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Auto-consistent test of Galaxy star formation histories derived from resolved stellar population and integral spectroscopy

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Abstract. We present the first results of our observational project 'Starfish' (STellar Population From Integrated Spectrum). The goal of this project is to calibrate, for the first time, the properties of stellar populations derived from integrated spectra with the same properties derived from direct imaging of stellar populations in the same set of galaxies. These properties include the star-formation history (SFH), stellar mass, age, and metallicity. To date, such calibrations have been demonstrated only in star clusters, globular clusters with single stellar populations, not in complex and composite objects such as galaxies. We are currently constructing a library of integrated spectra obtained from a sample of 38 nearby dwarf galaxies obtained with GEMINI/GMOS-N&S (25h) and VLT/VIMOS-IFU (43h). These are to be compared with color magnitude diagrams (CMDs) of the same galaxies constructed from archival HST imaging sensitive to at least 1.5 magnitudes below the tip of the red giant branch. From this comparison we will assess the systematics and uncertainties from integrated spectral techniques. The spectra library will be made publicly available to the community via a dedicated web-page and Vizier database. This dataset will provide a unique benchmark for testing fitting procedures and stellar population models for both nearby and distant galaxies.

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1. Introduction

The study of the stellar content of galaxies is an important tool for deciphering galaxy evolution. It provides a way to recover the star formation history, which itself yields insight about stellar mass growth. In the last decade, large surveys have collected significant amounts of galaxy spectra from the local to the distant Universe. At the same time, stellar evolutionary synthesis models have matured enough to provide robust interpretations of such spectra. Full spectral fitting methods are now used to extract from thousands of galaxies (often simultaneously) properties such as stellar mass, star formation rates, dust extinction and stellar metallicities. Such spectral analysis requires accurate stellar synthesis population models and realistic descriptions of how light from the different components of the galaxy is mixed. Additionally, it needs inversion algorithms, full-spectra fitting or model libraries using a bayesian approach, to separate distinct populations within each galaxy and to determine their relative contributions to the total flux. However, obtaining reliable results using these methods requires an accurate accounting of the systematics and uncertainties from *both* observations and models.

To date, the synthesis of photometric color magnitude diagrams (CMDs) and stellar population models is the most accurate way to determine the star formation histories (SFHs) of galaxies back to their earliest epochs. This method has its limitations: uncertainties associated with single stellar population models; uncertainties from photometry of crowded fields; the degeneracy between age and metallicity. However, the Coimbra experiment (Skillman & Gallart 2001) demonstrated the robustness of CMDs + population models. Several different stellar population models and inversion techniques were applied to the same high-quality, deep imaging from the Hubble Space Telescope (*HST*). All of the models converged to solutions consistent with each other. Since then, deep *HST* imaging has been obtained for a larger number of nearby galaxies, providing us with a wealth of information about the star formation history (SFH) and metal content of local nearby galaxies (Dolphin 2005; Gallart 2007; McQuinn et al. 2010; Weisz et al. 2011; Dacalton et al. 2009). While locally, different models converge to the same properties with color magnitude diagrams CMDs, this is not the case for different stellar population models when applied to the integrated spectra of galaxies. The effects of using different input physics in synthetic integrated spectra for stellar population models and the further degeneracies which arise as a function of SFH have been investigated using Monte-Carlo simulations (Chen et al. 2010; Conroy et al. 2009, 2010; Conroy & Gunn 2010). Koleva et al. (2008) and Gonzalez Delgado & Cid Fernandes (2010) compared the ages and metallicities derived from model decomposition of integrated stellar spectra of star clusters with the properties obtained from CMDs of the same clusters [1]. These comparisons have been

[1] (see also tests reported at IAU Symposium 241 (http://www.astro.rug.nl/~sctrager/challenge/)

relatively successful for star clusters. However, the stellar populations of galaxies are more complex than star clusters, due to multi-epoch SFHs, inhomogeneous distributions of dust, gas, stars and are often further complicated by nebular emission. The first steps to solve this puzzle were taken by Alloin (2002) and Fritze & Lilly (2007) by comparing properties from integrated light and CMDs in a small field close to the bar of the Large Magellanic Cloud. They found that SFHs obtained from integrated light can be ambiguous and emphasized the difficulty in extracting the age and mass fractions of stellar populations with ages (t) > 4 Gyr. In Makarova et al. (2010), the comparison was been extended to dwarf spheroidals, whose stellar population is comprised of only old and intermediate age stars. They compared the SFH and metal enrichment in two dE/dSph members of the nearby M81 group of galaxies and found that the two methods yielded consistent results. We have begun to carry out a similar program, but significantly broader in scope. We are systematically comparing the properties of integrated spectral light and CMDs for 38 local galaxies within an 8 Mpc volume. All 38 systems have been observed with *HST* using either the Wide Field Planetary Camera 2 (WFPC) (Dolphin et al. 2005) or the Advanced Camera for Surveys (ACS) (Weisz et al. 2011).

2. A auto-consistent test of full spectral fitting methods

The goal of this work is to calibrate the use of integrated spectroscopy as applied to the study of galaxy stellar populations locally and at high redshifts. Our methodology consist on comparing the stellar population properties (mean age, metallicity (Z), stellar mass, SFH) derived from CMDS with the same properties extracted from full spectral fitting in a sample of 38 nearby galaxies. We will answer three critical questions: (1) How does the description of the star formation history, and dust treatment affect the derivation of the galaxy properties from integrated spectra? This is known as the "inversion problem"; (2) How precisely can one obtain the age of the burst and the oldest ages from integrated spectra compared to the same properties obtained from CMDs? (3) What are the effects of sampling different sized spatial regions and inhomogeneous stellar, gas, and dust distributions on the final derived star formation histories?

2.1 Sample selection and observational strategy

We have started an observational campaign to obtain the integrated spectra of a sample of nearby galaxies. The sample was constructed from the following requirements: 1) within $D < 8Mpc$; 2) $\mu_B < 25.0$; and 3) archival *HST* optical imaging deep enough to resolve stars at least 1.5 magnitudes below the tip of the red giant branch. This restricts the population of potential targets to a sample of 38 dwarf galaxies – 4 transition dwarves, 2 dwarf spheroidals, 4 dwarf spirals, 10 irregulars and 18 starbursts. Our study is limited only by HST's ability to resolve stellar populations in galaxies.

This restricts to investigating low-mass systems with low metallicities, young ages, and stochastic SFHs. While this is not ideal, it nevertheless provides a starting framework until the arrival of the next generation of ground and space telescopes which will be able to resolve stars in more massive nearby systems. Our sample spans the northern and southern hemispheres. (1) Compact galaxies in the southern hemisphere with apparent dimensions < 4′ have been observed on the VLT using the wide field integral field unit (IFU) on VIMOS (40hr completed); (2) Galaxies with wider dimensions, or in the northern hemisphere, have been observed with the GMOS long slit spectrograph at either GEMINI-North or Gemini-South (20hr completed). Depending upon the size of the target, several pointings of identical exposure times may be required in order to cover an area similar to that of integrated spectroscopy of unresolved galaxies. See Figure 1 for an example of the VIMOS and GMOS setups.

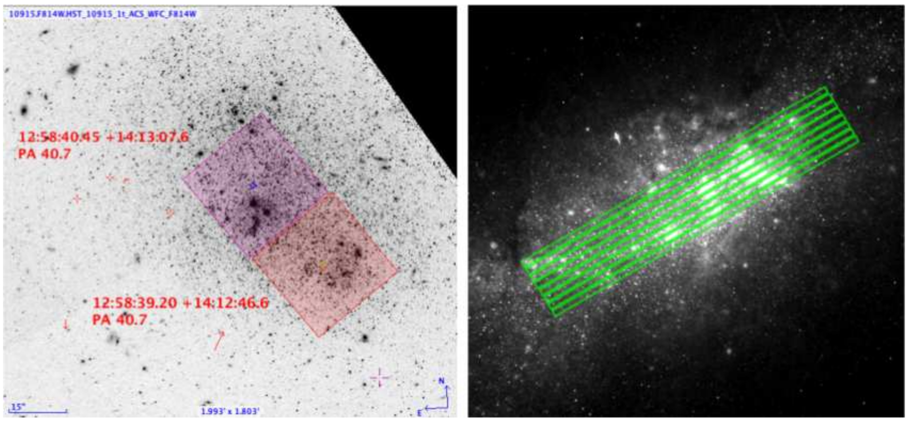

Figure 1. The two observational setups used for the acquisition of integrated spectra. Left: *UGC* 9128 observed with VLT/VIMOS IFU. The area observed with VIMOS two pointing (color) is over-plotted on the *HST* deep imagery. Right: Observational setup for *NGC* 1569 using a mosaic of 6 long slit pointings with GEMINI/GMOS-S (green).

2.2 Data reduction

Data reduction and analysis of the VIMOS data is currently underway, and is nearly complete for the GMOS-N&S observations. Individual 2D frames have been reduced following the standard data reduction procedures (bias subtraction, application of flat-fields, wavelength calibration). The reduced 2D frames have been inspected for possible contamination from foreground stars. The areas affected by such contamination have been masked before co-adding all of the 2D images from the same target. Thereafter, the 2D data have been collapsed into a final 1D summed spectrum for each galaxy. This is done to approximate the integrated spectrum one would obtain in extragalactic studies (e.g. SDSS fibers).

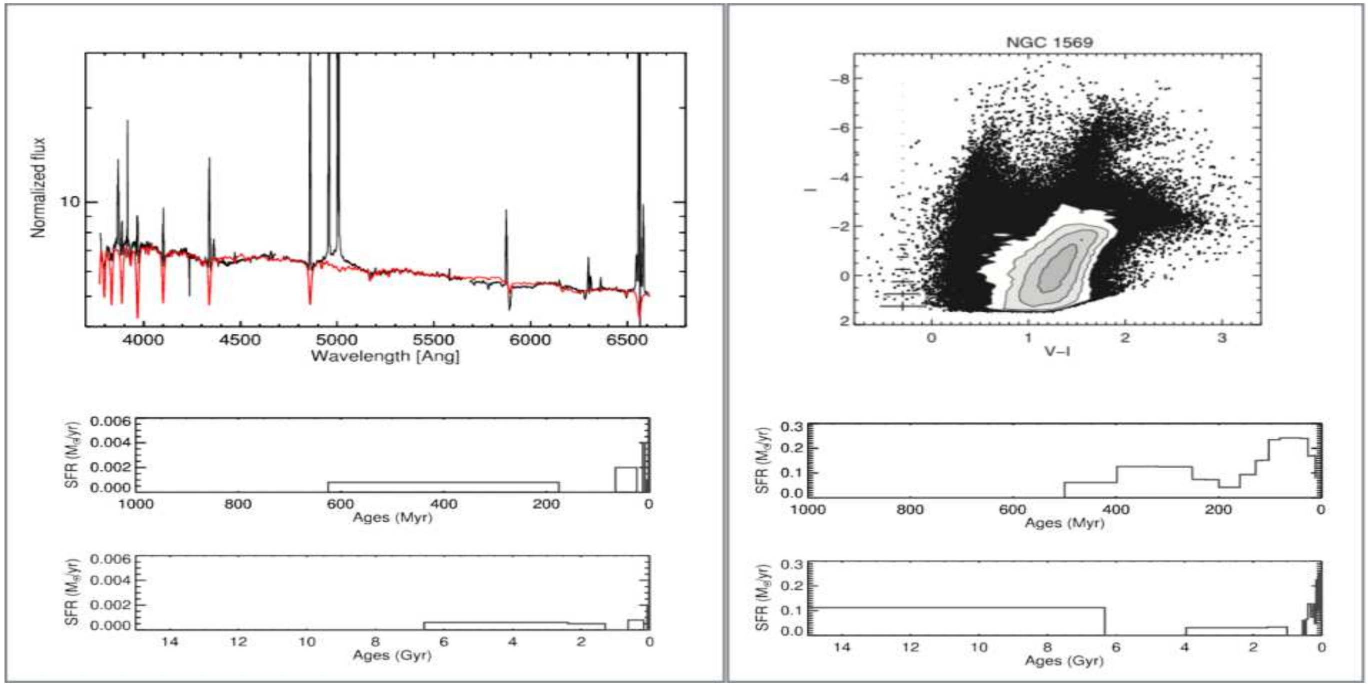

Figure 2. Left panel: The SFH extracted from full-spectra fitting of a NGC 1569 using the STARLIGHT software. From top to bottom : The integrated spectrum in black and the best fit stellar continuum in red line. At the bottom, the SFH estimated from the integrated spectrum. **Right panel** : SFHs derived from color magnitude diagram in the nearby galaxy, NGC 1569, with resolved stellar populations. From top to bottom: Color-magnitude diagrams (CMDs) derived from *HST*/ACS imagery and the star-formation histories (SFHs) from synthetic CMDs (images from Mc Quinn et al. 2010).

Since some of the full spectral fitting algorithms use the information contained in the slope of the stellar continuum, the method can potentially be sensitive to mismatches in the flux calibration and/or other instrument residuals. To minimize and control these uncertainties, we have monitored the flux calibration stability with a set of spectrophotometric standards during the observational campaign, and verified the relative flux of the spectra with photometric observations. The flux calibrations is accurate to less than 5% at $\lambda > 5000$Å and to about $\sim 15\%$ at $\lambda < 5000$Å. Each spectra have been individually inspected to discard that the spectral features (global slope, bumps and discontinuities) were not arising from instrumental or sky residuals.

The final spectra have a spectral resolution of 1600 for GMOS-S&N and 2000 for VIMOS, and with wavelength coverage of 3800 - 6560 Å and 3700-7400 Å respectively. The mean signal-to-noise at ~4600 Å is close to 40.

The photometric catalogues for the CMDs extracted from *HST* observations have been computed for areas wider than those observed by the integrated spectra. Thus, CMDs will be reconstructed to match the areas sampled by the spectroscopic observations. The library of integrated spectra and associated reconstructed CMDs for the same spatial regions will both be made publicly available.

3. First results : NGC 1569

We have analyzed the integrated spectrum of NGC 1569 with the full suite of fitting algorithms from STARLIGHT (Cid Fernandes et al. 2005). We have modeled the stellar continuum using linear combinations of a grid of simple population synthesis (SSP) models. These have been attenuated with a dust component and convolved with a kinematic component describing the motions of the stellar populations. Our grid of templates come from a set of 45 SSPs from the updated stellar evolutionary population models of Charlot & Bruzual 2007. These SSPs on the 1994 Padova stellar evolutionary tracks and the empirical stellar library MILES (Sanchez-Blazquez et al. 2006). The SPP grid spans 3 metallicities (0.004, 0.02, 0.05000), 15 formation ages (from 10 Myrs to 13 Gyrs), and assumes a Chabrier initial mass function (Chabrier 2003) with a Cardelli et al. (1989) extinction law (Rv=3.1). The mass weighted fraction of each SSP has been converted into a smooth star formation history, following the conversion described in Asari et al. (2007). The SFH has been compared with those estimated by the CMD study from Weisz et al. (2011). Figure 2 demonstrates that the full spectra fitting method has successfully recovered the burst at 200-600 Myr and part of the young burst at 50 Myr. On the other hand, part of the oldest populations with ages above 4 Gyr have been underestimated. Moreover, the model fits to the integrated spectra suggest the presence of a young stellar component ($\sim$10 Myr) which is *not* detected from the CMDs, and is therefore likely to be an artifact. This discrepancy between integrated light and CMDs could arise from three problems: 1) calibration uncertainties; 2) the contribution of nebular continuum; and 3) the low spectral resolution of the input SSP library at young ages. We emphasize that these are preliminary results and that the SFHs from the CMDs have yet to be recomputed to cover the same spatial area as the observed spectra.

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