmberg radius of 77'.44, following Zaritsky et al. (1994). Using a distance modulus to M31 of $(m-M)_0 = 24.44$ (Madore & Freedman 1991), we have that $\rho = 1.00$ corresponds to 17.4 kpc.

median galactocentric distances in the two samples are $\rho = 0.51$ (8.9 kpc) and $\rho = 0.73$ (12.7 kpc). There is little difference in metallicity over this range of galactocentric distance in M31; using the gradient given by Zaritsky et al. (1994), we expect the oxygen abundance to change by only $\Delta \log(\mathrm{O/H}) = -0.06$ dex between these samples.

Thus we echo AM91's conclusion that the differences we are seeing in the spectral properties of WC stars are due to metallicity differences: without a change in Z, we see no difference. Higher metallicity seems to result in weaker and narrower lines for WC stars. This seems to be true even within a spectral subtype: consider the distribution of WC5 stars in the two Milky Way distributions of Figure 10. The average line width of the WC5 in the inner portion of the Milky Way is smaller than that of the WC5 stars in the outer portions. Schild et al. (1990) likewise described this effect for the M33 WC4–5 stars.

We offer here a radical explanation for this effect. Perhaps we should view the various WC subtypes not as stars of differing physical properties so much as simply a reflection of the effect that metallicity has on the structure of the stellar wind. After all, we expect that the same mass range of O stars are present regardless of metallicity, as demonstrated by the consistency found for the initial mass functions in the OB associations of the SMC, LMC, and Milky Way (Massey et al. 1995b, 1995c; Massey 1998a). Let us consider for the moment the *lack* of WC4 in the relatively higher abundance of the Milky Way. How can the *lower* mass-loss rates present in the LMC produce only WC stars of subtype WC4 while none are produced in higher metallicity regions? If it were simply a matter of the mass-loss rates being higher in the inner part of the Milky Way, then we would expect to see WC4 stars that were born of somewhat lower luminosity stars, but, instead, we don't see any. We can explain this if the atmosphere structure in WC stars is essentially invariant with mass and luminosity but is instead controlled by the initial metallicity.

No such correlation with location or metallicity has been found for stars of the WN subclass (AM91).

3.3. *Comparison of the WR and RSG Populations*

Maeder, Lequeux, & Azzopardi (1980) proposed that the relative number of RSGs and WR stars should be an extremely sensitive indicator of metallicity. As described in § 1, we expect that some massive stars spend most of their He-burning sequences as Wolf-Rayet stars, while stars of somewhat lower mass spend their He-burning time primarily as RSGs. (There may be a mass range for which stars go through both a RSG and a WR phase.) What these masses are is uncertain, and of course evolution beyond the main sequence is notoriously difficult to model, even without the complication of mass loss. In the framework of the Conti scenario, we expect that the mass range of stars that become WRs is lower at higher metallicity, and that higher mass stars become RSGs (rather than WRs) in lower metallicity environments. Indeed, this is consistent with the fact that most of the WR stars known are found inward of the solar circle, while most of the RSGs are found in the outer parts of the Milky Way, exactly as one would expect if these are viewed as relative high- and low-metallicity environments, respectively. Maeder et al. used the data then available and showed evidence of an incredible gradient within the Milky Way (more than a factor of 90 change in the relative number of RSGs and WRs within 3 kpc of the sun!), with the trend continuing to the LMC and the SMC. Humphreys, Nichols, & Massey (1985) noted some of the incompleteness problems, however, for these data sets, in particular in the number of RSGs. (Our discussion in § 3.1 would argue that the WR population in the Milky Way is also more incompletely known than is commonly assumed.) Humphreys et al. nevertheless attempted to extend this study to M33. Our results of the present survey underscore the previous completeness problem for WR stars in M33. However, an equally important problem has been the erroneous assumption that all red stars seen against the face of M33 are true RSGs located within M33.

Massey (1998b; hereafter Paper I) has recently developed a method for photometrically distinguishing foreground dwarfs from RSGs and has applied this to selected regions of M31, M33, and NGC 6822, with the areas selected on the basis of having been surveyed for WR stars. With these data, and the results of the current M33 survey, we are now prepared to investigate anew the connection between metallicity and the relative number of RSGs and WRs.

In Table 7 we list the number of RSGs and WRs in NGC 6822, in M31, and at three different galactocentric distances

TABLE 7

RELATIVE NUMBER OF RSGS AND WRS IN NGC 6822, M33, AND M31

Galaxy	Abundance[a] [12 + log (O/H)]	Number of RSGs (N_R) $M_V < -5$	$M_{bol} < -7$	Number of WR Stars (N_{WR})	$N_R(M_V)/N_{WR}$	$N_R(M_{bol})/N_{WR}$
M31 (5 CCD fields)	9.00	32	12	19	1.7	0.6
M33 (6 CCD fields)						
$0.0 < \rho \leq 0.25$ ($\bar{\rho} = 0.20$)	8.70	26	6	17	1.5	0.4
$0.25 < \rho \leq 0.5$ ($\bar{\rho} = 0.30$)	8.60	48	17	22	2.2	0.8
$\rho > 0.5$ ($\bar{\rho} = 0.66$)	8.35	121	45	18	6.7	2.5
NGC 6822	8.25	33	19	4	8.3	4.8

[a] References to the abundances can be found in Table 5.

within M33. Some fields surveyed for WR stars in M31 and M33 were not included in RSG survey, and so we have restricted our census only to the areas in common. (Because the center field in M33, "X," was not included in the RSG survey, we have changed the galactocentric bins slightly from those used in Table 5 in order to smooth the statistics.) Most of NGC 6822 was surveyed for WR stars, but only four stars were found; there is not good overlap with the NGC 6822 RSG survey, but we have taken the survey areas as equivalent. We have restricted out counts to the number of RSGs with $M_V < -5$, given the completeness limit of -4.5 estimated in Paper I. We also include the number of RSGs with $M_{bol} < -7$; this sample should similarly be complete even for the coolest stars. Although M_{bol} is of greater physical importance, the uncertainties in the conversion from colors to bolometric corrections render this less well established; see the discussion in Paper I. We plot the number ratios as a function of metallicity in Figure 13.

We see that indeed there is a very strong trend with metallicity: for instance, within M33 the number ratio changes by a factor of 5 between our inner and outer bins; the metallicity difference is $\Delta \log$ (O/H) $= -0.35$. Furthermore, this trend continues to NGC 6822, despite the only small metallicity difference. Similar trends are seen whether we use $M_V < -5$ or $M_{bol} < -7$ (Table 7). The relationship may flatten out at the higher metallicity indicated by the M31 point, although using a slightly more luminous cut-off ($M_{bol} < -7.5$) makes this relationship monotonic.

Although this trend is highly striking, it is nearly a factor of 20 less than the gradient reported by Maeder et al. (1980)

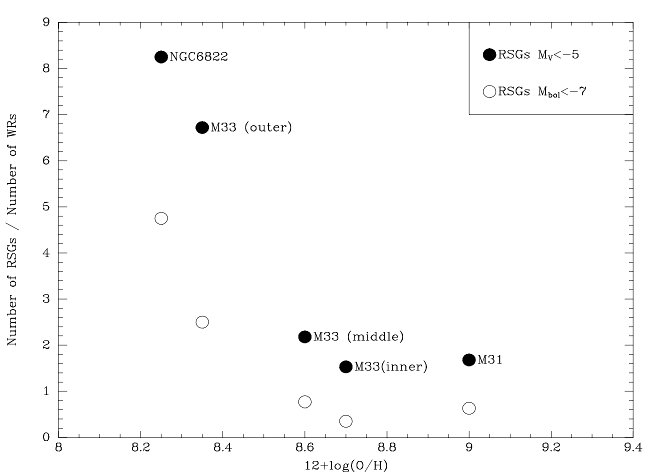

FIG. 13.—Ratio of the number of RSGs to the number of WRs is plotted as a function of metallicity for the data in Table 7.

within the Milky Way. They observed a factor of >90 change in N_R/N_{WR} within ± 2 kpc of the sun. Over this distance, we might expect the metallicity to go from 12 + log (O/H) = 8.75 to 8.40 (Fig. 1 of Esteban & Peimbert 1995), a $\Delta \log$ (O/H) that matches that for our inner and outer M33 bins, over which we observe only a factor of 5 change. We believe this is simply due to the considerable uncertainties in the Milky Way data. (See discussion in Humphreys et al. 1985 and in § 3.1 above.)

This test demonstrates again the validity of the Conti scenario—that large differences exist in the evolved products of massive stars, and that these differences correlate with metallicity, as expected from the fundamental importance of mass loss for these high-luminosity objects. Paper I found that there were strong differences in the number of the highest luminosity ($M_{bol} < -8$) RSGs in M31, M33, and NGC 6822 compared to those of lower luminosity ($M_{bol} \sim -6.5$), in the sense expected: in the higher metallicity regions there are proportionally fewer of the most luminous RSGs, suggesting that these stars are instead spending their He-burning lives principally as WRs. Interesting, the histograms for NGC 6822 and M33 show extended tails on the high-luminosity ends of the distribution rather than a sharp cutoff, suggesting that in these galaxies even the high-luminosity stars still go through an RSG stage, although perhaps spending a proportionately shorter time as RSGs at high metallicity. The histogram for M31, however, did seem to indicate a sharp cut-off, suggesting that at higher metallicities stars more luminous than $M_{bol} = -7.5$ may become WRs without going through the RSG stage at all.

We can test this further by asking if RSGs ever occur in the same OB associations as do WR stars. If they do, then this provides strong evidence that WRs go through an RSG stage. Unlike the tests described so far, this one relies upon using coeval populations: we must assume that all the stars in a given OB association were born coevally and that stars that have left the H-burning main-sequence are all of roughly the same mass. We know that star formation has been highly coeval in most of the OB associations studied in the Milky Way and Magellanic Clouds, with the time span for the formation of the most massive stars $\Delta\tau < 1$ Myr (Massey et al. 1995b, 1995c). Even so, the presence of the occasional RSG of lower mass is sometimes seen, suggesting that a few 15 $M_\odot$ stars may have formed early. It is also clear that some of the associations identified in the Milky Way and the Magellanic Clouds encompass more than one star-forming event. This situation is compounded by the larger sizes of the OB associations in M31 compared with those of M33 or NGC 6822, and the large size of the associations in all three compared to those of the Magellanic Clouds. These differences are discussed by Hodge (1986), and are almost certainly artificial. The coevality of the OB associations identified in the more distant members of the Local Group will be answered by the on-going investigation of the unevolved massive star population described by Massey et al. (1995a). In the meanwhile, we will simply take these OB associations as coeval structures.

In Table 8 we list the number of WRs and RSGs found in the OB associations that both were surveyed for RSGs (Paper I) and have complete CCD surveys for WR stars (AM85; Massey et al. 1986; and the present study). If a star is located on or just outside the boundaries of an OB association, we indicate it by parentheses. Two things are immediately apparent: (1) that most OB associations that contain WR stars also contain luminous RSGs, and (2) that most OB associations that contain luminous RSGs also contain WRs. This is most apparent in M33 where multiple OB associations occur in a given survey field and where the statistics are good. We conclude that in general, the WRs and RSGs go hand in hand.

Humphreys et al. (1985) reached the opposite conclusion in their study of the relationship between RSGs and WRs in the OB associations of M33, finding that their presences were "anticorrelated." However, we know now that the WR estimate available at that time was a factor of 2 incomplete and that the RSGs were highly contaminated by foreground red dwarfs, leading to the relatively uniform appearance of the red stars across the face of M33 compared to the clumpy distribution of blue stars (compare Figs. 21–23 in Humphreys & Sandage 1980).

How real are the connections shown by the numbers in Table 8? We illustrate the situation for three fields in Figs. 14, 15, and 16, using $M_{\rm bol} < -7$ as our criterion for counting an RSG as "luminous." In M33-A (Fig. 14), we show a sparse area in an outer region of M33. The OB associations OB 88 and OB 89 contain two WR stars each, along with one RSG each. Two RSGs fall outside of the association boundaries. Figure 15 shows a rich region, M33-G, containing a multitude of OB associations. The ones that contain multiple WRs almost invariably also contain one or more RSGs. There are few OB associations (OB 7 is one) that contain any RSGs without containing WRs. In M31's OB 48 (Fig. 16), we see again see the good connection between the spatial distribution of WRs and RSGs. Although OB 48 might be divided into two (or more) associations in keeping with the discussion of Hodge (1986), this connection would continue, as witness the proximity of the RSG to the star OB 48-527 in the northern clump and that of the three WRs and two RSGs in the southern clump.

TABLE 8

NUMBER OF WRs AND RSGs IN SURVEY OB ASSOCIATIONS

	Number of WRs			Number of RSGs	
OB Association	WRs	WCs	WNs	$M_V < -5$	$M_{\rm bol} < -7$
			M33 Field A		
OB 88	2	1	1	2	1
OB 89	2	1	1	2	1
			M33 Field B		
OB 65	2	0	2	2	1
OB 66	3	0	3	3	2
OB 67	2	0	2	1	0
OB 68	0	0	0	0	0
			M33 Field D		
OB 20	(1)	0	(1)	4	1
OB 21	2	0	2	15	6
OB 22	0	0	0	1	1
OB 24	0	0	0	0	0
			M33 Field E		
OB 17	1	0	1	2	2
OB 115	2	0	2	3	3
OB 127	2	0	2	8	7
OB 128	(2)	0	(2)	4	2
			M33 Field F		
OB 110	0	0	0	6	0
OB 112	1	0	1	10	5
			M33 Field G		
OB 3	1	0	1	0	0
OB 6	1	0	1	0	0
OB 7	0	0	0	7	3
OB 8	0	0	0	0	0
OB 9	1	1	0	2	1
OB 10	0	0	0	4	1
OB 11	0	0	0	0	0

TABLE 8—*Continued*

	Number of WRs			Number of RSGs	
OB Association	WRs	WCs	WNs	$M_V < -5$	$M_{bol} < -7$
OB 12	4	2	2	3	2
OB 14	2	0	2	3	1
OB 49	2	0	2	1	0
OB 50	3	1	2	4	2
OB 51	0	0	0	1	0
NGC 6822 Field A					
OB 1............	0	0	0	0	0
OB 2............	1	0	1	0	0
OB 3............	0	0	0	0	0
NGC 6822 Field B					
OB 6............	0	0	0	0	0
OB 7............	1	0	1	(1)	(1)
OB 8............	0	0	0	0	0
OB 9............	0	0	0	6	3
OB 11	0	0	0	(1)	(1)
NGC 6822 Field C					
OB 15	1	0	1	0	0
M31 OB 8, 9, 10					
OB 8............	0	0	0	0	0
OB 9............	0	0	0	(1)	0
OB 10	1	1	0	0	0
M31 OB 48					
OB 48	5	3	2	10	6
M31 OB 69					
OB 69	4	1	3	2	1
M31 OB 78					
OB 78	4	2	2	11	5
M31 OB 102					
OB 102	1	0	1	3	0

The connection between luminous RSGs and WRs seems irrefutable.

Of the 22 OB associations in M33, 15 contain both WRs and luminous RSGs, three contain only RSGs, four contain only WRs, and five contain neither. Thus in 20 (out of 22) the presence and lack of WRs and RSGs are correlated. In M31 the statistics are more limited, but of seven associations, three have both WRs and RSGs and three have neither, while one contains only WRs. The numbers would vary somewhat if we had used a different cut-off in what constitutes a "luminous" RSG: for instance, if we used $M_{bol} < -8$, we would find that only one association in M31, OB 69, contained both "luminous" RSGs and WRs, but that is because there is only one such star known in all of the survey fields of M31. Similarly if we had used the looser criterion of $M_V < -5$, we would find more associations that contained only RSGs. For NGC 6822 the statistics are too limited to be of use; only two (of the four) OB associations that contain WR stars were surveyed for RSGs in Paper I.

If these regions are coeval, then this argues that massive stars go through both an RSG and a WR stage, at least at $M_{bol} \sim -7$. We should recall, though, that this corresponds to a mass of only 15 $M_{\odot}$.

We conclude from this test that some stars with masses of 15 $M_{\odot}$ and higher indeed do go through both an RSG and a WR stage in M31 and M33, at least if the associations are coeval. Interestingly, the trend is unaffected if we were to consider only the associations that contain WC-type WR stars. With the available evidence, we cannot yet determine whether or not there is a difference in the cohabitation rate between WRs and luminous RSGs as a function of metallicity. However, work is progressing on extending such studies to the Magellanic Clouds, which should provide the basis for comparisons for lower metallicity systems.

4. SUMMARY AND CONCLUSIONS

We have conducted a deep survey for WR stars in eight $5'.2 \times 5'.2$ regions of M33, chosen to cover a good range in galactocentric distances and to be coincident with the recent survey for RSGs presented in Paper I. Follow-up spectroscopy confirms 22 new WR stars (all WN type) and suggests that we are reliably detecting WN stars as weak as any known. The only WR stars known to have been missed in these fields are those that are particularly crowded. We consider this sample to be as complete as that known for the Magellanic Clouds, NGC 6822, IC 1613, IC 10, and selected regions of M31, and to be probably more complete than

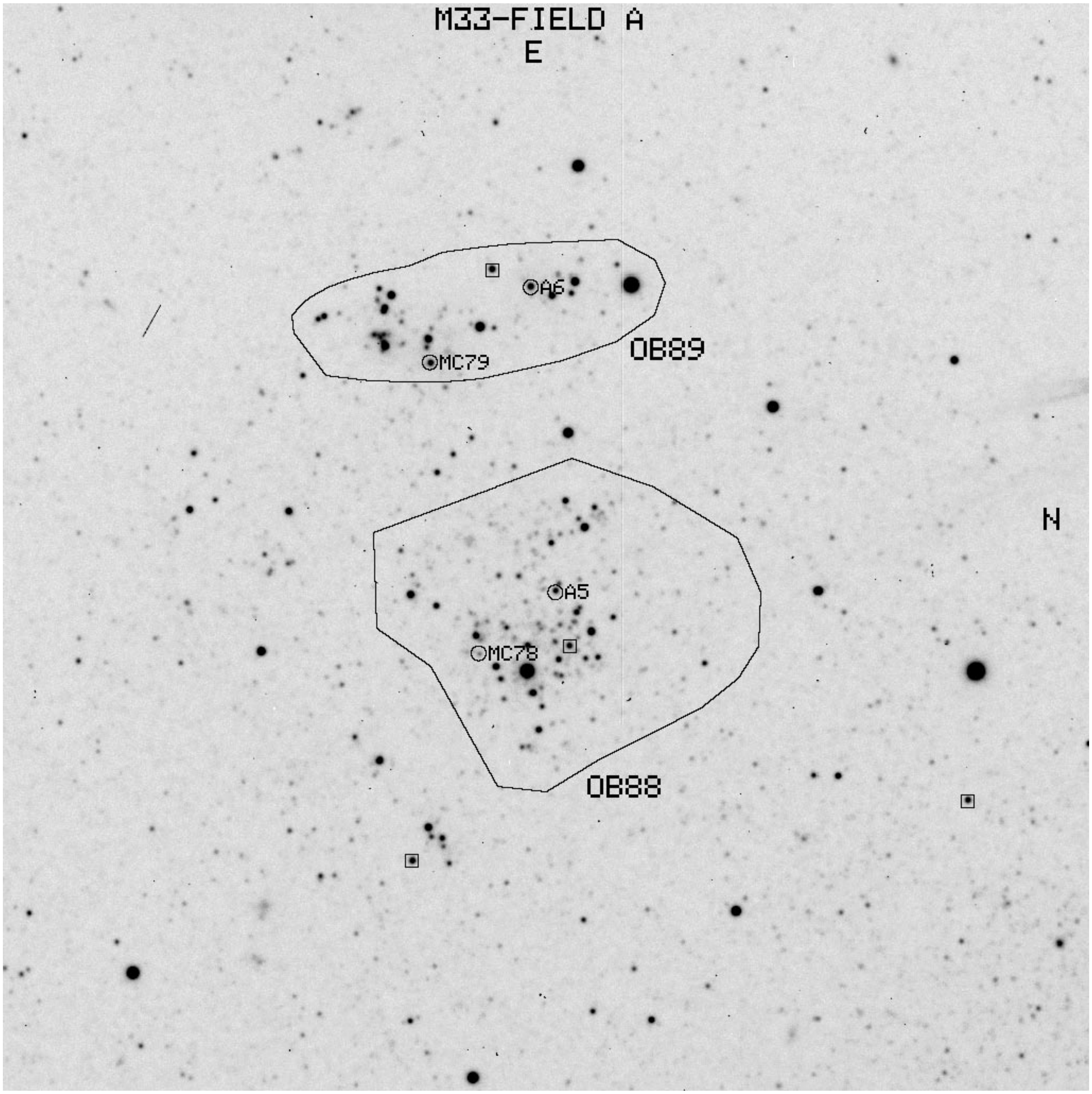

FIG. 14.—We compare the distribution of WR stars (*labeled circles*) and RSGs (*squares*). The WRs shown are those counted as bona fide via either spectroscopic confirmation or high significance levels. The RSGs shown are those with $M_{bol} < -7$. The size of the image is 5'.2 × 5'.2. The boundaries of the OB associations are taken from Humphreys & Sandage (1980). The sparse region M33 field A contains OB 88 and OB 89. Each contains two Wolf-Rayet stars. Note the close proximity of the RSGs.

that of the region in the Milky Way within 3 kpc of the sun.

We draw upon all the available data to provide three demonstrations of the Conti scenario, the prediction that mass loss has a dominant effect on the evolution of massive stars. Since the mass-loss rates should scale with metallicity, we expect to see considerable differences in the evolved massive star populations of these galaxies—and we do. Specifically, we find the following.

1. The relative number of WC to WN stars changes by a factor of ~ 3 within the disk of M33, with a high value near the center and a low value in the outer regions. Considering the full set of Local Group galaxies named above, we find an excellent correlation between the WC/WN ratio and metallicity for all but IC 10. In IC 10, the ratio is very anomalously high, for reasons likely having to do with its currently undergoing a starburst. The number ratio for the Milky Way is slightly high, consistent with our expectation that not all WN stars within 3 kpc of the sun have been found, given what we know of typical reddenings. For the remainder, we find a change from a WC/WN number ratio of 0.0 at $12 + \log(O/H) = 8.15$ to a number ratio of 1.0 extrapolated to $12 + \log(O/H) = 9.2$.

2. We discuss and expand the findings by Armandroff &

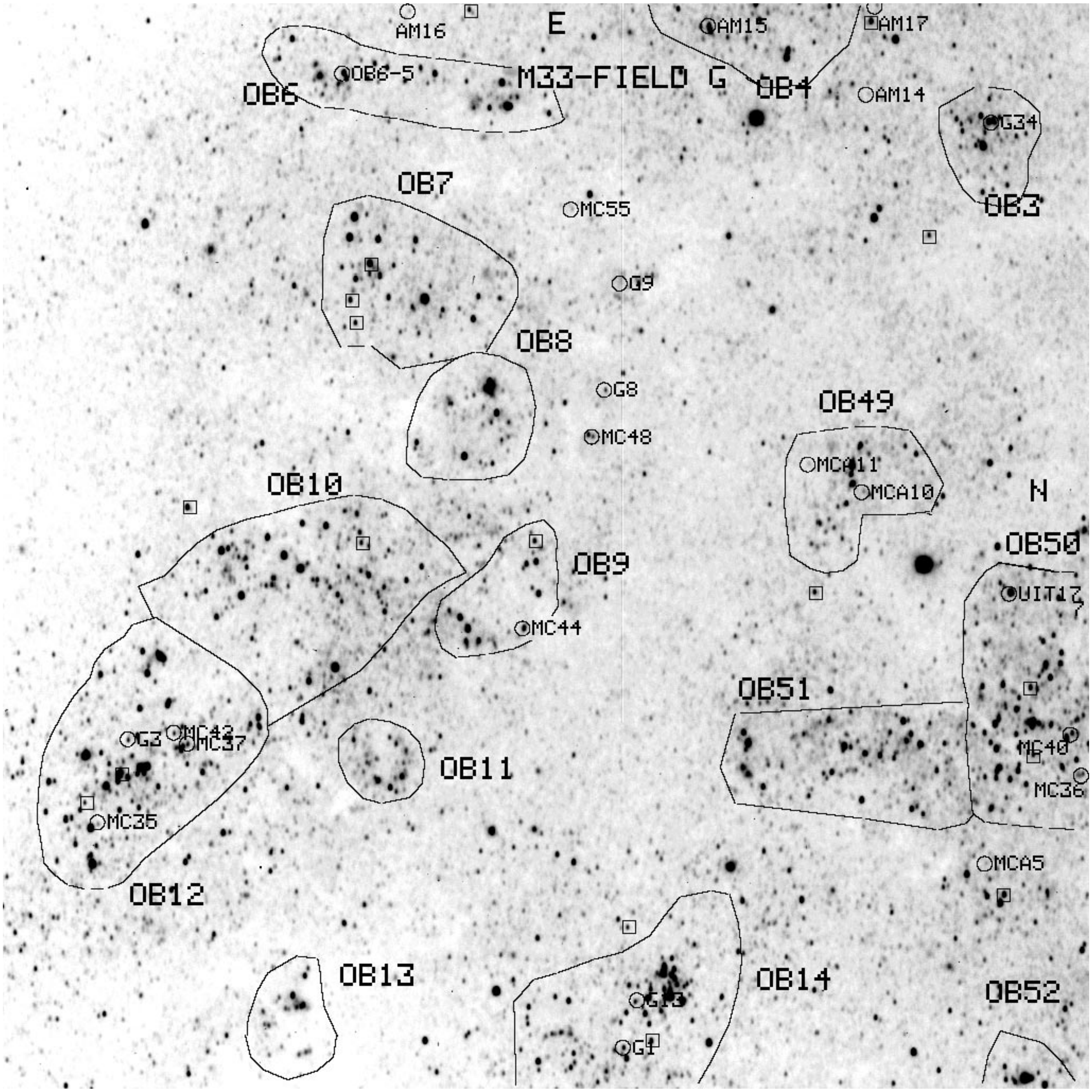

FIG. 15.—Same as Fig. 14, except that we show a more crowded region located in the inner part of M33, field G

Massey (1991) that the spectral properties of WC stars depend upon metallicity: that in regions of lower metallicity the lines are broad and strong, while in regions of high metallicity the lines are narrow and weaker. We propose here that the WC spectral subclasses tell us less about the physical properties of the star than about the initial metallicity out of which the star was born.

3. We draw upon the recent RSG survey of NGC 6822, M31, and M33 to test the prediction by Maeder et al. (1980) that the number ratio of RSG and WR stars ($N_{\rm R}/N_{\rm WR}$) should be an extremely sensitive indicator of metallicity. Indeed, we find a factor of 5 change within the disk of M33 [Δlog (O/H) = 0.35], with a trend that continues to the slightly lower metallicity galaxy NGC 6822. The relationship may level out at higher metallicities (M31).

4. There is an excellent correlation between the presence of WR stars and that of RSGs with $M_{\rm bol} < -7$ in the same OB associations in M31 and M33. To the extent that these associations are coeval, some stars of 15 $M_{\odot}$ and above must go through both an RSG and a WR stage. Since stars of both WC and WN are seen in these associations, it suggests that some massive stars go through all three stages.

P. M. gratefully acknowledges useful interactions with his colleagues at the 1996 Liège conference on Wolf-Rayet stars, where some preliminary results of this study were presented. Over the years, he has benefited from many valued collaborations with Peter Conti and Taft Arman-

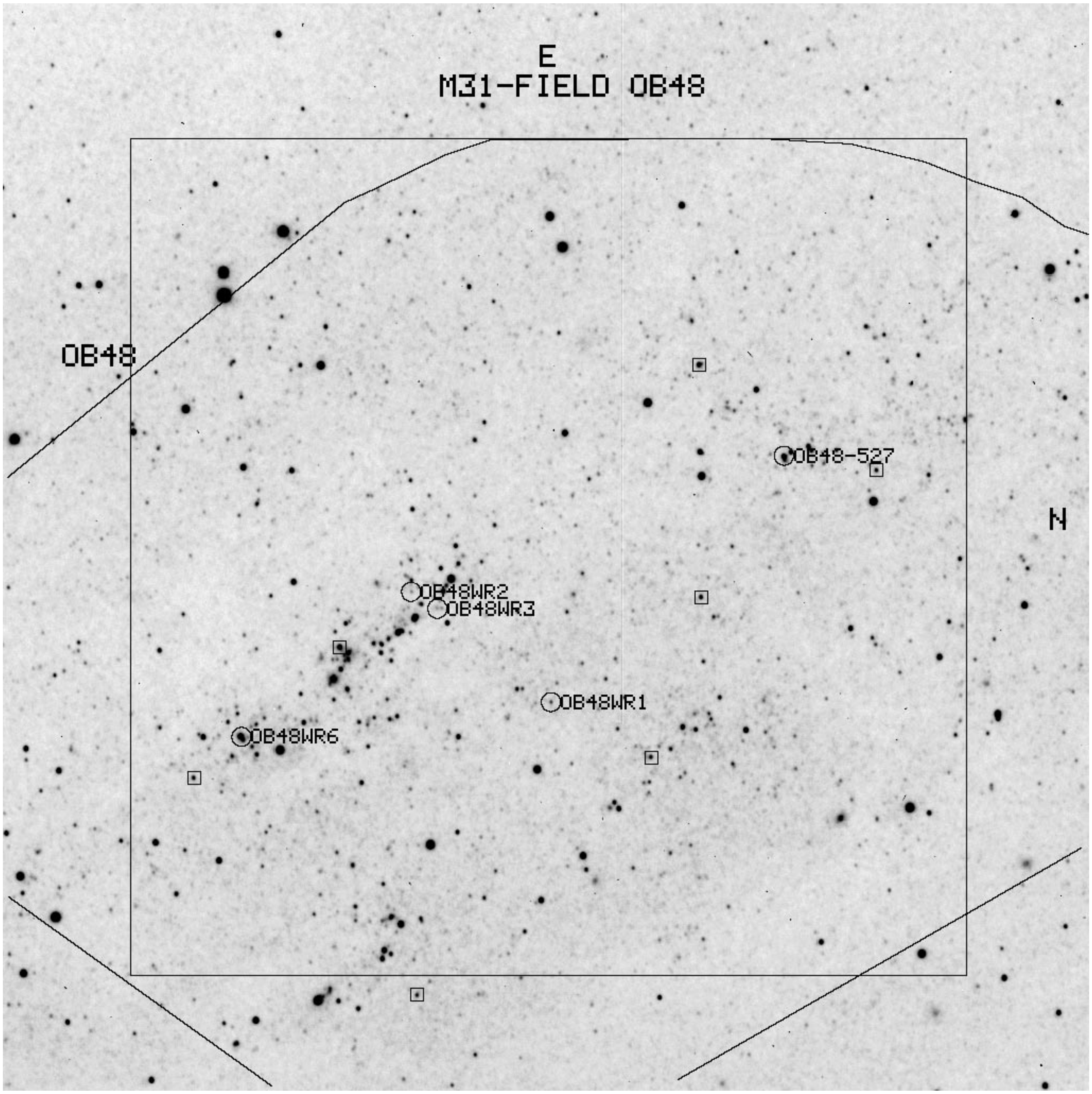

FIG. 16.—Same as Figs. 14 and 15, but for the OB 48 association in M31. The outline of the association comes from van den Bergh (1964) and extends partially outside the field. We also show the square outline of the field surveyed for WR stars by Massey et al. (1986).

droff, which helped formulate and address many of these issues. Deidre Hunter has contributed numerous scientific suggestions and made many useful comments on the manuscript. We also thank Conti, Sidney van den Bergh, and the anonymous referee for their kind comments on the paper. Kathy DeGioia-Eastwood provided a variety of aid, including assistance with some of the spectroscopy and the use of her computer and office.

APPENDIX

CATALOG OF WOLF-RAYET STARS IN LOCAL GROUP GALAXIES BEYOND THE MAGELLANIC CLOUDS

In this appendix, we give a complete catalog of all of the spectroscopically confirmed Wolf-Rayet stars in galaxies of the Local Group beyond the Magellanic Clouds. Data on the known Wolf-Rayet content of the Milky Way can be found in van der Hucht et al. (1981). The primary reference for the LMC WR stars is that of Breysacher (1981). A number of the Galactic and LMC WRs were subsequently reclassified by Conti & Massey (1989). For the SMC, Azzopardi & Breysacher (1979) provide a complete list; some of these stars were reclassified by Conti, Garmany, & Massey (1989).

Beyond the Magellanic Clouds, Wolf-Rayets have been identified within the Local Group in M33, M31, NGC 6822, IC 1613, and IC 10. Surveys for WR stars in galaxies outside of the Local Group have begun, taking advantage of the improved image quality achievable from the ground with modern means; e.g., the survey by Breysacher et al. (1997) for WR stars in NGC 300 in the Sculptor Group. We give here a short history of the discovery of WR stars in each of the Local Group galaxies, attempting to correct confusion in identifications and cross references.

A1. M33

Wolf-Rayet stars have been found in M33 both by dedicated searches via imaging through interference filters and by "accidental" spectroscopic discovery. Examples of the former include the photographic searches by Wray & Corso (1972), Massey & Conti (1983), and Massey et al. (1987b) and the CCD imaging of AM85, Drissen, Moffat, & Shara (1993), and the present study. Examples of the latter include the spectroscopy of stars in H II regions by Boksenberg, Willis, & Searle (1977), Conti & Massey (1981), Rosa & D'Odorico (1982), the spectroscopy of luminous blue stars by Massey et al. (1995a) and Massey et al. (1996), and the discovery by Willis, Schild, & Smith (1992) of the first Ofpe/WN9 star identified in M33.

The first discovery of Wolf-Rayet stars in M33 was by Wray & Corso (1972), whose interference-filter photography yielded 25 candidates in M33; subsequently, Boksenberg et al. (1977) and Wampler (1982) confirmed 24 of these spectroscopically and showed that the other was a supernova remnant (SNR). Boksenberg et al. (1977) also found one additional WR star in IC 132, one of M33's large H II regions. Conti & Massey (1981) identified 13 additional Wolf-Rayet stars (and one Of star) in M33 by spectroscopically sampling additional stars in H II regions, including the giant H II regions NGC 604, NGC 595, and NGC 592. (At the same time, Rosa & D'Odorico 1982 also discovered that NGC 604 contained many WR stars.) Massey & Conti (1983) gave the results of their spectroscopy of many WR candidates that had been found by blinking image-tube plates obtained through an interference filter at the Canada-France-Hawaii Telescope (CFHT); they also discussed the spectra of all the previously known M33 WR stars and included these in their catalog of 79 M33 WR stars. Finding charts for the blink survey were eventually published by Massey et al. (1987b), who included a list of 16 additional stars that had been confirmed spectroscopically since then; these spectra were discussed in detail by MCA87 and are known by their "MCA" numbers. Massey et al. (1987b) also presented an additional 35 unconfirmed candidates of rated with "A" to "D" confidence levels; only one of these has ever been observed to our knowledge (MCMS 26, now a confirmed WR star.)

AM85 identified 27 Wolf-Rayet candidates using CCD imaging similar to that conducted in the present study. Of these stars, 16 were previously known (i.e., in Massey & Conti 1983). Of the other 12, six were subsequently confirmed spectroscopically (Armandroff & Massey 1991). Embarrassingly, author Massey overlooked the fact that the spectroscopically confirmed WR stars "MCA 13" and "MCMS 26" were in fact the CCD candidates AM 15 and AM 26, respectively, and should have appeared as such in Table 1 of AM91. Of the remaining six, one was ruled out as a WR star, and five were either unobserved or judged to have insufficient data; these six were the ones with the lowest significances ($< 3.2\ \sigma$) of the list. AM85 failed to identify four known WR stars in their fields: MC 30, MC 31, and MCA 4 in their field 2, and MC 63 in their field 1. MC 30 and MC 31 are the two brightest knots of NGC 595 (identified as CM 4 and CM 5 in Conti & Massey 1981); the western component (MC 30) of these was called an "Of" star by Conti & Massey, but the classification was revised to "WNL" by Massey & Conti (1983) using the same data. The star was not detected by Drissen et al. (1993) in their imaging of NGC 595. A spectrum obtained on 1997 December 20 at the MMT fails to reveal any He II λ4686 emission despite the good exposure, and we speculate that the spectrum of MC 31 contaminated the that of MC 30 within the 3″ aperture used. The stars MCA 4 and MC 63 were very faint, and we believe they were simply below the detection limit of their CCD frames.

Drissen et al. (1993) looked for WR stars in the giant H II regions NGC 595 and NGC 604 using a He II λ4686 filter compared to a broadband "*B*-like" filter using pre-COSTAR *Hubble Space Telescope* (*HST*) and CFHT imaging. There was only limited spectroscopy (two stars), and because of their filter choice, red stars would also be revealed as possible WR candidates. Of the 11 WR candidates they identified in NGC 595, six well-isolated candidates had already been shown to be WR stars by Massey & Conti (1983), AM85, and AM91, although Drissen et al. (1993) may have been unaware of this as they provided no cross references. Four additional stars (NGC 595 WR 2a, 2b, 11, and possibly 9) were separate components of MC 31. Interestingly, they did not detect MC 30, the star discussed above. All of their WR candidates in NGC 595 had been previously found by ground-based studies; all were single objects except for the multiple components of MC 31. In NGC 604, they identified 14 WR candidates, and confirmed one spectroscopically. Here the crowding is considerably more severe: star NGC 604 WR 6 corresponding to MC 76; NGC 604 4a, 4b, and 3 corresponding to MC 75; and NGC 604 WR 1 and WR 2 corresponding to MC 74. The others were too crowded or lost in nebulosity to be detected on the photographic blink survey of Massey et al. (1987b).

Willis et al. (1992) intended to observe MCA 1 but instead observed a brighter star 2″away and found to their delight that it was a WN9/Ofpe star (Smith, Crowther, & Willis 1995). They called the star MCA 1-B, although in fact it had been cataloged as a blue star (HS B5) by Humphreys & Sandage (1980). As part of their effort to observe the unevolved O-type stars in M33, Massey et al. (1995a) list seven WR stars; two of these (OB 66 F-61 and OB 66-25) had been previously discussed by AM91 as HS B267 and HS B205, respectively. The latter is actually a blend of two stars (OB 66-23 and 66-25), which may account for the difference in classification ("Of" and "WN8"). Massey et al. (1995a) list the star OB 3-11 as "WN:"; however, examination of an *HST* WFPC2 image of the region reveals that OB 3-11 is itself double, as is the nearby (1″) star OB 3-12. The star G34 in the present survey is coincident with the OB 3-12 blend (the two stars are separated by a few tenths of an arcsecond), and we believe that the "WN" designation really belongs to OB 3-12 and not OB 3-11. Similarly, the star W91-129 was found by Massey et al. (1995a) to have a spectral type of "WN7 + abs"; however, its photometry from the present survey is much

TABLE 9

Wolf-Rayet Stars in M33

Star[a] New (1)	Star[a] Previous (2)	Position (2000) α (3)	Position (2000) δ (4)	ρ (5)	CT (6)	OB Association[b] (7)	Spectral Type: Type (8)	Spectral Type: References (9)	Comments[a] (10)
Spectroscopically Confirmed M33 Stars									
WR 1	MCA 1	01 32 37.59	+30 40 04.2	1.11	...	Fld	WC	1	
WR 2	UIT 003	01 32 37.70	+30 40 05.7	1.10	17.4	132	Ofpe/WN9	2, 3, 4	MCA 1B, HS B5
WR 3	MC 1	01 32 40.73	+30 24 54.5	1.01	20.9::	121	WNE	5	
WR 4	MC 2	01 32 41.88	+30 40 24.7	1.05	22.0:	(132)	WCE	1	
WR 5	UIT 008	01 32 45.38	+30 38 58.6	0.97	17.7	27	Ofpe/WN9	4	HS B7 (NGC 588)
WR 6	MC 3	01 32 45.74	+30 38 55.1	0.96	16.8:	27	WN	1, 4	UIT 011 CM 1 (NGC 588) HS B10
WR 7	MC 4	01 32 56.03	+30 31 57.2	0.76	21.5:	129	WC	1	
WR 8	OB 21-65	01 32 56.33	+30 35 35.4	0.76	18.4	21	WN6+abs	6, 7	
WR 9	MC 5	01 32 56.80	+30 27 24.8	0.79	21.5::	122	WN	1	
WR 10	MC 6	01 32 57.87	+30 35 49.9	0.74	19.5	21	WC4–5	2, 8	UIT 023(?) SE mem of 3 stars
WR 11	MJ E1	01 33 00.20	+30 30 15.2	0.71	18.7	(128)	WN8	7	HS B47
WR 12	MC 7	01 33 02.67	+30 31 20.2	0.67	20.5	(128)	WNE	5	
WR 13	MC 10	01 33 03.21	+30 34 08.7	0.66	20.6	(20)	WNL	1	
WR 14	MC 8	01 33 02.74	+30 11 40.0	1.20	16.3:	MA1	WN (composite)	1	Coords uncertain; in MA1
WR 15	MC 9	01 33 02.74	+30 11 41.0	1.20	17.2:	MA1	WN	1	Coords uncertain; in MA1
WR 16	MC 11	01 33 03.68	+30 23 26.4	0.80	19.4:	Fld	WC	1	SE of brt star
WR 17	MC 12	01 33 04.98	+30 32 00.0	0.64	22.1	(19)	WNE	1	
WR 18	MC 13	01 33 05.64	+30 28 57.5	0.67	20.6	Fld	WNE	5	
WR 19	UIT 041	01 33 07.47	+30 42 58.5	0.72	17.2	28	WNE+B I	4	HS B52
WR 20	MC 14	01 33 07.64	+30 33 15.9	0.60	21.2:	19	WN	1	W mem of 2 fnt stars
WR 21	MC 15	01 33 07.77	+30 29 51.1	0.63	20.9	127	WNE	5	
WR 22	UIT 045	01 33 09.10	+30 49 54.5	0.90	18.0	28	Ofpe/WN9	4	
WR 23	MC 16	01 33 08.52	+30 28 05.5	0.65	20.5	Fld	WNE	5	
WR 24	MCA 2	01 33 10.74	+30 39 00.4	0.59	...	Fld	WN	1	S of brter star
WR 25	MC 17	01 33 11.86	+30 38 53.8	0.57	16.9:	59	WNL	1, 9	UIT 056, CM 3 (NGC 592), HS B67; W of 2
WR 26	UIT 052	01 33 11.42	+30 48 56.9	0.84	16.5	135	WNE+B3 I	4	HS B92a
WR 27	MJ E5	01 33 12.15	+30 27 40.4	0.63	21.1	115	WN	7	
WR 28	MC 18	01 33 12.91	+30 44 59.1	0.69	21.8:	(29)	WN	1	
WR 29	MJ E6	01 33 14.30	+30 29 55.3	0.56	20.0	127	WN	7	
WR 30	MC 19	01 33 14.99	+30 39 07.0	0.52	19.9:	59	WCE	1	N mem of 2 fnt stars
WR 31	MC 20	01 33 15.28	+30 45 03.3	0.66	17.8:	29	WN3, WN/CE	4, 8	UIT 081(?), CM 2; SE mem of 2 brt stars
WR 32	MC 21	01 33 15.44	+30 45 10.7	0.66	20.9:	29	WN	5	NE of brter star
WR 33	MC 23	01 33 15.78	+30 56 44.9	1.08	16.7	IC 132	WN4.5+neb	4	UIT 087 (IC 132)
WR 34	MC 22	01 33 16.14	+30 47 52.1	0.74	21.7::	(30)	WC	1	
WR 35	MCA 3	01 33 16.47	+30 32 21.5	0.49	20.2	17	WNL	1	
WR 36	MC 24	01 33 18.45	+30 26 58.1	0.60	19.1:	114	WC4–5	2	
WR 37	MC 25	01 33 22.05	+30 16 51.4	0.96	19.0:	Fld	WN	1	
WR 38	AM 1	01 33 26.64	+30 40 40.5	0.38	21.8	(61)	WC5–6	5	MC 26
WR 39	MJ C7	01 33 27.23	+30 39 09.2	0.34	17.8	58	Ofpe/WN9	4, 7	UIT 104
WR 40	MC 27	01 33 27.70	+30 31 50.8	0.39	20.0:	15	WN	1	
WR 41	AM 2	01 33 32.61	+30 41 27.4	0.30	19.0	62	WNL	5	MC 28, NGC 595 WR 6
WR 42	AM 3	01 33 32.80	+30 41 46.2	0.31	18.1	62	WNL	5	UIT 118, NGC 595 WR 5
WR 43	AM 4	01 33 32.95	+30 41 36.2	0.30	18.0	62	WNL	5	UIT 119, NGC 595 WR 4
WR 44	MC 30	01 33 33.41	+30 41 33.0	0.30	16.9:	62	WNL?	4, 9	UIT 120, CM 4 (N595), HS B167; Of? No emis?
WR 45	AM 5	01 33 33.28	+30 41 29.8	0.30	19.7	62	WC	5	MC 29, NGC 595 WR 3
WR 46	MJ C22	01 33 33.55	+30 42 19.4	0.32	18.1	(62)	WN	7	HS B164
WR 47	MC 31	01 33 33.71	+30 41 33.0	0.29	16.7:	62	WNL	4, 9	UIT 123, CM 5, HS B171, NGC 595 WR 2a, 2b, 9, 11
WR 48	MCA 4	01 33 33.97	+30 41 17.4	0.28	...	62	WN	1	NGC 595 WR 8
WR 49	AM 6	01 33 34.22	+30 41 38.1	0.29	18.1	62	WNL	5	UIT 126, MC 32, CM 6, NGC 595 WR 1

TABLE 9—*Continued*

Star[a] New (1)	Star[a] Previous (2)	Position (2000) α (3)	Position (2000) δ (4)	ρ (5)	*CT* (6)	OB Association[b] (7)	Spectral Type: Type (8)	Spectral Type: References (9)	Comments[a] (10)
WR 50	MJ G13	01 33 34.24	+30 33 47.5	0.29	20.7	14	WN	7	
WR 51	AM 7	01 33 34.28	+30 41 30.5	0.28	19.8	62	WNL	5	NGC 595 WR 7
WR 52	AM 8	01 33 35.45	+30 42 20.4	0.29	20.4	(62)	WC	5	MC 33
WR 53	MC 34	01 33 35.66	+30 36 29.6	0.22	18.3:	Fld	WC	9	CM 7
WR 54	MCA 5	01 33 37.30	+30 35 27.2	0.22	20.9	(50)	WN	1	
WR 55	MC 35	01 33 38.16	+30 31 12.6	0.36	21.0	12	WC	10	W&C3
WR 56	MC 36	01 33 39.27	+30 35 54.9	0.19	19.6	50	WN	10	W&C4
WR 57	UIT 154	01 33 39.50	+30 45 40.8	0.36	17.2	Fld	B0.5 Ia + WNE	4	
WR 58	MCA 6	01 33 39.69	+30 21 01.9	0.80	20.2	112	WNE	1	
WR 59	MC 37	01 33 39.92	+30 31 38.4	0.34	19.1	12	WN	10	W&C5
WR 60	MJ G3	01 33 40.01	+30 31 21.3	0.35	19.4	12	WN	7	
WR 61	AM 9	01 33 40.05	+30 42 38.8	0.24	20.0	Fld	WC4–5	5	MC 39
WR 62	MC 42	01 33 40.16	+30 31 34.5	0.34	19.7	12	WC4–5	5	W&C8 fnt comp 1.3″N
WR 63	MC 40	01 33 40.18	+30 35 51.8	0.19	19.1	50	WC	10	W&C9
WR 64	MC 38	01 33 40.21	+30 41 02.1	0.18	20.8	Fld	WN	5	W&C6
WR 65	AM 10	01 33 40.26	+30 40 53.6	0.18	22.0	Fld	WC	5	MC 41; W&C7
WR 66	MJ B13	01 33 40.30	+30 46 01.0	0.37	22.1	Fld	WN?	7	
WR 67	MJ C3	01 33 41.63	+30 38 55.3	0.12	20.2	Fld	WN	7	
WR 68	AM 11	01 33 40.68	+30 42 54.0	0.24	20.6	Fld	WN	5	
WR 69	AM 13	01 33 41.81	+30 41 55.0	0.19	20.6	Fld	WC6–7	5	MC 43; WC10
WR 70	MCA 7	01 33 41.89	+30 42 02.9	0.19	20.3	Fld	WN	1	
WR 71	MC 44	01 33 42.50	+30 33 14.6	0.27	18.7	9	WC4–5	8	
WR 72	"W91 129"	01 33 43.17	+30 39 06.3	0.10	16.6	Fld	WN7 + abs	6	UIT 176, not star ident. by Wilson.
WR 73	MJ C4	01 33 43.19	+30 39 00.5	0.10	18.6	Fld	WC	7	
WR 74	MCA 8	01 33 43.30	+30 44 50.7	0.29	21.1	66b	WN	1	
WR 75	UIT 177	01 33 43.31	+30 35 34.2	0.18	17.5	50	WN4.5 + O6–9	4	HS B221
WR 76	MC 45	01 33 44.34	+30 38 44.5	0.08	...	Fld	WC	10	Anon Wampler 1982
WR 77	OB 66-25	01 33 44.65	+30 44 36.8	0.26	18.4	66b	WN8	6, 7	Blend with OB 66-23 (Of?); UIT 184 = HS B205 Multiple
WR 78	MCA 9	01 33 45.21	+30 38 41.1	0.07	20.1	Fld	WN	1	
WR 79	MCA 10	01 33 45.56	+30 34 51.9	0.21	20.4	49	WNL	1	
WR 80	MC 46	01 33 45.98	+30 36 02.4	0.16	20.1	48	WN	1	W&C11
WR 81	MCA 11	01 33 46.17	+30 34 36.4	0.22	21.1	49	WNE	1	
WR 82	MC 47	01 33 46.54	+30 37 00.3	0.12	20.9	(48)	WC	10	W&C12
WR 83	MC 48	01 33 46.77	+30 33 34.4	0.27	20.1	(8)	WN/CE	2, 8	W&C13
WR 84	MC 49	01 33 47.14	+30 37 02.5	0.12	21.0	(48)	WC	10	
WR 85	OB 66 F–61	01 33 47.65	+30 43 51.4	0.20	18.6	(66)	WN6	6	UIT 201; HS B267
WR 86	MJ G8	01 33 47.81	+30 33 38.0	0.27	19.6	8	WN	7	
WR 87	MC 51	01 33 47.93	+30 45 06.7	0.26	21.0::	66c	WN	1	
WR 88	MJ X4	01 33 48.82	+30 39 49.4	0.02	19.5	Fld	WN	7	
WR 89	MC 52	01 33 50.06	+30 38 56.2	0.04	20.1	142	WC	10	W&C15; W of 3 brter stars
WR 90	MJ X6	01 33 50.06	+30 38 18.8	0.07	18.3	142	WN + O8–9	7	
WR 91	MJ G9	01 33 50.18	+30 33 42.4	0.28	22.3	Fld	WN	7	
WR 92	MC 53	01 33 50.18	+30 41 35.1	0.08	19.1:	64	WC4–5	2, 8	W&C16; NW of brter star
WR 93	UIT 213	01 33 50.42	+30 38 33.8	0.06	15.9	142	B1 Ia + WN	4	
WR 94	MC 54	01 33 51.27	+30 38 11.7	0.08	18.5	142	WCE	7, 10	W&C17; NE of brter star
WR 95	MC 55	01 33 51.82	+30 33 28.3	0.30	21.1	Fld	WC	5	W&C19
WR 96	MC 56	01 33 51.99	+30 40 23.5	0.03	21.4	(64)	WC	10	W&C18
WR 97	MCA 12	01 33 52.40	+30 43 51.7	0.17	19.0	65	WNL	1	
WR 98	MC 50	01 33 52.69	+30 39 07.3	0.06	21.4	142	WNE	7	W&C20; coords improved
WR 99	MC 57	01 33 52.67	+30 45 02.0	0.23	20.8	Fld	WC	5	
WR 100	MJ B4	01 33 52.72	+30 44 44.4	0.21	20.7	Fld	WN	7	
WR 101	MC 58	01 33 52.78	+30 43 47.8	0.17	20.3	65	WNE	9	CM 8

TABLE 9—*Continued*

Star[a] New (1)	Star[a] Previous (2)	Position (2000) α (3)	Position (2000) δ (4)	ρ (5)	*CT* (6)	OB Association[b] (7)	Spectral Type: Type (8)	Spectral Type: References (9)	Comments[a] (10)
WR 102	MC 59	01 33 53.21	+30 44 13.6	0.19	20.4	Fld	WC	1	
WR 103	MJ X15	01 33 53.58	+30 38 51.5	0.08	17.8	142	Ofpe/WN9	4, 7	UIT 236
WR 104	MJ G34	01 33 53.79	+30 35 28.9	0.22	18.5	3	WNE	6	OB 3-11, UIT 237, HS B353
WR 105	AM 14	01 33 54.40	+30 34 53.0	0.25	21.6	Fld	WC	5	MC 60, W&C21
WR 106	OB 6-5	01 33 54.83	+30 32 22.7	0.37	17.9	6	WN8	6	
WR 107	MJ B17	01 33 55.60	+30 45 34.7	0.24	21.0	67	WN	7	
WR 108	MJ B8	01 33 55.68	+30 45 01.2	0.22	18.4	67	WN7	4, 7	UIT 245, HS B327
WR 109	AM 15	01 33 55.92	+30 34 07.7	0.30	20.2	4	WC4–5	8	MCA 13, several comps <1″
WR 110	AM 16	01 33 56.21	+30 32 41.5	0.37	21.3	5	WC	5	MC 61; W&C22
WR 111	AM 17	01 33 56.36	+30 34 55.5	0.27	20.9	4	WC	5	MC 62; W&C23
WR 112	MCA 14	01 33 57.07	+30 35 11.3	0.27	…	107	WNL	1	
WR 113	MC 63	01 33 57.61	+30 34 16.2	0.31	20.6:	4	WN	1	Very faint; coords approx.
WR 114	AM 18	01 33 58.48	+30 34 31.1	0.31	20.3	4	WNL	5	MC 64; W&C24
WR 115	OB 2-4	01 33 58.72	+30 35 26.6	0.27	17.1	2	B1 Ia+WNE	6	UIT 267, multiple
WR 116	AM 19	01 33 59.27	+30 33 38.0	0.35	20.0	5	WC6	2	MC 65; coords approx.
WR 117	AM 20	01 33 59.71	+30 34 07.7	0.34	20.9	4	WNL	5	MC 66; coords approx.
WR 118	MJ X16	01 34 00.55	+30 38 09.1	0.20	20.1	Fld	WN	7	
WR 119	MJ X8	01 34 00.88	+30 39 18.0	0.17	20.0	Fld	WN5	7	
WR 120	MJ X19	01 34 01.29	+30 40 04.3	0.16	17.9	Fld	WCL	7	
WR 121	MJ X9	01 34 01.74	+30 36 19.8	0.27	19.0	1	WNL?	7	
WR 122	UIT 289	01 34 02.24	+30 37 49.5	0.23	18.5	Fld	WN4	4	
WR 123	UIT 303	01 34 06.78	+30 47 27.1	0.34	17.1	71	WN7+neb	4	HS B393
WR 124	MC 67	01 34 07.75	+30 41 43.0	0.24	21.7::	94	WN	1	Middle of 3 stars
WR 125	MC 68	01 34 09.09	+30 39 06.8	0.30	…	96	WC	5	W&C25
WR 126	AM 24	01 34 15.38	+30 34 23.3	0.52	20.3	101	WN	5	MC 69; coords substantially improved
WR 127	AM 26	01 34 15.55	+30 33 44.9	0.55	20.1	101	WN (E)	5	MCMS 26; coords substantially improved
WR 128	AM 27	01 34 15.70	+30 34 01.1	0.54	18.7	101	WNL	5	UIT 337
WR 129	MC 70	01 34 16.28	+30 36 46.8	0.46	19.1:	100	WC	5	
WR 130	UIT 343	01 34 16.35	+30 37 12.5	0.45	18.3	100	WN7	4	HS B516
WR 131	MC 71	01 34 17.12	+30 32 51.7	0.60	19.7:	(101)	WC4–5	2	
WR 132	UIT 349	01 34 18.66	+30 34 11.6	0.58	18.7	101	Ofpe/WN9	4	
WR 133	MC 72	01 34 22.56	+30 33 17.2	0.66	21.5:	102	WN	1	NE of brter star
WR 134	MC 73	01 34 31.39	+30 57 18.8	0.80	18.4:	44	WN	1	
WR 135	MC 74	01 34 32.43	+30 46 58.8	0.59	15.8:	84	WC	1	UIT 363, CM 11, NGC 604 WR 1, WR 2
WR 136	MC 75	01 34 32.62	+30 47 05.9	0.60	15.2:	84	WNL	4, 9	UIT 364, CM 12, NGC 604 WR 3, WR 4a, WR 4b
WR 137	MC 76	01 34 33.57	+30 47 04.8	0.61	16.0:	84	WN8+neb	4	UIT 369, CM 13, NGC 604 WR 6
WR 138	MCA 16	01 34 40.39	+30 43 21.8	0.71	19.2	(87)	WN	1	
WR 139	MC 77	01 34 44.59	+30 44 45.0	0.76	…	(86)	WC	1	
WR 140	MC 78	01 34 58.90	+30 41 29.1	1.01	21.3	88	WC4	2	comp 1.5″S
WR 141	MC 79	01 35 05.38	+30 41 14.9	1.11	19.1	89	WC4–5	2	isolated

TABLE 9—*Continued*

Star[a]		Position (2000)					Spectral Type		
New (1)	Previous (2)	α (3)	δ (4)	ρ (5)	*CT* (6)	OB Association[b] (7)	Type (8)	References (9)	Comments[a] (10)
Remaining candidates									
WR 6A	MJ D16	01 32 51.06	+30 35 34.9	0.84	19.1	21	Cand WN	7	6.0 σ, detected once.
WR 11A	MJ D15	01 33 01.13	+30 35 07.9	0.69	19.6	21	Cand WN	7	5.8 σ, detected once.
WR 23A	MJ E16	01 33 10.71	+30 27 34.1	0.64	21.0	115	Cand WN	7	12.3 σ, detected twice.
WR 24A	MJ E34	01 33 11.28	+30 31 47.1	0.56	18.4	Fld	Cand WN	7	5.9 σ, detected twice.
WR 30A	UIT 077	01 33 15.18	+30 53 18.2	0.95	18.5	30	Of or WN	4	
WR 43A	MJ G1	01 33 33.19	+30 33 43.4	0.30	19.3	14	Cand WN	7	8.1 σ, detected twice.
WR 43B	MJ G35	01 33 33.19	+30 33 43.3	0.30	19.3	14	Cand WN	7	5.9 σ, detected once.
WR 53A	MJ G14	01 33 37.05	+30 35 00.9	0.23	21.4	Fld	Cand WN	7	5.2 σ, detected once.
WR 55A	MJ C21	01 33 38.39	+30 43 02.1	0.27	19.7	Fld	Cand WN	7	18.7 σ
WR 75A	MJ C24	01 33 43.61	+30 39 10.2	0.09	19.1	Fld	Cand WN	7	UIT 178, 5.7 σ
WR 102A	MJ B16	01 33 53.33	+30 47 43.0	0.34	20.9	Fld	Cand WN	7	19.2 σ, detected once.
WR 117A	UIT 274	01 33 59.77	+30 51 50.0	0.51	18.6	36	Of or WN	4	HS B318
WR 121A	MJ X24	01 34 01.91	+30 38 19.0	0.21	17.5	Fld	Cand WN	7	14.4 σ, detected twice.
WR 125A	AM 21	01 34 12.39	+30 32 48.6	0.54	20.0	Fld	Cand WN	5	Coords substantially improved
WR 125B	AM 22	01 34 13.68	+30 34 23.4	0.50	20.1	101	Cand WN	5	Coords substantially improved
WR 125C	AM 23	01 34 14.77	+30 33 43.6	0.54	20.7	101	Cand WC	5	Coords substantially improved
WR 125D	AM 25	01 34 15.37	+30 33 53.5	0.54	20.0	101	Cand WN	5	Coords substantially improved
WR 140A	MJ A7	01 34 58.90	+30 40 27.0	1.03	18.2	(88)	Cand WN	7	5.7 σ, detected once.
WR 140B	MJ A5	01 35 00.26	+30 41 51.0	1.02	19.4	88	Cand WN	7	6.5 σ, detected twice.
WR 142	MJ A6	01 35 07.06	+30 41 43.7	1.13	18.4	89	Cand WN	7	5.2 σ, detected twice.

[a] Star identifications are AM = Armandroff & Massey 1985; MC = Massey & Conti 1983; W&C = Wray & Corso 1972; MCA = MCA87; "ob" = Massey et al. 1995a; UIT = Massey et al. 1996; W91 = (see Massey et al. 1995a and present text); CM = Conti & Massey 1981; HS B = Humphreys & Sandage 1980 blue star; NGC 595 and NGC 604 are WR candidates from the Drissen et al. 1993 survey with *HST*.

[b] OB association designations from Humphreys & Sandage 1980.

References.—(1) MCA87; (2) Willis et al. 1992; (3) Smith et al. 1995; (4) Massey et al. 1996; (5) AM91; (6) Massey et al. 1995a; (7) this paper; (8) Schild et al. 1990; (9) Conti & Massey 1981; (10) Massey & Conti 1983.

TABLE 10

WOLF-RAYET STARS IN M31

STAR[a]	POSITION (2000) α	δ	ρ	CT	OB ASSOCIATION[b]	SPECTRAL TYPE Type	References	COMMENTS[a]
MS 21	00 39 11.00	+40 38 16.6	0.88	...	127	WCE	1	Coords. approx.
OB 136 WR 1	00 39 19.50	+40 22 10.9	0.87	19.8	136	WN/C	2	
OB 138 WR 1	00 39 33.43	+40 20 18.4	0.92	19.7	138	WC	2	
OB 135 WR 1	00 39 45.78	+40 23 02.9	0.88	19.4	135	WNE	2, 3	
MS 12	00 40 19.46	+40 52 24.8	0.62	...	132	WC	2	Coords. approx.
MS 14	00 40 20.42	+40 48 07.7	0.56	...	72	WC	2	Improved coords.
MS 20	00 40 21.01	+40 35 19.5	0.67	...	80	WN	2	Improved coords.
MS 11	00 40 22.47	+40 52 33.8	0.60	...	132	WC4–5	4	Coords. approx.
OB 78 WR 5	00 40 23.01	+40 44 54.3	0.55	21.2	78	WN/C	2	MS 15
OB 78 WR 2	00 40 26.22	+40 44 59.6	0.53	19.1	78	WNL	2, 3, 5	OB 78-82 = IT 5-25
MS 18	00 40 29.06	+40 39 19.0	0.60	...	75	WC	6	Improved coords.
MS 17	00 40 31.60	+40 39 09.4	0.60	...	75	WN	6	Improved coords.
OB 78 WR 3	00 40 34.17	+40 43 39.5	0.53	20.3	78	WC6–7	7	
OB 78 WR 4	00 40 34.65	+40 44 32.6	0.52	22.0	78	WC5	2	MS 16
OB 69 WR 2	00 40 56.44	+41 03 08.6	0.56	18.2	69	Ofpe/WN9	2, 3, 8	
OB 69 WR 1	00 40 56.66	+41 02 55.2	0.55	20.2	69	WNE	6	
OB 69 WR 3	00 40 58.40	+41 04 14.5	0.57	23.0	69	WC	2	
OB 69 WR 4	00 41 01.95	+41 04 45.6	0.56	22.2	69	WNL	2	
OB 69 F1	00 41 07.24	+41 04 16.9	0.50	20.2	(69)	WC6–7	2	
MS 8	00 41 34.95	+41 05 51.6	0.32	...	19	WCL	1	Improved coords.
MS 10	00 41 44.44	+40 45 15.8	0.73	...	76	WC6	3, 1	Improved coords
MS 6	00 42 14.38	+41 25 41.4	0.60	...	63	WCL	1	Improved coords.
MS 5	00 42 34.40	+41 30 22.2	0.61	...	61	WC7–8	3	Improved coords.
MS 7	00 42 41.93	+41 23 13.0	0.28	...	(13)	WCL	1	Coords. approx.
MS 4	00 43 31.08	+41 12 04.8	0.57	...	Fld	WC7–8	4	Improved coords.
MS 2	00 43 41.61	+41 23 03.6	0.31	...	2	WC	1	Improved coords.
MS 3	00 44 06.46	+41 19 20.9	0.64	...	36	WC	1	Coords. approx.
OB 10 WR 1	00 44 10.16	+41 32 52.4	0.33	19.6	10	WC6–7	7	IT 5-19
IT 5-15	00 44 12.39	+41 29 41.3	0.39	...	Fld	WC6	2	Improved coords.
IT 1-40	00 44 20.55	+41 54 11.7	0.75	...	Fld	WN	9	Coords. approx.
OB 32 WR 1	00 44 22.29	+41 18 56.7	0.79	...	32	WC6–7	2	
OB 33 WR 2	00 44 25.45	+41 20 43.4	0.76	...	33	WC6–7	2	
OB 33 WR 3	00 44 27.99	+41 21 00.2	0.78	...	33	WNL/Of	2	
OB 54 WR 1	00 44 37.56	+41 52 03.3	0.61	21.1	54	WN	2	IT 1-38
IT 5-3	00 44 44.17	+41 27 36.4	0.71	...	41	WC	9	Coords. approx.
IT 5-2	00 44 51.82	+41 29 06.3	0.73	...	41	WC	2	Coords. approx.
IT 1-48	00 44 53.49	+41 53 54.2	0.62	...	Fld?	WC	2	Coords. approx.
OB 42 WR 1	00 44 55.54	+41 31 04.2	0.71	...	42	WC6–7	2	IT 5-4
OB 42 WR 2	00 45 01.07	+41 30 54.1	0.76	...	42	WC6–7	2	IT 5-10
OB 48 WR 6	00 45 10.36	+41 36 46.2	0.69	18.2	48	WC6–7 + abs	2	
OB 48 WR 1	00 45 11.26	+41 38 14.9	0.66	20.7	48	WC6–7	6	IT 5-01
OB 48 WR 3	00 45 13.64	+41 37 42.3	0.69	21.1	48	WC + abs	6	
OB 48 WR 2	00 45 14.07	+41 37 34.8	0.70	21.2	48	WNE	2	
OB 48-527	00 45 17.56	+41 39 21.6	0.69	18.5	48	WN	2	Coords. approx.
IT 4-01	00 45 24.12	+41 53 50.8	0.62	...	Fld	WC	9	Coords. approx.
OB 102 WR 1	00 46 28.59	+42 11 27.2	0.89	20.9	102	WN	2	
IT 4-13	00 45 37.09	+41 42 01.6	0.78	...	Fld	WC	2	Coords. approx.
IT 4-14	00 45 51.26	+41 42 40.4	0.87	...	Fld	WC	9	Coords. approx.
Remaining candidates								
OB 136 WR 2	00 39 20.14	+40 22 06.8	0.87	21.2	136	Cand WN	7	
OB 78 WR 9	00 40 31.93	+40 43 24.0	0.54	20.1	78	Cand WN	7	
OB 69 WR 5	00 41 00.64	+41 04 01.0	0.55	21.9	69	Cand WN	7	
IT 6-1	00 43 02.61	+41 37 05.7	0.64	...	59	Cand WC	9	Coords. approx.
OB 33 WR 1	00 44 25.24	+41 21 14.7	0.74	...	33	Cand WR	2	
OB 102 WR 2	00 46 33.63	+42 12 08.0	0.91	21.2	102	Cand WN	7	

[a] Star identifications are: ob = Massey et al. 1986; MS = Moffat & Shara 1983; IT = Moffat & Shara 1987.

[b] OB associations designations are from van den Bergh 1964. We have assumed that OB 75 is the small, unlabeled association direction north of OB 80.

REFERENCES.—(1) Moffat & Shara 1983; (2) AM91; (3) Schild et al. 1990; (4) Willis et al. 1992; (5) Massey et al. 1995a; (6) MCA87; (7) Massey et al. 1986; (8) Massey 1998c; (9) Moffat & Shara 1987.

brighter than that of the star identified by Wilson (1991). The coordinates of Wilson (1991) suffered from a cos δ problem, and we believe that the cross reference to "W91-129" was simply incorrect. The star's coordinates and identification as a UIT source are correct. We have reluctantly retained the name "W91-129" as we feel this is less likely to create confusion.

Several of the Massey & Conti (1983) stars were reobserved spectroscopically by Schild et al. (1990) and Willis et al. (1992). We have included their revised types in Table 9. Smith & Maeder (1991) also provided "improved" spectral types for a number of these stars; however, this was based upon measuring line widths (from photocopied enlargements of previously published spectra), rather than upon the actual line ratios on which the classification scheme is based. An interesting question concerns whether or not the stellar wind laws (velocity and ionization temperatures as a function of radius) scale in a homologous fashion in galaxies of differing metallicities when we know that the mass-loss rates (at least for unevolved stars) do not. Assigning a "WC4" spectral type to a star simply because its line widths are the same as that of a Galactic WC4 star presupposes the answer; in point of fact, Schild et al. (1990) found a correlation with metallicity in the line widths of WC stars with the same subclass, as described above in § 3.2.

Most recently, Massey et al. (1996) describe spectroscopic classification of UV-bright sources they identified from *UIT* images. Included in their list are 34 WR stars, of which 14 were newly found, including five additional Ofpe/WN9 stars. Two of these were found as part of the present study.

We give a complete census of the spectroscopically confirmed M33 stars in Table 9. In keeping with the IAU Task Group on Designations, we have provided a consecutive numbering system for the M33 WRs in an attempt to rationalize the naming convention, and we urge other researchers to refer to these stars as, e.g., "M33-WR 3" rather than "MC 1." As the finding charts published by Massey et al. (1987b) were not always usable in crowded regions, or in toward the nucleus, and since some of the coordinates previously published were not always reliable, we have remeasured the coordinates for all stars in Table 9, except as indicated. For this, we used 4 m CCD frames with astrometric solutions tied to the *HST* guide star catalog plate "00DV" and compared the fields to our original finding charts. These positions are now expected to be good to a few tenths of an arcsecond.

A2. M31

Eight fields in M31 were surveyed for Wolf-Rayet stars using a CCD and interference-filter imaging by Massey et al. (1986), using identical methods to that described above for M33. Spectroscopy eventually confirmed 19 of these original candidates (AM91). CCD imaging at the CFHT reported by AM91 revealed an additional five WR stars that were spectroscopically confirmed (AM91).

Moffat & Shara (1983, 1987) identified WR candidates in larger regions of M31 using photography (both direct and with an image tube). These searches revealed only the strongest lined stars; the detection limit was determined by AM91 as probably complete to log [$-$EW (Å)] $\sim$ 2.0, about an order of magnitude poorer than what was needed for completion for WN types.

We give the complete list of all spectroscopically confirmed WR stars in Table 10. Coordinates were remeasured for some of the Moffat & Shara (1983, 1987) stars as indicated. Schild et al. (1980) and Willis et al. (1992) reclassified a few of the stars, generally from higher S/N data than that obtained by the original authors, and we have kept their classifications when in doubt. Moffat & Shara (1983, 1987) classified a number of their WC stars as very late (WC8 or WC8.5) based upon poor S/N spectra. When these stars were reexamined at higher S/Ns, the classifications have invariably proven to be of somewhat earlier type (see discussion in MCA87; Schild et al. 1990; and Willis et al. 1992). When other classifications were unavailable, we used their published spectra to reclassify the stars as "early" and "late" type as appropriate.

The star OB 69 WR 2 was originally classified as WNL by MCA87; it was subsequently called a WN7 by Schild et al. (1990). However, a recent, high S/N spectrum of it obtained with the MMT clearly shows that it is of type Ofpe/WN9. Its spectrum is compared to that of HDE 269927c, an LMC Ofpe/WN9 star, in Figure 13 of Massey (1998c), in a figure kindly constructed by Paul Crowther. This is the only Ofpe/WN9 star identified in M31 so far.

A3. NGC 6822 AND IC 1613

The first Wolf-Rayet star in NGC 6822 was discovered by Westerlund et al. (1983) using a "grism" to survey the entire galaxy. Their follow-up spectrum revealed that this was an early-type WN star; spectrophotometry by MCA87 showed that this star was very strong lined [log ($-$EW [Å]) = 2.2]. This helped demonstrate the usefulness of various detection techniques: AM85 surveyed nearly all of NGC 6822 and detected this star at the 66 σ level! This can be contrasted with the photographic interference filter imaging of Moffat & Shara (1983), who included NGC 6822 as part of the same program that surveyed M31 as described above; they failed to detect this star, and concluded that NGC 6822 contained no WR stars.

Subsequent spectroscopy of the other AM85 WR candidates confirmed a total of four (including the Westerlund et al. 1983 star), all of WN type. We list these stars in Table 11. All four WR stars fall within the OB association boundaries drawn by Hodge (1977).

IC 1613 was also surveyed by AM85, who found eight candidates, of which only one was of high significance. This star was

TABLE 11

WOLF-RAYET STARS IN NGC 6822 AND IC 1613

Star[a]	Position (2000) α	Position (2000) δ	CT	OB Association[b]	Spectral Type: Type	Spectral Type: Reference	Comments[a]
N6822 WR 3	19 44 31.94	−14 44 09.0	19.6	2	WN	1	
N6822 WR 4	19 44 37.92	−14 51 07.6	19.8	4	WN	1	
N6822 WR 5	19 44 49.28	−14 45 39.7	19.8	7	WN	1	
N6822 WR 12	19 45 13.44	−14 45 12.1	19.2	15	WNE	2	Westerlund et al. 1983 star
IC 1613 WR 6......	01 05 01.57	+02 04 20.0	20.0	...	WCE	1	

[a] Star identifications are from AM85.

[b] OB association numbers for NGC 6822 are from Hodge 1977. The IC 1613 WR star falls within H II Region No. 3 cataloged by Sandage 1971.

REFERENCES.—(1) MCA87; (2) Westerlund et al. 1983.

TABLE 12

WOLF-RAYET STARS IN IC 10

	Position (2000)			
Star[a]	α	δ	CT	Spectral Type[b]
WR 1	00 19 57.00	+59 17 08.3	21.7	WC
WR 2	00 19 59.68	+59 16 55.4	21.5	WC
WR 4	00 20 11.60	+59 18 58.6	20.1	WC
WR 5	00 20 12.89	+59 20 08.9	>21.8	WNE
WR 7	00 20 21.97	+59 17 41.9	19.3	WC
WR 9	00 20 22.71	+59 18 47.6	>22.8	WN
WR 10......	00 20 23.39	+59 17 42.9	21.6	WC6–7
WR 12......	00 20 26.23	+59 17 27.1	21.3	WC
WR 13......	00 20 26.74	+59 17 33.7	22.0	WC
WR 14......	00 20 26.99	+59 17 20.7	21.0	WC
WR 15......	00 20 27.03	+59 18 18.5	21.1	WC6–7
WR 17......	00 20 29.11	+59 16 52.5	21.2	WN
WR 19......	00 20 31.09	+59 19 04.8	22.9	WNE
WR 20......	00 20 34.56	+59 17 15.4	22.5:	WC
WR 21......	00 20 41.68	+59 16 25.5	23.8:	WN
Remaining candidates				
WR 3	00 20 09.19	+59 17 58.0	22.0	Cand WN
WR 16......	00 20 27.56	+59 18 09.8	21.5	Cand WN

[a] Star identifications are from Massey et al. 1992.
[b] All spectral types are from Massey & Armandroff 1995.

discovered to be a Wolf-Rayet during spectroscopy of the H II region in which it is located by both D'Odorico & Rosa (1982) and Davidson & Kinman (1982). The former describe it as a peculiar WC + WN star, but the latter correctly identified the He II λ4686 emission as nebular. Based on the spectrum published by MCA87, we classify the star as WCE. Another IC 1613 WR candidate was shown to be an SNR by Azzopardi, Lequeux, & Maeder (1988).

IC 1613's WR star does not fall within any cataloged OB association; Hodge (1978) mistook its H II region (No. 3 in Sandage 1971) for a background galaxy.

A4. IC 10

The small, often-neglected member of the Local Group IC 10 was surveyed for Wolf-Rayet stars by Massey et al. (1992). Much to their surprise, this survey yielded 22 WR candidates. Of these, 16 were expected to be real on statistical grounds, and indeed Massey & Armandroff (1995) subsequently confirmed 15. There are two additional WR candidates of moderate significance level without sufficient spectroscopy to determine if they were real or not. We list these stars in Table 12.

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