The puzzling origin of the “UV-upturn” phenomenon, observed in some elliptical galaxies, has recently been settled by identifying hot HB stars as main contributors to galaxy ultraviolet luminosity excess. While a blue HB morphology seems a natural characteristic of metal-poor stellar populations, its appearance in metal-rich systems, often coupled with a poorer rate of planetary nebulae per unit galaxy luminosity, might be calling for an intimate connection between UV excess and AGB properties in early-type galaxies. In this work, we want to briefly assess this issue relying on infrared surface brightness fluctuations as a powerful tool to trace AGB properties in external galaxies with unresolved stellar populations.

1 Introduction

The so-called “UV-upturn” phenomenon (Code & Welch, 1979), i.e., the rising ultraviolet emission shortward of 2000 Å, sometimes seen in the spectral energy distribution of elliptical galaxies and the bulges of spirals, has been for long a puzzling problem for old galaxy environments dominated by stars of mass comparable to that of the Sun.

Spectroscopy and imaging (Brown et al., 1997, 2000) of resolved color–magnitude (c-m) diagrams of stellar populations in M32 have definitely shown that this UV excess traces the presence of long-lived O-B stars, hotter than 30 000 - 40 000 K —mostly hot HB stars further complemented, to a lesser extent, by a post-AGB contribution of PN nuclei. However, at least two important issues need to be properly addressed to understand the real nature of the UV-upturn phenomenon.

(i) For such hot HB stars (naturally residing in old, metal-poor globular clusters) to be an output of super metal-rich environments, theory requires a quite delicate “fine tuning” of metallicity and stellar mass-loss efficiency, in order to achieve (a) the suitable partition between stellar internal He core and external envelope, and (b) a total mass $M_* \lesssim 0.52 \, M_\odot$ at the HB onset (Dorman et al., 1993; Castellani et al., 1992).
(ii) Observations indicate that metal-rich ellipticals display, at the same time, a stronger UV-upturn (Burstein et al., 1988) and a poorer planetary nebula (PN) production per unit galaxy luminosity (Buzzoni et al., 2006). If the PN event is the final fate of AGB stars at the end of their thermal pulsing phase (Iben & Renzini, 1983), then a PN deficiency might be evidence of an incomplete (or fully inhibited) AGB evolution of low-mass stars under special environment conditions of the parent galaxy.

As a central issue in this discussion, it is clear, therefore, that a preeminent connection should exist between UV excess and AGB distinctive properties of stellar populations in early-type galaxies.

2 Infrared surface-brightness fluctuations as AGB probes

Tonry & Schneider (1988) first realized the potentially useful information, about their stellar populations, hidden in the surface brightness fluctuations (SBFs) of external galaxies with unresolved stellar populations. This problem has since received a more general theoretical assessment (Buzzoni, 1993; Cerviño et al., 2002), exploring in many of its different facets the basic relationship of the theory:

\[ \frac{\sigma^2(L_{\text{gal}})}{L_{\text{gal}}} = \frac{\sum \ell^2}{\sum \ell} = \ell_{\text{eff}}. \]  

The l.h. side of the equation links an observable quantity (namely, the relative variance of the galaxy surface brightness) with the second-order statistical moment of the composing stars. The r.h. side of eq. (1) is a natural output of any population synthesis code, and can easily be computed for different photometric bands and distinctive evolutionary properties of simple stellar populations (SSPs).

Because of the quadratic \( \ell \) dependence of the numerator summation in eq. (1), the effective luminosity (and its derived effective magnitude, \( M = -2.5 \log \ell_{\text{eff}} + \text{const} \)) at any optical or near-infrared band is highly sensitive to the giant stars, and only marginally responds to a change in the IMF slope (see, e.g., Buzzoni, 1993). Likewise, as probe of the brightest stars in a population at a given wavelength, the effective magnitude is relatively insensitive to underlying older populations in the case of composite systems.\(^3\)

As statistically representative of the stellar system as a whole, \( \overline{M} \) cannot be physically associated to any specific star or stellar group along the c-m diagram of a stellar aggregate; nonetheless, it can be instructive to assume \( \overline{M} \) as the magnitude of the “prevailing” stars in the population at the different photometric bands. In this respect, \( \overline{K} \) is potentially the best tracer of the SSP tip stellar luminosity (\( K_{\text{tip}} \)), since both quantities are expected to depend in quite

\(^3\) For an observational confirmation, see González-Lópezlira et al. (2005).
Fig. 1. Theoretical relationship between infrared effective magnitude (\(K\)) and AGB tip luminosity of composing stars (\(K_{\text{tip}}\)), for a full collection of SSP models from the Buzzoni (1989, left panel) and Charlot & Bruzual (2007, in preparation, right panel). SSP ages span from 1 Gyr (top right) to 18 Gyr (bottom left), with a metallicity range \(0.0001 \leq Z \leq 0.05\). The Buzzoni (1989) models are for a fixed Reimers (1975) mass-loss parameter \(\eta = 0.3\) and a Salpeter IMF, while the Charlot & Bruzual (2007) calculations use a Chabrier (2003) IMF, and inherit from Marigo & Girardi (2007) the formalisms for \(\dot{M}\) derived from pulsating dust-driven wind models of AGB stars. The tight correlation between \(K\) and \(K_{\text{tip}}\) appears quite robust along the entire range of explored parameters and, remarkably enough, nearly model independent.

the same way on the overall distinctive parameters of the stellar population, including age, metallicity, IMF, and mass-loss (see Fig. 1).

The tight relationship predicted by population synthesis theory is nicely confirmed when comparing with real stellar clusters spanning a wide range of evolutionary parameters, like for instance in the Magellanic Clouds (MC). Actually, age of star clusters around these galaxies is distributed over four orders of magnitude, with objects as young as a few Myr, and as old as \(\sim 10^{10}\) yr. In addition, for these resolved stellar systems we can easily and consistently determine both the fluctuation luminosity and the tip of the red giant stars from direct inspection of their c-m diagrams. The results of such an experiment are shown in the left panel of Fig. 2, for the sample of 191 MC star clusters of González et al. (2004, 2005). In fact, note from the figure that the claimed relationship between \(K_{\text{tip}}\) and effective \(K\) magnitude is in place along the entire age range, and even for ultra-young (classes pre-SWB and SWB I) MC clusters, that would barely sport any standard AGB or RGB phases...

On the other hand, it is definitely worth stressing that the link between \(K\) and \(K_{\text{tip}}\) is a much more deeply intrinsic property of SSPs, and not exclusively related to age evolution. For instance, if one explores the impact of
stellar mass-loss via a Reimers (1975) standard parameterization (right panel of Fig. 2), we have that quite the same relationship is still found.

3 UV upturn and AGB extension in elliptical galaxies

A suitable way to size up the strength of the UV-upturn in elliptical galaxies is via the integrated (1550 − V) color (Burstein et al., 1988), that is basically a measure of the relative galaxy luminosity at 1550 Å compared to the visual band. 4 Figure 3 is a striking summary of the situation, as far as the comparison between UV-upturn and infrared SBF for a number of elliptical galaxies in Virgo, Leo, and the Local Group. A nice sequence is evident between UV excess and K-band effective magnitude; in particular, UV-enhanced galaxies are about 1 mag fainter in $K_s$, compared to UV-poor “standard” systems. Once translated into tip stellar luminosity (via Fig. 1), the brightest red giants

4 So, UV-upturn ellipticals have “bluer” [i.e., (1550 − V) → 0] color.
in UV-upturn ellipticals turn out to be about $K_{\text{tip}} \approx -7.0$, or roughly 0.7 mag fainter than those in UV-poor systems.

At this stage, a number of interesting conclusions can be drawn from the analysis of the figure and the overall interpretative framework depicted by the synthesis model scenario.

(i) If we entirely ascribe the dimming of the red giant tip luminosity of Fig. 3 to mass-loss, then there should be a spread $\Delta \eta \approx 0.4$ among the early-type galaxy population, with UV-enhanced ellipticals consistent with a Reimers parameter $\eta = 0.3-0.4$, as found for Galactic globular clusters (Renzini & Fusi Pecci, 1988). However, this is likely an upper limit to the mass-loss rate range. Although elliptical’s high metallicity may be correlated with a higher mass-loss rate at a fixed age (e.g., Groenewegen et al., 1995), $M$ certainly diminishes with older age; and metal-rich giant ellipticals are expected to be, on average, older than low-mass metal-poor systems (e.g. Pahre et al., 1998; González-Lópezlira et al., 2005), as predicted by a standard monolithic scenario (see, e.g., Larson, 1974) and directly inferred, for example, by the

**Fig. 3.** The $K$-band SBF magnitudes vs. (reddenning corrected) ultraviolet color $(1550 - V)$, for a sample of elliptical galaxies in the Virgo cluster, the Leo group, and the Local Group (from Buzzoni & González 2007, in preparation).

**Fig. 4.** Lick $H\beta$ index vs. $(1550 - V)$ color for the elliptical galaxies of Fig. 3. As $H\beta$ basically probes the temperature location of the turn-off point of galaxy main sequence stars (Buzzoni et al., 1994; Jensen et al., 2003), the inferred physical trend confirms that UV-upturn is stronger among $H\beta$-poor old and super metal-rich galaxies.
observed correlation between galaxy $H\beta$ index and $(1550 - V)$ color, like in Fig. 4.

(ii) The involved $K$-band tip luminosity definitely implies that, in UV-upturn galaxies, the AGB luminosity extension barely exceeds the RGB tip, and only for UV-poor systems we have to expect the branch to fully deploy, with stars 1-1.5 mag brighter than the RGB tip (Buzzoni, 1995).

(iii) A more careful comparison with the evolutionary synthesis models indicates that, on average, AGB stars in ellipticals always experience the thermal-pulsing phase likely giving rise to the PN event. However, given a reduced AGB extension among UV-enhanced galaxies, this situation is increasingly countered when either galaxy age or metallicity increase, and a higher number of stars end up as UV-bright AGB-\textit{manqué} objects (Greggio & Renzini, 1990), thus escaping the PN phase and directly feeding the high-temperature region of the galaxy c-m diagram.

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