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An Analysis of Blue Straggler Stars in Open Clusters

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ABSTRACT

The presence of blue straggler stars (BSSs) in open clusters (OCs) presents an opportunity to study star formation and cluster dynamics. Our paper analyzes several properties of BSSs across 161 OCs of different ages, metallicities, and sizes. Specifically, we examine the impact of cluster age and metallicity on the number of BSSs as well as the spatial distribution of BSSs within each cluster. We report a positive correlation between the age of the cluster and the number of BSSs present. This investigation into BSSs provides valuable insights into their formation as well as the dynamics and interactions within open clusters.

1. INTRODUCTION

Blue straggler stars (BSSs), typically found in star clusters, are a unique category of stars that are unusually bluer and more luminous than those at the main sequence (MS) turn-off (Sandage 1953). Specifically, BSSs are high-mass, high-temperature stars situated on a prolongation of the MS in the color-magnitude diagram. This is an area where most stars of similar mass have already exhausted their supply of hydrogen and evolved toward the red giant branch, yet BSSs remain, seemingly contradicting the anticipated course of stellar evolution.

Our analysis was multifaceted. First, we examined the relationship between the age of a cluster and the concentration of BSSs, which may provide insights into the formation timeline for BSSs. Second, we considered cluster metallicity in relation to the frequency of BSSs in an attempt to relate metallicity, binary frequency, and BSS frequency. Third, and finally, we examined the distance of BSSs with respect to the center of their host clusters seeking to shed light on BSS formation and migration patterns.

2. DATA COLLECTION

We made use of the detailed catalog of 50 open clusters with BSSs from Li, Chunyan et al. (2023). We use an additional data set with 111 OCs containing BSSs from Rain et al. (2021) for data on cluster age and number of BSSs. The data sets were subsequently modified and filtered to best fit our analyses. Preliminary analysis revealed the dataset from Li, Chunyan et al. (2023) contained 87 BSSs, 57 probable blue straggler stars (PBSs), and 14 yellow straggler stars (YSSs), while the dataset in Rain et al. (2021) contained 897 BSSs, 77 PBSs, and no YSSs.

We used several Python libraries to conduct our analysis. Our data was organized using a combination of Pandas and NumPy. Data visualizations were created using Plotly and Matplotlib.

3. RESULTS AND ANALYSIS

3.1. *Number of BSSs and Age of Cluster Relationship*

Our analysis revealed the number of BSSs and the age of a cluster show a positive correlation: low counts of BSSs are present at every age, with larger numbers of BSS only visible in a portion of clusters with $\log(age) \geq 8.7$, as seen in Figure 1(A). In other words, older OCs ($\log(age) \geq 8.7$) generally tend to have more BSSs than younger OCs ($\log(age) < 8.7$).

As the most plausible leading theories suggest, the majority of BSSs form through dynamical processes and binary interaction mechanisms such as mass transfer and merging (Gosnell et al. 2019). Consequently, we hypothesize that the larger number of BSSs seen in older OCs is due to mass transfer and binary merging within close binary star systems, which are expected to grow with time.

3.2. *Cluster Metallicity and the Number of BSSs*

We graphed the number of BSSs in the 50 OCs dataset from Li, Chunyan et al. (2023) as a function of the cluster metallicity Z. The results show that metallicity has little correlation to the number of BSSs in these clusters. Specifically, the average cluster metallicity varied between 0.010 and 0.018, without significant apparent differences or trends in the number of BSSs. This is illustrated in Figure 1(B).

However, it is important to note there is some evidence to support that cluster metallicity may be correlated to the number of BSSs present. Hurley et al. (2004) conducted simulations using N-body code to investigate how metalicity affects the dynamics within open clusters. In these simulations, they found a greater number of BSSs in high-Z OCs. It was theorized that "a greater MS turn-off mass makes it more likely that an MS star will be involved in an exchange interaction and more likely that this MS star would be retained in the emerging binary (Hurley et al. 2004)." While our dataset did not show a significant correlation between metallicity and the number of BSSs, it is possible that the range of metallicities we examined (0.010 to 0.018) was not sufficiently high to observe the effects noted in Hurley et al. (2004). Higher metallicity values might be necessary to see a clear correlation between metallicity and the number of BSSs, potentially indicating that OC metallicity only affects the number of BSSs when it is substantially higher than that of a typical middle-aged OC.

3.3. *BSS Distance from Cluster Centers*

Another factor analyzed was the relationship between straggler status and distance to the center of a cluster. The cluster center locations were given in the data, and each star's location was also provided. As such, we were able to approximate the distance to the center using the Euclidean distance based on right ascension and declination measurements. We did not include the parallax of each individual star in these measurements, since it could add significant noise to the data—these tend to have higher error, and finding parallax differences between stars and cluster centers would require much higher precision. As a result, this is a 2D approximation of the true 3D distance for each star to its cluster's center. However, since there are multiple data points aggregated for our analysis, and since we would expect the distribution of true star parallaxes to be normal and centered around the cluster's parallax, we estimated that it would be relatively safe to draw conclusions about distances based solely on right ascension and declination. Essentially, we assumed that each star's parallax was the same as that of the cluster's center, since this would eliminate any noise in these measurements.

In order to find the distance between a given star and the center of the cluster, we first calculated the angular distance in degrees using the Euclidean distance formula. Then, we calculated the distance between these two points by factoring in the cluster's parallax. The following formulas describe our calculations:

$$a = \sqrt{(RA_c - RA_s)^2 + (Dec_c - Dec_s)^2}$$

$$d = \frac{1000}{Plx} \cdot \tan\left(\frac{\pi}{180} \cdot a\right)$$

The parameters utilized above are listed as follows:

- RA_c is the measured right ascension for the center of the cluster, measured in degrees.
- RA_s is the measured right ascension for the star, measured in degrees.
- Dec_c is the measured declination for the center of the cluster, measured in degrees.
- Dec_s is the measured declination for the star, measured in degrees.
- a is the angular distance between the star and the center of the cluster, measured in degrees, as given by the above formula (which utilizes Euclidean distance).
- Plx is the measured parallax for the cluster, measured in milliarcseconds (mas).
- d is the calculated distance between the center of the cluster and the star, measured in parsecs (pc).

Upon conducting our analysis of these clusters, we noticed no statistically significant difference between the average distance of straggler stars (SSs) compared to non-straggler stars (NSSs) to the center of their clusters, as shown in Figure 1(C). For each category, the mean distances were all between 10 and 15 parsecs, and the standard deviations were between 13 and 19 parsecs. Using a two-sample T test, we determined that there was no statistically significant difference between the sample of NSSs and each of the three samples of SSs. Specifically, when compared against the sample of NSSs, the p-values evaluated to 0.926 for the BSSs, 0.894 for the PBSs, and 0.249 for the YSSs. These p-values were relatively high because the means between each of the samples were relatively similar and the standard deviations were relatively large.

We hypothesize one reason for this lack of difference in distance is possibly due to the weaker central gravitational force in OCs compared to globular clusters (GCs). Generally, GCs have been observed to have a strong central concentration of BSSs (Mapelli et al. 2006). In contrast, OCs tend to be larger and sparser than GCs, meaning they would likely have less dynamical friction, and the BSSs within them would experience less significant mass segregation compared to those in GCs (Rain et al. 2021).

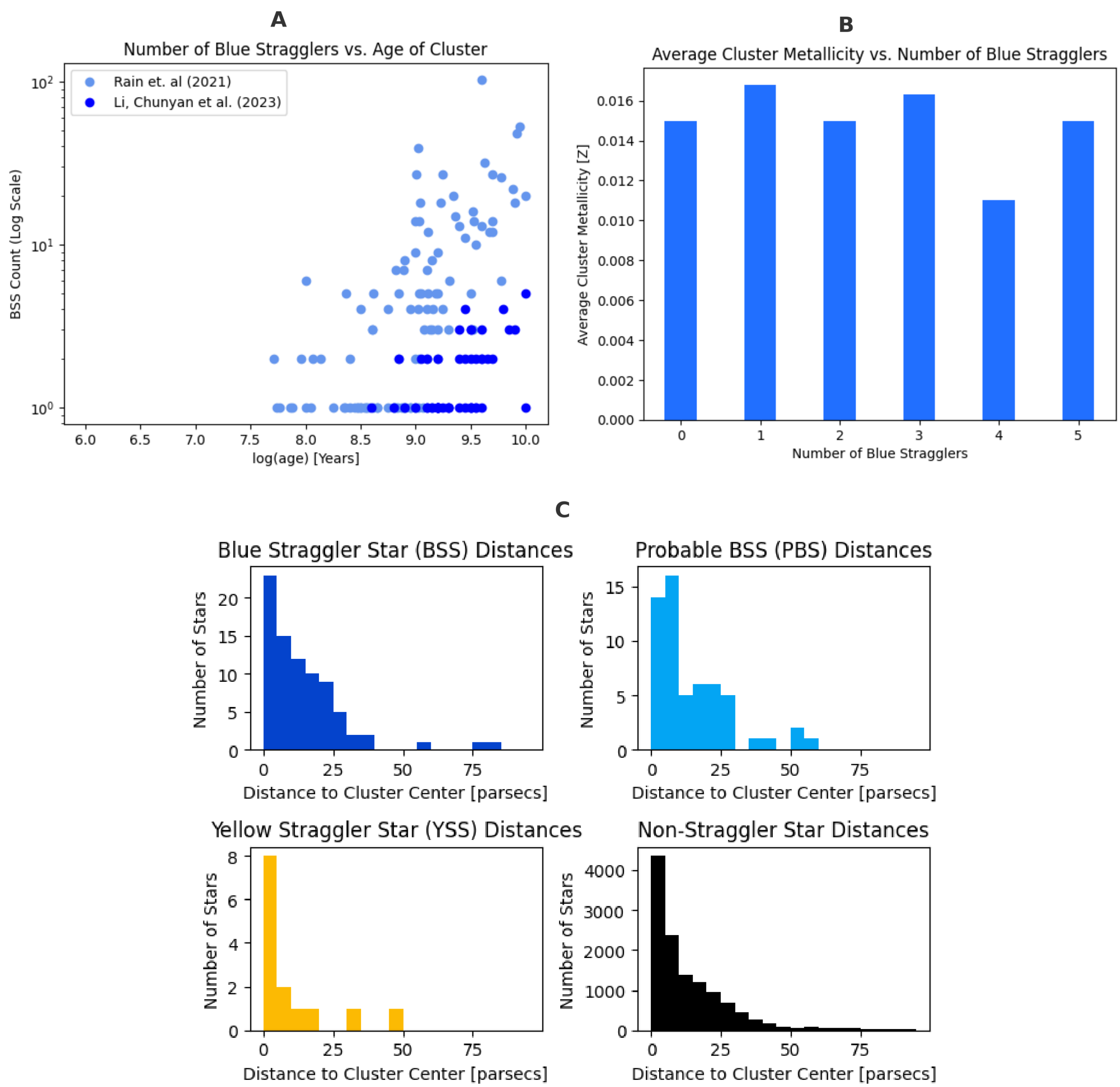

Figure 1. (A) Number of BSSs and age of cluster positive correlation; (B) Number of BSS compared to average cluster metallicity; (C) Distances to the center of a cluster for BSS, PBS, YSS, and all other stars

4. CONCLUSION

The positive correlation between the age of a cluster and its BSS frequency suggests that the formation and evolution of BSSs are linked to the dynamic processes within these clusters over time. This corroborates with the leading mass transfer and binary merger theories for the formation of BSS. In investigating various properties, we gathered meaningful insights into BSSs, OCs, and their unique characteristics and patterns.

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