Estimation of the Low-End Mass Function of the Arches Cluster

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Abstract. It has been suggested that the nonstandard star formation environment near the Galactic Center (GC) may lead to an initial mass function (IMF) skewed toward relatively massive stars and having an elevated mass cutoff. Two GC star clusters, the Arches and the Quintuplet, may give an answer to this hypothesis, but the most recent high-resolution IR observations for these clusters can only resolve stars with masses down to \( \sim 5\,M_\odot \). Here, we present a new method for estimating the low-end mass function (MF) from a background-limited observation of a star cluster. We empirically find the mass function that gives the best match between the pixel intensity histograms of the observed image and the model image that is constructed for an assumed mass function. This method also employs Fokker-Planck (FP) models to reproduce the spatial distribution of stars as a function of mass.

1. Introduction
To make up for the limitation of conventional photometric methods, we introduce a novel method that utilizes the pixel intensity histogram of the cluster image. We apply this method to the HST/NICMOS image for the Arches cluster, which was analyzed by Figer et al.[1] with a conventional PSF (point-spread function) fitting technique. Our new method has the advantage of utilizing the unresolved, faint pixels, that are discarded in the conventional PSF fitting technique. Our goal is to search the best-fit initial mass function (IMF) by comparing the intensity histograms of the observed image and the artificial images created with an assumed IMF. We perform FP simulations to obtain the density profile as a function of stellar mass at the observed age of the cluster for each comparison.

2. The Control Fields
In order to find how the background/foreground sources affect the intensity histogram of the cluster, we analyze the control field image first. The locations of the control fields are close enough to the cluster to be assumed as background/foreground sources of the Arches, and far enough from the cluster to be not affected by outer stars of the cluster. A conventional PSF-fitting photometry was performed to obtain the luminosity function (LF) of bright, resolved stars. We find that our photometry is at least 80% complete down to \( \sim 8\,M_\odot \) (K \( \sim 15\)mag). For stars fainter than this mass, we adopt a galactic structure model by Wainscoat et al.[2].

The combined LF is shown in Figure 1. Artificial images are made by randomly positioning artificial stars with PSFs that are obtained from observations. To make the artificial image
Figure 1. The solid line shows the model LF, and the dashed line shows the observed LF. We connect two LFs at 15th mag where the recovery rate is 80%. The thick line shows the combined LF.

Figure 2. Comparison between intensity histograms of the observed control field image and the artificial image.

resemble the real control field image, several noises are added: dark noise, readout noise and telescope thermal noise. The pixel intensity histograms of the artificial images obtained by
this way are in good agreement with that of the observed control field images (Fig. 2). It means that we understand the phenomenon that constitutes the control field images and the background/foreground sources of the Arches.

3. The cluster
To relate MF to LF, we adopted the Geneva isochrone and assumed the age of the Arches cluster to be 2 Myr [1]. The central region of the cluster is dominated by a number of very bright stars, while the outer part is dominated by background/foreground stars. Thus for the comparison the observation and our model, we consider two radius bins: 6" < r < 9" and 9" < r < 12" (1" ≈ 0.04 pc). Two variables, the peak intensity (hereafter, \( P \)) and the height of the peak (hereafter, \( H \)) of the

Figure 3. Comparing the intensity histogram of artificial cluster (\( \alpha = 2.3, \ M_l = 0.3 M_\odot, \ R_g = 30 \text{ pc} \)) image and the Arches cluster image for each radius bin. Two parameters, \( P \) and \( H \) determines the shape of the intensity histogram.

histogram, were chosen to compare intensity histograms quantitatively. These two parameters determine the shapes of the intensity histograms (Fig. 3). The intensity histograms are found to be nearly log-normal, and we fit a log-normal function to the intensity histogram to obtain \( P \) and \( H \).

3.1. Survey in the Initial \([\alpha, M_l] \) Space
FP simulations were performed to obtain the spatial distribution of stars as a function of mass at the age of the cluster, 2 Myr, under four initial condition: the power-law slope of the IMF (\( \alpha = 2.35 \) being the salpeter IMF), total cluster mass (\( M_t \)), tidal radius (\( R_t \)), and lower mass cutoff (\( M_l \)). Since \( M_t \) can be derived from \( \alpha, R_g, \) and \( M_l \) and \( R_t \) can be derived from galactocentric radius (\( R_g \)) and \( M_t \), the number of parameters for initial conditions becomes 3: \( \alpha = (1.4, 1.7, 2.0, 2.3, 2.6), M_l = (0.1, 0.3, 1.0, 3.0 M_\odot), \) and \( R_g = (30, 60, 90 \text{ pc}) \); a total of 60 models.

For \( R_g = 30 \text{ pc} \), we find that models 9 and 15 show a good agreement to the observation. These models have \( \alpha = 2.3, M_l = 0.3 M_\odot \) and \( \alpha = 2.6, M_l = 1 M_\odot \), respectively (Fig. 4). When \( R_g = 60 \) or 100 pc, no models give a satisfactory agreement between our calculation and the observation.

3.2. Survey in the Present-Day \([\alpha, M_l] \) Space
To see the reliability of the above procedure, we perform the same analysis again without the information on the spatial distribution of stars from the FP simulations (Fig. 5). As for the control fields, the bright-end LF is from the observation and the faint-end LF is modeled as a power-law with various \( \alpha \) and \( M_l \) values. Since here we are comparing the assumed LF directly
Figure 4. Comparison of the intensity histograms between the artificial images and the observed one (Rg=30pc). Thick lines: Artificial cluster image (upper lines: 6”<r<9”, lower lines: 9”<r<12”). Thin lines: Observed cluster image (upper lines: 6”<r<9”, lower lines: 9”<r<12”). Figures outlined are assumed to be the most appropriate models.

Figure 5. Variations of $P$ and $H$. Gray lines show the Arches cluster’s $P$ and $H$. The circles show reliable MF crossed by two gray lines. The square show the models of 9 and 15 of Figure 4, the most appropriate FP models for the Arches.

with the observation (i.e., without dynamically evolving the cluster), what we find here is the present-day MF or LF. The region in $\alpha$ and $M_l$ space that results in $P$ and $H$ that are consistent with the observation is shown with the gray lines in Figure 5. The overlapping region between the $P$ and $H$ maps has $\approx\sim2.7$ and $M_l\approx0.25M_\odot$. This is very close to the present-day $\alpha$ and $M_l$. 
values of Model 09 (2.5 and 0.3M⊙, respectively), implying that Model 09 probably represents the observed cluster better.

4. Conclusions
We have analyzed HST/NICMOS data of the Arches cluster near the GC with the implementation of the pixel intensity histogram method. We find that our new method can be used to estimate the faint-end LF that cannot be recovered by the conventional photometric techniques. By comparing pixel intensity histograms between the artificial and observed images, we find that the best-fit power-law IMF parameters are α=2.3≈2.6, M_l=0.3≈1.0M⊙. α and M_l values larger or smaller than these values give much less satisfactory fits to observations. None of the Kroupa IMFs with various M_l values give acceptable agreement with the observations. Thus our analyses imply that the IMF of the Arches cluster has a similar power-law slope to the disk population, but a significantly elevated lower-mass cutoff at around 0.3 to 1.0 M⊙.

References
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[2] Wainscoat, R. J., Cohen, M., Volk, K., Walker, H. J., Schwartz, D. E. 1992, ApJ, 83, 111.