Mem. S.A.It. Vol. 75, 198
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Surface Brightness Fluctuations: a powerful tool for investigating unresolved stellar populations

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Abstract. On the basis of new models for Surface Brightness Fluctuations (SBFs) we show the effectiveness of these quantities in constraining the properties of bright stars and in deconvolving information on the evolutionary state of galaxies, in terms of age and chemical content.

Key words. distance scale — globular clusters: general — galaxies: stellar content

1. Introduction

The advent of CCD detectors and telescopes with improved seeing has allowed to put into practice the idea determining distances from the "bumpiness" of a galaxy CCD image. This idea is based on the statistic (Poissonian) nature of the stellar sources that contribute to the total light of a galaxy; this technique has come to be known as the Surface Brightness Fluctuations (SBF) method.

Following the formalism by Tonry & Schneider (1988), the SBF flux ($\bar{F}$) is defined as the flux variance normalized to the mean flux of the galaxy (F):

$$\frac{\sigma_F^2}{F} = \frac{\sum_i n_i f_i^2}{\sum_i n_i f_i} = \bar{F} \qquad (1)$$

where n_i is the number of stars with flux f_i. Then, $\bar{F}$ expected in a specific photometric band is a quantity that depends on different kinds of stars that populate the stellar system, i.e. stars in different evolutionary phases, with different age and chemical compositions. Therefore, in addition to their utility as a distance indicator, SBF amplitudes are a promising tool for recovering information on the properties of stellar populations.

The procedure adopted in the present paper to derive SBFs is strictly correlated with the definition of SBF amplitudes in Eq. 1, and

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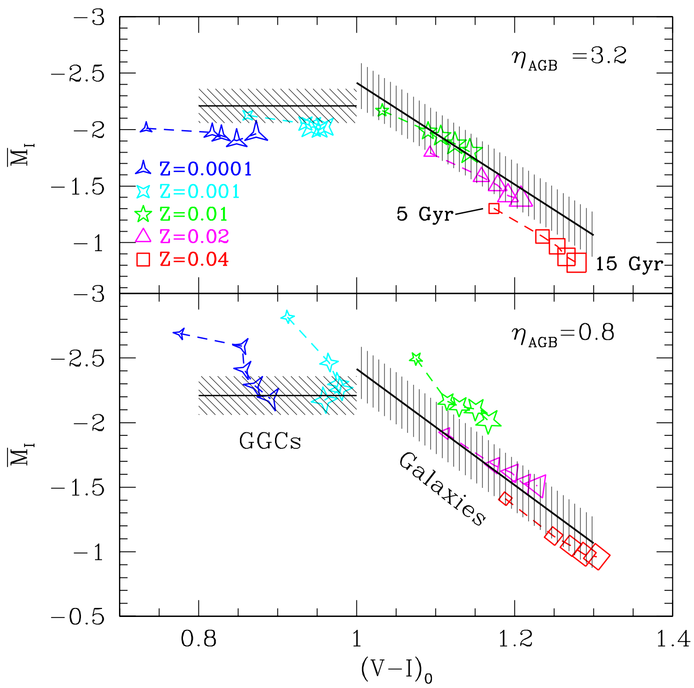

Fig. 1. Theoretical SBF models for various chemical compositions are reported for different ages. The symbol size increases according to age (t = 5, 9, 11, 13, and 15 *Gyr*). Our predictions are compared with the empirical calibration by Tonry et al. (2001, hereafter T01) (slanted solid line) and the observational locus of GGCs (horizontal solid line) by Ajhar & Tonry (1994). The uncertainties of the two relations are also reported: for the first relation we consider an uncertainty of 0.20 *mag*, due to the uncertainties in the Cepheid zero point (Freedman et al. 2001) and in the Large Magellanic Cloud distance modulus (e.g. Benedict et al. 2002). For the second one the zero point has an indetermination of at least 0.1 − 0.15 *mag* rising from the uncertainty of the GGCs distances. In addition, the rms scatter is ~ 0.25 *mag*.

with the statistical basis of our code for constructing stellar-population synthesis models: a Monte-Carlo (MC) technique is used to populate randomly the *Initial Mass Function (IMF)* [Brocato et al. (1999), Brocato et al. (2000)]. We remind the reader to Cantiello et al. (2003) for an extensive description of the method. Here, we only recall that we use the same set of stellar-population parameters *(t, Y, Z, IMF, etc.)* to compute N_{sim} *independent simulations*. Thus, SBF amplitudes are explicitly calculated as:

$$\bar{F}_X = \frac{\langle (F_X - \langle F_X \rangle)^2 \rangle}{\langle F_X \rangle}, \quad (2)$$

where $\langle F_X \rangle$ is the expected mean flux in the generic filter X. From an observational point of view – neglecting the blurring due to the seeing – each computed simulation can be considered as the stellar population projected into each pixel of the galaxy CCD image.

2. Investigating the properties of the brightest stars

Since SBF amplitudes are the ratio of the second to the first moment of the stellar luminosity function, the latest luminous evolutionary stages are crucial for SBF calculations. For old stellar systems this implies that accurate

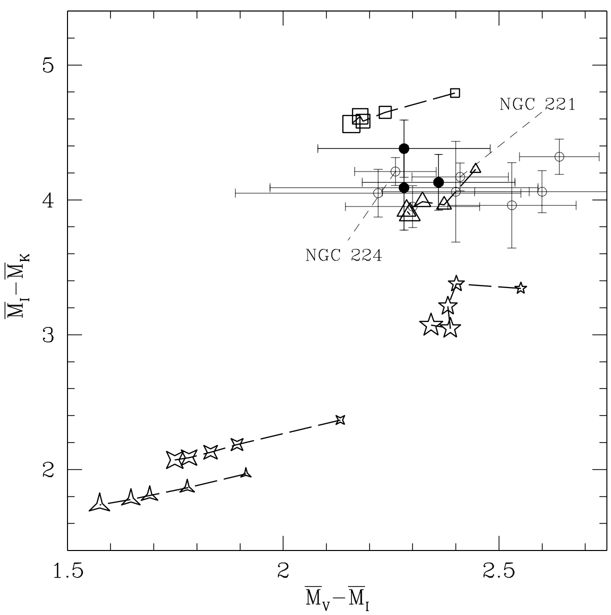

Fig. 2. Theoretical ($\bar{M}_V - \bar{M}_I$) *vs.* ($\bar{M}_I - \bar{M}_K$) colors are plotted against observational data. The observed SBF amplitudes of galaxies are: *V*-band from Blakeslee et al. (2001) (filled circles), Tonry et al. (1990) (open circles), and Ajhar & Tonry (1994) (NGC 224); *I*-band from T01; *K*-band from Luppino & Tonry (1993) and Jensen et al. (1998).

models for stars on the red and asymptotic giant branches (RGB and AGB) are needed. Nevertheless, once known the distance of the stellar system, SBFs can be used to determine the properties of stars in luminous evolutionary phases.

In Fig. 1 we report a "SBF"-calibration of the luminosity tip of the AGB in terms of the efficiency of mass loss indicated by the parameter η_{AGB}, according to the formalism by Reimers (1975). We plot the theoretical $\bar{M}_I$ as computed by adopting two different values η_{AGB} = 0.8 and 3.2. The calibration is performed by comparing the prediction with the available empirical relations.

The assumption of $\eta_{AGB} = 0.8$ leads to a remarkable fit with models of 13 − 15 *Gyr* for GGCs; on the contrary, the SBF models computed with $\eta_{AGB} = 3.2$ appear definitively fainter than observations. In conclusion, for the theoretical background we adopted, we find that $\eta_{AGB} = 0.8$ simulates the mass-loss process on AGB in such a way that the resulting distribution of stars on the AGB is able to reproduce at the same time the SBF measurements in galaxies and in GGCs. Let us note that for the RGB stars we assumed a mass loss fixed by $\eta_{RGB} = 0.4$, since this value is such that the synthetic RGBs well reproduce the observed RGBs in GGCs (Brocato et al. 2000).

3. Estimating age and metallicity

Once the distance of an object is known or in the case of several objects all at the same distance (e.g. cluster galaxies), one can use the SBF models for deriving ages and metallicities of the stellar populations. In particular, theoretical models have shown that SBF-colors can help in resolving the age-metallicity degeneracy affecting integrated colors of stellar populations.

By comparing models with observations in the plane ($\bar{M}_I - \bar{M}_K$) *vs.* ($\bar{M}_V - \bar{M}_I$), we find that the present models for simple stellar populations match, at least within the observational uncertainties, the locus of the available measurements (Fig. 2). In particular, the two Local Group galaxies NGC 221 and 224 are well fitted, i.e. we are able to reproduce their mean metallicity and age (e.g. Trager et al. 2000). Of course, in order to better reproduce the SBFs of each individual galaxy, it could be useful to introduce composite stellar populations, even if this implies to adopt *ad hoc scenarios* (e.g. Blakeslee et al. 2001).

Of course the problem of evaluating the age and metallicity of stellar populations in elliptical galaxies is a largely debated topic [see for example Henry & Worthey (1999), and reference therein]. Moreover, SBF measurements refer to a relatively large portion of a galaxy, thus they represent a sort of average value of the overall measured region. However, for "not too far" galaxies, precise observations, performed with the aim of deriving the radial distribution of SBF measurements, would be very effective in studying the details of stellar populations in such galaxies.

4. Conclusions

In this paper we support the use of surface brightness fluctuations measurements for stellar population studies. As shown by the two examples illustrated above, this innovative technique appears to be a powerful tool in constraining stellar evolution and in supporting stellar population synthesis investigations. Multiband and radial distribution of SBF measurements as obtained by new observational facilities (for example the VLT Survey Telescope and the ACS@HST) are recommended to provide a solid observational counterpart to the highly refined theoretical framework disclosed by the present SBF models.

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