ON THE DENSITY PROFILE OF THE GLOBULAR CLUSTER M92*

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Abstract

We present new number density and surface brightness profiles for the globular cluster M92 (NGC 6341). These profiles are calculated from optical images collected with the CCD mosaic camera MegaCam at the Canada–France–Hawaii Telescope and with the Advanced Camera for Surveys on the Hubble Space Telescope. The ground-based data were supplemented with the Sloan Digital Sky Survey photometric catalog. Special care was taken to discriminate candidate cluster stars from field stars and to subtract the background contamination from both profiles. By examining the contour levels of the number density, we found that the stellar distribution becomes clumpy at radial distances larger than ∼13′, and there is no preferred orientation of contours in space. We performed detailed fits of King and Wilson models to the observed profiles. The best-fit models underestimate the number density inside the core radius. Wilson models better represent the observations, in particular in the outermost cluster regions: the good global agreement of these models with the observations suggests that there is no need to introduce an extra-tidal halo to explain the radial distribution of stars at large radial distances. The best-fit models for the number density and the surface brightness profiles are different, even though they are based on the same observations. Additional tests support the evidence that this fact reflects the difference in the radial distribution of the stellar tracers that determine the observed profiles (main-sequence stars for the number density, bright evolved stars for the surface brightness).

Key words: globular clusters: general – globular clusters: individual (M92) – stars: kinematics and dynamics – stars: Population II

Online-only material: color figures

1. Introduction

The Galactic globular clusters (GCs) are the oldest (∼11–13 Gyr) Galactic systems and have complex internal and external dynamics (Gnedin & Ostriker 1997). The internal dynamics is driven by two-body relaxation with a timescale that is typically shorter than their age (Meylan & Heggie 1997). Therefore, the density profile of the innermost regions is expected to be well described by King models (1962, 1966). The outermost regions are characterized by the interaction with external tidal forces (Spitzer 1958; Spitzer & Chevalier 1973; Aguilar et al. 1988) and by the evaporation of low-mass stars (Spitzer & Harm 1958). These phenomena are expected to produce deviations from the spherical King models. By moving beyond the cluster truncation radius (r_t) the escaping stars can form halos or extended tidal tails.

The first empirical evidence of extra-tidal structures in GCs was found from photographic plates (Grillmair et al. 1995; Lehmann & Scholz 1997; Testa et al. 2000, hereafter T00; Leon et al. 2000). More recently, investigations based on CCD photometry found evidence either of tidal tails (Odenkirchen et al. 2001, 2003; Grillmair & Johnson 2006; Chun et al. 2010; Jordi & Grebel 2010, hereafter JG10) or of surrounding halos (Lee et al. 2003, hereafter L03; Olszewski et al. 2009; JG10; Correnti et al. 2011) around more than 30 GCs.

An accurate determination of the truncation radius of M92 and of the shape of its external regions is still missing, even though several investigations have been carried out on this topic (see Table 1). The oldest surface brightness (SB) profile (obtained from photographic plates and small-format CCD images) was provided by Trager et al. (1995, hereafter T95). The same was later analyzed by McLaughlin & van der Marel (2005, hereafter MLvdM05). By using photographic plates, T00 found evidence of extra-tidal stars at 30′ from the cluster center, and provided a surface density map, which shows only marginal evidence for an elongation orthogonal to the direction of the Galactic center. More recently, L03 by using a mosaic CCD camera, confirmed the occurrence of extra-tidal stars and showed that the marginal elongation appears only for the brightest stars. JG10 analyzed the Sloan Digital Sky Survey (SDSS) photometric catalog and found the same elongated contours detected by T00, even though their data do not cover the entire M92 area.
Figure 1. Panel (a)—area of the sky across the globular cluster M92 covered by the different sets of space images collected with the Advanced Camera for Surveys (ACS) on board the HST. The field of view of the sky plot is $1^\circ \times 1^\circ$. The red and the blue squares show the images collected with the Wide Field Channel (WFC, pointings $\beta$, $\gamma$), while the green square those collected with the High Resolution Channel (HRC, $\alpha$). The black dots display the photometric catalog based on ground-based images collected with CFHT. The orientation is shown in the bottom right corner. Panel (b)—same as panel (a), but for data sets collected with ground-based telescopes, namely CFHT (black dots) and SDSS (brown dots). Note that the latter data set does not uniformly cover the area of the sky around M92. The field of view of the sky plot is $4^\circ \times 4^\circ$. See the text for more details.

(A color version of this figure is available in the online journal.)

### Table 1

| Profile     | King Models | Spherical Wilson Models |
|-------------|-------------|-------------------------|
|             | $\Psi$      | $c$         | $r_s$       | $r_t$       | $\Psi$      | $c$         | $r_s$       | $r_t$       |
| ND          | 6.91 ± 0.02 | 1.50 ± 0.01 | 34.25 ± 0.38 | 18.11 ± 0.44 | 5.84 ± 0.02 | 1.73 ± 0.01 | 48.03 ± 0.42 | 42.63 ± 1.19 |
| SB          | 8.40 ± 0.01 | 1.95 ± 0.00 | 15.22 ± 0.02 | 22.80 ± 0.18 | 6.65 ± 0.01 | 2.14 ± 0.00 | 48.03 ± 0.05 | 48.80 ± 0.85 |
| SB-15       | 7.20 ± 0.01 | 1.59 ± 0.00 | 19.43 ± 0.05 | 12.56 ± 0.10 | 6.52 ± 0.01 | 2.06 ± 0.00 | 24.33 ± 0.06 | 46.67 ± 0.42 |
| SB-17       | 6.95 ± 0.01 | 1.51 ± 0.00 | 23.17 ± 0.06 | 12.63 ± 0.12 | 6.29 ± 0.01 | 1.94 ± 0.00 | 29.04 ± 0.06 | 41.97 ± 0.53 |
| T95         | 7.92        | 1.81        | 23.67        | 15.20        | 5.9         | 1.75        | 26.51        | 24.85        |
| T00         |             |             |             |             | 6.34        | 1.96        | 19.33        | 29.58        |
| L03         | 8           | 1.83        | 12.42        | 14.00        |             |             |             |             |
| L03+N06     |             |             |             |             | 6.61        | 2.12        | 18.94        | 41.72        |
| MLvdM05     | 7.5         | 1.68        | 16.15        | 12.88        |             |             |             |             |
| JG10        | 6.93        | 1.51        | 23.37        | 12.55        |             |             |             |             |
| T95+N06     | 7.54        | 1.69        | 14.72        | 12.07        |             |             |             |             |
| L03+N06     | 7.84        | 1.78        | 13.46        | 13.67        |             |             |             |             |

**Notes.** For each model, we list the dimensionless parameter $\Psi$, the concentration $c$, the scale radius $r_s$ (arcseconds), and the truncation radius $r_t$ (arcminutes). The different profiles are identified by the label in the first column. The cases indicated as T95+N06 and L03+N06 refer to the fits we performed on composite profiles, obtained by combining the profiles from T95 and L03 with the profile from Noyola & Gebhardt (2006, hereafter N06), which covers the innermost regions of the cluster.

2. PHOTOMETRIC DATA SETS

We used both ground-based data collected with the 36 CCD mosaic camera MegaCam at the Canada–France–Hawaii Telescope (CFHT) and space data collected with the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope (HST). The MegaCam images were collected in the $g', r', i', z'$ bands. To increase the radial extent of the sky area covered by our data set, the ground-based data (MegaCam images) were supplemented with multiband ($g, r, i, z$) data collected by the SDSS (Aihara et al. 2011). As a whole the ground-based data cover $\sim 4^\circ \times 4^\circ$ around the cluster center, but they do not uniformly cover the sky area around M92.

The ACS data were collected with three different pointings: pointing $\alpha$, High Resolution Channel (HRC), six F435W ($t = 340$ s each), and 155 F555W (with exposure times ranging from 10 to 100 s) images located across the cluster center; pointing $\beta$, Wide Field Channel (WFC), three F606W ($t = 0.5, 5, 90$ s), and three F814W ($t = 0.5, 6, 100$ s) images located across the cluster center; pointing $\gamma$, WFC, three F475W ($t = 3, 20, 40$ s), and three F814W ($t = 1, 10, 20$ s) images located 2$'$ from the cluster center in the southeast direction. The reduction and the photometry of the F555W and F814W images have been presented and discussed by Di Cecco et al. (2010, hereafter DiC10). Panels (a) and (b) of Figure 1 display the sky coverage of the space- and ground-based data sets.

To estimate the completeness of the CFHT data we adopted the data of the pointing $\gamma$ (ACS–WFC). We found that the

11 Proposal ID: 2004AC03, PI: J. Clem.
12 GO-10335, PI: H. Ford.
13 GO-9453, PI: T. Brown.
14 GO-10505, PI: C. Gallart.
Completeness for $i \leq 22$ mag is 54% for $75 \leq R \leq 150$ arcsec, 82% for $150 \leq R \leq 200$ arcsec, and complete for larger distances. We applied the above completeness corrections to the star counts (DiC10). We also estimated the completeness of the SDSS data by using the CFHT data and we found that for radial distances larger than 700 arcsec and $i \leq 22$ mag they are complete. For radial distances smaller than 75″ we adopted the data of pointing $\gamma$. These data display a gap of 2.5″ between the two CCDs. To fill this gap we selected two regions of 2.5″ at the edges of the gap and we randomly extracted half of the stars in each of the two regions. Once the gap was filled, we assumed that the data of pointing $\beta$ located between 20″ and 75″ are complete (DiC10). The completeness of pointing $\beta$, for radial distance—$R$—smaller than 11″, was estimated using pointing $\alpha$. In this case we found that in the magnitude range between the Main Sequence Turn Off (MSTO) and $F555W \sim 21.5$ mag the pointing $\beta$ data set was complete at the 70% level. The star counts in this cluster region were corrected accounting for the above completeness correction.

In summary, we are dealing with three different data sets.

1. ACS–WFC, pointing $\beta$, $R \leq 1.25$. For radial distances smaller than 0.18 the completeness was estimated using ACS–HRC, pointing $\alpha$. For radial distances 0.18 $\leq R \leq 1.25$ we only filled the gaps.

2. CFHT, $1.25 < R \leq 30\,\prime$. For radial distances $1.25 < R \leq 3.33$ the completeness was estimated using ACS–WFC, pointing $\gamma$. The comparison of CFHT with pointing $\gamma$ indicates that the former data set for $i \leq 22$ mag is complete at larger distances.

3. SDSS, $30\,\prime < R \leq 2\,^\circ$. The completeness was estimated using CFHT data; they are complete for $i \leq 22$ mag and radial distances larger than 700 arcsec. However, they do not uniformly cover the sky region around the cluster (see panel (b) in Figure 1) and the star counts were accordingly corrected.

Panels (a)–(c) of Figure 2 show the color–magnitude diagrams (CMDs) of pointing $\alpha$, $\beta$, and $\gamma$. Stars plotted in these panels were selected according to the sharpness ($|sh| \leq 1$) DAOPHOT index (see, e.g., Stetson 1987, 1994). These CMDs display well-defined sequences in the evolved phases as well as along the main sequence (MS). The red giant branch (RGB) stars brighter than red horizontal branch (HB) stars ($F555W \sim 14$ mag) are saturated in pointing $\alpha$.

To provide homogeneous star counts across the entire GC, the $i$ and the $r$ band from the SDSS, as well as the $F814W$ and the $F606W$ band of pointing $\beta$ were transformed into the $i'$ and the $r'$ band of the MegaCam photometric system. The accuracy of the transformations is better than 0.02 mag (DiC10). In the following, we use the $g, r, i, z$ bands (without prime) to refer to the CFHT bands. The reason for the above transformations is threefold: (1) $i$ and $r$ bands are common to the different data sets; (2) the data in these bands have good photometric accuracy ($\sigma_{r-i} = 0.06$ mag, at least three magnitudes fainter than the MSTO); (3) the $i$ band is minimally affected by saturation problems and it was adopted to compute the density profiles.

3. RADIAL DENSITY PROFILE

The field of view of the CFHT data set ($1^\circ \times 1^\circ$) and of the SDSS data set fully encloses the estimated radial extent of M92 (see Table 1). In order to constrain the cluster edges, candidate cluster, and field stars must be distinguished. The method used to identify the two different groups of star is described below.
We selected the photometric catalog by using the intrinsic photometric error ($\sigma_{r-i} \leq 0.10$ mag), the separation\(^{15}\) ($\text{sep} \geq 2.5$), and the distance from the cluster center ($10' \leq R \leq 180'$). We computed a fiducial line (ridge) in the $i$, $r-i$ CMD by means of a three-dimensional Hess diagram (I. Ferraro et al. 2013, in preparation). Note that the above selection criteria were only applied to estimate the ridgeline.

Panel (a) of Figure 3 shows the $i$, $r-i$ CMD for the entire sample of stars together with the above ridgeline. Stars plotted in this figure were selected according to the radial distance and sample of stars together with the above ridgeline. Stars plotted in the outermost cluster regions. Data plotted in Figure 4 show the $i$, $r-i$ CMD for stars in radial bins located between $13'$ and $2'$ from the cluster center. The first three radial bins—panels (a)–(c)—are entirely included inside the CFHT data set, while the last two—panels (d) and (e)—are entirely located inside the SDSS data set. The two solid lines display the acceptance region we defined in Figure 3. The photometric precision in the outermost cluster regions is clearly supported by the thin distribution of MS stars. Data plotted in the three innermost radial bins indicate that MS stars are crucial to trace the radial extent of candidate cluster stars. Moreover, the ratio between the number of cluster stars and the total number of stars is steadily decreasing when moving toward the outermost cluster regions. It decreases from almost 50% ($N_A/N_T = 0.49 \pm 0.02$) for $R \sim 14.5'$ to slightly less than one third ($N_A/N_T = 0.30 \pm 0.01$) for $R \sim 25'$. This radial distance appears to be a preliminary plausible lower limit for the truncation radius, and indeed the same ratio in the two outermost radial bins attains smaller constant values. Note that the main vertical sequence partially overlapping with the acceptance region is almost entirely made up of field stars.

To further constrain the plausibility of the above working hypothesis concerning the radial extent of M92, we decided to investigate the radial distribution of extragalactic sources. We

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\(^{15}\) The separation index quantifies the degree of crowding, i.e., the amount of spurious light, due to neighboring stars, affecting the magnitude of individual stars (Stetson et al. 2003).
adopted the entire set of r-band images collected with MegaCam at CFHT and performed a new independent photometry by using SExtractor (Bertin & Arnouts 1996). The non-point-like sources were selected—following Evans et al. (2010)—as the objects with a local point spread function 90% enclosed counts fraction larger than 1′′.4. The adopted value was fixed by eye inspection of the mean r-band image. Figure 5 shows the radial distribution of the non-point-like sources (blue dots) over the mean r-band image with apparent magnitudes between r ∼ 19 and r ∼ 22 mag. To help the eye to identify the sky area covered by M92, the red and the purple circles display the Wilson truncation radius based on both the number density (ND) and the SB profile (see Section 4). The smaller orange circles show the candidate galaxy clusters identified from the SDSS DR6 (Wen et al. 2009). A glance at data plotted in this figure shows that the candidate galaxy clusters are located either close to the truncation radius or beyond it. The innermost candidate galaxy cluster appears a bit suspicious, since it is located in a cluster region with a high stellar density.

We selected the objects located inside the sky region covered by the five candidate galaxy clusters beyond the truncation radius and plotted them in the CMD and we found that a significant fraction (~65%) of them are located outside the acceptance region (blue triangles in panel (c) of Figure 4). This fraction agrees, within the errors, quite well with the ratio between accepted and total number of stars (see the discussion above in this section).

To remove spurious stars that were erroneously accepted, we used the method described by Walker et al. (2011) for the GC IC 4499. This method works particularly well for our data sets, due to the large sky area they cover. To estimate the density of the rejected stars, the sky area covered by CFHT (R ≲ 30′) and by SDSS (0.5 ≲ R ≲ 2°) data was divided into concentric annuli. The star counts based on SDSS data were corrected to account for the non homogeneous coverage of this photometric catalog. Panel (a) of Figure 6 shows the logarithmic surface density of these objects (number of rejected stars, N_R, per arcmin²) as a function of the inverse of the radial distance. We performed a linear fit to the individual points and by extrapolating to infinite radial distance we found that the asymptotic value is μ_1 = 0.42 ± 0.10 (logarithmic number of stars per arcmin²). We also estimated the asymptotic value as the mean of the five outermost values, finding μ_2 = 0.36 ± 0.10. We adopted the mean of the above estimates: μ = 0.39 ± 0.14.

In panel (b) of Figure 6 we plotted the logarithm of the ratio between the number of accepted stars and the number of rejected stars (N_A/N_R). This ratio was estimated using the entire data set. To estimate the mean asymptotic value, we adopted the average of the outermost three radial bins, obtaining χ = −0.41 ± 0.03. Eventually, by multiplying the number of rejected stars per arcmin² by N_A/N_R, we found the number of candidate field stars that were erroneously classified as candidate M92 stars. Notably, we found that the asymptotic number of spuriously accepted stars is 10^μ × 10^χ ∼ 0.95 star arcmin^-2. By subtracting this value from the number of the accepted stars per unit area, we obtained the final Count Catalog of the candidate M92 stars. This catalog was used to compute the ND radial profile. We divided the cluster into concentric annuli and we...
counted the number of stars per arcmin$^2$ that fall inside each region, obtaining a radial profile ranging from $R \sim 1.5$ out to $R \sim 2\arcmin$. The error on each of the points is calculated as the square root of the number of stars, divided by the area of the annulus.

Following Walker et al. (2011), we measured the spurious stellar flux which affects the stellar luminosity of accepted stars. The logarithmic flux density of the rejected stars per arcmin$^2$ ($\text{Flux}_{R}$) and the ratio between the flux of accepted and rejected stars ($\text{Flux}_{A}/\text{Flux}_{R}$) are plotted in panels (c) and (d) of Figure 6. The logarithm of the surface flux density of the rejected stars approaches $\epsilon_1 = \log_{10} F_{\text{rej}} = -5.72 \pm 0.03$ (logarithmic star flux per arcmin$^2$) when extrapolated to infinite radial distance, whereas it is $\epsilon_2 = \log_{10} F_{\text{rej}} = -5.76 \pm 0.03$ when we use the mean value of the last three points. The mean of these values is $\epsilon = \log_{10} F_{\text{rej}} = -5.74 \pm 0.04$, whereas the logarithm of the ratio between accepted and rejected stars is $\xi = -0.82 \pm 0.07$. In this case, the flux of spurious accepted stars is $10^\epsilon \times 10^\xi \sim 0.310^{-6}$ Flux/arcmin$^2$. By subtracting this last value from the accepted stellar flux density, we obtained an independent final Flux Catalog for the candidate M92 stars. This catalog was used to calculate the SB radial profile. As in the previous case we divided the cluster into annular regions, and the SB for each annulus was computed by adding the flux contribution of the stars located inside the annulus and by dividing for its area. Data plotted in panels (b) and (d) of Figure 6 show that the ratio between the number of accepted and rejected stars is more robust than the ratio between the flux of accepted and rejected stars, since the intrinsic dispersion of the former one is at least a factor of two smaller than the latter one. The difference is caused by the fact that the number ratio is rooted in the radial distribution of MS stars, while the flux ratio traces the radial distribution of bright evolved stars. To further constrain the role of bright stars in determining the radial slope of the SB, we calculated two more SB profiles by considering only stars fainter than a limiting magnitude of $i = 15$ (SB-15) and $i = 17$ (SB-17) mag (see Section 4).

The error on the SB profile was estimated by propagating the error on individual measurements of star magnitudes. The intrinsic photometric error, in the magnitude range adopted...
Figure 6. Panels (a) and (b): logarithm of the number density of the rejected stars and of the ratio between the number of accepted and rejected—$N_A/N_R$—stars as a function of the inverse of the radial distance. Panels (c) and (d): logarithm of the flux density of the rejected stars, and of the ratio between the flux of accepted and rejected—$\text{Flux}_A/\text{Flux}_R$—stars. The vertical arrows display the edge of outermost annulus, the solid lines show the linear fits over the entire samples, and the dashed lines indicate the mean of the outermost annuli (red points). See the text for more details.

(A color version of this figure is available in the online journal.)

We evaluated the symmetry of the ND as a function of the radial distance by using the Count Catalog. To avoid possible systematic uncertainties in the radial distribution, the symmetry of the ND was estimated on the basis of ACS and CFHT data. The SDSS data were neglected since they do not uniformly cover the area of the sky around the cluster center. The conclusions concerning the departure from circular symmetry of the radial distribution for distances between 6' and 30' are not affected by the inclusion of the SDSS data set. We computed the contour levels of the candidate M92 and field stars (black and red lines in panel (a) of Figure 7). The contour levels become less circular symmetric when moving toward the outermost regions, and for radial distances between 6' and 10' the stellar density decreases by almost one order of magnitude (see top panels of Figure 7). The contour levels become asymmetric at a distance of $\sim 13'$ (see panel (a) of Figure 7), which is almost equivalent to the truncation radius of M92 (see Column 5 in Table 1) available in the literature. Outside this region the distribution of candidate cluster stars becomes clumpy. Panels (b) and (c) of Figure 7

to estimate the SB profile, is typically of the order of a few hundredths of a magnitude (see Section 2), because ground-based images were collected in good seeing conditions (DiC10) and we typically have more than 10 images per band. The same applies for ACS images adopted in the central regions. We also calculated the error of the absolute photometric zero points. Following DiC10, we calibrated the CFHT photometric catalog by using the local standards by Clem et al. (2007). The ACS and the SDSS photometric catalogs were also transformed into the same photometric systems by using the new local standards. We ended up with a mean calibration error in the $i$ band of $0.02 \pm 0.04$ mag (Di Cecco 2009). This error was eventually summed in quadrature with the intrinsic photometric error.

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The residuals plotted in panel (d) of Figure 7 show that the innermost contour levels display symmetric radial distributions, and indeed the residuals attain vanishing values out to $R \sim 3\arcmin$. At larger radial distances, the asymmetry increases out to $R \sim 9'–10' \ (R \sim 500''–600'')$, where the residuals show a shoulder clearly connected with the density drop detected in the contour plot. At even larger distances the contours become more asymmetric (residuals $\sim 26''$ for distances of $R \sim 13'');$ the fit in the outermost regions fails to converge because of the large asymmetries. The increase in asymmetry that we found in the outer regions could be the consequence of the fluctuations associated with the decrease in density. To validate this working hypothesis we performed a series of simulations by using the observed density profile to compute synthetic GCs; the radial distribution of the synthetic GCs was required to be symmetric. We applied to these GCs the same procedure to evaluate the contour levels and the same fit with circles of variable radius. The vertical hatched area plotted in panel (d) of Figure 7 marks the residuals calculated for the synthetic GCs. The comparison between this area and the plotted points indicates that the asymmetry in the real cluster is at least 3$\sigma$ larger than in the synthetic clusters. To characterize further the nature of the asymmetries in the contour levels, we show two green arrows, in the top panel of Figure 7, indicating the direction of the Galactic center (long arrow) and of the M92 proper motion (short arrow) according to Dinescu et al. (1999). We found no clear correlation between these directions and the clumpy distribution of candidate M92 stars at large radial distances.

Evidence of a clumpy stellar distribution in the outskirts of M92 was also present in the stellar density maps provided by Testa et al. (2000, see their Figure 6), by Lee et al. (2003, see their Figure 12) and by Jordi & Grebel (2010, see their Figure 17). The above results support the findings by Lee et al. (2003), concerning the marginal evidence of an elongation of outermost clumpy stars in the direction orthogonal to the direction of the Galactic center.

4. DYNAMICAL MODELS AND FITS

We carried out fits of dynamical models to the observed radial profiles. We considered the King (1966) and the Wilson (1975) spherical and isotropic dynamical models, defined by the following distribution functions:

$$f_K = A \left( e^{-aE} - e^{-aE_0} \right) \ E \leq E_0, \quad (1)$$

$$f_W = A \left( e^{-aE} - e^{-aE_0} [1 - a(E - E_0)] \right) \ E \leq E_0. \quad (2)$$

The quantity $E$ is the specific star energy $E = v^2/2 + \Phi(r)$, where $\Phi(r)$ is the mean-field gravitational potential, to be determined from the Poisson equation. Both distribution functions vanish for energies larger than the threshold energy $E_0$, corresponding to stars to be considered as unbound. The energy truncation can be translated into a truncation radius, $r_t$, which indicates the boundary of the system. For each family of models, the constants $A$, $E_0$, and $a$ in Equations (1) and (2) define two-dimensional scales (a typical radius and a typical mass or velocity) and one dimensionless parameter, the central depth of the potential well (related to the concentration parameter).

We recall that fitting by a one-component dynamical model assumes that the underline stellar populations are distributed homogeneously. To identify the best-fit model we adopted the procedure described by Zocchi et al. (2012). The results are
of the best-fit models are listed in the upper part of Table 1. Shown in Figures 8 and 9; the values of the relevant parameters (A color version of this figure is available in the online journal.)

The fit to the ND profile is shown in the top panel of Figure 8. Both King and Wilson models underestimate the central ND profile, failing with respect to the four innermost points. A quantitative interpretation of this discrepancy remains unavailable, but the problem is likely to be related to the failure of the assumptions at the basis of a one-component dynamical model in the central regions. Concerning the King models, the good agreement with observations that can be found in the middle part of the profile breaks down around 700”, where the profile approaches the background level (0.95 star arcsec⁻²). In the case of the Wilson models, instead, only the two outermost points are discrepant, and the model fits the data out to a distance greater than 1000”. Note that the two outermost points are likely to be affected by errors in the subtraction of background stars. The bottom panel of Figure 8 shows the fits to the SB profile. When compared to the King best-fit model, the Wilson best-fit model provides a more adequate overall description, not only in relation to the outermost points, as in the ND profile, but also in the central part of the profile. The satisfactory performance of the Wilson models indicates that the observations can be explained by means of a less abrupt truncation radius, with no need to introduce extra-tidal halos. In this case, the two outermost points were not taken into account to calculate the best-fit parameters, since they are expected to be even more affected by errors in the subtraction of background stars, compared to the corresponding points in the ND profile. In the figure, the background level (25.30 mag arcsec⁻²) is indicated as a horizontal dashed line.

Surprisingly, even if the ND and the SB profiles come from the same set of observations, the best-fit parameters determined by the fits are significantly different. We argue that this behavior is due to the fact that each profile represents a different aspect of the density distribution of the cluster. On the one hand, the ND profile, derived by considering the radial distribution of both luminous and faint stars, is dominated by the MS stars, which greatly outnumber evolved (RGB, HB) stars (Castellani et al. 2007). On the other hand, the SB profile is heavily affected by the presence of the brighter RGB stars. The difference in the best-fit models reflects the intrinsic difference in the radial distribution of the stellar tracer that determines each profile. This behavior should be interpreted as a signature of mass segregation. Indeed, the evolved slightly more massive stars appear to be more centrally concentrated compared to stars with lower masses (see the values of the concentration parameter c in Table 1).

This interpretation is confirmed by an additional test. We carried out the same fitting procedure on the SB-15 and the SB-17 profiles (as defined in Section 3). The resulting parameters are listed in the third and fourth rows of Table 1. The fits are shown in the top and in the bottom panel of Figure 9, respectively. Inspecting the values of the best-fit parameters, it appears that by eliminating the brightest stars, the profiles tend to approach the ND profile. Indeed, the values of the concentration parameter and of the radial scale—r_s—follow a monotonic trend from the SB profile to the SB-15, to the SB-17, and finally to the ND profile. Interestingly enough, for the SB-15 and SB-17 profiles, the King models reproduce the data better than the Wilson models, in contrast to what we found for the previously described ND and SB profiles. A reason for this can be found by

16 The occurrence of mass segregation in M92 was also suggested by Andreuzzi et al. (2000).

17 Note that hot HB stars are less massive than MSTO stars, but they are a minor fraction of evolved cluster stars.
The values of the parameters listed in Table 1 are not consistent with each other, within the errors. In conclusion, we believe that a proper comparison of the values of the best-fit parameters found by fitting models to different (ND, SB) profiles requires that we take into account the role of the different stellar tracers in determining their shape, which makes standard one-component dynamical models questionable.

5. DISCUSSION AND FINAL REMARKS

We studied the radial distribution of stars of the GC M92 by using ground-based (MegaCam at CFHT, SDSS) and space (ACS on HST) data.

The contour levels, based on star count data, are symmetric in the innermost regions, and exhibit an increasing asymmetry for radial distances between 3′ and 9′–10′. For distances larger than ∼13′ the stellar distribution becomes clumpy. The contour levels do not exhibit a preferred orientation in space. We calculated two independent radial profiles, to describe the distribution of stars in the cluster, the ND and the SB profile. To calculate these profiles, we subtracted the background contamination with two independent methods. We performed fits of spherical King and Wilson models to the above profiles. Wilson models appear to reproduce, better than King models, the behavior of the outermost regions of the cluster with no need of extra-tidal halos. Interestingly, for the ND profile, both models significantly underestimate the observations in the innermost regions.

We also found that the best fit to the ND and to the SB profile are provided by two different models for the two families, even though the profiles are derived from the same data sets. We argue that this difference is caused by a difference in the radial distribution of the stellar tracers that characterize the two observed profiles. The ND profile traces the radial distribution of MS stars, whereas the SB profile that of bright evolved (RGB, HB) stars. This conclusion is supported also by the results of a test that has been carried out on two additional profiles, calculated by considering only stars fainter than a given magnitude.

Hopefully, a thorough discussion of the behavior in this and other clusters should determine which of the various profiles considered is best suited for a study in terms of one-component models. To our knowledge, this is the first investigation in which independent estimates of both ND and SB profiles are provided, starting from the same set of data, and compared.

In this context a key role can be played by the new generation of wide field imagers that are available at the 4–8 m class telescopes (Dark Energy Camera and Survey at the CTIO 4 m Blanco telescope, Mohr et al. 2012; Hyper SuprimeCam at Subaru19). In a single pointing they can cover the entire extent of a large number of GCs and with modest exposure times will allow us to perform homogeneous and accurate photometry several magnitudes fainter than the MSTO.

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19 http://www.naoj.org/Projects/HSC/index.html
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