Mem. S.A.It. Suppl. Vol. 9, 305

Memorie della
Supplementi

SBF Gradients of E-galaxies detected with ACS

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Abstract. We study Surface Brightness Fluctuations (SBF) for a sample of eight elliptical galaxies (NGC 1407, NGC 3258, NGC 3268, NGC 4696, NGC 5322, NGC 5557, NGC 1344, NGC 404) imaged with the Advanced Camera for Surveys (ACS) on board of HST. The data analysis is performed paying particular attention to the detection of radial SBF Gradients (SBFG). Thanks to the high capabilities of ACS we succeeded in measuring SBF, and SBFG from F814W band ($\sim I_{Cousins}$) images. The detection of SBFG allows to derive SBF-based distances for most of the galaxies considered. Moreover, assuming the galaxies' distance from other indicators, SBF and SBFG are adopted to analyze the chemical and physical properties of the stellar component in the galaxy.

Key words. galaxies: distances and redshift — galaxies: evolution — galaxies: photometry — galaxies: stellar content — stars: evolution

1. The SBF Method

The SBF method was originally introduced by Tonry & Schneider (1988) as a Distance Indicator (DI) useful to derive distances of elliptical galaxies up to 20 Mpc. In the latter decade a deeper understanding of the method - which is based on the statistical analysis of the spatial fluctuations present in the brightness profile of the galaxy - coupled with the technical improvements of telescopes, allowed a twofold result. First, to extend the family of objects for which SBF can be measured: elliptical, as well as bulges of spirals, dwarf galaxies, galactic globular and Magellanic Clouds star clusters. Second, to expand the range of applicability of this DI, which ranges from few kpc, up to ∼150 Mpc, slightly more than 4 order of magnitudes (Ajhar & Tonry 1994; Jerjen et al. 2001; Tonry et al. 2001; Jensen et al. 2003; Raimondo et al. 2005a). In addition, a big effort has been done by several authors in order to derive a reliable calibration of the absolute SBF magnitude, which is of paramount interest to properly use the SBF as a DI (Tonry et al. 1997). The wide range of applicability, coupled with the typically low intrinsic uncertainty of SBF distances, puts the method among the most powerful secondary DIs.

Parallel to the experimental development of the method, few authors have made a substantial effort aimed to study, via numerical simulations, the relations existing between SBF magnitudes and the stellar populations

Send offprint requests to: M. Cantiello age, and chemical composition. The first theoretical works on this side, were mainly devoted to compare/verify the empirical calibration of SBF absolute magnitudes vs. color, with the predictions from stellar populations models (Buzzoni 1993; Worthey 1993). However, the latest studies, have shown that SBF amplitudes are also efficient to partly disentangle the age/metallicity degeneracy (Blakeslee, Vazdekis, Ajhar 2001; Jensen et al. 2003; Cantiello et al. 2003), and to test our knowledge on the evolution of bright/fastly-evolving stars (Cantiello et al. 2003; Raimondo et al. 2005a,b).

In the following sections we present the early results of a project devoted to reveal the existence of radial SBFG along the brightness profile of a set of eight elliptical galaxies imaged with the *Advanced Camera for Surveys* (ACS, archive data).

2. SBF with ACS

Our interest to use ACS images in order to derive SBF measurements raised mainly due to the poor number of studies devoted to the detection of SBF differences between various regions of the same galaxy. Thanks to its exceptional resolution, indeed, ACS is ideal for the detection of SBF variations within one single galaxy, out to relatively distant galaxies (Distance Modulus: DM~33.5); differently from the few previous works which detected SBF variations in Local Group galaxies (Tonry et al. 2001), or nearby external ellipticals (DM~30.1, Sodemann & Thomsen 1995).

Moreover, apart from the usual application as DI, the inspection of SBFG, coupled with the measurement of SBF colors, is of primary interest if stellar populations issues are considered. In fact, as SBF color analysis, SBFG analysis does not need any distance assumption (at least in first instance), since it is based on the study of intrinsic SBF variations in the profile of one single galaxy.

By refining the usual pipeline adopted to measure SBF, we succeeded in measuring SBF in different (annular) regions for all galaxies for which we have data. Some of the by-products obtained applying this procedure are presented in Figure 1. As a result of the SBF-measurements campaign, we find that all the galaxies inspected, but NGC 404[1], exhibits a clear SBF- and color-Gradient (Figure 2), the inner regions being systematically fainter and redder [$(B-I)_0 \gtrsim 2.1$] than the outer ones.

Table 1. The DM estimated in this work. For comparison we also report DM obtained averaging data taken from literature (see Cantiello et al. 2005 for the details)

Galaxy	$DM_{This\,Work}$	DM_{Others}
NGC1407	32.0 ± 0.10	32.1 ± 0.15
NGC3258	33.0 ± 0.15	33.0 ± 0.15
NGC3268	33.0 ± 0.15	32.9 ± 0.15
NGC4696	33.0 ± 0.1	32.8 ± 0.15
NGC5322	32.6 ± 0.15	32.4 ± 0.15
NGC5557	33.4 ± 0.1	33.4 ± 0.1

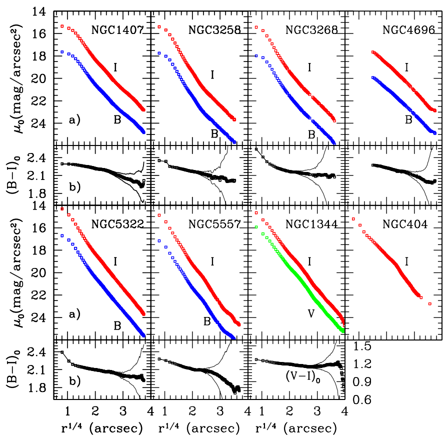
Using these data, in the following we will address both issues: SBFG for distance studies, and SBF for stellar populations analysis.

2.1. Measuring distances

Applying a shifting algorithm similar to the one adopted by Tonry et al. (1997), we derive accurate relative distances between galaxies. Assuming the distance of NGC1344 as reference (Fornax cluster: DM=31.5±0.1, Tonry et al. 2001), we obtain the distance moduli reported in Table 1.

Furthermore, if the interest is on the calibration of the *absolute SBF mag* vs. $(B-I)_0$ *color* relation, instead of determining distances, the available data can be successfully used to obtain such relation. Applying a least squares method we derive: $\bar{M}_I = (1.6 \pm 0.1) + (3.0 \pm 0.3) \cdot [(B-I)_0 - 2.1]$, in nice agreement with theoretical predictions (Cantiello et al. 2005). As mentioned before, this relation is fundamental in order to derive reliable SBF-based distances.

[1] This galaxy is a nearby dwarf elliptical, for which we do not have any color data.



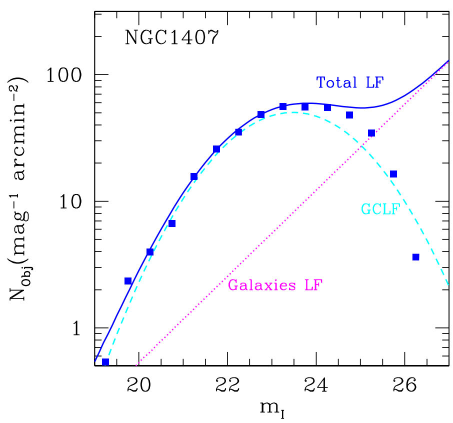


Fig. 1. *Upper panel.* Surface Brightness profiles and color profiles derived inspecting the ACS B-band (V, for NGC 1344), and I-band frames. *Lower panel.* The Luminosity Function of point-like, and extended sources present in the I-band frame (the case of NGC 1407 is shown).

2.2. SBF and stellar populations

By assuming the galaxy's distance modulus from other authors (Blakeslee et al. 2002), we can compare the absolute SBF magnitudes with models predictions, so that stellar populations properties can be inferred (Figure 3). Inspecting this Figure we reach the following conclusions:

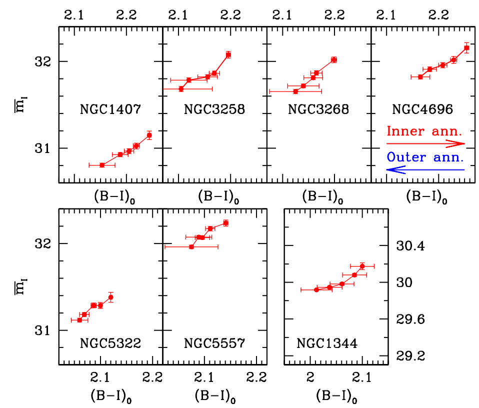


Fig. 2. SBF amplitudes measured in the various galaxy's annuli plotted against the $(B-I)_0$ color of the annulus. As indicated by arrows (upper right panel) the innermost regions are bluer than the outer ones, such regions have also correspondingly brighter SBF magnitudes.

(*i*) SBFG seem to be mainly driven by radial chemical composition variations. In fact, in the case of gradients driven by age variations, the models predict a shallower SBFG amplitude, respect to what observed. Interestingly the galaxy with the lowest SBFG (NGC 1344) exhibits disturbed morphology, that is it shows evidences of a merging or accretion event occurred in the recent past which is expected to have enriched the galaxy of a bluer, i.e. younger, stellar component. Thus, for this galaxy we expected to observe the shallower SBFG.

(*ii*) In agreement with the indications from other photometric and spectroscopic indicators, the average metallicity of galaxies increases with the galaxy absolute magnitude.

(*iii*) The outer regions of the galaxies are more metal poor than the inner ones.

(*iv*) The detailed inspection of Figure 3 allows to derive age and chemical composition properties for each galaxy. For example NGC1344 lies in the locus of populations with 9 Gyr $\lesssim$ Age $\lesssim$ 11 Gyr, and is slightly more metal poor than the bulk of galaxies lying at $(B-I)_0 \gtrsim 2.1$, and $\bar{M}_I \sim 1.2$ mag. However, such results are strongly dependent on the set

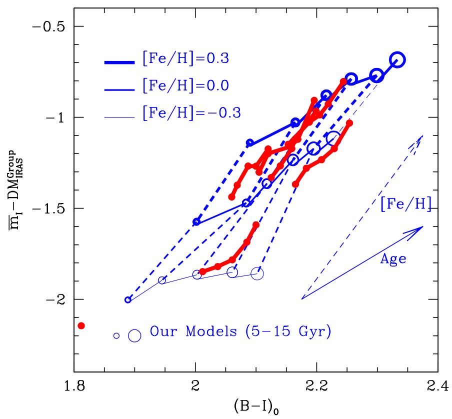


Fig. 3. Absolute SBF magnitude versus the galaxies $(B-I)_0$ color (red lines). SBF models, for ages 5,7,9,11,13,15 Gyr and three metallicities ([Fe/H]=-0.3,0.0,+0.3) are plotted as blue lines (models from Cantiello et al. (2003, 2005); Raimondo et al. (2005a)). Models of increasing age are marked with circles of increasing size, the direction of the increase is shown by the *Age* arrow. The dashed arrow indicates the direction of increasing $[Fe/H]$.

of models adopted, and the DM assumed. It is expected that SBF color data should give more useful constraints on this side.

3. Ongoing works - Future projects

We plan to analyze a new set of galaxies imaged with ACS images - mainly peculiar ellipticals - in order to possibly detect new SBFG. Moreover, we have already started a project aimed to measure B-band SBF amplitudes for the sample of galaxies listed in Table 1; once completed this study will give one of the largest sample of SBF color data available up to now. As mentioned before, and widely discussed in literature, the comparison of SBF multi-band data with theoretical models is very efficient to disentangle the age/metallicity degeneracy[2] which affects the interpretation of photometric/spectral data of unresolved stellar populations (Worthey 1993). With the new available data we expect to strengthen the present results on SBFG. In particular, we intend to explore the SBFG vs. *galaxy mass* correlation which seems to exist in present data.

In addition to ACS data, we plan to consider the possibility of using new generation telescopes (Large Binocular Telescope: LBT; VLT Survey Telescope: VST) for a campaign dedicated to the optical and near-IR measurements of SBF and, possibly, SBFG for an extended sample of galaxies spanning a wide range in mass. From these new data we hope to obtain detailed SBF information which could be useful to shed new lights on the processes lying at the basis of the formation and evolution of galaxies.

[2] It must be noted, however, that colors involving one near-IR band and one optical data are best indicated for these studies.

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