Publications of the Astronomical Society of the Pacific, **116**:170–177, 2004 February

A Newly Discovered Open Cluster Surrounding the Wolf-Rayet Stars WR 38 and WR 38a

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Received 2003 July 22; accepted 2004 January 6; published 2004 February 3

ABSTRACT. Photoelectric and CCD *UBV* survey data are presented for stars brighter than about $V \sim 16.5$ in the field of the faint Carina Wolf-Rayet (WR) stars WR 38 and WR 38a. Both WR stars appear to belong to an associated compact cluster (nuclear diameter ∼0′.3) of at least six faint OB stars reddened by $E_{B-V} = 1.60 \pm 0.02$ s.e. and lying at a distance of ∼14.5 ± 1.6 kpc ($V_0 - M_V = 15.80 \pm 0.25$ s.d.). As cluster members, the two WR stars have estimated luminosities of $M_v = -5.8$ (WR 38, type WC4) and $M_v = -5.0$ (WR 38a, type WN5). The former value is slightly more luminous than expected for Galactic WR stars.

1. INTRODUCTION

Much of what we know about the intrinsic properties of Wolf-Rayet (WR) stars is tied to the study of those that belong to open clusters and associations (e.g., Lundström & Stenholm 1984; van der Hucht 2001). Population I Wolf-Rayet stars are linked to terminal stages in the evolution of massive OB stars (e.g., Maeder & Meynet 1987), and generally represent post–main-sequence evolutionary stages in which the thermonuclear by-products of core hydrogen-burning via the CNO cycle or core helium-burning appear at the stellar surface, where they appear in stellar winds. Wolf-Rayet stars are therefore relatively young objects; in nearly all cases their surrounding open clusters and associations have main-sequence turnoffs no later than spectral types O9 to B0. Their implied ages are less than ∼6×10^6 yr (e.g., Meynet, Mermilliod, & Maeder 1993).

Information on the intrinsic parameters of WR stars is essential for using them as tracers of spiral structure in the Milky Way, for delineation of the Galactic metallicity gradient as a function of Galactocentric distance, or for linking their properties to those of stellar evolutionary models. That is where WR stars in open clusters and associations play a crucial role. Confirmation of membership of a WR star in a group of stars of measurable distance and reddening allows one to transform the observed apparent magnitude and color for the star into absolute magnitude and intrinsic color, which are related to luminosity and effective temperature. The *Seventh Catalogue of Galactic Wolf-Rayet Stars* (van der Hucht 2001) indicates that perhaps a quarter of known WR stars in the Milky Way are members of open clusters or OB associations. Such stars serve an important function in establishing the intrinsic properties of the various WR subtypes and chemical classes.

The frequency of open clusters in the Milky Way decreases sharply as a function of increasing cluster age (e.g., Wielen 1971). Dynamical interactions between cluster members gradually deplete the original stellar population through energy exchange and subsequent escape of stars from the cluster. Because WR stars are very young, it follows that a sizable fraction still ought to be members of the open clusters and associations in which they were created. Indeed, regularly published lists of WR stars suspected to be members of clusters and associations (van der Hucht et al. 1981; van der Hucht 2001) imply that the cluster sample is growing, primarily through rigorous searches for new clusters in the vicinity of known WR stars.

The present study grew from a search for overlooked open clusters near WR stars listed in the *Sixth Catalogue of Galactic Wolf-Rayet Stars* (van der Hucht et al. 1981), which contains finder charts for all Population I WR stars recognized at the time. An inspection of the finder charts confirmed all of the obvious cases of known cluster-WR star coincidences, but also revealed the existence of additional unstudied cluster-WR star pairs in which the associated clusters, if they were indeed real, were somewhat poorly populated. The field of the Wolf-Rayet stars WR 37, WR 38, and WR 39 at ($\alpha_{2000} = 11^h06^m$, $\delta_{2000} = -61°14'$), coincident with the more recently discovered Wolf-Rayet stars WR 38a and WR 38b (Shara et al. 1991), was one such region. Our purpose here is to describe photometric observations of stars in the field that reveal a likely

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association of WR 38 and WR 38a with a previously unstudied open cluster, which may itself be a double with a suspected cluster surrounding WR 39 and WR 38b. Such an association is of particular importance because of the spectral types of the associated WR stars: WC4 for WR 38, WN5 for WR 38a, WC7+OB for WR 38b, and WC7+OB? for WR 39 (van der Hucht 2001). The last list of cluster WR stars contains none of type WC4.

2. OBSERVATIONAL DATA

Photoelectric *UBV* photometry was obtained for a sequence of 10 stars in the field of WR 38 in 1987 January using the 0.6 m Helen Sawyer Hogg Telescope of the University of Toronto's Southern Observatory when it was located on Cerro Las Campanas, Chile. The observations were obtained in similar fashion to those described by Turner (1986) and are summarized in Table 1. The stars are identified in Figure 1. None of the stars are associated with the nearby Wolf-Rayet stars, but they served as important calibration objects for subsequent CCD photometry of the field.

CCD observations for the field of WR 38 were obtained at the University of Toronto's Southern Observatory during one night in 1996 June. The observations employed a Metachrome-coated 512 × 512 PM512 CCD, which has a 4′ × 4′ field. The CCD chip was cooled by liquid nitrogen for all observations. A "standard" set of *UBV* filters was employed (see Shelton 1996).

Long and short exposures in each waveband were taken for each pointing of the telescope, in which the durations for each exposure were somewhat ambiguous, depending upon the transparency and seeing conditions at the time. The field was divided into east and west regions, both of which overlapped the sequence of photoelectric standards. Because of variable transparency during much of the observing run, all magnitude calibrations for the data frames were done using the Table 1 stars as standards.

All CCD data frames were calibrated using bias and flat-field exposures for each waveband, and instrumental *UBV* magnitudes were established using the IRAF package and DAOPHOT, as outlined by Massey & Davis (1992). Simple relations derived from the data for the standard stars were then used to reduce the instrumental magnitudes to the standard system.

The Balmer discontinuity at 3646 Å in stellar continua presents problems for accurate *U*-band photometry because it affects the effective wavelength of the filter/starlight combination for observations of stars near spectral type A0. As noted by Moffat & Vogt (1977), the problem is particularly acute for photometric detectors with starlight/filter response functions that deviate noticeably from those of the standard Johnson *UBV* system, a feature most commonly encountered for *U*-band data. Simulations by Straižys & Lazauskaitė (1995) also illustrate the extent of the problem.

It is not generally recognized how serious the problem can be for CCD photometry, yet its effects can be detected, even at a marginal level, in a variety of published papers that contain CCD *UBV* photometry of early-type stars. Our concern here is for possible Balmer discontinuity effects in *U*-band photometry with the University of Toronto's Metachrome CCD camera used at its Southern Observatory. For that reason we tested our CCD photometry of the photoelectric standards and similarly obtained CCD photometry of stars in other southern hemisphere fields from Shelton (1996) with published *UBV* photometry in order to search for a possible Balmer discontinuity effect in *U–B* as a function of known or inferred spectral type. The signature of such an effect was indeed found in the data and was corrected by adjusting the *U–B* colors of stars earlier than spectral type A6 in a systematic fashion. All corrections were typically small (less than 0.05), except for those near spectral type A2–A3 (roughly 0.15). Details are provided by Shorlin (1998).

TABLE 1
PHOTOELECTRIC *UBV* SEQUENCE NEAR WR 38

Star	V	$B-V$	$U-B$	n
1	9.23	+1.05	+0.84	2
2	10.97	+0.46	+0.07	1
3	11.22	+1.18	+1.10	2
4	11.47	+0.17	−0.04	2
5	11.69	+0.08	−0.37	2
8	12.14	+1.93	+2.21	1
9	12.11	+0.32	+0.16	1[a]
	12.19	+0.28	+0.25	CCD
10	12.65	+1.61	+1.37	1
11	12.77	+0.12	−0.32	2
16	13.55	+0.56	+0.27	1

[a] Has faint optical companion suspected of contaminating the data. CCD values preferred.

The adjusted CCD data are presented in Table 2, and the stars are identified in Figure 2. The *UBV* data are averages from at least two frames in each passband, and in the central part of the field are averages from four frames in each passband. The internal uncertainties in V are estimated to be ± 0.015 mag at $V = 14$, increasing to ± 0.03 mag at $V = 16$; in B they are ± 0.01 mag at $B = 15.5$, increasing to ± 0.04 mag at $B = 17$; and in U they are ± 0.01 mag at $U = 15$, increasing to ± 0.05 mag at $U = 17.5$. The uncertainties in the $B-V$ and $U-B$ colors are therefore of order ± 0.01 mag for the brightest stars and up to ± 0.08 mag for the very faintest stars observed.

3. ANALYSIS

A color-color diagram for the field of WR 38 is plotted in Figure 3. Prior work on interstellar reddening in several Carina clusters (Turner 1976b, 1977, 1978; Turner & Moffat 1980) established a reddening relation suitable for the analysis of Carina stars of slope $E_{U-B}/E_{B-V} = 0.74$ (Turner et al. 1980), with a curvature term of $+0.02$ (Turner 1989). Since the field of the present study overlaps many of the fields in the studies

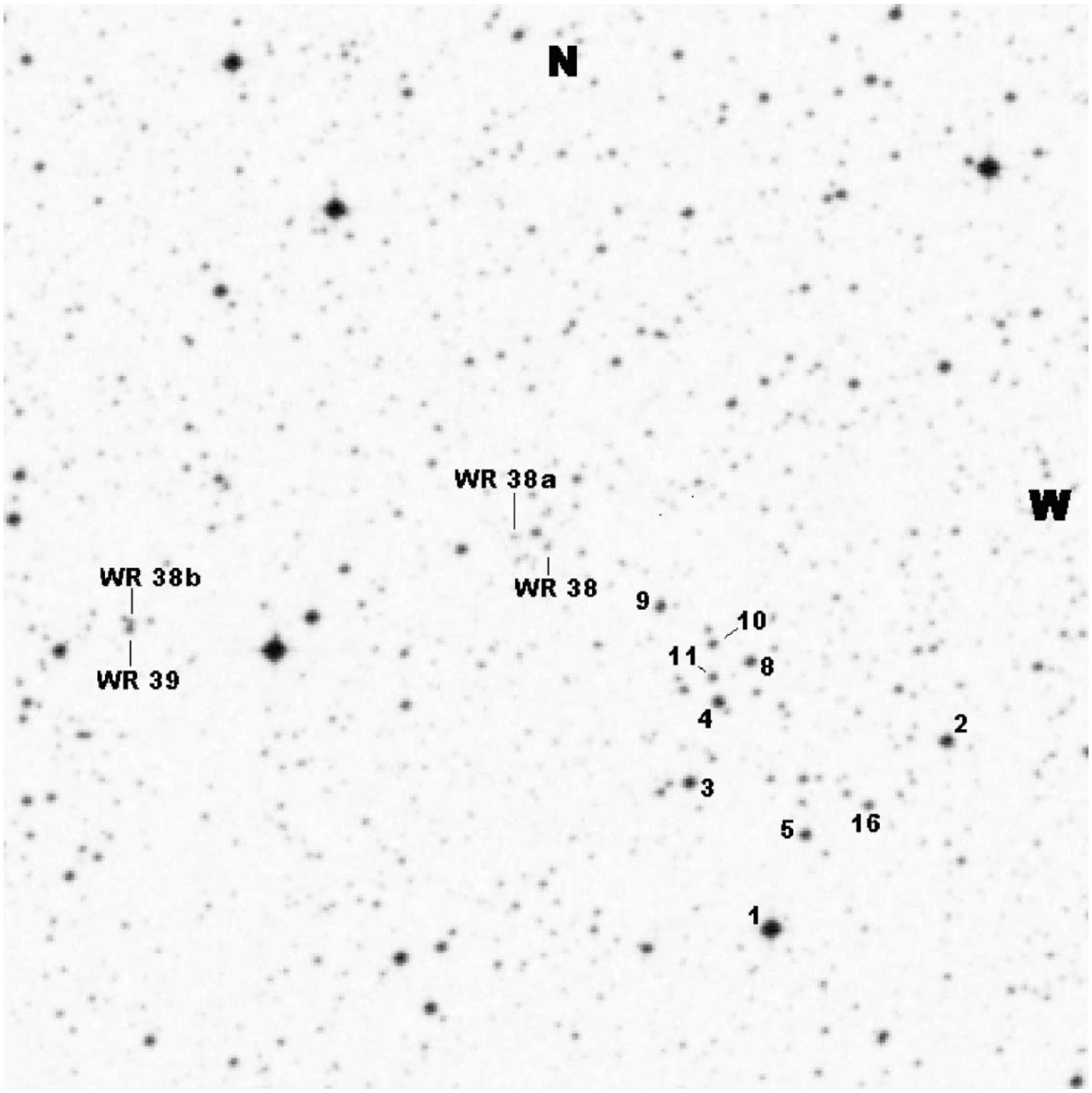

FIG. 1.—Finder chart from the Digitized Sky Survey for the photoelectric sequence of stars near WR 38 at ($\alpha_{2000} = 11^h06^m$, $\delta_{2000} = -61°14'$), including the four Wolf-Rayet stars in the region. The field of view measures 10′ × 10′.

identified above, it seemed reasonable to adopt the same relationship here. Likewise, previous *UBV* studies of Carina star fields surrounding the Cepheids U Car and XZ Car (van den Bergh, Younger, & Turner 1985), and XY Car and GT Car (Turner et al. 1993) indicate that A-type stars and late B-type stars of small reddening ($E_{B-V} \simeq 0.1$–0.25) are a common constituent of lines of sight through the Carina portion of the Galaxy. Identical conclusions apply to the field of WR 38, according to the data of Figure 3, in which only two groups of distinct reddening are apparent in the data of Tables 1 and 2: (1) a group of mid to late B-type stars, A-type stars, and F-type stars reddened by $E_{B-V} \simeq 0.26$, and (2) a small group of OB-type stars reddened by $E_{B-V} = 1.60$.

In plotting the data for WR 38 (WC4) and WR 38a (WN5) in Figure 3, we first corrected the broadband colors of the stars for the effects of emission-line contamination (Table 3), in similar fashion to the procedure adopted for the WN6 star WR 67 in the cluster Pismis 20 (Turner 1996), i.e., using the results of Pyper (1966). The adopted corrections for WR 38 are $\Delta(B-V) = +0.09$ and $\Delta(U-B) = -0.30$, values obtained for the WC4+OB? star WR 143 by Pyper (1966) but adjusted for a probable B-type companion from a comparison with similar corrections obtained by Pyper (1966) for WR 4 (WC5 + ?) and WR 111 (WC5). A correction of $\Delta V = +0.6$ was adopted from Pyper (1966). The corrections for WR 38a are $\Delta(B-V) = +0.09$ and $\Delta(U-B) = -0.06$, which are the values obtained by Pyper (1966) for the WN5+B? star WR 138. A correction of $\Delta V = +0.2$ was also adopted from Pyper (1966). Pseudo

TABLE 2
CCD *UBV* Data for Stars near WR 38

Star	V	$B-V$	$U-B$	Note	Star	V	$B-V$	$U-B$	Note	Star	V	$B-V$	$U-B$	Note
6	11.99	+0.16	−0.26	1	54	15.10	+0.70	+0.15	1	97	15.82	+1.03	+0.46	1
7	12.10	+1.13	+0.97	1	55	15.11	+0.41	+0.31	1	98	15.84	+0.60	+0.16	1
12	12.90	+1.29	+0.05	1	56	15.12	+0.66	+0.16	1	99	15.86	+0.68	+0.18	1
13	13.00	+0.37	+0.31	1	57	15.12	+1.15	+0.06	2, WR 38a	100	15.89	+0.75	+0.12	1
14	13.06	+0.46	+0.05	1	58	15.15	+1.53	+1.27	1	101	15.90	+1.27	−0.04	2
15	13.14	+0.33	+0.24	1	59	15.16	+0.46	+0.31	1	102	15.92	+0.49	+0.27	1
17	13.55	+1.28	+1.32	1	60	15.17	+0.84	+0.29	1	103	15.94	+0.64	+0.15	1
18	13.57	+0.42	+0.25	1	61	15.22	+0.52	+0.23	1	104	15.94	+0.70	+0.17	1
19	13.57	+0.26	+0.18	1	62	15.23	+0.98	+0.25	1	105	15.96	+0.62	+0.29	1
20	13.80	+0.56	+0.28	1	63	15.24	+1.45	+1.01	1	106	15.97	+0.88	+0.42	1
21	13.87	+1.55	+0.71	1	64	15.29	+0.69	+0.14	1	107	15.97	+1.04	+0.98	1
22	13.91	+0.36	+0.28	1	65	15.32	+0.48	+0.23	1	108	16.03	+0.87	+0.37	1
23	13.91	+1.08	+0.84	1	66	15.33	+0.51	+0.27	1	109	16.05	+0.90	+0.43	1
24	13.93	+0.79	+0.33	1	67	15.34	+0.43	+0.31	1	110	16.06	+0.92	+0.33	1
25	14.01	+0.63	+0.12	1	68	15.43	+0.83	+0.29	1	111	16.08	+1.05	+0.74	1
26	14.06	+0.65	+0.12	1	69	15.45	+0.55	+0.19	1	112	16.11	+0.86	+0.19	1
27	14.11	+0.29	+0.22	1	70	15.46	+0.78	+0.27	1	113	16.12	+1.45	+0.11	3
28	14.19	+1.85	+1.52	1	71	15.48	+1.31	+0.81	1	114	16.12	+0.89	+0.41	1
29	14.23	+1.57	+1.42	1	72	15.48	+1.07	+0.59	1	115	16.14	+0.68	+0.30	1
30	14.36	+1.26	+0.99	1	73	15.49	+0.72	+0.34	1	116	16.15	+0.84	+0.39	1
31	14.40	+0.42	+0.31	1	74	15.50	+0.73	+0.22	1	117	16.19	+0.69	+0.28	1
32	14.42	+0.68	+0.19	1	75	15.51	+0.73	+0.17	1	118	16.19	+0.89	+0.33	1
33	14.45	+0.84	+0.41	1	76	15.51	+1.28	+0.10	2	119	16.21	+1.23	−0.15	2
34	14.46	+0.59	+0.28	1	77	15.51	+0.81	+0.48	1	120	16.22	+0.68	+0.03	1
35	14.52	+0.41	+0.33	1	78	15.54	+0.50	+0.26	1	121	16.23	+0.57	+0.27	1
36	14.56	+0.81	+0.33	1	79	15.55	+0.56	+0.23	1	122	16.28	+0.67	+0.32	1
37	14.56	+0.91	+0.63	1	80	15.56	+0.79	+0.21	1	123	16.30	+0.73	+0.19	1
38	14.59	+0.30	+0.26	1	81	15.58	+0.52	+0.14	1	124	16.31	+0.82	+0.28	1
39	14.59	+0.26	+0.05	1	82	15.60	+0.46	+0.30	1	125	16.32	+0.80	+0.25	1
40	14.66	+1.28	+0.65	2, WR 38	83	15.61	+0.90	+0.50	1	126	16.32	+0.70	+0.12	1
41	14.67	+0.47	+0.28	1	84	15.63	+0.62	+0.19	1	127	16.34	+1.29	+0.23	2
42	14.70	+0.76	+0.18	1	85	15.66	+0.71	+0.30	1	128	16.35	+0.80	+0.36	1
43	14.77	+0.42	−0.52	1	86	15.66	+1.05	+0.90	1	129	16.38	+0.67	+0.42	1
44	14.78	+0.65	+0.12	1	87	15.69	+0.96	+0.51	1	130	16.40	+0.68	+0.18	1
45	14.80	+0.34	+0.28	1	88	15.71	+0.66	+0.08	1	131	16.44	+1.19	+0.12	3
46	14.86	+0.59	+0.18	1	89	15.73	+0.59	+0.21	1	132	16.45	+0.71	+0.10	1
47	14.97	+0.38	+0.32	1	90	15.73	+0.74	+0.32	1	133	16.46	+0.77	+0.21	1
48	14.97	+0.77	+0.43	1	91	15.74	+0.82	+0.27	1	134	16.49	+0.82	+0.22	1
49	14.99	+0.61	+0.06	1	92	15.74	+0.55	+0.30	1	135	16.49	+0.82	+0.35	1
50	15.03	+1.30	+1.10	1	93	15.75	+1.32	+0.82	1	136	16.49	+0.74	+0.17	1
51	15.03	+1.52	+1.30	1	94	15.78	+0.80	+0.23	1	137	16.51	+1.30	+0.04	2
52	15.06	+0.79	+0.40	1	95	15.80	+0.57	+0.21	1	138	16.56	+1.33	+0.08	2
53	15.06	+0.70	+0.22	1	96	15.82	+0.76	+0.12	1					

Notes.—(1) Field star; (2) likely cluster member; (3) probable outlying cluster member.

$u-b$ colors for WR 38a were obtained by adjusting the synthetic *ubv* data for WR 4 from Massey (1984) for the difference in its interstellar reddening relative to WR 38a.

The agreement between adjusted broadband *UBV* magnitudes and colors and narrowband *ubv* magnitudes and colors corrected to the *UBV* system is less than ideal for both Wolf-Rayet stars, but is probably the best one can hope for under the circumstances. The broadband data are affected by a restricted match to the standard Johnson system, as well as by low-intensity counts for the stars on our CCD frames, while the narrowband data are synthetic observations derived from noisy spectra. Although the emission-corrected magnitudes and colors for both stars from broadband and narrowband observations agree rather poorly to within the cited uncertainties, they are both consistent with the colors of stars belonging to the faint, compact, heavily reddened group of OB stars lying near WR 38 and WR 38a. More worrisome is the systematic color difference between the CCD photometric data and the synthetic narrowband data, which are noticeably bluer. The source of such a difference is unknown.

The photometric data for stars in the WR 38 field were

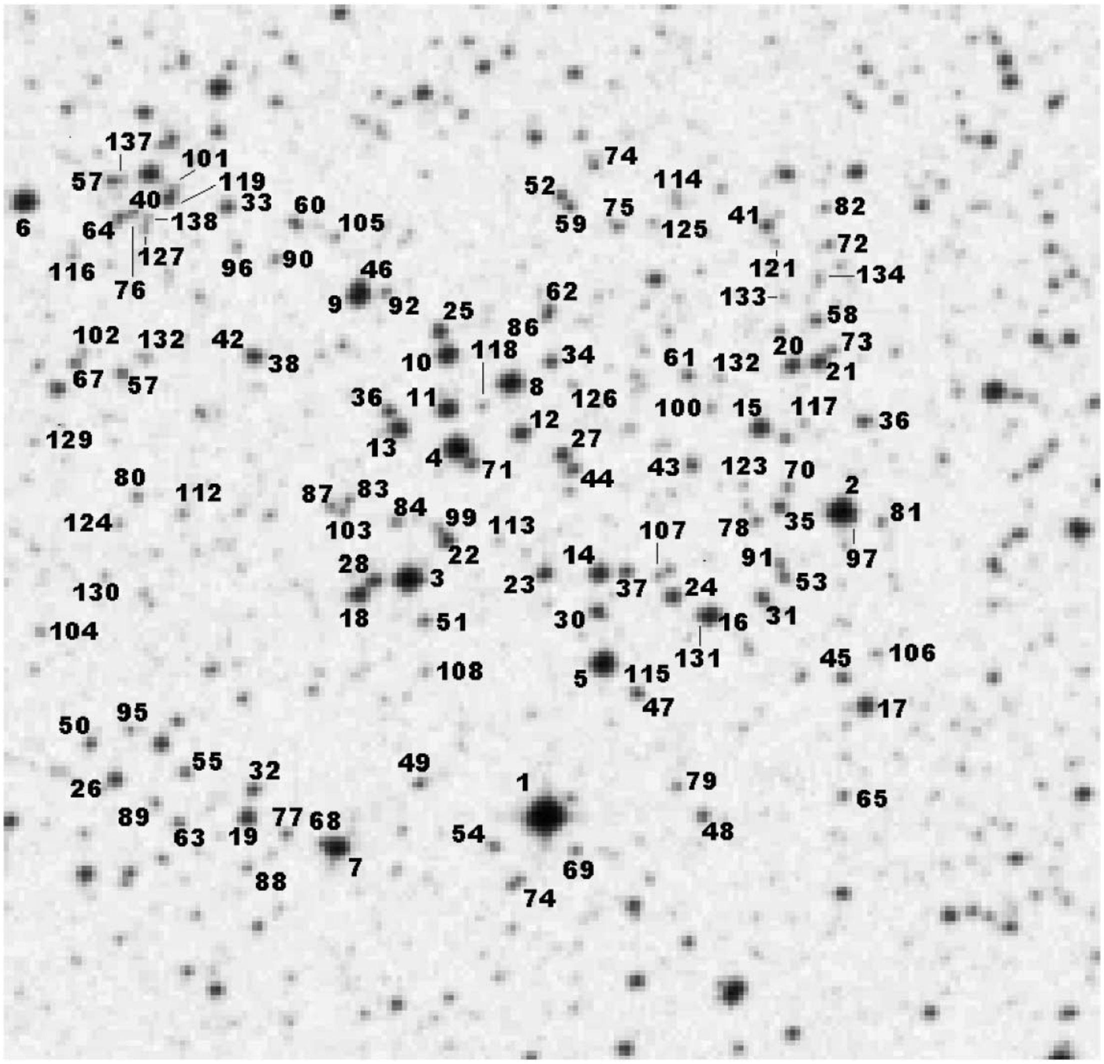

Fig. 2.—Finder chart from the Digitized Sky Survey for the smaller section of Fig. 1 included in the CCD survey. Stars are numbered sequentially according to the ordering by magnitude adopted in Table 2. The field of view measures 5′ × 5′.

analyzed by the variable-extinction method (cf. Turner & Moffat 1980) in order to separate problems of establishing the likely distances to stars in the field from potential questions surrounding the value of $R = E_{B-V}/A_V$ appropriate for the dust responsible for the extinction. A variable-extinction diagram for early-type stars near WR 38 is plotted in Figure 4, in which the zero-age main-sequence (ZAMS) values of M_V adopted for the stars were taken from the compilations of Turner (1976a) and Turner (1979), which are tied to a Pleiades distance modulus of $m - M = 5.56$.

A number of conclusions can be made on the basis of the data in Figure 4. First, the value of $R = E_{B-V}/A_V$ cannot be of the order of ∼5, otherwise one would be confronted with the paradox of the most heavily reddened stars in the field lying closer than the least reddened stars. Tests with the single early-type star in the field of intermediate reddening (star 43, $E_{B-V} = 0.71$) suggest that the reddening law near WR 38 must be described by $R \sim 3$. We therefore adopted a value of $R = 3.1$ based upon the results for stars in other Carina fields (Turner 1976b, 1977, 1978; Turner & Moffat 1980). A second conclusion is that only late-type stars in the WR 38 field are unreddened. All early-type stars in Figure 3 are reddened by $E_{B-V} = 0.07$ or more.

There may be a physically related group of B- and A-type stars lying along the line of sight at $V_0 - M_V = 12.33$ ($d = 2.9$ kpc), as argued by (Shorlin 1998), in which star counts appear to confirm the existence of a poorly populated foreground cluster in the field. Indeed, the impetus for the present study was just such a possibility. The subject of this paper, however, is the poorly populated OB cluster of at least six stars that appears to be associated with WR 38 and WR 38a. The distance to the latter group, indicated by ZAMS fitting in the

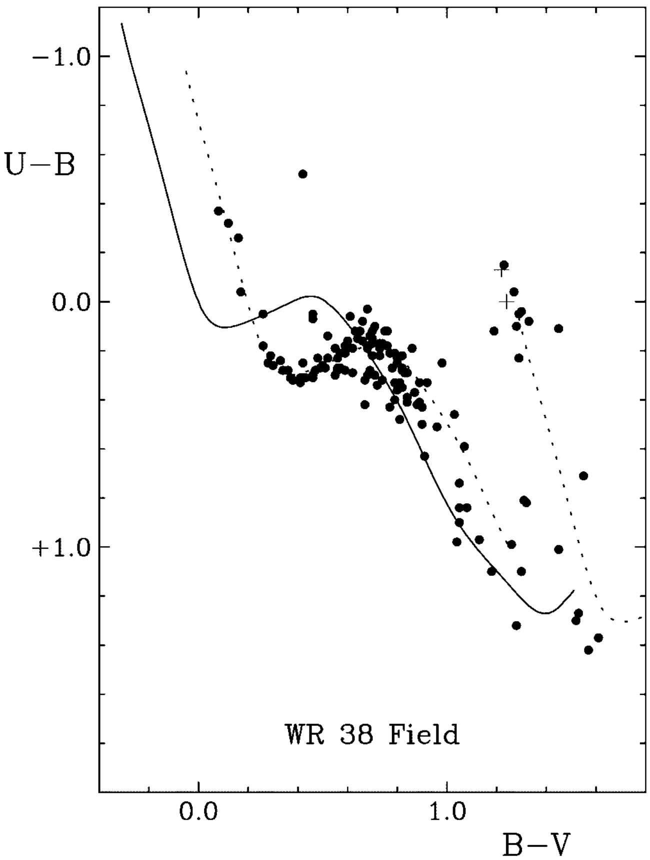

FIG. 3.—A color-color diagram for the stars surveyed in Tables 1 and 2. Crosses denote adjusted colors for the two Wolf-Rayet stars WR 38 and WR 38a, selected from Table 3. The intrinsic relation for main-sequence stars is plotted as a solid line, while dotted lines indicate the intrinsic relation reddened by $E_{B-V} = 0.26$ and $E_{B-V} = 1.60$.

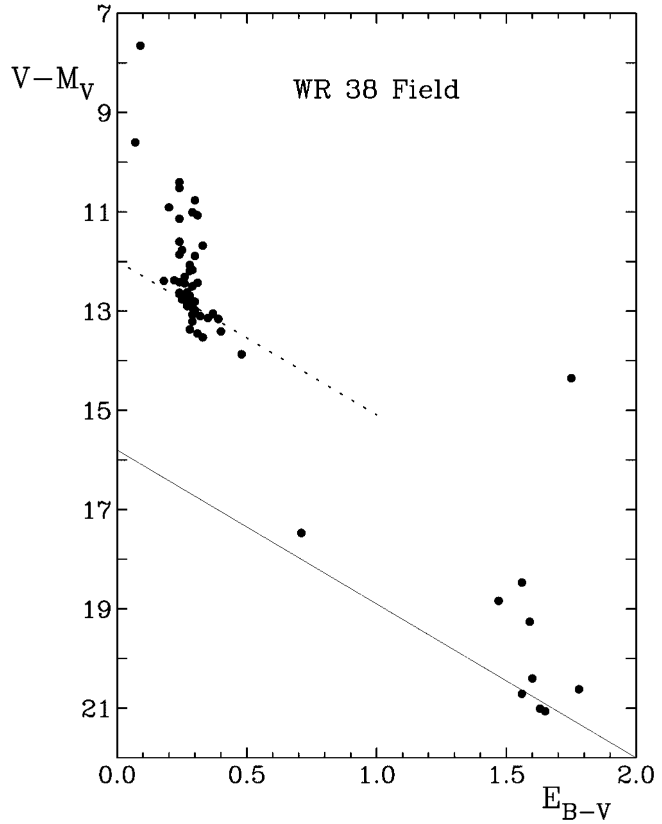

FIG. 4.—Variable extinction diagram for the stars surveyed in Tables 1 and 2. Lines of slope $R = 3.1$ are drawn for intrinsic distance moduli of $V_0 - M_V = 11.99$ (*dotted*) and 15.80 (*solid*), corresponding to the two main groups along the line of sight.

TABLE 3
PARAMETERS FOR WR 38 AND WR 38a

Photometric System	V	$B-V$	$U-B$	Source
WR 38, Spectral Type WC4				
Johnson-Morgan system *UBV* observations	14.66	+1.28	+0.65	1
Johnson system corrected for emission	15.26	+1.37	+0.35	1
Narrowband system *ubv* observations	15.40	+0.87	+0.47	2, 3
Continuum-adjusted *ubv* data	15.57	+0.91	+0.57	2
ubv data adjusted to *UBV*	15.20	+1.22	−0.13	1
WR 38a, Spectral Type WN5				
Johnson system *UBV* observations	15.12	+1.15	+0.06	1
Johnson system corrected for emission	15.32	+1.24	+0.00	1
Narrowband system *ubv* observations	16.21	+0.83	...	4
Continuum-adjusted *ubv* data	16.22	+0.83	(+0.64)	1, 5
ubv data adjusted to *UBV*	15.88	+1.12	(−0.04)	1

REFERENCES.—(1) This paper; (2) Torres-Dodgen & Massey 1988; (3) Smith, Shara, & Moffat 1990; (4) Shara et al. 1991; (5) Massey 1984.

variable-extinction diagram of Figure 4, is $V_0 - M_V = 15.80 \pm 0.25$ s.d. (± 0.14 s.e.), which corresponds to an estimated distance of $d = 14.5 \pm 1.6$ kpc. The average values for the foreground stars, most of which are suspected members of the foreground cluster identified by Shorlin (1998), are $V_0 - M_V = 11.99 \pm 0.27$ s.d. (± 0.05 s.e.), which corresponds to an estimated distance of $d = 2.5 \pm 0.3$ kpc.

The rather large distance inferred for the group of OB stars associated with WR 38 and WR 38a is consistent with the small angular extent of only ~0′.3 for the central cluster nucleus (cf. Wallace et al. 1999) and the extreme faintness of potential members. By way of comparison, the cluster Pismis 20, containing WR 67 (type WN6), has an angular diameter of ~1′.4 for the central nucleus of bright stars (the literature value for the angular diameter of the entire cluster is 4′.5). The inferred distance to Pismis 20 is 3.27 ± 0.30 kpc (Turner 1996), which scales to 15.3 ± 1.4 kpc for an angular diameter of 0′.3, consistent with what we obtain for the WR 38/WR 38a cluster. The cluster presumably lies well beyond the Sagittarius-Carina Arm of the Galaxy, possibly in an extension of the Perseus Arm running background to the young stars in Carina. The relatively low extinction for such a distant group is consistent with recent maps of the spiral arm structure and dust distribution in the Galaxy (Drimmel & Spergel 2001; Vallée 2002).

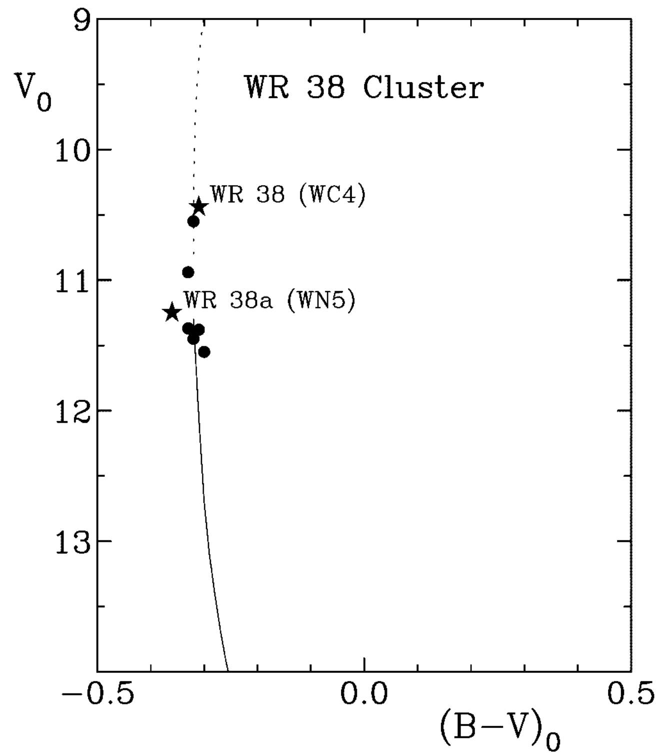

FIG. 5.—Reddening-free color-magnitude diagram for the cluster of stars associated with WR 38 and WR 38a. The solid curve represents the zero-age main sequence corresponding to $V_0 - M_V = 15.80$, and the dotted line represents an isochrone from Meynet et al. (1993) for $\log t = 6.5$. The two Wolf-Rayet stars are plotted by star symbols.

4. THE WOLF-RAYET STARS

Figure 5 is a reddening-free color-magnitude diagram for the cluster of stars associated with the two Wolf-Rayet stars. Estimates for the unreddened parameters of WR 38 and WR 38a were obtained using the mean reddening of $E_{B-V} = 1.60 \pm 0.02$ s.e. found for the six OB-type members of the cluster nucleus. The derived parameters for the two stars are (1) for WR 38 (WC4), $(b-v)_0 = -0.45 \pm 0.02$ and $M_v = -5.84 \pm 0.16$, and (2) for WR 38a (WN5), $(b-v)_0 = -0.49 \pm 0.02$ and $M_v = -5.03 \pm 0.16$. If the broadband data are used to infer intrinsic colors for the stars, the values are $(b-v)_0 = -0.29 \pm 0.02$ for WR 38 and $(b-v)_0 = -0.39 \pm 0.02$ for WR 38a.

The inferred luminosity of $M_v = -5.0$ for WR 38a (WN5) is consistent with values ranging from -2.9 to -5.2 obtained for other WN5 stars in clusters (van der Hucht 2001). We note in particular the similarity to $M_v = -5.24$ derived for the WR 139 system (V444 Cyg, WN5+O6 III–V) belonging to Berkeley 86 (van der Hucht 2001). The inferred colors are slightly bluer than expected, but still consistent with what is anticipated for an early-type star. The value of $M_v = -5.8$ for WR 38 (WC4), however, is somewhat luminous relative to the spectral subtype trend observed for other Galactic WC stars in clusters, which range from average values of -4.6 at WC9 to -3.3 at WC5. The derived value of $(b-v)_0$ is similar to that found for other WC stars, although the synthetic narrowband photometry for both stars does appear to be too blue (see earlier comments).

The cluster associated with WR 38 and WR 38a can be designated as C1104–610a on the basis of its 1950.0 coordinates. Its zero-age main sequence is populated to the extreme blue limits, according to the photometric data, with no turnoff evident. That implies an extremely young age for its member stars, certainly no more than about $\sim 3 \times 10^6$ yr (e.g., Meynet et al. 1993), typical of clusters associated with WR stars of hot temperature subtype. Naturally, it is desirable to extend the photometry of cluster stars to fainter limits in order to confirm these conclusions.

An "a" is appended to the number designation for the cluster because the spatially adjacent WR stars WR 38b and WR 39 (left side of Fig. 1) also appear to belong to an anonymous cluster of faint stars of similar compactness to the cluster associated with WR 38 and WR 38a. We designate the former as C1104–610b, since its 1950.0 coordinates are indistinguishable from those of the latter. Double clusters are relatively common in the Galaxy, which means that there may be four cluster WR stars (WR 38, WR 38a, WR 38b, and WR 39) in the field available for use as calibrators.

5. DISCUSSION

The high luminosity derived for WR 38 is difficult to resolve with the apparent trend of decreasing luminosity with decreasing numerical subtype observed in Galactic WC stars, yet evolutionary calculations for massive stars do predict high-luminosity WC4 stars for the situation of low metallicity and/or high mass-loss rates (Meynet et al. 1994). Such calculations predict the existence of WC4 stars with luminosities up to $10^6\ L_\odot$, which is the approximate luminosity of WR 38 ($L = 1.13 \times 10^6\ L_\odot$) for a bolometric correction of BC = −4.5 (Smith, Meynet, & Mermilliod 1994).

The WC stars in the Large Magellanic Cloud (LMC) are examples of high-luminosity WC4 stars produced in a low-metallicity environment (e.g., Smith & Maeder 1991; Bartzakos, Moffat, & Niemela 2001). The average luminosity of a LMC WC4 star is $M_v = -4.5$, consistent with theoretical predictions for WR stars produced in an environment in which the typical metallicity is less than solar. The key to understanding the currently derived high luminosity for the WC4 star WR 38 therefore rests on its membership in a very distant open cluster that lies well outside the solar circle at a Galactocentric distance of ~14.0 kpc, independent of one's choice of distance to the Galactic center. Given a Galactic metallicity gradient of decreasing mean metallicity with increasing distance from the Galactic center on the order of -0.07 dex kpc^{-1} (Hou, Prantzos, & Boissier 2000), the environment in which C1104–610a was created was most likely on the order of 2 or 3 times lower metallicity than is typical of the solar neighborhood. The metal abundance of WR 38 is therefore likely to be closer to that of LMC WR stars than to most Galactic WR stars. Under such circumstances, the high luminosity inferred for WR 38 is probably not anomalous (Smith & Maeder 1991). Most Galactic WR stars used as calibrators, for example, lie in clusters belonging to the inner regions of the Galaxy.

The reddening of stars belonging to the sparse cluster associated with WR 38 and WR 38a is uncertain, given their faintness and the bright photometric limits of the present study. Precise information on the intrinsic colors of the two WR stars is therefore difficult to establish from the available observational data. A deeper survey of the region surrounding WR 38 and WR 38a is necessary to acquire an improved picture of the reddening of cluster members, as well as to confirm the large distance obtained for the cluster. A deeper survey should also provide more accurate values for the intrinsic properties of the two member WR stars.

The present study was supported by research funding awarded through the Natural Sciences and Engineering Research Council of Canada (NSERC) to D. G. T. We are grateful to Tony Moffat for comments on the original manuscript.

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