Star Clusters: From the Milky Way to the Early Universe
Proceedings IAU Symposium No. 351, 2019
A. Bragaglia, M. Davies, A. Sills & E. Vesperini, eds.

doi:10.1017/S1743921319007683

Dynamical effects on the stellar mass function of multiple stellar populations in globular clusters

Enrico Vesperini[1], Jongsuk Hong[2], Jeremy J. Webb[3], Franca D'Antona[4] and Annibale D'Ercole[5]

[1]Department of Astronomy, Indiana University, Bloomington, IN 47401, USA
email: evesperi@indiana.edu

[2]Kavli Institute for Astronomy and Astrophysics, Peking University, Yi He Yuan Lu 5, HaiDian District, Beijing 100871, China

[3]Department of Astronomy and Astrophysics, University of Toronto, Toronto, ON, M5S 3H4, Canada

[4]INAF, Osservatorio Astronomico di Roma, I-00040 Monteporzio Catone, Rome, Italy

[5]INAF, Osservatorio Astronomico di Bologna, I-40129 Bologna, Italy

Abstract. We present a brief summary of the results of a study of the effects of dynamical evolution on the stellar mass function of multiple-population globular clusters. Theoretical studies have predicted that the process of multiple-population cluster formation results in a system in which second-generation (2G) stars are initially more centrally concentrated than first-generation (1G) stars. In the study presented here, we have explored the implications of the initial differences between the 2G and 1G structural properties for the evolution of the local (measured at different distances from a cluster center) and global mass function. We have studied both systems in which 1G and 2G stars start with the same initial mass function (IMF) and systems in which 1G and 2G stars have different IMFs. Finally we have explored the evolution of the spatial mixing and found that the multiscale nature of the clusters studied leads to a dependence of the mixing rate on the stellar mass.

Keywords. globular clusters: general, stellar dynamics, stars: luminosity function, mass function

1. Introduction

Numerous observational studies (see e.g. Carretta *et al.* 2009a,b; Piotto *et al.* 2015; Milone *et al.* 2017; Gratton this volume, and references therein) have shown that globular star clusters host multiple stellar populations and raised many new challenging questions concerning all the aspects of the formation history, the dynamical and chemical evolution of these stellar systems.

According to different formation scenarios (see e.g. D'Ercole *et al.* 2008; Decressin *et al.* 2007; Bekki 2010; Bastian *et al.* 2013; Gieles *et al.* 2018; Calura *et al.* 2019) second-generation (2G) stars would form more centrally concentrated in the inner regions of the first-generation (1G) system; observational studies have indeed found evidence that in several clusters 2G stars are more spatially concentrated than 1G stars (see e.g. Bellini *et al.* 2009; Lardo *et al.* 2011; Simioni *et al.* 2016; see also Dalessandro *et al.* 2014; Nardiello *et al.* 2015 for clusters in which the initial spatial differences have been dynamically erased and the two populations are spatially mixed).

The initial differences in the spatial distributions of 1G and 2G stars and the formation processes that produced them can have important implications for the evolution of the cluster dynamical properties and its stellar content. A number of studies (see e.g. Richer *et al.* 2013; Bellini *et al.* 2015; Cordero *et al.* 2017; Henault-Brunet *et al.* 2015; Milone *et al.* 2018; Tiongco *et al.* 2019; Cordoni *et al.* 2019) have explored the implications for the internal kinematical properties and the expected differences between the 1G and the 2G velocity anisotropy, and between the 1G and the 2G rotational velocity. The differences between the structural properties of 1G and 2G stars have been also shown to result in significant differences in the evolution and survival of 1G and 2G binary stars and their spatial distribution (see e.g. Vesperini *et al.* 2011; Lucatello *et al.* 2015; Hong *et al.* 2015, 2016, 2019; Dalessandro *et al.* 2018). Finally a number of theoretical investigations have been devoted to the study of the evolution of the 1G and 2G structural properties and the spatial mixing of the two populations (see e.g. Vesperini *et al.* 2013; Miholics, Webb & Sills 2015).

In this contribution we briefly summarize the results of a suite of N-body simulations (Vesperini *et al.* 2018) aimed at exploring the dynamical effects on the evolution of the local and global 1G and 2G stellar mass function (MF). On the observational side the only study of the MF of multiple populations has been carried out by Milone *et al.* (2012) for NGC2808; additional studies exploring this issue for other clusters and for a broader range of stellar masses will be necessary.

2. Results

We have explored the evolution of systems in which the 1G and the 2G have the same initial mass function (IMF) and systems in which the 1G and the 2G have different IMFs.

Our simulations show that if the 1G and the 2G populations start with the same IMF, the evolution of the 1G and 2G global MF is similar and both the 1G and the 2G MF flattens to a similar extent as a result of the preferential loss of low-mass stars. As a consequence of the differences between the 1G and 2G structural properties, however, the two populations have different relaxation timescales and different rates of mass segregation; this implies that, despite the fact that they have similar global mass function, dynamical evolution can produce differences between the local (measured at given distances from the cluster center) 1G and 2G MFs.

Another implication of the structural differences between the 1G and the 2G populations is that the spatial mixing rate of the two populations depends on the stellar mass. More specifically, our simulations have revealed that low-mass stars tend to mix more rapidly than massive stars although the difference is not very large and it will probably be difficult to observe it.

For simulations starting with systems in which the 1G and the 2G do not have the same IMF, our simulations show that the differences between the global 1G and the 2G MFs are not erased by dynamical effects during most of a cluster's evolution. Similarly to what found in simulations starting with the same 1G and 2G IMF, we find that also in these simulations the local 1G and 2G MFs may be significantly different; in this case differences in the local MFs of the 1G and the 2G are due to a combination of dynamical effects and the different global MFs.

The results of our investigation show that observational evidence of differences in the global 1G and 2G MFs would imply differences between the IMFs of the two populations thus providing an additional important constraint on the formation of multiple populations.

In the interpretation of differences between the local 1G and 2G MFs, on the other hand, it is necessary to consider that these differences could be either entirely due to dynamical effects in systems in which the 1G and the 2G populations formed with the same IMF (and in this case they would be an interesting manifestation of the multiscale nature of multiple-population clusters) or might be due the joint effect of dynamics and primordial differences in the 1G and 2G IMFs. Our simulations suggest that, in general, large differences between local 1G and 2G MFs tend to be present in systems with different 1G and 2G global MFs but additional simulations tailored to specifically model individual clusters will be needed to further clarify the origin of differences between 1G and 2G local MFs.

A more detailed and complete description of the simulations and the results obtained are presented in Vesperini *et al.* (2018).

References

Bastian, N., Lamers, H. J. G. L. M., de Mink, S. E., Longmore, S. N., Goodwin, S. P., & Gieles, M. 2013, *MNRAS*, 436, 2398
Bellini, A. *et al.* 2009, *A&A*, 507, 1393
Bellini, A. *et al.* 2015, *ApJ*, 810, L13
Bekki, K. 2010, *ApJ*, 724, L99
Calura, F., D'Ercole, A., Vesperini, E., Vanzella, E., & Sollima, A. 2019, *MNRAS*, 489, 3269
Carretta, E. *et al.* 2009a, *A&A*, 505, 117
Carretta, E., Bragaglia, A., Gratton, R., & Lucatello, S. 2009b, *A&A*, 505, 139
Cordero, M. J., Henault-Brunet, V., Pilachowski, C. A., Balbinot, E., Johnson, C. I., & Varri, A. L., 2017, *MNRAS*, 465, 3515
Cordoni, G., Milone, A. P., Mastrobuono-Battisti, A., Marino, A. F., Lagioia, E. P., Tailo, M. 2019, *ApJ*, in press (arXiv:1905.09908)
Dalessandro, E. *et al.* 2014, *ApJ*, 791, L4
Dalessandro, E. *et al.* 2018, *ApJ*, 864, 33
D'Ercole, A., Vesperini, E., D'Antona, F., McMillan, S. L. W., & Recchi, S. 2008, *MNRAS*, 391, 825
Decressin, T., Meynet, G., Charbonnel, C. Prantzos, N. & Ekstrom, S. 2007, *A&A*, 464, 1029
Gieles, M. *et al.* 2018, *MNRAS*, 478, 2461
Henault-Brunet, V., Gieles, M., Agertz, O., & Read, J. I. 2015, *MNRAS*, 450, 1164
Hong, J., Vesperini, E., Sollima, A., McMillan, S. L. W., D'Antona, F., & D'Ercole, A. 2015, *MNRAS*, 449, 629
Hong, J., Vesperini, E., Sollima, A., McMillan, S. L. W., D'Antona, F., & D'Ercole, A. 2016, *MNRAS*, 457, 4507
Hong, J., Patel, S., Vesperini, E., Webb, J. J., & Dalessandro, E. 2019, *MNRAS*, 483, 2592
Lardo, C., Bellazzini, M., Pancino, E., Carretta, E., Bragaglia, A., & Dalessandro, E. 2011, *A&A*, 525, A114
Lucatello, S., Sollima, A., Gratton, R., Vesperini, E., D'Orazi, V., & Carretta, E. 2015, *A&A*, 584, A52
Miholics, M., Webb, J. J., & Sills A. 2015, *MNRAS*, 454, 2166
Milone, A. P. 2012, *A&A*, 537, A77
Milone, A. P. *et al.* 2017, *MNRAS*, 464, 3636
Milone, A. P., Marino, A. F., Mastrobuono-Battisti, A., & Lagioia E. P. 2018, *MNRAS*, 479, 5005
Nardiello, D., Milone, A. P., Piotto, G., Marino, A. F., Bellini, A., & Cassisi S. 2015, *A&A*, 573, A70
Piotto, G. *et al.* 2015, *AJ*, 149, 91
Richer, H. B., Heyl, J., Anderson, J., Kalirai, J. S., Shara, M. M., Dotter, A., Fahlman, G. G., & Rich, R. 2013, *ApJ*, 771, L15

Simioni, M., Milone, A. P., Bedin, L. R., Aparicio, A., Piotto, G., Vesperini, E., & Hong, J. 2016, *MNRAS*, 463, 449

Tiongco, M., Vesperini, E. & Varri, A. L. 2019, *MNRAS*, 487, 5535

Vesperini, E., McMillan, S. L. W., D'Antona, F., & D'Ercole, A. 2011, *MNRAS*, 416, 355

Vesperini, E., McMillan, S. L. W., D'Antona, F., & D'Ercole, A. 2013, *MNRAS*, 429, 1913

Vesperini, E., Hong, J., Webb, J. J., D'Antona, F., & D'Ercole, A. 2018, *MNRAS*, 476, 2731

https://doi.org/10.1017/S1743921319007683 Published online by Cambridge University Press