Galactic Structure Toward the Carina Tangent

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ABSTRACT. This investigation presents a photometric study of the Galactic structure toward the Carina arm tangent. The field is located between 280° and 286° Galactic longitude and /C0 4° to 4° Galactic latitude. All currently available uvbyβ data are used to obtain homogeneous color excesses and distances for more than 260 stars of spectral types O to G. We present revised distances and average extinction for the open clusters and cluster candidates NGC 3293, NGC 3114, Lodén 46, and Lodén 112. The cluster candidate Lodén 112 appears to be a very compact group at a true distance modulus of 11.06 ± 0.11(s.e.) (1629±84/80 pc), which is significantly closer than previous estimates. We found other OB stars at that same distance and, based on their proper motions, suggest a new OB association at coordinates 282° < l < 285° and /C0 2° < b < 2°. Utilizing BV photometry and spectral classification of the known O-type stars in the very young open cluster Wd 2, we provide a new distance estimate of 14.13 ± 0.16 (s.e.) (6698±512 pc), in excellent agreement with recent distance determinations to the giant molecular structures in this direction. We also discuss a possible connection between the H II region RCW 45 and the highly reddened B+ star CPD −553036 and provide a revised distance for the luminous blue variable HR Car.

Online material: color figures, machine-readable table

1. INTRODUCTION

In the fourth Galactic quadrant, the direction toward 282°–285° Galactic longitude corresponds to maxima in the thermal radio continuum, H I and CO emissions (Taylor & Cordes 1993; Bronfman et al. 1990; Bronfman 1992). Other kinds of tracers also indicate that in this direction the line of sight is tangential to a large segment of the Carina arm. Based on a multiwavelength study of star-forming complexes, it is found that longitudes 283°–284° correspond to a tangential direction in both the three- and four-arm models of the grand design of the Milky Way (Russeil 2003; Vallée 2008).

The OB stars observed in the 283°–284° longitude range delineate a sharp outer edge of the Carina arm at about 2–3 kpc from the Sun (Graham 1970; Kaltcheva & Scorcio 2010). The field located between the associations in Vela (262° < l < 268°) and Car OB1 (284° < l < 288°) is not known to be dominated by any prominent OB association (Humphreys 1978; Melnik & Efremov 1995). The only known supernova remnant in the region is G279.0 + 1.1 (Duncan et al. 1995).

Local and intermediate-scale features of the Galactic disk, like arm-splitting and branching, are an important part of the grand design of the Milky Way (see Russeil [2003] for a recent discussion). This article is focused on a field between 280° and 286° in the Galactic disk with the aim to address the present deficiency in the study of the structure toward the edge of the Carina arm. Our study is based on uvbyβ photometric distances and provides new insights on the apparent groupings and layers in this region.

2. THE SAMPLE

The field under consideration is located between 280° and 286° Galactic longitude and −4° and 4° Galactic latitude. All uvbyβ data within this coordinate range were extracted from the catalog of Hauck & Mermilliod (1998) and combined with the uvbyβ photometry from the catalog of Kaltcheva (2003). The sample contains more than 300 stars of spectral types O to G with complete uvbyβ photometry and is listed in Table 1. Figure 1 presents these stars plotted in Galactic coordinates. All known open clusters and all Lodén cluster candidates are shown as well and are listed in Table 2.

3. CALCULATION OF INTERSTELLAR EXTINCTION AND DISTANCES

To infer the physical stellar parameters from the photometry, the spectral and luminosity classifications (MK) were extracted from the SIMBAD database and used in conjunction with the
| ID               | 1           | b           | V  | b - y | m_1 | c_1 | β   | [c_1] | [m_1] | MK   | (b - y)_0 | c_0 | m_0 | E(b - y) | V_0 | M_V  | DM   |
|------------------|-------------|-------------|----|-------|-----|-----|-----|-------|-------|------|---------|-----|-----|---------|-----|------|------|
| HD 300814AB      | 284.7081    | 1.1309      | 9.299 | 0.337 | -0.055 | 0.102 | 2.601 | 0.035 | 0.056 | B3    | -0.115 | 0.016 | 0.094 | 0.452 | 7.356 | -3.54 | 10.90 |
| HD 300813        | 284.673     | 1.135       | 9.58  | 0.394 | -0.073 | 0.067 | 2.602 | -0.012 | 0.057 | B0    | -0.119 | -0.031 | 0.096 | 0.513 | 7.372 | -3.69 | 11.06 |
| LID -5603492     | 284.752     | 1.137       | 10.86 | 0.386 | -0.062 | 0.1   | 2.638 | 0.023 | 0.065 | -0.116 | 0.005 | 0.104 | 0.502 | 8.701 | -2.75 | 11.45 |
| LID -5603496     | 284.804     | 1.14        | 10.69 | 0.318 | -0.056 | 0.134 | 2.64  | 0.070 | 0.049 | -0.111 | 0.052 | 0.086 | 0.429 | 8.844 | -2.53 | 11.37 |
| HD 300811        | 284.6227    | 1.2106      | 9.88  | 0.496 | -0.084 | 0.073 | 2.608 | -0.026 | 0.080 | B     | -0.121 | -0.044 | 0.12  | 0.617 | 7.227 | -3.61 | 10.84 |
| Lod 112 group    |             |             |      |       |       |      |      |       |       |       |        |      |      |         |      |      |      |
| HD 89714ABV      | 283.5801    | -0.3534     | 9.04  | 0.193 | -0.024 | 0.011 | 2.608 | -0.028 | 0.040 | B2Iab | -0.056 | -0.036 | 0.058 | 0.249 | 7.97  | -3.57 | 11.54 |
| HD 90135         | 282.434     | 2.26        | 9.373 | 0.136 | 0.018 | -0.002 | 2.6  | -0.029 | 0.063 | B1/B2Ib | -0.068 | -0.041 | 0.085 | 0.204 | 8.495 | -3.79 | 12.29 |
| HD 90102         | 284.063     | -0.358      | 8.706 | 0.178 | -0.009 | 0.054 | 2.605 | 0.018 | 0.050 | -0.116 | -0.002 | 0.088 | 0.294 | 7.44  | -3.49 | 10.93 |
| LID -5403538     | 282.651     | 1.835       | 10.0  | 0.176 | 0.000 | 0.088 | 2.637 | 0.053 | 0.058 | -0.113 | 0.033 | 0.095 | 0.289 | 8.757 | -2.65 | 11.41 |
| HD 89174         | 280.2494    | 3.6794      | 7.953 | 0.173 | -0.029 | -0.003 | 2.581 | -0.038 | 0.028 | B1/B2I | -0.112 | -0.057 | 0.065 | 0.285 | 6.727 | -4.46 | 11.18 |

**NOTE**—Stellar identifications (HD, LID, or other), followed by Galactic coordinates, uvbyβ photometric data, spectral classification (as they appear in the SIMBAD database), dereddened photometry and color excess, calculated absolute magnitude, and distance modulus. Table 1 is published in its entirety in the electronic edition of the *PASP*. A portion is shown here regarding its form and content.
classification $c_1$ versus $m_1$ diagram (Strömgren 1966) to study the spectral content of the sample. The sample contained about 40 A–F–G type stars of luminosity classes III–II–Ib, which were clearly separated on the $c_1$ versus $m_1$ diagram. Since a reliable estimate of distance is not available for these types at present in the $uvby\beta$ system, they were excluded from the following analysis. The location of the rest of the stars on the classification $c_1$ versus $m_1$ diagram shows a fair agreement with the SIMBAD MK (Fig. 2, top right panel).

The procedure applied here to obtain the color excesses and stellar distances for the O and B stars in the sample is described in detail in Kaltcheva & Hilditch (2000). The color excesses for LC III, IV, and V are obtained via Crawford’s (1978) calibration. The calibration by Kilkenny & Whittet (1985) is used for LC II, Ib, Iab, and Ia. We used $R = 3.2$ and $E(B - V) = E(b - y)/0.74$ to obtain $V_\alpha$. The calibration by Balona & Shobbrook (1984) is utilized for all O–B9 stars to derive the $M_V$ values. Since we are dealing with early spectral types, the presence of emission lines in the stellar spectra is the largest source of error in the calculated absolute magnitudes. However, the $\beta$ versus $c_0$ diagram (not shown here) reveals that very few O and B stars in the sample deviate from the main sequence and have photometry affected by emission. For all stars with observed $\beta$ values outside the limits of the $M_V$ calibration and all known emission-line stars, $\beta$ calculated from $c_0$ was used to obtain $M_V$ (for details, see Balona 1994; Kaltcheva & Hilditch 2000). Note that this procedure yields distance in excellent agreement with the recalculated Hipparcos data (Kaltcheva & Makarov 2007).

Recently, Kaltcheva & Golev (2011) presented a comparison between the Hipparcos and $uvby\beta$ photometric $M_V$ quantified as a function of the spectral subtype in the B0–B9 range. This comparison was done for field stars with good-quality Hipparcos parallaxes that are subject to relative errors of less than 10% and shows that the agreement is in place over the entire B-type spectral range.

For the rest of the sample we follow Crawford (1975a, 1979) and separate the A2–F2 stars from the F2–G2 stars according to their $\beta$ indices. We refer to all stars with $\beta$ in the range of 2.55 to 2.7 as F-type, and we consider all stars with $\beta$ between 2.7 and 2.9 to be A-type. This photometric classification agrees very well with the SIMBAD MK types. To derive the individual color excesses and absolute magnitude for these stellar types, we apply the calibrations of Crawford (1975a, 1979). The calibration of Hilditch et al. (1983) is applied to the A0–A2 stars in the sample, for which photometric classification based on the $c_1$ versus $m_1$ diagram is also in excellent agreement with the SIMBAD MK types.

The photometric data and the derived stellar parameters are summarized in Table 1, which includes the stellar identifications.
followed by the Galactic coordinates, MK type and $uvby\beta$ photometric data, color excess and dereddened photometry, calculated absolute magnitude, and true distance moduli. The expected uncertainties in $M_V$ are of the order of $\pm 0.3$ mag for O and B types of LC III–V and for A–F V–IV types, and $\pm 0.5$ mag for B-type supergiants. An uncertainty of $\pm 0.3$ mag in $M_V$ propagates to an asymmetric error of $-13\%$ to $+15\%$, and uncertainties of $\pm 0.5$ mag result in $-21\%$ to $+26\%$ error in the derived distances. Since the photometry used in this article comes from different sources, the homogeneity of the sample is an important issue. Comparisons of existing $uvby\beta$ datasets collected by various authors for the field of the Carina spiral feature present a good agreement in general (see Kaltcheva et al. 2000). The latter authors estimated that the uncertainty in the calculated stellar distances due to possible systematic deviations in the existing photometric data should not exceed 3–5%.

Note that in the $uvby\beta$ system, both the color excess and absolute magnitude calculations do not rely on a precise determination of spectral type, since the calculations are carried on in the same way for types from O to B9, A0–A2, A2–F2, and F2–G2. Inspecting the reddening-free $[e_1]$ versus $[m_1]$ diagram is sufficient to identify and resolve spectral type misclassifications, but
we did not notice any for our sample. However, great care was taken to resolve all cases of suspected luminosity class misclassification, since different calibrations are used to calculate the color excesses for different LC types, which is especially important in the O–B9 spectral range. To ensure as proper an LC classification as possible, the database was divided into groups according to the LC available in SIMBAD, and each group was considered separately. The reddening-free $c_1$ versus $m_{11}$ and $c_1/\beta$ diagrams (not shown here) built for each LC were used to examine for possible LC misclassifications and also for stars with H/β emission. The individual sources of spectral classification were also considered for all cases of observed inconsistencies, especially the catalog of Reed (2003) for OB stars and its updates. Again, we did not notice inconsistencies between the LC types listed in SIMBAD and the photometric classification diagrams we built and inspected or in other literature sources of luminosity classification involved in the comparisons.

4. PHOTOMETRY-DERIVED RESULTS

The diagrams showing color excess $E(b - y)$ versus distance moduli, $V_0$ versus $(b - y)_0$, and $M_V$ versus $(b - y)_0$ are presented in Figure 2 and are used to reveal spatially coherent structures in the studied longitude range. Figures 3, 4, and 5 show the stars with available distances plotted in Galactic coordinates. The backgrounds in these figures present the distributions of H/α, $^{12}$CO ($J = 1 \rightarrow 1$, 115 GHz), and dust infrared emission and are described in the captions of the figures.

There are a number of articles devoted to star formation in dense interstellar matter (ISM) in the surroundings of H II regions, both from theoretical and observational points of view (see, for example, Cichowolski et al. [2009] and the references therein). According to the current theories, massive stars tend to stimulate star formation at larger distances, but destructively affect their immediate neighborhood, since they tend to disrupt the parental molecular cloud. It can be seen in Figures 4 and 5 that the location of the stars in the sample does not correlate with the dense molecular clouds represented by the distribution of the $^{12}$CO flux and with zones of high reddening. On the other hand, the stellar distribution correlates with the location of ionized hydrogen in Figure 3. Studying the distributions of OB stars together with the distributions of H/α (a tracer of ionized hydrogen), $^{12}$CO (a tracer for neutral hydrogen and molecular clouds), and dust infrared emission could give more complete picture of the massive stellar population in the region, the different components of the ISM, and the interactions among them.

4.1. Lodén 112 and IC 2581

Lodén 112 is a poor cluster candidate that contains about 10 OB stars. Five of them are included in our sample: HD 300811, HD 300813, HD 300814AB, CPD $-56^\circ3492$, and CPD $-56^\circ3496$ (see Table 1). These stars form a very compact group at a (median) true distance modulus $DM = 11.06 \pm 0.28$ s.d.; $\pm 0.12$ s.e.) and average color excess $E(b - y) = 0.5 \pm 0.07$ s.d.; $\pm 0.03$ s.e.). For all groups under consideration in this article we will indicate both the standard deviation (s.d.) and standard error (s.e.) when providing distance modulus and color excess. When calculating the distance to the groups, the uncertainties will be based on the standard error in the distance modulus. Our distance estimate of $1629 \pm 84$ pc for Lodén 112 is significantly smaller than the presently adopted 2500 pc (see, for example, the WEBDA database). The 2500 pc distance is based on the $V$ versus $B - V$ diagram of the cluster (Kharchenko et al. 2005). Since all known possible members of Lodén 112 are found in the upper part of the main sequence (MS), a determination based on the location of these stars on the color-magnitude diagram is difficult. The $uvby/3$ photometry allows us to obtain the distance to each star and to find an average distance to the cluster. Lodén 112 has been last
studied by Lodén (1977), who performed $UBV$ and $uvby\beta$ photometry of stars in the Carina-Crux-Centaurus-Norma region suspected of belonging to poor open clusters or associations. However, the characteristics of these cluster candidates have not been photometrically studied based on $uvby\beta$ photometry. The photometric diagrams and individual stellar distances presented here (Fig. 2) indicate that one of these candidates, Lodén 112, is possibly a physical group. In our sample there are nine other early B main-sequence stars located at that distance: HD 84361, HD 89174 (both found at the edge of the studied field at a Galactic longitude of approximately 280°), HD 88661, HD 90102, HD 90273, HD 90288AB, HD 90615, CPD $-543538$, and CPD $-553036$. Two relatively evolved stars (HD 89714 and HD 90135) are also found in this distance range. For all 16 stars mentioned in this paragraph, the (median) true DM is 11.12 ($\pm 0.6$ s.d.; $\pm 0.15$ s.e.).

The open cluster IC 2581 seems to be part of the feature of OB stars mentioned previously. The two brightest OB stars of the cluster (HD 90706 and HD 90707) have $uvby\beta$ data available. They are found at an average true DM $= 11.56$ ($\pm 0.63$ s.d.; $\pm 0.45$ s.e.), corresponding to a distance of 2051 pc (vs. 2446 pc provided by Dias et al. 2003), and have average color excess $E(b - y) = 0.43$ ($\pm 0.02$ s.d.; $\pm 0.02$ s.e.). The cluster has been previously studied by Lloyd-Evans (1969), who found DM $= 12.0$ (2500 pc), and Turner (1973), who found DM $= 11.65$ (for $R = 3$, corresponding to 2140 pc).

The field considered in this paragraph clearly stands apart from the large H ii features toward Car OB1 ($\eta$ Car complex) and contains several smaller but prominent H ii nebulosities, among which are RCW 48 and RCW 49 (Fig. 6, top). This field is often called the “preceding end of the Carina complex” (see Lloyd-Evans 1969, for example). It is difficult to judge if the OB
stars considered in this subsection are spatially connected to these H II regions or are foreground. Note that the distant cluster Wd 2 (6.7 kpc, see § 4.6) is found at the center of RCW 49. On the other hand, IC 2581, at only about 2—2.5 kpc, seems to be located at the edge of RCW 49, with the angular distance between IC 2581 and Wd 2 being about 25'. IC 2581 is considered of intermediate age and thus should not be involved in the bright nebulosity. However, this may not be true for the two brightest OB stars in the cluster, considered here. Note that it is not certain that these two stars are actually members of the cluster. A loose constraint between 2 and 5 kpc of the distance to RCW 49 has been derived by Tsujimoto et al. (2007) from the mean X-ray luminosity of T-Tauri stars. Ascenso et al. (2007) proposed 2.8 kpc based on NIR magnitudes and colors of RCW 49 sources on the Henyey track.

For all stars considered in this subsection, proper motions are available (Fig. 6, bottom) and are similar for the majority of them. Thus, based on distances and proper motions, we suggest a new OB association at coordinates $282^\circ < l < 285^\circ$ and $-2^\circ < b < 2^\circ$, connected to the compact Lodén 112 group and containing HD 90706 and HD 90707 (probable members of IC 2581). The (median) true DM for all 18 stars studied in this subsection is 11.13 ($\pm$0.59 s.d.; $\pm$0.14 s.e.), corresponding to $1682_{-153}^{+110}$ pc. Keeping in mind the independently obtained constraints and estimates of the distance to RCW 49, it is difficult to judge whether this feature of OB stars is connected to the H II nebulosities seen in this direction or is foreground.

4.2. HR Car

HR Car (HD 90177) is a luminous blue variable known to undergo slow irregular spectrophotometric variations of about 1.5 mag over timescales of months (Carlson & Henize 1979). The most recent attempt to obtain the distance to HR Car (van Genderen et al. 1991) is based on the reddening-distance method of field stars and yields $5 \pm 1$ kpc. This estimate well matches the 5.4 kpc distance to the Carina arm obtained kinematically (Hutsemékers & van Drom 1991). Other existing distance estimates are based on the assumption that HR Car belongs to the Carina complex at the canonical distance of 2.5 kpc (Viotti 1971). However, the line of sight to the Carina complex is tangential to the Carina spiral arm, so the luminous stars seen in this direction may have a very large range in distance (see, for example, Kaltcheva & Scorcio 2010). The Hipparcos distance obtained via the revised parallaxes (van Leeuwen 2007) is $592_{-194}^{+597}$ pc, thus locating the star much closer than any other estimate. We stress, however, that HR Car lies in a relatively crowded region and that this could affect the accuracy of the Hipparcos parallax.

The visual magnitude of HR Car varies between 7.6 and 8.6 mag in general (Parthasarathy et al. 2000). The measured $\beta = 2.392$ indicates that the star is observed in emission, and a $\beta$ index obtained via $c_6$ should be used when calculating the absolute magnitude (see Kaltcheva & Hilditch 2000). This yields $M_V = -8.3$ mag. The emission usually does not affect the color excess calculation. Here, we adopt $E(b - y) = 0.912$ and a visual magnitude of 8.076, which provides a distance modulus 12.37, corresponding to 3 kpc (see Table 1). This is the second most reddened star in our sample. We estimate $A_V = 3.96$ mag (for $R = 3.2$).

HR Car is variable in photometry, spectral type, and luminosity class. The available MKK classifications indicate spectral...
type from B2 to B9 and luminosity class I. Since the \((b - y)_0\) versus \(c_0\) relations used for reddening determination are identical for LC I-II near to the upper part of the MS (Kilkenny & Whittet 1985), a variable-luminosity class should not influence the obtained color excess. As previously mentioned, both color excess and \(M_V\) determination do not depend of the spectral subtype. In this sense, the variability in spectral classification of HR Car should not influence the obtained distance.

The distance and absolute magnitude of HR Car are important for a variety of reasons, like the theoretical interpretation of this stellar type (van Genderen et al. 1991), studying the spatial distribution of dust around the star (Umana et al. 2009), etc. Apparently, an ambiguity in both estimates is still present. However, despite the peculiarity of this star, our method based on \(uvby\) photometry provides reasonable estimates of both quantities and indicates that the currently accepted distance of 5 kpc is overestimated and should be applied with caution. On the other hand, the \(M_V\) estimate obtain here is in agreement with the one derived by van Genderen et al. (1991).

### 4.3. RCW 45 and CPD —553036

RCW 45 (BRAN 295) is a rather isolated H II region (Fig. 6, top), located at coordinates \(l = 282.13\)° and \(b = -0.11\)°, with angular size of 16' and radial velocity \(V_{\text{rad}} = -9.8\) km s\(^{-1}\). RCW 45 is included in the star-forming field Avedisova 2297, at an accepted distance of 6500 pc and angular size of 30.25'.

The distance estimate of 6500 pc is based on the survey of H II 21 cm emission in the southern Milky Way by McClure-Griffiths et al. (2000). These authors have detected two large shells in the interstellar neutral hydrogen near the Carina tangent, centered at \((l, b) = (277, 0)\) and \((l, b) = (280, 0)\) that share a common line of sight. The center velocities are \(\sim 36\) km s\(^{-1}\) and \(\sim 59\) km s\(^{-1}\), which puts the shells at kinematic distances of 6.5 ± 0.9 kpc and at 10 kpc, respectively. GSH 277 + 00 + 36 can be classified as a supershell on the basis of its large size and expansion energy. The previous authors find evidence for molecular clouds along the supershell’s edges, indicating that a star formation may have been initiated by the supershell’s expansion. They suggest that the prior interpretation of this large void as an interarm region is inappropriate on the basis of the supershell’s chimney and shell-like morphology. The shells should rather be considered as interarm voids, as previously suggested by Grabelsky et al. (1987).

The relation of RCW 45 to this supershell is not clear. In their catalog of candidates for Galactic worms (the walls surrounding the superbubbles), Koo et al. (1992) noted that the H II regions RCW 45 and RCW 46 lie at the base of GW 281.5 + 1.5, which places them in the eastern edge of the shell (McClure-Griffiths et al. 2000). Note that RCW 45 and RCW 46 do not overlap with the worm, but are located at the plane just below the worm candidate (Table 5 of Koo et al. 1992). Also note that RCW 45 is marked with a question mark in their Table 5. All of this means that accepting the supershell distance of 6.5 kpc as a distance to RCW 45 has to be done with caution.

CPD —553036 (LS 1448; \(l = 282.166\)° and \(b = -0.025\)°; \(V_{\text{rad}}\) is not available) is located in the direction of RCW 45 and is the most reddened star in our sample. Using \(UBV\) photometry, Denoyelle (1977) obtained \(E(B - V) = 1.62\) \((A_V = 5.18\) for \(R = 3.2\)) and a distance of 1380 pc. Based on \(UBV\beta\) photometry Wramdemark (1980) obtained \(A_V = 5.1\) mag and DM = 9.2 (700 pc). The star is included in the extensive \(uvby\) photometric study of the luminous stars in the southern Milky Way by Kilkenny & Whittet (1993). Kilkenny (1993) presents \(\beta\) photometry of the star and obtains \(A_V = 5.14\) and a distance of 1200 pc. In this article we determine \(A_V = 5.36\) mag and DM = 10.21 mag, which corresponds to a distance of 1101 pc.

The high interstellar extinction toward CPD —553036 and its proximity to RCW 45 in terms of Galactic coordinates may indicate a possible relation. However, the uncertainty in the distance of RCW 45 discussed previously and the lack of radial velocity measurements for the star would make further conclusions preliminary at this point.

### 4.4. Lodén

Lodén (1979) performed \(uvby\beta\) of 15 stars of the cluster candidate in field 46 (Lodén 46) and estimated a distance of 1.24 kpc and \(E(B - V) = 0.22\) mag. Lodén 46 is represented in our sample by nine stars of spectral class A0–A2. We determine a true median DM = 8.67 (±1.42 s.d.; ±0.47 s.e.), corresponding to a distance of 542 pc, in good agreement with the adopted distance of 540 pc (see the WEBDA database). The relatively large spread in individual distances for these stars may be due to the fact that the \(uvby\beta\) system is not very suitable for the A0–A2 spectral range.

### 4.5. NGC 3293 and NGC 3114

These clusters are studied in detail by various authors. Here, we present only revised distances and color excesses in order to provide homogeneous estimates for all groups with \(uvby\beta\) photometry in the field under consideration.

NGC 3293 is a bright open cluster embedded in an emission nebula. Shobbrook (1980) obtained \(uvby\beta\) photometry of a significant amount of cluster members and calculated true DM = 12.75 (3.55 kpc). This estimate, however, has been based on a preliminary \(M_V - \beta\) calibration, later found to overestimate the brightness, and was corrected to 11.95 ± 0.1 mag (2455 pc; Shobbrook 1983). Our estimate is based on 61 stars with available \(uvby\beta\) photometry and yields a true (median) DM = 12.15 (±0.43 s.d.; ±0.05 s.e.), corresponding to a distance of 2691 pc. A distance of 2373 pc is provided in the Dias et al. (2003) catalog, while Kharchenko et al. (2005) estimate 2471 pc. Although a fair agreement exists between our estimate and the most recently published distances, our result locates the cluster some 250 pc farther than currently
accepted. The stars are uniformly reddened with average color excess $E(b - y) = 0.20$ (±0.05 s.d.; ±0.01 s.e.).

NGC 3114 has been observed in the $uvby$ system by Schmidt (1982) and Schneider & Weiss (1988). In this cluster, there are 29 stars earlier than B9 with $uvby$ data presently available. The cluster is located in a crowded low-reddened field, thus complicating the separation of cluster members from field stars. Carraro & Patat (2001) obtained $UBVRI$ photometry of more than 2000 stars near the center of the cluster. They found this region to be heavily contaminated by field stars and separated two populations: several low-reddened stars that are presumably cluster members and field stars with larger reddening. All stars in our sample are low-reddened. We estimate an average color excess $E(b - y) = 0.053$ (±0.01 s.d.; ±0.009 s.e.), in agreement with Schmidt (1982) and Carraro & Patat (2001). However, these stars show a significant spread in distance and not well-defined MS on the $V_0$ versus $(b - y)_0$ diagram (Fig. 2). After excluding one star with very large distance, the remaining 28 stars yield a median true DM = 10.06 (±0.71 s.d.; ±0.13 s.e.), corresponding to 1028 pc (vs. 911 pc listed by Dias et al. [2003] and 1130 pc provided by Schmidt [1982]). Excluding the stars to the left of MS does not significantly affect this distance estimate. Nineteen stars, however, appear to be nicely grouped between distance moduli 9.7 and 10.5 mag, at an average true DM = 10.01 (±0.29 s.d.; ±0.067 s.e.). Thus, we provide a revised distance of 1005±31 pc to NGC 3114, which is in fair agreement with the estimate of Carraro & Patat (2001) of 920±50 pc and Schneider & Weiss (1988) of 940±60 pc.

4.6. Westerlund 2

The massive, young stellar cluster Wd 2 ($l = 284.2^\circ$, $b = -0.33^\circ$) is considered to be one of the five superclusters known in the Milky Way. The cluster is thought to be spatially connected to the H II complex RCW 49, a remarkable infrared nebula as revealed by Spitzer (Churchwell et al. 2004), and perhaps to the extended t paraelectron-volt $\gamma$-ray source HESS J1023-575 (Aharonian et al. 2007). Recently, $\gamma$-rays in the MeV/GeV energy domain have been reported from the same direction by the Fermi collaboration (Abdo et al. 2009). Fujita et al. (2009) present an analysis of the diffuse X-ray emission of Wd 2, which may indicate a recent ($\sim 10^6-10^7$ yr ago) explosion of a massive star. Recently, a new hard-spectrum t paraelectron-volt $\gamma$-ray source, HESS J1026582, was discovered by the H.E.S.S. collaboration (Abramowski et al. 2011). Ackermann et al. (2011) showed that this emission is due to a $\gamma$-ray pulsar with a preferred distance of 2.4 kpc. Since the most recent distance estimates to Wd 2 were established to be in the 5–8 kpc range, this $\gamma$-ray emission might be unrelated to Wd 2, and this would cast serious doubt on a connection between the pulsar and the cluster (see Rauw et al. [2011] for a thorough discussion). Wd 2 is one of the clusters in the Galaxy for which associated molecular clouds have been identified (Furukawa et al. 2009, see also Dame 2007). Fukui et al. (2009) discovered a spectacular jet and arc of molecular gas detected with the NANTEN telescope in the $^{12}$CO $J = 1 - 1$ 115 MHz emission-line survey (Muzuno & Fukui 2004).

The total stellar mass in Wd 2 is of the order of 4500 $M_\odot$, including 12 O stars and two WR stars (Rauw et al. 2007). Due to the high (and apparently local) extinction, most of the photometric and spectroscopic studies are restricted to the brightest stars. The only deep $BV$ CCD photometry is presented by Carraro & Munari (2004). The distance to Wd 2 has been a very controversial issue (see Dame [2007] and the references therein) and varies between 2 and 8.3 kpc.

Distances to RCW 49 have been presented by several authors (see also § 4.1). In the study of Grabelsky et al. (1988) Wd 2 and RCW 49 are associated with GMC 7, at an optical distance of 4 kpc. Russeil (2003) determined a kinematic distance of 4.7 (+0.6, −0.2) kpc to RCW 49. On the basis of an analysis of the CO emission and 21 cm absorption along the line of sight to Wd 2, Dame (2007) argued that Wd 2 must be associated with GMC 8 of the study of Grabelsky et al. (1988), in the far side of the Carina arm. Dame (2007) determined a kinematic distance of 6.0 ± 1.0 kpc to the molecular structure toward Wd 2, while Furukawa et al. (2009) obtained 5.5 ± 1.5 kpc. In their original study, Grabelsky et al. (1988) reported a kinematic distance of 6.6 kpc to GMC 8.

Although $uvby$ photometry of the stars in Wd 2 is not available, we attempt a distance estimate here for this cluster. The 12 O-type stars, studied by Rauw et al. (2007), are listed in Table 3. Following Rauw et al., we use the MK type to obtain $M_V$ and $E(B - V)$, but utilizing the calibration by Deutschman et al. (1976). We have tested this calibration based on a large sample of O-B stars and found it to provide $M_V$ that is in agreement with the $uvby$ photometry. For example, the $uvby$ sample used in this article contains six O-type stars. For them, the average $M_V$ derived by $uvby$ photometry is $-5.2 ± 0.26$ mag, and the average spectroscopic $M_V$ is $-5.08 ± 0.13$ mag. To do another check we recalculated the distance moduli of the stars of the Lodén group with available spectral classification and found a median value of 11.19 (±1.46 s.d.; ±0.55 s.e.), which, despite of the somehow larger spread, is in agreement with the $uvby$ estimate.

The $E(B - V)$ and $M_V$ obtained here are listed in columns (7) and (8) of Table 3. Columns (9), (10), and (11) contain the distance moduli calculated for three values of $R$ (3.2, 4.2, and 5.2). The average distance moduli are shown at the bottom of Table 3, together with the mean error, and correspond to distances of 6700 pc, 3090 pc, and 1432 pc, respectively. Since the $A_V$ toward Wd 2 is more than 5 mag, one could expect an abnormal value of $R$, but, as mentioned by Rauw et al. (2007), the present photometric data do not allow us to evaluate the reddening law toward Wd 2. Another way to test our distance estimate is to obtain $(b - y)_0$ from $(B - V)_0$ and plot the Wd 2 stars on the $M_V$ versus $(b - y)_0$ diagram. To do this,
the study of Crawford (1975b) on the O-type stars was used. The average $(b-y)_0$ and $M_V$ values for the 12 stars are $-0.14$ and $-5.5$ mag (obtained via the calibration of Deutschman et al. 1976), respectively, providing a good agreement with the location of the MS in Figure 2, where the $M_V$ values are obtained via the calibration of Balona & Shobbrook (1984). This points out that both $M_V$ and $(b-V)_0$ obtained from the Deutschman et al. (1976) calibration for the Wd 2 stars are in agreement with the parameters provided by the Strömgren photometry. Thus, utilizing $R = 3.2$, we provide a new photometric distance to Wd 2 of 6698 $^{\pm} 312$ pc.

The accurate and deep $BV$ CCD photometry by Carraro & Munari (2004) provides a distance of $6.4 \pm 0.4$ kpc, also in excellent agreement with the one of $6.7$ kpc derived here. However, an investigation of the value of $R$ is clearly warranted in order to pinpoint the exact distance to the cluster.

In their study, Rauw et al. (2007) have used the new calibration for O-type stars by Martins & Plez (2006). In order to closely evaluate both calibrations, we used the database of Maíz Apellániz et al. (2004) and calculated color excess and absolute magnitude for all 273 stars with $uvby$ photometry. Then we obtained these parameters via the calibrations of Martins & Plez (2006) and Deutschman et al. (1976). The comparisons led to the following results. For LC V (96 stars) Deutschman et al. (1976) provide a DM that is practically identical with those of $uvby$ photometry, while Martins & Plez (2006) seem to slightly underestimate the DM by $0.25 \pm 0.47$. For LC III (44 stars) Martins & Plez (2006) provide a DM that is practically identical with those of $uvby$ photometry, while Deutschman et al. (1976) seem to underestimate the DM by $0.29 \pm 0.73$. In the Wd 2 sample, seven of the stars are of LC V and five stars are LC III. The calibration of Deutschman et al. (1976) provides $DM = 14.095 \pm 0.43$ for the seven LC V stars and $DM = 14.18 \pm 0.77$ for the five LC III stars. For the same sample the calibration of Martins & Plez (2006) provides $DM = 14.08 \pm 0.53$ for LC V and $DM = 14.72 \pm 0.79$ for LC III. It seems that in this particular case the Deutschman et al. (1976) calibration provides more consistency between LC V and LC III. Overall, this is an acceptable difference in the average DM, which yields to 6.7 kpc using Deutschman et al. (1976) and 7.4 kpc if Martins & Plez (2006) are utilized. All of the preceding calculations are for $R = 3.2$. In their study, Rauw et al. (2007) use $R = 3.1$, which, since the reddening of Wd 2 is quite high, results in a distance of 8 kpc. All of this points out that our result is actually consistent with that of Rauw et al. (2007), and the discrepancy is mostly due to the utilized value of $R$.

Figure 7 presents the plots of DM versus Galactic longitude and Galactic latitude for all stars of this sample, with calculated distances. The clusters and cluster candidates are shown, together with the giant molecular cloud (GMC) from the study of Grabelsky et al. (1988). For the clusters studied here we use the new estimates and utilize the distances listed in Table 2 for the rest of the clusters. The edge of the Carina arm based on the distribution of the bright OB stars (Graham 1970; Kaltecheva & Scorcio 2010) is indicated with a solid line. The distances to GMC 3 and GMC 7 are optical, and all other GMC distances are kinematic (see Grabelsky et al. 1988). Any distance larger than 3.5 kpc would place Wd 2 beyond the edge of the Carina arm, but a large distance is in agreement with the location of the edge of the arm delineated by the GMC. There is an excellent agreement between the newly obtained distance of 6.7 kpc to Wd 2 and the kinematic distance of GMC 8.

| MSP no. | MK  | $B$ | $V$ | $(B-V)_0$ | $M_V$ | $E(B-V)$ | DM ($R = 5.2$) | DM ($R = 4.2$) | DM ($R = 3.2$) |
|--------|-----|-----|-----|-----------|-------|-----------|----------------|----------------|----------------|
| 18     | O5V | 14  | 12.8| 1.2       | $-0.34$| $-5.6$    | 1.54           | 10.39          | 11.93          | 13.47          |
| 151    | O6III| 15.6| 14.33| 1.27     | $-0.332$| $-5.5$   | 1.60           | 11.50          | 13.10          | 14.70          |
| 157    | O6.5V| 15.5| 14.14| 1.36     | $-0.332$| $-5.3$   | 1.69           | 10.64          | 12.33          | 14.03          |
| 167    | O6III| 15.48| 14.19| 1.29     | $-0.332$| $-5.5$   | 1.62           | 11.26          | 12.88          | 14.50          |
| 171    | O5V  | 15.83| 14.44| 1.39     | $-0.34$  | $-5.6$   | 1.73           | 11.04          | 12.77          | 14.50          |
| 175    | O6V  | 15.15| 13.93| 1.22     | $-0.335$| $-5.4$   | 1.55           | 11.24          | 12.80          | 14.35          |
| 182    | O4III| 15.69| 14.43| 1.26     | $-0.34$  | $-5.6$   | 1.60           | 11.71          | 13.31          | 14.91          |
| 183    | O3V  | 15.03| 13.61| 1.42     | $-0.34$  | $-5.6$   | 1.76           | 10.06          | 11.82          | 13.59          |
| 188    | O4III| 14.6 | 13.32| 1.28     | $-0.34$  | $-5.6$   | 1.62           | 10.50          | 12.12          | 13.74          |
| 199    | O3V  | 15.74| 14.39| 1.35     | $-0.34$  | $-5.6$   | 1.69           | 11.20          | 12.89          | 14.58          |
| 203    | O6III| 14.66| 13.22| 1.44     | $-0.332$| $-5.5$   | 1.77           | 9.51           | 11.28          | 13.05          |
| 263    | O6V  | 16.5 | 14.91| 1.59     | $-0.335$| $-5.4$   | 1.92           | 10.30          | 12.22          | 14.15          |

Average: $\ldots$ $10.78$ $12.45$ $14.13$
Mean error $\ldots$ $\pm 0.19$ s.e. $\pm 0.17$ s.e. $\pm 0.16$ s.e.
5. CONCLUSIONS

We present a uvbyβ photometric investigation of a number of clusters and cluster candidates and field stars located in the Galactic plane toward the tangent of the Carina arm. Based on the derived homogeneous distances and color excesses of more than 260 stars of spectral types O to G, we provide revised distances for the stellar groups and layers present in this sample. The main findings are as follows:

1. The cluster candidate Lodén 112 seems to be a physical group at \(1629^{+84}_{-80}\) pc. We found other OB stars with similar proper motions at that same distance, and we suggest a new OB association at coordinates \(282^\circ < l < 285^\circ\) and \(-2^\circ < b < 2^\circ\). This feature appears connected to Lodén 112 and contains at least the two brightest OB stars of IC 2581. It is located at \(1682^{+113}_{-104}\) pc and is probably related to the H II nebulosities seen in this direction.

2. The following parameters are obtained for the luminous blue variable HR Car: \(M_V = -8.3, A_V = 3.96\) mag (for \(R = 3.2\)), and a distance of 3 kpc (adopting a visual magnitude of 8.076). The currently accepted distance of 5 kpc to this star seems overestimated.

3. The high interstellar extinction toward CPD \(-55^\circ 30^\prime 36^\prime\) \((A_V = 5.36\) mag) and its proximity to RCW 45 in terms of Galactic coordinates may indicate a possible relation to the nebula. The star is located at 1101 pc photometric distance.

4. The distance of \(542^{+131}_{-105}\) pc to the open cluster Lodén 46 is in good agreement with the currently accepted value. However, one can notice that the photometric distances obtained here somehow show a spread that is larger than expected for a nearby cluster. This does not necessarily mean a doubtful nature for this cluster and can be due to the fact that the stars in Lodén 46 are of spectral types A0–A2, and the uvbyβ system may not provide accurate stellar parameters for this spectral range.

5. Based on 61 B-type stars with available uvbyβ photometry in NGC 3293 we find a distance of 2691 pc. Although a fair agreement exists between our estimate and the most recently published distances, our result locates this cluster some 250 pc farther than currently accepted.

6. We provide a revised distance of \(1005^{+31}_{-31}\) pc to the open cluster NGC 3114.

7. Utilizing BV photometry and spectral classification of the known O-type stars in Wd 2, we provide a new distance estimate of \(6698^{+512}_{-475}\) pc, in excellent agreement with recent distance determination to the giant molecular structures in this direction. This estimate does not contradict the 8 kpc distance provided by Rauw et al. (2007), as the difference is due, to a large extent, to the utilized value of \(R\).

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