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Using surface brightness fluctuations for stellar populations studies

G. Raimondo, M. Cantiello, E. Brocato, and I. Biscardi

Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Teramo, Via Maggini snc, I-64100 Teramo, Italy, e-mail: raimondo@oa-teramo.inaf.it

Abstract. We briefly review some potential applications of the surface brightness fluctuation (SBF) technique for studying stellar population properties in galaxies. The applications summarized here show that the SBF method is able not only to provide accurate distances of resolved and unresolved stellar systems from ∼ 10 Kpc to ∼ 150 Mpc, but also to reliably constrain some physical properties of unresolved stellar systems.

Key words. Galaxies: stellar content — Galaxies: distances

1. Introduction

Most of our knowledge on the formation and evolution of galaxies comes from the study of the physical and chemical properties of their stellar components. Classical tools, such as integrated colors and spectroscopic indices, allow to investigate the integrated starlight from galaxies, whose distance prevents the use of single-star analysis. However, in the last decade surface brightness fluctuations (SBFs), originally defined as a distance indicator, have proven to be also effective to supply information on unresolved stellar systems.

The Poisson statistics, which governs the numbers and the luminosities of stars within individual pixels, is the physical base of the method. SBFs measure the intrinsic pixel-to-pixel flux variance resulting from these statistical fluctuations normalized to the local mean flux, mathematically expressed by the ratio of the second to the first moment of the stellar luminosity function (Tonry & Schneider, 1988). In the following we present some appealing applications of the technique. All the results presented are based on computing techniques developed by our group (Raimondo et al., 2005, and references therein), which take advantage of the procedures adopted in the stellar population synthesis code *Teramo–SPoT* specifically designed to reproduce stellar populations in detail, for both resolved and unresolved systems (see e.g. Raimondo, 2009a, for a recent full description of the ingredients and procedures).

Send offprint requests to: G. Raimondo

2. Resolved stellar clusters

The flexibility of the SPoT code leads us to investigate how SBF magnitudes and colors are connected to the features of resolved stellar populations, star clusters in particular, observed in the color-magnitude diagram (CMD). The remarkable advantage of studying SBFs of star clusters is twofold. First, they can be directly connected to the distribution, stellar counts and photometric properties of individual stars in the CMD. This permits a detailed study of the origin of the SBF signal. Second, they are (relatively) simple systems, defined by a single age and single metallicity. This allows a straightforward connection between predicted SBFs and stellar population properties, such as age and metallicity.

On the other hand, for star clusters some cautions arise. In the case of systems with a small number of stars, the SBF signal is affected by the properties of an handful of stars (Raimondo et al., 2005; Raimondo, 2009b). For instance, SBFs of young-intermediate age clusters in the near-infrared strongly depend on red giant stars, whose predicted properties suffer of large uncertainties. This warning has prevented the study of SBFs at intermediate ages, likely dominated by giants and thermally pulsing asymptotic giant branch stars, for a long time. Only recently more attention has been dedicated to young/intermediate age populations (see e.g. González et al., 2004; Raimondo et al., 2005; Mouhcine et al., 2005; Lee et al., 2009).

In the case of star clusters, a specific procedure is needed to measure SBF amplitudes. In fact, SBF measurements are derived from stellar photometry, and from the total integrated flux of the cluster in the selected band. This procedure was applied to measure SBFs for star clusters in the Milky Way by Ajhar & Tonry (1994) and in the Magellanic Clouds by González et al. (2004) and Raimondo et al. (2005). The latter authors applied for the first time an analogous procedure to compute SBF amplitudes. They used a large (statistically relevant) number of independent synthetic CMDs to simulate the luminosities of individual stars (i.e. stellar photometry) and then the cluster's magnitudes. It is worth-noticing that this procedure is formally different from that usually adopted for unresolved stellar systems for both measuring (see e.g. Tonry et al., 1997) and modeling (e.g. Cantiello et al., 2003) SBFs. Whether the results of the two procedures coincide or not it depends on the richness of the cluster, as theoretically shown by Raimondo et al. (2005).

After corrections for field contamination, reddening, crowding effects, and completeness, the data and models comparison provide a solid calibration of SBF models. As an example, in Fig. 1 we plot the difference between observed and predicted J and K SBF magnitudes (upper panels) and J-K colors (lower panel) versus age for 19 star clusters in the Large Magellanic Cloud (see Raimondo, 2009a, for more details). Note that when using colours no information on the object distance is required. Here we recall that in the two upper panels we have adopted a distance of LMC $(m - M)_0 = 18.40 \pm 0.1$, while the colors plotted in the lower panel are free from distance indetermination, thus the nice accordance stands for a good match between models and data. The Figure also shows that models succeeded in reproducing (within statistical fluctuations) the relationship between SBF magnitudes (color) and the cluster's age in a wide range of ages, from tens of Myr up to a few Gyr.

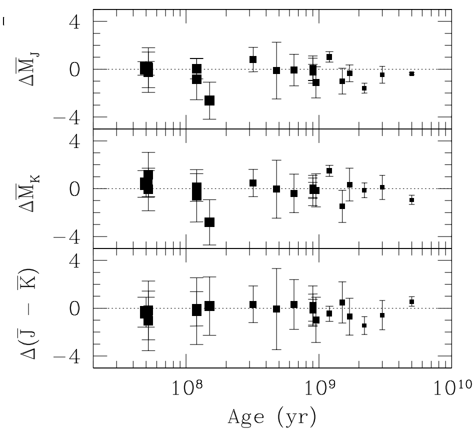

Fig. 1. Difference between observed and predicted J and K SBF magnitudes (upper panels) and $J - K$ color for 19 star clusters in the Large Magellanic Cloud. Clusters' metallicity ranges from [Fe/H] = −1.8 to 0.0.

3. Unresolved galaxies

Once the reliability of SBF for investigating young-intermediate ages is shown, it is inter-

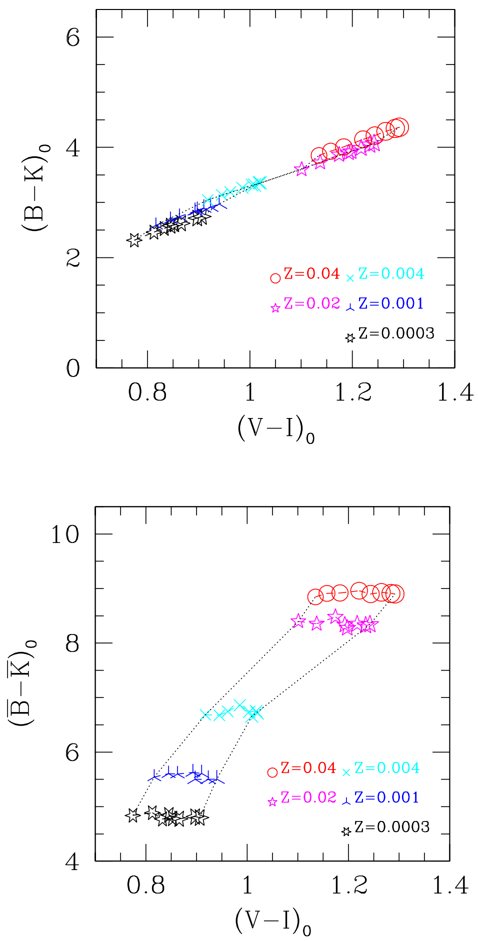

Fig. 2. $B-K$ versus $V-I$ integrated colors (upper), and SBF-color (lower), for SSP models with metallicity [Fe/H] = −1.8, −1.3, −0.7, −0.3, 0.0, 0.3 dex, and age t = 1-14 Gyr (bigger squares refer to older ages). Models are from Raimondo et al. (2005).

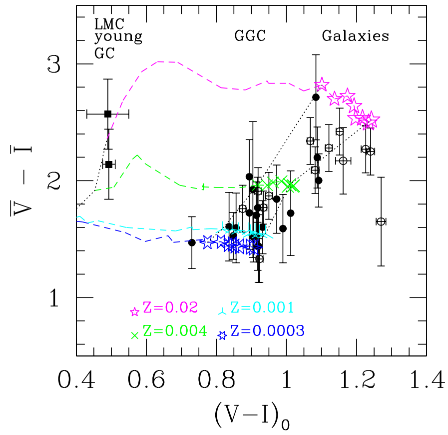

Fig. 3. SBF V-I color versus V-I integrated color. Galactic globular clusters data (filled circles, Ajhar & Tonry 1994), two young clusters of the Large Magellanic (filled squares, Raimondo et al. 2005) and data of a sample of galaxies (open circles, Cantiello et al. 2007). SSP models of Raimondo et al. (2005) are superimposed according the labelled metallicities. The age ranges from ∼ 100 Myr up to 14 Gyr.

esting to see what is the situation for stellar populations having older ages and different chemical compositions, like ellipticals and old globular clusters.

SBFs are more sensitive to the brightest stars of the population in a given passband than the simple integrated light. Thus, SBFs promise to be very useful for disentangling population properties in unresolved stellar systems. Models suggest that the SBF method provides remarkable advantages with respect to the classical tools, such as integrated colors. Owing to their definition, SBFs are, indeed, less affected by the age/metallicity degeneracy (see e.g. Worthey, 1994), which acts on integrated colours so that differences in the measures could be interpreted as due either to age or chemical composition variations. This is shown in Figure 2, where we plot a color-color diagram build up with integrated colors (upper panel), and SBF-colour versus integrated-color (lower panel). From the figure, it is clear that it is hard to constrain the mean age, t, or chemical composition, [Fe/H], using integrated colours, while SBF-color data *may* help in constraining such quantities for the dominant stellar components in the galaxy.

The use of SBF colors acquires even more interest in those cases, where distance may be affected by large uncertainties. Moreover, uncertainties of SBF measurements can achieve a precision that can be set below ~ 0.1 mag (e.g. a value lower than the separation between models at different [Fe/H]). This permits to investigate the characteristics of the dominant stellar populations in galaxies, and the radial behaviour of the stellar content by studying the SBF signal as a function of the galactocentric distance (Cantiello et al., 2005, 2007).

Figure 3 shows the location of a sample of galaxies (Cantiello et al., 2007) in the plane $V - I$ SBF-color versus the integrated galaxy color $V - I$. For reference, the position of a sample of Galactic globular clusters (Ajhar & Tonry, 1994) and two young clusters of the Large Magellanic (Raimondo et al., 2005) is also plotted together model predictions (SSP models from Raimondo et al. 2005) with metallicity [Fe/H] = −1.8, −1.3, −0.7, −0.3, 0.0 and ages from ~ 100 Myr (at the left of the figure) up to 14 Gyr (on the right). It is worth-noticing that the objects collected in the figure span a wide range of age, metallicity, mass, morphological and physical complexity, etc..., thus the agreement with model predictions suggests that the both the theoretical framework (ingredients, algorithms) and observational procedures to compute/measure SBFs is solid.

Therefore, SBFs represent an intriguing tool to probe stellar populations in galaxies where resolving individual stars is unfeasible. In particular, multi-band SBF studies, and SBF colours can help in lifting the age-metallicity degeneracy. Multi-wavelength SBF data involving optical to near-IR observations (as shown in Fig. 2) are of paramount interest to push forward the SBF technique, as they are not affected by the models degeneracy. In addition, SBF colour gradients measured within individual galaxies can give clues on galaxy formation and evolution.

SBF amplitudes in different bandpasses are sensitive to different evolutionary stages. For instance, near-infrared SBF magnitudes are sensitive to the evolution of stars within the AGB phase, especially the thermally pulsing AGB (see e.g. Raimondo et al., 2005), while SBFs in the blue and UV are sensitive to the hot horizontal branch and post-AGB stages (see e.g. Cantiello et al., 2003). Thus, such color data are sensitive to stars in different phases of their evolution, and two SBF-colors diagrams appear a further step to scrutinize the properties of different contributors (see Fig. 1 in Cantiello et al., 2009). The current state of SBF models allows for a robust determination of some properties of stellar populations in galaxies, as the mean metallicities. A further improved understanding of the stellar evolution phases important for SBFs might allow the use of this method for detailed population studies in the future.

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