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THE YOUNG OPEN CLUSTERS IN THE GALAXY

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RESUMEN

Se presenta una lista de 42 cúmulos abiertos jóvenes ubicados en la Galaxia. El plan consiste en analizar su distribución y características. Cuarenta de estos cúmulos tienen estrellas de tipo espectral O, lo que indica que sus edades no son mayores de 10 millones de años. Se detectan claramente 3 brazos espirales con una separación de aproximadamente 2 kpc entre ellos. Una notable concentración de cúmulos en la región de Carina posee el mayor número de estrellas de tipo O. Las estrellas de campo de tipos espectrales O y WR muestran una distribución similar comparadas con el mismo tipo de estrellas ubicadas en los cúmulos estelares jóvenes.

ABSTRACT

We are presenting a list of 42 young open clusters located in the Galaxy. The plan is to analyze their distribution and characteristics. Forty of those clusters have O-type stars, which means that their ages are not older than 10 million years. Three spiral arms with a separation among them of about 2 kpc are shown very clearly. A large concentration of clusters in the Carina region has the largest number of O-type stars. Field O and WR stars show the same distribution as compared with the same type stars in young open clusters.

Key words: **OPEN CLUSTERS AND ASSOCIATIONS: GENERAL — GALAXY: STRUCTURE — STARS: WOLF-RAYET — STARS: EARLY–TYPE**

1. INTRODUCTION

It has been well known for about 40 years that young open clusters let us figure out the location of the ›iral arms of the Galaxy. For several decades many open clusters were observed photoelectrically and are now ›ing observed with the new CCD techniques. Many details about them have been determined: especially their stances, color excesses, composition of the member stars and their evolutionary conditions, which indicate their ;es: from 10^6 to 10^9 years. This would suggest that the formation of these structures followed continuously om just near the birth of the Milky Way up to now.

During the last 15 years we have had a program to observe open clusters, especially those with an age about 10^7 years, at La Plata. It is well known that those with ages less than ten million years would be lequate to analyze their distribution, and particularly some of their characteristics in relation to the Galaxy. hus, all this will allow us to know something more about galactic structure.

2. DATA

We have selected all those clusters with ages not greater than 10^7 years from the literature and our list observed clusters. To do this we have chosen those having O-type stars to assure that they are very young. wo open clusters that do not contain O-type stars are also included, as they almost fulfill the condition we ıve established about age.

We have listed 42 open clusters (see Table 1). The first column quotes the name, the second and third ›lumns give the coordinates: right ascension and galactic longitude respectively; the fourth and fifth columns

Table 1. List of Young Open Clusters

Name	l	d (kpc)	$E(B-V)$	V	$(M_V - M_0)$	Stars O	Stars Of	Stars WR	Stars Be
NGC 6530	6	1.9	0.36	5.93	11.4	2	1	...	18
NGC 6611	12	2.6	0.79	8.20	12.1	8	3	...	4
NGC 6604	18	2.1	0.96	6.0	11.6	6	2	...	...
NGC 6823	59	2.3	0.80	9.37	11.8	5	2	...	2
NGC 6871	72	1.9	0.46	5.6	11.4	2	2	...	1
Be 87	75	0.95	1.35	9.05	9.9	1	...	...	1
NGC 6913	76	1.5	0.78	8.80	10.85	5	2	...	2
Tr 37	89	0.95	0.54	7.4	9.9	4	...	...	5
IC 1805	134	2.4	0.80	8.1	11.9	10	3	...	...
NGC 884	135	2.2	0.59	9.08	11.7	1	...	...	5
IC 1848	137	2.3	0.72	...	11.8	2	2	...	...
NGC 1502	143	0.96	0.75	7.0	...	1	...	...	...
NGC 1893	173	4.0	0.55	9.10	...	6	...	...	1
NGC 2169	195	0.83	0.18	8.1	9.60	...	...	...	...
NGC 2264	203	0.95	0.62	8.0	9.85	1	1	...	...
NGC 2244	206	1.67	0.48	7.2	11.11	6	5	...	1
NGC 2362	238	2.4	0.10	6.5	11.9	1	...	...	...
Ru 44	245	4.5	0.70	11.0	13.22	10	...	1	1
Bo 15	248	3.0	0.54	10.0	12.4	4	...	...	...
NGC 3293	285	2.6	0.3	8.0	12.1	1	...	...	2
NGC 3324	286	3.12	0.47	8.2	12.47	1	...	...	...
Tr 14	287	2.75	0.55	7.0	12.20	5	5	...	...
Tr 15	287	2.6	0.5	7.3	12.1	5	1	...	1
Cr 228	287	2.6	0.4	8.0	12.0	21	3	1	2
Tr 16	287	2.6	0.5	7.4	12.1	20	5	1	1
Cr 240	290	2.42	0.40	7.8	11.92	3	...	...	...
Hogg 10	290	2.8	0.49	7.11	12.24	1	1	...	...
St 13	290	2.9	0.27	8.7	12.3	1	...	...	...
NGC 3603	291	7.2	1.37	11.00	14.29	1	...	3	...
IC 2944	294	2.0	0.26	6.5	11.5	12	...	...	1
St 14	295	2.78	0.26	8.5	12.22		...	...	1
St 16	306	1.90	0.49	8.0	11.39	1	...	...	...
Ps 20	320	3.70	1.28	10.75	12.8	2	...	2	...
NGC 6193	336	1.4	0.2	5.7	10.75	3	2	...	...
Hogg 22	338	2.78	0.66	7.3	12.22	1	1	...	...
NGC 6231	343	1.6	0.44	5.2	11.0	11	5	1	1
NGC 6322	345	1.26	0.67	7.5	10.5	2	...	...	...
Ps 24		353	2.09	1.76	10.43	11.6	1	...	...
NGC 6334	351	1.74	1.0	8.07	11.20	5	4	...	...
Tr 27	355	2.0	1.35	10.7	11.5	3	...	2	...
NGC 6383	355	1.4	0.33	5.7	...	1	...	...	2
C1715-387	355	2.9	1.85	11.16	12.3	4	2	2	...

list the distance in kpc and the color excess respectively. The apparent magnitude of the brightest star and th distance modulus are presented in the sixth and seventh columns. The number of O, Of, WR and Be-type star in each cluster are in the last four columns.

The most important value we need for our analysis is the distance to each cluster. For distance value smaller than 3 kpc, the error might be small, perhaps no more than 10%, but for larger distances there ar severe discordances among observers. Such is the case for the clusters Ru 44 and NGC 3603, which show ver large discrepancies in the literature. For Ru 44, Moffat & FitzGerald (1974) and FitzGerald & Moffat (1976 assign $d = 6.6$ and 6.8 kpc, respectively. However, Turner (1981) lists a different value for its distance: $d = 4.$ kpc.

The situation for NGC 3603 becomes worse as we can see in Table 2. The last determination (Moffat 1983) s probably the most precise derivation of its distance, so we adopt this value, but the large so we adopt this ʼalue, but the large discrepancy in the distance values has to be kept in mind.

Table 2. Distances to NGC 3603

d (kpc)	Reference
3.5	Sher (1965)
5.7	Becker & Fenkart (1971)
8.1	Moffat (1974)
7.2	van den Bergh (1976)
7.0	Moffat (1983)

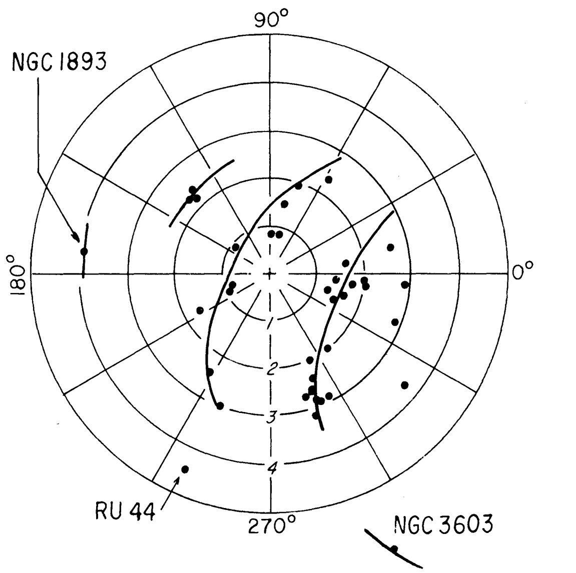
3. DISCUSSION

In Figure 1 the position of all these open clusters is plotted according to their galactic longitude and istance. We drew lines through the location of the points to suggest the position of the center of each of ıe spiral arms. Clearly there are three distributions of clusters displayed: one on the inner side of the Sun Sagittarius-Carina arm), other on the outer side (Orion arm), and a third one at a larger distance from the alactic center (Perseus arm).

The positions of the two clusters cited above: Ru 44 and NGC 3603, are not obviously correlated with ıe location of the other clusters. However, if Ru 44 is at a distance of d = 4.5 kpc, it may belong to the ırther arm: the Perseus arm. The other distant open cluster, NGC 3603, would be at the inner arm: the agittarius-Carina arm, if we assume that the distance of about 7 kpc is correct. Both are the most distant oung open clusters in our list.

It is interesting to mention that the cluster NGC 1893, at a distance of 4 kpc, appears beyond the last two uter arms. Is this an indication of another spiral arm?

The separation of the main lines drawn between the inner and the outer arm is about 2 kpc, and may be naller between the two outer arms. From the distribution of clusters in each arm their width is of about 1 pc, or perhaps less. The Sun seems to be located about 1.5 kpc from the center of the inner arm, and 0.5 kpc ·om the outer arm. Obviously, it is not in any arm.



ʻig. 1. The position of the young open clusters and he spiral arms.

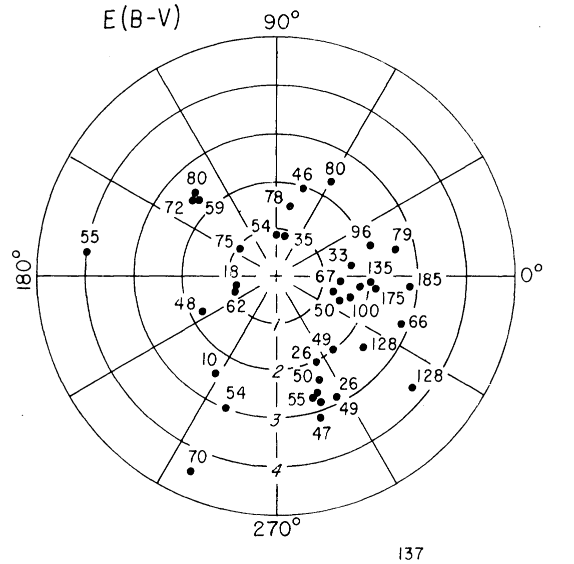


Fig. 2. The color excess (in 0.01 mag) in the position of each open cluster.

There are a few clusters with large color excesses values in the inner arm. They appear to be on the inner edge of the arm, but farther than the width we suggested above. We think that perhaps their distances were overestimated. With these few exceptions all the open clusters are evidently within the three arms.

It is interesting to mention that the WR stars belonging to the open clusters are located mostly in the inner arm of the Milky Way, (see Table 1). In the outer region of the Milky Way the number of WR stars decreases. It is also worthwhile to mention that the open clusters with some WR stars are those having a large number of O-type stars.

4. THE EXTINCTION IN THE DIRECTION OF THE CLUSTERS

In Figure 2, the color excess values $E(B-V)$ in units of 0.01 are plotted. It can be seen from this figure that all the open clusters are visible because the absorption up to them is not very large; typically it is smaller than 1 mag. The inner border of the Sagittarius-Carina arm displays color excesses not larger than about half a magnitude. Some clusters behind this border display larger values. That is the case of C1715–387 with $E(B-V) = 1.85$ at $d = 2.9$ kpc, perhaps located nearly the inner border of this arm. But, in another case, Hogg 22, at nearly the same distance, $d = 2.78$ kpc, the color excess is only $E(B-V) = 0.66$.

The distribution of young open clusters confirms that the region between $20° < l < 60°$ is a very difficult one to observe due to its very high interstellar absorption.

All the open clusters in the second arm (Orion arm) have low values of $E(B-V)$. There is one exception, Be 87 with $E(B-V) = 1.35$, considering that its distance is not large, $d = 0.95$ kpc. There is clearly a window in the arm at $l = 135°$, and it is possible to detect three open clusters in the second outer arm. Their $E(B-V)$ values are in the range 0.59 to 0.80, at a distance of $d = 2.3$ kpc. It would very important to check the characteristics of the open cluster cited above, NGC 1893, which at a distance of about 4 kpc and with a small color excess value, $E(B-V) = 0.55$, might be situated in another spiral arm.

The cluster Ru 44 at a distance of $d = 4.5$ kpc appears to be located in the Perseus arm. Thus, with four open clusters located in this arm, its existence is confirmed.

On the other hand, in the Carina region there are about 11 young open clusters at a mean distance of $d = 2.6$ Kpc, all of them having a color excesses of about $E(B-V) = 0.50$. This means that we can see the extremely large young structure in and near the Carina Nebula because the interstellar absorption in this region is evidently very small.

5. O–TYPE STARS

Figure 3 shows the number of O-type stars for each stellar group in the location of each open cluster. Many O-type stars appear in the clusters located in the Perseus arm and in Ru 44. Another large number is also

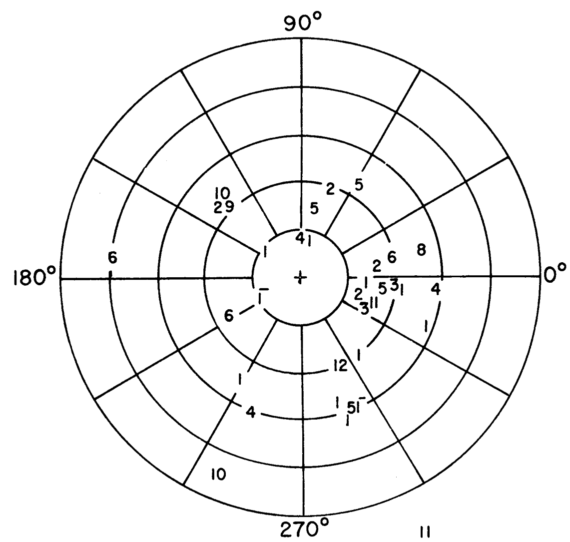


Fig. 3. The number of O-type stars in the location of each open cluster.

·esent in the Carina region of the Sagittarius-Carina arm. In fact, this is the largest grouping of O-type stars ıown. NGC 3603 and NGC 6231 also contain a large number of O stars.

In this context the open clusters that define the Orion arm have few O-type stars in comparison with those the Sagittarius-Carina arm. It also becomes interesting to compare the distribution of young open clusters ith the field O-type stars. From a graph of the distribution of these stars (Figure 4), we discover that there is great accumulation at galactic longitudes 10, 70, 130, 280 and 340°. On the other hand, very few O-stars are ; 40, 150, 220, 270 and 320°. This result is in agreement with that derived from open clusters.

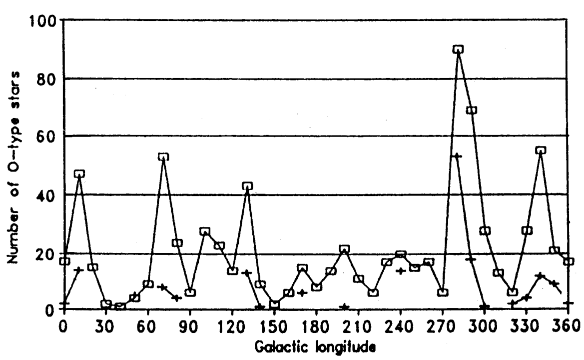
From the distribution of O-type stars, their large number in the first and fourth quadrant —which ıaracterizes the Sagittarius-Carina arm— in comparison with the smaller number at the second and third ıadrant, also becomes clear. The same result is obtained from open clusters with a large number of O-type ars. Thus, in the Orion arm, the number of early-type stars appears smaller than in the Sagittarius-Carina ·m.

The distribution of O-type stars, also displays a high concentration at $l = 280°$. This involves the well-ıown Carina nebula. Here, more than half of the O-stars belong to the young open clusters in the region of ıe nebula. The color excess in this region is quite low, $E(B-V) = 0.5$, considering the large distance at which ıey are located, about $d = 2.6$ kpc. It becomes clear that a discontinuity of the interstellar material of the ›iral arm allows us to detect the Carina region.

It is not obvious from all these data that dust is located in some particular border of the spiral arms. We) not find large systematic differences in the mean color excesses of the young open clusters located in the ıgittarius-Carina and Orion arms.

6. THE WR-TYPE STARS

The WR stars in the field display nearly the same distribution as the field O-type stars (Figure 5). There :e more WR stars in the first and fourth quadrants than in the second and third. Those stars inside open usters follow the same distribution.



'ig. 4. The total number of O-type stars (squares) ,nd those located in open clusters (crosses).

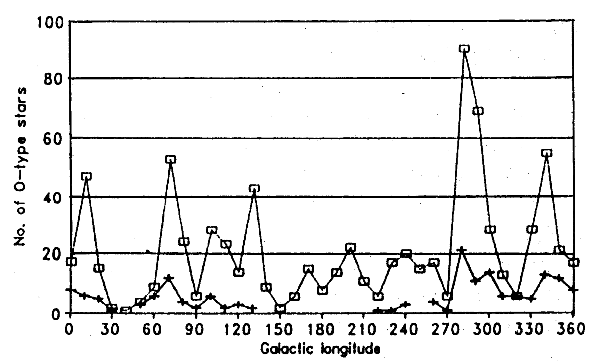


Fig. 5. The total number of O- and WR-type stars (squares and crosses).

7. CONCLUSION

The data available from young open clusters, i.e. those with ages $< 10^7$, lead to the following results:

1. A clear picture of the structure of three spiral arms in the Galaxy is presented. In the direction to the ıner side is located the Sagittarius-Carina arm, and toward the outer side appears the Orion arm, and much ,rther out the Perseus arm.

2. The separation between the centers of the spiral arms is of approximately 2 kpc.

3. The Sun is about 1.5 kpc from the Sagittarius-Carina arm, and about 0.5 kpc from the Orion arm.

4. Clearly there are more young open clusters and more field O-type stars in the inner arm than in the 'rion arm.

5. The number of WR stars in young open clusters and in the field is higher in the Sagittarius-Carina arm than in the Orion arm.

6. The color excesses are not remarkably different in both arms, but some open clusters inside the Sagittarius-Carina arm show large interstellar absorption.

7. The Orion arm appears to be less dense and compact than the Sagittarius-Carina arm from the several windows we can see through.

8. According to the number of O-type stars it becomes clear that the star formation rate is greater in the Sagittarius-Carina arm than in the Orion arm.

In conclusion, a clearer picture of the structure of the Milky Way can be obtained by enriching our information on young objects, particularly open clusters.

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DISCUSSION

Robledo-Rella: Do you think there would be a general trend of massive stars (in clusters) towards the galactic center, or is only a local effect?

Feinstein: There are clearly more O-type stars in the Sagittarius arm than in the Orion arm.

Wing: It will be interesting to compare your results with those of an on-going survey for M-type supergiants described by MacConnell, Wing, & Costa (1992, AJ., 104, 841). In the Carina region we have found M supergiants with distances ranging from 2 to more than 10 kpc and with extinctions A_V averanging from $\sim$ 1 mag to 9-10 mag. There is clearly a lot of dust within the Carina Arm. Do any of your young clusters contain M-type supergiants? They would be very useful for calibration purposes.

Feinstein: In the list of open clusters I presented some of them have M supergiants and I agree with you that these stars will be very useful to follow the structure of the arms.

Garrison: There is a big, black nearby cloud in the direction 250–270°. Until we can penetrate that cloud, I will always be suspicious of pictures of spiral structure. We should plot the spiral structure diagram to a given limiting distance not limiting magnitude. This is a good task for the large telescopes, and modern detectors. We can penetrate the cloud now and we should get rid of those false radial features.

Feinstein: You are right. But I try to get some information about what we know right now and then to investigate some particular regions.

Turner: As one who has worked on WR stars in open clusters, I must point out that there are many WR stars in clusters which you have omitted from your summary. These include Be87 and Be86 in the Cygnus-Orion Arm, Mk 50 in the Perseus arm, and even Ru44, wherever you place it. Could you comment upon your selection of the objects?

Feinstein: I use the list of WR stars which are assumed to be true members of open clusters.

Rosado: I think that it is necessary to complement this study with data on other objects like H II regions which can be detected, at radio wavelengths even behind the dark cloud mentioned by R. Garrison. To my knowledge the pattern is the same and kinematical distances to H II regions agree quite well with photometric ones, except for the Perseus region (1976, Y. Georgelin, Ph. D. Thesis).

Feinstein: It becomes difficult to compare with H II regions because their distances are obtained with stars or clusters, so we will get the same values of the distances.

Roman: a) Do you observe variable extinction within individual clusters? b) Have you investigated selection effects? For example, is the fact that you find color excesses of about $0\overset{m}{.}55$ on the edges of the arms a selection effect?

Feinstein: a) I know that there is variable extinction inside each cluster, but I am interested the value up to the clusters. 2) Yes, it is clear that there are selection effects in the list I present.

Peimbert: Is there a latitude effect associated with the open clusters located in the direction of dust poor windows?

Feinstein: I didn't check the latitude of these objects to know how wide it is in these windows.

Dufour: How does your young cluster distribution, compare with that of H II regions?

Feinstein: The distance of H II regions are obtained by the star or/and open cluster nearby, so you will get more or less the same values.

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