ASTRONOMIA EN LAS CATACUMBAS: ESTRELLAS CON PECULIARIDADES ESPECTRALES COMO MIEMBROS DE CUMULOS ABIERTOS

ASTRONOMY IN THE CATACOMBS: STARS WITH SPECTRAL PECULIARITIES AS MEMBERS OF OPEN CLUSTERS

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RESUMEN: Las estrellas con líneas de emisión de tipos Of, WR y Be son analizadas como miembros de cúmulos abiertos de acuerdo a sus datos fotométricos. De una detallada discusión se encuentra que entre las estrellas más luminosas, los objetos de tipo Of son más comunes que las estrellas WR entre los miembros más brillantes de los cúmulos abiertos. Entre 10% y 30% de las estrellas WR son miembros de cúmulos abiertos. Los cúmulos con estrellas Of tienen sus estrellas brillantes más luminosas que los que poseen estrellas WR. Con respecto a las estrellas Be, están fuera de la secuencia principal; los excesos de color en E(B-V) del material circunestelar llegan a ser en casos extremos hasta de 0,3 magnitudes.

ABSTRACT: The emission-line Of-, WR- and Be-type stars as members of open clusters are analyzed in particular related to their photometric data. It is found that among the high-luminosity objects, the Of stars are the more common stars among the brightest members of open clusters. About 10% to 30 % of the WR stars are members of open clusters. Those clusters with Of stars have much brighter apparent magnitude stars than those with WR-type stars. Concerning the Be stars, mostly are situated away of the main sequence; their color excesses E(B-V) of the circumstellar envelope is up to 0.3 magnitudes in extreme cases

1. Introduction

Most stars in galactic open clusters have normal spectral types according to the MK system, that is membership stars have absorption lines with no peculiar characteristics. However, in a few cases some stars display emission lines, suggesting the presence of a circumstellar material around them.

We will refer here to these kind of stars located in the upper part of the main sequence (MS): stars with masses greater than $10\mathfrak{M}_\odot$. On the other hand, there are also stars with emission-line spectra in the lower MS (less than $1\mathfrak{M}_\odot$), which we will not discuss in this review.

Stars with emission-line spectra in the upper MS includes: Of stars, Wolf-Rayet stars (WR) and Be stars. The first two are hot and luminous objects, and among the brightest members in young open clusters. A certain number of O-type stars with emission only in the H lines, at least Hα, but no emission in N III or other lines, have been defined as Oe stars (Conti and Leeop, 1974). A few other O-type stars have a P-Cygni profile in the emission lines, that is a shortward displaced absorption component and a more or less undisplaced emission component (Walborn, 1973).

In next paragraphs we will discuss each type of stars related to the open clusters where they are members. It is important to notice that the best method to derive information of the characteristics of all those stars is to study the relation to the cluster where each one is located.

2. Of-type stars: characteristics.

The high temperature O-type stars are characterized by an optical absorption-type spectrum in which the lines of the hydrogen Balmer series, He I, He II and ions of C, N O and Si are visible. But the O-type stars have a subset called Of-type which have λ 4686 He II, and usually accompanied by Hα emission. The emission is interpreted as an indication of a presence of a high velocity stellar wind. Walborn (1971) employed these emission features as a luminosity discriminator. Depending on the λ 4634-40 NIII emission, the Of-stars are classified as O((f)), O(f) and Of, whether λ 4686 He II is in absorption, filled in, or in emission.

This classification of the Of-stars depends very much on the dispersion employed. Besides this, Walborn (1972, 1973) in a series of papers defined another type of Of stars having other emission lines as λ 4057 NIV, and λ 4089, 4116 Si IV. Also a few other O-type stars with emission in the Balmer lines are related to the Be stars (Conti and Leep, 1974).

In a catalogue of 765 O-type stars (Garmany, Conti and Chiosi, 1982), only 74 stars are classified as known very early type stars. However these numbers may be changed with a more detailed spectroscopic research in fainter O-type stars.

3. Of-type stars in open clusters.

In a compilation of the Of-type in young open clusters, Feinstein, Vazquez an Benvenuto (1986) analyzed the photometric and spectroscopic data for 54 Of-stars belonging to 21 open clusters. It was found that all then are high-luminosity objects but slightly evolved from the ZAMS. Also, it appears that these objects are quite common in young open clusters, but more difficult to detect than the Wolf-Rayet stars.

The UBV data give us the possibility to check the position of the Of-stars in the photometric diagrams. In this way they are plotted in the first diagram the observed (B-V) color versus the (U-B) color (Figure 1) for the Of stars. It becomes very clear that all them are in the same reddening line, which means that they have nearly the same intrinsic color indices $(B-V)_o$ and $(U-B)_o$. These values are in a range between -0.30 and -0.33 for $(B-V)_o$, and between -1.06 and -1.20 for the $(U-B)_o$. Therefore, the mean values for all Of stars result, $<(B-V)_o> = -0.32 \pm 0.015$ and $<(U-B)_o> = -1.155 \pm 0.054$. In Figure 2 the intrinsic color index versus the magnitude absolute diagram is presented.

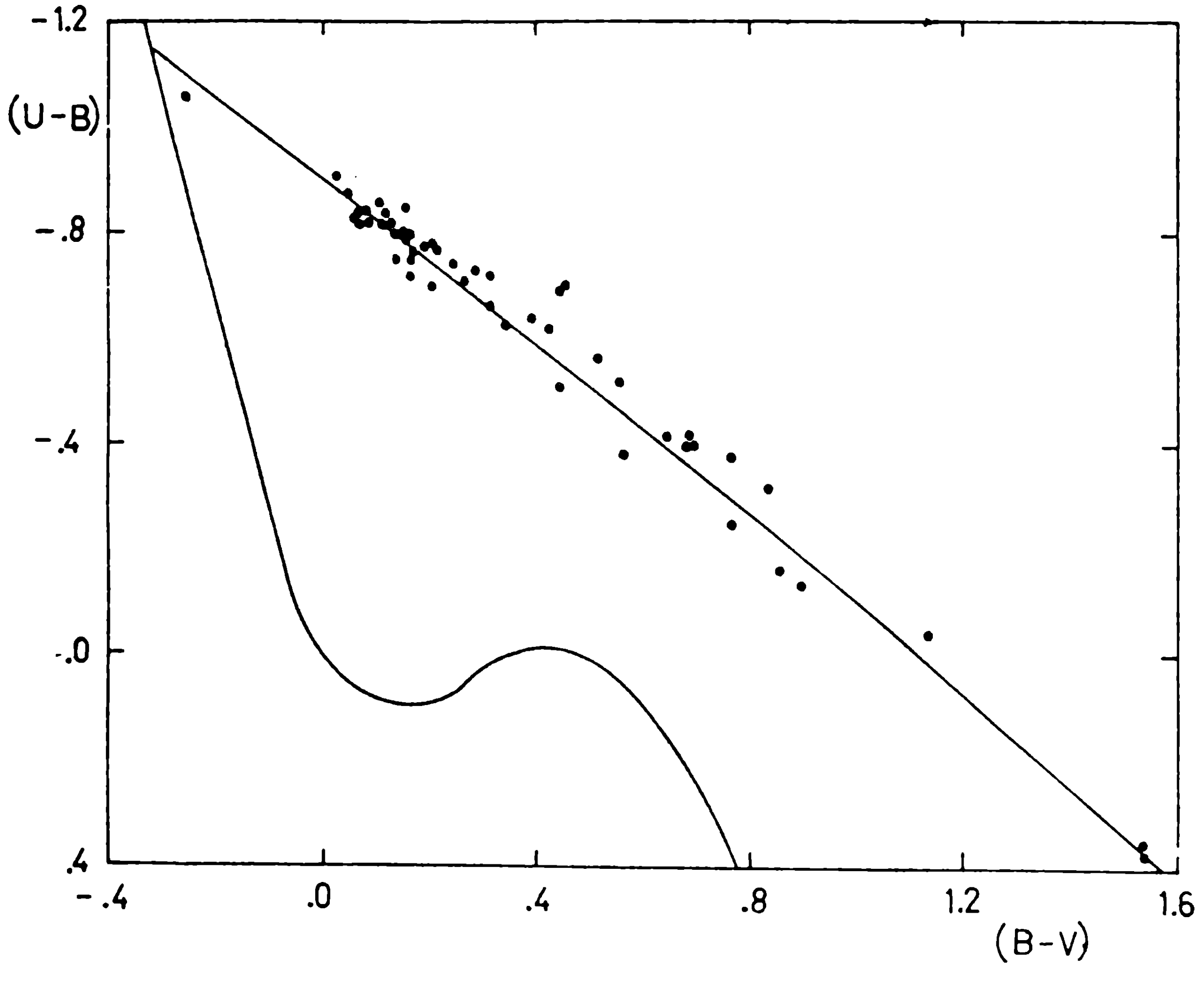

Figure 1: The observed color indices (B-V) versus (U-B) diagram for the Of stars belonging to open clusters. The location of the ZAMS and the standard reddening line for early-type stars are also indicated.

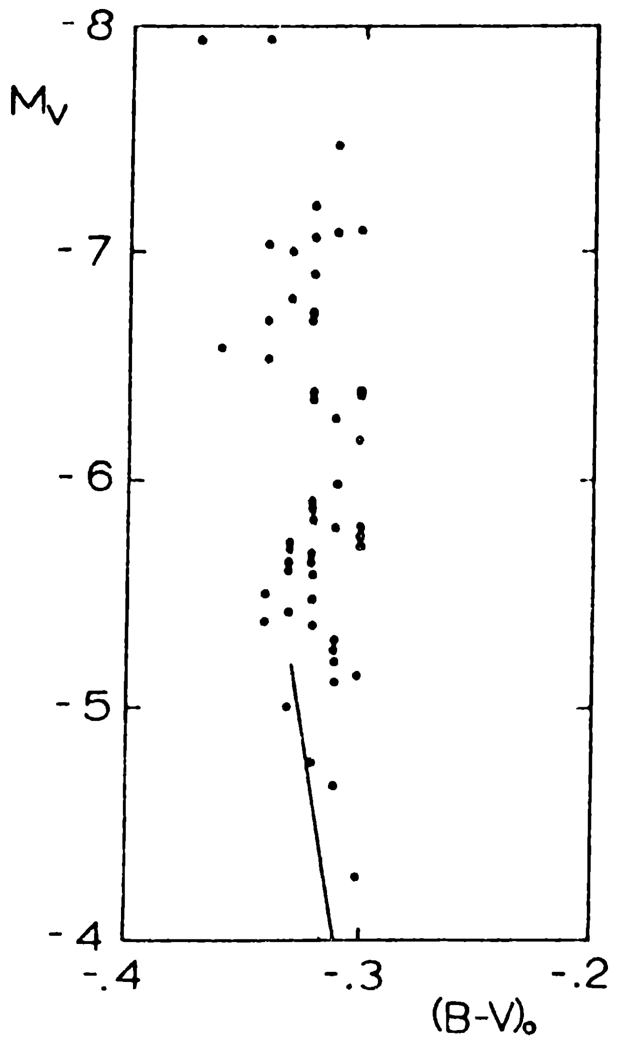

Figure 2: The absolute magnitude M_V versus the intrinsic color index $(B-V)_o$ diagram for Of stars. The ZAMS from Schmidt-Kaler (1982) is also drawn.

In order to compare the location of the Of stars in the HR diagram to the theoretical models for large mass stars, the effective temperature T_{eff} and the bolometric correction BC were computed with the Schmidt-Kaler's tables (1982). In the paper of Feinstein et al. (1986) the log T_{eff} and M_{bol} for Of stars are listed. These values are plotted in Figure 3, where the theoretical ZAMS according to Maeder (1984) is also drawn. Meader computed these models with moderate mass loss. The right border of the main sequence band suggested by Maeder is also indicated. The "wide" of the main sequence depends very much of the initial mass of the stars, and becomes much wider for masses in the range 60 m_o to 120 m_o.

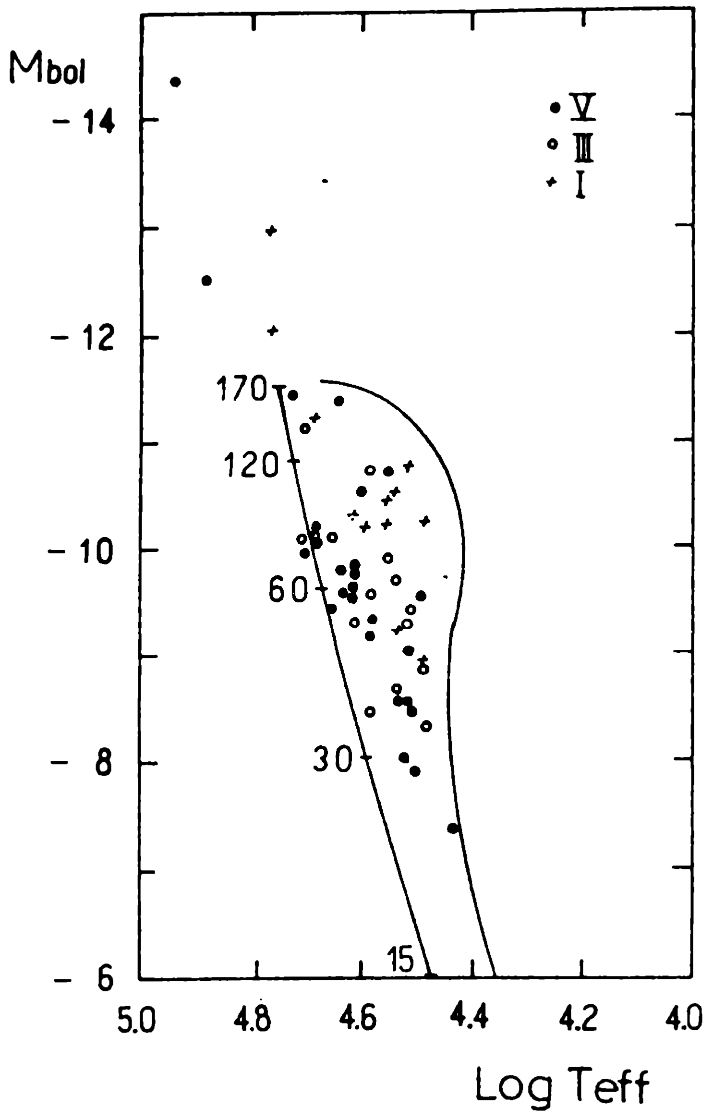

Figure 3: The bolometric absolute magnitude versus the effective temperature diagram for the Of stars. The location of the ZAMS and the masses of the stars on it according to Maeder (1984) are also plotted.

From Figure 3 the masses of the Of stars would correspond to values between 20 and 170 solar masses, if they would be on the main sequence. Mass loss eventually would reduce the star's masses by an amount of 20 to 30%.

The distribution of the Of-stars in the HR diagrams suggests that they have already evolved from the ZAMS (Feinstein et al., 1986), and in all cases the open clusters having stars with Of characteristics should not be older thn 5.5 x 10^6 yr.

It is expected that the number of Of-type stars would increase in the future if spectroscopic research in fainter and bluer open clusters having O stars will be more detailed classified.

Appendix A

Of-type stars as members of open clusters

Cluster	Name	V	B-V	U-B	S. Type
IC1805	15558	7.81	0.52	-0.56	O5III(f)
	15570	8.10	0.70	-0.40	O4If^{+}
	15629	8.42	0.43	-0.62	O5V((f))
IC1848	17505	7.06	0.40	-0.64	O6.5V((f))
	17603	8.45	0.65	-0.42	O7.5Ib(f)
IC2944	101131	7.16	0.05	-0.88	O6V((f))
	101190	7.32	0.06	-0.83	O6V((f))
	101205	6.48	0.07	-0.82	O7IIIn((f))
	101223	8.08	0.17	-0.72	O8V((f))
	101298	8.07	0.09	-0.82	O6V((f))
NGC2244	46150	6.76	0.13	-0.82	O5V((f))
	46223	7.28	0.22	-0.77	O4V((f))
NGC2264	47839	4.67	-0.25	-1.06	O7V((f))
NGC2467	64568	9.39	0.11	-0.86	O3V((f*))
CR228	93130	8.04	0.27	-0.71	O6III(f)
	93222	8.08	0.08	-0.84	O7III((f))
	93632	8.39	0.29	-0.73	O4III(f)
TR14	93128	8.84	0.25	-0.74	O3V((f))
	93129AB	6.97	0.16	-0.78	O3If*
	93160	7.82	0.17	-0.77	O6III(f)
	93161	7.82	0.21	-0.70	O6.5V((f))
	-58°2620	9.40	0.17	-0.75	O6.5V((f))
TR16	93250	7.37	0.16	-0.85	O3V((f))
	303308	8.17	0.12	-0.84	O3V((f))
	-59°2600	8.61	0.21	-0.78	O6V((f))
	-59°2603	8.77	0.14	-0.79	O7V((f))
	112	9.29	0.32	-0.72	O4.5V((f))
TR18	97434	8.08	0.13	-0.82	O7.5III(n)((f))
C1715-387	LSS4067	11.16	1.54	0.37	O4f
	6	11.64	1.54	0.35	O5f
NGC6193	150135	6.89	0.17	-0.80	O6.5V((f))
	150136	5.62	0.16	-0.79	O5III:n(f)
HOGG22	150958	7.29	0.32	-0.66	O6.5Ia(n)f+
NGC6231	151804	5.22	0.07	-0.84	O8Iaf
	152233	6.56	0.14	-0.80	O6III:(f)p
	152248	6.16	0.12	-0.82	O7Ib:(n)(f)p
	152408	5.77	0.14	-0.75	O8:Iafpe
	326331	7.71	0.14	-0.75	O7.5IIIn((f))
NGC6334	156738	9.36	0.90	-0.14	O6.5III(f)
	319699	9.63	0.80	-0.24	O5V((f))
	319702	10.16	0.93	-0.12	O8III((f))
	319703A	10.71	1.14	0.04	O7.5III((f))

Appendix A (cont.)

NGC6530	164794	5.97	0.03	-0.91	O4V((f))
NGC6604	167971	7.50	0.77	-0.38	O8Ib(f)p
	168112	8.52	0.69	-0.40	O5III(f)
NGC6611	168075	8.76	0.45	-0.69	O6V((f))
	168076	8.20	0.46	-0.70	O4V((f))
	-13°4927	9.53	0.84	-0.32	O7Ib(f)
NGC6823	186980	9.97	0.69	-0.42	O7.5III((f))
	+23°3782	9.34	0.56	-0.52	O7V((f))
NGC6871	190429A	6.61	0.16	-0.80	O4If+
	190864	7.76	0.20	-0.78	O6.5III(f)
NGC6913	192639	7.11	0.35	-0.63	O7Ib(f)
	193514	7.38	0.45	-0.51	O7Ib(f)

4- WR stars: characteristics.

The Wolf-Rayet spectra are dominated by strong and broad emission lines. These emission lines correspond to ions of He, N, C and O, on a continuous spectra. They are classified in two groups according to the lines which appeared in the spectra: a) the WN stars in which the emission lines of ions of He and N dominated, and b) the WC stars in which ions of He, C and O are seen. Absorption lines are generally not visible in both types, with the exception of very few WN stars. Both classes, WN and WC, seem to differ in composition from one another, the WN have more N and the WC more C and O, than the other class. Also, these groups can be ordered in sequences with numerical subtypes, but there is no evidence that these sequences correspond to a monotonic change in any physical parameter, like T_{eff} or log g (see Abbott and Conti, 1987).

From the strong emission lines it is expected that these stars have significant mass loss, which suggests that there are in a post main sequence state of evolution, perhaps evolving from a massive star.

5. WR stars in open clusters

An analysis of the WR stars in open clusters and associations was presented by Lundstrom and Stenholm (LS) (1984), who concluded that 10% to 30% of the galactic WR are probably members of open clusters and a larger number are members of OB associations. About 157 WR are classified in our Galaxy (van den Hucht et al., 1988). Their membership to open clusters are not always clear due to the fact that their magnitudes and colors are very much altered by the influence of the strong emission lines, which introduce difficulties in locating them in the color-magnitude diagram. A narrow-band photometric system, defined specially for these stars, has been started to apply by Smith (1968), and later by other authors. With this method it is possible to derive their intrinsic parameters.

LS listed 15 WR stars as members or probably members of open clusters, but this number increased to about 21 WR in a more recent paper of van den Hucht et al. (1988). However, there are a few more which would be dubious members of open clusters.

Comparing in Figure 4 the open clusters having Of stars with those with WR stars, those clusters with Of stars have much brighter apparent magnitude stars than clusters with WR stars. Therefore, it becomes evident that the young open clusters with WR stars, but without Of objects have more interstellar absorption than those having both type of stars, or only Of objects. This could be explained by a selection effect due to the difficulty of detecting Of stars in faint or more distant clusters. It appears obvious that stars with WR characteristics are easier to found, as their emission lines are stronger and wider than the weak emission lines of the Of stars. Furthermore, our results suggest that Of stars might be more numerous than WR objects. It may be possible than clusters showing only WR objects might have also Of stars as members, but they would be not easy to discover.

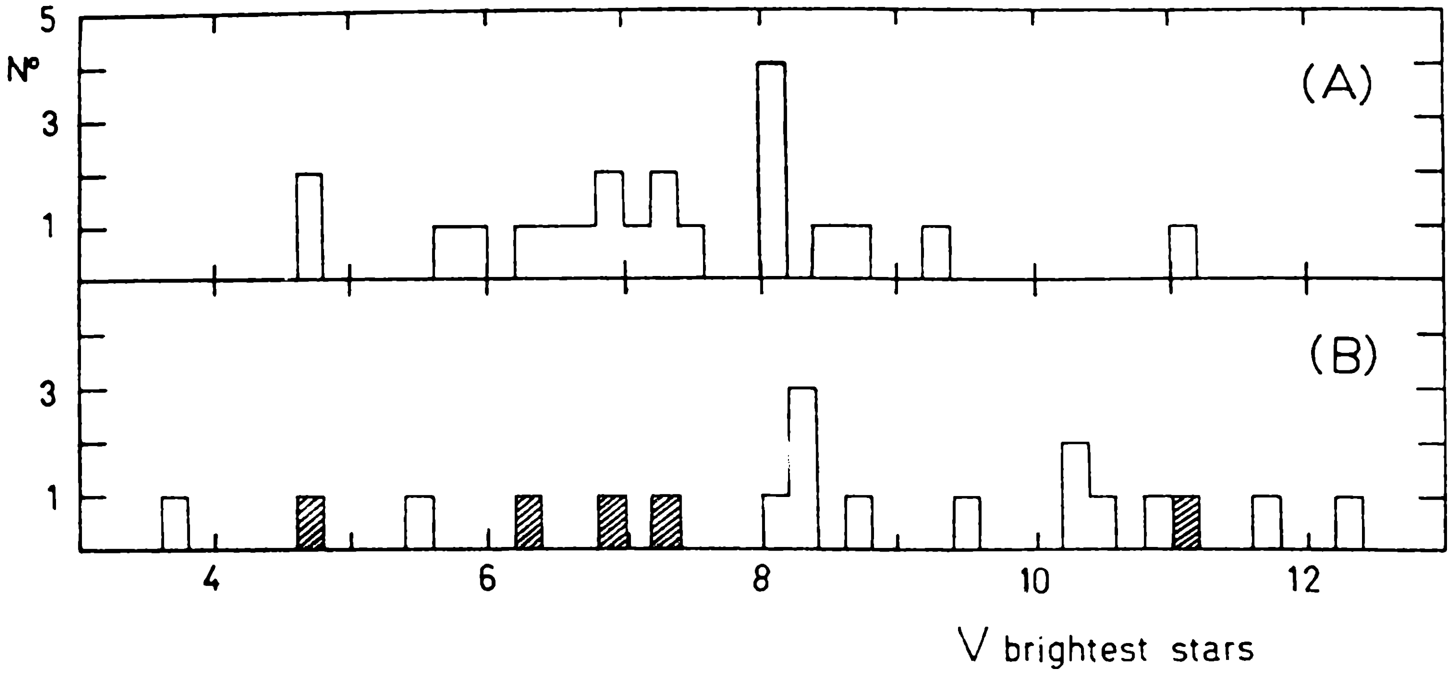

Figure 4: a) Histogram of the apparent visual magnitude of the brightest star of open clusters with Of. b) The same for open clusters with WR stars. Cross-hatched bars indicate clusters having Of and WR stars.

In a composite color-magnitude diagram with the brightest stars of very young open clusters it appears obviously a larger percentage of Of stars in comparison to WR stars (Figure 4).

The process which originate the WR stars has been the subject of many papers. To mention the more recent one, van den Hucht et al. (1988) indicated that in general the WR stars descend from O-type stars with initial masses $\mathcal{M} > 25 \mathcal{M}_\odot$, but for the WC stars the progenitors have masses greater, that is $\mathcal{M} > 35 \mathcal{M}_\odot$. These results were confirmed by Vazquez and Feinstein (1989), who found that late WN and late WC stars have initial masses greater than 50 $\mathcal{M}_\odot$, while the early WN objects preferentially result from less massive stars. In conclusion, the WR phase would be one stage of evolution for stars more massive than 40-50 $\mathcal{M}_\odot$, being the Of-objects a possible transition phase.

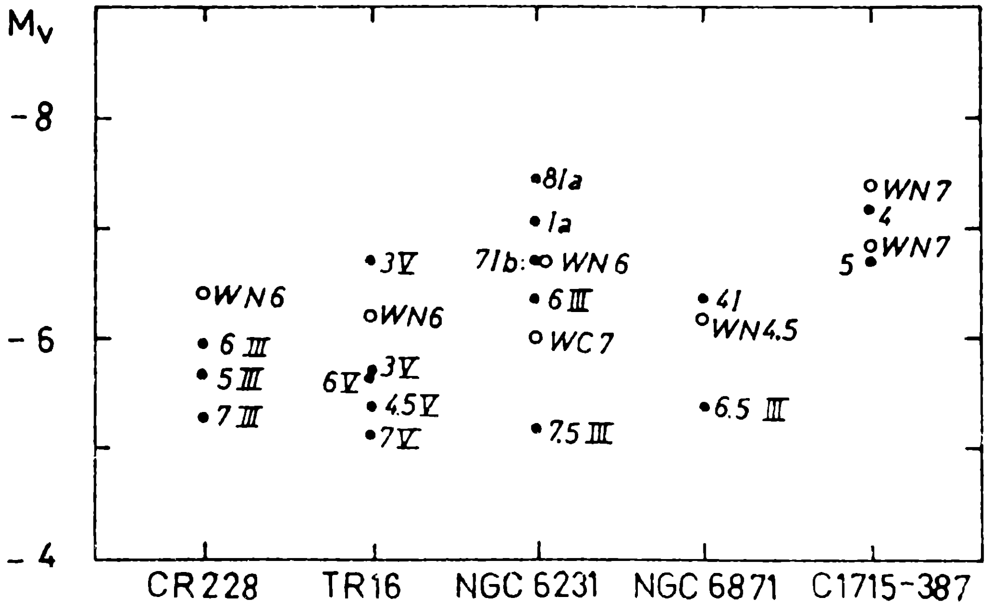

Figure 5: The absolute magnitudes of Of and WR stars belonging to open clusters with both types of objects. The letter O is not included for the Of stars.

6. Be-type stars: characteristics.

The Be-type stars are defined as "non-supergiants stars of spectral type B which display at some times hydrogen lines in emission" (Collins, 1987). The Balmer line Hα is the strongest emission line, but in the cases when this line is very strong, also are seen in emission the Hβ and Hт lines. These stars display sometimes irregular variations in the structure of the line profiles as much as in the intensity of the emission, which sometimes disappears. These photometric variations are displayed in short and long time scales. All these phenomena can be interpreted by changes in the continuum energy distribution of its circumstellar envelope. The presence of this material around the star can be explained by either one or both of the following causes: a) evolutionary effects of stars being in the core-contraction stage of the evolutionary phase following the hydrogen exhaustion of the core, b) stars which rotates very rapid, near the critical velocity at which centrifugal force balances gravitational attraction. The measurement of rotation velocities in Be stars confirms that many are rotating very fast.

The survey of the field Be stars indicates a greater maximum distribution at spectral type B2 (Jaschek et al., 1983), and another smaller one at about spectral type B7-8. Some emission-line O- and A-type stars are assumed to be associated to this group of stars.

7. Be-type stars in open clusters.

A list of 121 Be-type stars belonging to 50 open clusters has been compiled (Appendix C). All they have photometric UBV data and spectral types in the MK system. In this list are only included stars which were classified as being on the main sequence or very near it according to the definition of Be stars.

The distance modulus and the mean color excess for each cluster where the Be stars are assumed to be members allow us to obtain the absolute magnitude and the intrinsic color indices of each Be star.

Appendix B

WR stars in open clusters

Cluster	Name	Classification
Cr 121	HD 50896	WC6
Ru 44	HD 65865	WN4.5+OB
Cr 173	HD 68273	WC8 + O9I
Bo 7	CD-454482	WN7
Bo 10	HD 92809	WC6
Cr 228	HD 93131	WN7+a
Tr 16	HD 93162	WN7+a
NGC 3603	HD 97950	WN6+O5
Hogg 15	HDE 311884	WN6+O5V
C1309/10-624	G305IRS44	WC8
Pi 20	LSS 3329	WN6
NGC 6231	HD 151932	WN7
	HD 152270	WC7+O5-8
C1715-387	LSS 4065	WN7
	LSS 4064	WN7
Pi24	HD 157504	WC7+O7-9
Tr 27	LSS 4261	WN7+WC7
	105	WC9
Bo 14	Ve2-45	WC9
Do 33	Vy1-3	WN7
NGC 6871	HD 190918	WN4.5+O9.5Ib:
Be 86	HD 193576	WN5+O6
Be 87	St 3	WO2
Ma 50	HD 219460	WN4.5+B1III

Appendix C

Be stars with UBV data as members of open clusters

Cluster	Star	V	B-V	U-B	Spec.Type	Remarks
NGC 457	13	11.29	0.28	-0.49		
	128	9.83	0.38	-0.54	B6 Ve	-57°248
	153	9.49	0.26	-0.55	B0 IVe	-57°243
	238689	9.47	0.29	-0.42	B1.5 Vpe	-57°240
NGC 581	87	11.35	0.26	-0.39	B3 V	
	178	10.04	0.19	-0.58		
	76	11.48	0.22	-0.30		
NGC 663	141	10.65	0.65	-0.34	B0 Vne	
NGC 869	309	9.62	0.32	-0.70	B1 IIIe	56°484
(h Persei)	566	9.62	0.19	-0.66	B1 Vpe	56°493
NGC 884	1702	9.30	0.46	-0.56	B1.5 IIIe	56°548
(chi Per)	2088	9.45	0.32	-0.65	B1.5 Vne	56°583
	14422	9.03	0.50	-0.65	B1 Vpe	56°565
	2165	8.66	0.40	-0.62	B1 Vne	56°566
	2284	9.66	0.40	-0.59	B1 Vne	56°573
NGC 957	4	9.86	0.58	-0.32	B1 V	56°657
	7	11.13	0.66	-0.38	B3 V	
	11	11.90	0.54	-0.28		
TR 2	18080	8.38	0.28	-0.06	B7 V	
NGC 1893	43	11.53	0.14	-0.68		
Alfa Per	21551	5.83	-0.03	-0.33	B7 V no em.	HR1051
	22192	4.23	-0.06	-0.58	B5 IIIe-shell	
	25940	4.04	-0.02	-0.58	B4 Ve	MX Per
Pleiades	23302	3.71	-0.11	-0.41	B6 IIIe	17 Tau
	23480	4.18	-0.06	-0.43	B6 IVe	23 Tau
	23630	2.87	-0.09	-0.34	B7 IIIe	Eta Tau
	23862	5.09	-0.08	-0.28	B8(V)e-shell	Pleione BU Tau
NGC 1960	34°1113	9.23	0.05	-0.69	B2 (III)e	
(M36)	245483	8.63	0.02	-0.73	B2 (III)e	33°1103
NGC 2244	33	11.95	0.34	-0.25	B6 Vne	
CR 121	48917	5.29	-0.13	-0.92	B2 Ve around	FT CMa
	58978	5.64	-0.12	-1.05	B0 IVpe around	FY CMa
NGC 2421	LSS579	11.48	0.24	-0.40	B7:	
	SS141	10.91	0.31	-0.32		
	SS142	12.24	0.26	-0.36		
NGC 2422	60855	5.68	-0.13	-0.74	B2 IV:e	
NGC 2439	6	10.48	0.21	-0.61		
	83	11.29	0.21	-0.27		
	81	11.30	0.15	-0.58		
NGC 2451	61925	5.99	-0.04	-0.45	B5 IIIne	
NGC 2453	40	12.88	0.38	-0.38	B5 (V)e	
RU 44	LS885	10.98:	0.34:	-0.62	B0 Ve far fr. nucl.	-21°5154
NGC 2516	66194	5.76	-0.09	-0.80	B2 Vne	
	65663	6.77	0.00	-0.27	B7 V	Cox A
	60.868	9.01	0.02	-0.09	(B9p)	COX 41
NGC 3105	7	13.25	0.99	0.42	B2:e	
IC 2581	302840	9.80	0.20	-0.62	B0.5 Ve	No.4
	302842	9.60	0.27	-0.70	B1 Ve	No.7
	90187	8.81:	0.25	-0.75:	B1 IIne	LSS 1524
NGC 3293	303075	9.90	0.13	-0.82	B1 IVne backgr.?	-57°3490
	32	12.87	0.20	-0.16	B8 Ve	
Tr 15	93190	8.58	0.33	-0.82	B0:IV:pe	
Cr 228	305515	10.35	0.09	-0.59	B1.5 V sn	Fe 44
	305533	10.32	0.13	-0.51	B0.5:Vnn+shell	Fe 7
Tr 16	5	10.83	0.24	-0.67	B2:Vn +weak shell ?	

NGC 3766	100856	8.58	0.01	-0.81	B2 IVp(e)		
	-60.3157	8.56	0.07	-0.63	B2 III		
	-60.3125	9.06	-0.07	-0.60	B2 IVne		
	-60.3128	8.46	-0.04	-0.64	B2 IV-V		LSS 2400
	-60.3149	10.33	0.03	-0.50	B4 Vne		
	-60.3126	9.26	0.01	-0.61	B1.5 Vn		
	-60.3122	10.00	0.04	-0.21	Be npe	shell	
	306797	9.58	0.00	-0.58	B5		
	306798	9.45	-0.01	-0.62	B2 V		
IC 2944	308819	10.08	0.14	-0.22	B9 p(e)		
STOCK 14	101794	8.67	0.04	-0.76	B0.5 IVne		
NGC 4103	-60.3743	9.19	0.21	-0.70	B0: e	small beta	
NGC 4463	108719	8.41	0.21	-0.63	B III e?		
NGC 4755	-59.4531	10.82	0.18	-0.56	Bnn		
	-59.4540	9.58	0.22	-0.59			
	-59.4546	9.73	0.22	-0.72	B2 IVne		
	-59.4553	9.72	0.20	-0.63	B1.5 pne		
	-59.4558	10.04	0.13	-0.61	B1 V		
	-59.4559	9.88	0.22	-0.65	B2 IVne		
	II-24	10.31	0.16	-0.62	B0 V		BV Cru
NGC 5168	-60.4735	10.36	0.13	-0.40	B III e?		
NGC 5281	119682	7.98	0.13	-0.88	e?		
NGC 6025	143448	7.30	-0.05	-0.76	B3 IVe		-60°6348
NGC 6087	14	9.70	0.09	-0.26	B8 Ve	small beta	-57°7791
NGC 6167	330950	9.49	0.51	-0.51	B1 Ve		
NGC 6231	226327	9.74	0.27	-0.60	B1.5 IVe-shell		
NGC 6383	317861	9.83	0.24	-0.40	Be:Vne		
	24	11.35	0.18	-0.25	B8 VNe		
NGC 6530	152	10.51	0.11	-0.58	B3 Ve		
(M 8)	315032	9.18	0.04	-0.75	B2 Vne		161
	315023	10.08	0.15	-0.64	B2.5 Ve		W55
	-24°13829	9.03	0.10	-0.71	B1.5 Vne		176
	-24°13830	9.86	0.18	-0.65	B2 Ve		180
	184	9.66	0.07	-0.66	B1 Ve		
	W61	10.29	0.12	-0.61	B2 Ve		
	164906	7.42	0.16	-0.76	B0 IV pne		193
	-24°13831	10.14	0.11	-0.65	B2 Vpe		192
	197	10.45	0.15	-0.61	B2 Ve		
	202	10.69	0.10	-0.56	B2.5 Ve		
	315024	9.56	0.06	-0.78	B2.5 Ve		204
	-24°13837	9.39	0.07	-0.72	B1 Ve		W80
	210	10.49	0.13	-0.61	B2.5 Vne		
	-24°13840	9.75	0.16	-0.58	B2 Vne		215
	-24°13844	10.81	0.09	-0.52	B2.5 Vne		230
	164947	8.88	0.06	-0.56	B2 IVe		W100
	315095	10.81	0.25	-0.45	B2.5 Ve		256
NGC 6611	210	11.41	0.49	-0.58	B1.5 V(e)		
	-13°4928	9.94	0.60	-0.50	B0.5 Vne		280
	351	11.30	0.46	-0.56	B1 Vne		
	503	9.83	0.50	-0.72	B0e		
IC 4725	-19°6889	10.16	0.43	-0.18	B7 Vne		44
NGC 6709	10	10.88	0.19	-0.08	B9: V(e)		
NGC 6823	8	11.84	0.75	-0.29	B0 V:pe		
	E4	10.42	0.78	-0.30	B0 IVe		
NGC 6830	345105	10.44	0.38	-0.15	B6 IVe		
NGC 6871	227611	8.82	0.35	-0.70	B0pe		35°3950
TR 37	239712	8.56	0.44	-0.35	B3 Vnpe		57°2354
	57°2358	10.12	0.33	-0.33	B3 Vnnpe		
	206773	6.79	0.22	-0.84	B0 Vnnpe		57°2374
	57°2376	9.74	0.30	-0.38	B2.5 Vpnne		
	239758	9.50	0.24	-0.57	B2 IV:nnep		58°2320
NGC 7160	208392	7.04	0.26	-0.56	B1 IV		EM Cep
NGC 7380	4	10.19	0.40	-0.12	B6 Vne		57°2615
NGC 7654	778	11.90	0.56	-0.02	Be		
	930	11.57	0.51	-0.11	Be		
	989	11.85	0.41	-0.06			

Then, in the observed color-color diagram (Figure 6) are plotted all the Be stars (Feinstein, 1987), which shows clearly that with a few exceptions all are located away of the main sequence. On the other hand, in the intrinsic color-color diagram (Figure 7), many stars are situated to the right of the main sequence suggesting an additional reddening besides that of the cluster in which it is member. In an intrinsic color $(B-V)_0$ versus absolute magnitude M_v diagram (Figure 8), most of the stars are also to the right of the main sequence band. However, a few are to the left which may be due to various facts: a) errors in the measurements due to the contamination from a bright nebula in the field of the star, or b) wrong corrections of the color indices or perhaps, c) very blue open clusters with stars having abnormal intrinsic colors.

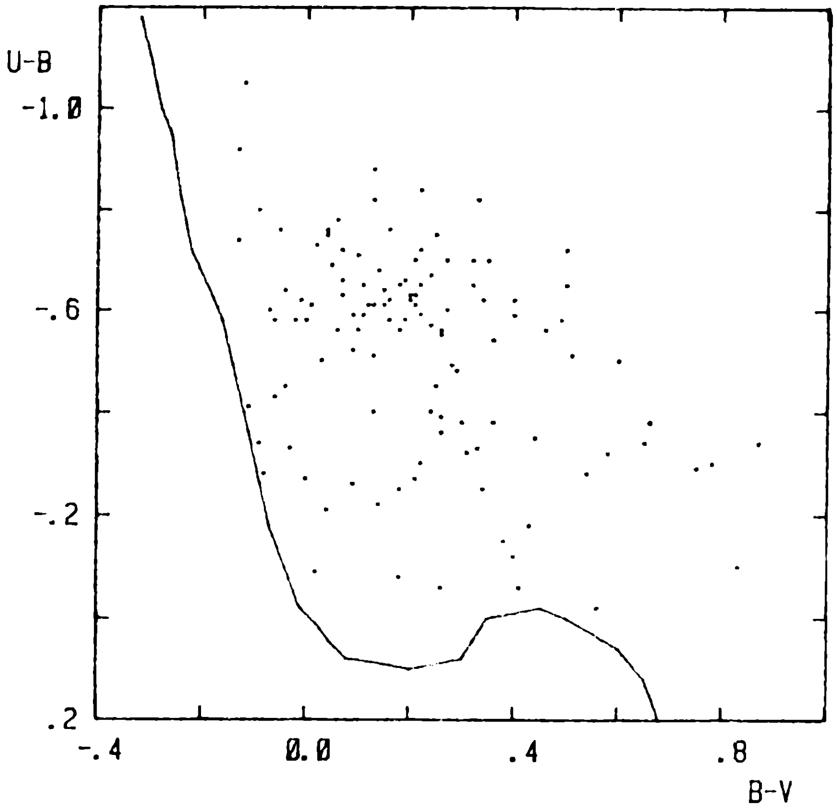

Figure 6: The observed two-color indices diagram for the Be stars in open clusters.

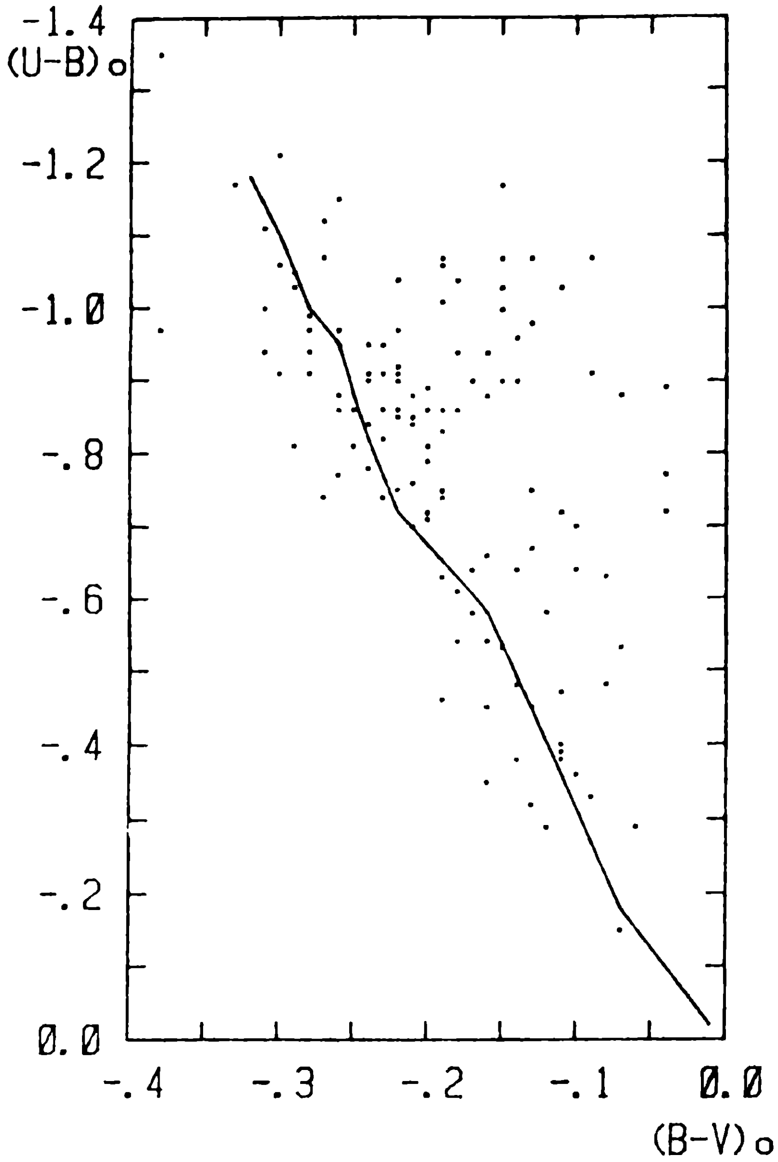

Figure 7: The intrinsic two-color indices diagram for the Be stars in open clusters using values derived from the cluster data.

The additional color excesses for the stars to the right of the main sequence are assumed to be due to their circumstellar envelopes. Some of the more luminous stars are in the range up to 0.3 magnitudes farther in $(B-V)_o$ from the main sequence. It seems that the higher the absolute magnitude, the larger is the possible range in the color excess E(B-V) due to the circumstellar material. The same conclusion becomes evident in the $(U-B)_o$ versus M_v diagram (Figure 9).

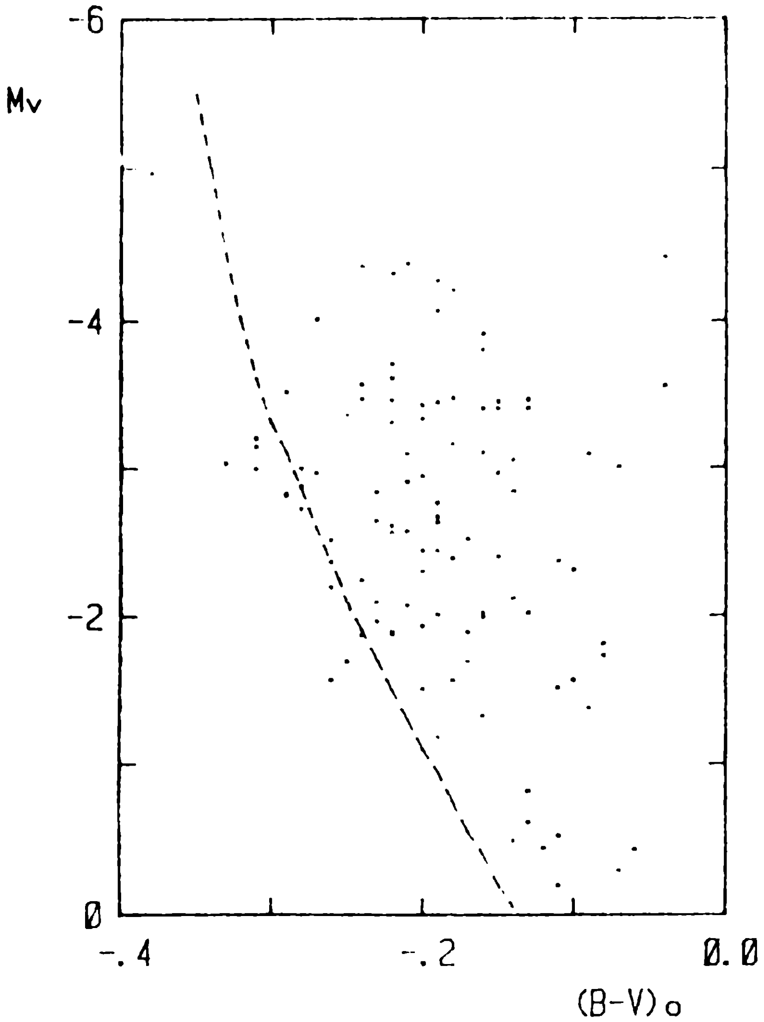

Figure 8: The intrinsic color-absolute magnitude diagram of Be stars belonging to open clusters. The ZAMS of Schmidt-Kaler (1982) is also included.

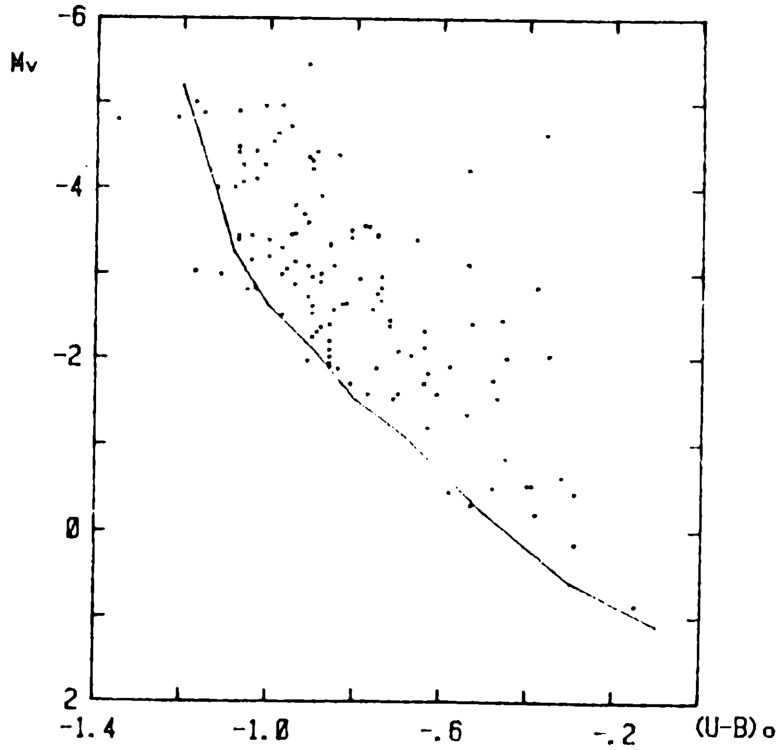

Figure 9: The intrinsic color-absolute magnitude diagram of Be stars belonging to open clusters. The ZAMS of Schmidt-Kaler (1982) is also included.

In Figure 10 is plotted the histogram of the number of Be stars in open clusters according to the age of the cluster where these stars are located. The ages listed by Lyngå (1985) were employed. It is found that a maximum distribution corresponds to ages about log t = 7.4, that is t = 2.5 x 10^7 years old, but clusters from 10^6 to 10^8 years old have Be stars. The particular case of the young open cluster NGC 6530 with the largest number or bright Be stars is also indicated in the same figure.

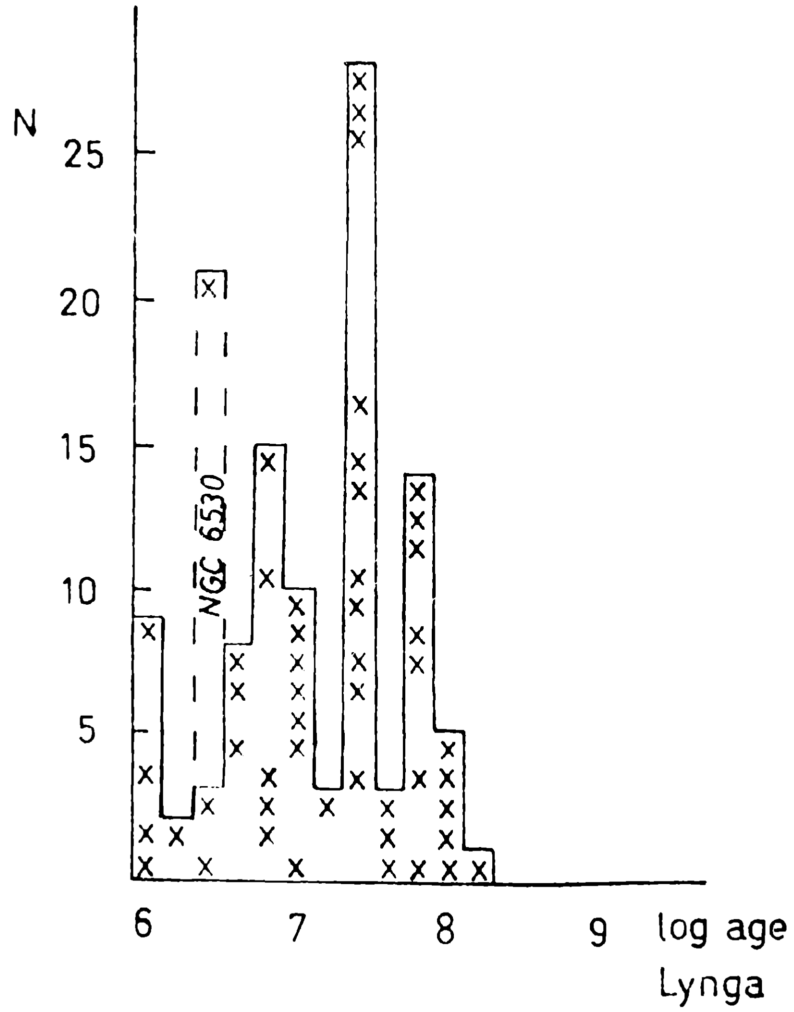

Figure 10: The number of Be stars in open clusters according to the age of the cluster (Lynga, 1985).

8. Conclusion

From the above analysis of the Of, WR and Be stars, all they appear to be related with some state of the stars during their evolution away from the main sequence.

In Figure 11 are plotted all the bright stars which are members of open clusters, and with absolute magnitudes Mv < -5.5. The O-type stars are plotted by a number which gives the sub class corresponding to the O-type. In the same figure the WR stars are underlined, and the Of-stars are inside a square. A few Be-type stars are encircled. The location of the ZAMS (Vazquez, 1989) is also drawn.

All the O, the WR and Of stars have intrinsic color indices smaller than $(B-V)_o = -0.3$. Mostly of the very bright stars, Mv < -6.5 are of Of-type. Consequently, the Of stars would be the more common objects among the very bright stars. Also it becomes clear that these objects are nearby the ZAMS, indicating that they are the result of some processes produced after the stars leave the main sequence, or perhaps coming back from the red stage. The location of the WR stars is more difficult tho explain as the intrinsic UBV colors and magnitudes are affected by the strong emission lines.

In conclusion, the Of- and WR-types are spectral classifications assigned to very hot and luminous stars with emission lines, but in different evolutionary states. On the other hand, the Be-type corresponds to less luminous stars with smaller temperatures. It would be interesting to know if these types of emission-line stars are whether different aspects of the same phenomenon or different kind of conditions in the stars themselves.

Appendix A listtes all the Of stars which are assumed to be members of open clusters at the time this paper os written (February 1990). The WR stars are included in Appendix B and the Be stars in Appendix C.

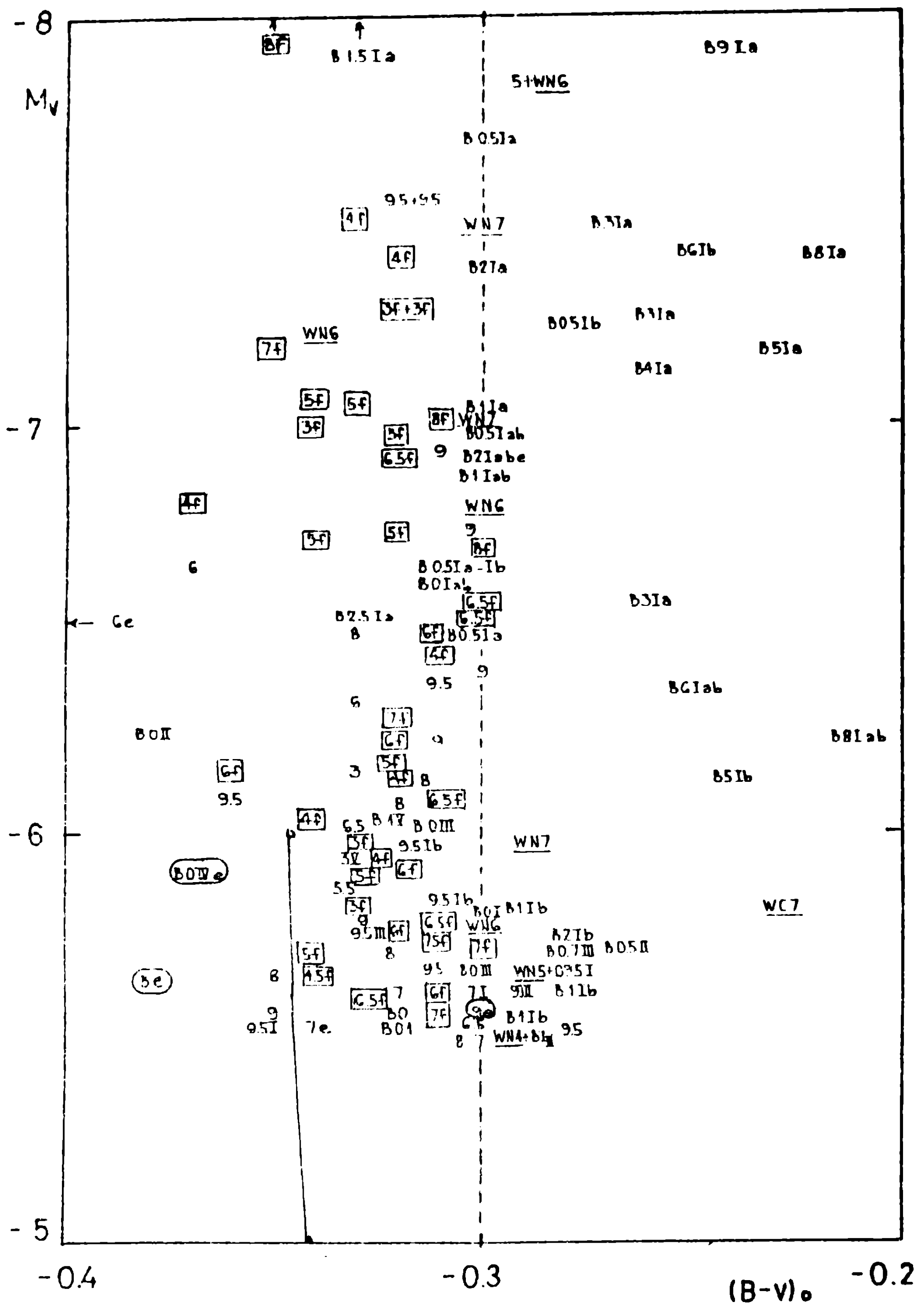

Figure 11: The intrinsic color-absolute magnitude diagram for stars in open clusters brighter than M_V = -5.5 and with MK spectral types. The O-type stars have not included the letter O. For Of stars the spectral type is shown within a square; the WR stars are underlined and Be stars are encircled. The ZAMS from Vazquez (1989) is also drawn.

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