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# SHARDS: a spectro-photometric analysis of distant red and dead massive galaxies

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## Abstract

SHARDS, an ESO/GTC Large Program, is an ultra-deep (26.5 mag) spectro-photometric survey carried out with GTC/OSIRIS and designed to select and study massive passively evolving galaxies at $z = 1.0$–$2.5$ in the GOODS-N field. The survey uses a set of 24 medium band filters (FWHM $\sim$ 15 nm) covering the 500–950 nm spectral range. Our observing strategy has been planned to detect, for $z > 1$ sources, the prominent Mg absorption feature (at rest-frame $\sim$280 nm), a distinctive, necessary, and sufficient feature of evolved stellar populations (older than 0.5 Gyr). These observations are being used to: (1) construct for the first time an unbiased sample of high-$z$ quiescent galaxies, which extends to fainter magnitudes the samples selected with color techniques and spectroscopic surveys; (2) derive accurate ages and stellar masses based on robust measurements of spectral features such as the Mg(UV) or D(4000) indices; (3) measure their redshift with an accuracy $\Delta z/(1 + z) < 0.02$; and (4) study emission-line galaxies (starbursts and AGN) up to very high redshifts. The well-sampled optical SEDs provided by SHARDS for all sources in the GOODS-N field are a valuable complement for current and future surveys carried out with other telescopes (e.g., *Spitzer*, HST, and *Herschel*).

## 1 Introduction

In this 2012 SEA Meeting, we presented the basics of the *Survey for High-z Absorption Red and Dead Sources* (SHARDS), an ESO/GTC Large Program awarded 180 hours of GTC/OSIRIS time during 2010–2013. This project consists of an ultra-deep ($m < 26.5$ AB mag) imaging survey in 24 medium-band filters covering the wavelength range between 500 and 950 nm and targeting the GOODS-N field. The observations carried out by SHARDS allow to accurately determine the main properties of the stellar populations present in these

*See http://guaix.fis.ucm.es/∼pgperez/SHARDS/team.html

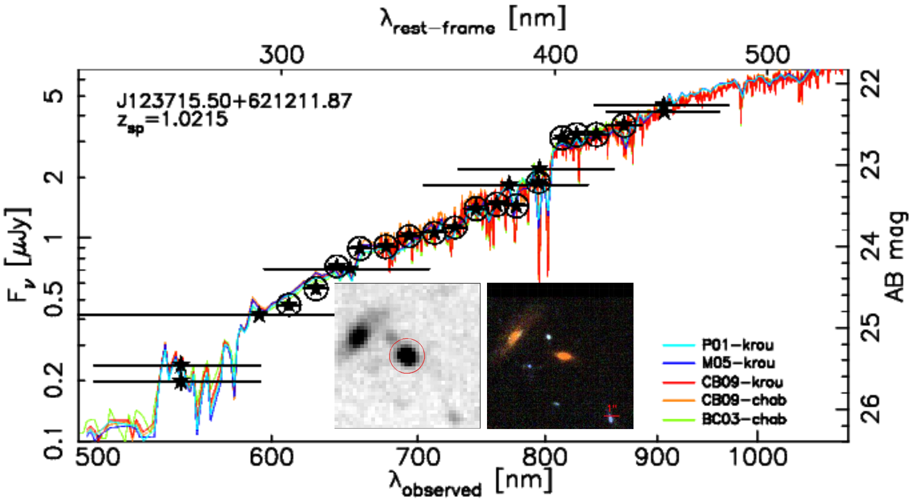


Figure 1: Examples of the stellar population synthesis models carried out on quiescent massive galaxies with spectroscopic redshifts at $z > 1$. We also depict an RGB postage stamp of the source built from HST data, and cutout image of the galaxy in one SHARDS band. The SHARDS spectro-photometric data (plotted with stars surrounded by a circle) and the broad-band data have been fitted to stellar population models from different libraries: BC03 [6], CB09 (Charlot & Bruzual 2009 –2007 models as referred in other papers, but updated in 2009–), M05 [25], and P01 [15].

galaxies through spectro-photometric data with a resolution $R \sim 50$, sufficient to measure absorption indices such as the D(4000) [4, 2, 20, 23] or $\mathrm{Mg}_{UV}$ index [33, 26, 32, 11, 10] . The analysis of these spectral features is a powerful method to constrain the solutions of stellar population synthesis models and to improve our estimations of parameters such as the age, SFH, mass, and extinction of galaxies at cosmological distances.

In this conference contribution, we outline some of our science verification results about absorption systems. Details about the selection and study of emission line galaxies with SHARDS data are given in [8]. We present detailed spectral energy distributions of massive quiescent galaxies at $z > 1$, and demonstrate the power of our spectro-photometric data to analyze the stellar populations in this kind of object through a detailed comparison with stellar population synthesis models.

## 2 Characterizing the SFH of massive quiescent galaxies at $z$>1

The main goal of the SHARDS project is to analyze in detail the stellar populations in massive galaxies at high redshift, especially those that are already evolving passively. The observational strategy of the survey was devised to be able to construct rest-frame UV/optical SEDs for this kind of sources with enough spectral resolution to measure absorption indices correlated with important physical parameters such as the age of the stellar populations.

The main absorption index targeted by SHARDS for high-z passively evolving sources is the Mg index, $Mg_{UV}$. This index probes several absorption lines (e.g., MgI $\lambda$2852, MgII $\lambda\lambda$2796,2804, FeII $\lambda\lambda$2600,2606) and has been shown to be an extremely reliable means to detect quiescent massive galaxies. In addition, the absorption lines can be used to easily distinguish the SED of a quiescent massive galaxy from the featureless spectrum of a dusty starburst [12]. The relative intensity of these absorptions can be measured with the $Mg_{UV}$ spectral index, directly linked to the age of the stellar population [5]. The index is easily and robustly measurable even in low resolution spectra ($R < 100$, [12]). The $Mg_{UV}$ index has been successfully used in the past to obtain redshifts and ages of stellar populations in massive galaxies at high-$z$ [33, 9, 26, 32, 12, 13, 14].

Other interesting absorption features probed by SHARDS (for galaxies at different redshifts) are the Balmer and 4000 Å break, or the Ca HK lines, the G-band, and the $Mg_1$, $Mg_2$ and $TiO_2$ molecular bands (among others). All these have been extensively used to study stellar population ages [7, 34, 35, 2, 24, 17, 21, 16, 18, 22, 23, 31, 27]. The spectral resolution of the SHARDS dataset is adequate for measuring the Balmer or D(4000) breaks with high accuracy. For galaxies with spectroscopic redshifts or very accurate photometric redshift (errors below 1%), we have very similar accuracies to those achieved in standard spectroscopic studies of nearby galaxies and synthesis models, which typically use bands of 10–20 nm around the feature [4]. In the case of the molecular bands, the widths of the SHARDS filters are larger than the amplitude of these absorptions, but, given their strength, they should have a measurable effect on the photometry through filters such as ours. In any case, our filters are narrower (by at least a factor of $\times 2$) than those used by other optical and NIR medium-band surveys (such as MUSYC or NMBS). This allows us to probe these features with higher resolution.

As part of the SHARDS Science Demonstration Phase, we have analyzed the SHARDS data in combination with ancillary observations for a sample of quiescent massive galaxies. The main goal was carrying out the most reliable analysis possible of their stellar population properties. We concentrate our study on $z \sim 1$–2, a critical redshift range in which massive quiescent galaxies assembled a significant fraction of their mass [1, 29, 19, 28, 3]. In this redshift interval, the D(4000) and/or $Mg_{UV}$ absorption features are probed by the SHARDS data.

The galaxy shown in Fig. 1 lies at $z \sim 1$ and our currently available SHARDS data do not cover the $Mg_{UV}$ absorption feature, but it nicely encloses the 4000 Å break region. The stellar population synthesis analysis carried out with different models point out to an age of around 2.5 Gyr and an e-folding time of around 200 Myr, moderate extinction $A(V) \sim 0.3$ mag, and sub-solar metallicity $Z = 0.4 Z_{\odot}$. The accurate constrain of the D(4000) index with our data turns into in a highly confident determination of the stellar population properties, with very similar results obtained with the different models. The same analysis, if carried out with only broad-band data, would be subject to significant uncertainties due to the typical stellar population modeling degeneracies (age-metallicity, age-extinction, etc.).

Indeed, our results demonstrate that including the SHARDS spectro-photometric data in the analysis of the stellar populations in high-$z$ passively evolving galaxies helps to break these degeneracies. When using the SHARDS data, the statistical significance of the best

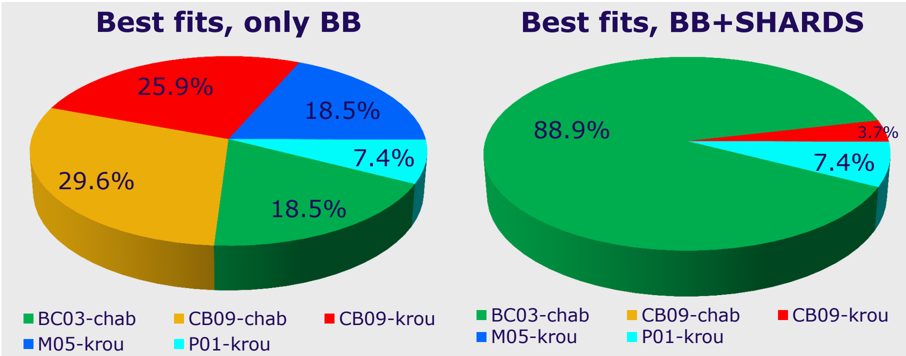


Figure 2: Results of the stellar population synthesis model analysis of the SEDs of massive quiescent galaxies at $z \sim 1$. On the left, we depict a sector diagram showing the fraction of galaxies which are best fitted with a given set of models when only using broad-band data (from the UV to the MIR). The $\chi^2$ values obtained are very similar and no significant statistical differences are found between models, i.e., they all provide very similar results. However, when adding the medium-band SHARDS data (spectral resolution $R \sim 50$ between 600 and 900 nm), the BC03 models provide the best fitting results for 90% of the galaxies. We conclude that BC03 models are the most suited to study the rest-frame UV/optical part (up to ∼400 nm) of the SEDs for our sample. The results may also be interpreted in terms of the difficulties in reproducing the rest-frame NIR emission of galaxies when the UV/optical is very well constrained (in this case, with the SHARDS data), maybe related to uncertainties in the characterization of the emission from stellar phases such as the thermally-pulsating AGB phase.

solution (that with the highest significance) is typically 10–20% larger than when fitting broad-band data alone. Typical values of the statistical significance of the best solution when fitting all available photometry is 75% (i.e., one solution is favored at the 75% probability level). Interestingly, among the different stellar population synthesis libraries used in this paper, BC03 models (with a Chabrier IMF) provide the best fits (the ones with the best reduced $\chi^2$ values) for more than 90% of the sample when fitting SHARDS' and broad-band data. When only fitting broad-band data, all models are (roughly) equally good in reproducing the data. We conclude that BC03 models are the most suited to study the rest-frame UV/optical part (up to ∼400 nm) of the SEDs for our sample (see Fig. 2). We refer the reader to [30] for a detailed description of the modeling procedure and the results, including a discussion of the degeneracies.

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