The CALIFA survey: Status Report

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Abstract

We present here a brief summary of the status of the on-going CALIFA survey with an emphasis on the results that have been recently published. In particular, we make a summary of the most relevant results found regarding the properties of H II regions discovered using this survey, and the evidence uncovered for an inside-out growth of galaxies.

1   Introduction

The Calar Alto Legacy Integral Field Area (CALIFA) survey [23] is an ongoing large project of the Centro Astronómico Hispano-Alemán at the Calar Alto observatory to obtain spatially resolved spectra for 600 local ($0.005< z <0.03$) galaxies by means of integral field spectroscopy (IFS). CALIFA observations started in June 2010 with the Potsdam Multi Aperture Spectrograph (PMAS), mounted to the 3.5 m telescope, utilizing the large (74" × 64") hexagonal field-of-view (FoV) offered by the PPak fiber bundle [30, 12]. PPak was created for the Disk Mass Survey [2]. Each galaxy is observed using two different setups, an intermediate spectral resolution one (V1200, $R \sim 1650$), that cover the blue range of the optical wavelength range (3700–4700Å), and a low-resolution one (V500, $R \sim 850$, that covers the first octave of the optical wavelength range (3750–7500Å). A diameter-selected sample of 939 galaxies were drawn from the 7th data release of the Sloan Digital Sky Survey (SDSS) which is described

in [32]. From this mother sample the 600 target galaxies are randomly selected, of which we have currently observed 517 objects (December 2014), being near to its conclusion.

Combining the techniques of imaging and spectroscopy through optical IFS provides a more comprehensive view of individual galaxy properties than any traditional survey. CALIFA-like observations were collected during the feasibility studies [16, 31] and the PPak IFS Nearby Galaxy Survey (PINGS, [19]), a predecessor of this survey. First results based on those datasets already explored their information content (e.g., [19, **?**]).

Compared with other IFS surveys, CALIFA offers an unique combination of (i) a sample covering a wide range of morphological types in a wide range of masses, sampling the Color-Magnitude diagram for $M_g > -18$ mag; (ii) a large FoV, that guarantees to cover the entire optical extension of the galaxies up to $2.5\,r_e$ for an 80% of the sample; and (iii) an accurate spatial sampling, with a typical spatial resolution of $\sim 1\,$kpc for the entire sample, which allows to optical spatial resolved spectroscopic properties of most relevant structures in galaxies (spiral arms, bars, buges, Hii regions...). The penalty for a better spatial sampling of the galaxies is the somehow limited number of galaxies in the survey, e.g., MaNGA [4] and SAMI [5]. In terms of the spectral resolution, while in the red both survey have better spectral resolution than CALIFA, in the the blue wavelength range both three have similar resolutions.

As a legacy survey, one of the main goals of the CALIFA collaboration is to grant public access of the fully reduced datacubes. In November 2012 we deliver our 1st Data Release [10], comprising 200 datacubes corresponding to 100 objects [1]. After almost two years, and a major improvement in the data reduction, we present our 2nd Data Release [6], comprising 400 datacubes corresponding to 200 objects [2], the 1st of October 2014.

2 CALIFA: Main Science Results

The data products that can be derived from the IFU datasets obtained by the CALIFA survey comprise information on the stellar populations, ionized gas, mass distribution and stellar and gas kinematics. Similar data products are derived for any of the indicated projects: Atlas3D, MaNGA or SAMI. In summary, they conform a panoramic view of the spatial resolved spectroscopic properties of these galaxies

Different science goals have been already addressed using this information: (i) New techniques have been developed to understand the spatially resolved star formation histories (SFH) of galaxies We found the solid evidence that mass-assembly in the typical galaxies happens from inside-out [18]. The SFH and chemical enrichment of bulges and early-type galaxies are fundamentally related to the total stellar mass, while for disk galaxies it is more related to the local stellar mass density [8, 9]; negative age gradients indicate that the quenching is progressing outward in massive galaxies [8], and age and metallicity gradients suggest that galaxy bars have not alter significantly the SFH of spirals [29]; (ii) We explore the origin of the low intensity, LINER-like, ionized gas in galaxies. These regions are clearly

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[1]`http://califa.caha.es/DR1/`
[2]`http://califa.caha.es/DR2/`

not related to star-formation activity, or to AGN activity. They are most probably related to post-AGB ionization in many cases [17]; (ii) We explore the aperture and resolution effects on the data. CALIFA provides a unique tool to understand the aperture and resolution effects in larger single-fiber (like SDSS) and IFS surveys (like MaNGA, SAMI). We explored the effects of the dilution of the signal in different gas and stellar population properties and proposed an new empirical aperture correction for the SDSS data [11]; (iv) CALIFA is the first IFU survey that allows gas and stellar kinematic studies for all morphologies with enough spectroscopic resolution to study (a) the kinematics of the ionized gas [7], (b) the effects of bars in the kinematics of galaxies [1]; (c) the effects of the interaction stage on the kinematic signatures (Barrera-Ballesteros et al., submitted), (d) measure the Bar Pattern Speeds in late-type galaxies (iv) extend the measurements of the angular momentum of galaxies to previously unexplored ranges of morphology and ellipticity; and (v) finally we explore in detail the effects of galaxy interaction in the enhancement of star-formation rate and the ignition of galactic outflows [33]. The results based focused on the analysis of the H II regions will be discussed in the next Section.

3   Results of our studies of the H II regions

The program to derive the properties of the H II regions was initiated based on the data from the PINGS survey [19]. This survey acquired IFS mosaic data for a dozen of medium size nearby galaxies. In [22] and [20] we studied in detail the ionized gas and H II regions of the largest galaxy in the sample (NGC 628). The main results of this studies are included in the contribution by Rosales-Ortega in the current edition. We then continued the acquisition of IFS data for a larger sample of visually classified face-on spiral galaxies [16], as part of the feasibility studies for the CALIFA survey [23]. The spatially resolved properties of a typical galaxy in this sample, UGC9837, were presented by[31].

In [24] we presented a new method to detect, segregate and extract the main spectroscopic properties of H II regions from IFS data (HIIexplorer). A preliminar catalog of $\sim$2600 H II regions and aggregations extracted from 38 face-on spiral galaxies compiled from the PINGS and CALIFA feasibility studies was presented. We found a new local scaling relation between the stellar mass density and oxygen abundance, the so-called Σ-Z relation [21].

The same catalog allows us explore the galactocentric radial gradient of the oxygen abundance [24]. We confirmed that up to $\sim$2 disk effective radius there is a negative gradient of the oxygen abundance in all the analyzed spiral galaxies. The gradient presents a very similar slope for all the galaxies ($\sim -0.12\,\mathrm{dex}\,r_{\mathrm{e}}^{-1}$), when the radial distances are measured in units of the disk effective radii. Beyond $\sim$2 disk effective radii our data show evidence of a flattening in the abundance, consistent with several other spectroscopic explorations, based mostly on a few objects [3].

In [25] we presented the first results based on the catalog of H II regions extracted from a enlarged sample of galaxies ($\sim$ 100). We studied the dependence of the $\mathcal{M}$-Z relation with the star formation rate. We found that no secondary relation different than the one induced
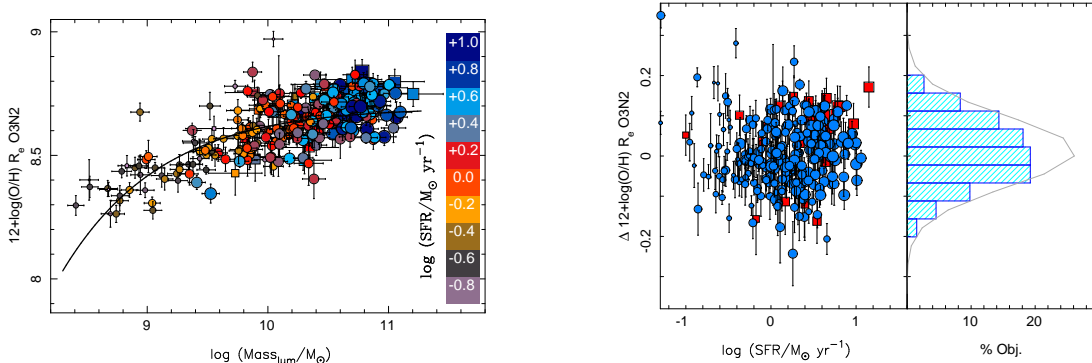
Figure 1: . *Left panel:* Distribution of the oxygen abundances at the effective radii as a function of the integrated stellar masses for the CALIFA galaxies (236, circles), together with those from the CALIFA feasibility studies (31, squares). *Right Panel:* Distribution of the differential oxygen abundances with respect to the solid-line shown in the left-panel (i.e., the dependence on the stellar mass), as a function of the integrated SFR for the CALIFA galaxies.

by the well known relation between the star formation and the mass, contrary to what was claimed other authors [13, 14], based on single aperture spectroscopic data (SDSS). Although the reason for the discrepancy is still not clear, we postulate that simple aperture bias, like the one present in previous datasets, may induce the reported secondary relation. Figure 1 presents an updated version of these results, including the last list of analyzed galaxies, until July 2014 (236 galaxies from the CALIFA sample together with 31 galaxies from the CALIFA-pilot studies). The left panel shows the $\mathcal{M}$-Z relation found for these galaxies, with color code indicating the integrated SFR for each galaxy. It is appreciated that the stronger gradient in SFR is along the stellar mass, as expected for star-forming galaxies. Once subtracted the best fitted function to the $\mathcal{M}$-Z relation, the residual of the abundance do not present any evident secondary relation with the SFR (as it is seen in the right panel). Thus, the results presented in [25] are confirmed with a sample of galaxies enlarged by almost a factor two.

We also confirmed the local Σ-Z relation unveiled by [20], with a larger statistical sample of H II regions (~ 5000). This nebular gas Σ-Z relation is flatter than the one derived for the average stellar populations [9], but both of them agree for the younger stars, as expected if the most recent stars are born from the chmical enriched ISM. In [26], we confirmed that the abundance gradients present a common slope up to ~ 2 effective radii, with a distribution compatible with being produced by random fluctuations, for all galaxies when normalized to the disk effective radius of $\alpha_{O/H} = -0.1\,\mathrm{dex}\,r_{\mathrm{e}}^{-1}$. Finally, in [27], we found evidence that H II regions keep a memory of their past, by analysing the correspondance between the properties of these ionized regions with that of their underlying stellar populations.

4   Conclusions

In summary the results from the CALIFA survey present a coherent picture of the mass-growth and chemical enrichment of galaxies. All the results indicate that the bulk of the galaxy population presents an inside-out growth (at the mass range covered by the survey), with a chemical enrichment dominated by local processes, and limited effects by processes like outflows or radial mixing.

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