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On the globular clusters of the Milky Way and the data obtainable from their spectra

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Abstract. Globular clusters are stellar systems found in many galaxies. Their general properties have been since long ago in the focus of the astronomical community interest. At the moment some 150 globulars connected to our own Galaxy - the Milky Way - are listed and the data are available via Internet. Spectroscopy has also given its contribution here. The spectral lines analysis enabled to find velocities of globular clusters and their dynamical masses, as well as their chemical composition. So these stellar systems are known to move around the galactic centre in a way quite different from nearly circular orbits with the same sense characteristic for objects of the galactic disc, their masses indicate that they contain tiny portions of the dark matter only, or no dark matter at all. Besides, on the average, they are much poorer in the chemical elements the atoms of which are more massive than those of hydrogen and helium, than the disc objects.

Key words. Stars: abundances – Stars: atmospheres – Stars: Population II – Galaxy: globular clusters – Galaxy: abundances – Cosmology: observations

1. Introduction

Globular clusters (GCS) are well known celestial objects. Their shapes are the closest to perfect spheres among all stellar systems. Usually the number of stars within a GC is between $10^4 – 10^6$ (see e. g. Ninkovic (2005a)).

The first discovery of a GC took place in 1665 - M22 in Sagittarius. It is attributed to Abraham Ihle who thought the cluster to be a nebula. It is interesting to note that by the end of the XVII century the first southern GC was also discovered. Curiously, it was GC known today as the most luminous and, most likely, the most massive in the Milky Way (MW) - Omega Centauri - discovered by E. Halley in 1677 during his journey to St. Helena. The century to come - XVIII - was rich in discovering new GCS. For example, till the time of W. Herschel 33 GCS were known. He, himself, discovered other 37 ones to attain a total of 70 known GCS. For Herschel it may be justified to say that he was the founder of stellar astronomy; this is also seen from the fact that just he was the first, to resolve all GCS known at that time into stars, and to use the term "globular cluster" (Globular Clusters 2005).

It is well known that C. Messier, who lived in the XVIII-XIX century, formed a catalogue, i. e. a list of celestial objects, including many GCS, as well. As a consequence, the GCS listed by him are still very often referred to as M followed by the corresponding Messier number. However, real catalogues, or lists, of

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GCS appear only in the XX century, for instance Melotte's list from 1915, Shapley's one from 1930, etc. At the present time there is a catalogue compiled by Harris (1996) available via Internet at the same site as Globular Clusters mentioned above, which is, certainly, most frequently used. At the moment it contains 150 objects "regarded as GCS" belonging to MW.

Our own Galaxy - MW - is not the only one known to contain GCS. They have been found in a number of galaxies, even in dwarf ones (e. g. Fornax, Local Group member). Their total number in some galaxies exceeds that in MW, for instance the Andromeda Nebula, considered often as similar to MW, contains several hundreds of GCS (see e. g. Ninkovic (1994)), M87 even several thousands, etc.

2. Internal structure of GCS

There are different aspects in the studying of GCS. Their internal structure is, certainly, the first to be attacked. The rather large total number of stars contributes that they, similarly to galaxies, may be treated as continuous media, i. e. their internal motions are governed by their gravitational potential resulting from the mass distribution via Poisson's equation. Bearing in mind the statement given above concerning their shapes, the most frequent approach has been to assume steady state with spherical symmetry. Of course, in a variety of papers (see e. g. Meylan & Mayor (1986)) the deviations from the spherical symmetry and the rotation of a GC have been taken into account. However, due to the limited space here the present author's intention is to speak about spherically symmetric models only. However, there is an important difference with galaxies - the mean relaxation time within a GC is significantly shorter than in a galaxy. This is also true for dwarf galaxies though the lower mass limit for a typical dwarf galaxy is practically equal to the upper mass limit for GCS. In the connection with these problems we recommend Lightman & Shapiro (1978) as a classical review.

Star countings, which is equivalent to the measuring of the light distribution in the recent times, are observational methods of establishing empirically the mass distribution within GCS. Although the former ones were practised as early as hundred years ago (see e. g. Plummer (1915)), it can be said that the first models were more theoretical than empirical due to the insufficient reliability of these early star countings. Plummer's article, mentioned in the preceding sentence, may be used as a good example, since he concluded that the number density of stars within GCS, at least in MW, follows the Schuster density law (polytrope already well known at that time due also to the studies of internal star structure). Such points of view were, later on, subjects of revisions (for more details e. g. Ninkovic (2005a)). Star countings of a sufficient quality became available at about 1960. King's (King 1962) model, today almost generally accepted as an explanation of mass distribution within GCS, is approximately from that time. It should be said that Veltmann (1961), practically at the same time, indicated another mass-distribution model (alternative model) yielding almost an identical fit as King's one. It should be added that this alternative model is also known under the name of modified Hubble-Reynolds formula (see e. g. Binney & Tremaine (1987) - p. 39). Additionally, in King's model the stellar spatial distribution is characterised with three quantities: total mass (central density) and the two structural parameters - core radius and tidal radius. The former one is the distance where the surface density is half of the central value, whereas the latter one is the distance within which the total mass is concentrated. As for the total mass, in addition to its estimates based on the star countings (generally the fraction of insterstellar matter is very low in GCS), the mass evaluation is also possible by means of the virial theorem. Except for galaxies, the agreement between the results of these two approaches is good. Therefore, the conclusion is that GCS contain few, or no dark matter at all. However, pulsars, planetary nebulae and white dwarfs have been detected there, and the existence of black holes is not excluded, but these black holes have not very high masses, so that the total-mass fraction contained within them is, most likely, very low (Globular Clusters 2005).

This is the way to construct an empirical model of a GC. Due to the shortness of relaxation time the next assumption is that the velocity distribution is isotropic. Therefore, one forms a system of two differential equations - in addition to Poisson's one there is also Euler's equation. The model is said to be empirical because the density is obtained empirically. After solving Poisson's equation one solves Euler's one, i. e. one finds the pressure (the mean velocity square as function of the radius). Of course, instead of this hydrodynamical approach one can use Boltzmann's equation, i. e. to look for a good fit of the density function resulting from the kinematical distribution function to the observational data. Finally, it should be, certainly, said that this approach contains a taciturn assumption - a GC is treated as isolated, i. e. external forces are not taken into account. However, in the very outer parts, GC stars are, without doubt, influenced by non-negligible tidal action. In principle, it can be said that there are three main types of phenomena affecting the internal dynamical evolution of a GC (Globular Clusters 2005)

encounters of stars, tending to randomise the velocity distribution towards some kind of Maxwellian distribution, but also resulting in permanent evaporation of stars, mass segregation and even core collapse;

effects of stellar evolution contributing to the gas losing;

tidal effects affecting the shape of the outer boundary, depending also on the orbit of a GC around the centre of its parent galaxy.

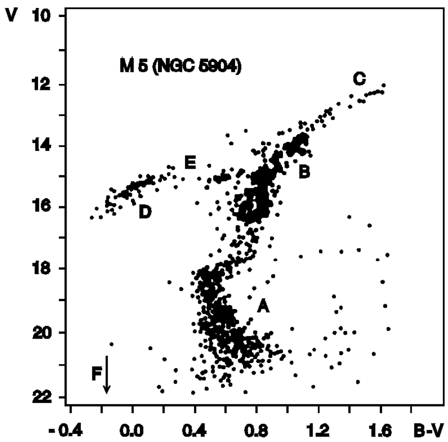

Fig. 1. HR diagram for a GC.

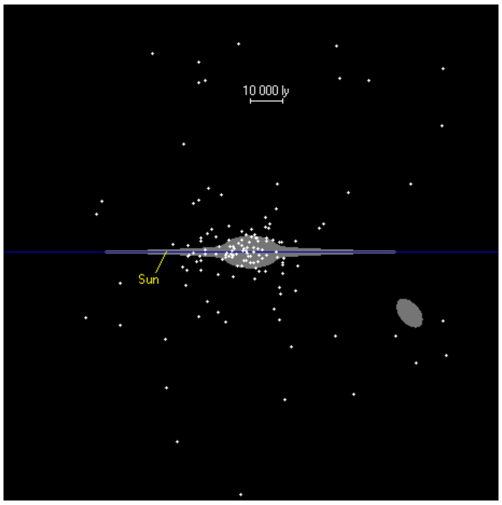

Fig. 2. Spatial distribution of GCS belonging to MW given in projection to a plane containing the galactic rotation axis.

3. GCS of the Milky Way

GCS in MW are known to be old, but this is not always the case, since there are galaxies where one also finds young GCS, as for instance the Magellanic Clouds. The way to establish the age of a GC is to obtain its HR diagram. Here we have the example of M5 (Fig. 1) which is, practically, typical for all GCS of MW. What is clearly seen is the absence of a significant part of the Main Sequence and this feature indicates the high age, probably between 12 and 16 Gyrs. Additional details concerning the age determination will be discussed below in the sections devoted to the chemical composition.

The spatial distribution of GCS in MW shows (Fig. 2) that they belong to the MW subsystem known as halo. In other words they concentrate towards the galactic centre rather than

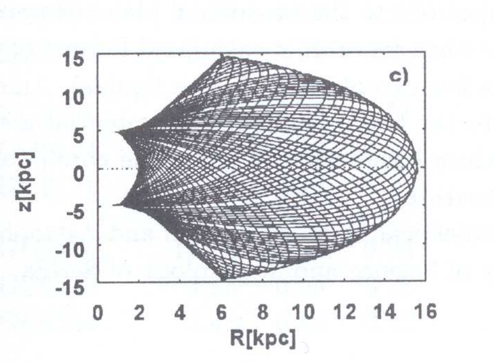

Fig. 3. The galactocentric orbit of a GC (Pal 5); it is taken from (Ninkovic et al. 1999).

towards the galactic plane. This circumstance has been very often used to estimate the distance of the Sun from the centre of MW, where H. Shapley was the well known pioneer.

Such a spatial distribution is a consequence of their motion with respect to the galactic centre. The galactocentric orbits of GCS are said to be very elongated and highly inclined to the galactic plane although the actual calculation of these orbits is followed by a difficulty, due to the low and insufficient accuracy of their proper motions. An example of the galactocentric orbit of a GC is given in Fig. 3. For this reason the internal proper motions are very rarely used to obtain the mean velocity square necessary to apply the virial theorem. They are used practically only to establish the membership to GCS. Instead, one uses the line-of-sight velocities so that spectroscopy provides the data source in estimating the mean velocity square inside a GC (However, the rapid progress is near to provide already now, reliable proper motions, so that their use in the calculations of the star velocities in the GC fields is expected to become justified soon).

At the end of this section one should say that the steady-state picture corresponding to an orbit, like that in Fig. 3, is an approximation only. GCS, besides, suffer from close encounters with very massive objects and also strong energy exchange during their passing through the galactic plane. Therefore, many of them may have been disrupted and, as a consequence, we see many halo stars, now not members of GCS, but which may have been their members long ago. Subdwarfs, RR Lyrae, etc, typical field stars of the galactic halo, are also frequent in GCS.

4. Chemical composition of GCS in MW

Spectroscopy is also important as a data source in another aspect - for the purpose of establishing abundances of chemical elements. It is very well known that the kinematics and chemical composition in MW are correlated. The two best known subsystems - disc and halo - not only differ in their kinematics, i. e. spatial distribution, but also in the chemical composition. The round halo is much poorer in the heavy elements (all except hydrogen and helium), or metals, how they are called in stellar astronomy, than the flat disc. The open clusters of MW, for instance, are much more “metallic” than the GCS belonging to the same galaxy.

The property known as metallicity (see e. g. Ninkovic (2003)) and which has designation [Fe/H] is used as a quantitative indicator of the metal content for a celestial object. When the GCS of MW are concerned, their metallicity distribution can be seen from Fig. 4. Harris’ Catalogue, already mentioned above, gives metallicity for 148 globular clusters. The distribution seen in Fig. 4 can be characterised by existence of three groups here called:

metal-poor GCS - metallicity less than or equal to -0.8;

metal-rich GCS - metallicity over -0.8, but less than or equal to -0.4;

”supermetallic” GCS - metallicity exceeding -0.4.

The first group is by far the most numerous, it contains 110 GCS. The second one contains 30 GCS, whereas the last group contains only eight GCS.

It is clear that these group limits in metallicity are rather arbitrary. This is especially true for the last group where, in fact, there is no crowding. We have just a few GCS with large metallicity values, which are typical for the galactic disc, not for the halo. This can be seen

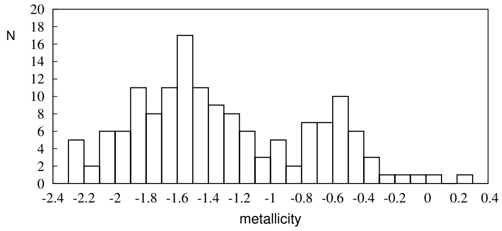

Fig. 4. The metalliicity distribution for GCS of MW (from (Ninkovic 2005b)).

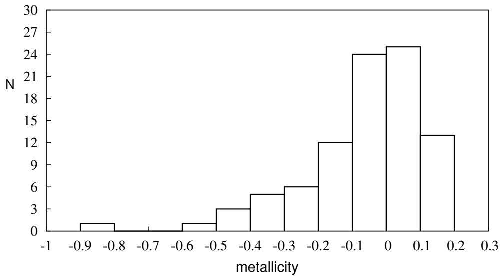

Fig. 5. The metallicity distribution for open clusters of MW (data from Twarog's Catalogue - Twarog).

from Fig. 5 where for the purpose of comparison the metallicity distribution of open clusters is presented. It is curious to note that the metallicity value of -0.4 appears again as, in some way, "critical". Namely, only a few open clusters have metallicity under this value. If the usual boundaries are assumed for the galactic bulge, say the semimajor axis of about one third solar of distance to the galactic rotation axis, the axial ratio 0.5-0.6, then out of the eight "supermetallic" GCS, five are "within" the bulge. With regard that three of them have metallicities between -0.4 and -0.3 the same question can be considered for the other five. Then, there is only one exception - Pal 10 which is not "within" the bulge. The two most metallic ones - Liller 1 (more metallic than the Sun!) and Terzan 5 (as metallic as the Sun) - are near the galactic centre. Of course, in view of the very small number of "supermetallic" GCS, the question if they, perhaps, belong to the galactic bulge can hardly have a meaningful answer.

Do the two groups of GCS - metal-poor and metal-rich ones - represent two substantially different populations of GCS? Since the metal-rich ones are generally closer to the galactic plane, there have been points of view that they should be, perhaps, associated with the galactic disc. Such a discussion is, certainly, beyond the scope of the present contribution. However, a short analysis may be presented.

One possibility is that a star cluster is regarded as, say, a globular cluster, but it is rather an open one. Though the two kinds of star clusters in MW seem to be significantly different, it is not always trivial to distinguish them. There is a number of criteria which can help in such situations, for instance the method based on the HR diagram is very well known (see e. g. Kulikovskij (1985) - p. 117). Regarding that the space for presentation is limited here, there is, really, no need to discuss these distinguishing criteria in details. Instead, only one aspect, following the present author's choice based on his recent paper (Ninkovic 2005b), will be mentioned. Namely, stars within GCS are known to be very strongly concentrated towards their centres, unlike, say, open clusters where this effect is much weaker. Therefore, the Briggs logarithm of the ratio of the two radii mentioned above - the tidal radius and the core one - referred to as concentration parameter and denoted as c, can be used to form a distinguishing criterion. Here two plots, both taken from the present author's paper mentioned above, will be given (Figs. 6-7). In these figures the distribution of the concentration parameter is presented for two different groups of GCS in MW - metal-poor ones and metal-rich ones (including supermetallic clusters as well). As can be seen, there is no essential difference concerning the distribution of the concentration parameter between the two groups of GCS. Thus, in addition to the finding that all GCS of MW have almost the same age regardless to the metal abundances contained, there are other indicators in favour that GCS of MW form a rather homogeneous population.

However, if practically all GCS of MW are associated with the halo subsystem, then, in connection with the chemical composition, another question arises; it concerns the correlation between the metallicity and the galactocentric position. If such a correlation does exist, then it can be said that the metallicity

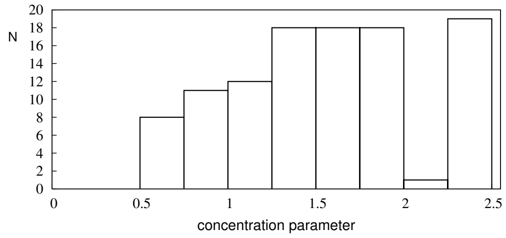

Fig. 6. The distribution of concentration parameter for metal-poor GCS of MW.

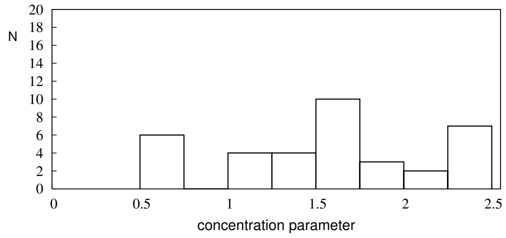

Fig. 7. The distribution of concentration parameter for metal-rich GCS of MW.

gradient is different from zero and vice versa. For this occasion only a short comment will be given. It seems that the correlation between the metallicity and galactocentric position for the galactic halo, as can be concluded taking into account the example of GCS, exists, just as in the case of open clusters (see e.g. Ninkovic (2003)). In other words, GCS closer to the galactic centre are more metal-rich than those situated farther from the centre of MW.

5. Conclusion

GCS are, no doubt, important stellar systems and they deserve and require further studies. Such studies could be those concerning the distribution of the surface brightness, mass segregation within GCS, as well as statistical ones devoted to the MW system which also include the search for other, still undiscovered, GCS.

Spectroscopy has an important place here. Although it has already provided a large body of data as for the motions of stars belonging to GCS, new spectroscopical data are always welcome, especially those which can contribute to our better knowledge of the chemical composition of GCS and of the halo of MW in general. A short comment could be that the use of another abundant heavy element, say carbon, nitrogen, oxygen, etc, instead of iron for the purpose of determining metallicity would bring, practically, no changes in the general picture concerning the presence of the heavy elements in the galactic halo.

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