Globular and Open Clusters in our Galaxy

Introduction

By looking at the sky in a clear moonless night through a small telescope or even casual binoculars, it comes out myriads of stars that were not previously suspected just by seeing at naked eye. Patiently searching at random across the starry field, chances are to detect groups of stars that happen to be relatively concentrated together, technically known as stellar clusters.

Visually beautiful as they are, those stellar clusters are always worth observing. But far more important than their simple contemplation, from the analysis and comparative study of star clusters it is possible to obtain information that leads to understand essential stellar topics, such as the structure and the evolution of any single star, not only inside our own Galaxy, but around the whole universe as well.

Stellar clusters

A star cluster is any physically related group of stars that, *having been formed together,* they still remain together due to their *mutual gravitational attraction*. It doesn't mean that the stellar membership of any considered cluster has to remain invariant over the time; *in fact star clusters do lose stars*. But as long as the original group of sibling stars majority remains held together by mutual attraction, those stars are still composing a single entity generically called a cluster.

All clusters have been formed from *giant molecular clouds* of hundreds of solar masses of material that were somehow compressed, emerging a lot of protostars *that began to evolve together.* Each protostar then became a newborn star after completing its own formation process, the more massive ones being the first to reach the steady hydrogen burning stage. Regarding to cluster lifetimes, all their stars *are considered to be of the same age.*

Having been formed from a single common source, all the stars of any particular cluster *must have about the same chemical composition*, which has properly been corroborated by spectroscopy analysis.

Also from spectroscopic studies it has been found out that the entire star population of any cluster *have about the same radial velocity*, which proves that those stars *have kept moving as a single entity since their common origin,* remaining held together by their mutual attraction. Being so far as they are, all the stars belonging to the same cluster *can be roughly considered as being at the same distance from us.*

Summarizing, the term "cluster", no matter kind or particularities, implies that all its star members, even despite great variety of different masses, verify that they have about the same chemical composition and age *due to their common origin*, and about the same radial velocity and distance *due to their still prevailing mutual attraction.*

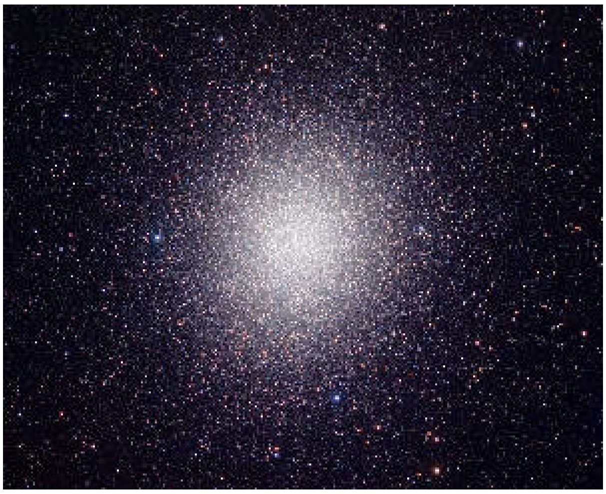

Figure 1
NGC 5139 Omega Centauri (dist = 5,300 pc)

Figure 2
M 45 The Pleiades (dist = 120 pc)

Figure 1 and Figure 2 show two photographs of different clusters in the Milky Way. Each cluster, by definition, must carry out all the common features previously discussed. But from the very first glance it becomes evident that the different optical appearance due to the large disparity in member stars -*and therefore in mass*- must imply quite dissimilar characteristics between those showed clusters.

The cluster at the Figure 1, Omega Centauri, exhibits a spherical gradual increased concentration of a huge number of stars that becomes very compact at its center. This is the typical optical appearance of a particular kind of star clusters, known as "Globular Cluster".

The cluster at the Figure 2, the Pleiades, depicts an irregular and loose group of far less stars, each of them individually distinguishable. This is the typical optical appearance of another type of star clusters ([1]), known as "Open Cluster".

Globular and open clusters are the two major kinds of stellar clusters ([2]), each having its own peculiar characteristics. From the analysis of each type it can be obtain specific and relevant information, which is presented next.

[1] The also observed presence of the inside nebula is characteristic of only young open clusters.
[2] Sometimes very loose open clusters of few members and special characteristics are also considered as a third type of star clusters, called "*stellar associations*" or "*OB associations*"[1].

Globular Clusters in our Galaxy

Figure 3 exhibits another four examples of globular clusters, all Messier objects.

NGC 7089 (M 2) in Aquarius
diameter: 45 pc – distance: 11,500 pc

NGC 5272 (M 3) in Canes Venatici
diameter: 50 pc – distance: 10,400 pc

NGC 5904 (M 5) in Serpens
diameter: 40 pc – distance: 7,500 pc

NGC 6779 (M 56) in Lyra
diameter: 20 pc – distance: 10,100 pc

Figure 3
Examples of Globular Clusters in our Galaxy

As previously said, the unmistakable optical appearance of a globular cluster, which properly accounts for its name, is its distinctive spherical shape. Each globular cluster *is composed by a great number of stars*, typically from ten thousand up to ten million stars, so that the overall contained mass goes from 10^4 to 10^5 solar masses, becoming deeply gravitationally concentrated around its compact center although embracing diameters up to about 100 parsecs [**2**].

The overall number of currently known globular clusters in our Galaxy is about 150. They can be find about anywhere in the celestial sphere, but with a significant concentration towards the Milky Way center, which explains why the constellations of Sagittarius, Ophiuchus and Scorpius solely congregate half of them.

By means of measuring Doppler wavelength shifts of different globular clusters in our Galaxy it has been obtained large radial velocities (between 200 and 400 km/s), revealing that most of them *are moving around the galactic center in highly eccentric elliptical orbits in any possible inclination*, independently from the common Galaxy's disk rotation. Those orbits form some kind of spherical aureole concentrated around our galactic center, known as the "*halo*", but reaching out distances of about 100,000 parsecs, *far outside the dimensions of the Milky Way's disk* [**2**].

The stellar chemical composition of globular clusters invariably shows that the two lightest elements accounts for almost all the matter. As the heavier elements -collectively called *"metals"*- appear far less abundant (about only 3%) than at other stars like our Sun, such stars are said to be "metal-poor" or technically referred to as *"Population II stars"*.

The presence of relatively abundant metal elements is a natural direct consequence of the stellar evolution, so its scarcity implies that globular clusters become from the very first generations of stars formed in our Galaxy. Therefore *all globular clusters must be very old.*

Since all the stars in a cluster are essentially at the same distance, their relative apparent magnitudes also correspond to their relative physical luminosities. Figure 4 depicts the color-magnitude diagram of a typical globular cluster.

As expected, it shows only low-mass (*slowly evolving*) stars remaining at the main-sequence, while all high-mass ex-main-sequence stars have evolved long ago into red giants ([3]). The prominent *horizontal-branch* stars, another sign of old age, appears due to stars that recently experienced the helium flash and now exhibit both core helium burning and shell hydrogen burning, "transiting" towards the red-giant region. Since evolution after ending the main-sequence lifetime imply entering into large-mass-losing processes, by means of evolution or just by birth, *globular clusters only have low-mass stars*.

The age of any cluster can be found from the *turnoff point*, which is the top of the surviving portion of the main-sequence. The stars at that particular point are just now exhausting the hydrogen in their cores*, so their main-sequence lifetime results equal to the age of the cluster*. Therefore the cluster age can be estimated by comparison with theoretical H-R diagrams that follow the changes in stars of various masses with time. Also it allows to look for discrepancies between current stellar evolution theories and reality.

[3] With the only possible exception of the "blue-straggler stars", that is, stars that seemed to be lagging behind the rest of the cluster's members in their evolution. They are supposed to be the product of direct stellar collisions that result in a single star with a mass higher than that for the main sequence turnoff [3].

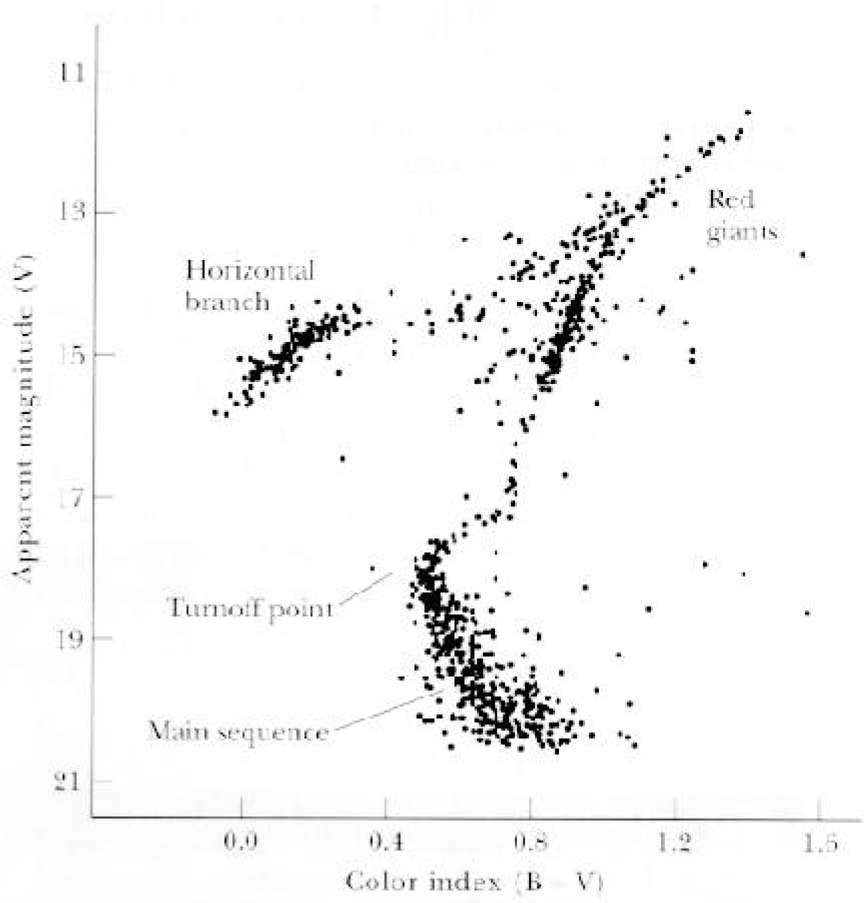

Figure 4
Color-magnitude diagram of a typical globular cluster

Recent analysis have estimated that the age of Milky Way's globular clusters *between 12 to 16 billion years, surprisingly all seeming to be of approximately the same age*, which leads to think that they were all formed in a short period when the whole universe was young [**2**]. Thus the surviving globular clusters *are older than any other structures in our Galaxy* [**4**].

Due to their old age, globular clusters typically contain a large number of white dwarfs and also many variable stars, in particular *RR Lyrae variables* –evolved stars always older than one billion years, found to have roughly the same absolute magnitude ($M_V = 0.6$) and hence *allowing to directly determinate their distances from us*.

Despite their "strong" internal gravitational bound, globular clusters *are disturbed endlessly by galactic tides acting for stripping away their stars*. It is now generally believed that our galaxy's entire stellar halo was produced from disintegrated star clusters along with some dwarfs satellite galaxies. The 150 or so globular surviving today *are probably just a small fraction* of those that once populated the galactic halo [**3**].

Open Clusters in our Galaxy

Figure 5 shows four more examples of open clusters, all of them Messier objects.

NGC 1960 (M 36) in Auriga
60 stars, ext 4 pc, dist 1,100 pc, age 25 Myr

NGC 2099 (M 37) in Auriga
150 stars, ext 7 pc, dist 1,100 pc, age 300Myr

NGC 1912 (M 38) in Auriga
100 stars, ext 5 pc, dist 900 pc, age 220 Myr

NGC 6616 (M 16) in Serpens
ext 4.5 pc, dist 2,200 pc, age 0.8 Myr

Figure 5
Examples of Open Clusters in our Galaxy

Open clusters are groups of stars that also share a common gravitational attraction, but as they posses quite few star members (typically from 20 to less than 1,000) *they barely have enough mass to hold themselves together by gravitation*. Open clusters do not present any defined shape, nor any compact concentration around its center, achieving diameters typically far less than 30 parsecs [**1**].

Over 1,100 open clusters are presently known in our Milky Way, but it is suspected that they could be actually as many as 100,000 [**5**]. They all have been originated from large diffuse nebulae -cosmic gas and dust clouds- *in the disk of our Galaxy.* Since open clusters are usually found in the Milky Way's plane they are also referred as *"galactic clusters"*.

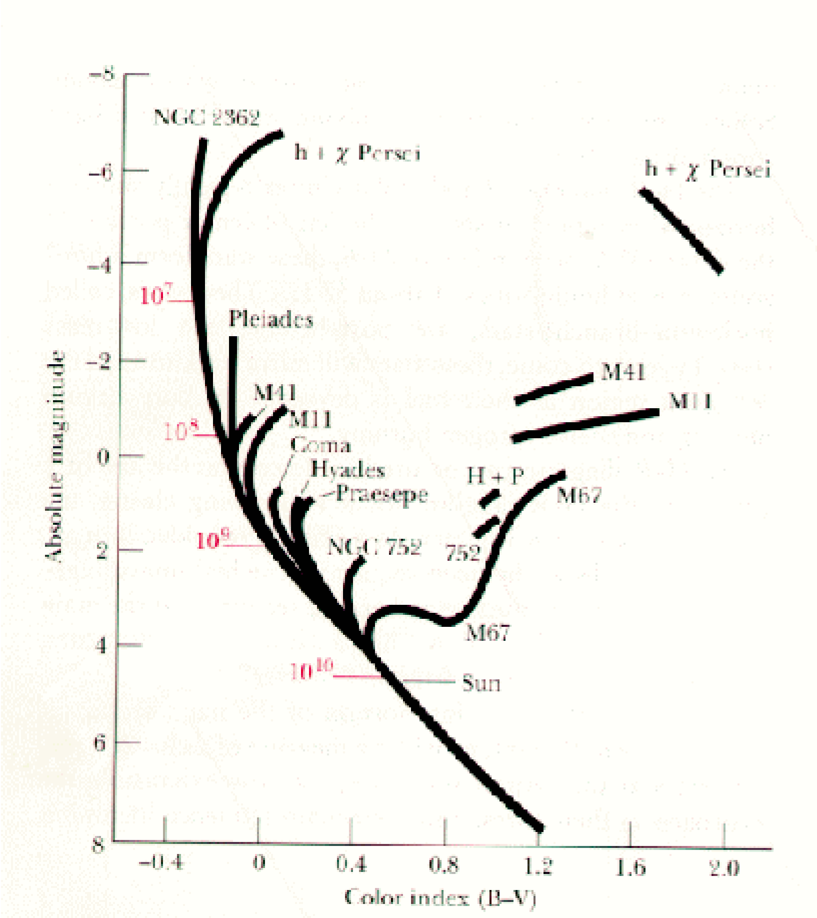

Figure 6
An H-R diagram plotting together some open clusters

The loose gravitational attraction allows that occasionally stars can escape from their open cluster due to having been accelerated *beyond the escape velocity* by means of closer encounters with other stars, galactic tidal forces or interstellar crossing clouds. That explains why average open clusters *have relatively "short" lifetimes*, as they spread most of its original stellar members after several hundred million years; only few open clusters have reached an age counted by billions of years [**5**].

Figure 6 shows an H-R diagram of many open clusters, specifically comparing its different turnoff points (*ages*), from the young NGC 2362 to the relatively very old M 67.

The fact that open clusters are mostly composed by young (metal rich) *Population I stars* corroborates the idea of their short life as entities. As expected, all the currently observed formation of "*new*" open clusters inside several diffuse nebulae inside our Galaxy *show only stars of second stellar generation.*

The escaped individual stars continue to orbit our Galaxy as "*field*" stars. Extrapolating this observation *it is supposed that all field stars in any galaxy actually are runaway cluster members* [**5**].

Conversely to globular clusters, *there are open clusters of many different ages*. As they are even nearer, *which implies more accuracy in the distance determination and hence narrower main sequences*, they have become *an invaluable tool for verifying theoretical models referring about essential stellar topics*, from its nuclear physics up to their overall structure and evolution. Once the age and distance of different clusters have been known, clues for understanding how our Galaxy was formed are being obtained by mapping their positions and features, *process that almost surely has been repeated in the creation of other galaxies anywhere in the whole universe.*

A comparative study

Figure 7 depicts the different relative location of both kinds of star clusters in the Milky Way, as they would appear if seen from an extragalactic edge-on vantage point.

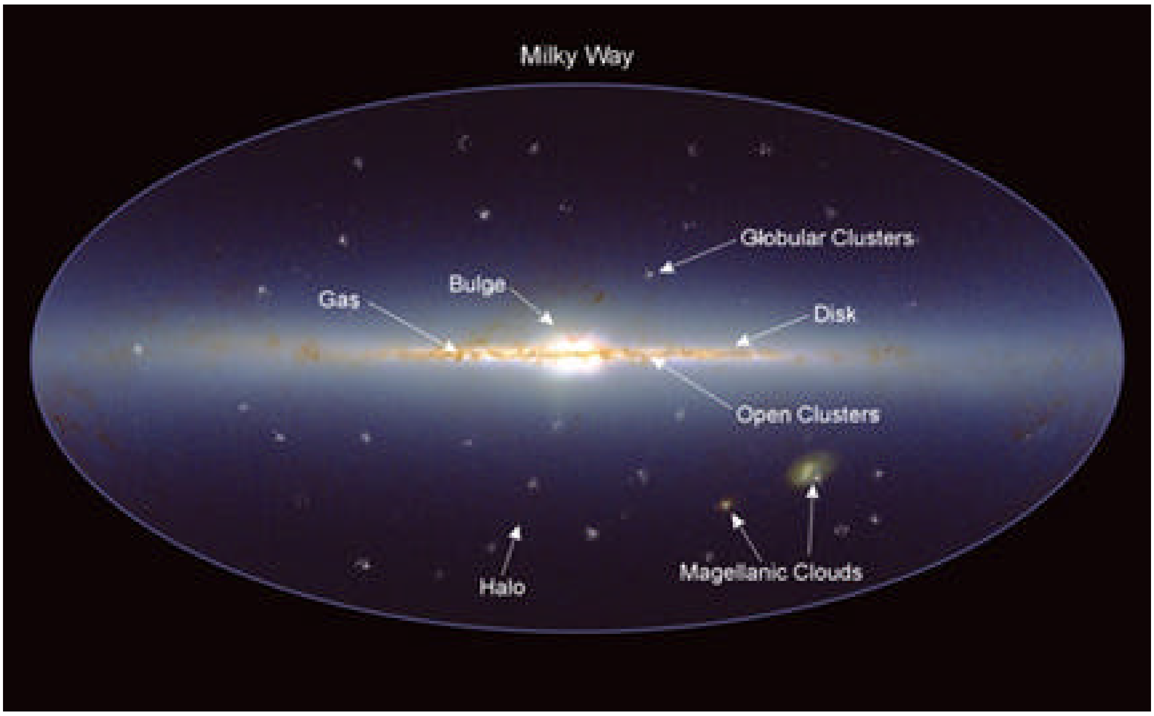

Figure 7
An overview of the Milky Way Galaxy

From the already analyzed features of each kind of cluster it comes out that *they are quite different*. The following table summarizes their respective characteristics:

Comparative table of current clusters in the Milky Way Galaxy		
	Globular Clusters	**Open Clusters**
Quantity of known clusters	150	1,100
Star concentration	very compact at the center	loose
Overall shape	spherical symmetry	no particular shape
Location	far away, at the halo	closer, inside the disk
Number of member stars	10,000 to 10,000,000	20 to 1,000
Overall size	20 to 100 parsecs	less than 30 parsecs
Overall mass	10,000 to 100,000 M_{Sun}	100 to 1,000 M_{Sun}
Overall luminosity	10,000 to 1,000,000 L_{Sun}	100 to 1,000,000 L_{Sun}
Mass distribution per star	0.08 to about 4 M_{Sun}	0.08 to 100 M_{Sun}
Star density	0.5 to 1,000 per cubic parsec	0.1 to 10 per cubic parsec
Stellar chemical composition	only Population II stars	basically Population I stars
Stellar spectroscopic types	no O and B types, seldom A	could be any from O to M
Stellar distribution by luminosity classes	many of class V (G, K, M) many of classes I, II and III	majority of class V (any type) practically no giants
H-R diagram features	short main-sequence about the same turnoff horizontal branch	long main-sequence very different turnoffs no horizontal branch
Age	all very old (~15 Gyr)	from very young to old
Evolution lifetime	can be very large (~15 Gyr)	relatively short (less few Gyr)
Currently been formed	no	yes
Presence of nebulae	no	usual inside young clusters
Closest cluster	NGC 6397 (at 2,800 pc)	The Hyades (at 45 pc)

Conclusions

Both globular and open clusters are groups of sibling stars that still remain together by mutual attraction, but keeping completely dissimilar characteristics. However, only two features basically accounts for their overall group differences: *gravity* due to quite different masses and *origin* due to quite different time-location births. Old star-rich globular clusters are found forming a halo around our Galaxy, while young star-poor open clusters are found in the disk near regions of gas and dust.

Clusters are of special interest because they provide the opportunity of studying groups of stars of the same age, thus allowing to improve our current astrophysical knowledge about stellar evolution, not only learning from the observed "agreements" with our state-of-the-art theories but also from the unexpected "discrepancies" that imply the necessity of new upgrade revisions.

References

1. Alejandro Feinstein and Horacio Tignanelli: "***Objetivo Universo***", 1999, Ediciones Colihue S.R.L., Buenos Aires, Argentina
2. "***Globular Star Clusters***": http://www.seds.org/messier/glob.html

3. S. George Djorgovski: "***The Dynamic Lives of Globular Clusters***", Sky & Telescope magazine, october 1998
4. The ESA/ESO Astronomy Exercise Series 4: "***Measuring a Globular Star Cluster's Distance and Age***", http://www.astroex.org/english/ex4/pdf.php
5. "***Open Star Clusters***": http://www.seds.org/messier/open.html

Overall sources:

- Roger A. Freedman and William J. Kaufmann III: "***Universe: Stars and Galaxies***", 6th edition, 2001, R.R. Donnelley et Sons Company, New York, USA
- Gonzalo Vicino: "***Las estrellas***", 1992, A. Monteverde & Cía S.A., Montevideo, Uruguay

Clusters data:

- The Royal Astronomical Society of Canada - "***Observer's Handbook 2002***", 2001
- Robert A. Strong and Roger W. Sinnott - "***Sky Atlas 2000.0 Companion***", 2nd edition, 2000

Figure credits:

1. *Omega Centauri*: http://www.xware.ru/db/msg/1176029
2. *The Pleiades*: http://www.geocities.com/carlc93906/Carl/m45.html
3. *Globular clusters*: http://www.concentric.net/~Richmann/subpage.html
4. *Color-magnitude diagram*: http://zebu.uoregon.edu/~js/ast122/lectures/lec12.html
5. *Open clusters*: http://www.concentric.net/~Richmann/subpage.html
6. *H-R diagram*: http://zebu.uoregon.edu/~js/ast122/lectures/lec12.html
7. *Overview of the Milky Way*: http://www.astroex.org/english/ex4/images-rgb/ex04-fig04-450.jpg