Massive Stars Near and Far
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In-Situ Field Massive Star Formation in the Small Magellanic Cloud

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Abstract. A fundamental question for theories of massive star formation is whether OB stars can form in isolation. We assess the contribution of any in-situ OB star formation by using 210 field OB stars in the Small Magellanic Cloud (SMC) from the Runaways and Isolated O-Type Star Spectroscopic Survey of the SMC (RIOTS4). We search for tiny, sparse clusters around our target OB stars using cluster-finding algorithms. Employing statistical tests, we compare these observations with random-field data sets. We find that $\sim 5\%$ of our target fields do show evidence of higher central stellar densities, implying the presence of small clusters. This frequency of small clusters is low and within errors, it is also consistent with the field OB population being composed entirely of runaway and walkaway stars. Assuming this small cluster fraction is real, it implies that some OB stars may form in highly isolated conditions. The low frequency could be caused by these clusters evaporating on a short timescale. However, another interpretation is that the low fraction of small clusters is observed because these form rarely, or not at all, implying a higher cluster lower-mass limit and generally consistent with a relationship between maximum stellar mass (m_{max}) and the cluster mass (M_{cl}).

Keywords. massive stars — field stars — Small Magellanic Cloud — open star clusters — star formation — runaway stars — multiple star evolution — OB associations — stellar populations

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1. Introduction

Field stars account for $25-30\%$ of normal OB star populations (Oey et al. 2004). Field stars have two different possible origins: runaways, i.e., stars that are ejected from their parent cluster; or stars that form in situ in apparent isolation. The latter could happen, for example, if the stellar initial mass function (IMF) and cluster mass function (CMF) behave as probability density functions, allowing smaller, sparser clusters with a single massive star to form. We call the massive star in such a cluster a Tip-of-the-Iceberg Star (TIB). Simulations by Lamb et al. (2010) are consistent with the existence of these TIB clusters, and observations of field stars (Oey et al. 2013) have found evidence of potential in-situ formation. However, the frequency of in situ formed field OB stars has not been well established. Therefore, we used The Runaways and Isolated O-Type Star Spectroscopic Survey of the SMC (Lamb et al. 2016; RIOTS4) and OGLE III photometry (Udalski et al. 2008) to identify a 210-target sample to search for TIB clusters using cluster-finding algorithms to assess the contribution of any in-situ OB star formation in a complete sample of field stars.

2. Methods & Results

Our two cluster finding algorithms are Friends-of-Friends (FOF) and Nearest Neighbors (NN). FOF identifies associated stars ("friends") as those that are within a given clustering length (l_c) of another member. Each l_c is specific to each target field ($l_{c,field}$). Clusters are more likely to be those with a greater number (N_*) of stars identified or those with a higher M value, where $M = \frac{l_{c,SMC}}{l_{c,field}} N_*$ and $l_{c,SMC}$ is the average l_c for all our target-star fields. A higher M-value corresponds to a larger number of stars closely spaced together. The NN algorithm measures the stellar surface densities Σ_j associated with a given target star, calculated by counting the number of stars within radius r_j defined by its jth nearest neighbors: $\Sigma_j = \frac{j-1}{\pi {r_j}^2}$. We compare the resulting Σ_j with the background densities Σ_{bg} calculated for each target. The larger the difference, the more likely the target belongs to a cluster.

We compare the observed data with randomly generated fields for each target that serve as controls, and are therefore not independent of the observed data. We use two statistical tests for these comparisons: the Wilcoxon test (W), which looks for differences between two non-parametric, non-independent datasets; and the Rosenbaum test (R), which evaluates differences in the tails of two non-independent distributions, and are thus more sensitive to the presence of TIB clusters. We also compare known runaway stars (Oey et al. 2018), which should not show TIB clusters, with the rest of our targets, the non-runaways, using the K-S test and the Anderson-Darling (AD) test, which are valid when comparing independent samples. The AD again gives more weight to the tails of the distributions.

Both our FOF and NN results show a very small presence of positive detections. However, the statistical significance of the FOF results for the non-runaway sub-sample against the random fields is lower (W p-values: 0.00 – 0.1), relative to the NN results (W p-values: 0.00 – 0.03). The NN algorithm also shows a greater significant difference between the non-runaways and the runaways (KS and AD p-values: 0.02 – 0.07), which is expected of real detections. However, some statistical tests of the non-runaways against the random fields do not confirm a detection (R p-values: –0.50 – 0.50), thus these ambiguous results imply that TIB clusters are only marginally detected. Overall, we estimate a percentage of TIB clusters of $\sim 4\%$. For a complete discussion, please see Vargas-Salazar et al. (2020).

In summary, there is evidence that $\sim 4\%$ of field stars do form in situ in TIB clusters. The rest of the population is overwhelmingly composed of runaways. There are three possible scenarios for this result: 1) TIB clusters usually do not form with OB stars. 2) The cluster lower-mass limit is high, preventing the formation of TIB clusters. 3) Clusters evaporate quickly, thus our detections are clusters that have not yet evaporated. Our results place stringent constraints on the formation of OB stars in isolation.

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S1743921322002691.

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