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OB STARS NEAR THE SUPERNOVA REMNANT RCW 86;
OB STARS NEAR THE SUPERNOVA REMNANT RCW 103
and
THE GALACTIC STRUCTURE IN NORMA

by

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PART I

OB STARS NEAR THE SUPERNOVA REMNANT RCW 86

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ABSTRACT

The filamentary nebula RCW 86, identical with the non-thermal radio source MSH 14 - 63, is part of a supernova remnant. A group of OB stars is found near the radio source. The distance of the group is 2500 pc; this agrees well with the radio distance of the remnant. It is suggested that the remnant was formed by the explosion of a member of the group; the explosion occurred probably in 185 A. D.

INTRODUCTION

Some years ago Shklovsky (1960) suggested that supernovae of Type II may result from explosions of O and B stars. As these stars are members of young associations and clusters, it is reasonable to assume that remnants of Type II supernovae should also be connected with such groups of young stars. Recent indentifications of supernova remnants in the Large Magellanic Cloud (Westerlund and Mathewson 1966) confirm this assumption. There, the remnants were found in associations situated in huge H I clouds. We have tentatively suggested that Cas A is connected with the stellar association Cas Vb (Westerlund 1966) which is likewise embedded in H I. It appears quite likely that IC 443 is in the association I Geminorum, and that the possible supernova remnant in Auriga (Dickel et al 1965) is in the association Auriga I. A number of other galactic remnants may be more or less certainly connected to other associations; the distances of the remnants as well as of most associations are not yet well-known. The fact that virtually all associations in the Large Magellanic Cloud are embedded in large H I clouds, may be considered as an indication that the same may occur in our Galaxy, thus allowing optical and radio data to be more firmly tied together.

An additional reason to assume that Type II remnants are still in the associations of which the initial object was a member, lies in their ages. The oldest known galactic remnant is the Cygnus Loop; its

age is estimated to be of the order of 40,000 years.

The emission nebula RCW 86 (Rodgers et al 1960) has an extremely filamentary structure (Plate I). It forms part of the non-thermal radio source MSH 14 - 63 (Mills et al 1961), Parkes No. 1439 - 62, which has been extensively studied by Hill (1967). A few previously unknown filaments can be seen in Plate II. They are obviously connected with the radio structure. We have suggested that this source is the remnant of the supernova of 185 A.D. (See also Hill 1967 and Minkowski 1968). As the remnant is undoubtedly of a Type II supernova this would mean that it is the first object of its kind in our Galaxy with the explosion observed.

The distance to the non-thermal source has been determined by Aizu and Tabara (1967) and by Poveda and Woltjer (1968), and the distance of the supernova has been estimated by Minkowski (1968). It is naturally very important to obtain an accurate optical measure of the distance to the object. The method of using the radial velocity of the nebula and a particular velocity model of galactic rotation fails in this case, because the radial velocity is rather insensitive to changes in the distances at this galactic longitude.

In Lyngå^O's recent catalogue of OB stars (Lyngå^O 1964) there are 10 stars near the position of the non-thermal radio source. Their positions are shown in Plate II. We note that only one star falls inside the borders of the optical remnant; this star is found to be a foreground star (Ly. 130). In the following the observational data of these stars will be presented and discussed.

THE OBSERVATIONS

The photoelectric observations. - The 40-inch telescope at Siding Spring Observatory was used with an 1P21 photomultiplier, refrigerated with dry ice, and the following filters: U, Corning 9863, 2.5 mm; B, Corning 5030, 2.9 mm + Schott GG 13, 2 mm; V, Corning 3384, 2.3 mm. The relations between the instrumental system and the UBV system were determined each night from observations of bright UBV standards, sequence stars in IC 4665 (Johnson 1954), and stars in the E regions (Westerlund 1963). All stars were observed on at least two separate nights. The results are given in columns 4 - 6 of Table 1. The probable errors of the listed data are smaller than ± 0.007 .

The spectrographic observations. - The nebular spectrograph at the Newtonian focus of the Mt. Stromlo 74-inch telescope was used to obtain the spectra of the stars and the nebula. The f/1.2 camera was used together with a 400 lines grating, giving a dispersion in the second order blue of $140 \text{ \AA/mm}$ for the stellar spectra, and in first order red of $280 \text{ \AA/mm}$ for the spectra of the nebula. In the time available, spectra of seven of the stars were obtained as well as two filaments in RCW 86.

The stellar spectra have been used for the classification of the stars in the Yerkes system (col. 3, Table 1); for the determination of the central absorption in the interstellar $\lambda 4430$ band (expressed in per cent below continuum, col. 7) and of the equivalent width of $H\gamma$ (col. 8, the value given is $= \frac{1}{3} [W(H\gamma) + W(H\delta) + 0.97 (W(H\epsilon) - 0.03)]$); and for some stars also for the determination of the radial velocity (col. 9). These velocities are of low weight as they are

based on one spectrum of each star, only.

The intensities of the emission lines, the line ratios and the derived temperatures and densities for the filaments in RCW 86 have been published previously (Westerlund and Mathewson 1966). We repeat here only that the derived data are in general agreement with data for other possible supernova remnants. Of more importance for the present discussion is to state that the velocities of the two filaments observed are 1 km/sec and 27 km/sec respectively. These velocities are similar to the stellar velocities in Table 1. This is perhaps not so surprising as the combined radio isophotes and H α structure of the object indicate that the expansion in this part of the remnant may be almost completely perpendicular to the line of sight.

DISCUSSION

The two-color diagram for the 10 stars is given in Fig. 1. It is obvious that 8 of the stars are reddened early B stars, whereas some doubt may exist regarding the two remaining ones, Ly 130 and Ly 135. We have classified them B9V and B7III: from the spectra.

Table 2 gives in part "a" the data derived from the photometry and from spectroscopy of 7 of the stars, and in part "b" the data derived from the photometry of the remaining 3 stars. The intrinsic colors for the stars in Table 2a are from Johnson (1963); those in Table 2b have been derived according to Johnson (1958). The absolute visual magnitudes, $M_V(\text{Sp})$ are from Blaauw's recent discussion (Blaauw 1963); the tabulated values of $M_V(\text{H}\gamma)$ have been determined from the equivalent widths in Table 1 according to Petrie (1966). The corrections for spectral type as given by Petrie have also been applied. We note that the agreement between the two sets of absolute magnitudes is satisfactory.

The spectral types given for the three stars in Table 2b are based on the derived $(B-V)_0$, $(U-B)_0$ colors, and their absolute visual magnitudes are taken from the derived types.

All the data, including A_{4430} , indicate that Ly 130 is a foreground star. The other stars form a homogeneous group as far as reddening, E_{B-V} , and interstellar absorption, A_{4430} , is concerned, and, with the possible exception of Ly 135, also with regard to distance moduli.

The distance modulus for the 9 stars, Ly 131 - Ly 158, is

$$V - M_V = 12.0 \pm 0.2 ,$$

and the corresponding distance is $D = 2500$ pc. Fig. 2 gives the color-magnitude diagram with the absolute visual magnitudes for this distance.

The distance determinations for the radio source, the supernova and the stellar group are given in Table 3. The agreement between three of the values is good. With regard to Minkowski's estimated values for the supernova of 185 A. D. it should be noted that a change in the apparent visual magnitude from -7, as used by Minkowski, to -4, combined with the total visual absorption of $A_V = 2$ mag as measured by us, and an estimated absolute visual magnitude of $M_V = -18$ at maximum light, will give a distance that agrees well with the three other determinations.

We conclude that the supernova remnant and the group of OB stars are in the same volume of space.

At the distance of 2500 pc the radius of the remnant is 11 pc. If we apply the similarity solution for a strong explosion in a gas of constant heat capacity (cf. Minkowski 1968), we find the initial total energy $E = 1.6 \times 10^{52} \times n_H$ ergs, where n_H = the number of H atoms/cm³. At the distance above the plane of this object, we may expect $n_H = 0.1$ cm⁻³, and thus $E = 1.6 \times 10^{51}$ ergs. This is large as compared with the values for Type II supernovae given by Minkowski (1968) but about what would be expected according to Shklovsky (1960). Finally, we use the equations given by Minkowski (1968) to derive the present velocity of expansion to $v = 2350$ km/sec.

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TABLE 1
OB STARS IN THE REGION OF RCW 86

Ly. No.	Sp. Ly.	Sp.	V	B-V	U-B	A(4430) %	W(H γ) Å	Rad. Vel. km/sec
130	OB	B9 V	10.22	+0.23	+0.13	0	10.5	
131	OB	B2 III	10.39	+0.36	-0.52	7	3.5	-16
132	OB	B2 III	11.17	+0.48	-0.36	6	3.4	
134	OB		11.77	+0.42	-0.45			
135	OB -	B7 III:	11.15	+0.44	+0.08	6	7.0	+12
142	OB	B1 III	9.44	+0.31	-0.61	1:	2.8	+20
145	OB +		11.72	+0.45	-0.44			
153	OB	B3 III	11.10	+0.45	-0.27	8	3.6	+5
155	OB	B3 III	11.34	+0.59	-0.08	6	4.6	-14
158	OB -		11.53	+0.36	-0.27			

Note: Ly No. 142 is classified B1 III by FEAST ET AL (1961)

TABLE 2
ABSOLUTE MAGNITUDES, COLOR EXCESSES, AND DISTANCE
MODULI FOR THE STARS

a. STARS WITH SLIT SPECTRA

Ly. No.	$M_V(\text{Sp})$	$M_V(\text{H } \gamma)$	$(B-V)_O$	E_{B-V}	V_O	$V_O - M_V(\text{Sp})$	Remarks
130	+0.6	+0.4	-0.06	0.29	9.35	8.8	not member
131	-3.6	-4.1	-0.24	.60	8.59	12.2	
132	-3.6	-4.1	-0.24	.72	9.01	12.6	
135	-1.6	-1.6	-0.12	.56	9.47	11.1	doubtful member
142	-4.4	-4.6	-0.26	.57	7.73	12.1	
153	-2.9	-3.9	-0.20	.65	9.15	12.1	
155	-2.9	-3.1	-0.20	.79	8.97	11.9	

b. STARS WITH PHOTOMETRY, ONLY

Ly. No.	$(B-V)_O$	$(U-B)_O$	Sp.	E_{B-V}	V_O	$M_V(\text{Sp})$	$V_O - M_V(\text{Sp})$
134	-0.26	-0.93	B1 V	0.67	9.76	-2.3	12.1
145	-0.26	-0.95	B1 V	.71	9.59	-2.3	11.9
158	-0.17	-0.62	B5 III	.53	9.94	-2.2	12.1

TABLE 3

DISTANCE DETERMINATIONS FOR THE RADIO SOURCE,
THE SUPERNOVA AND THE STELLAR GROUP.

Object	Distance (pc)	Method	Reference
Radio source	2700	Shklovsky	Aizu and Tabara, 1967
Radio source	2300	Radio surface brightness/radius	Poveda and Woltjer, 1968
Supernova AD 185	750	Assumed maximum brightness	Minkowski, 1968
Stellar group	2500	Photometry, spectrography	Present paper

Legends to the figures.

Plate 1.- The emission nebula, RCW 86, in red light. The photograph was taken at the Newtonian focus of the Mt. Stromlo 74-inch telescope.

North is up and East is to the left. The scale is 4.8 seconds of arc/mm.

Plate 2.- The region of the non-thermal radio source 1439 -62. A few of the contours from Hill's observations at a frequency of 2650 Mc/s are superimposed on the photograph. The filamentary nebula RCW 86 can be seen in the lower left part of the source. Another filament is seen in the upper part (at $14^{\text{h}}38^{\text{m}}, -62^{\circ}$). The observed OB stars are marked as white dots. The print is part of a plate taken in H α light with the Uppsala Schmidt telescope.

Fig. 1.- The two-color diagram for stars observed in the vicinity of RCW 86. The standard main sequence relation is drawn. The arrow indicates the effect of reddening.

Fig. 2.- The color-magnitude diagram for the nine possible members of the group. Luminosity class III stars are plotted as dots in circles.

PLATE I

PLATE II

FIGURE 1

FIGURE 2

PART II

OB STARS NEAR THE SUPERNOVA REMNANT RCW 103

AND

THE GALACTIC STRUCTURE IN NORMA

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ABSTRACT

The small emission nebula, RCW 103, is identical with a non-thermal radio source, Parkes 1613-50. It is most likely a remnant of a supernova of Type II and a member of an OB association at a distance of 3900 pc. Another group of OB stars is found in the field at a distance of 1800 pc. Interstellar dust causes heavy absorption well within one kiloparsec from the sun, and another strongly absorbing cloud appears at the distance of RCW 103. The available optical and radio data show that at $l^{\text{II}} = 332^{\circ}$ portions of the Sagittarius arm and the Norma arm are seen. The latter contains most of the thermal radio sources in this direction as well as RCW 103 and its OB association.

INTRODUCTION

In the preceding paper (Westerlund 1969) we have discussed the fundamental assumption by Shklovsky (1960) that supernovae of Type II result from explosions of massive O and B stars. Our results for RCW 86 appear to confirm this hypothesis.

Here we present the results of a similar study of the OB stars in the region of the emission nebula RCW 103 (Plate I). Some time ago we suggested that this nebula was a supernova remnant. The emission line intensities and line ratios confirming this assumption have been presented (Westerlund and Mathewson 1966). Its non-thermal character has been established by Beard (1966).

The region of RCW 103 (Plate II) is more complex than that of RCW 86. Therefore, our investigation includes radio and optical observations of objects that do not fall in the same volume of space as RCW 103 but which contribute to the understanding of the spiral structure in this direction, $l^{\text{II}} = 331^{\circ} - 334^{\circ}$, $b^{\text{II}} = +1 - -2^{\circ}$ and in adjacent parts.

THE OBSERVATIONS

All the observations were carried out at Mt. Stromlo and Siding Spring Observatories with the same equipment and in the same way as described in the preceding paper (Westerlund 1969). Lyngå's survey (1965) of OB stars covers part of the present field, only, and we have completed it by using plates taken with the 20/26-inch Schmidt telescope of Uppsala Southern Station at Mt. Stromlo Observatory. A number of OB stars were found on the objective prism plates (dispersion 480 Å/mm at H γ). On the direct plates, taken in several colors from ultraviolet to the near infrared, we noted a small previously unknown cluster of stars with high interstellar reddening.

Photoelectric photometry was carried out of 58 stars, and photographic photometry was obtained of a number of stars in the region of the cluster. Slit spectra were taken of 17 of the objects. Spectroscopic as well as photometric information is available in the Radcliffe catalogues (Feast and Thackeray 1963, Feast et al 1961) for a number of these stars. From these catalogues we have also added 6 stars which are outside the field searched by us, to the material to be discussed.

The observational data are presented in Tables 1 - 7, which are all self-explanatory. The U-B values in Table 3 are obtained by using the following relation between the Radcliffe (U-B)_R and the standard UB_V system:

$$U-B = 1.58 (U-B)_R - 1.37$$

Photoelectric observations on the UBV system have been obtained for eleven of the present stars by Haug et al (1966, called HPD below) and on the BV system for twelve of the stars by Feast et al (1961, called FSTW below). However, three of these stars are probably binaries or variables (Feast and Thackeray 1963) and should not be considered in a comparison. Further, we have to consider the effect of the rich star field on the observations. In the FSTW observations a 45" diaphragm was used, and in the HPD investigation the minimum diaphragm was 35". Several of the present stars cannot be observed with so large apertures without inclusion of other stars, and we have used an aperture of 14" for all our observations. The material suitable for comparisons is thus limited to 8 HPD and 7 FSTW stars. The mean differences and the errors in these means are given in Table 8.

We conclude that the agreement between the three systems is satisfactory except for V where the HPD system has a zero point differing -0.08 mag from the other two systems.

DISCUSSION

The Two-Color Diagrams.- In Fig. 1 the U-B/B-V diagram is given for all the stars observed photoelectrically. The main sequence relation is drawn as well as the reddening line for the early B stars. Different symbols are used to identify stars of known luminosity classes as well as stars which from their position in the field appear to belong to a certain group. Most of the stars are obviously highly reddened B stars.

In Fig. 2 the corresponding diagram is given for the stars in and near the anon. cluster. It is clear that six of the photographically measured stars (open circles) are similar to the photoelectrically observed cluster members (filled circles). Five additional stars, slightly less reddened, may also belong to the cluster. This possibility is investigated further by plotting the V, B-V diagram (Fig. 3). Here, the highly reddened stars appear to form a fairly well-defined sequence with the less reddened possible members being between $15 - V - 16$ at $B - V = 1.0$. Obviously a correction for the color excesses and total absorptions of the two groups will leave a gap of about 2 magnitudes between the faintest of the highly reddened group and the brightest of the less reddened. It is difficult to conclude from this whether the latter stars are members or not, and a more detailed investigation is obviously needed.

The distribution of the stars.- Table 9 gives data derived from the observations. It is divided into two sections according to the completeness of the observational data. In Section "a" there are 21 stars with very similar distance moduli; they are tentatively considered to form the "RCW 103 association" and identified as members (103) in col. 8 of the table. The mean distance modulus is

$$V_o - M_V (Sp) = 12.95 \pm 0.11.$$

This corresponds to a distance of 3900 pc.

A second group of stars is found in RCW 105. In addition to the four member stars in the nebula Wd 5 and FSTW 152 may belong to this group. Its distance modulus is about

$$V_o - M_V (Sp) = 11.3,$$

(the binary is excluded in the calculation) corresponding to a distance of 1800 pc.

Section "b" of Table 9 contains stars with photoelectric data, only. We have applied Johnson's method (1958) to derive their $(B-V)_o$ and $(U-B)_o$; this assumes that the stars are of luminosity classes V, IV, or III. The spectral types given in col. 4 are based on these colors. Most of the stars have been given luminosity class III from the $(U-B)_o$ values. This is to be expected, as there is every reason to assume that the stars in section "b" are similar to those classified from slit spectra in section "a".

The distance moduli of the stars in section "b" show more of a scatter than those in section "a" and in some cases it is difficult to decide if the stars are members of RCW 103 or of RCW 105. In Fig. 4 we have plotted V_o versus $(B - V)_o$ for all the stars observed photoelectrically; in this case all the material has been reduced by the Johnson method.

In this way an estimate of the scatter due to the method should be obtained.

It is obvious from the diagram that the stars fainter than $V_o = 8$ having $(B - V)_o > -0.20$ cannot be members of either grouping. These stars have also much smaller distance moduli (Table 9) than the others. For the other stars in section "b" we give in column 9 the group they appear to belong to. Six stars have been added to the RCW 103 association and nine stars to the RCW 105 group.

In Fig. 4 the photoelectrically observed stars in the anon. cluster are also plotted. The absolute visual magnitudes of the brightest stars in the cluster are about -8.5 if the cluster is at the distance of RCW 103 and about -7 if it is at the distance of RCW 105; the latter possibility appears most likely. As these stars are then supergiants, the intrinsic colors given in Table 10 should be corrected by +0.07 mag in $B - V$. V_o (col.7) then becomes 0.2 mag fainter than the given value.

In Fig. 5 the color excesses, E_{B-V} , are plotted against the distances of the individual stars for the objects with known spectral types. The stars in the RCW 103 association show a considerable scatter of the absorption values; a more detailed study shows that this is partly a function of the galactic latitude. The RCW 105 stars (X) have the highest reddening in spite of being nearest to us. Their galactic latitudes are about $b^{II} = +2^\circ$. The foreground absorption decreases from this latitude towards the galactic equator (cf. Plate 2) and becomes continuously lower at negative latitudes.

Although the present material does not permit detailed conclusions regarding the distribution of the dust along the line of sight, there is no indication that the absorption increases steadily with the distance from the sun. This has been suggested by Haug et al (1966) for part of the present field, and by Drilling (1968) for the nearby LF 15. When large inhomogeneous areas are treated as units such conclusions are too frequently erroneously drawn.

The following interpretation of the structure in our area is suggested on the basis of the color excess, distance diagram (Fig. 5), the K-line velocities (Fig. 6) and Neckel's results (1967) for his areas 136 and 137, which correspond closely to the RCW 103 and RCW 105 regions, respectively:

At latitudes $b^{\text{II}} > 0.5$ heavy absorption occurs in a nearby cloud, well within one kiloparsec from the sun. This cloud thins out towards the southern galactic latitudes and it is unlikely that it contributes more than 0.4 mag in the southern part of the field. The remainder of the absorption in the latter part occurs more or less at the distance of the RCW 103 association. We believe that we have only penetrated the thinner parts of this dust cloud, as the strong HII regions observed on radio frequencies are barely or not at all visible (though a large number of foreground(?) stars can be seen), and none or few of the exciting stars may have been detected. The relations between the present two groupings of stars and others in their neighborhood may be seen in Table 11. It appears likely that we see portions of two spiral arms: The Sagittarius arm, represented by I Ara, OB Norma II, OB Norma I and other nearby groups, and the Norma arm with the distant group in Ara and the RCW 103 association.

The RCW 103 Nebulosity.- The distance to the nonthermal radio source centered on RCW 103 has been determined from the radio data by Aizu and Tabara (1967) and by Poveda and Woltjer (1968) to 5700 pc and to 4300 pc, respectively. We conclude that these values are in satisfactory agreement with the value of 3900 pc found here for the richest stellar grouping in this direction. Minkowski, in a private communication, has suggested that the minimum distance is 2200 pc.

At a distance of 3.9 kpc the diameter of the remnant is about 7 pc.

If it is similar to the Cygnus Loop, its age is over 4500 years, if it is similar to RCW 86 it must be much younger. In the latter case the supernova explosion should perhaps not have escaped detection. A tentative calculation gives $V_{\max} = -2$, if $M_V^{\max} = -18$, $V - M_V = 13$ and $A_V = 3$. It is, however, a fairly southern object.

The Star in the Center of RCW 103.- Very near the geometrical center of RCW 103 there is a red star with $V \sim 12.7$ mag. Objective prism plates in the near infrared give the spectral type as M2. Current theories for supernovae do not predict the stellar remainder to be a red star. Nevertheless, we have observed the object photoelectrically and the result is given in Table 5. The table gives also the most likely value on the interstellar absorption, and the absolute visual magnitude needed to place the star at the distance of the remnant. The value, $M_v = -2.3$, corresponds to luminosity class II. Blanco (1965) has suggested that M giants which are members of clusters and associations are more luminous than the M stars in the field. Thus the possibility still exists that the present star may be a member of the association.

The Distribution of Gas in the Region.- The present region contains several HII regions. Apart from RCW 103 and RCW 105, RCW 106 from the Mt. Stromlo survey (Rodgers et al 1960) can be seen. Most important are, however, the strong thermal sources observed on radio wavelengths by Beard (1966) on 11 cm and by Hill (1968) on 20 cm. For several of these sources McGee et al (1967) have observed OH in emission and in absorption, and McGee and Gardner (1967) have observed the excited atomic hydrogen lines 126λ and 127λ .

In Fig. 6 we have plotted the radial velocities derived from the stellar as well as from the interstellar CaII lines against the distances of the stars. The velocities are taken from Feast and Thackeray (1963) whenever possible; low weight is given to velocities measured in the present investigation from one spectrum per star, only. The curve in the figure represents the radial velocities to be expected from galactic circular motion. Finally, Fig. 6 gives in four columns the OH emission (e) and absorption (a) velocities as well as the 126λ and 127λ lines velocities (α). The four sources, identified by their declinations, are $16^{\text{h}}08^{\text{m}}-51^{\circ}$, $16^{\text{h}}17^{\text{m}}-50^{\circ}$ I and II, and $16^{\text{h}}18^{\text{m}}-49^{\circ}$.

The diagram shows that RCW 105 as well as its CaII cloud are nearer to the sun than RCW 103 and its CaII cloud. This result was referred to above to support the conclusion from the color-excess data that most of the absorption in the RCW 103 area occurs at its very distance.

Attention is called to the apparently very distant star, Wd 1, at $V_0 - M_V(\text{Sp}) = 13.9$ in Fig. 6, which has a very low radial velocity and from which also a low interstellar velocity has been derived. The latter may be explained as due to the CaII cloud also seen in front of the RCW 105 stars, as its galactic latitude is $+1.6^{\circ}$. It is extremely unlikely that the star itself could have a distance modulus smaller than 12.9; this value is obtained by changing the classification from 09.5I to 0 8.

The $H\gamma$ measures also confirm the high luminosity of the star. It is important to note that most of the radial velocities from the high transition hydrogen lines fall within the range of the RCW 103 stars. This is also true for the OH velocities for the 16 17 -50 source. The OH absorption measures for the 16 18 -49 source cover a much wider range, however, and the 16 08 -51 source, which is completely invisible on our plates has higher (negative) velocities than the majority of the stars in our investigation.

The derived mean velocities and their dispersions are:

RCW 103 association:	Stellar (9 stars)	-34 km/sec	$\pm$ 23 km/sec
	Interstellar	-31.5	12
RCW 103 nebula:	Two filaments	-30 km/sec	
	(Individual values -70 and + 10 km/sec)		
RCW 105 group:	Stellar (3 stars)	-27	$\pm$ 10
	Interstellar	-9	3
16 ^h 17 ^m -50 ^o :	126 χ , 127 χ	-40	20
16 18 -49			

The velocity data appear to permit the conclusion that the HII regions and the OH emission areas are at the same distance as RCW 103. The scatter in the diagram may be partly due to the expansion of the whole complex.

The interstellar band 4430.- Table 4 gives the central absorption A_{4430} of the λ 4430 band in percentage below the continuum. In Fig. 7 A_{4430} is plotted against the color excesses E_{B-V} . The straight lines drawn represent a) the mean relation for field stars from Wampler's (1966) investigation and b) the extreme mean values for Wampler's material divided into longitude zones (dashed lines). It should be noted that we have not been able to compare our system with Wampler's for individual stars and further that Wampler's investigation does not cover the present longitude interval. Considering this we conclude that there are no particularly unexpected features in Fig. 7. A few stars with very low 4430 intensities appear, a similar result is found for the 7 stars near RCW 86 (open circles).

CONCLUSIONS

The investigations of the OB stars in the region of RCW 86 (Westerlund 1969) and of RCW 103 have shown the existence of OB associations at distances which agree well with those derived for the two supernova remnants from radio astronomical data. Both associations contain evolved stars; the most luminous are in the RCW 103 association. Shklovsky's suggestion that Type II supernovae result from explosions of O or B stars is thus supported by the fact that the two remnants under consideration are in the same volume of space as groups of young massive stars.

The known stellar associations in the Norma-Ara direction (Table II) define portions of two spiral arms. The Sagittarius arm is seen from I Ara, at $\ell^{\text{II}} = 337^{\circ}$, to OB Norma I, at $\ell^{\text{II}} = 328^{\circ}$; the distance from the sun increasing from 1400 pc to 2500 pc. The Norma arm is identified by the Ara grouping at 3500 pc, $\ell^{\text{II}} = 337^{\circ}$, and the RCW 103 association and the Norma grouping at about 3900 pc, $\ell^{\text{II}} = 332^{\circ}$. The latter arm contains most of the thermal radio sources in the present region as well as the supernova remnant RCW 103. In addition to having a large amount of ionized gas it is also rich in dust. Only the most luminous stars in the RCW 103 association have been identified.

There is also a strongly absorbing dust cloud well inside one kiloparsec from the sun. Its strongest absorption occurs north of the galactic plane and affects mostly the RCW 105 group. It appears

likely that the observed interstellar CaII lines originate in this cloud as well as in the Norma arm; the radial velocities derived from the CaII lines of the more distant stars (cf. Fig. 6) are probably averaged over the two clouds.

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TABLE 1

OB STARS IN THE REGION OF RCW 103

Star No.	R. A. (1950)	Dec.	Sp.	V	B-V	U-B	n	Lynga's types and Remarks
Wd 1	16 ^h 05 ^m .7	-49°28'5	09.5I	10.07	+0.54	-0.39	2	HD 144647.Var?R
2	06.4	-49 33.0		10.83	.60	- .20	2	
3	06.4	-49 36.1		10.42	.74	+ .42	2	
4	07.5	-50 29.4	B1 II	10.60	.89	- .15	3	HD 145217.Var ?R
5	08.4	-50 10.6		9.94	.90	- .29	3	
6	09.5	-50 15.8		12.87	.99	- .05	2	
Ly 395	09.9	-50 59.1		10.88	.57	- .34	3	OB +,R
398	10.3	-51 07.6	B1 III	10.58	.37	- .39	2	OB
399	10.8	-51 36.8		11.31	.53	- .12	2	OB -.Var?
Wd 7	11.0	-50 41.2	B0.5 III-IV	10.34	.36	- .40	2	
Ly 401	11.1	-51 06.7	B2-3 III	11.12	.52	- .15	2	OB
Wd 8	11.2	-50 07.7		11.20	.51	+ .17	2	
9	11.4	-50 04.8		10.73	.57	- .32	2	
Ly 404	11.5	-50 48.4		10.46	1.05	+ .54	1	OB. double
406	11.7	-51 02.4	B2-3 III	10.85	.48	- .18	2	OB -

TABLE 1 (Cont.1)

Star No.	R. A.	Dec.	Sp.	V	B-V	U-B	n	Remarks
		(1950)						
Ly 407	16 11.7	-50 51.8	B0 III	9.75	+0.37	-0.64	2	OB +
Wd 10	12.4	-50 18.8	B1 III	10.77	.56	- .25	2	
11	12.5	-50 18.0		11.90	.46	- .09	2	
12	12.6	-50 29.0	B0.5 I	9.59	.47	- .48	2	
Ly 417	13.1	-51 41.6		10.88	.96	- .01	2	OB +
418	13.5	-51 38.8	B0.5 Ia	9.94	.94	- .13	2	OB + .R
421	13.9	-51 33.0	B2 III	11.00	.51	- .22	2	OB -
428	14.7	-51 19.5	B0.5 III	10.33	.38	- .51	2	OB. R
431	14.9	-51 21.2		10.31	1.33	+ .43	2	OB +
432	15.0	-50 56.3		10.33	.50	- .43	2	OB
Wd 13	15.0	-50 54.2		11.18	.17	- .10	3	
Ly 435	15.2	-50 46.8		11.06	.50	- .30	2	OB
442	15.7	-51 21.4	B1 III	11.11	.37	- .45	2	OB +
Wd 14	15.8	-51 20.4		11.70	.52	+ .02	2	
Wd 15	15.9	-49 38.2	09 I	9.94	.66	- .37	2	HD 146628.R.

TABLE 1 (Cont. 2)

Star No.	R. A. (1950)	Dec.	Sp.	V	B-V	U-B	n	Remarks
Wd 16	16 ^h 16 ^m .0	-50° 19' 3	B2 II	10.15	+0.71	-0.12	2	R
17	18.2	-51 05.3		11.11	.59	- .06	2	Var?
Ly 468	21.2	-51 31.5		10.88	.37	- .37	2	OB
469	21.6	-51 55.0	B0: III	9.80	.24	- .73	2	OB+.HD147617.R.
471	22.0	-51 41.9	B0.5 III	10.31	.31	- .47	2	OB
472	22.5	-51 41.3	B2 II-III	9.62	.20	- .57	2	OB.R.

Remarks to TABLE 1

Star No.

Wd 1.- FSTW No. 153: 08.

Wd 5.- FSTW No. 159: 08.

Ly 395.- FSTW No. 160: B1 III

Ly 418.- FSTW No. 165: B0.5 Ia.

Ly 428.- FSTW No. 166: B0.5 III.

Wd 15.- FSTW No. 167: 09.5Ia

Wd 16.- FSTW No. 168: B3 III

Ly 469.- FSTW No. 177: 09.5 III

Ly 472.- FSTW No. 178: B2 III

TABLE 2
OB STARS IN RCW 105

Star No.	R.A. (1950)	Dec.	Sp.	V	B-V	U-B	n	Remarks
105: 1	16 06.0	-48°57'4		10.45	+0.61	- .30	1	
2	06.2	57'8		11.67	.63	- .28	1	
3	06.5	50.5	O9V	9.70	.74	- .34	1	FSTW 155=HD 144900
4	06.6	55.8	O7	10.01	.80	- .30	1	FSTW 156=HD 144918 binary?
5	06.8	57.6		12.05	.87	- .10	1	
6	07.0	54.3	BOV e	9.87	.81	- .34	1	FSTW 157=HD 144970
7	07.0	40.4	B0.5Ia	8.31	.96	- .14	1	HD 144969
8	07.1	46.7		11.36	.61	- .36	1	
M1				10.13	1.70	+1.86	1	
2				10.06	1.91	2.16	1	
3				8.80	.97	.79	1	

TABLE 3
STARS ADDED FROM THE RADCLIFFE CATALOGUE

Star No.	R.A. FSTW	Dec. (1950)	Sp.	V	B-V	U-B	Remarks
152	16 ^h 00 ^m .2	-49°45'	B0.5V	10.27	+0.65	-0.38	
154	16 05.9	-50 58'	B2.5V	10.46	.83	- .09	
162	16 12.8	-51 52	B0Ia	9.87	.85	- .19	Ly 413: OB +
163	16 12.8	-52 01	B0Ia	9.79	.85	- .22	Ly 414: OB +
169	16 17.6	-52 28	B3:V	9.65	.18	- .49	
170	16 19.0	-49 57'	B3V	10.42	.60	- .22	

TABLE 4
SPECTROSCOPIC DATA

Star No.	W(H γ) Å	A(4430) %	Stellar velocity km/sec		CaII velocity km/sec Radcliffe	Remarks
			Mt Stromlo	Radcliffe		
Wd 1	1.8	5	-28	-18	-9	
4	2.2	4				
Ly 395				-40	-28	
Ly 398	4.6	6	-12			
Wd 7	2.6	2	-21			
Ly 401	4.7	8	-61			
Ly 406	4.5	8	-17			
Ly 407	1.8	6	+27			
Wd 10	3.4	6	-57			
Wd 12	2.1	7	-106			
Ly 418	1.7	10	-53	-61:	-35	RV Variable
Ly 421	2.8	4	-13			
Ly 428	2.6	7	-25	-30:	-27	RV Variable
Ly 442	3.3	7:	-57			
Wd 15	2.0	6	-44	-32	-28	

TABLE 4 (Cont)

Star No.	W(H γ)	A(4430)	Stellar velocity km/sec		CaII velocity km/sec	Remarks
			Mt. Stromlo	Radcliffe	Radcliffe	
Wd 16	2.5	10	-45	-26	-25:	
Ly 469	2.0	2	-80:	-52	-41	
Ly 471	1.6	4	-50			
Ly 472	3.4	0-1	-55			
FSTW:						
152				-14	-14	Probably Var. RV
154				-41	-20	
162				-48	-50	
163				-77:	-40	RV Var.
RCW						
105:3				-18	- 7	
4				(-40)	(-22)	Binary
6				-38	-8	
7				-24	-13	

Note: Correction to local standard of rest: +4 km/sec

TABLE 5
THE STAR IN THE CENTER OF RCW 103

R.A. 1950	Dec.	Sp.	V	B-V	U-B	n
16 ^h 13.6	-50°56.4	M2	12.71	2.11	2.14	2
Assume	E_{B-V}	~	0.7,			
then	A_{B-V}	~	2.1			
and	V_o	~	10.6.			
	$M_V = -$		2.3	to make		V-M=12.9
	Luminosity class II					

TABLE 6
PHOTOELECTRIC OBSERVATIONS OF
STARS IN THE ANON. CLUSTER
R.A. = $16^{\text{h}}10^{\text{m}}.2$; Dec. = $-51^{\circ}45'5$ (1950)

Star No	V	B-V	U-B	n
1	11.71	+1.99	+1.90	2
2	12.61	2.63	1.17	1
3	13.15	2.27	.92	1
4	13.19	2.30	1.12	1
5	13.35	2.12	.86	1
6	12.95	2.19	.86	1
7	14.01	2.37	.73	1
8	13.54:	0.72:	.13:	2
9	7.77	1.56	1.79	2
10	11.31	1.30	1.14	1

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TABLE 7

PHOTOGRAPHIC OBSERVATIONS OF STARS IN THE REGION
OF THE ANON. CLUSTER

Star No.	V	B-V	U-B	
11	13.87	+1.01	+0.62	
12	14.28	1.33	+ .77	
13	14.99	2.0	.0	M
14	13.96	2.25	+ .65	M
15	15.7	1.0	+ .1	X
16	14.89	2.1	+ .7	M
17	14.23	2.29	+ .5	M
18	15.77	.6	+ .3	
19	15.3	2.0	+ .4	M
20	15.9	1.0	+ .1	X
21	15.5	2.0	+ .4	M
22	15.1	.5	+ .23	
23	14.23	.59	+ .39	
24	15.1	.92	- .01	X
25	14.19	.55	+ .14	
26	15.4	.63	+ .18	
27	15.6	.9	+ .10	X
28	15.7	1.0	+ .20	X
29	15.8	2.0	—	M:
31	14.6	1.5	+ .9	
32	13.83	.40	.41	
33	14.6	.46	.39	
34	15.3	.7	.19	
35	13.78	.56	.53	
36	14.40	.41	.33	
37	14.33	.43	.38	
38	14.44	1.46	.74	
39	14.01	1.15	.61	
40	11.87	1.77	1.57	

Note: 3 plates have been measured in each color

TABLE 8
 COMPARISONS WITH THE PHOTOMETRY
 BY FEAST ET AL (FSTW) AND BY HAUG ET AL (HPD)

	Wd - FSTW (7 stars)	Wd - HPD (8 stars)
V	0.00 ± 0.012	$+0.08 \pm 0.022$
B-V	0.00 ± 0.012	$+0.01 \pm 0.014$
U-B	—	-0.02 ± 0.021

TABLE 9

DERIVED DATA FOR THE STARS

a. STARS WITH SLIT SPECTRA OBTAINED

Star No.	$M_V(\text{Sp.})$	$M_V(\text{H}\gamma)$	$(B-V)_O$	E_{B-V}	V_O	$V_O - M_V(\text{Sp})$	Member
Wd 1	-6.2	-5.8	-0.25	0.79	7.70	13.9	103:
4	-5.0	-5.4	-0.24	1.13	7.21	12.2	103
5	-5.2		-0.31	1.21	6.34	11.5	
Ly 395	-4.4		-0.26	0.83	8.39	12.8	103
398	-4.4	-2.9	-0.26	0.63	8.69	13.1	103
Wd 7	-4.6	-4.7	-0.28	0.64	8.42	13.0	103
Ly 401	-3.6	-2.9	-0.22	0.74	8.90	12.5	103
406	-3.6	-3.1	-0.22	0.70	8.75	12.4	103
407	-5.0	-5.8	-0.30	0.67	7.74	12.7	103
Wd 10	-4.4	-4.0	-0.22	0.78	8.43	12.8	103
12	-6.2	-5.4	-0.20	0.67	7.58	13.8	103
Ly 418	-6.4	-6.1	-0.20	1.14	6.52	12.9	103
421	-3.6	-4.6	-0.24	0.75	8.75	12.4	103
428	-4.7	-4.7	-0.28	0.66	8.35	13.1	103
442	-4.4	-4.1	-0.26	0.63	9.22	13.6	103
Wd 15	-6.2	-5.4	-0.28	0.94	7.12	13.3	103
16	-4.8	-5.0	-0.22	0.93	7.36	12.2	103:
Ly 469	-5.0	-5.6	-0.30	0.54	8.18	13.2	103
471	-4.7	-6.7	-0.28	0.59	8.54	13.2	103
472	-4.2	-4.0	-0.24	0.44	8.30	12.5	103

TABLE 9 (Cont.1)

Star No.	$M_V(\text{Sp.})$	$M_V(\text{H}\gamma)$	$(B-V)_O$	E_{B-V}	V_O	$V_O - M_V(\text{Sp})$	Member of:
FSTW:							
152	-4.0		-0.28	0.93	7.48	11.5	
154	-2.1		-0.22	1.05	7.31	9.4	
162	-6.2		-0.22	1.07	6.66	12.9	103
163	-6.2		-0.22	1.07	6.58	12.8	103
169	-1.7		-0.20	0.38	8.51	10.2	
170	-1.7		-0.20	0.80	8.02	9.7	
RCW 105:3	-4.8		-0.31	1.05	6.55	11.4	105
:4	-5.3:		-0.32	1.12	6.65	12.0	
:6	-4.4		-0.30	1.11	6.54	10.9	105
:7	-6.4		-0.20	1.16	4.83	11.2	105

b. STARS WITH PHOTOMETRY, ONLY

Star No.	$(B-V)_O$	$(U-B)_O$	Sp.	E_{B-V}	V_O	$M_V(\text{Sp})$	$V_O - M_V(\text{Sp})$	Member of
Wd 2	-0.21	-0.76	B3 III	+0.81	8.40	-2.9	11.3	105
3	- .04	-0.11	B9.5 III	0.78	8.08	-0.4	8.5	
6	- .27	-1.00	B1 III	1.26	9.09	-4.4	13.5	103
Ly 399	- .17	- .59	B5 III	0.70	9.21	-2.2	11.4	105:
Wd 8	- .04	- .20	B9 III	0.55	9.55	-0.4	10.0	
9	- .25	- .91	B2 III	0.82	8.27	-3.6	11.9	105
Ly 404	- .07:	- .22:	B9 III:	1.12:	7.10	-0.4	7.5	
Wd 11	- .14	- .48	B6 V	0.60	10.10	-0.6	10.7	105
Ly 417	- .25	- .89	B2 III	1.21	7.25	-3.6	10.9	105

TABLE 9 (Cont.2)

Star No.	(B-V) _o	(U-B) _o	Sp.	E _{B-V}	V _o	M _V (Sp)	V _o - M _V (Sp)	Member of:
Ly 431	-0.18	-0.64	B5 II:	1.51	5.78	-4.4	10.2	
432	-0.26	-0.98	B1 III	0.76	8.05	-4.4	12.5	103
Wd 13	-0.07	-0.25	B8.5 III	0.24	10.46	-0.7	11.2	105
Ly 435	-0.22	-0.80	B2.5 III	0.72	8.90	-3.3	12.2	103
Wd 14	-0.12	-0.47	B7 III	0.74	9.48	-1.6	11.1	105
Wd 17	-0.16	-0.56	B5 V	0.75	8.86	-1.0	9.9	
Ly 468	-0.21	-0.76	B3 III	0.58	9.14	-2.9	12.0	103
RCW 105:								
1	-0.26	-0.93	B1 V	0.87	7.84	-3.6	11.4	105
2	-0.25	-0.91	B1.5 V	0.88	9.03	-3.0	12.0	105
5	-0.25	-0.92	B1 V	1.12	8.69	-3.6	12.3	103
8	-0.27	-1.00	B1 III?	0.88	8.72	-4.4	13.1	103

TABLE 10
DERIVED DATA FOR STARS
IN THE ANON. CLUSTER

Star No.	E_{B-V}	V_o	$(B-V)_o$	$(U-B)_o$
2	2.92	3.85	-0.29	-1.31
3	2.53	5.56	-0.26	-1.15
4	2.49	5.72	-0.19	-0.75
5	2.36	6.27	-0.24	-1.01
6	2.45	5.60	-0.26	-1.09
7	2.71	5.88	-0.34	-1.60

Note: The data are derived under the assumption that the stars are of luminosity class III - V. If they are supergiants $(B-V)_o$ should be corrected with $+0.^m07$. V_o is then 0.2 mag fainter than given in the table.

TABLE 11
ASSOCIATIONS IN THE NORMA - ARA REGION

Association or area	ℓ^{II}	b^{II}	Distance (pc)	Reference
OB Norma I	328°	-1°	2500 ± 300	Bok et al (1963)
Norma	328	-1	720 ± 170	Bok et al (1963)
LF 15: OB max.	330	-2	2500	Drilling (1968)
RCW 103	332	-0.5	3900	present paper
Norma (group?)	332	-2	4000	Haug et al (1966)
OB Norma II	333°	+2	1600 ± 300	Lyngå ^o (1964)
RCW 105	333	+2	1800	present paper
I Ara	337	-1.5	1400 ± 200	Whiteoak (1963)
Ara	337	-1.5	3500 ± 900	Whiteoak (1963)

Legends to the figures.

Plate I.- The emission nebula RCW 103. The photograph is a 2.5 hours exposure in red light at the Newtonian focus of the Mt. Stromlo 74-inch telescope. The scale on the print is 6 seconds of arc/mm. In the lower right corner is an extremely weak emission patch which is probably not connected with RCW 103.

Plate II.- The region of RCW 103. On the photograph, taken in red light with the Uppsala Schmidt telescope, are superimposed some contours from Hill's 20-cm survey. The identified OB stars are plotted as white dots. The three overlapping dots in the lower part mark the position of the anon. cluster discussed in the text.

Plate III.- Identification chart for stars measured in the region of the anon. cluster.

Fig. 1- Two-color diagram for the OB stars in the region of RCW 103. Open circles identify luminosity class I; dots in circles luminosity classes II - III, and filled circles stars for which no spectra are available. Members of the RCW 105 association are plotted as squares. Stars from the catalogue by Feast et al are plotted as crosses.

Fig. 2- The two-color diagram for stars in the cluster region. Filled circles represent photoelectric and open circles photographic observations. Crosses represent photographic observations of stars in a comparison field near the cluster (stars 31 - 40 in Plate III). Probable and possible cluster members have symbols in circles.

Fig. 3- The color-magnitude diagram for the stars in the cluster region. Symbols as in Fig. 2.

- Fig. 4- The color-magnitude diagram for all stars observed photoelectrically. Possible members of the RCW 105 association are plotted as triangles; those of RCW 103 as circles. Open symbols identify stars with spectra available. Members of the anon. cluster are plotted as crosses. The dashed line identifies the zero-age main sequence relation for the RCW 105 group and the full-drawn line the corresponding relation for the RCW 103 association.
- Fig. 5- The color excess, E_{B-V} , plotted as a function of the distance. Members of the RCW 103 association are plotted as filled circles, members of the RCW 105 association as crosses, and foreground stars as open circles.
- Fig. 6- The radial velocities plotted against the distance moduli. The curve represents the velocities to be expected from galactic circular motion. Stellar velocities are plotted as circles (Radcliffe data) or dots (this paper); RCW 105 members have their symbols in circles. Interstellar-line velocities (Radcliffe data) are plotted as crosses. For comparison, OH (in absorption, "a", or emission, "e",) and $126\text{ }\mu$ and $127\text{ }\mu$ lines velocities are given in the left part of the diagram with the identification of each source at the top of the column.
- Fig. 7- The relation between the central absorption of the $\lambda 4430$ band and the color excess. Dots represent stars in the region of RCW 103, circles stars in the region of RCW 86. The full-drawn line is Wampler's relation for field stars, and the dashed lines are the extreme values with his material divided into galactic longitude groups.

PLATE I

PLATE II

PLATE III

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7