PHOTOMETRY OF STAR CLUSTERS IN THE M31 GALAXY. APERTURE SIZE EFFECTS

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Abstract. A study of aperture size effects on star cluster photometry in crowded fields is presented. Tests were performed on a sample of 285 star cluster candidates in the South-West field of the M 31 galaxy disk, measured in the Local Group Galaxy Survey mosaic images (Massey et al. 2006). In the majority of cases the derived *UBVRI* photometry errors represent the accuracy of cluster colors well, however, for faint objects, residing in crowded environments, uncertainties of colors could be underestimated. Therefore, prior to deriving cluster parameters via a comparison of measured colors with SSP models, biases of colors, arising due to background crowding, must be taken into account. A comparison of our photometry data with *Hubble Space Telescope* observations of the clusters by Krienke and Hodge (2007) is provided.

Key words: galaxies: individual (M 31) – galaxies: star clusters – galaxies: photometry

1. INTRODUCTION

The accuracy of star cluster parameter quantification, based on a comparison of colors, derived from UBVRI photometry with single stellar population (SSP) models, has been tested by Narbutis et al. (2007). It was demonstrated, that an uncertainty of cluster colors less than ~0.03 mag is required to achieve a reasonable accuracy of age and extinction. Therefore, to estimate the influence of background contaminants on the accuracy of object colors, we studied aperture size effects, based on a sample of 285 star cluster candidates in the South-West field of the M 31 galaxy published by Narbutis et al. (2008).

The aperture photometry errors of extended objects are determined by photon noise, photometric background uncertainty and calibration procedure errors. However, in the case of extragalactic star clusters projected on a crowded galaxy disk (e.g., M31), the flux from contaminating stars biases true colors of the objects, and in some cases the contamination effect exceeds photometric errors. The colors and density of dominating contaminants depend mainly on the age of background stellar populations and on the object location in the galaxy. In general, background stars are distributed randomly, therefore, a probability of their contaminating effect increases with the aperture size.

The resolution of ground-based images is limited by the atmospheric seeing.

Therefore, colors of star clusters are affected by contaminating objects to a degree which depends on the quality of images, characterized by the full width at half maximum (FWHM) of the point spread function (PSF), and the location of the contaminant in respect to the aperture. An alteration of cluster's true colors also depends on the contaminant and the object luminosity ratio – faint star clusters are more affected.

Contaminants, residing outside the aperture, can be partly avoided by using high resolution imaging, e.g., with the *Hubble Space Telescope* (HST), however, the sky background determination becomes more complicated in this case (see discussion by Krienke & Hodge 2007). In order to estimate the resolution effect, we performed a comparison of the cross-identified cluster photometry from our sample and from the sample studied by Krienke & Hodge (2007).

2. THE DATA

An initial survey of star clusters in the South-West field of the M 31 disk was conducted by Kodaira et al. (2004) in an area of about 500 square arcminutes, making use of the high-resolution imaging capability of the Subaru Suprime-Cam (Miyazaki et al. 2002), and a catalog of star cluster candidates up to $V \sim 19.0$ mag was presented. The study of the structural parameters of this sample was based on the V-band Suprime-Cam image analysis (Šablevičiūtė et al. 2006, 2007), showing a wide range of the intrinsic object sizes. The UBVRI (R and I passbands being in the Cousins system) photometry of these clusters was performed on the Local Group Galaxy Survey (LGGS; Massey et al. 2006) images by Narbutis et al. (2006).

A sample of objects has been extended up to $V \sim 20.5$ mag, and the catalog of 285 star cluster candidates, supplemented with multi-band color maps combined from the ultra-violet, optical, infra-red and radio images, was provided by Narbutis et al. (2008). The photometry presented in this study was performed on the LGGS mosaic images through individually selected circular apertures by employing the XGPHOT package in the IRAF program system (Tody 1993). The shape of mosaic image PSFs (scale is 0.27''/pix) was homogenized to the resolution of FWHM = 1.5'', and was used for photometry. This procedure ensures a constant aperture correction for an object measured in all passbands. A typical aperture diameter was set to 3'' for the majority of clusters, and was extended up to 10'' for the brightest objects. The photometric background was determined in individually selected and object-centered circular annuli with typical inner and outer diameters of 6'' and 16'', respectively. For some objects, residing on the largely variable background, the circular background determination zones were selected individually in representative areas.

Each object was measured in two or three different LGGS fields. The Vband magnitude and colors were transformed to the standard system using the prescription given by Massey et al. (2006). The reliability of the calibrations was discussed by Narbutis, Stonkutė and Vansevičius (2006). V-band magnitudes and colors of each object, measured in different fields, were examined interactively, and their weighted averages were calculated. The photometric errors provided in the catalog account for the photon noise and the errors of calibration procedure. We note that $\sim 10\%$ of the objects from our sample have suspected variable stars contaminating the aperture photometry results. They were revealed by comparing overlapping LGGS fields observed on different nights.

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Fig. 1. Aperture size test results of the 285 star cluster candidates. ΔV is the difference of V magnitudes measured through the apertures increased or decreased by 0.6" in respect to the the main aperture (open/filled circles, respectively) and V magnitudes, measured trough the main aperture. The aperture diameter of 3" was adopted for the majority of clusters and up to 10" for the brightest objects.

2.1. Aperture size test

In order to study aperture size effects, arising due to contamination by background stars, on the accuracy of colors, all star cluster candidates were additionally measured trough the circular apertures increased/decreased by 0.6'' in respect to the main aperture diameter. The same photometry reduction procedure, as that applied for the main aperture data, was used, and the differences of the V magnitudes and colors, measured through the increased or decreased and the main apertures, were calculated. These results also provide an estimate of possible star cluster color bias, arising due to aperture centering and size mismatch when measured in images from different surveys.

In Figure 1 we plot ΔV versus V. Here ΔV are differences of V magnitudes measured through the apertures increased or decreased by 0.6" and V magnitudes obtained trough the main aperture. Since bright objects were measured through large main apertures, that resulted in small magnitude differences. However, for faint objects (V > 18.5 mag) ΔV is significantly larger and has to be taken into account for the star cluster mass estimate.

In Figure 2 we plot $\Delta(B-V)$, $\Delta(U-B)$ and $\Delta(V-I)$ versus V magnitudes. The distribution of $\Delta(B-V)$ is symmetric. However, for faint objects (V > 18.0 mag) the distributions of $\Delta(U-B)$ and $\Delta(V-I)$ are asymmetric, suggesting that some objects are affected by blue and red contaminants, respectively. The same color differences are plotted versus B-V in Figure 3. $\Delta(U-B)$ shows an asymmetric distribution due to the influence of blue contaminants, which is stronger for star cluster candidates with B-V > 0.5. $\Delta(V-I)$ shows an asymmetric distribution for the objects with B-V < 0.75 due to the influence of red contaminants.

Uncertainties of cluster colors, arising due to the influence of contaminants,



Fig. 2. The same as in Figure 1, but for the $\Delta(B-V)$, $\Delta(U-B)$ and $\Delta(V-I)$ color differences.



Fig. 3. The same as in Figure 2, but the $\Delta(B-V)$, $\Delta(U-B)$ and $\Delta(V-I)$ color differences are plotted versus B-V.

were estimated for each object based on $\Delta(U-B)$, $\Delta(B-V)$ and $\Delta(V-I)$. U-Bversus B-V diagrams of 285 star cluster candidates are plotted in Figure 4. The error bars indicate photometric errors, $\sigma(U-B)$, $\sigma(B-V)$ (panel a), and $\Delta(U-B)$, $\Delta(B-V)$ (panel b). Due to the influence of contaminants for a fraction of objects, 4% for U-B and 7% for B-V, the Δ values exceed the σ values. In Figure 5 the corresponding V-I versus B-V diagrams are plotted. The $\Delta(V-I)$ values exceed the $\sigma(V-I)$ values for 21% of star clusters.

In the majority of cases photometric errors represent a true uncertainty of cluster colors well, however, for some faint objects, residing in crowded environments, these errors can be largely underestimated. It is noteworthy to stress that possible biases of colors have to be taken into consideration prior to the cluster parameter quantification procedure, based on the SSP models.

2.2. Comparison with HST data

A large sample of star clusters in M 31 has been studied recently with HST by Krienke & Hodge (2007). They provide a catalog of BVI photometry (transformed from the HST to the Johnson-Cousins system) for 343 star clusters detected in the Wide Field and Planetary Camera 2 (WFPC2) images. Krienke & Hodge (2007) measured integrated magnitudes of star clusters through individual isophotal apertures. Note, that the aperture size distribution, provided in their Fig. 7, peaks at $\sim 3''$ and is equal to a typical aperture diameter used for photometry of our cluster sample.

Eight HST data sets, used by Krienke & Hodge (2007) and overlapping with our field, were obtained from the Multimission Archive at the Space Telescope Science Institute $(MAST)^1$, and used for object identification and analysis of their environment.

In total, 36 common objects were cross-identified in the studies by Krienke & Hodge (2007) and Narbutis et al. (2008). Differences of V (34 objects), B-V (14) and V-I (25) are shown in Figure 6 versus V magnitude. The error bars indicate photometric errors from Krienke & Hodge (2007); for objects without provided errors we assumed representative errors of V magnitude. Faint objects show a larger magnitude and color difference scatter. Two bright objects with $V \sim 14.3$ mag and $V \sim 15.7$ mag, not shown in Figure 6, have V magnitude differences of 0.08 and 0.03 mag, respectively. Four objects, all residing in one HST field, have a significant V magnitude difference, presumably due to a zeropoint inaccuracy. However, their colors do not show significant discrepancies. A much smaller aperture size was used in our study for the semi-resolved star cluster indicated by a filled triangle, however, the measured B-V color matches well between both studies.

Color differences are shown as a function of colors in Figure 7. Vertical and horizontal error bars show photometric errors from Krienke & Hodge (2007) and Narbutis et al. (2008), respectively. The B-V colors are mostly affected by blue contaminants and the V-I colors – by red contaminants due to differing aperture centers, shapes and sizes. Different photometric background determination strategies used in both studies might also be responsible for the observed scatter. Note, that four objects, shown in panel (a) with $B-V \sim 0.3$, all reside in one HST field. Therefore, the difference of colors could be of systematic origin. Variable stars

¹ See http://archive.stsci.edu/hst/search.php



Fig. 4. The U-B vs. B-V diagrams for the 285 star cluster candidates. Error bars indicate photometric errors, σ , and the aperture size effects, Δ , in panels (a) and (b), respectively. In the insets $\Delta(B-V)$ of the aperture size test vs. photometric error, $\sigma(B-V)$, and $\Delta(U-B)$ vs. $\sigma(U-B)$ are shown in panels (c) and (d), respectively.



Fig. 5. The same as in Figure 4, but V-I vs. B-V diagrams are plotted. Panel (c) is the same as in Figure 4; in panel (d) $\Delta(V-I)$ vs. $\sigma(V-I)$ is shown.



Fig. 6. Differences of V magnitudes and colors from Krienke & Hodge (2007) (marked with KH) and Narbutis et al. (2008) are shown for 34, 14 and 25 clusters in panels (a), (b) and (c), respectively. Error bars indicate photometric errors from Krienke & Hodge (2007). The deviations of V magnitudes of four objects (filled circles), residing in the same HST field, are presumably subject to zero-point inaccuracy. However, this does not affect their colors. A significantly smaller aperture size was applied in our study for a cluster marked by a filled triangle.



Fig. 7. The same as in Figure 6, but color differences are plotted vs. corresponding colors. Vertical and horizontal error bars show photometric errors from Krienke & Hodge (2007) and Narbutis et al. (2008), respectively. Due to differing aperture centering, shapes and sizes used in both studies, the B-V colors are predominantly affected by blue contaminants, and V-I colors by red contaminants. Note, that four objects making a compact group in panel (a), $B-V \sim 0.3$, reside in one HST field. For description of the objects, shown by filled circles and a filled triangle, see Figure 6.

residing close to the studied objects might contaminate aperture magnitudes and colors, when observations from multiple epochs are compared. However, objects with the smallest error bars show a reasonably good match between LGGS and HST photometry data over a wide range of star cluster colors.

3. SUMMARY

In order to study crowding effects on star cluster aperture photometry, we performed an aperture size test for a sample of 285 star cluster candidates in the South-West field of the M31 galaxy (Narbutis et al. 2008). The influence of background contaminants was estimated by measuring cluster colors through additional apertures increased or decreased by 0.6" in respect to the main aperture diameter (typically 3"). Photometric errors for 4% (for U-B), 7% (for B-V) and 21% (for V-I) of clusters are smaller than the errors arising due to the influence of contaminating background stars. The U-B color of red objects tends to be systematically bluer (contaminated by blue stars), and an opposite effect is observed for V-I of blue objects (contaminated by red stars).

We cross-identified 36 objects from our sample (LGGS) with the star clusters from Krienke & Hodge (2007) (HST). Despite different apertures (sizes, shapes and centering), photometric background determination and photometric calibration strategies used in both studies, V magnitudes and B-V, V-I colors show a reasonably good agreement.

The aperture size test allows us to identify star clusters which have integrated colors affected by background contaminants. The influence of background objects can be eliminated (to some degree) by measuring clusters trough individually selected isophotal apertures on high resolution images (e.g., HST; Krienke & Hodge 2007). However, the influence of contaminants, projected on star clusters within the applied aperture, can be estimated only statistically. Using ground-based (lower resolution) images for aperture photometry of faint star clusters it is difficult to avoid a strong contamination of colors by neighboring stars. Therefore, biases of the object colors have to be accounted for prior to deriving cluster parameters via a comparison of the observed colors with the SSP model data.

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