Origin of lower velocity dispersions of ultra-compact dwarf galaxy populations in clusters of galaxies

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ABSTRACT

Recent observations have revealed that velocity dispersions of “ultra-compact dwarf” (UCD) galaxies are significantly smaller than those of other galaxy populations in the Fornax and the Virgo clusters of galaxies. In order to understand the origin of the observed lower velocity dispersions of UCDs, we numerically investigate line-of-sight velocity dispersion ($\sigma_{\text{los}}$) of galaxy populations with variously different orbits in clusters of galaxies with the total masses of $M_{\text{cl}}$. We particularly investigate radial velocity dispersion profiles ($\sigma_{\text{los}}(R)$) and velocity dispersions within the central 200 kpc of a cluster model ($\sigma_m$) for galaxies with different pericenter distances ($r_p$) and orbital eccentricities ($e$) in the model with $M_{\text{cl}} = 7.0 \times 10^{13} M_\odot$, reasonable for the Fornax cluster. We find that $\sigma_{\text{los}}(R)$ and $\sigma_m$ of galaxies with smaller $r_p$ are steeper and smaller, respectively, for a given initial $e$ distribution of galaxies. For example, we find that $\sigma_m$ is $\sim 260$ km s$^{-1}$ for galaxies with $r_p < 50$ kpc and $\sim 336$ km s$^{-1}$ for all galaxies in the model with the mean $e$ of 0.6. These results imply that the observed lower velocity dispersion of UCD population is consistent with the UCDs having significantly smaller $r_p$ than other galaxy populations in the Fornax. We discuss these results in the context of the “galaxy threshing” scenario in which UCDs originate from nuclei of nucleated dwarf galaxies. We suggest that the observed differences in kinematical properties between UCDs and other dwarf galaxy populations in clusters of galaxies can be understood in terms of the differences in orbital properties between UCDs and the dwarf populations.

Key words: globular clusters: general – galaxies: star clusters – galaxies: stellar content – galaxies: formation – galaxies: interactions

1 INTRODUCTION

Since very compact and luminous stellar systems were discovered in the central region of the Fornax cluster of galaxies (e.g., Hilker et al. 1999; Drinkwater et al. 2000a, b), physical properties of these systems – now referred to as “ultra-compact dwarf” (UCD) galaxies – have been extensively investigated by observational studies (e.g., Phillipps et al. 2001; Mieske et al. 2002, 2004, 2006; Drinkwater et al. 2003; Haşegan et al. 2005; Karick et al. 2006; Firth et al. 2006). These observations have reported very unique properties of UCDs, such as very compact sizes ($< 100$ pc), possibly higher mass-to-light-ratio ($M/L$) indicative of the presence of dark matter, and scaling relations of dynamical properties (e.g., internal velocity dispersions) different from those of GCs (e.g., Drinkwater et al. 2003; Haşegan et al. 2005). Physical properties of UCDs in different clusters and groups of galaxies are now being investigated (e.g., Jones et al. 2006; Kilborn et al. 2005).

In spite of these observational progresses, it remains unclear how UCDs formed and evolved in the central regions of clusters of galaxies (e.g., Bekki et al. 2001, 2003a; Fellhauer & Kroupa 2002). Bekki et al. (2001, 2003a) proposed the “galaxy threshing” scenario in which UCDs originate from nuclei of nucleated dwarf galaxies that had been destroyed by strong tidal fields of clusters of galaxies. Fellhauer & Kroupa (2002) proposed that numerous smaller young star clusters, such as those observed in actively star-forming Antennae galaxy, can finally evolve into a single UCD after merging of them. Although the observed structural properties of UCDs (e.g., De Propris et al. 2005), scaling relations of dynamical properties of UCDs (e.g., Evstigneeva et al. 2007), and dynamical masses including possible dark matter halos (Hilker et al. 2007) have given some constrains on the above theoretical models, it has not yet been determined which model can be regarded as more reasonable.

Recent spectroscopic observations have reported that the line-of-sight velocity dispersion ($\sigma_{\text{los}}$) of UCDs ($\sigma_{\text{los}} =$...
246 ± 25 km s$^{-1}$) is significantly smaller than those of other dwarf galaxy populations (396 ± 41 km s$^{-1}$) in the Fornax cluster of galaxies (Gregg et al. 2007). They also reported that $\sigma_{\text{los}}$ of UCDs is even smaller than that of GCs ($\sigma_{\text{los}} = 334 ± 11$ km s$^{-1}$) around NGC 1399 derived by Dirsch et al. (2004). Mieske et al. (2004) have also reported that the bright compact objects in the Fornax cluster shows a lower velocity dispersion than the dwarf galaxy population. The lower velocity dispersion has been also observed in the six UCDs of the Virgo cluster of galaxies (Jones et al. 2006). The origin of the observed lower of $\sigma_{\text{los}}$ of UCDs in these two clusters is one of important unresolved problems related to the origin of UCDs.

The purpose of this paper is thus to try to explain the observed lower velocity dispersions of UCDs based on somewhat idealized orbital evolution models of galaxies in clusters of galaxies. The galaxy threshing scenario suggested that nucleated dwarf galaxies with small pericenter distances ($r_p$) can become UCDs: galaxy populations with only a limited range of orbital properties can be progenitors of UCDs (Bekki et al. 2001; 2003a). We therefore investigate how radial profiles of $\sigma_{\text{los}}(\sigma_{\text{los}}(R))$ and velocity dispersions within the central 200 kpc ($\sigma$) for galaxies in a cluster depend on orbital properties of the galaxies (e.g., more circular or eccentric orbits) and thereby find galaxy populations that show a lower velocity dispersion in the cluster.

The plan of the paper is as follows: in the next section, we describe the orbital evolution models of galaxies in a cluster of galaxies. In §3, we present the results on $\sigma$ for galaxies with different orbital properties. §4, we discuss the origin of flattened spatial distribution of UCDs in the Fornax cluster of galaxies based on our previous numerical simulations. We summarise our conclusions in §5.

2 THE MODEL

2.1 The threshing scenario for UCD formation

Although there could be a number of explanations for the origin of the observed lower velocity dispersions of UCDs in clusters of galaxies, we here focus exclusively on the threshing scenario and thereby discuss the observation. The predictions of the threshing scenario are summarized as follows: (i) dE,Ns with smaller pericenter distances ($r_p$) and higher orbital eccentricities ($e$) are more likely to be transformed into UCDs, (ii) dE,Ns in the Fornax cluster can be transformed into UCDs, if the pericenter distances ($r_p$) of their orbits (with respect to the center of the cluster) are smaller than the “threshing radius” ($R_{th}$), (iii) $R_{th}$ is typically ∼ 50 kpc for dE,Ns that have B-band magnitudes ($M_B$) of ∼ −16 mag and are embedded in dark matter halos with large cores (see Figure 7 in Bekki et al. 2003a), and (iv) $R_{th}$ depends on $M_B$ for a given cluster mass in such a way that $R_{th}$ is smaller for larger (i.e., fainter) $M_B$.

The proposed threshing radius has been discussed in the context of the observed compact spatial distribution of UCDs in the Fornax cluster (Bekki et al. 2003a). The orbital properties of the UCDs transformed from dE,Ns with $r_p < R_{th}$ however have not been discussed at all even in a qualitative way. The threshing scenario implies that orbital properties might well be different between UCDs (“destroyed populations”) and the presently observed dwarfs (“survived ones”) and thus result in the observed kinematical differences. In the present paper, we consider that the observed line-of-sight velocity dispersions of UCDs and dwarf ellipticals (dEs) can reflect the intrinsic differences in orbital properties between these two dwarf galaxy populations. We thus investigate kinematical properties of different galaxy populations with different $r_p$ and $e$ in the Fornax cluster model.

2.2 Orbital evolution of galaxy populations in the Fornax cluster

We investigate orbital evolution of “galaxies” represented by test particles in fixed gravitational potentials reasonable for clusters of galaxies. We adopt orbital evolution models similar to those used by Bekki et al. (2003a) for better understanding the origin of the spatial distributions of UCDs in clusters and groups. We consider that particles with the total number of $N$ orbit a cluster dominated by a massive dark matter halo with the total mass of $M_d$. To give our model a realistic radial density profile for the dark matter halo of the cluster, we base it on the predictions from the standard cold dark matter cosmogony (Navarro, Frenk, & White 1996, hereafter NFW). The NFW profile is described as:

$$\rho(r) = \frac{\rho_0}{(r/r_s)(1 + r/r_s)^2},$$

where $r$, $\rho_0$, and $r_s$ are the distance from the center of the cluster, the central density, and the scale-length of the dark halo, respectively.

We mainly investigate the “Fornax” model with $M_d = 7.0 \times 10^{13} M_\odot$, $r_s$ of 83 kpc, and “c” parameter of 12.8, because we are interested in the observed kinematics of UCDs and other galaxy populations in the Fornax. The adopted set of parameters can be consistent with the X-ray observations of Jones et al. (1997) and the mass estimation of the Fornax cluster derived from kinematics of the cluster galaxies by Drinkwater et al. (2001). We do not consider gravitational influences of cluster member galaxies including NGC 1399 in the Fornax model, because the influences can be very minor owing to the total mass of the galaxies much smaller than that of the background dark matter halo.

For the projected radial number distribution of particles ($\Sigma(R)$) within the cluster, we adopt a King profile with a core radius ∼ 0.6 times smaller than the cluster scale radius, $r_s$, in each cluster model (Adami et al. 1998). In order to derive the three dimensional (3D) density field ($\rho(r)$, where $r$ is the distance from the center of the cluster) from $\Sigma(R)$, we can use the following formula (Binney & Tremaine 1987):

$$\rho(r) = -\frac{1}{\pi} \int_r^{\infty} d\Sigma(R) \frac{dR}{\sqrt{R^2 - r^2}}$$

We numerically estimate the spherical symmetric $\rho(r)$ profile for a given $\Sigma(R)$ in a model.

Each particle is given an initial orbital eccentricity ($e$) and a pericenter distance ($r_p$) for a given cluster potential. We give each particle $e$ so that the $e$-distribution for $N$ particles has a Gaussian with the mean $e$ value and the dispersion of $e$ being $\sigma_{e,0}$ and $\sigma_0$, respectively. Since we adopt spherical distributions of particles, we do not introduce initial anisotropy in velocity dispersion for the $x$, $y$, and $z$ direc-
tions: the velocity ellipsoid of particles can be anisotropic in radial (r) direction only. In this calculation, we consider that the mean orbital eccentricity of galaxies in a cluster (e_{m,0}) is 0.6, which is consistent with recent high-resolution cosmological simulations (Ghigna et al. 1998). We however investigate different five sets of models with 0.5 \leq e_{m,0} \leq 0.7 and 0.1 \leq \sigma_0 \leq 0.3.

We investigate radial profiles of (projected) line-of-sight velocity dispersions (\sigma_{los}(R)) and velocity dispersions within 200 kpc (\sigma_m) for “selected particles” and all ones. We investigate \sigma_m within 200 kpc, mainly because all UCDs are located within the central 200 kpc of the Fornax (e.g., Drinkwater et al. 2003; Gregg et al. 2007). We consider that particles with different r_p and e can have different kinematics, and accordingly we investigate \sigma_{los}(R) and \sigma_m for “selected particles” with r_p (e) being within a certain parameter range. We introduce two key parameters; (1) \rth which r_p of selected particles are smaller than and (2) \eth which e of the particles are larger than. We consider that \rth and \eth are key, because our previous simulations of UCD formation based on the threshing scenario suggest that these two are important for UCD formation.

We investigate the models with 25 kpc \leq \rth \leq 175 kpc and 0.5 \leq \eth \leq 0.7 for a given e_{m,0} and \sigma_0. We mainly show the results of the “standard” model (M1) with e_{m,0} = 0.6 and \sigma_0 = 0.2, because the adopted parameters are the most reasonable in the present study. The parameter values of other four models (M2, M3, M4, and M5) are given in the Table 1. Since most UCDs are located at 50 kpc \leq R \leq 200 kpc in the Fornax cluster (Gregg et al. 2007), we estimate \sigma_m for particles with 50 kpc \leq R \leq 200 kpc. For conveniences, \sigma_m for selected and all particles are referred to as \sigma_{m, sel} and \sigma_{m, all}, respectively, in the present study. N is set to be \num{1e4} for all models so that the error bar in each i-th radial (R) bin due to the smaller number of particles (i.e., \approx 1/\sqrt{N}) can be as small as \approx 20 km s^{-1}. For models with N as large as \num{1e4}, we can more clearly see differences in kinematics between selected and all particles owing to the smaller error bars, though N \approx \num{1e4} could be significantly larger than a reasonable number of galaxy populations and intracluster stellar systems like UCDs.

Thus we adopt somewhat idealized orbital evolution models for galaxies in the cluster and thereby investigate kinematical differences between different orbital populations. The results presented in this study will be useful and helpful not only in interpreting observational results on UCD kinematics but also in understanding the results of much more sophisticated simulations with UCD formation models in our future numerical studies. Orbital properties, ages and metallicities, spatial distributions of UCDs derived in our cosmological simulations will be given in our future papers (Bekki & Yahagi 2007, in preparation). Gregg et al. (2007) have revealed that the spatial distribution of UCDs in the Fornax is quite compact and appears to be significantly flattened. We will also discuss the origin of the observed flattened spatial distribution in the context of formation of hosts galaxies of UCDs at very high redshifts (z > 10) based on the results of these future cosmological simulations.

### 3 RESULTS

#### 3.1 The standard model

Figure 1 clearly shows that \sigma_{los}(R) is significantly steeper and systematically smaller in selected particles with \r_p < \rth than in all ones for the central 200 kpc of the standard model with \rth = 50 kpc. The steeper \sigma_{los}(R) profile in the particles with \r_p < 50 kpc is due to a large number of more eccentric orbits (i.e., a radially anisotropic velocity

| Model no. | e_{m,0}^{a} | \sigma_0^{b} | comments       |
|---------|--------------|--------------|----------------|
| M1      | 0.6          | 0.2          | standard model |
| M2      | 0.5          | 0.2          | more circular orbits |
| M3      | 0.7          | 0.2          | more eccentric orbits |
| M4      | 0.6          | 0.1          |               |
| M5      | 0.6          | 0.3          |               |

\(a\) The initial mean of orbital eccentricities (e) for particles.  
\(b\) The initial dispersion in e for particles.
ellipsoid). The difference in $\sigma_{\text{los}}(R)$ becomes progressively larger with larger $R$, which reflects the fact that the outer selected particles need to have more eccentric orbits to have $R_p < 50$ kpc. The velocity dispersions within the central 200 kpc for all particles ($\sigma_{\text{m,all}}$) and selected ones ($\sigma_m$) are 336 km s$^{-1}$ and 260 km s$^{-1}$, respectively, for this standard model.

Figure 2 shows that $\sigma_m$ depends on $r_p < r_{\text{th}}$ (25 kpc $\leq r_{\text{th}} \leq 175$ kpc) such that it is smaller for smaller $r_{\text{th}}$ in the standard model: $\sigma_m/\sigma_{\text{m,all}}$ is 0.54 for $r_{\text{th}} = 25$ kpc and 0.99 for $r_{\text{th}} = 175$ kpc. The physical reason for this dependence is that the model with smaller $r_{\text{th}}$ has a larger number of particles with more eccentric orbits in the outer part of the simulated region (50 kpc $\leq R \leq 200$ kpc). Figure 3 shows that the standard model with $r_{\text{th}} = 150$ kpc shows a very minor difference in $\sigma_{\text{los}}(R)$ between all and selected particles, which confirms that $r_{\text{th}}$ is a key parameter for kinematics in the present models for a given $e_{m,0}$ and $\sigma_0$.

Figure 4 shows that $\sigma_m$ depends very weakly on $e_{\text{th}}$ for $0.5 \leq e_{\text{th}} \leq 0.7$ in the sense that $\sigma_m$ is smaller for larger $e_{\text{th}}$ (i.e., more eccentric orbits). It is confirmed that $\sigma_{\text{los}}(R)$ is steeper in the selected particles with $e > e_{\text{th}}$ than in all ones for the central region ($R < 20$ kpc). These results strongly suggest that $r_{\text{th}}$ is a much more important parameter than $e_{\text{th}}$ for velocity dispersions in the standard model. These results in Figures 1–4 imply that the observed lower velocity dispersions of UCD populations in clusters of galaxies have physical origins: the lower dispersions are unlikely to result from some uncertainties in observational methods to derive $\sigma_m$ for a smaller number of UCDs.

3.2 Parameter dependences

The three important parameter dependences of $\sigma_m$ and $\sigma_{\text{los}}(R)$ on initial orbital properties of particles in cluster models (i.e., $e_{m,0}$ and $\sigma_0$) are briefly summarized as follows. Firstly, the dependence of $\sigma_m$ on $r_{\text{th}}$ derived in the standard model is seen in the models with different $e_{m,0}$ and $\sigma_0$. Figure 5 clearly shows that irrespective of $e_{m,0}$ and $\sigma_0$, $\sigma_m$ is smaller for smaller $r_{\text{th}}$, which confirms that $r_{\text{th}}$ is a key parameter for kinematical properties of galaxy populations in clusters.

Secondly, $\sigma_{\text{los}}(R)$ is significantly steeper and systematically smaller in the selected particles with $r < r_{\text{th}}$ than in all ones for models with different $e_{m,0}$ and $\sigma_0$, though the details of the profiles depends slightly on $e_{m,0}$ and $\sigma_0$. Thirdly, dependences of $\sigma_m$ and $\sigma_{\text{los}}(R)$ on $e_{\text{th}}$ are much weaker than those on $r_{\text{th}}$ for different models, which suggests that $r_{\text{th}}$ is a more important parameter for kinematics of galaxy populations. These results for different models are thus all consistent with those derived for the standard model.

4 DISCUSSIONS

4.1 UCDs originate from destroyed building blocks of clusters?

The present study has first shown that galaxies with smaller $r_p$ (< 50 kpc) can show smaller velocity dispersions in the central 200 kpc of the cluster models. This result implies that the observed lower velocity dispersions in the Fornax and the Virgo can be due to UCDs having smaller $r_p$ (< 50 kpc) in comparison with other galaxy populations in these clusters. The result also suggests that the observed lower
dispersions are consistent with the galaxy threshing scenario in which only galaxies with very small $r_p$ can become UCDs after the destruction of the galaxies via strong cluster tidal fields (Bekki et al. 2001; 2003a). Thus the observed lower velocity dispersions of UCD populations can provide a clue to the formation processes of UCDs in clusters.

It should be however stressed that the observed lower dispersions of UCDs can not rule out the alternative scenario by Fellhauer & Kroupa (2002) in which UCDs can be formed by merging of numerous smaller clusters in starbursting galaxy mergers (“cluster merger scenario”): if young UCDs formed in galaxy mergers are tidally stripped to have more radial orbits and smaller $r_p$ (for some physical reasons) in the central regions of clusters, the observed lower dispersions would be explained equally. Since galaxy merging is highly unlikely after the formation of clusters at low redshifts (e.g., Ghigna et al. 1998), galaxy merging that can form UCDs probably needs to occur in the very early stages of clusters of galaxies. Thus, although the observed lower velocity dispersions of UCDs are consistent with the threshing scenario, they still appear not to be evidences strong enough to determine which of the above two scenarios is more reasonable.

### 4.2 Possible kinematical differences between UCDs and ICGCs

Recent observational studies of GCs in clusters of galaxies have suggested that there can be a population of GCs that are bounded by cluster gravitational potentials rather than those of cluster member galaxies (e.g., West et al. 1995; Bassino et al. 2003; Jordán et al. 2003; Tamura et al. 2006; Bergond et al. 2007; Williams et al. 2007). Previous numerical simulations showed that these intracluster GCs (ICGCs) can be formed from tidal stripping of GCs that are located in the outer parts of galaxies orbiting clusters of galaxies (e.g., Bekki et al. 2003b). Given that the UCDs can be the nuclei of destroyed (thus defunct) galaxies, spatial distributions and kinematics of ICGCs and UCDs in a cluster can be significantly different.

Bekki & Yahagi (2006) suggested that ICGCs can show more isotropic line-of-sight velocity dispersions, which can be in a contrast with the possibly (radially) anisotropic ones of UCDs suggested by the galaxy threshing scenario (Bekki et al. 2003). Although observational studies on structural and kinematical properties of ICGCs in nearby clusters have just started (e.g., Tamura et al. 2006; Bergond et al. 2007), these dynamical properties for relatively faint ICGCs have not yet been derived for the entire regions of the clusters. It is therefore observationally unclear whether spatial distributions and kinematics within clusters are different between UCDs and ICGCs. Future observations on the differences in $\sigma_{\text{los}}(R)$ between UCDs and ICGCs may well help us to understand the differences in formation processes (e.g., threshing vs stripping) between these two intracluster populations.

### 5 CONCLUSIONS

We have mainly investigated orbital evolution of galaxies with different orbital parameters (i.e., $e$ and $r_p$) in the central region ($R < 200$ kpc) of the Fornax cluster model in order to understand the origin of the observed lower velocity dispersion of UCDs in the Fornax. We have introduced two key parameters $r_{\text{th}}$ and $e_{\text{th}}$ and thereby investigated $\sigma_m$ and $\sigma_{\text{los}}(R)$ for galaxies with $r_p < r_{\text{th}}$ (or with $e < e_{\text{th}}$) for a given $e_{m,0}$ and $\sigma_0$. We have particularly focused on the kinematical differences between all galaxies (e.g., $\sigma_m$) and those selected with $r_p < r_{\text{th}}$ (e.g., $\sigma_m$). We summarise our principle results as follows.

1. $\sigma_{\text{los}}(R)$ is steeper in selected galaxies with $r_p < r_{\text{th}}$ than in all ones for the standard model with $e_{m,0} = 0.6$ and $\sigma_0 = 0.2$. $\sigma_m$ is significantly smaller than $\sigma_{m,0}$ in the standard model and the differences between $\sigma_m$ and $\sigma_{m,0}$ depend on $r_{\text{th}}$ in such a way that they can be larger for smaller $r_{\text{th}}$ (25 kpc $\leq r_{\text{th}}$ $\leq$ 175 kpc).

2. $\sigma_{\text{los}}(R)$ is steeper in selected galaxies with $e_p > e_{\text{th}}$ than in all ones for the standard model. Although $\sigma_m$ of the selected galaxies with $e_p > e_{\text{th}}$ is slightly smaller than $\sigma_{m,0}$ in the standard model, the difference between the two can be quite small ($\approx 20$ km s$^{-1}$) for $0.5 \leq e_{\text{th}} \leq 0.7$.

3. The above results derived for the standard model are seen in the models with different $e_{m,0}$ and $\sigma_0$, which implies that lower velocity dispersions of UCDs can be due to their smaller $r_p$ in comparison with other galaxy populations in the Fornax. Thus the observed kinematical differences in UCDs and other dwarf galaxy populations are due to differences in intrinsic orbital properties between these galaxy populations in the Fornax cluster.

Although the observed significantly flattened spatial distribution of UCDs in the Fornax cluster can potentially have important implications on dwarf galaxy formation in the cluster (Gregg et al. 2007), we did not discuss the origin of the distribution. We plan to discuss the observed distribution in the context of the picture that UCDs originate from galaxies embedded in dark matter halos already virialized at $z > 10$ in the proto-cluster environment (Bekki & Yahagi 2007, in preparation).

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### REFERENCES

Adami, C., Mazure, A., Katgert, P., Biviano, A., 1998, A&A, 336, 63
Bassino, L. P., Cellone, S. A., Forte, J. C., Dirsch, B. 2003, A&A, 399, 489
Bekki, K., Couch, W. J., Drinkwater, M. J., 2001, ApJL, 552, 105
Bekki, K., Couch, W. J., Drinkwater, M. J., Shioya, Y. 2003a, MNRAS, 344, 399
Bekki, K., Forbes, D. A., Beasley, M. A., Couch, W. J., 2003b, MNRAS, 344, 1334
Bekki, K., Yahagi, H., 2006, MNRAS, 371, 1019
Bekki, K., Couch, W. J., Shioya, Y., 2006, ApJL, 642, 133
Bekki, K., Yahagi, H., Forbes, D. A., 2007, preprint (astro-ph/0702088)
Bergond, G. et al., 2007, accepted by A&A Letters (astro-ph/0701378)
Binney, J., Tremaine, S., 1987 in Galactic Dynamics.
De Propris, Phillipps, S., Drinkwater, M. J., Gregg, M. D., Jones, J. B., Evstigneeva, E., Bekki, K., 2005, ApJL, 623, 105
Dirsch, B. et al., 2004, AJ, 127, 2114
Drinkwater, M. J., Phillipps, S., Jones, J. B., Gregg, M. D., Deady, J. H., Davies, J. I., Parker, Q. A., Sadler, E. M., Smith, R. M. 2000a, A&A, 355, 900
Drinkwater, M. J., Jones, J. B., Gregg, M. D., Phillipps, S. 2000b, PASA, 17, 227
Drinkwater, M. J., Gregg, M. D., Colless, M. 2001, ApJL, 548, 139
Drinkwater, M. J., Gregg, M. D., Hilker, M., Bekki, K., Couch, W. J., Ferguson, J. B., Jones, J. B., Phillipps, S. 2003, Nat, 423, 519
Evstigneeva, E. A., Gregg, M. D., Drinkwater, M. D., Hilker, M., 2007, accepted for AJ, (astro-ph/0612483)
Fellhauer, M., Kroupa, P. 2002, MNRAS, 330, 642
Firth, P. et al., 2006, in the Globular Clusters to Guides to Galaxies (astro-ph/0606041)
Ghigna, S., Moore, B., Governato, F., Lake, G., Quinn, T., Stadel, J. 1998, MNRAS, 300, 146
Gregg, M. D. et al, 2007, submitted to AJ
Hajegn et al., 2005, ApJ, 627, 203
Hilker, M., Infante, L., Richtler, T. 1999, A&AS, 138, 55
Hilker, M., Baumgardt, H., Infante, L., Drinkwater, M. D., Evstigneeva, E. A., Gregg, M. D., 2007, accepted for A&A, (astro-ph/0612484)
Jones, C., Stern, C., Forman, W., Breen, J., David, L., Tucker, W., Franx, M. 1997, ApJ, 482, 143
Jones, J. B. et al., 2006, AJ, 131, 312
Jordán, A., West, M. J., Côte, P., Marzke, R. O., 2003, AJ, 125, 1642
Karick, A. M., Gregg, M. D., Drinkwater, M. J., Hilker, M., Firth, P., 2006, in the Globular Clusters to Guides to Galaxies (astro-ph/0605515)
Kilborn, V. A. et al., 2005, PASA, 22, 326
Mieske, S., Hilker, M., Infante, L., 2002, A&A, 383, 823
Mieske, S., Hilker, M., Infante, L., 2004, A&A, 418, 445
Mieske, S., Hilker, M., Infante, L., Jordán, A., 2006, AJ, 131, 2422
Navarro, J. F., Frenk, C. S., White, S. D. M. 1996, ApJ, 462, 563
Phillipps, S., Drinkwater, M. J., Gregg, M. D., Jones, J. B., 2001, ApJ, 560, 201
Tamura, N., Sharples, R. M., Arimoto, N., Onodera, M., Ohta, K., Yamada, Y., 2006, MNRAS, 373, 601
West, M. J., Côte, P., Jones, C., Forman, W., Marzke, R. O., 1995, ApJ, 453, L77
Williams, B. et al., 2007, ApJ, 654, 835
Yahagi, H., Bekki, K., 2005, MNRAS, L364, 86

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