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Formation History of Binary Clusters in the Large Magellanic Cloud

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Abstract. Global history of star or cluster formation in the Large Magellanic Cloud (LMC) has been the center of interest in several studies as it is thought to be influenced by tidal interaction with the Small Magellanic Cloud and even the Milky Way. This study focus on the formation history of the LMC in relation with the context of binary star clusters population, the apparent binary fraction (e.g., percentage of cluster pairs) in different epoch were calculated and analyzed. From the established distributions, it can be deduced that the binary clusters tend to be young (~ 100 Myr) while their locations coincide with the locations of star forming complexes. There is an indication that the binary fraction increases as the rise of star formation rate in the last millions years. In the LMC, the increase of binary fraction at age ~ 100 Myr can be associated to the last episode of close encounter with the Small Magellanic Cloud at ~ 150 Myr ago. This observational evidence supports the theory of binary cluster formation through the fission of molecular cloud where the encounter between galaxies enhanced the clouds velocity dispersion which in turn increased the probability of cloud-cloud collisions that produce binary clusters.

Keywords. galaxies: star clusters, statistics, evolution

1. Introduction

Large Magellanic Cloud (LMC) is not only one of the nearest galaxy from the Milky Way but also a good laboratory to study star and star cluster evolution through time. This dwarf irregular hosts more than 3000 star clusters with wide range of ages, such that part of LMC's history is reflected in its cluster population. Baumgardt *et al.* (2013) studied star cluster formation history of the LMC with a clear sign of burst formation about 1 Gyr ago. From the same study, further analysis to the cluster frequency over time indicated that LMC clusters disrupt ten times faster than normally expected.

With a prominent footprint of dynamical interaction with the Small Magellanic Cloud and even the Milky Way, LMC is also recognized as the host of significant fraction of binary and multiple star clusters whose dynamical and physical nature are interesting (Bhatia & Hadzidimitriou 1988). The expected lifetime of this system is $\lesssim 100$ Myr since internal and external dynamics push the system to merger or separation ending (Priyatikanto *et al.* 2016). The formation of binary clusters is possible through several alternative mechanisms such as instantaneous fragmentation of molecular cloud, cloud fission induced by collision, sequential formation, and the capture of closely passing cluster. Among those, cloud fission triggered by oblique collision (Fujimoto & Kumai 1997; Bekki *et al.* 2004) is the most likely mechanism to inject sufficient kinetic energy to the cloud such that orbiting binary cluster could be formed. It is believed that the latest collision between two Magellanic Clouds ~ 150 Myr ago increased the velocity dispersion within the galaxies and the probability of cloud-cloud collisions that produce binary and multiple star clusters. This significant fraction of multiple clusters may be affecting the global history of star cluster population in the LMC. To explore the formation history of binary clusters in the LMC and its possible influence to the whole population become the aim of current study.

2. Data and Methods

The main catalog used in this study came from Bica *et al.*(2008) which enlisted 9305 extended objects in Large Magellanic Cloud, Small Magellanic Cloud, and the interconnecting bridge. Among those objects, there are 3086 star clusters located in the LMC (excluding associations). For every object, they provided position (α, δ), dimension (major and minor axis), and classification (e.g., C for clusters). The clusters' equatorial coordinates were transformed into $2D$ cartesian system using Gnomon projection centered on $(\alpha_0, \delta_0) = (80°, -69°45')$.

From their positions in $2D$ space, cluster pairs were identified as two clusters with projected separation $s < 20$ pc ($< 1.37'$ assuming distance modulus of 18.49). Using this criterion, 281 binary and multiple systems were identified: 10 overlapped systems, 217 doubles, 39 triples, 9 quadruples, and 5 multiple systems with more than four components. This group list actually consists of 634 individual clusters.

The ages of the clusters were compiled from literatures. Various approaches were used in those literatures, including SWB classification of young clusters, color-magnitude diagram fiitting, and spectral energy distribution modeling. If any cluster has more than one published ages, then the arithmatic mean of those ages were adopted. However, the compiled cluster ages only cover 65% of the identified pairs/groups. To increase the completeness, a number of conspicious clusters were re-analysed photometrically such that their ages could be estimated. The photometric data for these analysis came from the Optical Gravitational Lensing Experiment (OGLE, Udalski *et al.* (1997)) and the Magellanic Clouds Photometric Survey (MCPS, Zaritsky *et al.* (2004)) catalogue. PARSEC isochrones Bressan *et al.* (2012) were used to model the observed color-magnitude diagram of the clusters. This process increased the number of clusters with known age up to 88% (557) of the initial sample.

3. Results and Discussion

Figure 1 are the plots depicting the formation history of binary and multiple clusters in the Milky Way both in time and spatio-temporal domain. The cluster frequency (dN/dt) shows several important features which can be interpreted as the slight increase of cluster formation rate at ~ 30 Myr ago and prominent burst formation at ~ 100 Myr, while the rise of formation rate at ~ 1 Gyr is rather vague. This result is quite different from Baumgardt *et al.* (2013), but it is comparable with the star formation history from Harris & Zaritsky 2009. More young cluster sample used in this study seems to accentuate proxies of recent history of cluster formation.

Binary and multiple cluster frequency was also calculated at the same age bin and the binary fraction can be computed. The average uncorrected binary fraction is 20%. From Monte Carlo simulation of randomly positioned clusters, it was concluded that 10% of the cluster pairs are statistical or non-physical such that the appropriate value of binary cluster fraction in the LMC is 10%. Apart from possible contamination of statistical pairs, relative variation of binary fraction displayed in Figure 1 implies the episodes of binary clusters formation history in the LMC.

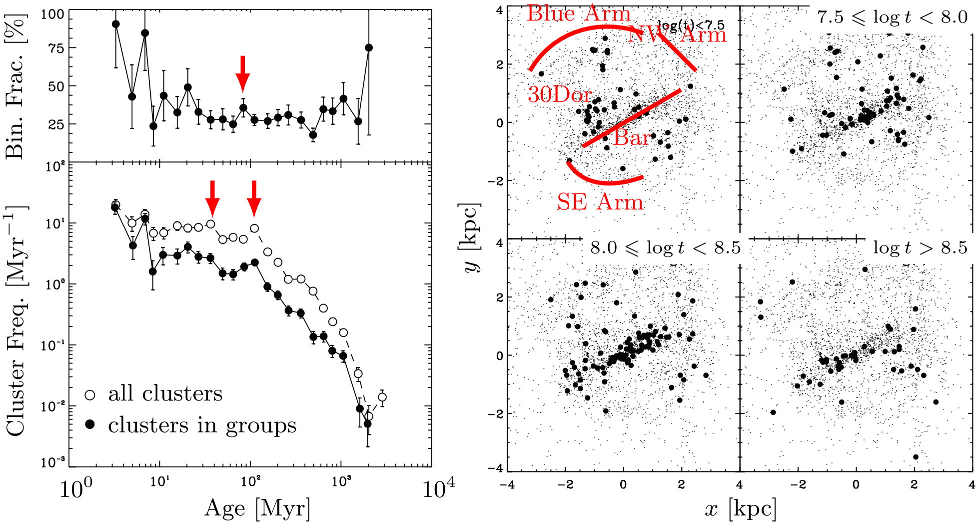

Figure 1. Lower left: cluster frequency (dN/dt) as a function of age constructed from all clusters sample (filled circle) and clusters in groups (empty circle). Upper left: binary cluster frequency through time, uncorrected from statistical pairs. Right: spatio-temporal distribution of cluster pairs.

First, higher binary fraction at age $\lesssim 30 Myr$ is a bold evidence that star clusters tend to form in group or in other word, most of young binary and multiple clusters were formed through fragmentation of molecular clouds. The resulted multiple clusters systems are not stable for very long time and they will disperse or merge in < 10 Myr (e.g., Fujji *et al.* (2012).

Second episode to consider is the increase of binary fraction from 25% to $\gtrsim 30\%$ at age ~ 100 Myr happens just after the burst formation. If the cluster formation was induced by close encounter between the Magellanic Clouds 150-200 Myr ago, then rise of binary fraction is consistent with the cloud fission scenario (Fujimoto & Kumai 1997, Bekki *et al.* 2004). Some of the binary clusters is located in the Northeast and Blue Arm of the LMC wher the density was possibly enhanced due to encounter (Bekki & Chiba 2007).

At age $\gtrsim 200$ Myr, the binary fraction is considerably high ($\sim 25\%$) with positive trend as a function of age, expect at ~ 2 Gyr where the error is large. Older clusters tend to be located in densely populated region, e.g., the Bar, such that more statistical pairs contaminate the sample. High density environment is also magnify the chance of cluster-cluster encounter and also tidal capture.

From the evolution perspective, significant fraction of binary star clusters is expected to affect the global history of clusters in the LMC. Depends on the strength of internal and external gravitation field, some of binary clusters will eventually merge into clusters with significant degree of rotation while the other will be separated. The merger processes often include burst of mass loss and enhanced evaporation rate due to excess of kinetic energy (Priyatikanto *et al.* 2016). This may contribute to the faster dissolution process as concluded by Baumgardt *et al.*(2013).

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