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Stellar population studies in the incoming J-PAS survey.

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Abstract

Our main goal is to determine the stellar population properties of galaxies from the Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS) in order to perform various galaxy evolution studies up to $z \sim 1$. In our galaxy evolution group at the Instituto de Astrofísica de Andalucía (IAA), we have tested and developed our proper SED-fitting and Artificial Neural Network (ANN) codes to constrain a wide set of stellar population parameters (e.g. age, metallicity, extinction, stellar mass, equivalent widths, etc.) by making use of a preliminary data release referred as mini-JPAS. We obtained consistent results from the ANN and SED-fitting analysis of J-PAS-like galaxies in order to constrain their stellar population properties. In addition, we demonstrated that these results are conducive to exploring the cosmic evolution of the star formation rate (SFR) density, the star formation main sequence, the role of environment for quenching galaxies, the radial variation of the stellar content properties of galaxies in clusters, and the evolution of the luminosity and stellar mass functions since intermediate redshift.

1 Introduction

The state-of-the-art multi-filter surveys (e.g. [13, 14, 1, 3]) present promising advantages over standard spectroscopy for galaxy surveys. For instance, there is not a preliminary selection of galaxies, which is only limited by the depth of the survey that is in turn typically deeper than spectroscopic studies with similar telescopes and observational times. In this regard, the photometric calibration of the spectral energy distribution (SED) of galaxies is typically performed for each individual band, which diminishes the annoying systematic colour terms. In addition, multi-band imaging open the possibility of performing pixel-by-pixel studies of galaxies whose apparent sizes are larger than the point spread function (PSF) of the system. Therefore, these surveys bring us the opportunity to study the stellar content of large samples of galaxies in an alternative way. In fact, during the last years there is an increasing number of studies setting constraints over the stellar content properties of galaxies using this kind of data up to intermediate redshift (see e.g. [5, 6, 7] and references therein). Consequently, these studies offer complementary and very valuable results to the ones obtained by standard spectroscopic data.

The Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS, see [1]) is an ongoing large-scale photometric survey planning to observe 8500 $\deg^2$ of the sky making use of the 2.55m Javalambre Survey Telescope (JST) at the Observatorio Astrofísico de Javalambre (OAJ). J-PAS is an unprecedented multi-filter survey with a unique photometric system that will allow us to observe a huge amount of galaxies since $z \sim 1$ with an equivalent resolving power of $R \sim 60$ in the optical range. This photometric system comprises 54 narrow-band filters with a full width at half maximum of $FWHM \sim 145$ Å (equally spaced every 100 Å), one broad band ($FWHM \sim 495$ Å) and one high-pass filter extending to the UV and near-infrared ends of the optical range, which results in an effective optical range of 3500–9300 Å (further details in [1] and [2]). Prior to the installation of the main camera, since J-PAS is an ongoing survey, there is a first data release dubbed mini-JPAS [2]. This previous survey imaged a stripe of 1 $\deg^2$ in the AEGIS field with the J-PAS photometric system and the JPAS-Pathfinder camera installed in the JST. The mini-JPAS survey is being used by the J-PAS collaboration for testing the potential of the J-PAS survey and the performance of the telescope optical system, as well as performing a first scientific exploitation of the data. As detailed in [2] and [8], the primary mini-JPAS photometric catalogue includes more than 15k galaxies at $z \leq 1$ and is 99 % complete at $r = 23.6$ and $r = 22.7$ for point-like and extended sources, respectively. Owing to the mini-JPAS configuration, the typical error for the photometric redshifts (hereafter photo-z) of galaxies is $\sigma_{\rm NMAD} = 0.013$ with an outlier rate of $\eta = 0.39$ at $r < 23$ [10]. It is also of note that $\sim 5\,200$ galaxies per $\deg^{-2}$ are expected to present an accuracy of $\sigma_{\rm NMAD} = 0.003$ and $\eta = 0.05$.

We aim at exploring the stellar population properties of galaxies in the mini-JPAS survey with the ultimate goal of preparing all the techniques and methodologies for the incoming J-PAS survey to carry out galaxy evolution and formation studies. In the following, we outline part of the stellar population results and work that we are conducting in our galaxy evolution group at the IAA.

2 Determination of the properties of mini-JPAS galaxies

The methodologies that we developed for determining the stellar population properties of the mini-JPAS galaxies are based on SED-fitting codes for the stellar continuum [4, 8] and on Artificial Neural Networks (ANNs) for measuring and detecting emission lines in galaxies [11]. In our group, we are using two SED-fitting codes: an updated version of the MUlti-Filter FITting code for stellar population diagnostics (MUFFIT, [4]) and another one using Bayesian statistics (BaySeAGal, de Amorim et al., in prep). One of the differences between both codes lies in the star formation historiy (SFH) assumed. MUFFIT is based on non-parametric composite stellar population models (mixtures of two simple stellar population models or SSPs) and BaySeAGal adopts a parametric SFH (the so-called delayed-τ model). In addition, MUFFIT includes the full redshift probability distribution function (zPDF) from [10] for each of the mini-JPAS galaxies, whereas BaySeAGal assumes a unique photo-z value, which corresponds to the maximum of the zPDF from [10]. From the SED-fitting analysis, we obtain luminosities (all bands), stellar mass, rest-frame colours, age, metallicity, extinction, etc., along with uncertainties and correlations for each galaxy in mini-JPAS (more details in [8]).

Thanks to the width and configuration of the narrow band filters, J-PAS will be a very competitive survey to identify and characterise emission line galaxies. For this purpose, [11] developed a methodology based on ANN algorithms to detect and measure the equivalent width (EW) of Hα, Hβ, [NII], and [OIII] lines up to $z = 0.35$. Moreover, another ANN was developed to classify mini-JPAS galaxies as emission line or quiescent galaxies. These ANNs were trained with synthetic photometry, which was obtained by convolving galaxy spectra from SDSS, CALIFA, and MaNGA with the J-PAS photometric system (further details in [11]).

3 Stellar population studies in mini-JPAS

Using our SED-fitting results, we performed a first study about the stellar content of mini-JPAS galaxies in [8]. The aim of this study was to check the reliability and consistency of the results to identify and characterise galaxy populations since $z \sim 1$ with real data. After correcting for extinction and following the method detailed in [5], we found consistent results pointing out that galaxies exhibit a bimodal distribution of colours in rest-frame colour diagrams, which is tightly related to their stellar content, with a precision equivalent to that obtained for spectroscopic surveys of similar signal-to-noise ratio (S/N). As a reference and for mini-JPAS galaxies with $S/N > 10$, we expect to constrain the stellar population properties of stellar mass and mass-weighted age with a precision of 0.07 ± 0.03 dex and 0.16 ± 0.07 dex, respectively [8]. Furthermore, we are able to constrain the cosmic evolution of the star formation rate density, $\rho_{\star}$, by the mini-JPAS galaxies at $0.05 \leq z \leq 0.15$ via fossil record methods and our SED-fitting results (see left panel in Fig. 1). All this in good agreement with previous work including spectroscopic data.

Making use of the results obtained from BaySeAGal and the complete and mass-sensitive catalogue of galaxy groups in the J-PAS collaboration (Maturi et al., in prep.), in [9] we studied the role of environment in galaxy evolution up to $z \sim 1$. At increasing stellar mass, the fraction of red and quiescent galaxies also increases, but it is always higher in groups than in the field. Our results point out that the quenching fraction excess (QFE), or the excess of quiescent galaxies in groups with respect to the field, ranges from < 10 % to 60% at stellar masses of 10^{10} and $10^{11.5}$ $M_{\odot}$, respectively. A similar result was found for transition galaxies or galaxies quenching their star formation but in a more modest way. The fraction of field star-forming galaxies that are quenched per unit of time (or galaxy quenching rate, R_i) also depends on redshift (see right panel in Fig. 1 and [9]).

Through the ANN methodology introduced in Sect. 2, we studied the emission line galaxies (ELGs) in mini-JPAS up to $z = 0.35$ in [12], which is the limit to which the Hα line can be observed with the J-PAS filter system. Thanks to this method, we are able to measure the equivalent widths of the Hα, Hβ, [OIII], and [NII] emission lines, as well as the ionization mechanism via BTP and WHAN diagrams. According to these criteria, we identify ~ 1800

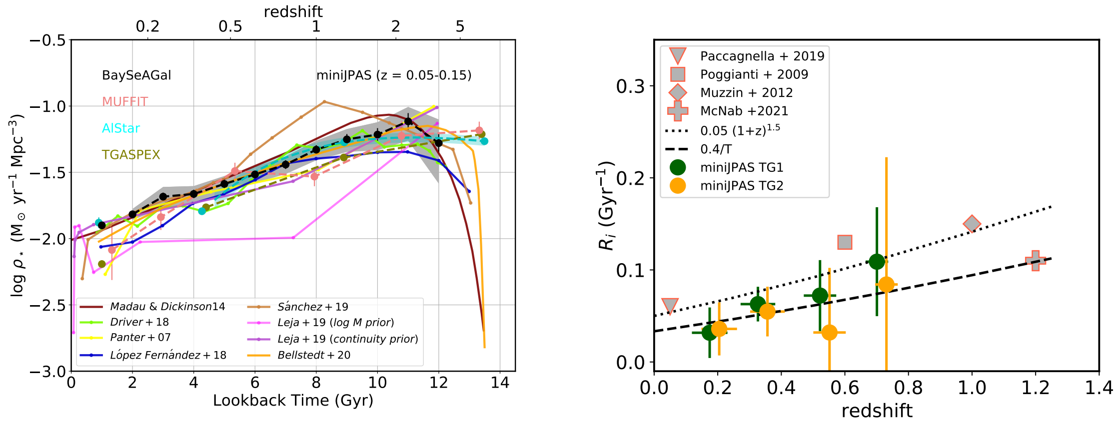

Figure 1: *Left panel*, cosmic evolution of the star formation rate density obtained from mini-JPAS galaxies at $0.05 \leq z \leq 0.15$ with MUFFIT and BaySeAGal (coral and black dots, respectively). *Right panel*, evolution with redshift of the rate of group galaxy quenching for mini-JPAS galaxy groups for two definitions of transition galaxies (green and orange dots). Figures from [8] and [9], respectively.

ELGs up to $z = 0.35$ in mini-JPAS, which are classified as star-forming (SF), active galactic nucleus (Seyfert), and quiescent galaxies (see left panel in Fig. 2). In addition, the SFRs obtained from Hα and Hβ along with the stellar mass obtained via SED-fitting are in agreement with previous studies exploring the star formation main sequence and the cosmic evolution of the SFR density (see right panel in Fig. 2, further details in [12]).

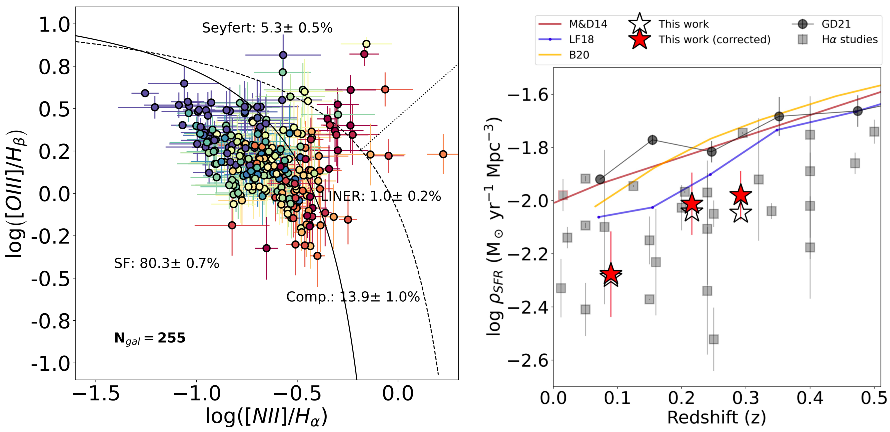

Figure 2: *Left panel*, BPT diagram obtained with the ANNs developed in our group for mini-JPAS galaxies at $z \leq 0.35$ and errors lower than 0.2 dex. Redder colours illustrate more massive galaxies. *Right panel*, evolution with redshift of the star formation rate density obtained from the Hα luminosity using the ANNs (star-shaped markers). Figures from [12].

In a complementary manner, we successfully checked the capability and potential of mini-

JPAS to characterise the stellar population properties of galaxies in clusters (see [15]). In particular, we determined the variation of the stellar population properties of galaxies as a function of the cluster-centric radius in the most massive mini-JPAS galaxy cluster: the mJPC2470-1771 case ($R_{200} \sim 1300$ kpc, $M_{200} \sim 3 \times 10^{14}$ $M_{\odot}$, and $z = 0.29$). For this aim, we used the SED-fitting and ANN results obtained in [8, 12]. In general, the fraction of red galaxies increases in the inner parts of mJPC2470-1771. More precisely, the number of red and blue galaxies within the $0.5 \times R_{200}$ region is roughly the same. We also found that the redder, more metallic and massive galaxies tend to be inside the central part of the cluster, closer to the brightest galaxy of the cluster. On the other hand, blue, less metallic and less massive galaxies are mainly located at distances larger than $0.5 \times R_{200}$ (see Fig. 3). These results suggest that quenching mechanisms are more efficient shutting down the star formation and start at earlier epochs in the inner parts of galaxy clusters.

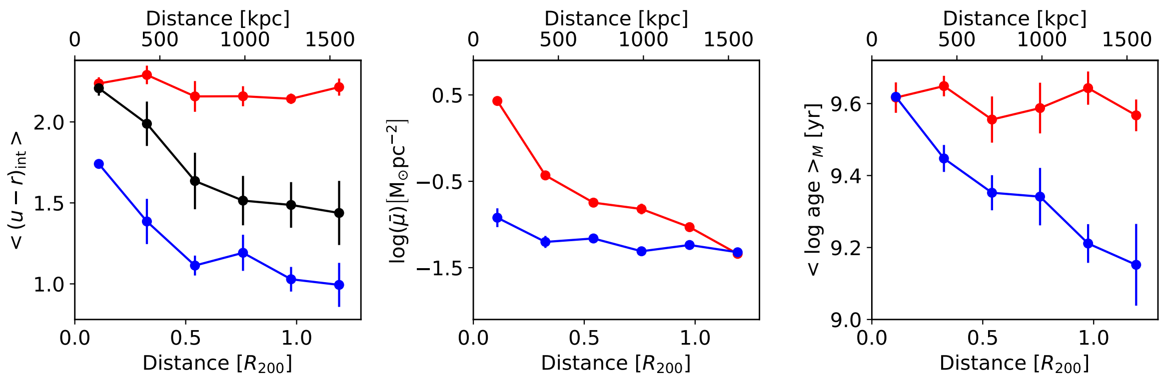

Figure 3: Stellar population properties as a function of the cluster-centric radius in the mini-JPAS galaxy cluster mJPC2470-1771. *From left to right*, $(u - r)$ rest-frame colour corrected for extinction, stellar mass surface density, and mass-weighted age for star-forming and quiescent galaxies (blue and red lines, respectively). Figure from [15].

From the scratch, we developed a statistical methodology to determine the evolution of the parametric stellar mass and luminosity functions of mini-JPAS galaxies up to $z \sim 0.7$ (Díaz-García et al., in prep.). This method is based on a Monte Carlo Markov Chain (MCMC) method involving the probability distribution functions obtained from MUFFIT and will account for all the uncertainties and correlations involved in the analysis, spectral-type, photo-z uncertainties, galaxy-star classification, etc. As a preliminary result, the cosmic evolution of the stellar mass and B-band luminosity densities obtained from the MUFFIT analysis is in good qualitative agreement with previous work in deeper surveys (see Fig. 4).

As a conclusion, we developed a set of methodologies and techniques that have proven to provide reliable stellar population properties of galaxies only using J-PAS-like data. Nowadays, we are ready to perform very promising stellar population studies with the incoming J-PAS survey involving stellar population properties, environment, and emission lines that can be used to carry out galaxy evolution and formation studies in a reliable way up to $z \sim 1$.

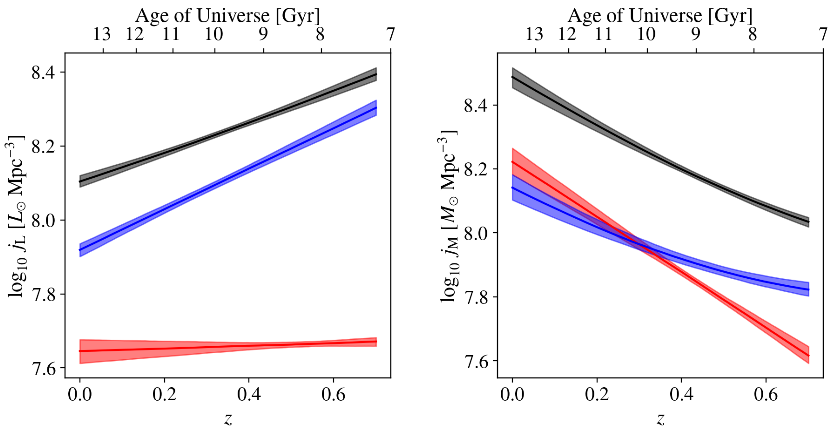

Figure 4: Cosmic evolution of the B-band luminosity and stellar mass densities for quiescent and star-forming mini-JPAS galaxies (red and blue solid lines, respectively). The solid black line illustrates the values for the full galaxy sample.

Acknowledgments

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