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Exploring the stellar populations of nearby and high redshift galaxies with ELTs

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Abstract. The high sensitivity and spatial resolution of future ELTs facilities will offer the unique opportunity to probe directly the stellar populations of the very inner regions of galaxies in the local Universe and to derive morphological and photometric information for high redshift galaxies. We present our project aimed at assessing the expected capabilities of ELTs in the study of nearby and high-redshift stellar populations. To this end, we simulated imaging observations of different stellar populations in the local Universe and in high-redhshift galaxies with the MICADO camera at the E-ELT. Detailed photometric analyses of these images were used to probe the feasibility of science cases dealing with photometry of resolved stars in crowded fields, and with surface photometry of distant galaxies. We find that the future facilities will allow us to greatly improve our knowledge of the stellar populations in galaxies, especially in the innermost and most crowded regions. Accurate photometry of turn-off stars in nuclear star clusters of intermediate age will be possible up to distances of $\sim$ 3 Mpc. The exquisite spacial resolution will also drive great progress in unresolved stellar populations studies, enabling the detailed measurement of structural parameters, colour profiles, and the detection of signature of star formation sub-structures in galaxies at redshifts up to z=3.

Key words. instrumentation: adaptive optics – instrumentation: high angular resolution – galaxies: clusters: general – galaxies: fundamental parameters – infrared: stars

1. Introduction

The advent of next-generation ground-based extremely large telescopes (ELTs) will offer completely new scientific opportunities to study fundamental issues of distant galaxies like their stellar content in their centres and the morphological structures at early cosmic epochs. The combination of extraordinary sensitivity and spatial resolution will in fact allow us to characterise the photometry and structural parameters of stellar system with unprecedented precision. The E-ELT will be the largest operating telescope and the Multi-AO Imaging Camera for Deep Observations (MICADO Davies et al. 2010) that will be mounted on it will be the best instrument to achieve a wide range of scientific goals requiring extremely deep and high resolution photometry. To explore the new challenges that we could face using this unique instrument, we started to study the feasibility of a number of science cases for MICADO. For each of them, we simulated imaging observations and performed a detailed photometric analysis on the images. The results were used to evaluate the photometric performances of the instrument and then asses the reliability of the scientific results. The first results of our project were presented by Greggio et al. (2012) and Schreiber et al. (2014) where we demonstrated the feasibility of the reconstruction of the star formation history in galaxies the inner parts of disk galaxies in the Sculptor group, as well as the measurement of the photometric metallicity of red giant branch stars in the central regions of Ellipticals in the Virgo cluster. Recently we further developed our project by investigating the performances of MICADO and other imagers to be mounted on ELTs and the JWST on the study of extremely crowded stellar systems. Here we present two new science cases, focusing on resolved and unresolved stellar populations, respectively.

2. Simulated images

Simulated images were produced using the Advanced Exposure Time Calculator (AETC) tool (Falomo et al. 2011). We adopted as baseline the parameters from the phase A study of MICADO, the instrument designed for the 39 aperture E-ELT to provide diffraction limited imaging over a $\sim\ 1'$ field of view. We used the point spread functions (PSFs) of the multi conjugate adaptive optics post focal relay (MAORY) for the E-ELT, calculated for a $0\farcs6$ seeing at the centre of the corrected field of view. The final simulated images were obtained as the stack of 180 images with 60s exposures (total exposure time of 3h). Further details are given in Gullieuszik et al. (2014).

3. Resolved stellar populations in nuclear star clusters

The study of the nuclei of galaxies are extremely important to understand the processes that drive the formation and the evolution of galaxies. An important point that is not still completely understood is the formation and evolution mechanism of the nuclear star clusters (NSC) and the possible links between NSCs and the central super-massive blackholes (SMBHs). A detailed study of NSC stellar populations is a key tool to understand the main physical processes involved in the formation and evolution of these stellar systems. Even for the closest NSCs, current instrumentation allows us to study their properties only from integrated light data. The extremely high stellar density in NSCs is an ideal test-bed to explore the photometric capabilities of MICADO at the E-ELT in severe crowding conditions.

Our aim is to explore under which conditions MICADO would provide photometry with an accuracy suitable to reconstruct the star formation history of NSCs. The most reliable age indicator for a stellar population is the magnitude and colour of its main-sequence turn off (MSTO). We therefore aim at understanding for which NSCs MICADO would be able to measure the magnitude of the MSTO. The feasibility of this measurement and its accuracy will clearly depend on the crowding conditions and on the age of the NSC stellar populations, as the MSTO luminosity increase at decreasing stellar ages. In our study we thus produced a grid of six synthetic single stellar populations, representative of six NSCs located at two different distances (2 and 4 Mpc) with three ages (1, 4, and 10 Gyr). Stars were spatially distributed following a King profile model with the same structural parameters as the NSC in NGC 300, a typical nearby NSC. For each simulations we added a stellar component to include the contribution of the host galaxy stellar population (for details, see Gullieuszik et al. 2014). We simulated observations in the I, J, H, and K bands of the six stellar populations using AETC as described in the previous section.

We performed PSF photometry on each simulated image using Starfinder (Diolaiti et al. 2000), a package specifically developed for images obtained with high resolution AO images. The resulting photometric catalogues and colour-magnitude diagrams were analysed and compared with the lists of input magnitudes to asses the accuracy of our photome-

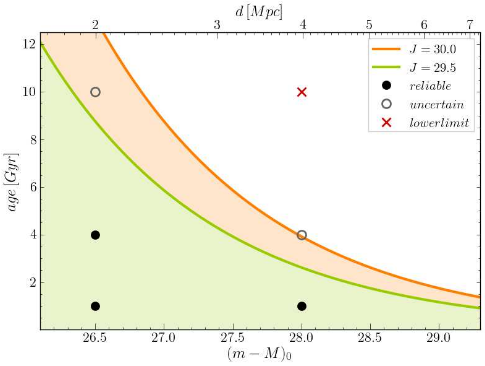

Fig. 1. Age of the oldest MSTO detectable in a nuclear star clusters at different distances. We show the results obtained adopting a detection magnitude limit of 30.0 and 29.5 in the J-band. These are the magnitudes corresponding to the 50% and 80% photometric completeness level.

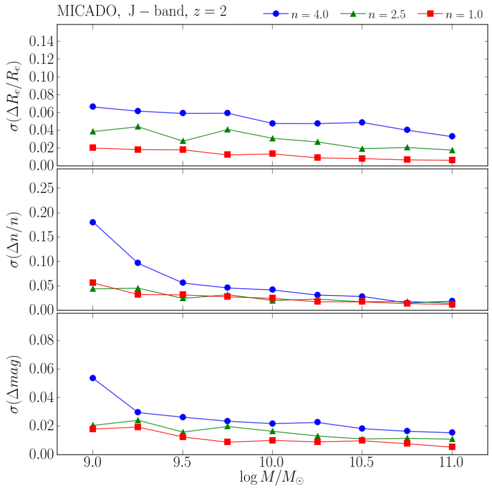

Fig. 2. Uncertainties in the measurements of the R_e, Sersic index, and magnitudes for z 2 galaxies of different masses expected to be derived from MICADO at the E-ELT observations.

try. We estimated the photometric errors and completeness for each simulated image. The results depends on the NSC age and distance, but on average we found that the 50% completeness level is found at $I \simeq 30.5$ mag and $J \simeq 30.0$ mag. These results apply to the region beyond a few (~ 3) effective radii from the cluster centre, because stellar blends strongly increase the photometric errors and reduce the photometric depth in the crowded central regions of the NSCs. Figure 1 summarises our results on the reliability of age estimates of NSCs as function of their age and distance. Under the above conditions, E-ELT photometry could be used to age-date NSCs up to 10 Gyr in galaxies at 2 Mpc. For the oldest stellar populations the MSTO at this distance fall close to the detection limit, so that the corresponding age estimate will be affected by some uncertainties. For the case at 4 Mpc, we found that the MSTO is below the detection limit for the 10 Gyr NSC and at the detection limit for the 4 Gyr one. Therefore in the latter case the age of the NSC stellar population can be estimated with accuracy only for young clusters. We extrapolated our results to galaxies at different distances. By using our estimates of the photometric completeness and the theoretical relations between the MSTO magnitude and the cluster age, we calculated the maximum age of a stellar population whose MSTO would result to be brighter than the 50% ad 80% completeness level of typical MICADO photometry of a NSC. Results are over-plotted in Fig. 1. We also explored the feasibility of this science case with the Thirty Meter Telescope and we found that, for this specific case, the performances of TMT and E-ELT will be comparable. A detailed discussion of this result can be found in Gullieuszik et al. (2014).

4. Structural parameters in high-redshift galaxies

To extend our project, we explored the possibilities offered by the unique spatial resolution of the E-ELT in the study of unresolved stellar population. Galaxies at high redshift are extremely small, with half-light ratios of a few Kpc at $z \sim 2$. They therefore have sizes of the order of just a few times the resolution of HST. As a result, to date, the measurements of the structural properties of galaxies with intermediate and small masses are strongly affected by relevant uncertainties. To provide a detailed analysis of the impact of MICADO photometry on this research field, we simulated two

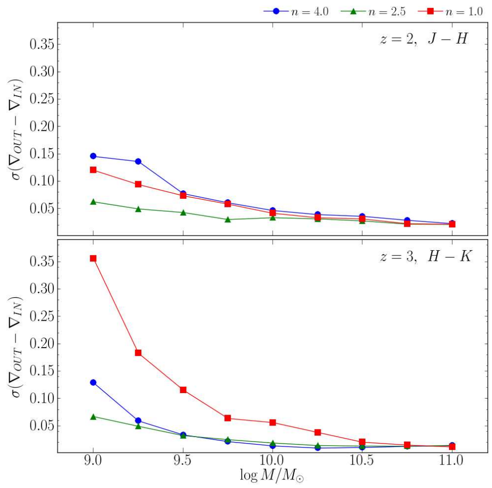

Fig. 3. Uncertainties in the colour gradient in high-redshift galaxies at redshift 2 (*upper panel*) and 3 (*lower panel*) measured from MICADO observations. The three series of dots, connected by lines shows results for galaxies with Sersic index od 1.0, 2.5, and 4.0 (see the top-legend).

large sets of observations of galaxies at redshift 2 and 3 with the goal of understanding the capabilities of the E-ELT for the study of compact galaxies at high z. We defined a grid of template galaxies with masses in the range 10^9 to 10^{11} $M_\odot$, and Sersic index of 1.0, 2.5, and 4.0. To study the dependences of the results on the size and morphological type. The structural parameters of the simulated galaxies were chosen by extrapolating the scaling relations obtained from observed galaxies (van der Wel et al. 2014). The effective radii adopted for the late-type galaxies range between 1.5 and 4.2 Kpc (corresponding to 170 and 500 mas), and between 0.04 and 1.5 Kpc (5 and 170 mas) in the case of early-type galaxies. To evaluate the effect of statistical noise on the results, we performed 50 simulations for each template galaxy.

We used the GALFIT program to fit Sersic structural parameters to the galaxies in the simulated images. The accuracy of the results were derived by comparing the measured values of the effective radii, Sersic index and total magnitude with the input parameters are shown in Fig. 2. We conclude that the size of galaxies could be measured with errors smaller than 10% in all cases. The error on the Sersic index is around 5% for most galaxies. Only for the smallest ones, with mass smaller than $10^{9.5}$ $M_\odot$ the uncertainties result to be $\sim$ 10%. The very good quality of the reconstruction of the surface brightness profiles allowed us also to reliably measure the colour gradients. Results are shown in Fig. 3. At $z = 2$ errors in the retrieved colour gradients are smaller than 0.15 mag even for the smallest galaxies. At $z = 3$ the uncertainties are somewhat larger, in particular for the compact early-type galaxies. In any case, for galaxies more massive than $10^{9.5}$ $M_\odot$ colour gradients will be measured with an accuracy of $\sim$ 0.15 mag. We calculated that with this accuracy it will be possible to detect radial variations of $\sim$ 25% in age and/or 0.3 dex in metallicity, that will provide extremely accurate insight in the spatial distribution of the stellar populations in high-redshift galaxies. This will in turn provide extremely clear clues to understand the details of the mechanisms driving galaxy formation and evolution.

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