Disentangling age and metallicity in distant unresolved stellar systems

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Abstract. We present some results of an observational and theoretical study on unresolved stellar systems based on the Surface Brightness Fluctuations (SBF) technique. It is shown that SBF magnitudes are a valuable tracer of stellar population properties, and a reliable distance indicator. SBF magnitudes, SBF-colors, and SBF-gradients can help to constrain within relatively narrow limits the metallicity and age of the dominant stellar component in distant stellar systems, especially if coupled with other spectro-photometric indicators.

Keywords: Elliptical Galaxies; Stellar Populations; Distances

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INTRODUCTION

The detailed study of the properties of distant stellar systems relies on the details to which the stellar population can be observed. The observation of single stars is, in principle, the way to extract the best information from a system. However, even with modern telescopes, single stars can be observed only in nearby galaxies, and, typically, at magnitudes significantly brighter than the main sequence. Here, we discuss a technique that has proved to be very powerful to disentangle the physical and chemical properties of distant, unresolved stellar population, the Surface Brightness Fluctuations (SBF) method. Here, we summarize the main characteristics of the technique - for a more detailed description of the SBF method see G. Raimondo, and J. P. Blakeslee’s contributes to this Volume.

First introduced as a distance indicator for nearby elliptical galaxies [1], the SBF method has been applied to Galactic globular clusters at a few kpc, cluster ellipticals out to $\sim 150$ Mpc, and numerous lenticulars, spiral bulges, and dwarf spheroidals at intermediate distances [e.g. 2, 3, 4]. By definition the SBF signal corresponds to the ratio of the 2nd to the 1st moment of the Luminosity Function (LF) of the stellar population. Therefore, the dominant contribution to SBF comes from bright stars which, acting as “lighthouses” on a smooth background of faint stars, generate the great part of the fluctuation signal. Further, the relative stellar luminosities depend on the observed bandpass, so the lighthouses at shorter wavelengths (hot stars) are different from those at longer wavelength (cool stars), and the main contributors to the SBF change according to the filter. This makes SBF magnitudes and colors potential candidate to trace the properties of stellar population in unresolved systems.

Based on such evidences we have carried out an extensive study of SBF, and correlated photometric indicators, both on the theoretical and observational point of view. The main results of these studies and future perspectives are briefly outlined below.
SBF: A DIFFERENT THEORETICAL APPROACH

SBF magnitudes, as most other distance indicators, rely on the calibration of the absolute magnitude. The most common SBF calibration has been derived by Tonry et al. [2]. Such empirical calibration uses cluster membership to derive the slope, while the zeropoint relies on 6 galaxies with Cepheid’s distances. Empirical calibrations, however, are time consuming, and may suffer for zeropoint bias. For such reasons, we started (since 1997) a campaign to derive theoretical SBF calibrations in optical and near-IR bands, using the stellar population synthesis method.

Taking advantage of the specific characteristic of the stellar population synthesis code developed by the Teramo “Stellar Population Synthesis” (SPoT) group [5, 6, 7], we developed an original method to obtain SBF magnitudes from Simple Stellar Populations, SSP, simulations [8, 9]. The code uses the most reliable and up to date physical inputs for stellar population synthesis. Some ingredients of the models are: Initial Mass Function is from Scalo [10] in the mass range $0.1 \leq M/M_\odot \leq 10$. Stellar evolution tracks from Pietrinferni et al. [11]. The horizontal branch morphology is fully reproduced taking into account the effects due to age, metallicity, and the stellar mass spread due to the stochasticity of the mass-loss phenomena along the RGB [6]. The RGB mass-loss rate is evaluated according to the Reimers [12] law. Thermal Pulses along the AGB phase are simulated using the analytic formulations by Wagenhuber and Groenewegen [13]. We provide models computed assuming three different atmosphere models (see www.oa-teramo.inaf.it/spot for more details, and models download).

The accuracy of SPoT models has been proved against various observable characteristics of resolved and unresolved stellar populations (CMD, integrated colors, etc.), in all cases the agreement is satisfactory. Then, we have checked SBF models versus available optical and near-IR SBF data, obtaining either for local GC systems, or for distant elliptical galaxies an excellent agreement with data [8, 9].

The positive result of the tests on SPoT models, lead us to study more in details how SBF magnitudes and colors can help to scrutinize the properties of unresolved stellar populations. Figure 1 shows one particular application with SBF colors. Both panels show color-color comparisons: integrated colors on the left, and SBF-colors on the right. The figure shows how observational data placed on the grid of models in the left panel would not significantly constrain the mean age, $t$, or chemical composition, [Fe/H], of the stellar population in the galaxy. However, SBF-color data can constrain, within relatively narrow limits, the main properties of the dominant stellar component. In other words the “age-metallicity” degeneracy is broken. This is also due to the fact that the SBF measurement uncertainties can be below $\sim 0.1$ mag, less that the separation between models at different [Fe/H].

SBF MEASUREMENTS

Most of the observational work on SBF has been carried out based on the needs of distance measurements, and little or no effort has been put to secure good wavelength coverage on a single galaxy, so that a homogeneous set of SBF measurements can be obtained. Using archival ACS data, we have made an attempt to derive optical SBF
FIGURE 1. \(I-K\) versus \(B-I\) integrated colors (left), and SBF-colors (right), for SSP models with metallicity \([Fe/H] = -1.8, -1.3, -0.7, -0.3, 0.0, 0.3\) dex (three, four and five pointed stars, triangles, squares and circles, respectively), and age \(t = 1-14\) Gyr (bigger squares refer to older ages). Models are from [9]. The arrows in the left panel indicate the direction of larger \([Fe/H]\) and older stellar populations, according to labels.

colors for a sample of \(\sim 20\) galaxies. The results of the study have been encouraging on a twofold basis. First, the comparison of data to models has shown a general good agreement on optical bands like \(V\), and \(I\). Moreover, it has shown that for bluer bands, like \(B\), the effect of stellar population properties becomes non-negligible and, for example, composite stellar population models have to be used instead of SSPs [14]. Second, data to models comparisons have been successfully used to constrain the properties of stars in galaxies. Although optical SBF colors are not the first choice colors to reliably constrain the \(t\) and \([Fe/H]\) of the stellar system, the good matching of the stellar population properties derived with SBF-colors and other derivations taken from literature has demonstrated the feasibility of this kind of applications.

Furthermore, for what concerns SBF and stellar population properties, we have recently demonstrated that radial SBF gradients can be measured out to \(\sim 30\) Mpc, with present observing facilities, and used as another important analysis tool [15]. As an example, using ACS data of 7 ellipticals, we found that the observed color and SBF gradients are likely due to metallicity variations along the galaxy radius, rather than to age variations. The additional step of measuring SBF-color gradients can reveal subtle variations in stellar population properties within the galaxy, so that the past history of merging, interactions, or passive evolution can be scrutinized from a promising new point of view.
FUTURE APPLICATIONS

SBF and SBF-colors predictions from detailed stellar population synthesis models show that specific applications of this method are capable to lift the age-metallicity degeneracy which affects the study of distant unresolved stellar systems. In particular, SPoT models predict that the use of optical to near-IR SBF colors should be preferred for stellar population studies.

In addition, present optical facilities have proved that SBF gradients can be measured and used, for example, to understand how stellar population properties change with radius in spheroidal galaxies. At present no near-IR detection of SBF gradients exist. However, it is well reasonable to expect that modern large telescopes equipped with large format near-IR detectors can be used to detect near-IR SBF gradients. Such possibility appears even more realistic with future 30-40 m class telescopes, or space-based facilities, like JWST or WSO (the latter for the blue and UV wavelength regime). Such telescopes will, in fact, allow to secure good wavelength coverage from UV to near-IR (and possibly mid-IR) with high efficiency and spatial resolution.

Coupling optical and near-IR SBF gradients, i.e. using SBF-color gradients, will provide very accurate data to be used for the study of how galaxies formed and evolved.

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