1. INTRODUCTION

The age and mass distributions of a population of star clusters provide important clues to their formation and disruption. Recent studies of the cluster populations in nearby star-forming galaxies have suggested that the observed distributions are dominated by the disruption, rather than the formation, of the clusters. Some physical processes (e.g., the evaporation of stars as a result of two-body relaxation) are known to disrupt low-mass clusters earlier than high-mass clusters, thereby imprinting as a result of two-body relaxation) are disrupted low-mass clusters earlier than high-mass clusters, thereby imprinting a characteristic timescale for cluster disruption processes that depends on the mass of the clusters, and this timescale depends strongly on the local environment.

The motivation for this work is threefold: to empirically determine the age and mass distributions of star clusters in the nearby spiral galaxy M83, to understand how the selection of the clusters affects the results, and to test whether clusters are disrupted at a rate that depends on their mass.

We use multiband observations of two fields in M83, taken as part of our program GO-11360, for this purpose. These images were observed with the Wide Field Camera 3 (WFC3) onboard the Hubble Space Telescope (HST). We present new cluster catalogs selected using different methods and compare with catalogs previously published by Chandar et al. (2010) and Bastian et al. (2012). The cluster age and mass distributions observed in each field are then compared with predictions from mass-dependent and mass-independent disruption models.

The rest of this paper is organized as follows. Section 2 summarizes the observations and photometry, describes the selection procedures used to create the various star cluster catalogs, and explores the similarities and differences between these catalogs. This section also summarizes the method used to determine the ages and masses of the clusters. Section 3 presents the age and mass distributions of the clusters in the two fields in M83 using all of the cluster catalogs. Section 4 discusses the implications of the mass–age results from the two fields for the formation and disruption of the clusters. Section 5 summarizes the main results of this work.

2. OBSERVATIONS, PHOTOMETRY, AND CLUSTER CATALOGS

2.1. HST Data and Photometry

Multiband images of two 3.6 × 3.6 kpc² portions of M83 were taken with the WFC3 on the HST, one covering the nucleus (inner field) and presented previously in Chandar et al. (2010), and a second pointing to the north (outer field). These
observations were taken as part of the Early Release Science program 1 (GO-11360; PI: O’Connell). In this work, we use observations taken in five filters, $F_{336W}$, $F_{438W}$, $F_{555W}$, and $F_{814W}$ filters, normalized by the typical root mean square in each image. This results in a white light image, which gives approximately equal weight to the different filters. This procedure allows us to include objects in our source list that are very blue or very red, such as blue and red supergiant stars, that otherwise might not be detectable in any given filter. We identified all sources, both point-like and slightly extended, using the IRAF task DAOFIND on a median-divided white light image (see discussion in Miller et al. 1997). This initial source catalog contains individual stars, close blends of a pair or a few stars, star clusters, and background galaxies.

We perform circular aperture photometry of all detected sources on the drizzled images for each filter using the IRAF task PHOT with an aperture radius of 3 pixels and a background annulus between 10 and 13 pixels. For the narrowband $F_{657N}$ (H$\alpha$) image, we perform photometry on the original image without subtracting the stellar continuum flux. Aperture corrections were made on the basis of the measured size of each cluster, using the formula given in Chandar et al. (2010). We convert the instrumental magnitudes to the VEGAMAG magnitude system by applying the following zeropoints: $F_{336W} = 23.46$, $F_{438W} = 24.98$, $F_{555W} = 25.81$, $F_{657N} = 22.35$, and $F_{814W} = 24.67$, which are provided by STScI at the following URL: http://www.stsci.edu/hst/wfc3/phot/zp/lbn. We loosely refer to these as “$U$,” “$B$,” “$V$,” “H$\alpha$,” and “$I$” band magnitudes, although we do not make any transformations to the Johnson–Cousins system.

### 2.2. Cluster Selection and Comparison Between Catalogs

One of the goals of this work is to assess the impact that the method used to select stellar clusters has on the resulting mass and age distributions. Bastian et al. (2012) discussed the impact of selection by comparing their results with those presented in Chandar et al. (2010) for the inner field, but this is the first time that such a comparison has been made for the outer field in M83.

The following are three methods of cluster selection: (1) Fully automated selection based on criteria that find objects that are slightly broader than the point spread function (PSF), followed by minimization of blends using algorithms discussed in Chandar et al. (2010); (2) fully manual selection, based on a detailed by-eye examination of the sources within the images to assess whether they are broader than the PSF (Chandar et al. 2010); and (3) a hybrid method where contaminants are rejected on the basis of visual inspection after generating an automated catalog (Bastian et al. 2012). While automatic methods are preferred in terms of repeatability and objectivity, these methods often have difficulty distinguishing close pairs of stars from resolved star clusters, especially in crowded regions. Although manual methods are subjective, they have the advantage that each candidate is examined individually. We find many cases that are easily classified by eye but incorrectly identified by automated techniques (e.g., a diffuse cluster with a very nearby star or diffraction spikes from saturated stars). For these reasons, we construct both manual and automatic catalogs and use the differences between them to help estimate uncertainties in the resulting mass and age distributions.

One of the key differences between the Bastian et al. (2012) selection and ours is that they attempt to make a distinction between bound and unbound clusters by eliminating sources that are asymmetric or that do not have a strong central concentration. This effectively eliminates mostly very young $\tau \lesssim 10^7$ yr clusters, such as source S652 in Figure 2, which is slightly asymmetric, but appears to be a bona fide compact

### Figure 1. Color images of two fields in M83 produced using the HST/WFC3 observations described in this work. $U$ plus $B$ band images are shown in blue, the $V$ band in green, and a combination of the $I$ and H$\alpha$ filters in red. The rectangular region is used in Figure 2 to compare different cluster catalogs.
star cluster. We do not attempt to make a distinction between bound and unbound clusters on the basis of morphology, because it is not possible to determine from the appearance of a cluster whether it has positive or negative total (potential plus kinetic) energy (e.g., Baumgardt & Kroupa 2007). Even with velocity dispersion measurements made from high-resolution spectroscopy, it is difficult to determine whether a cluster is bound or unbound.

In this work, we use six catalogs of compact star clusters, three each in the inner and outer fields, selected using the aforementioned methods. The total number of clusters in each catalog are as follows: (1) Manual: \( \approx 490 \) inner field, \( \approx 530 \) outer field; (2) Automatic: \( \approx 660 \) inner field, \( \approx 720 \) outer field; and (3) Hybrid: \( \approx 460 \) inner field, \( \approx 480 \) outer field.

The top panel of Figure 2 compares the three cluster catalogs in the portion of the outer field outlined in Figure 1. This figure shows several interesting results. Our automatic catalog misses very diffuse clusters; it includes as clusters some questionable sources in the most crowded regions. Our manual catalog appears to do significantly better, but it is subjective and therefore difficult to assess completeness quantitatively. The Bastian et al. (2012) catalog has few sources in crowded regions, and it appears to go deeper in regions of low background. The lists of cluster candidates in this area agree at about the 40\%–70\% level, similar to the \( \approx 60\% \) level of agreement found by Bastian et al. (2012) for the catalogs covering the inner field. The reader is referred to Whitmore et al. (2014) for more detailed discussion, including a comparison with a fourth catalog obtained using automatic criteria on Hubble Legacy Archive (http://hla.stsci.edu) source lists, which also agrees at roughly the 60\% level. The key question, however, is whether these different cluster catalogs based on different selection criteria yield strongly different mass and age distributions.

2.3. Age Dating Technique

Figure 3 compares the \( U - B \) versus \( V - I \) colors measured for the clusters in each catalog with predictions from the twice solar
metallicity stellar population models of S. Charlot & G. Bruzual (2009, hereafter CB09, private communication; see also Bruzual & Charlot 2003). The model predictions, shown as the solid line, cover the age range from $10^6$ to $10^{10}$ yr, starting from the upper left end of the curve to $10^{10}$ yr at the bottom right end. An $A_V = 1.0$ reddening vector is shown in the upper left panel.

We estimate the age $\tau$, extinction $A_V$, and the mass for each cluster as we have done in previous works (for details, see Fall et al. 2005; Chandar et al. 2010), by comparing the observed and predicted $U$, $B$, $V$, $I$, and $H\alpha$ magnitudes. We perform a $\chi^2$ fit to the predictions from the CB09 stellar population models with solar metallicity. The narrowband $H\alpha$ filter contains both stellar continuum and nebular line emission, allowing us to include it directly in the fit for clusters of all ages. The mass of each cluster is estimated from the extinction-corrected $V$ band luminosity, assuming a Galactic extinction law (Fitzpatrick 1999), and the age-dependent mass-to-light ratios ($M/L_V$) predicted by the CB09 models. We assume a Chabrier (2003) initial stellar mass function; if we had adopted the Salpeter (1955) initial mass function (IMF) rather than the Chabrier IMF, the $M/L_V$, and hence the estimated masses, would increase by a near constant $\approx 40\%$, but the ages would remain the same.

We note that the predictions from the BC09 models assume that the stellar IMF for each cluster is fully sampled. The colors of clusters with masses below $\approx 10^5 M_\odot$ begin to spread significantly around these predicted models because the upper end of the stellar IMF within these clusters are not fully populated. These stochastic fluctuations in the number of massive stars can lead to variations in the intrinsic optical colors of clusters with similar ages (and masses). However, Fouesneau et al. (2012) found that the resulting age and mass distributions are similar for clusters more massive than a few $10^5 M_\odot$ regardless of whether the observed colors are compared with fully sampled or stochastic model predictions. Using this as a guideline, we use $\approx 3 \times 10^5 M_\odot$ as a lower limit for our analysis.

3. RESULTS

3.1. Cluster Mass versus Age Diagrams

In Figure 4, we show the log $M$-log $\tau$ diagrams for the different cluster catalogs in the inner (upper panels) and outer (lower panels) fields observed in M83. The method used to determine the cluster masses and ages for the catalogs presented here is described in Section 2.3. We do not rederive the masses and ages of clusters in the Bastian et al. (2012) catalogs; rather, we use their values directly.

The solid (approximately) diagonal line in each panel shows predictions for a $M_V = -6.0$ cluster in the mass–age plane, and it is a reasonable estimate of the magnitude limit of our cluster catalogs. A comparison of the results shows that, at least qualitatively, the three different catalogs provide similar distributions in the inner and outer fields. The $M$ – $\tau$ diagrams show that clusters in our fields have formed with a continuous range of ages from $\approx 10^6$ to $10^{10}$ yr. The diagrams also show a number of small-scale features, with gaps at some ages and apparent overdensities of clusters at other ages. These types of features are expected when estimating ages by comparing observed cluster spectral energy distributions with predicted stellar evolution models. This is because the predicted colors loop back on themselves, creating a fairly small range in the predicted shapes of the spectral energy distributions over a relatively large age span, resulting in gaps and other small-scale artifacts. These small-scale features do not, however, affect the broad distribution of cluster masses and ages in a significant way (e.g., Fouesneau et al. 2012).

3.2. Cluster Age Distributions

The cluster age distribution, $dN/d\tau$, provides important information about the formation and disruption of the clusters.
We determine this distribution by simply counting clusters above a given mass limit, in equal-size bins of $\log \tau$. The age distributions determined from each cluster catalog are plotted for two different ranges of mass, selected to stay above the approximate magnitude limit shown by the diagonal fading track and to masses higher than $\log M \approx 3.5$ (where stochastic fluctuations do not have a significant affect on the distributions; see Section 2.3). To make a fair comparison among all three catalogs, we do not plot clusters younger than 10 Myr in this particular diagram, since the Bastian et al. (2012) catalogs are likely incomplete at these very young ages. In a future study, we will present the age distributions of clusters over the entire age range for all seven fields observed in M83. We use a typical bin width of $\approx 0.4$–0.5 in $\log \tau$ to have a sufficient number of bins, although these bins are somewhat too narrow to fully account for gaps and other small-scale features resulting from the age-dating procedure.

Figure 5 shows the resulting age distributions for two different mass-limited samples determined for each catalog. Each age distribution has a steadily declining shape, with no obvious bends or other features, except possibly for $\tau \lesssim 10^7$ yr in a few cases. The shapes of the cluster age distributions in each field are approximately the same for both plotted intervals of mass. This indicates that the age distribution is independent of the mass of the clusters, at least over the range studied here. The age distributions can be approximated by power laws...
The mean is therefore \( \log (\tau) \propto -\gamma \log M + \text{const.} \). We perform a least squares fit to \( \log (dN/d\tau) = \gamma \log \tau + \text{const.} \) and present the best-fit values of \( \gamma \) in Figure 5 and compile them in Table 1. The age distributions determined from the different catalogs of the inner field are all similar, with a mean \( \gamma = -0.84 \). The outer field distributions give a mean of \( \gamma = -0.48 \). If we include clusters younger than 10 Myr, we find slightly steeper values for \( \gamma \) in both fields (for the inner field, see results presented in Chandar et al. 2010).

The relative age distributions can be affected by differences in the star-formation histories between the two fields, as also pointed out by Bastian et al. (2009, 2012). We make a first attempt to correct for this difference by using the relative star-formation rates for the inner and outer M83 fields determined by Silva-Villa et al. (2013) from an analysis of the colors and luminosities of individual stars in \textit{HST}/ACS observations taken at somewhat different locations within M83, and presented in Figure 11 of Bastian et al. (2012). This figure shows that the star-formation rate in the inner field is approximately a factor of three higher than in the outer field between the ages of \( \log \tau = 7.0-7.6 \), but that this ratio appears to decline to a factor of two at an age of \( \log \tau = 8.0 \). Making a simple relative correction of \( \log (3/2) = 0.18 \) to \( \gamma \) would result in the \( \gamma \) values in the two fields becoming more similar, with \( \Delta \gamma = 0.18 \).

However, given the large uncertainties in the determination of the relative star-formation histories between the two fields over the studied range of ages, it is also possible that there is little difference between the two. Hence, we bracket the difference in \( \gamma \) between the two fields to be within the range \( \Delta \gamma = 0.18-0.36 \).

To assess whether this is a statistically significant difference, we need to estimate the uncertainties on the values of \( \gamma \). Previous experiments have shown that the absolute uncertainty is typically 0.2 (e.g., Chandar et al. 2010; Fouesneau et al. 2012). However, we are more interested here in the relative uncertainties rather than the absolute ones. In this case, many of the systematic differences, which dominate the absolute uncertainties (e.g., use of different model predictions, age-dating methods), tend to cancel out. Other systematic differences, such as those in the relative star-formation histories between the two fields, will still be present. The scatter between the six different fit values in Table 1 for each field is \( \approx 0.10 \), and the error in the mean is therefore \( \approx 0.04 \) (i.e., scatter/\( \sqrt{N} \)). This is probably an underestimate, however, because the cluster samples are not fully independent; rather, they overlap by \( \approx 60\% \), and so dividing by \( \sqrt{N} \) is not fully justified. Any difference in star-formation history between the two fields will introduce an additional uncertainty. The true relative error is likely to be somewhere between 0.04 and 0.20, and we adopt the average value of \( \approx 0.12 \), which is similar to the scatter in the mean, as the uncertainty. Any difference in the age distribution between the inner and outer fields is therefore tentative. The addition of five more fields recently observed with the \textit{HST}/WFC3 (proposal = 12513, principal investigator = Blair) will provide a more definitive test in the future.

### 3.3. Cluster Mass Functions

The shape of the cluster mass function, \( dN/dM \), is one of the key diagnostics of whether cluster disruption is dependent or independent of mass. We determine these distributions by counting clusters in different intervals of age and restricting the low-mass end to stay above the magnitude limit shown in Figure 4. The following are the specific age intervals: (1) \( \log \tau = 6.0-7.0 \) (blue), (2) \( \log \tau = 7.0-8.0 \) (green), and (3) \( \log \tau = 8.0-8.6 \) (red). Because the small-scale features observed in the mass–age diagram have less impact on the mass function, we plot \( dN/dM \) using equal numbers of clusters in each bin of \( \log M \). In Chandar et al. (2010), we showed that the particular method of binning, whether equal in width or in cluster number, only affects the value of \( \beta \) at the \( \pm 0.05 \) level, smaller than the actual uncertainties.

Figure 6 shows the mass functions resulting from the three different catalogs (our manual catalog, our automatic catalog, and Bastian et al.’s 2012 hybrid catalog) for the inner (upper panels) and outer (lower panels) fields, in the three aforementioned intervals of age. Each of these distributions can be well represented by a simple power law. We perform fits of the form \( dN/dM = \beta \log M + \text{const.} \), show the best fit as the solid line in each figure, and record the value of \( \beta \) in Table 2.

The inner field mass functions have a mean of \( \beta = -1.98 \), and the outer field distributions give \( \beta = -2.34 \). Absolute

### Table 1

| Cluster Catalog                  | Mass Range log(M/M\(_{\odot}\)) | \( \gamma \)   |
|----------------------------------|---------------------------------|----------------|
| Inner field, manual              | >4.0                            | -0.83 ± 0.29   |
| Inner field, automatic           | >4.0                            | -0.91 ± 0.30   |
| Inner field, Bastian             | >4.0                            | -0.97 ± 0.20   |
| Inner field, manual              | 3.5–4.0                         | -0.70 ± 0.27   |
| Inner field, automatic           | 3.5–4.0                         | -0.78 ± 0.28   |
| Inner field, Bastian             | 3.5–4.0                         | -0.86 ± 0.28   |
| Outer field, manual              | >4.0                            | -0.54 ± 0.21   |
| Outer field, automatic           | >4.0                            | -0.42 ± 0.31   |
| Outer field, Bastian             | >4.0                            | -0.54 ± 0.06   |
| Outer field, manual              | 3.5–4.0                         | -0.49 ± 0.05   |
| Outer field, automatic           | 3.5–4.0                         | -0.59 ± 0.12   |
| Outer field, Bastian             | 3.5–4.0                         | -0.31 ± 0.23   |

**Note.** Least-squares fits to \( \log (dN/d\tau) = \gamma \log \tau + \text{const.} \).
uncertainties for $\beta$, on the basis of experiments with different age-dating methods, filter sets, binning, and so forth, are $\approx 0.2–0.3$ (see Chandar et al. 2010). The scatter between the nine different fit values in Table 2 is 0.20 for the inner field and 0.39 for the outer field, and the uncertainty in the means are 0.07 and 0.13, respectively. For the uncertainty in $\beta$ for each field, we adopt the mean value between the scatter and the uncertainty in the mean, resulting in $-1.98 \pm 0.14$ for the inner field and $-2.34 \pm 0.26$ in the outer field. If the most discrepant value of $\beta$ (i.e., lower-right panel in Figure 6) in the outer field is excluded, we find $\beta$ of $-2.44 \pm 0.19$.

Therefore, although the mass function may be somewhat steeper in the outer field when compared with the inner field, this result is significant only at the $\approx 1\sigma–2\sigma$ level. Just as for the inner field, we find no significant change in the shape of the cluster mass function in the outer field when moving from youngest to oldest. This is one of our key results, that the shapes of the cluster mass functions in the inner and outer fields are similar at different ages, and show no systematic flattening, particularly at the low-mass end, from youngest to oldest. To better demonstrate this result, we show the mass functions normalized to lie on top of one another in Figure 7. This figure clearly shows that, although different ranges of mass are plotted in each age interval, the shapes are essentially the same within the uncertainties, and the oldest (red) clusters at the low-mass end do not fall below the dashed lines.

Perhaps the strongest deviation in shape is the slightly steeper slope for the oldest clusters in the two upper left panels (red
points in Figure 7). We note that this is opposite to the trend predicted by a short disruption time scale inferred for the inner field by Bastian et al. (2012), as will be discussed further in Section 4.3. We also note that the intermediate interval of age, log \( \tau = 7-8 \), particularly in the outer field for our manual and the Bastian catalogs, appear to be somewhat flatter than in the other age ranges. This effect may be related to the age-dating artifact mentioned in Section 3.1.

Bastian et al. (2012) suggested that the cluster mass function in the two fields is inconsistent with a simple power law; rather, it requires a Schechter-like cutoff at the high-mass end, where \( dN/dM \propto M^\beta \exp(-M/M_C) \). To assess whether this is the case, we first examine the mass functions of 100–400 Myr old clusters from the three different catalogs. The mass functions for clusters in the inner field, shown in Figure 6, are consistent with a pure power law in all three catalogs. In the outer field, there is a hint of a Schechter-like cutoff at the high-mass end in the Bastian et al. catalog, but it is not statistically significant (<2\( \sigma \)). We do not see a similar feature in our best catalog, the manual catalog presented here. Next, we experimented with cumulative mass functions in the different age intervals and different catalogs with simulated ones drawn from a single power law. We find similar results to the binned case, that the simulated and observed cumulative mass functions match well, if values of \( \beta \) similar to those compiled in Table 2 are used. The one exception is the mass function for 100–400 Myr clusters in the outer field, which appears to be slightly deficient in massive clusters. The Bastian et al. (2012) conclusion is based on a comparison of the cumulative distribution of cluster masses with those for a pure power law and Schechter functions with different values for \( M_C \). However, for this test, shown in their Figures 15 and 16, they have required an exact value of \( \beta = -2.0 \). They have also used a different interval of cluster ages, from 3 to 100 Myr, than in their subsequent analysis (e.g., in their Figure 17), Incompleteness in their cluster catalog below ages of 10 Myr may, however, bias their result. In any case, the number of clusters involved is only a few out of a sample of a couple hundred.

4. DISCUSSION

4.1. Predictions of Cluster Disruption Models

There are currently two popular models being discussed in the literature for the disruption of star clusters over approximately the first few hundred million years of their lives, one where lower-mass clusters are disrupted earlier than their higher-mass counterparts (mass-dependent disruption; e.g., Bastian et al. 2012) and one where clusters disrupt at approximately the same rate, regardless of their mass (mass-independent disruption; e.g., Fall & Chandar 2012). The models make different predictions for the shape of the age distribution in different intervals of mass and for the mass function in different intervals of age. In the following, we summarize basic predictions from each model, and then compare them with the observed mass–age distributions of star clusters in our two M83 fields.

In gradual, mass-dependent disruption (MDD) models (e.g., Boultoukos & Lamers 2003; Fall et al. 2009), clusters lose mass at different fractional rates, leading to the earlier disruption of lower-mass clusters when compared with their higher-mass counterparts. This model predicts breaks or curvature in the mass (and age) distributions for a population of clusters. In this model, the disruption time \( \tau_d \) has been characterized as \( \tau_d(M) = \tau_\ast(M/M_\ast)\gamma \), where the exponent \( k \) and characteristic disruption timescale \( \tau_\ast \) are adjustable parameters, and \( M_\ast = 10^4 M_\odot \) is a fiducial mass scale (Lamers et al. 2005; Fall et al. 2009). We first assume that the initial shape of the mass function is a power law, and that clusters form at a constant rate. Mass-dependent disruption models predict that the cluster age distribution (for mass-limited samples, as presented here) will be flat at young ages, but then fall off exponentially at an age that reflects the characteristic disruption time. This behavior should occur at all mass ranges, but the break point will occur at younger ages for lower-mass clusters. The mass function for the youngest clusters will have a power-law shape, which will flatten toward lower masses at older ages if mass-dependent disruption affects the clusters. The reader is referred to Figures 10 and 11 in Fall et al. (2009) for graphical examples of these predictions. The predicted behavior of the mass function is similar if the initial shape is a Schechter function rather than a power law; an example is shown in Figure 8. For both assumed initial distributions, a critical prediction of mass-dependent disruption models is the flattening of the mass function at older ages and lower masses.

In the gradual, mass-dependent disruption model the two distributions are independent of one another, and can be written as follows: \( g(M, \tau) \propto M^\beta \exp(-\tau/\tau_\ast) \). This model predicts a power-law decline in the number of clusters at each mass with
age at a fractional rate that is independent of their masses. The age distribution declines as a power law in each interval of mass. Mass-independent disruption models predict that there should be no change in the shape of the cluster mass function, i.e., no flattening occurs at the low-mass end. Again, the reader is referred to Figure 12 in Fall et al. (2009).

4.2. Comparison between Predictions and Observations

We first compare our observed distributions with predictions from the mass-dependent disruption model. The age distributions (Figure 5) in the inner field, which are plotted only for \( \tau \gtrsim 10 \) Myr, are inconsistent with this model (i.e., no curvature is observed) and can be reasonably well represented by a single power law with \( \gamma \approx -0.7 \) to \(-0.9\), although the log (\( \tau/\text{yr} \)) = 7.0–7.5 bin does appear low in cases where a gap caused by the age-dating artifact (mentioned in Section 3.1) is present. The outer-field age distributions are relatively similar to those of the inner field, with any difference such that the outer field is shallower occurring at the \( \approx 2\sigma \)–3\( \sigma \) level (see Section 3.2).

More important, the shape of the mass functions in the inner and outer fields do not flatten over time. Figure 7 shows this explicitly, i.e., the red squares, showing 100–400 Myr old clusters having \( \approx -0.7 \) to \(-0.9\) and outer fields do not flatten over time. Figure 7 shows this explicitly, i.e., the red squares, showing 100–400 Myr old clusters having \( \approx -0.7 \) to \(-0.9\) and outer fields do not flatten over time. Figure 7 shows this explicitly, i.e., the red squares, showing 100–400 Myr old clusters having \( \approx -0.7 \) to \(-0.9\) and outer fields do not flatten over time.

We conclude that the M83 clusters studied here, in both the inner and outer fields, do not show evidence for mass-dependent disruption over the observed \( M - \tau \) domain.

Next, we compare our observed age and mass distributions with predictions from the mass-independent disruption model. The observed mass and age distributions in both fields are consistent with predictions from this model. The age distributions are well described by a single power law that is approximately independent of cluster mass, and the mass function can be described by a power law that is approximately independent of the age of the clusters. The main difference in the results between the two fields is in the exponent \( \gamma \), with the inner field having \( \gamma \approx -0.7 \) to \(-0.9\) and the outer field having \( \gamma \approx -0.5\). Adapting realistic uncertainties and bracketing a range of possible differences in the relative star-formation histories between the two fields (from no difference to the maximum suggested by Figure 11 in Bastian et al.), we find that the exponents differ only at the \( \approx 2\sigma \)–3\( \sigma \) level, as discussed in Section 3.2. We also note that a \( \gamma \) value of \(-0.5\) still indicates strong cluster disruption, with \( \approx 70\% \) clusters disrupting every decade in age (i.e., \( 1 - 10^{-0.5} \)) \( \times \) 100\% = 68\%, not very different from the approximately 80\%–90\% disruption suggested by Chandar et al. (2010), or found in this paper for the inner field (i.e., \( 1 - 10^{-0.8} \)) \( \times \) 100\% = 84\%.

4.3. Agreement and Disagreement with Previous Interpretation

Our results are similar, in most regards, to those found by Bastian et al. (2012), and our results are now supported by the addition of two cluster catalogs in each field selected using different methods. Both groups find similar-looking color–color diagrams (Figure 3), similar mass–age diagrams (Figure 4), and similar age and mass distributions (Figures 5–7), except for some differences at \( \tau \lesssim 10^7 \) yr, as expected because of differences in the selection criteria (see Section 2.2 here and Bastian et al. 2012). Both groups agree that mass-independent disruption provides a good description of the data, and that mass-dependent disruption models that assume an initial power-law mass function do not fit the data well.

The biggest area of disagreement is the contention by Bastian et al. (2012) that mass-dependent disruption models that assume an initial Schechter mass function can also fit the data. When they perform a two-dimensional fit to clusters in the \( M - \tau \) plane, they derive the specific values for \( \tau_c \) and \( M_c \) of 160 Myr and \( 1.5 \times 10^5 M_{\odot} \) in the inner field and 600 Myr and \( 5 \times 10^4 M_{\odot} \) in the outer field. In Figure 8, we compare the observed mass functions of 100–400 Myr clusters in both fields with predictions from the Bastian et al. (2012) mass-dependent disruption model. The panels on the left show the predicted evolution assuming their best-fit model parameters in each field. The dashed blue lines show the initial Schechter mass function, the dotted green lines and solid red lines show the predicted evolution for 10–100 Myr and 100–400 Myr cluster populations, respectively. In comparison with the bottom-left panel, the shorter disruption time \( \tau_c \) in the top-left panel leads to faster evolution and more flattening at the low-mass end of the cluster mass function. The panels on the right in Figure 8 compare the observed mass function for 100–400 Myr clusters with the model predictions. Here, we have allowed the flexibility of renormalizing the predicted 100–400 Myr mass distribution to best match the shape of the observed distribution by matching the predictions and observations at the high-mass end. However, even with this added degree of flexibility, the specific mass-dependent disruption model and parameters suggested by Bastian et al. (2012) do not provide a good match to the observations, i.e., the red curves are clearly flatter at the low-mass end than the observed ones. The initial Schechter function (blue curve), which represents no mass-dependent disruption, provides a much better fit to the observations. Therefore, mass-dependent disruption cannot have much of an effect on the observed \( M - \tau \) ranges of the cluster population in these two fields of M83. Any mass-dependent disruption, if it exists, must occur below the selection limits of these catalogs.

5. SUMMARY AND CONCLUSIONS

In this paper, we determined the mass and age distributions of star clusters detected in two fields observed with the HST/WFC3 in the nearby spiral galaxy M83, and we compared them with predictions from two different models of cluster disruption. We used three distinct catalogs in each field for this purpose, including one from the previously published work by Bastian et al. (2012), where the clusters were selected using different methods and criteria. In each case, to estimate the age (\( \tau \)) and mass (\( M \)) for each cluster, we compared the integrated \( UBV \) H\(\alpha \) photometric measurements with predictions from population synthesis models.

We found that the age and mass distributions, \( dN/d\tau \) and \( dN/dM \), of the clusters in each field did not differ significantly among the catalogs, particularly for \( \tau \gtrsim 10^7 \) yr. These distributions are reasonably described by single power laws, \( dN/d\tau \propto \tau^\gamma \) and \( dN/dM \propto M^\beta \). We found \( \gamma \approx -0.84 \pm 0.12 \) and \( \beta \approx -1.98 \pm 0.14 \), for the inner field, and \( \gamma \approx -0.48 \pm 0.12 \) and \( \beta \approx -2.34 \pm 0.26 \) for the outer field. The relative difference between the star-formation histories in the two fields is uncertain, but it results in a range \( \Delta \gamma = 0.18 - 0.36 \pm 0.12 \), i.e., if the \( \gamma \) values between the two fields differ, it is at the \( 2\sigma \)–3\( \sigma \)
level. We concluded that the shapes of the mass and age distributions of the clusters in the two fields are similar, as predicted by the quasi-universal model, although it is possible that other dependencies may play a weak role.

The shapes of the cluster age distributions were roughly independent of mass, and the shapes of the cluster mass functions were approximately independent of age, at least over the studied $M - \tau$ range. In addition, none of the distributions showed curvature at lower masses or older ages. Our results are consistent with the clusters being disrupted, starting soon after they form, at a rate that is approximately independent of their mass. Our results do not show evidence of mass-dependent disruption, where lower-mass clusters are disrupted earlier than their higher-mass counterparts. In a future study, we will include observations of clusters in five additional pointings within M83, observed with the WFC3 on the HST, to investigate the disruption histories of the clusters in more detail.

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Facility: HST

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