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Binary interactions and multiple stellar populations in globular clusters

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Abstract. Globular clusters (GCs) have multiple stellar populations, which show star-to-star abundance variations and multiple sequences (or spreads) in the Hertzsprung-Russell diagrams. It is explained by multiple generations of star-formation in GCs. However, the observed evidence of ongoing star-formation was not found within any clusters. Here we present a binary interactions scenario for the formation of multiple stellar populations in GCs, where GC stars were born in a single burst of star formation, but some of them are members of binary systems. Binary interactions can produce peculiar stars, e.g. the merged stars and the accretor stars. They are more massive than normal single stars in the same evolutionary stage, and they are rapidly rotating stars at the moment of their formation. Rotationally induced mixing can cause the variations of their surface chemical composition. This results in the single-generation GCs showing abundance anomalies.

Keywords. globular clusters: general, binary: general, stars: evolution, stars: rotation

1. Introduction

Globular clusters (GCs) are the oldest objects in our Galaxy, and they are gravitationally bound systems of thousand to about 10^6 stars. In the traditional view, all stars in the same GCs are commonly accepted to born at the same time and out of the same material, and then have the same age and the same metallicity. As a result, GCs have been considered as the best examples of single, simple stellar population for several decades, and the ideal laboratory for testing and calibrating the theory of stellar evolution and the dynamical evolution of star clusters.

However, recent spectroscopic and photometric observational results suggest that the parent GCs are more complex than a single, simple stellar population, and may present multiple stellar populations (Gratton, Sneden & Carretta 2004). Many GCs have an anomalous pattern in their chemical abundances, although all stars in a single GC share the same Fe abundance (see Gratton, Sneden & Carretta 2004, Piotto 2009, and references therein). Star-to-star variations are found in light-element abundances, rich in N, Na and Al, but poor in C, O and Mg, which are the typical results of the CNO, NeNa and MgAl cycles of hydrogen burning. There abundances of C and N, Na an O, or Mg and Al are anti-correlated with each other. However, Na-O and Al-Mg anticorrelations are almost absent among field stars (Gratton, Sneden & Carretta 2004). On the other hand, some GCs show rather than a single evolutionary sequence in the Hertzsprung-Russell (HR) diagrams (Piotto 2009).

Among the evolved stars of some GCs, the presence of star-to-star chemical variations has been known for several decades, and it is considered as the results of peculiar evolution of individual stars. But recently the extensive high-resolution spectroscopic

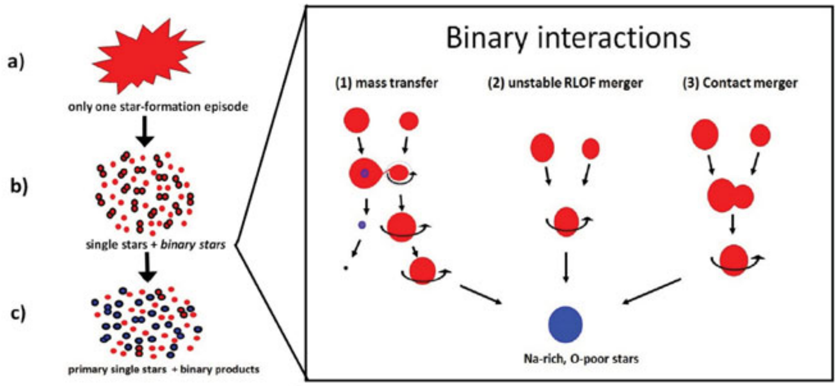

Figure 1. Schematic view for the formation of multiple stellar populations in GCs from binary interactions. a) all stars in a GC come from a single star-formation process; b) some stars in GC are born as close binary components while others are single stars; c) today, there are primary single stars and binary products (anomalous stars) in GC. Three main binary interactions are included in our model: (1) mass transfer; (2) unstable RLOF merger; (3) contact merger.

surveys in many GCs show that main-sequence and turn-off stars also have these variations (Gratton *et al.* 2001), which are considered as the evidence of primordial origin. Therefore, multiple stellar populations in GCs are explained to be formed from multiple star-formation processes, where the subsequent stellar generation (second generation stars) forms from gas chemically polluted by the ejecta from the previous generation (first generation stars) (Gratton, Sneden & Carretta 2004). However, many aspects of this self-pollution scenario are still unclear and currently debated (Gratton, Carretta, & Bragaglia 2012, and references therein). The nature of the first-generation polluter is uncertain, and the main candidates are asymptotic giant branch stars (D'Ercole *et al.* 2008), fast rotating massive stars (Decressin *et al.* 2007) and massive stars in interacting binary systems (de Mink *et al.* 2009). This scenario also does not agree with the observations of young massive clusters that appear to be well represented by a single burst of star formation (Kudryavtseva *et al.* 2012; Bastian & Silva-Villa 2013). Due to these shortcomings, Bastian *et al.* (2013) recently present a model for the formation of multiple stellar populations in GCs that does not require multiple star-formation episodes, where the low-mass stars accrete the enriched ejecta of high-mass stars through disc accretion.

It should be noted that some stars in GCs are members of binaries and many peculiar objects in GCs are closely related to binary interactions, e.g. W UMa contact binaries, blue stragglers and millisecond pulsars. Binary stars have peculiar evolution relative to single stars due to binary interactions. They can produce stars more massive than normal single stars in the same evolutionary stage by mass transfer and merger. These binary products may be hot enough for CNO cycle and NeNa cycle. Furthermore, they will be rapid rotating because binary interactions can convert orbital angular momentum into their spin angular momentum (de Mink *et al.* 2013). Rotationally induced mixing can bring part of the nuclear-processed products from the core to the surface (Decressin *et al.* 2007). Therefore, these binary products, e.g. the merged stars and the accretor stars, may have different surface abundances, effective temperatures, and luminosities.

2. Binary interactions scenario

In our scenario (Fig. 1), GC stars were still born in a single burst of star formation, but some of them are members of binary systems. The anomalous stars observed in GCs

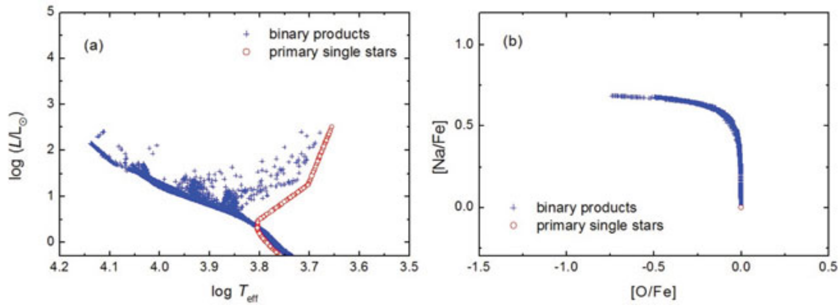

Figure 2. Distributions of the binary population at 10 Gyr. (a) the HR diagram. (b) the surface abundances (Na-O) plane. Blue pluses and red circles are binary products and primary single stars, respectively.

today are merged stars and the accretor stars produced by binary interactions. These binary products are rapidly rotating and more massive than the normal stars. They have different effective temperatures, luminosities, and surface abundances from single stars in the same evolutionary stage due to their evolution. Thus, the stellar population with binaries (the binary population) includes two sub-populations: (1) primary single stars with normal abundance (the initial abundance of GCs); (2) merged stars and accretor stars (produced by binary interactions) that have abnormal surface abundances through their own evolution.

There are three binary evolutionary channels for the formation of rapidly rotating stars: (1) a binary evolves into Roche lobe overflow (RLOF) and experiences stable mass transfer where the secondary obtains the mass and angular momentum transferred from the primary and subsequently becomes a rapidly rotating star (mass transfer channel for the accretor stars), (2) a binary evolves into RLOF and experiences unstable mass transfer while both components are still MS stars then merges into a rapidly rotating star (unstable RLOF merger channel for the merged stars), and (3) a binary evolves into contact and then merges into a rapidly rotating star (contact merger channel for the merged stars).

Using binary population synthesis, we simulate the distributions of the binary population at 10 Gyr(Fig. 2). The binary products show a different distribution from single stars in the HR diagrams, so the binary population show multiple/extended main sequences, turn-off, sub-giant branch and red-giant branch. It should be noted that most of these binary products will be blue stragglers or blue straggler progeny. On the other hand, these binary products also have anomalous surface abundances. They exhibit a large spread in sodium and oxygen abundances, while single stars do not show significant variations. The oxygen-depleted binary products have higher sodium abundances, e.g. the Na-O anticorrelation. Therefore, due to the present of binary products, the binary population has anomalous abundances and distribution in HR diagrams.

3. Conclusion

We suggested that multiple stellar populations in GCs may be formed from binary interactions. The anomalous stars are the binary products, include merged stars and accretor stars. This scenario does not require multiple star formation in GCs. Our results show that the binary population can reproduce the Na-O anticorrelation and multiple sequences in the HR diagrams. Therefore, binary interactions seem to be a possible scenario and we will further research in this direction.

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