THE STELLAR POPULATION OF A TYPICAL GLOBULAR CLUSTER

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Abstract. We discuss *typicalities* and *atypicalities* in the stellar population of a Galactic globular cluster.

1. Introduction

Sandage (1953, Fig. 1) presented the first detailed study of the stellar population of the Galactic globular cluster M3, and compared it with that of M92. Since then, people frequently assumed that the stellar population of a *typical* globular cluster (GC) is substantially represented by the CMD of M3, and it is basically constituted of stars located along the main sequence (MS), the sub-giant branch (SGB), the red giant branch (RGB), and the asymptotic giant branch (AGB).

Moreover, since the clusters studied in those early photometries showed very similar CMDs, it has become natural to speak indifferently of "the stellar population of a *typical* globular cluster" or of "the *typical* stellar population of a globular cluster". However, with increasing the size of the available data-base on GCs in galaxies, the definition of the *typical* globular cluster has become uncertain. In fact, as extensively reviewed in *The Globular Cluster-Galaxy Connection* (Smith and Brodie eds., 1993), GCs in galaxies may differ in size, chemistry, age, dynamics, and there are then objects such as the populous globular clusters in the Magellanic Clouds or the recently detected cluster candidates in NGC 1275 and NGC 3579, which have peculiar features and/or non-typical CMDs.

In the following we shall not consider the peculiar objects and, keeping the traditional definition of M3 as the *typical* GC, we restrict the discussion

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to M3-like globulars. The questions then become : what is truly *typical* or *atypical* when talking about the stellar population of a GC? and: is the stellar population of M3 truly *typical* for all the M3-like globulars?

TABLE 1.

TYPICAL IS :	ATYPICAL IS :
• Historically detected first	• Recently detected
• Always present in a cluster	• Randomly present in clusters
• Predicted by the Standard and Canonical Theoretical Models. Known parameters : M_i = initial mass Y = helium abundance Z = metallicity	• Unpredicted or hardly parameterized. Unknown parameters: $\dot{M}= f(Z)$ mass loss ω = rotation B = magnetic fields etc.
• Slowly varying with age : $\Delta t > 1$Gyr → CMD morphology varies accordingly	• Very sensitive to age variations or fast-evolving objects : $\Delta t < 0.1$Gyr → sampling problems
• Unrelated to : - binarism - interaction - environment	• Due to: - binarism - interaction - environment
TYPICAL IS DRIVEN BY :	ATYPICAL IS DRIVEN BY :
• The *normal* contributors to the integrated cluster light → sampling problems	• The *dominant* contributors to the integrated cluster light in UV and IR → sampling problems
TYPICAL CAN BE USED TO :	ATYPICAL CAN BE USED TO :
• Determine specific quantities - distances - dark matter - mixing - primordial He abundance - H_0, t_0	• Study the effects of : - mass loss - binarism - interaction - environment etc.

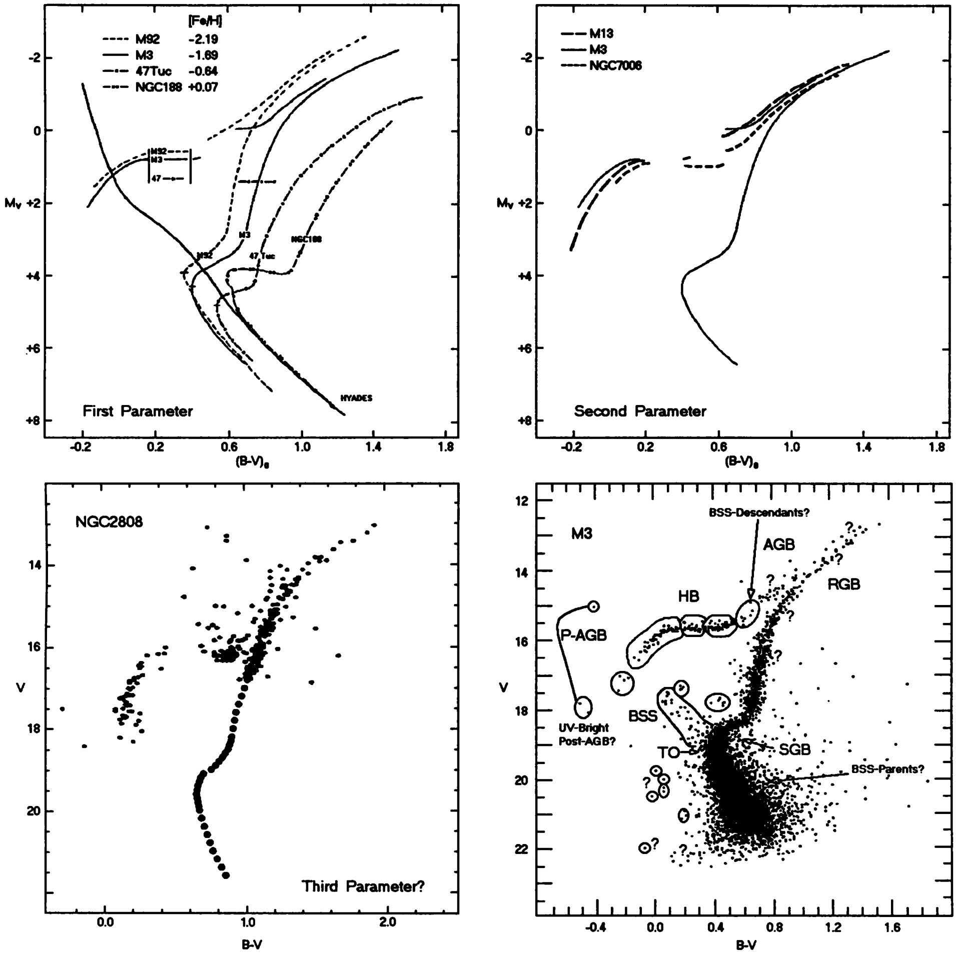

Figure 1. Composite Color Magnitude Diagrams, see Section 2.

2. What is "Typical" and What is "Atypical"?

We have summarized in Table 1 a number of definitions which may help to set the distinction between *typicality* and *atypicality* in the features of the CMD of a cluster and have collected in Fig. 1 the CMDs and main ridge lines for a number of clusters that well illustrate the problem. Fig. 1 shows also that the available data, even on a *typical* cluster such as M3, may lead to an increasingly complicate interpretative scenario.

Very schematically, *panel (a)* shows the composite CMD for three globular clusters (M92, M3, 47 Tuc) that bracket the known metallicity range, the old open cluster NGC 188, and the unevolved Population I MS (from

Sandage, 1986). This plot actually describes the overall *typicalities* of the cluster stellar populations. In particular, one has that:

- at constant age, t, and Helium abundance, Y, if the metallicity, Z (the so-called *first parameter*), decreases : the MS becomes bluer, the Turnoff (TO) mass decreases, the RGB becomes bluer and its slope steeper, and the HB-morphology becomes bluer going from a stubby red HB to a blue "non-horizontal" HB;
- at constant Y and Z, if t increases: their MS-TO becomes fainter, the TO-mass smaller, the RGB is substantially unaffected, and the HB-morphology becomes bluer [HB luminosity: M_V^{HB} ~const];
- at constant Z and t, if Y increases: the MS becomes bluer, and the HB becomes bluer and brighter.

The composite CMD of the three globular clusters (M13, M3, NGC 7006) presented in *panel (b)* shows the classic *atypicality* due to the so-called *second parameter* effect, i.e. clusters having same metallicity but strongly different HB-morphologies. As reviewed by Rood and Crocker (1989), there are several candidate second parameters (t, Y, [CNO/Fe], rotation, mass loss, etc.), age being the most fashionable one (Zinn, 1993; Lee, 1993).

However, as shown in *panel (c)*, it is possible to observe GCs like NGC 2808 (Ferraro *et al.*, 1990) where a stubby red HB is coupled with a blue HB tail (separated by a wide gap), as if two opposite second parameters were contemporarily at work. Roughly speaking, one may thus conjecture that a *third parameter* is involved (Fusi Pecci *et al.*, 1993), which may originate many other induced atypicalities.

Finally, *panel (d)* shows that even the CMD of the proto-type GC M3 (Buonanno *et al.*, 1994a) contains many special objects and could be analysed in a very atypical way. There are in fact a number of stars located outside the main branches worth of detailed study (e.g. Blue Stragglers, UV-bright stars, Post-AGB objects, etc.), and many others somehow related to binaries could well populate the main branches during particular stages of their evolution (Fusi Pecci *et al.*, 1992).

In conclusion, the stellar population of a typical GC contains an enormous wealth of information which could hardly be extracted by considering just the most *typical* features in its CMD.

3. Three Specific Items

3.1. YOUNG GLOBULARS AND THE "SECOND PARAMETER"

Although the *typical* stellar populations are practically identical, cluster ages may be significantly different, and this has a strong impact on the description of the formation and early evolution of the Galaxy.

A special emphasis in this respect has now the increasing set of globular clusters (Pal 12, Ruprecht 106, Arp 2, Terzan 7, IC 4499, see for ref. Buonanno *et al.*, 1994b) which have *typical* CMDs and, based on their MS-TO luminosities, appear to be significantly younger (3−5Gyr) than the bulk of GCs with similar metallicity in the Galaxy.

Since these clusters lie near great circles passing in proximity of most satellite galaxies of the Milky Way, including the Sagittarius dSph currently being disrupted and absorbed by the Milky Way (Ibata *et al.*, 1994), they could have been captured from a satellite galaxy or formed during a close interaction between the Galaxy and one of its companions. Therefore they could even be considered *atypical* clusters, originally members of one or more autonomous fragments.

However, these new evidences may have an important impact on the longstanding debate on the second parameter. In fact, the definition of "young" based on the HB-morphology may be different from that resting on the MS-TO, if age is not *the only* second parameter (see for instance Fig. 4c and Fusi Pecci *et al.*, 1993, Catelan and de Freitas Pacheco, 1994). Consequently, sub-groups of clusters individuated by using kinematical properties and the HB-morphology as age indicator could indeed contain clusters having very different TO-based ages, which would make their membership to common fragments unlikely.

3.2. WHITE DWARFS AND BROWN DWARFS

There is general consensus that white dwarfs (WDs) and brown dwarfs (BDs) should be a quite *typical* component of the stellar population of GCs. However, since they are intrinsically very faint, a fully reliable observational evidence is still lacking.

Besides being the final test-objects for the whole stellar evolutionary chain, the WDs cooling sequence could be used in Galactic GC distance determination (Fusi Pecci and Renzini, 1979) and, in turn, in estimating precise absolute ages. This is thus a classic example of the impact of the study of a *typical* GC stellar population on fundamental astrophysical problems. Detection of WDs in ωCen and M71 has been claimed by Ortolani and Rosino (1987), and Richer and Fahlmann (1988), and recently, a dozen reliable candidates have been detected in NGC 6397 using HST observations (Paresce *et al.*, 1994).

Many candidates exist for baryonic dark matter (DM), with masses ranging from black holes down to comets. Among the most popular candidates are the stars at the low mass end of the Initial Mass Function (IMF). However, to provide a significant quantity of baryonic DM to the Galactic halo, a steepening of the IMF slope at very faint limits, well into the very low mass (VLM) stars and BDs regions, is absolutely necessary. Globular clusters offer the environment where a sufficiently homogeneous group of VLM and BD objects could still live unless dynamical evolution and stripping have totally depleted the clusters. Though the clusters low metallicity makes the VLMs and BDs brighter than expected in the solar neighborhood and in the Galactic disk, these objects in the typical Galactic globulars (even in the closest ones) are very faint, V> $25-27$, and securing statistically complete and uncontaminated LF's is extremely difficult. By measuring deep I-band LFs of six GCs, Fahlman *et al.*(1989) and Richer *et al.*(1991) have claimed that most GC's probably have very steep IMF's (slope $x > 2.5$, with Salpeter IMF $x = 2.35$), implying a large number of low-mass Pop II stars in the halo.

On the other hand, Paresce *et al.*(1994) using deep HST-WFPC2 images have obtained the LF for the MS of NGC 6397 down to $m_I \sim 25$. Their corresponding IMF rises to a plateau between ~ 0.25 and $\sim 0.15M_\odot$, but drops towards the expected mass limit of the hydrogen-burning MS at about $\sim 0.1M_\odot$. As they note, this result is in clear contrast to that obtained from the ground for the same cluster by Fahlman *et al.*(1989) and may alter strongly the possible implications on dark matter problems.

The use of HST and the VLTs (specially in the IR) will surely solve the issue definitely.

3.3. BLUE STRAGGLERS AND BINARIES

The increasing number of recent observations reporting new detection of blue stragglers stars (BSS) in Galactic GCs from the ground and with HST has renewed the interest in this topic (see Saffer ed., 1993).

In this respect, Fusi Pecci *et al.*(1992), and Ferraro *et al.*(1993) have presented observational evidences supporting the existence of possible correlations between cluster structural parameters and BSS properties. In particular : i) the BSS Luminosity Function (LF) for low density GCs ($Log\rho_0 < 3$) turns out to be different from that obtained for the BSS detected so far in highly concentrated GCs ($Log\rho_0 > 3$), at 3σ level; ii) there are some (weak) indications that the ridge line of the BSS sequence in the CMD is progressively red-shifted compared to the bright extension of the Zero Age MS with increasing metallicity; iii) in M3, there is apparently a lack of BSS in an intermediate annular region of the cluster which could be ascribed to the existence of two different populations of BSS within the same cluster or to segregating effects in the BSS production and/or survival.

As widely reviewed in *Blue Stragglers* (Saffer ed., 1993), there is a growing belief that binaries via various mechanisms (e.g. coalescence, merging, interaction, capture) can be related to the origin of the BSS detected in

Galactic GCs.

In particular, it is possible that the combination of several phenomena somehow related to the binaries and/or the environment, may be responsible for the stellar population gradients, for the properties of the BSS and of the HB stars, for the existence of rare or even "exotic" objects (like extreme blue HB stars, Ba- and CH-stars, dwarf cepheids, cataclysmic variables, "nude" very blue objects), and for the production of millisecond pulsars and X-ray sources.

Concerning binaries, it is common belief that any object not accounted for in "standard evolutionary theory" could be composed by binaries (originally or now). The question is: Are there any binaries in GCs? Indeed, recent searches in the optical, X-ray, and radio bands have led to the identification of various classes of objects which may be direct or indirect evidence for binaries. Very synthetically one can mention (see for ref. Hut *et al.*, 1993) the observations of radial velocity variables, photometric variables (f.i. pulsating BSS and eclipsing BSS), cataclysmic variables and novae, and some hints for the existence of a "second parallel" MS in a few GCs.

In conclusion, we firmly believe that many new results are supporting the claim that dynamical evolution of GCs can affect the evolution of their stellar populations. And the consideration of both evolutionary and dynamical properties of the stars in a GC and of the GCs themselves within the Galaxy environment will probably open a new landscape on the study of any stellar population.

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References

Buonanno R., Corsi C.E., Buzzoni A., Cacciari C., Ferraro F.R., and Fusi Pecci F., 1994a, *A. & A.*, **290**, 69

Buonanno R., Corsi C.E., Fusi Pecci F., Richer H.B., and Fahlman G.G., 1994b, *Ap. J.*, **430**, L121

Catelan M., and de Freitas Pacheco J.A. 1994, *A. & A.*, **289**, 394

Fahlman G.G., Richer H.B., Searle, L., and Thompson I.B,. 1989, *Ap. J.*, **343**, L49

Ferraro F.R., *et al.*, 1993, *A. J.*, **106**, 2324

Ferraro F.R., Clementini G., Fusi Pecci F., Buonanno R., and Alcaino G., 1990, *A. & A.*, **84**, 59

Fusi Pecci F., and Renzini A., 1979, *Astronomical Uses of the Space Telescope*, eds. F. Macchetto, F. Pacini, and M. Tarenghi, ESO, p.181

Fusi Pecci F., Ferraro F.R., Corsi C.E., Cacciari C., and Buonanno R., 1992, *A. J.*, **104**, 1831

Fusi Pecci F., Ferraro F.R., Bellazzini M., Djorgovski S.G., Piotto G., and Buonanno R., 1993, *A. J.*, **105**, 1145

Hut P. *et al.*, 1992, *P. A. S. P.*, **104**, 981
Ibata R.A, Gilmore G., and Irwin M.J., 1994, *Nature*, **370**, 194
Lee Y.-W., 1993, *Astr. Soc. of the Pacific Conf. Ser.*, Vol. No. **48**, 142
Ortolani S., and Rosino L., 1987, *A. & A.*, **185**, 102
Paresce F., De Marchi G., and Romaniello M., 1994, STScI preprint
Richer H.B., and Fahlman G.G., 1988, *Ap. J.*, **325**, 219
Richer H.B., Fahlman G.G., Buonanno, R., Fusi Pecci F., Searle, L., and Thompson I.B., 1991, *Ap. J.*, **381**, 147
Rood R.T., and Crocker, D.A., 1989, *IAU Coll.* No. 111, ed. E.G. Schmidt, Cambridge University Press, p.103
Saffer R.A. (ed.), 1993, *Astr. Soc. of the Pacific Conf. Ser.*, Vol. No. **53**
Sandage A., 1953, *A. J.*, **58**, 61
Sandage A., 1986, *Ann. Rev. Astron. Astrophys.*, **24**, 421
Smith G.H, and Brodie J.P. (eds.), 1993, *Astr. Soc. of the Pacific Conf. Ser.*, Vol. No. **48**
Zinn R.J., 1993, *Astr. Soc. of the Pacific Conf. Ser.*, Vol. No. **48**, 38

VAN DEN BERGH: You mentioned the possibility that Terzan 7 might have been drawn out of the Magellanic Clouds. Is not its metallicity ([Fe/H]~ -0.6) too high for it to have been a true Cloud GC?

FUSI PECCI: Admittedly, if such an estimate is confirmed it would be hard to imagine how a rich cluster like Terzan 7 could come out from the Clouds or from the Sagittarius dSph. Our preliminary "photometric" metallicity of Terzan 7 from the $(B\text{-}V)_{0,g}$ is however [Fe/H]~ -1.

HARRIS: I think it's extremely important to note that the four or five *young* clusters that have been found in the outer halo are all very *low-mass, small* objects –on average, almost an order of magnitude less massive than the average old-halo clusters. If these objects formed out of "Searle-Zinn fragments" in the early halo, then it suggests that these gas clouds had already broken down tidally into smaller units after a few Gigayears.

FUSI PECCI: I agree completely.

RUSSELL: If the second sequence in NGC 288 is due to binaries, why are there so few members when $\sim 50\%$ of stars should be binaries?

FUSI PECCI: From the available CMDs it is very hard to estimate the real percentage of binaries. I simply mentioned that the CMD presented by Bolte (1992, ApJS 82, 145) may indicate the existence of a parallel MS as expected if there are MS binaries.

COHEN: You might do better looking at the widths of the sequences of metal rich GCs in the IR. It avoids the differential reddening across the clusters.

FUSI PECCI: This is what we are currently doing. We have almost reduced ESO IRAC-2 JK data for about 15 Galactic GCs almost down the MS-TO.