Star Clusters in Interacting Galaxies: The Case of M51

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1 Introduction

We present the results of an analysis of a population of stellar clusters in the interacting galaxy, M51, using \textit{HST-WFPC2} observations. The observations were made in five broad band filters; f336w (U), f439w (B), f555w (V), f675w (R), f814w (I), and transformed to the closest corresponding Cousins-Johnson filter magnitude using the equations defined by Holtzmann \cite{5}. Only sources that were found in every filter were analysed. By comparing the spectral energy distribution (SED) of each source with those those of evolutionary spectral synthesis models \cite{4}, we have derived an age, mass, and extinction for each source. The comparison was done using the \textit{3DEF} method \cite{2}, that is based on a least $\chi^2$ test. Only sources that were well-fit ($\chi^2_\nu \leq 1.0$) and resolved (fwhm $\geq 1.5$ pixels) \cite{1} were used in this study. 533 sources pass these criteria, and will be referred to as clusters for the remainder of the paper. With this sample we are able to study the cluster formation history, the cluster initial mass function (cIMF), and search for evidence of cluster disruption.

2 Distributions of the Resolved Population

2.1 Mass, Extinction and Luminosity profiles.

In the following sections, all fits were done without the R band, as this band has been found to be heavily contaminated by H$\alpha$ emission. Figure 1 shows the mass, extinction, and magnitude distributions of the cluster sample, as well as the age vs. mass diagram. The age distribution will be discussed in Section 3. We see that our sample is incomplete fainter than $M_V$ of -9.5 and cluster masses below $10^4 M_\odot$. The solid line in the age vs. mass distribution is the detection limit for $R_{lim} = 22.0$ mag. As expected the lowest observable mass increases as a function of age (after 10 Myr), as the clusters fade due to stellar evolution.

2.2 Cluster IMF

In order to look at the cluster IMF, one needs to look at the cluster population that has not been affected by disruption. Recently, Boutloukos & Lamers (2002) have found that the characteristic disruption timescale of a $10^4 M_\odot$ cluster is $\sim 40 Myr$ in M51, at a similar distance from the nucleus as the present observations.
Fig. 1. The mass, extinction, age vs. mass, and absolute magnitude distributions of the 533 clusters that are well fit and resolved.

Due to the uncertainties in age fitting, we adopt a conservative age cut-off of 10 Myr, when looking at the cluster IMF. Figure 2 shows the cumulative mass distribution of all well-fit clusters with ages \( \leq 10 \) Myr. Clearly \( \alpha = 2.0 \) is the best fit, though there is a significant deviation from this at higher masses. This may be evidence of a double power-law cIMF, though it cannot be ruled out as an effect of uncertainties in the mass calculations.

Fig. 2. The cumulative mass distribution of all well-fit clusters with ages \( \leq 10 \) Myr. Over plotted are the power laws of the form \( N(M_c) \propto M_{cl}^{-\alpha} \) for \( \alpha = 2.1, 2.0, 1.9 \) from top to bottom respectively.
3 Evidence for Disruption

Following the work of Boutloukos & Lamers (2002, BL02), we have searched our sample for evidence of cluster disruption. Our sample has the benefit over previous studies of disruption in M51 of covering a much larger area of the galaxy. The deficiency of this study is the brighter detection limit which hampers our analysis. We adopt the same method to find the characteristic cluster disruption timescale as BL02, which assumes that clusters disrupt as a function of their initial mass as

\[ t_{\text{dis}}(M_{cl}) = t_{\text{dis}}^4 \left( \frac{M_{cl}}{10^4 M_\odot} \right)^\gamma, \]

where \( t_{\text{dis}}^4 \) is the characteristic disruption timescale for a \( 10^4 M_\odot \) cluster.

Fig. 3 shows the age (clusters formed per Myr) and mass (clusters formed per \( M_\odot \)) distributions. We see that the distributions show little to no dependence on the distance from the center of M51, though we note that the expected break in the mass distribution is below our detection limit. The last mass bin in the \( 3.0 < D_{GC}(\text{kpc}) < 5.5 \) sample has only one cluster in it, and as such it should not be considered as a reliable data point. The age distributions do not show any significant evidence for a burst in cluster formation during the last Gyr. This may be physical or it may be caused by a low age resolution that we are able to reach with our data. The 3DEF method takes into account the observational errors in calculating the error associated with the determined age, and therefore smaller observational errors result in a more refined age determination.

Following the method prescribed in BL02, we have derived values for \( \gamma \), though we are not able to find values for \( t_{\text{dis}}^4 \) due to the lack of an observed break in the age and mass distributions. From the age distribution we derive \( \gamma = 0.69 \pm 0.15 \) in excellent agreement with the findings of BL02, while from the mass distributions we derive \( \gamma = 0.47 \pm 0.15 \) (assuming \( \alpha = 2.0 \)). These two values suggest that \( \gamma \simeq 0.57 \pm 0.11 \), in agreement with the mean value of \( 0.62 \pm 0.06 \) found by BL02 in four different galaxies.

4 Conclusions and Future Work

- The cluster Initial Mass Function is well represented as a power law with an index of \(-2.05 \pm 0.05\), although there is a significant deviation at higher masses.
- The derived values of the disruption parameter \( \gamma \) and the exponent of the cluster IMF \( \alpha \) is independent of the distance from the center of M51.
- The data was not deep enough to trace the characteristic disruption timescale as a function of increasing distance from the galactic center.
- We find values of \( \gamma \) of \( 0.69 \pm 0.15 \) and \( 0.47 \pm 0.15 \) from the age and mass distributions respectively. These values are only marginally consistent with each other.
- We will look for the dependence of the cluster disruption timescale on the cluster radius, which will give a more precise description of the disruption, and can be compared with predictions.
Fig. 3. The age (top figures) and mass (bottom figures) distributions for clusters broken into two different distance bins (the left plots are for clusters from $0.75 < D_{GC} < 3.0$ kpc, and the right plots are for clusters from $3.0 < D_{GC} < 5.5$ kpc, where $D_{GC}$ is the distance from the galactic center). The dashed lines represent the expected fading line for a continuous formation history of clusters (note that the vertical scaling of this line is arbitrary and it is used here just to denote the expected distribution if disruption was not important). The solid line is the slope predicted by BL02 if $\gamma = 0.62$. The dotted lines are the best fit to the data for clusters with $t_{cl} > 10^7$ yr and $M_{cl} > 10^4 M_{\odot}$ (i.e. above the detection limit) for the age and mass distributions respectively. The slope of this line is given for each distribution.

References

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