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Unexpected kinematics of multiple populations in globular clusters

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Abstract. Present-day structural and kinematical properties of multiple populations (MPs) can provide useful information about the physical mechanisms driving the formation and early evolution of globular clusters (GCs). As part of a large project aimed at characterizing the kinematics of MPs, here we present a detailed multi-epoch analysis of the low-mass GC NGC6362. We find that MPs in this system show significant differences in their line-of-sight velocity dispersion profiles. This result is totally unexpected given the dynamical age and fraction of mass lost by NGC6362. We also find that the binary fraction is remarkably larger in the first (FP) than in the second population (SP). We show that such a difference can efficiently inflate the velocity dispersion of FP at intermediate/large cluster-centric distances with respect to SP. Indeed, our results nicely match the predictions of state-of-the art N-body simulations of the co-evolution of MPs in GCs including the effect of binaries.

Keywords. globular clusters: general, globular clusters: individual (NGC6362), stars: kinematics and dynamics, stars: abundances

1. Introduction

The discovery of multiple populations (MPs) in globular clusters (GCs) that differ in light-element abundance (e.g. C, N, O, Na, Mg, Al) while having the same iron (and iron-peak elements) content, has seriously challenged our understanding of the physical mechanisms driving the formation and early evolution of these systems (see Bastian & Lardo 2018 for a recent review). Different scenarios have been proposed over the years to explain the formation of MPs. However, all models (see for example Decressin *et al.* 2007; D'Ercole *et al.* 2008; Gieles *et al.* 2018) proposed so far face serious problems to reproduce the observations and a self-consistent explanation of the physical processes at the basis of MP formation is still lacking.

Understanding the kinematical properties of MPs can provide new insights into GC formation and early evolution. In fact, one of the prediction of MP formation models is that MPs form with different structural and kinematical characteristics and some of them are expected to still be visible in present-day GCs. However, very few works can be found in the literature about MP kinematics (see for example Richer *et al.* 2013; Bellini *et al.* 2015; Cordero *et al.* 2017; Dalessandro *et al.* 2018; Dalessandro *et al.* 2019), mainly because of the technical limitations to derive kinematical information for large and significant samples of resolved stars in dense environments.

To move a leap forward in our understanding of stellar cluster internal kinematics, we are conducting an intense observational campaign, the Multi Instrument Kinematic Survey of Galactic GCs (MIKiS; Ferraro *et al.* 2018). MIKiS is a multi-instrument project based on two ESO-VLT Large and several additional normal Programs. The general idea beyond MIKiS is to derive a large number of line-of-sight radial velocities (RVs) in

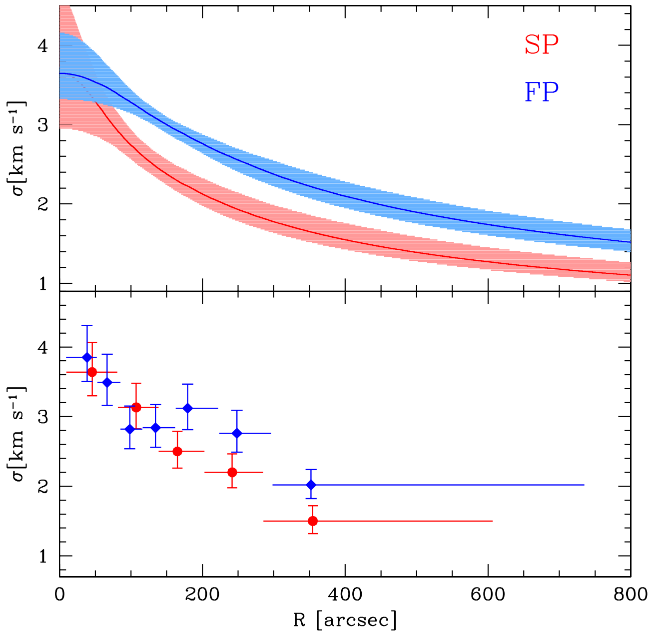

Figure 1. Best-fit dispersion profiles and $1-\sigma$ confidence regions (upper panel) and the binned velocity dispersion profile (bottom panel) for the FP and SP samples.

Galactic GCs with adequate spectral and spatial resolution from the innermost regions to the clusters' tidal radius. To this aim it takes full advantage of the IFU and multi-object capabilities of the available ESO instrumentation by properly combining data acquired with SINFONI, KMOS, MUSE and FLAMES. The target sample includes 30 GCs spanning a wide range in terms of mass, dynamical evolution and structural parameters.

In this context, here we report on the results of an extended kinematical analysis of MPs in the GC NGC6362 (see Dalessandro *et al.* 2018 for further details). The case of NGC6362 is particularly interesting. In fact, contrary to what is generally observed in other GCs, we have found that in this cluster the spatial distributions of MPs are consistent with complete mixing over the entire cluster extension (Dalessandro *et al.* 2014). This behavior suggests that the cluster underwent complete spatial redistribution of stars and severe mass-loss due to long-term dynamical evolution (Vesperini *et al.* 2013; Miholics *et al.* 2015).

2. Kinematic analysis and results

The data used in this work consists of ∼800 high-resolution spectra obtained using the multi-object facility FLAMES@ESO-VLT in the UVES+GIRAFFE combined mode secured in two observing runs (Prop IDs: 093.D-0618 and 097.D-0325, PI: Dalessandro). We refer to Dalessandro *et al.* (2018) for a full description of the RV, Fe and Na abundances derivations. Here we just recall that the kinematic analysis was performed on likely cluster members covering the entire cluster extension ($r_t \sim 850$") and selected based on their RVs and metallicities. Stars with [Na/Fe]$< +0.05$ are classified as FP, while the SP sample is composed by stars with [Na/Fe]$> +0.05$.

To characterize the kinematics of FP and SP stars, we used the maximum likelihood method described in Cordero *et al.* (2017). The upper panel of Figure 1 shows the result of this analysis, while in the bottom panel we show the binned dispersion profiles for

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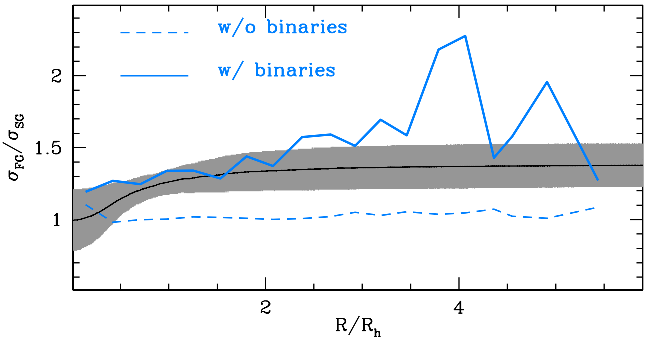

Figure 2. Radial variations of the ratio of the observed FP to SP line-of-sight velocity dispersions (σ_{FP}/σ_{SP}) from N-body models with (solid tick line) and without binaries (dashed line) compared to observations (gray dashed area).

illustration purpose only. Clearly the velocity dispersion profiles of SP and FP populations are remarkably different. In particular, the two profiles are indistinguishable out to ∼70"−80" (corresponding to $\sim 0.5 r_h$), while beyond this radius the SP velocity dispersion profile decreases more sharply than that of the FP and attains dispersion values smaller than those of the FP by ∼1 km s^{-1}. Such a difference corresponds to ∼30% of the observed central velocity dispersion values of FP and SP stars. The observed difference results to be significant based on both Kolmogorov-Smirnov and F- tests. We note that this is the first time that differences in the line-of-sight velocity dispersions of MPs are detected. Considering the results of our previous study about the radial distribution of MPs in NGC6362 (Dalessandro *et al.* 2014) the kinematic pattern we have found is surprising. In fact, once a cluster has attained complete spatial mixing, its MPs should also be characterized by similar velocity dispersion profiles.

To understand the unexpected kinematic properties observed for FP and SP stars in NGC6362, we derived the binary fraction of the two populations. We took advantage of the fact that a large fraction (384) of stars were repeatedly observed (from a minimum of 2 to a maximum of 6 times) within a period of ∼2 years. We stress that this is the largest sample ever used so far for this kind of analysis for an individual GC. By following the approach described in Lucatello *et al.* (2015) we find that the FP and SP binary fractions are respectively $f^{\rm FP} \sim 14.3\%$ and $f^{\rm SP} < 1\%$ (see details in Dalessandro *et al.* 2018).

To estimate the potential effect of such different binary fractions on the derived velocity dispersion profiles, we have studied the evolution of the line-of-sight velocity dispersions of FP and SP stars in a set of N-body simulations (Vesperini *et al.* 2018; Hong *et al.* 2019) also including binaries and compared them to the observations. Models are not tailored to fit in detail the dynamics of NGC6362, but rather to gather some fundamental insight into the dynamical ingredients necessary to explain the observational results. Figure 2 shows that for a dynamically old cluster in which FP and SP stars are completely spatially mixed, the radial profile of σ_{FP}/σ_{SP} (dashed line) is flat when the effect of binaries is not taken into account, at odds with the observations. On the contrary, when including binaries in the N-body simulations (solid thick line), observations and simulations nicely match (at least qualitatively) thus suggesting that binaries can play a major role in shaping the σ_{FP}/σ_{SP} radial gradient and could be the dynamical ingredient needed to reproduce the peculiar kinematical pattern observed in this system. Indeed, if SP stars form in a more compact and centrally concentrated subsystem than FP, all the processes altering the number and orbital properties of binary stars (ionization, hardening, softening, ejection) affect the SP binaries more efficiently than the FP ones. This has important consequences on both the relative binary fractions and their relative radial distributions. In turn, the difference in the fraction of FP and SP binaries and its radial variation imply that the possible velocity dispersion inflation due to binaries is stronger for the FP population and is increasingly more important at larger distances from the cluster center.

3. Conclusions

Besides the specific case of NGC6362, these results clearly demonstrate the importance of the study of the kinematics at several epochs to build a complete dynamical picture of MPs in GCs and to shed light in their dynamical history. In this context it will be important to extend this kind of analysis to other systems in order to understand whether NGC6362 is a peculiar case or similar effects are present in all GCs. Moreover, the addition of *Gaia* proper motions sampling the entire extension of the cluster will allow us to constrain the degree of anisotropy currently characterizing the system. More generally, for clusters at different dynamical stages a radial variation of the SP and FP velocity dispersion could be due to a combination of the effect of binaries and a radial gradient in the fraction of SP stars. Moving a step forward in our comprehension of the kinematics of MPs is in turn a key stage in the study of GC formation and evolution.

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