JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
40: 153 ~ 155, 2007

THE ARCHES CLUSTER MASS FUNCTION

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(Received December 2, 2007; Accepted December 18, 2007)

ABSTRACT

We have analyzed H and K_s–band images of the Arches cluster obtained using the NIRC2 instrument on Keck with the laser guide star adaptive optics (LGS AO) system. With the help of the LGS AO system, we were able to obtain the deepest ever photometry for this cluster and its neighborhood, and derive the background-subtracted present-day mass function (PDMF) down to $1.3\,M_\odot$ for the $5''$–$9''$ annulus of the cluster. We find that the previously reported turnover at $6\,M_\odot$ is simply due to a local bump in the mass function (MF), and that the MF continues to increase down to our 50 % completeness limit ($1.3\,M_\odot$) with a power-law exponent of $\Gamma = -0.91$ for the mass range of $1.3 < M/M_\odot < 50$. Our numerical calculations for the evolution of the Arches cluster show that the Γ values for our annulus increase by 0.1–0.2 during the lifetime of the cluster, and thus suggest that the Arches cluster initially had Γ of $-1.0 \sim -1.1$, which is only slightly shallower than the Salpeter value.

Key words : Galaxy: center — open clusters and stellar associations: general — stars: luminosity function, mass function — celestial mechanics, stellar dynamics

I. INTRODUCTION

The stellar initial mass function (IMF) is the most primary product of the star formation process. With this one relation, it is possible to directly probe the crucial predictions of star formation models. Surprisingly, the IMF is approximately universal, following the Salpeter law (Salpeter 1955) for masses between 1 and $120\,M_\odot$ (Kroupa 2002). On the low mass end, there appears to be a universal rollover around $0.8\,M_\odot$, and the high mass end seems to be truncated by a sharp cutoff near $150\,M_\odot$ (Weidner & Kroupa 2004; Figer 2005).

However, star formation theories predict that the lower mass cutoff (m_l) should be a function of environmental parameters, i.e. magnetic field strength and cloud temperature (e.g., Bonnell, Larson, & Zinnecker 2006). In the extreme environment of the Galactic center (GC), some of these models predict an elevated lower mass cutoff/rollover with respect to that observed in the disk (Morris 1993). If this prediction is true, then the GC should have an abnormally bright lower mass cutoff, something that has not been *directly* observed anywhere in the Universe.

The best places to trace the IMF near the GC are the two young star clusters therein: the Arches and Quintuplet clusters (see Figer et al. 1999 for findings and early studies on these clusters). These clusters are very young (2–4 Myr), compact ($\lesssim$ 1 pc), and only 20–30 parsecs away from the GC in projection, while they appear to be as massive as the smallest Galactic globular clusters ($\sim 2 \times 10^4\,M_\odot$; Kim et al. 2000). Of the two clusters, the Arches is preferred for studies of the low-end mass function (MF) as the Quintuplet is significantly more dispersed.

Eariler observational studies on the mass function of the Arches cluster include Figer et al. (1999), Yang et al. (2002), Stolte et al. (2002), and Stolte et al. (2005). In the present Proccedings paper, we present the Keck/NIRC2 laser guide star (LGS) AO observations of the Arches cluster and its nearby background populations, which were reported in Kim et al. (2006).

II. OBSERVATIONS

The images were obtained using the Keck/NIRC2 LGS AO system on 2006 May 4 & 5. The Arches cluster ($\alpha = 17^h45^m50^s.59$, $\delta = -28°49'20''.3$; J2000) was observed with the medium ($20'' \times 20''$, $0''.0198$ pixel^{-1}) and wide ($40'' \times 40''$, $0''.0397$ pixel^{-1}) field cameras, and three nearby control fields, separated $\sim 60''$ from the cluster center, were imaged with the medium field camera in order to sample the background population. All fields were imaged in H and K_s bands in a 9-point dither pattern with a leg size of $2''$. The multiple correlated double sampling (MCDS) mode was used with 10 coadds and a 10 s integration time per coadd, giving a total exposure time of 900 s per field. Obtained Strehl ratios for the K_s (H) images are 0.17 (0.08),

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0.19 (0.08), 0.25 (0.06), 0.13 (0.06), and 0.12 (0.06) for the medium cluster field, control fields A, B, C, and wide cluster field, respectively, resulting in FWHMs of 70–100 mas for K_s, and 61–98 mas for H. Detailed descrptions on the data reduction are given in Kim et al. (2006).

III. THE MASS FUNCTION

We convert the apparent magnitudes into masses using the Geneva models. Here, we only use K_s-band data as they provide deeper photometry. Figure 1 shows our completeness-corrected MF for the cluster intermediate region after background subtraction, along with the MF from Stolte et al. (2005) that is also completeness-corrected, but *not* background-subtracted; both are scaled to an area of 5″–9″ annulus. The MF of Stolte et al. (2005) shows a global turnover below $\log M/\mathrm{M}_\odot \simeq 0.35$ ($M \simeq 2.3\,\mathrm{M}_\odot$), which is also their 50 % completeness limit, but our cluster MF, whose 50 % completeness limit is at $\log M/\mathrm{M}_\odot = 0.1$ ($M \simeq 1.3\,\mathrm{M}_\odot$), still has a significant amount of stars below $M = 2.3\,\mathrm{M}_\odot$ and keeps increasing at least down to $M = 1\,\mathrm{M}_\odot$. Note that our MF increases even below our 50 % completeness limit.

Stolte et al. (2005) claim that there may be a turnover near $\log M/\mathrm{M}_\odot \simeq 0.8$ ($M \simeq 6.3\,\mathrm{M}_\odot$) in their MF and that this might indicate a global decrease of the background-subtracted MF below that mass. However, our data, which have a quarter dex lower completeness limit in mass, indicate that the MF globally increases down to our completeness limit even after background subtraction. Therefore, we presume that the turnover around $M = 6.3\,\mathrm{M}_\odot$ claimed by Stolte et al. (2005) is in fact a local bump in the MF as see in Figure 1. Eisenhauer et al. (1998) find a similar bump in their LF of the Galactic starburst template NGC 3603, and show that such a bump is an indication of the young age ($\lesssim$ 3 Myr) using the evolutionary pre-main-sequence tracks by Palla & Stahler (1993).

When fit to a single power-law relation, our cluster MF gives a power-law exponent of $\Gamma = -0.91 \pm 0.08$ (the Sapleter slope is $\Gamma = -1.35$) for the mass range of $\log M/\mathrm{M}_\odot = 0.1$–$1.7$. This is slightly steeper than the exponent for massive stars only ($\log M/\mathrm{M}_\odot = 0.7$–$1.7$), $\Gamma = -0.71 \pm 0.15$.

We have performed several Fokker-Planck calculations (for $m_l = 0.1$ & $1\,\mathrm{M}_\odot$) and N-body simulations (for $m_l = 1\,\mathrm{M}_\odot$) targeted for the Arches cluster with initial cluster conditions similar to those used in Kim, Morris, & Lee (1999) and Kim et al. (2000), one of which is no initial mass segretation. We find that the Γ values for the projected annulus of 5″–9″ increase by 0.1–0.2 during the lifetime of the Arches cluster, 2–2.5 Myr.* Therefore, our results suggest that the IMF of the cluster has $\Gamma = -1.0 \sim -1.1$. Figure 1 shows two MFs for our annulus from our Fokker-Planck calculations that best match the observed MF at 2 Myr. These two calculations have considerably different m_l's (0.1 & $1\,\mathrm{M}_\odot$), but result in nearly identical MFs for the annulus. Thus our estimate for the IMF from the simulations does not sensitively depend on the choice of m_l.

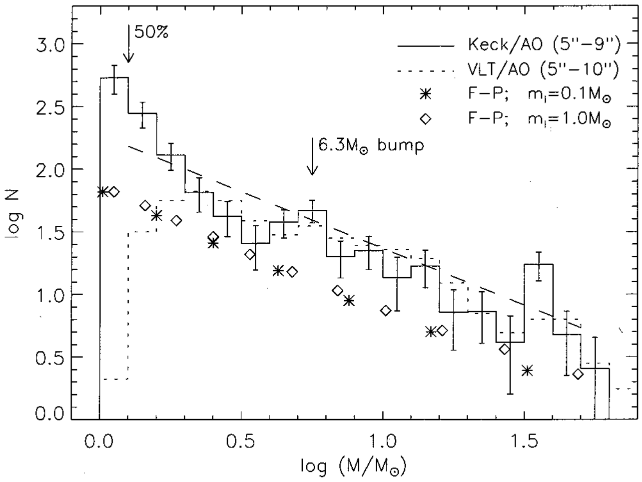

Fig. 1.— Background-subtracted mass functions derived from our K_s-band luminosity function for the 5″–9″ annulus of the cluster field (*solid*) and the mass function of Stolte et al. (2005) for the 5″–10″ annulus of the cluster (*dotted*). Error bars and the best-fit power-law relation ($\Gamma = -0.91$) for $\log M/\mathrm{M}_\odot = 0.1$–$1.7$ are shown for the former. The average of control fields A, B, and C were used as the background for the former, while the background population was not subtracted for the latter. Also plotted are the MFs for the same projected annulus from our Fokker-Planck calculations that fit the observed MF at 2 Myr the best (offset by −0.5 dex for clear presentation). The *asterisks* are for the calculation with $m_l = 0.1\,\mathrm{M}_\odot$ and the *diamonds* are for $m_l = 1\,\mathrm{M}_\odot$. Both calculations have an initial Γ of −1.1, and total mass of $4 \times 10^4\,\mathrm{M}_\odot$. The arrows indicate the locations of the 50 % completeness limit and the $6.3\,\mathrm{M}_\odot$ bump.

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ACKNOWLEDGEMENTS

Data presented herein were obtained at the W. M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Tech-

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*These calculations consider internal dynamics of the cluster such as mass segregation and tidal evaporation among others; see the references for model details.

nology, the University of California, and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation. This work was supported by the Astrophysical Research Center for the Structure and Evolution of the Cosmos (ARCSEC) of Korea Science and Engineering Foundation through the Science Research Center (SRC) program. The material in this paper is based upon work supported by NASA under award No. NNG05-GC37G, through the Long Term Space Astrophysics program. F.N. acknowledges PNAYA2003-02785-E and AYA2004-08271-C02-02 grants.

REFERENCES

Bonnell, I. A., Larson, R. B., & Zinnecker, H. 2006, astro-ph/0603447

Eisenhauer, F., Quirrenbach, A., Zinnecker, H., & Genzel, R. 1998, Stellar content of the galactic starburst template NGC 3603 from adaptive optics observations, ApJ, 498, 278

Figer, D. F., Kim, S. S., Morris, M., Serabyn, E., Rich, R. M., & McLean, I. S. 1999, Hubble space telescope/NICMOS observations of massive stellar clusters near the galactic Center, ApJ, 525, 750

Figer, D. F. 2005, An upper limit to the masses of stars, Nature, 434, 192

Kim, S. S., Morris, M., & Lee, H. M. 1999, Evaporation of compact young clusters near the galactic Center, ApJ, 525, 228

Kim, S. S., Figer, D. F., Lee, H. M., & Morris, M. 2000, N-body simulations of compact young clusters near the galactic center, ApJ, 545, 301

Kim, S. S., Figer, D. F., Kudritzki, R. P., & Najarro, F. 2006, The Arches cluster mass function, ApJ, 653, L113

Kroupa, P. 2002, The initial mass function of stars: evidence for uniformity in variable systems, Science, 295, 82

Morris, M. 1993, Massive star formation near the Galactic center and the fate of the stellar remnants, ApJ, 408, 496

Palla, F., & Stahler, S. W. 1993, The pre-main-sequence evolution of intermediate-mass stars, ApJ, 418, 414

Salpeter, E. E. 1955, The luminosity function and stellar evolution, ApJ, 121, 161

Stolte, A., Grebel, E. K., Brandner, W., & Figer, D. F. 2002, The mass function of the Arches cluster from Gemini adaptive optics data, A&A, 394, 459

Stolte, A., Brandner, W., Grebel, E. K., Lenzen, R., & Lagrange A.-M. 2005, The Arches cluster: evidence for a truncated mass function?, ApJ, 628, L113

Weidner, C., & Kroupa, P. 2004, Evidence for a fundamental stellar upper mass limit from clustered star formation, MNRAS, 348, 187

Yang, Y., Park, H. S., Lee, M. G., & Lee, S.-G. 2002, Gemini near-IR photometry of the Arches cluster near the Galactic center, JKAS, 35, 131