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A low surface brightness halo surrounding the globular cluster NGC 5694★

M. Correnti,[1,2]† M. Bellazzini,[1] E. Dalessandro,[3] A. Mucciarelli,[3] L. Monaco[4] and M. Catelan[5]

[1]*INAF-Osservatorio Astronomico di Bologna, Via Ranzani 1, 40127 Bologna, Italy*
[2]*INAF-Istituto di Astrofisica Spaziale e Fisica Cosmica di Bologna, Via Gobetti 101, 40129 Bologna, Italy*
[3]*Dipartimento di Astronomia, Universitá di Bologna, Via Ranzani 1, 40127 Bologna, Italy*
[4]*European Southern Observatory, Casilla 19001, Santiago, Chile*
[5]*Departamento de Astronomía y Astrofísica, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, 782-0436 Macul, Santiago, Chile*

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ABSTRACT

We report on the discovery of an extended stellar halo surrounding the distant Galactic globular cluster NGC 5694, based on new deep ($V \simeq 24.5$) wide-field ($24 \times 20\,\mathrm{arcmin}^2$) photometry acquired with the VIMOS at the VLT. Stars with colour and magnitude consistent with the main sequence of the cluster are clearly identified out to $r \simeq 9$ arcmin ($\simeq$93 pc) from the cluster centre, much beyond the tidal radius of the King model that best fits the inner profile ($r_t = 3.15$ arcmin). We do not find a clear end of the structure within our field. The overall observed profile cannot be properly fitted with either a King model, an Elson et al. model or a Wilson model; however, it is very smooth and does not show any sign of the break near the tidal radius that is typically observed in stellar systems with tidal tails. The density map we derived does not show evidence of tidal tails, within the considered field. The extra-tidal component contains $\simeq$ 3.5 per cent of the cluster light (mass) and has a surface density profile falling as $\sim r^{-3.2}$. The possible origin of the detected structure is discussed, as a clear-cut conclusion cannot be reached with the available data.

Key words: Galaxy: formation – globular clusters: individual: NGC 5694.

1 INTRODUCTION

NGC 5694 is a relatively poorly studied globular cluster (GC) residing in the outer halo of the Galaxy. Based on its large distance ($\gtrsim$30 kpc) and radial velocity ($V_r = -144\,\mathrm{km\,s^{-1}}$), Harris & Hesser (1976) suggested that the cluster is on a hyperbolic orbit not bound to the Milky Way (MW). Ortolani & Gratton (1990, hereinafter OG90) were the first to publish CCD photometry of the cluster [over a $\sim 4 \times 2.5\,\mathrm{arcmin}^2$ field of view (FoV)]. They concluded that NGC 5694 is a metal-poor ([Fe/H] = −1.65) stellar system with an age comparable to that of the oldest GCs of similar metallicity (age $\gtrsim$ 12.5 Gyr, see Dotter et al. 2010), lying at a distance $D \simeq 32$ kpc. From low-resolution Ca triplet spectroscopy of nine cluster giants, Geisler et al. (1995) obtained [Fe/H] = -1.87 ± 0.07, and slightly revised the systemic velocity, $V_r = -140.7 \pm 2.4\,\mathrm{km\,s^{-1}}$. The low metallicity and old age were confirmed by De Angeli et al. (2005), based on *HST*/WFPC2 photometry of the cluster centre. The horizontal branch (HB) is significantly populated only at colours bluer than the RR Lyrae instability strip and, indeed, no such variable was found in the cluster (Hazen 1996).

Eventually, Lee, López-Morales & Carney (2006, hereinafter L06) obtained high-resolution spectroscopy of a star on the red giant branch (RGB) of NGC 5694. They were able to derive the abundance of several elements, including Fe ([Fe/H] = -1.93 ± 0.07) and other iron-peak elements, α-elements, r- and s-elements. They found an abundance of α-elements (Ca + Ti)/(2Fe) $\simeq 0.0$, that is, much lower than that typical of old GCs in the MW halo ($\sim$+0.3) and similar to stars of similar metallicity in nearby dwarf spheroidal (dSph) galaxies, in GCs of the Large Magellanic Cloud and Fornax dSph, and in a handful of MW GCs (see e.g. Cohen 2004; Venn et al. 2004; Monaco et al. 2005; Sbordone et al. 2007) that are known (or strongly suspected) to have been accreted from disrupted/disrupting dwarf Galactic satellites (see Pritzl, Venn & Irwin 2005; Law & Majewski 2010; Kirby et al. 2011, for references and discussion). Moreover, NGC 5694 appears to have [Cu/Fe] and [Ba/Eu] ratios among the lowest of any stellar system for which the abundances of these elements have been measured. L06 interpret these chemical anomalies and the high velocity as evidence for an extragalactic origin of the cluster. They did not found any significant correlation with existing satellites and/or other GCs, thus concluding that the original parent galaxy is presently dissolved. Indeed,

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†E-mail: correnti@iasfbo.inaf.it

the association of several GCs in the outer halo of the MW and M31 with relics of partially or totally disrupted dwarf galaxies they originally belonged to is now quite firmly established (Bellazzini, Ferraro & Ibata 2003; Perina et al. 2009; Law & Majewski 2010; Mackey et al. 2010).

Triggered by this fascinating hypothesis on the origin of NGC 5694, we obtained new deep photometry over a wide FoV to search for the surroundings of the clusters for stellar features that might reveal hints on the origin and evolution of the system. In this paper, we report on the detection of stars far beyond the reported tidal radius of the cluster that appears to have a profile smoothly extending at least out to ≃9 arcmin from the centre.

2 OBSERVATIONS AND DATA REDUCTIONS

Observations were performed on the night of 2008 July 29 with the VIMOS camera mounted at the ESO-VLT UT3, Paranal Observatory (Chile), under stable and clear conditions (seeing ≃ 1 arcsec full width at half-maximum). The VIMOS is a mosaic of four $\simeq 2000 \times 2300$ pixel^2 CCDs (with the pixel scale 0.205 arcsec pixel^{-1}), each covering a FoV of 7×8 arcmin^2, separated by 2-arcmin gaps. We obtained one B and one V exposure per pointing, in four different pointings, thus covering a total FoV of $\sim 24 \times 20$ arcmin^2 centred on the cluster, without gaps. The exposure time was always set to $t_{\rm exp} = 200$ s.

The images were corrected for bias and flat-field with standard IRAF procedures. Photometry of individual stars was performed with the well-known point spread function fitting code DAOPHOT (Stetson 1987). The images were searched for sources with intensity peaks at $\geq 3\sigma$ above the background. The pixel coordinates of the catalogues with instrumental B, V magnitudes for each chip were transformed into J2000 equatorial coordinates by means of third-order polynomials obtained using several ($\gtrsim$60 per chip) astrometric standards[1] from the GSC2.2 catalogue.[2] As an independent test, we found that the standard deviation of the residuals in both RA and Dec. for the 513 stars in common with the 2MASS catalogue (Skrutskie et al. 2006) over the whole FoV of the mosaic is $\leq$0.2 arcsec. The instrumental magnitudes of all the catalogues were reported to the same instrumental system using stars in common in the overlapping regions between different chips. Then, all the individual catalogues were merged together into a total catalogue, averaging the magnitudes of the stars measured in more than one chip. Finally, the instrumental magnitudes were transformed into the Johnson–Kron–Cousins system using 74 standard stars from the set by Stetson (2000) that were in common with the total catalogue. The agreement in the photometric zero-points with the independent photometry by OG90 is excellent, with average differences smaller than 0.01 mag and rms scatter = 0.035 mag in both B and V (from 166 stars in common with $V \leq 21.0$).

We estimated the reddening by interpolating on the Schlegel, Finkbeiner & Davis (1998) maps on a grid covering the whole FoV at the resolution of the maps (≃5 arcmin). According to this source, the reddening is very uniform over the field, with maximum differences smaller than 0.015 mag. The average value is $E(B - V) = 0.099$ which is in excellent agreement with the result by OG90 and is adopted in the following. To estimate the distance, we matched, on the colour–magnitude diagram (CMD), the HB of NGC 5694 with that of M68 (from Walker 1994), a GC with a similar metallicity and a well-populated blue HB (BHB). The best match is obtained assuming $(m - M)_0 = 17.75 \pm 0.1$,[3] corresponding to $D = 35.5$ kpc, in agreement with the distance reported in the Harris (1996) catalogue (2010 edition), and slightly larger than what was found by OG90. At this distance, 1 arcmin corresponds to 10.3 pc. In the following, we will adopt the coordinates of the cluster centre provided by Noyola & Gebhardt (2006, hereinafter NG06). Since the incompleteness in the innermost 0.5 arcmin is quite large, due to the high degree of crowding, in this work, we will limit our analysis only to the stars at distances larger than 1 arcmin from the cluster centre.

3 RESULTS

In Fig. 1, we show the derived CMD for different radial annuli around the cluster centre. This is the deepest and cleanest CMD ever obtained for NGC 5694, for such a wide FoV. The upper left-hand panel shows the most central annulus considered here. In this diagram, the most prominent feature is the cluster main sequence [MS, from $(V, B - V) \sim (22.0, 0.45)$ to $\sim(24.5, 0.65)$], with the short subgiant branch (SGB) just above. A narrow and steep RGB and a BHB are also clearly visible. Most of the remaining stars are attributable to the Galactic foreground, except for the blob of faint blue sources at $V \gtrsim 23.5$ and $B - V \lesssim 0.5$ that are more likely background galaxies. The overall CMD is fully consistent with the age and metallicity reported in the literature. The limit at $r = 4.28$ arcmin corresponds to the tidal radius ($r_{\rm t}$, see King 1966) derived by Trager, King & Djorgovski (1995, hereinafter TKD). The upper right-hand and lower left-hand panels of Fig. 1 show that cluster stars (especially MS and SGB) are clearly present in significant numbers far beyond the TKD tidal radius, at least out to $r \simeq 9$ arcmin, corresponding to ≃93 pc. In fact, the comparison between the two lower panels suggests that cluster MS stars may also be present beyond that radius. With the available data, we were unable to detect any clear sign of an end of the distribution of cluster stars (see below). Hence, we cannot exclude that it extends beyond the 24×20 arcmin^2 field considered here.

By adopting the same procedure used and described in detail by Federici et al. (2007), we obtained the surface density profile from star counts on concentric annuli (before the subtraction of the background and limited to $r \gtrsim 1.2$ arcmin) that is shown in the upper panel of Fig. 2. SB profile star counts are reported in Table 1. The stars were selected as likely cluster members based on the selection boxes shown in the upper right-hand inset and were counted out to $r = 10$ arcmin, that is, the largest circle that is fully enclosed within our field. The area outside this circle was used to estimate the background density. It is clear that even in the outermost point of the profile the excess of surface density above the background is very significant ($>5\sigma$). This suggests that the distribution of cluster stars likely extends beyond this limit. If true, this would imply that the adopted background level is an overestimate of the true surface density of the background. To verify this possibility, we would need observations of similar deepness over a FoV wider than the one considered here, which are not available. In the lower panels of Fig. 2, we compare the observed CMD for the $r > 10$ arcmin region, with the corresponding synthetic CMD predicted by the Galactic model of Robin et al. (2003, hereinafter R03). To do that we (i) retrieved model predictions for a FoV of 1 deg^2 in the direction of NGC 5694,

[1] Using the CataPack suite of codes, developed by P. Montegriffo at the INAF-Osservatorio Astronomico di Bologna.

[2] http://tdc-www.harvard.edu/catalogs/gsc2.html

[3] $E(B - V) = 0.04$ and $(m - M)_0 = 15.14$ were adopted for M68, according to Ferraro et al. (1999, their table 2).

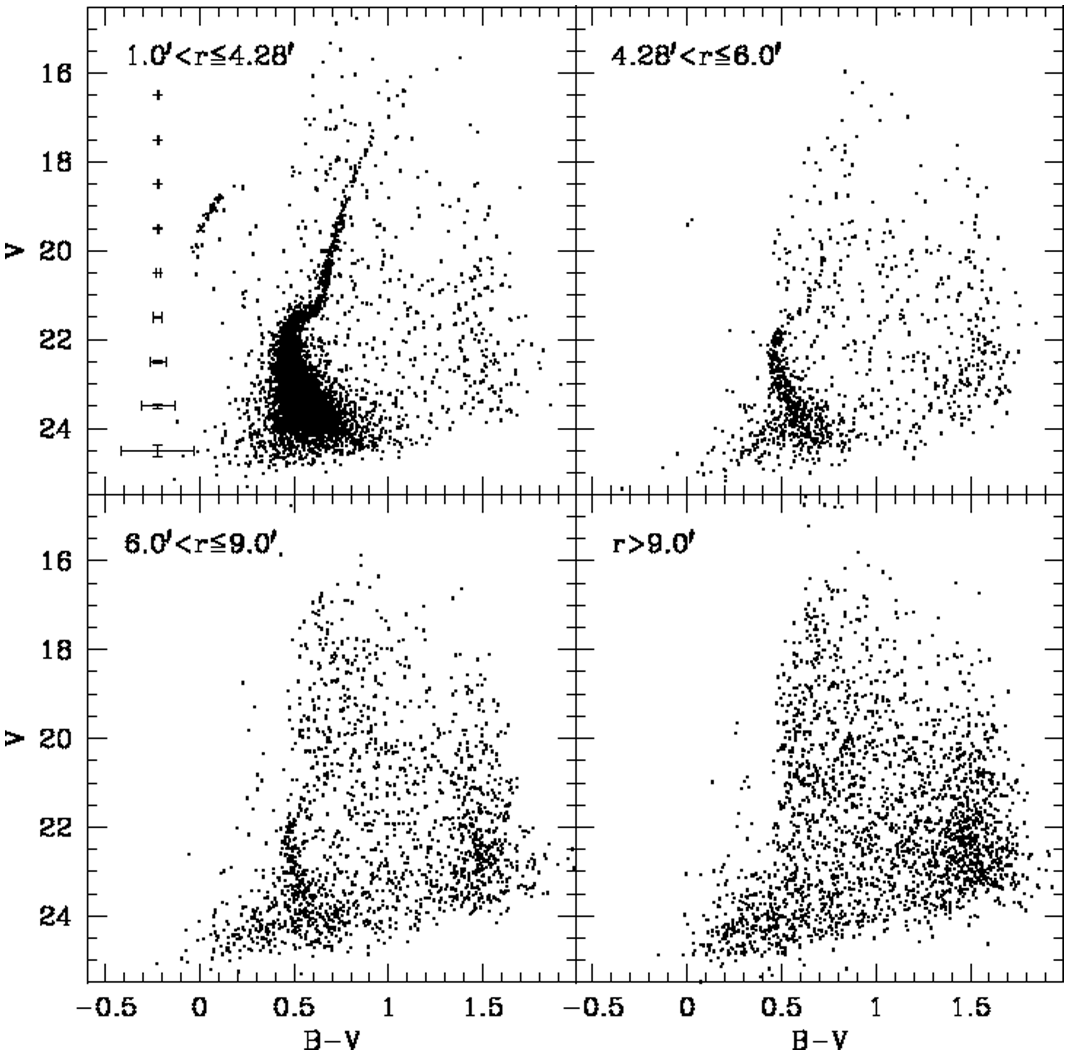

Figure 1. CMD of NGC 5694 in different radial annuli. $r = 4.28$ arcmin corresponds to the tidal radius derived by TKD. The average errors are reported as error bars on the blue side of the upper left-hand panel. A comparison with the predictions of the TRILEGAL Galactic model (Girardi et al. 2005) for this direction suggests that the sparse vertical plume of blue stars at $B - V \sim 0.3$ and $18.0 \lesssim V \lesssim 23.0$ that is seen in the lower two panels is likely due to nearby white dwarfs belonging to the Galactic disc.

(ii) rescaled the extinction of the model to have the same asymptotic value as the observed one and corrected the star magnitudes accordingly, (iii) randomly extracted a subsample by rescaling the number of stars to the ratio of the considered FoVs, (iv) cut the data according to the limiting magnitude line of the observed CMD, and (v) added an observational error to each magnitude of each star, randomly extracted from a Gaussian distribution having the same σ of observed stars of the same magnitude (see Fig. 1). We made 10^4 random extractions of the synthetic sample, like the one shown in the lower right-hand panel of Fig. 2. For each extraction, we counted the number of stars falling within the overplotted selection box and having $21.5 \le V < 23.5$. We limited the comparison to MS stars since the MS is the only cluster sequence that is populated at large radii, and we adopted $V < 23.5$ to minimize the contamination by background galaxies. The distribution of this number $N_{\rm mod}$ has average $\langle N_{\rm mod}\rangle = 57.3$, standard deviation $\sigma = 7.5$, a minimum $N_{\rm mod}^{\rm MIN} = 36$ and a maximum $N_{\rm mod}^{\rm MAX} = 86$, while the observed value is $N_{\rm obs} = 88$, that is, in excess of the model predictions in 100 per cent of the cases. Very similar results are obtained if the TRILEGAL Galactic model (Girardi et al. 2005) is adopted, instead of the R03 model. It should be noted that $N_{\rm mod}$ is an estimate for the upper limit of the expected $N_{\rm obs}$, since the synthetic sample is not affected by incompleteness, while the observed one is. On the other hand, it is still possible that some background galaxy spilled into the selection box, thus contaminating the counts of the observed sample.[4] The only conclusion that can be drawn is that the predictions of the R03 and TRILEGAL models are fully consistent with the hypothesis that the distribution of NGC 5494 stars extends beyond the limits sampled by the profile of Fig. 2.

The surface brightness (SB) profile of NGC 5694 was studied by TKD based on accurately assembled heterogeneous data from CCD and photographic images. McLaughlin & van der Marel (2005, hereinafter McV) re-analysed the same data set, finding slightly different solutions for the best-fitting K66 model (obtaining $r_{\rm t} = 5.09$ arcmin). On the other hand, NG06 used archival *HST* data to obtain accurate and homogeneous SB profiles in the innermost 2.4 arcmin. In Fig. 3, we adopted the smoothed version of the

[4] Note that this is not a problem for the profile shown in Fig. 3, below, since any contamination by unresolved galaxies should equally affect the cluster area and the (observed) background area, while these sources are not included in Galactic models.

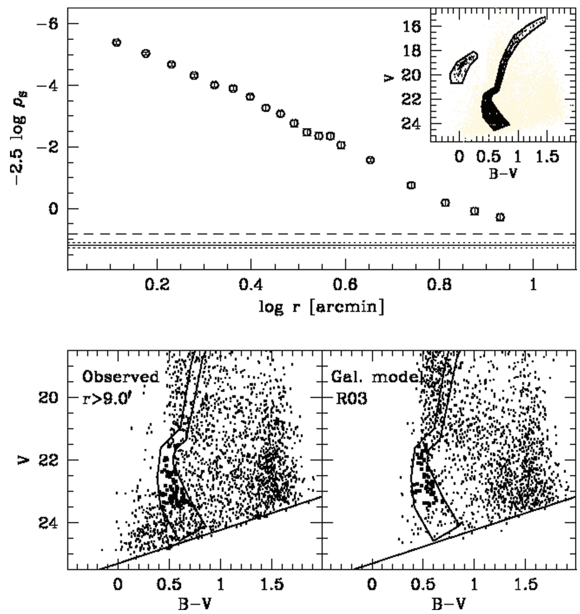

Figure 2. Upper panel: surface density profile from star counts (not background subtracted). The background level, estimated in the region $r > 9.0$ arcmin, is marked by a continuous line; the dotted lines are at $\pm 1\sigma$ from the background density. The dashed line is located at 5σ above the background level. In the inset at the upper right-hand corner, the selection on the CMD of the most likely cluster members used for star counts is displayed. Lower left-hand panel: observed CMD for $r > 9.0$ arcmin. The stars enclosed in the selection contour adopted for star counts (see also Fig. 3) and having $21.5 \leq V \leq 23.5$ are plotted as heavier dots. The diagonal line approximately marks the locus of the limiting V magnitude as a function of colour. Lower right-hand panel: the same as the lower left-hand panel for a synthetic CMD from the R03 Galactic model, for a FoV of the same area as the lower left-hand panel.

observed profile provided by NG06 as a reference to convert into absolute units the background-subtracted profile of the outer region that we obtained from star counts. The excellent match in the overlapping region $1.0 \lesssim r \lesssim 2.5$ arcmin guarantees that our profile is not affected by radial variations of the completeness, since the NG06 profile is obtained from integrated light that, by definition, cannot suffer from incompleteness (see Federici et al. 2007, for a thorough discussion).

It is quite clear that, while the innermost 1.0 arcmin of the profile (including $\gtrsim 80$ per cent of the cluster light) is well fitted by a K66 model with the reported parameters, having $r_t = 3.15$ arcmin, the observed profile smoothly extends far beyond this radius without any sign of a discontinuity. By numerical integration of the observed profile, we estimated that $\simeq 3.5$ per cent of the cluster light is found outside this radius; we also obtained purely empirical estimates of the half-light radius ($r_h = 0.28$ arcmin) and of the integrated absolute V magnitude ($M_V = -8.0$), both in good agreement with the values reported by Harris (1996). It is interesting to note that the newly derived profile extends beyond any estimate of r_t that can be found in the literature, by a factor of $\gtrsim 2$. We tried also to fit the SB distribution with an Elson, Fall & Freeman (1987, hereinafter EFF) profile, as these models were introduced to describe (young) extragalactic clusters that were more extended than what is allowed for by classical K66 models (see McV for discussion). Again, we find that the EFF model that fits well the inner parts is unable to fit the observed profile beyond $r \sim 1.2$ arcmin, because it predicts too much light (stars) in this region.

Table 1. SB profile from star counts, for $r \geq 1.5$ arcmin .

log r (arcmin)	μ_V [a] (mag arcmin^{-2})	err(μ_V) (mag arcmin^{-2})
0.1761	23.92	0.05
0.2304	24.27	0.06
0.2788	24.65	0.06
0.3222	24.93	0.07
0.3617	25.06	0.07
0.3979	25.36	0.08
0.4314	25.70	0.09
0.4624	25.89	0.09
0.4914	26.22	0.10
0.5185	26.52	0.12
0.5441	26.61	0.12
0.5911	26.94	0.13
0.6532	27.52	0.07
0.7404	28.46	0.11
0.8129	29.17	0.16
0.8751	29.57	0.20
0.9294	29.91	0.23

[a] Background subtracted. Not corrected for reddening.

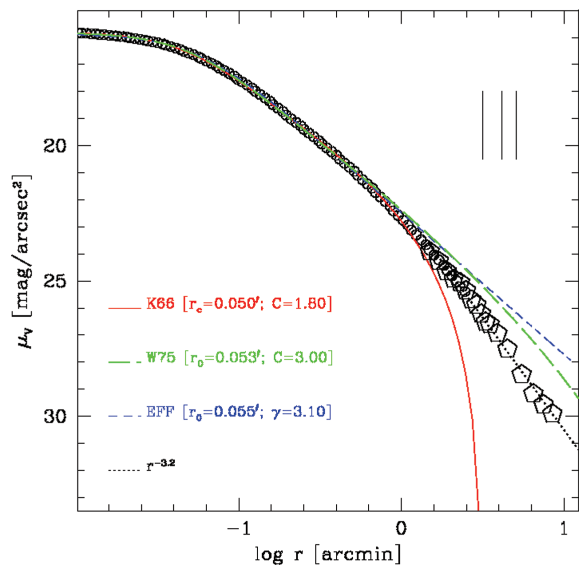

Figure 3. SB profile of NGC 5694. The open circles are the smoothed profile by NG06, whereas the large open pentagons are obtained from star counts on our data; μ_V values are *not* corrected for reddening and the uncertainties are smaller than the size of the points. The red continuous line, the blue short-dashed line and the green long-dashed line are the K66, EFF and W75 models, respectively, that best fit the inner part of the profile ($r \leq 1$ arcmin). The dotted line is the power law best fitting the profile beyond $\sim$1.2 arcmin. The small vertical segments mark the positions of the tidal radius as derived with K66 model fitting, from the left-hand to right-hand side, in this paper, by TKD and by McV, respectively.

Finally, McV fitted the observed profiles of all the GCs they considered, also with isotropic and spherical Wilson (1975, hereinafter W75) models, finding that '. . .*in the majority of cases*[5] *the Wilson models which are spatially more extended than King models*

[5] Including NGC 5694, where the three models have remarkably similar performances in fitting the observed profile, in the radial range covered by the data used by McV ($r \lesssim 3$ arcmin; see their table 10 and fig. 12l).

but still include a finite, "tidal" cut-off in density, fit clusters of any age... as well as or better than King models.' The long-dashed curve in Fig. 3 is the profile of a spherical and isotropic W75 model that provides an excellent fit to the observed profile within $r \leq 1.0$ arcmin, but it fails to match the outer branch, predicting a significant excess of light for $r > 1.2$ arcmin, even if less pronounced than the EFF model. By linear regression, we found that the power law that best fits the outer profile ($r \gtrsim 1.2$ arcmin) corresponds to $I \propto r^{-3.2}$, where $\mu_V \propto -2.5 \log I$.

4 SUMMARY AND DISCUSSION

The low SB extended component in NGC 5694 might be, of course, of tidal origin. In fact, it is well known that GCs lose stars because of tidal stripping (see Gnedin & Ostriker 1997; Combes, Leon & Meylan 1999; Montuori et al. 2007, and references therein) and, indeed, extended extra-tidal components or tidal tails have been observed in several cases (Grillmair et al. 1995; Leon, Meylan & Combes 2000; Odenkirchen et al. 2001; Belokurov et al. 2006; Federici et al. 2007; Chun et al. 2010; Jordi & Grebel 2010; Sollima et al. 2011, among others).

The main arguments supporting this interpretation are (i) the CMD of the stars found beyond the cluster tidal radius do not appear to differ from the CMD of stars residing in the main body of the cluster; and (ii) the surface density steadily (and steeply) decreases from the cluster centre out to the farthest radius sampled by our data, that is, the cluster appears as the centre of symmetry for the distribution of extra-tidal stars.

However, there are also relevant differences with respect to the ordinary cases of clusters tidal tails studied in the literature and NGC 5694. First of all, the observed extra-tidal portions of the profiles typically display a much shallower decline with radius, $\sim r^{-1}$, instead of $\sim r^{-3}$ as found here (Grillmair et al. 1995; Leon et al. 2000; Chun et al. 2010, and references therein).[6] Even more remarkably, we do not detect any break in the SB profile in the vicinity of the tidal radius, which is instead observed (Grillmair et al. 1995; Leon et al. 2000; Chun et al. 2010) and predicted (Combes, Leon & Meylan 1999; Johnston, Sigurdsson & Hernquist 1999) as a general feature of extra-tidal components. It is particularly interesting to note that the bright M31 GC B514, which is the only other case we are aware of presenting an extra-tidal component falling as r^{-3}, also displays an obvious break in the profile near the King tidal radius (Federici et al. 2007). On the contrary, the SB profile of NGC 5694 appears perfectly smooth and continuous over all its declining branch, that is, from the core radius out to the last observed point. Finally, the density map shown in Fig. 4 does not show any obvious elongation or characteristic S-shape structure that is typical of tidal tails (see e.g. Montuori et al. 2007), and also the inner isodensity levels are remarkably round (ellipticity $\epsilon = 0.04$; Harris 1996). An interesting analogy comes to mind with the case of the Galactic GC NGC 1851 that Olszewski et al. (2009) recently found to be surrounded by a low-SB halo extending out to $\gtrsim$250 pc from the cluster centre. Also in that case no sign of tidal tails was found. However, at odds with the present case, in NGC 1851, the onset of the extra tidal halo is marked by an obvious break in the profile, which, beyond the break, declines as $I \propto r^{-1.24}$.

[6] However, in their theoretical analysis, Combes et al. (1999) predicted a $\sim r^{-3}$ decline of the surface density of extra-tidal components in the immediate surroundings of the tidal radius.

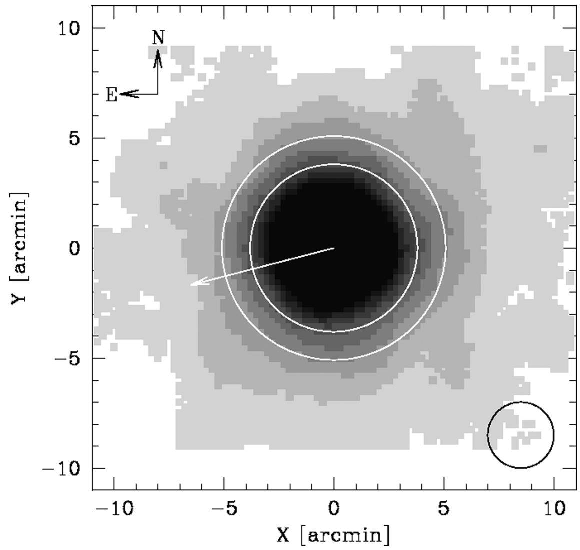

Figure 4. Density map of cluster MS stars with $V \leq 21.0$. The density is computed on a regular grid with step = 0.25 arcmin over a circle of radius 1.5 arcmin (plotted in the lower right-hand corner, for reference). The density scale goes from 3 to 21σ in steps of 2σ, from lighter to darker tones of grey. The white circles have radii equal to the cluster tidal radius as derived by TKD (inner) and McV (outer). The white arrow indicates the direction towards the centre of the Galaxy. The X, Y coordinates are defined as in equation (1) of van de Ven et al. (2006). In a recent theoretical investigation, Montuori et al. (2007) found that tidal tails within a few tidal radii from the cluster centre should align with the direction towards the Galactic Centre.

It could be interesting, in this context, to estimate the expected limiting radius imposed by the Galactic tidal field, or the Jacobi radius (r_t^J), computed with the formula

$$r_t^J = \frac{2}{3}\left(\frac{m_c}{2M_G}\right)^{1/3} R_{GC}, \quad (1)$$

which is formally correct for circular orbits within a logarithmic potential (see Bellazzini 2004, for references and discussion). m_c is the cluster mass, derived from the total luminosity by adopting $\frac{M}{L_V} = 2$, R_{GC} is the galactocentric distance of the cluster, M_G is the mass of the MW enclosed within R_{GC}, computed as $M_G = GV_{rot}^2 R$. Assuming $V_{rot} = 220\,\mathrm{km\,s^{-1}}$, this gives a total mass of the MW in good agreement with the most recent analyses (Watkins, Evans & An 2010). Adopting $R_{GC} = 29.9$ we obtain $r_t^J = 194$ pc for NGC 5694, more than a factor of 2 larger than the outermost point in our profile, at $r \simeq 93$ pc (assuming that the cluster does not extend much beyond this limit). Hence, at the present orbital phase, the Galactic tidal field cannot have a serious impact on the structure of the cluster, at least in the region of the profile sampled by our data. The Jacobi radius would match $r \simeq 93$ pc for a circular orbit at $R_{GC} \simeq 10$ kpc, thus suggesting that the peri-galactic point of the cluster orbit should be at a similar (or larger) distance, a quite plausible occurrence, given the large apo-galactic distance estimated by L06.

McV interpreted the good overall performance of spherical and isotropic W75 models in fitting the profile of any kind of massive clusters even if extended, as an indication that '*self-gravitating clusters commonly have envelope structures that do not match the extrapolations of simple K66 models fitting the cluster cores. This phenomenon is not confined exclusively to young clusters and is not obviously only transient; it may point instead to generic, internal cluster physics not captured by King's stellar distribution function*'. This can be the case also for NGC 5694. An obvious example of physics that are not captured by K66 models is provided by the initial conditions at the cluster birth. These may leave their imprint even after a Hubble time in the outer fringes of the cluster, where the effects of two-body relaxation may bee too slow to completely erase them, and Galactic tides possibly have not played a major role. Further theoretical work is clearly needed to fully understand the nature of these features (Oh, Lin & Aarseth 1992, 1995).

In this framework, NGC 5694 appears especially interesting, since the outer branch of its profile cannot be fitted even by W75 models that are considered by McV as rather ad hoc solutions. In any case, the present result, as well as many other recent findings (see e.g. Chun et al. 2010; Jordi & Grebel 2010; Sollima et al. 2011; Walker et al. 2011), suggests that there is still much to be learned about the outer structure of GCs that can be revealed with modern wide-field surveys, allowing us to probe the very low SB regime of cluster profiles ($\mu_V \gtrsim 26$ mag arcsec^{-2}) that is largely unexplored (see McV and NG06).

In summary, we are unable to draw a firm conclusion about the origin of the newly detected extended component surrounding NGC 5694. It is clear, however, that the evidence presented here, coupled with the results of L06, strongly indicates that this object deserves further investigation, as it may fit into the scenario in which (at least some) GCs are supposed to be the remnants of disrupted dwarf satellites, hence, one of the final end-states of the building blocks concurring to the hierarchical assembly of the MW (see Bellazzini et al. 2008; Böker 2008; Carretta et al. 2010, and references therein). Abundance analysis of a significant sample of NGC 5694 giants as well as a photometric survey covering a significantly wider area than that explored here is clearly needed to search for a metallicity spread and determine chemical abundance ratios to shed more light on the nature of this very interesting, and for a long time neglected, GC.

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REFERENCES

Bellazzini M., 2004, MNRAS, 347, 119
Bellazzini M., Ferraro F. R., Ibata R. A., 2003, AJ, 125, 188
Bellazzini M. et al., 2008, AJ, 136, 1147
Belokurov V., Evans N. W., Irwin M. J., Hewett P. C., Wilkinson M. I., 2006, ApJ, 636, L29
Böker T., 2008, ApJ, 672, L111
Carretta E. et al., 2010, ApJ, 714, L7
Chun S. H. et al., 2010, AJ, 139, 606
Cohen J. G., 2004, AJ, 127, 1545
Combes F., Leon S., Meylan G., 1999, A&A, 352, 149
De Angeli F. et al., 2005, AJ, 130, 116
Dotter A. L. et al., 2010, ApJ, 708, 698
Elson R. A. W., Fall S. M., Freeman K. C., 1987, ApJ, 323, 54 (EFF)
Federici L., Bellazzini M., Galleti S., Fusi Pecci F., Buzzoni A., Parmeggiani G., 2007, A&A, 473, 429
Ferraro F. R., Messineo M., Fusi Pecci F., De Palo A., Straniero O., Chieffi A., Limongi M., 1999, AJ, 118, 1738
Geisler D., Piatti A. E., Clariá J. J., Minniti D., 1995, AJ, 109, 605
Girardi L., Groenewegen M. A. T., Hatziminaoglu E., Da Costa L., 2005, A&A, 463, 895
Gnedin O. Y., Ostriker J. P., 1997, ApJ, 474, 223
Grillmair C. J. et al., 1995, AJ, 109, 2553
Harris W. E., 1996, AJ, 112, 1487
Harris W. E., Hesser J. E., 1976, PASP, 88, 377
Hazen M. L., 1996, AJ, 111, 1184
Johnston K. V., Sigurdsson S., Hernquist L., 1999, MNRAS, 302, 771
Jordi K., Grebel E. K., 2010, A&A, 522, A71
King I. R., 1966, AJ, 71, 276 (K66)
Kirby E. N., Cohen J. G., Smith G. H., Majewski S. R., Sohn S. T., Guhathakurta P., 2011, ApJ, 727, 79
Law D. R., Majewski S. R., 2010, ApJ, 718, 1128
Lee J.-W., López-Morales M., Carney B. W., 2006, ApJ, 646, L119 (L06)
Leon S., Meylan G., Combes F., 2000, A&A, 359, 907
Mackey A. D. et al., 2010, ApJ, 717, L11
McLaughlin D. E., van der Marel R. P., 2005, ApJS, 161, 304 (McV)
Monaco L. et al., 2005, A&A, 441, 141
Montuori M., Capuzzo-Dolcetta R., Di Matteo P., Lepinette A., Miocchi P., 2007, ApJ, 659, 1212
Noyola E., Gebhardt K., 2006, AJ, 132, 447 (NG06)
Odenkirchen M. et al., 2001, ApJ, 548, L165
Oh K. S., Lin D. N. C., Aarseth S. J., 1992, ApJ, 386, 506
Oh K. S., Lin D. N. C., Aarseth S. J., 1995, ApJ, 442, 142
Olszewski E. W., Saha A., Knezek P., Subramanian A., De Boer T., Seitzer P., 2009, AJ, 138, 1570
Ortolani S., Gratton R., 1990, A&AS, 82, 71 (OG90)
Perina S., Federici L., Bellazzini M., Cacciari C., Fusi Pecci F., Galleti S., 2009, A&A, 507, 1375
Pritzl B. J., Venn K. A., Irwin M., 2005, AJ, 130, 2140
Robin A. C., Reylé C., Derrière S., Picaud S., 2003, A&A, 409, 523 (R03)
Sbordone L., Bonifacio P., Buonanno R., Marconi G., Monaco L., Zaggia S., 2007, A&A, 465, 815
Schlegel D. J., Finkbeiner D. P., Davis M., 1998, ApJ, 500, 525
Skrutskie M. F. et al., 2006, AJ, 131, 1163
Sollima A., Martínez-Delgado D., Valls-Gabaud D., Peñarrubia J., 2011, ApJ, 726, 47
Stetson P. B., 1987, PASP, 99, 191
Stetson P. B., 2000, PASP, 112, 926
Trager S. C., King I. R., Djorgovski S., 1995, AJ, 109, 218 (TKD)
van de Ven G., van den Bosch R. C. E., Vrolme E. K., de Zeeuw P. T., 2006, A&A, 445, 513
Venn K. A., Irwin M., Shetrone M. D., Tout C. A., Hill V., Tolstoy E., 2004, AJ, 128, 1177
Walker A. R., 1994, AJ, 108, 555
Walker A. R. et al., 2011, MNRAS, 415, 643
Watkins L. L., Evans N. W., An J. H., 2010, MNRAS, 406, 246
Wilson C. P., 1975, AJ, 80, 175 (W75)

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