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OPEN CLUSTERS IN THE CARINA NEBULA

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RESUMEN

Uno de los detalles más llamativos de la Vía Láctea en el hemisferio sur es la Nebulosa Carina, NGC 3372, a una distancia de aproximadamente 2.5 kpc. Esta región H II contiene 8 cúmulos abiertos jóvenes con un total de 64 estrellas de tipo espectral O, y sólo 2 estrellas Wolf-Rayet. Los dos cúmulos más notables son Trumpler 16 y Collinder 228, ubicados en la región más brillante de la nebulosa. La edad de todos estos agregados es del orden de unos pocos 10^6 años. Aparecen 5 estrellas de tipo espectral O3 en Tr 16 y 1 en Tr 14; ésta última ha sido clasificada como una estrella doble. Incluyendo sólo las estrellas miembros, se estima que la masa estelar total es al menos de 4500 masas solares.

ABSTRACT

One of the most conspicuous features in the southern Milky Way is the Carina Nebula, NGC 3372, at a distance about 2.5 kpc. This H II region contains 8 young open clusters with a total of 64 O-type stars, but only 2 Wolf-Rayet stars. The 2 most remarkable open clusters are Trumpler 16 and Collinder 228, located in the brightest part of the nebula. The age of all these aggregates is of the order of a few 10^6 years. There are 5 stars of spectral type O3 in Tr 16 and 1 in Tr 14; this last one has been classified as a double star. The total stellar mass, including only the member stars, is estimated to be at least of 4500 solar masses.

Key words: **OPEN CLUSTERS AND ASSOCIATIONS — STARS: EARLY TYPE**

1. INTRODUCTION

The location of the young clusters according to their galactic coordinates, displays very clearly the position of the spiral arms of the Galaxy (Feinstein 1994). Young open clusters are those defined as having O-type stars and thus with ages younger than 10^7 years. In the particular case of the Carina region a rather small color excess is found up to this region, about $E(B-V) = 0.5$ (Figure 1). Therefore, this region is possible to observe due to the quite low value of the interstellar extinction in that direction, considering that this structure is at about $d = 2.5$ kpc.

The distribution of O-type stars (Figure 2) indicates that the largest number of early-type stars in the Milky Way is located in the Carina region. A total of 64 O-type stars are found in this region.

From these figures it is concluded that NGC 3372 is the H II region which appears as the most prominent optical feature in the southern Milky Way. It contains the strongest concentration of early type stars known in the Galaxy. It is also believed that we are seeing in this region a portion of the outer part of the spiral arm called Sagittarius-Carina arm.

The complete list of open clusters in this region from the Catalogue of Open Clusters of Lyngå (1985) is presented in Table 1. Only some of them have photometric and spectroscopic data. Those are: Bo 10 and 11, Tr 14, Tr 15, Tr 16, Cr 228, NGC 3293 and NGC 3324. The map of the region with the position of the six first open clusters is presented in Figure 3. A few other open clusters listed in the same catalogue of Lyngå as belonging to this region are just small groups inside those clusters cited above.

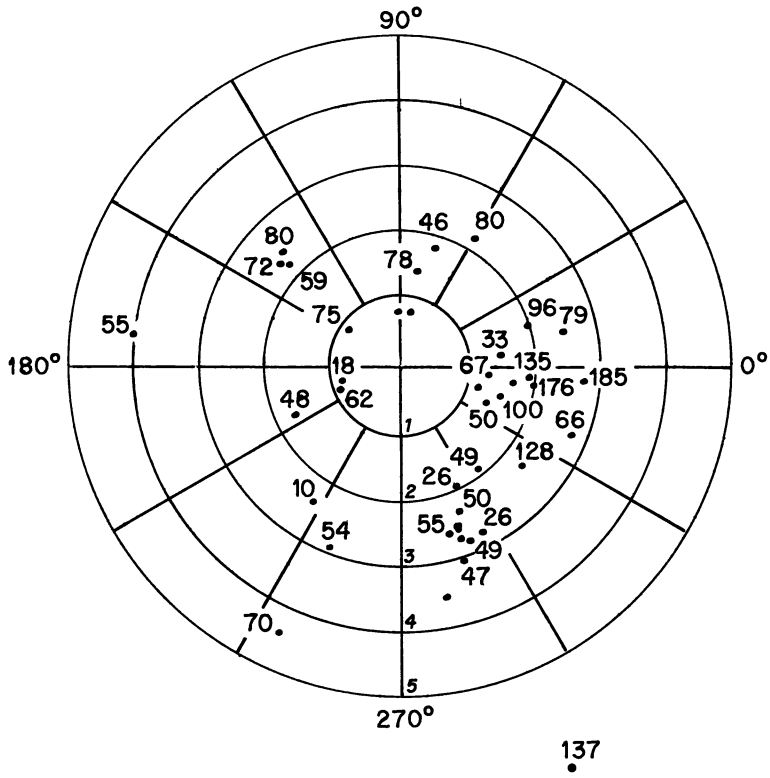

Fig. 1. Color excesses in units of 0.01 in galactic longitude versus distance for young open clusters in the Milky Way.

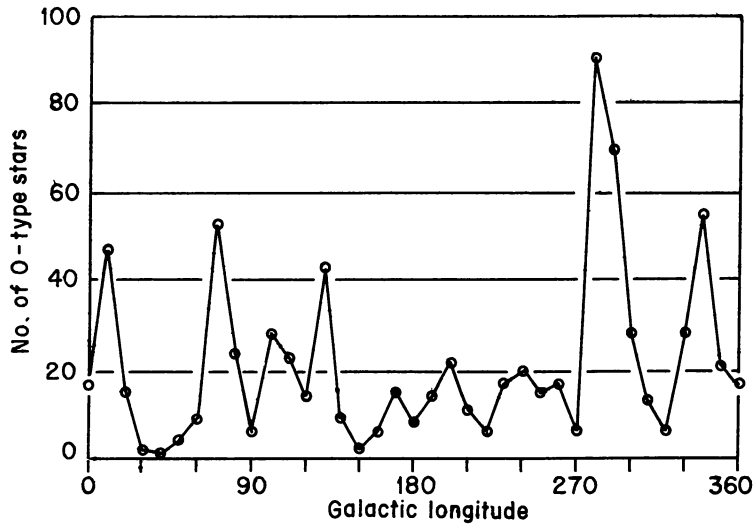

Fig. 2. Number of O-type stars in the Milky Way according to their galactic longitude.

Table 1. List of all Open Clusters in the Region of the Carina Nebula

Name	Designation	α	δ	l	b	Remarks[a]
NGC 3114	C1001-598	10 01.1	−59 52	283.34	−3.82	1
Bochum 9	C1033-598	10 33.9	−59 52	286.77	−1.58	1
NGC 3293	C1033-579	10 33.9	−57 58	285.85	+0.07	...
NGC 3324	C1034-580	10 35.4	−58 22	286.21	−0.16	...
Loden 165	C1035-584	10 35.0	−58 29	286.23	−0.30	1
VDB Hagen 99	C1036-589	10 36.0	−58 56	286.56	−0.63	1
Bochum 10	C1040-589	10 40.3	−58 53	287.03	−0.32	...
Trumpler 15	C1042-591	10 42.8	−59 06	287.41	−0.36	...
Trumpler 14	C1041-593	10 42.0	−59 18	287.43	−0.58	...
Collinder 228	C1041-597	10 41.1	−59 45	287.52	−1.02	...
Collinder 232	C1042-593	10 42.9	−59 18	287.52	−0.53	2
Trumpler 16	C1043-594	10 43.2	−59 27	287.62	−0.65	...
Collinder 234	C1043-594	10 43.4	−59 29	287.66	−0.67	1
Bochum 11	C1045-598	10 45.3	−59 50	288.03	−0.87	...

[a] 1. There is no data available for this cluster. 2. This group is assumed to be connected with Tr 16

In Table 2 are listed some data for those clusters more clearly related to the nebula, that is: the number of member stars according to the photometric and spectroscopic work, along with the visual magnitude and spectral type of the brightest stars in each one of them and its designation. On the other hand, in Table 3 is given the color excess, the distance modulus, the distance in kpc, and their estimated ages. All those data are taken from the references listed in the last column. Of course, all these data, which are not complete, are given as a reference information known today.

The color excesses as given in Table 3 show very small values with respect to the distances where these open clusters are located. It becomes quite evident that we are looking through a quite clear region between the two spiral arms where the Sun is located. The listed values confirm a mean color excess of about $E(B-V) = 0.5$ up to the Carina region. However, if we look at the data of each cluster, it is also noticed that in some of them there is a large intracluster variation, which suggests a large density of dust inside the clusters still left after the star formation.

Table 2. Stars in the Open Clusters

Open cluster	Number of member stars	the brightest star		Designation	Reference Sp. type
		m_v	Sp. type		
NGC 3293	87	8.22	O7 V ((f))	HD 91824	Walborn (1973)
NGC 3324	20	8.21	O6.5 V	HD 92206A	Walborn (1982)
Bochum 10	23	8.26	O9.5 III	HD 92725	FitzGerald et al. (1987)
Trumpler 15	39	8.36	O9 III	HD 93249	Morrell et al. (1988)
Trumpler 14	39	6.87	O3 (f)	HD 93129	Walborn (1971)
Collinder 228	63	6.28	O9.5I+O9.5III	HD 93206	Levato et al. (1981)
Trumpler 16	112	7.37	O3 V	HD 93250	Levato et al. (1982)
Bochum 11	11	8.40	O4-5 III (f)	HD 93632	Walborn (1973)

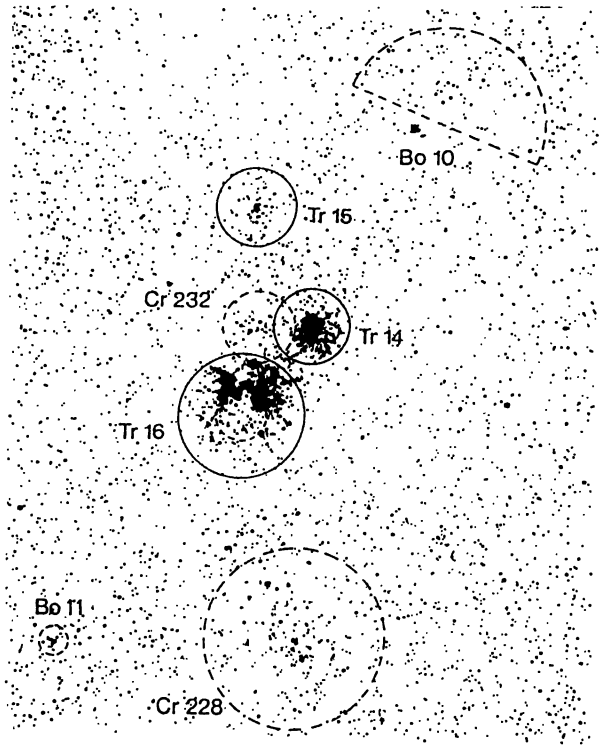

Fig. 3. The location of the open clusters in the Carina Nebula.

From the distance moduli of the open clusters as given in Table 3, it appears that most of them are located in the range between 12.0 and 12.5, with extremes branching 11.8 for Tr 16 (Levato & Malaroda 1982) and 12.99 for Tr 14 by Morrell, García, & Levato (1988). The largest discrepancy appears to be for Bochum 10 as Feinstein (1981) obtains 12.8, in comparison with FitzGerald & Mehta (1987) who give a smaller value of $V_o - M_V = 12.21$ kpc. In this last paper the data of Feinstein are rediscussed, obtaining 12.4 in better agreement with the value of FitzGerald & Mehta.

On the other hand, Clariá (1977) derived for NGC 3324 a distance modulus of $V_o - M_V = 12.47$, which would suggest similar distance with respect to the other clusters. Another discordant value is that of Bochum 11 by FitzGerald & Mehta (1987), who obtained $V_o - M_V = 12.70$, indicating a slightly farther aggregate.

2. SPECTRAL TYPES

The number of stars for each O-subtype in each open cluster is presented in Table 4. In the last column the total number of O-type stars for each cluster is also given.

The two brightest and most spectacular open clusters: Tr 16 and Cr 228 with 22 O-stars in each one of them, contain the largest concentration of O-type stars in the Galaxy. Following these two is Tr 14 with nine O-type stars. Moreover, Tr 16 is the only one with four O3-type stars, then Tr 14 follows with one double O3-type star. In Collinder 228 three stars of spectral type O5 are present.

If we take into account the spectral classification of the brightest stars, the open clusters Tr 16 and Tr 14 appear to be the youngest open clusters in the Galaxy, and of course the two with most massive stars.

Tr 15 and Bo 11 have both later O-type stars, but the first one has also a M-supergiant. Also a red giant star classified as K2 III appears to belong to Bochum 10.

Table 3. Photometric Data of the Open Clusters

Open cluster	$E(B-V)$	$m_o - M_V$	$d(kpc)$	age (10^6 yr)	References
NGC 3293	0.3v	11.99	2.50	5	Turner et al. (1980)
	...	12.1	2.6	7	Feinstein et al. (1980)
	0.31v	12.08	2.6	...	Feast (1958)
	...	11.9	...	...	Shobrook (1983)
NGC 3324	0.47	12.47	3.12	2.2	Clariá (1977)
Bochum 10	0.35	12.8	3.6	7	Feinstein (1981)
	0.37	12.21	2.51	7	FitzGerald et al. (1987)
Trumpler 15	0.48	12.1	2.6	6	Feinstein et al. (1980)
	...	12.14	...	...	Morrell et al. (1988)
Trumpler 14	...	12.26	...	...	Walborn (1982)
	0.55	12.20	2.7	5	Feinstein (1983)
	...	12.99	...	...	Morrell et al. (1988)
	...	12.55	...	3	Massey et al. (1993)
Collinder 228	0.4	12.0 (I)	2.5	5	Feinstein et al. (1976)
	...	12.6 (II)	...	...	Feinstein et al. (1976)
	...	...	2.5	...	Thé et al. (1980)
	...	12.06	2.6	...	Levato et al. (1981)
Trumpler 16	0.4v	12.12	2.65	3	Feinstein et al. (1973)
	...	11.98	...	...	Thé et al. (1980)
	...	12.12	...	3	Feinstein (1982)
	...	11.8	2.3	...	Levato et al. (1982)
	...	12.1	...	...	Walborn (1982)
	...	12.55	...	3	Massey et al. (1993)
Bochum 11	0.59	12.70	...	3	FitzGerald et al. (1987)
Tr 14, 15, 16, Cr 228		12.17	2.7	...	Turner et al. (1980)
Tr 14, 16		12.55	...	3	Massey et al. (1993)
all open clusters		11.9	2.4	...	Tapia et al. (1988)

3. HR DIAGRAMS

The observed color-magnitude diagrams of the six open clusters in the Carina region: Bochum 10 and 11, Collinder 228 and Trumpler 14, 15 and 16 are presented in Figure 4, and the observed color-color diagrams of the same clusters in Figure 5.

The CM diagrams show clearly that the interstellar absorption is very similar up to Tr 14, 15 and 16, but slightly smaller for Collinder 228. However, in this last one the distribution of observations have larger dispersion which suggests a variable interstellar absorption inside the open cluster. This fact appears also in Tr 16, but in a smaller amount.

Bochum 10 shows a similar interstellar absorption (A_V) as Collinder 228, and the same appears to be the

Table 4. Number of O-and WR-type Stars in the Open Clusters of the Carina Region[a]

open cluster	WR	O3	O4	O5	O6	O7	O8	O9	O?	total O-type stars
NGC 3293	...	...	...	...	...	1?	...	...	...	1
NGC 3324	...	...	...	...	1	...	1	...	...	2
Bo 10	...	...	...	...	...	...	...	1	...	1
Tr 15	...	...	...	...	...	...	...	4	1	5
Tr 14	...	1d	1	...	1	1	1	3	...	9
Cr 228	1	...	...	3	4	4	4	6(1d)	...	22
Tr 16	1	4	1	3	2	4	3	5	...	22
Bo 11	...	...	1	...	...	...	...	4	...	5

[a] d = double star

Table 5. Total Mass of each Open Cluster

Open cluster	solar mass units	reference
NGC 3293	559	...
NGC 3324	220	Clariá 1977
Bochum 10	153	...
Trumpler 15	480	...
Trumpler 14	478	...
Collinder 228	1363	...
Trumpler 16	883	...
Bochum 11	242	...
Total mass	= 4377 solar masses	
Total mass without NGC 3293 and 3324	= 3596 solar masses	

case for NGC 3293. On the other hand Bochum 11 and NGC 3324 (Figure 6), with about the same color excess, have larger values of A_V in comparison to Trumpler clusters.

None of all the clusters display a clear stellar evolutionary sequence. The color-magnitude and color-color diagrams including all stars of Collinder 228 and Tr 14, 15 and 16 are presented in Figure 7. Finally similar diagrams are presented for only Tr 14, 15 and 16 (Figure 8)

4. MASSES OF THE OPEN CLUSTERS

For each member star of all these clusters we have computed the mass using the available data, that is the absolute magnitude and intrinsic color index. The masses are derived through the transformation to bolometric magnitude and luminosity, comparing observations with the Maeder & Meynet (1988) evolutionary tracks. The results are given in Table 5. In the particular case of NGC 3324 the data was taken from Clariá (1977). A program to compute the mass values was developed by Baume et al. (1995). From Table 5 the total mass for the open clusters in the Carina region results about 4377 solar masses.

From a slightly different approach, using the tables of the bolometric corrections and effective temperature calibration (Schmidt-Kaler 1982), a total mass of about 4500 solar masses was obtained.

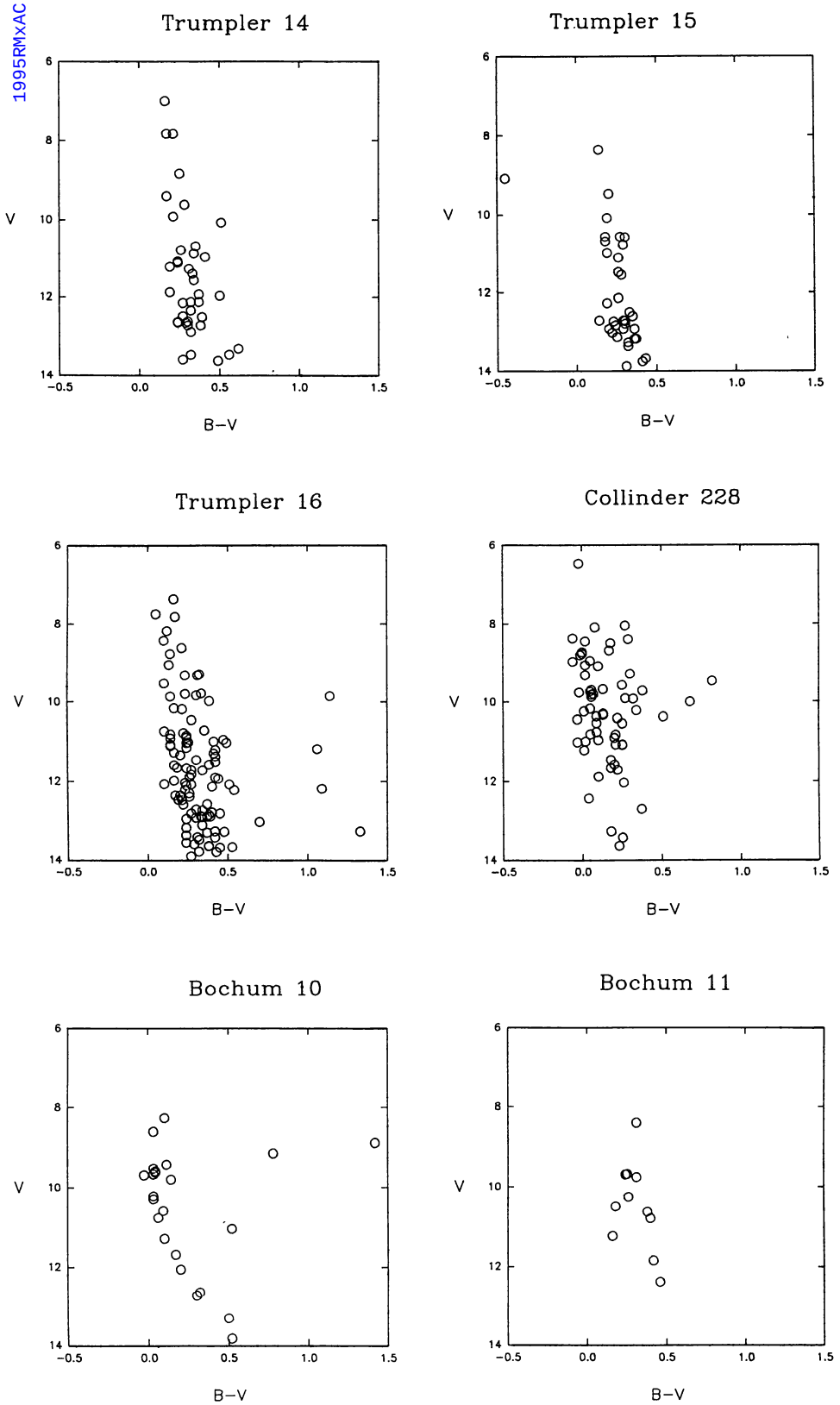

Fig. 4. Observed (V, $B-V$) diagrams of open clusters in the Carina region.

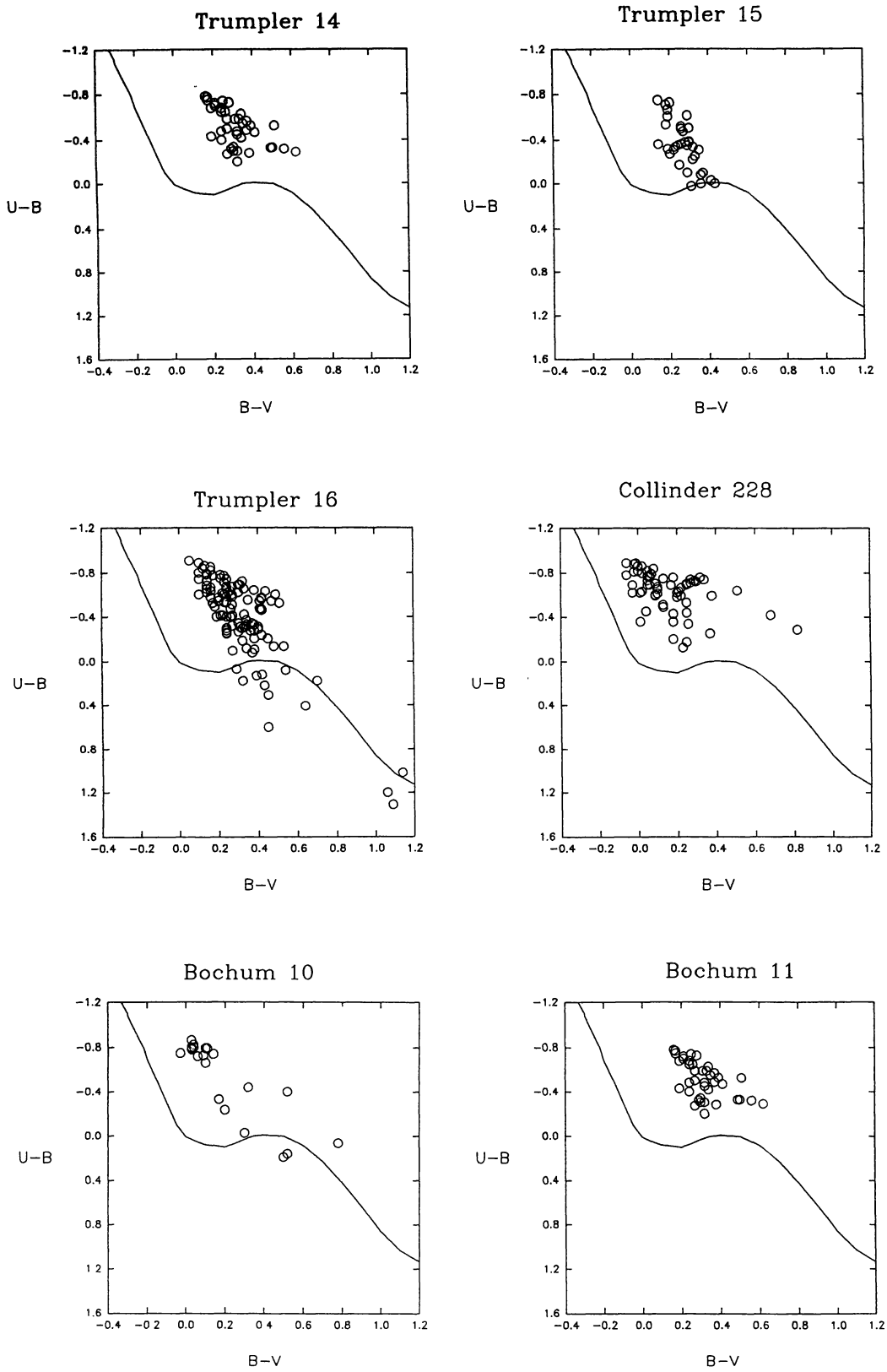

Fig. 5. Observed color-color diagrams of the open clusters in the Carina region.

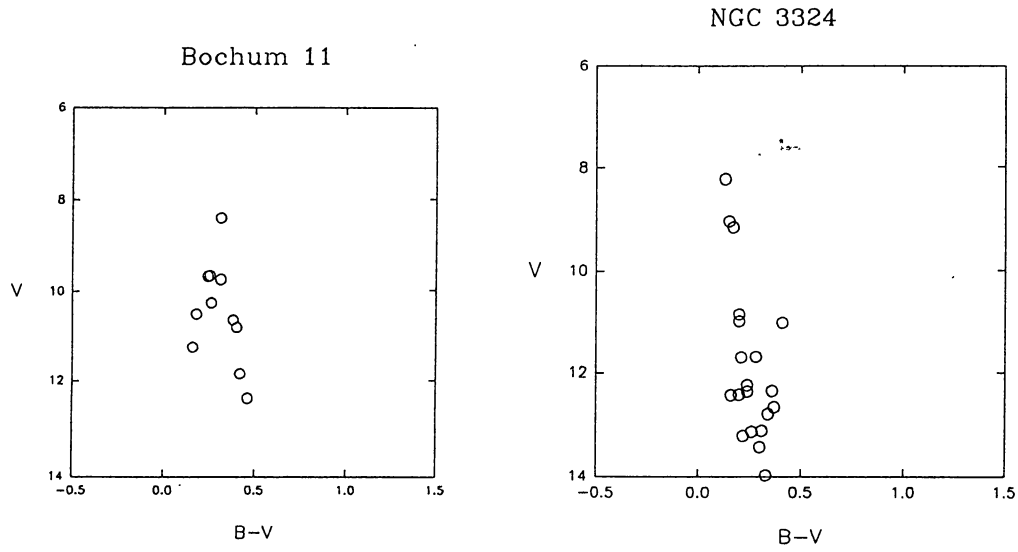

Fig. 6. Color-magnitude diagrams for Bochum 11 and NGC 3324.

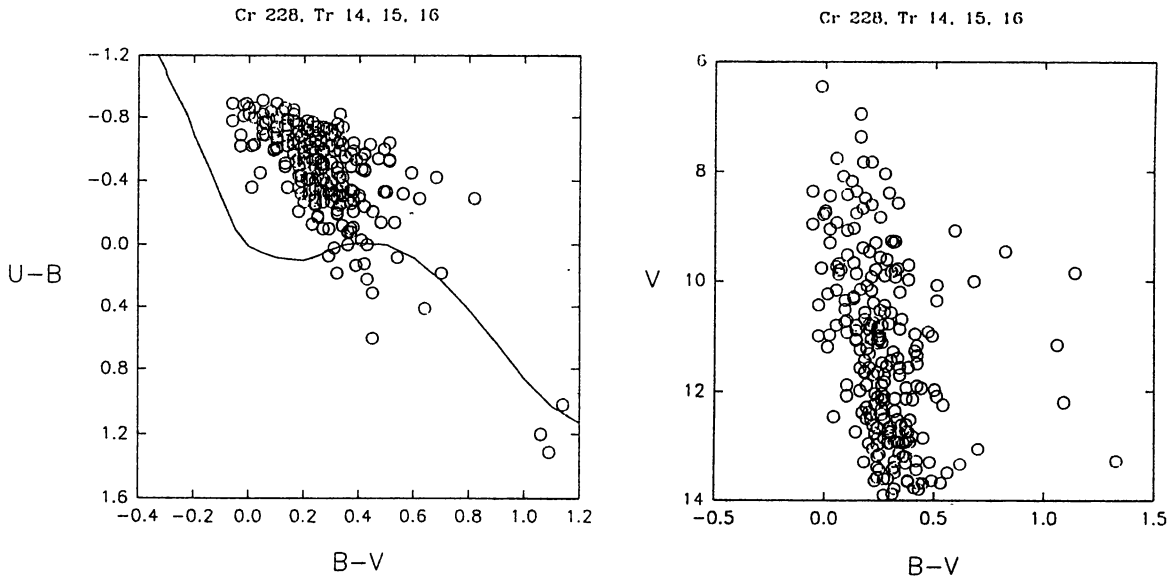

Fig. 7. Color-color and color-magnitude diagrams including all stars of Collinder 228 and Tr 14, 15 and 16.

5. ETA CARINAE OBJECT AND THE OPEN CLUSTER TR 16

The relation of the peculiar object Eta Carinae to the H II region and specially with the open cluster Tr 16 is a very interesting point. If it belongs to Tr 16, it must be very massive. Many years ago Feinstein (1963), published a paper with a color-magnitude diagram of the cluster with the probable location of this object in relation to the surrounding stars. It was concluded that the absolute magnitude would be about $M_V = -7.0$ with an intrinsic color of $(B-V)_o = 0.18$; then it would be similar to a F-supergiant, but with a large ultraviolet excess.

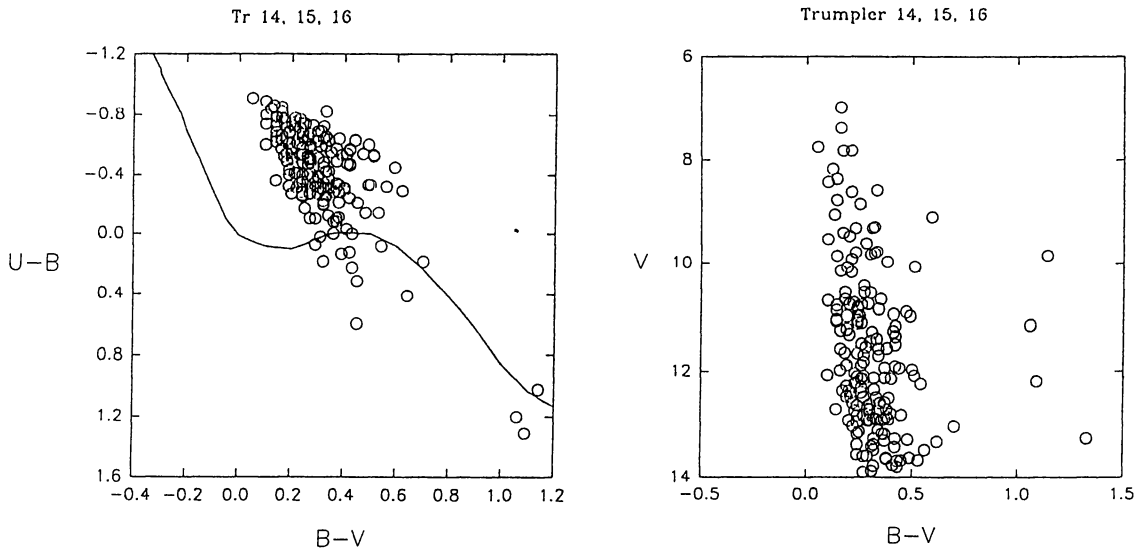

Fig. 8. Color-color and color-magnitude diagrams for stars in Tr 14, 15 and 16.

Recently Massey & Johnson (1993) discussed again the position of this star in their HR diagram. The position in their diagram suggests an object of about 85 solar masses, according to the evolutionary tracks of Maeder & Meynet (1988).

6. AGES

In all the open clusters the brightest stars are located in the ZAMS, therefore it appears quite difficult to detect differences in ages among them. Trumpler 16 is the cluster with most O3-type stars, therefore without doubt it is very young. However, on the other hand, Tr 14 appears to be the most compact group of them all; then it may also be quite young. None of these two aggregates shows a clear evolutionary sequence. Then, how to decide which one is the youngest? Perhaps the answer could be reached finding the stars which are still in the contracting stage. This could be done observing fainter stars photometrically with a CCD, similarly to what Massey & Johnson (1993) did recently, but with higher spatial resolution. But, of course, then the problem of deciding which are the member stars would add another difficulty.

7. FORMATION OF OPEN CLUSTERS

From the distribution of the young open clusters it appears difficult to accept the sequential formation of the open clusters in the Carina region. The three open clusters in the center of the nebula, Tr 16, Tr 14 and Cr 228 must be the youngest aggregates. At each extreme of this structure Bo 10, Tr 15 and Bo 11 are located (see Fig. 3), which may be not so young comparing them with the central ones. The other two clusters, NGC 3293 and 3324, slightly farther, are older than those in the central region of the nebula.

The formation of this structure has to be checked with a very precise determination of the ages of each of all the open clusters located in the main part of the nebula. As the youngest open clusters are in the center of this structure, perhaps the formation of the open clusters began at what it is right now the borders of the nebula and following toward the center of it.

8. SUMMARY

The giant H II region NGC 3372 in the Carina region includes at least 8 young open clusters. It appears to be one of the youngest structures known in the Milky Way, as it has 64 O-type stars in a region of about 40 pcs of diameter if the distance modulus ranges from 12.0 to 12.5. The most luminous stars are immersed in the brightest portion of the nebula. The structure is located in the outer part of the Saggitarius arm, and it is fairly easy to observe optically, due to the low value of the interstellar absorption in this direction.

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