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# Studying nearby disk galaxies with the CALIFA survey

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**Abstract.** CALIFA, the Calar Alto Legacy Integral Field Area survey, will provide the largest and most comprehensive wide-field IFU survey of galaxies carried out to date, addressing several fundamental issues in galactic structure and evolution. We will observe a statistically well-defined sample of ∼ 600 galaxies in the local universe using 210 observing nights already awarded with the PMAS/PPAK integral field spectrophotometer, mounted on the Calar Alto 3.5m telescope. The defining science drivers for the project are: a) star formation and chemical history of galaxies, b) the physical state of the interstellar medium, c) stellar and gas kinematics in galaxies, and d) the influence of the AGNs on galaxy evolution. The CALIFA project comprises researchers from a large number of institutions worldwide: 8 institutions in Spain, 4 in Germany (CAHA funding countries) and 11 elsewhere, and includes a total of 56 researchers. CALIFA will provide a valuable bridge between large single-aperture surveys such as SDSS and more detailed studies of individual galaxies with PPAK (e.g. PINGS), SAURON, VIRUS-P, and other instruments.

**Key words.** Survey – galaxies: abundances – galaxies: kinematics and dynamics – galaxies: star cluster – galaxies: individual (NGC 5668) – techniques: spectroscopy – techniques: survey

## 1. Introduction

The Calar Alto Large Integral Field Area Survey (CALIFA) aims at observing a statistically well-defined sample of ∼ 600 galaxies in the local universe with the PMAS/PPAK integral field spectrophotometer, mounted on the Calar Alto 3.5 m telescope. The CALIFA survey will provide the largest and most comprehensive wide-field IFU survey of galaxies carried out to date, addressing several fundamental issues in galactic structure and evolution. PMAS/PPAK is one of the few IFUs in the world with the required field-of-view and spectral coverage to study the main spectral features in the optical range with a single setup and with enough spectral resolution to achieve the science goals outlined in Section 3. The PPAK mode provides one of the largest field-of-view of an IFU in the world (>1 arcmin$^2$; only matched by VIRUS-P but with a better spatial sampling), with a high filling factor in one single pointing (65%), and good spectral resolution and sensitivity across the optical spectrum. In order to increase the spatial sampling (and to some extent also resolution), and to achieve a covering factor of 100% a three-point dithering scheme will be applied (Sánchez, Cardiel, Verheijen et al. 2007). The PPAK fiber bundle comprises a hexagonal array of 331 (science-fibers) densely packed optical fibers for the object, 36 fibers for the sky, distributed in 6 bundles located following a circular distribution at about 90″ of the center and at the edge of the central hexagon and 15 fibers for calibration purposes with 2.68″ per fiber diameter. The spectral range covered by CALIFA is 3700-7000 Å, obtained in two overlapping setups, one in the blue, the grating V1200 (3700-4700Å) with 3 exposures per pointing of 600s and one in the red V500 (4525-6922Å) with a single exposure per pointing of 900s, both unvignetted. The spectral resolutions in the blue and red are R$\sim$1650 and R$\sim$850, respectively, quoted at the overlapping wavelength range ($\lambda\sim$4500Å). This allows an unprecedented possibility to study simultaneously emission- and absorption-line mapping of galaxies. Data reduction was carried out using R3D (Sánchez et al. 2006), in a combination with E3D (Sánchez et al. 2004). The reduction is the standard one for fiber-fed integral-field spectroscopic observations and includes the bias subtraction, cosmic ray rejection, and extraction of the individual spectra. The extracted flux was stored in a row-stacked-spectrum file RSS (Sánchez et al. 2004) and wavelength calibrated. They were combined into a single RSS file scaling first the fluxes following an iterative procedure as explained in Sánchez et al. (2010). The fully reduced and flux calibrated data of this legacy survey will be made available to the public through the CALIFA web page[1]. For detailed information about the CALIFA survey and data reduction (see Sánchez et al. 2010).

## 2. Sample Selection

The CALIFA sample (600 objects) has been selected from the photometric catalog of the SDSS DR7 as a sample limited in apparent isophotal diameter (45″ < $D_{25}$ < 80″). An additional restriction is the covered redshift range (0.005< $z$ <0.03). The limits are driven by (1) covering entire galaxies in one single PPAK field and (2) having a large enough volume to include objects covering a wide range of luminosities and colors and in large numbers for a proper statistical analysis, but at the same time (3) having all spectral features of interest covered with the same grating settings. This parent sample covers a substantial fraction of the galaxy luminosity function at this redshift, with a shape similar to the one that would be obtained with a volume-limited sample (except for its very faint end). The color-magnitude space is also well covered and well-sampled with enough galaxies to perform proper statistical analysis. We will cover a range of $\sim$7 mag in luminosity and $\sim$2 mag in color, with about $\sim$40 objects in each box of 1×0.5 mag. We estimate that there are over 200 early-type galaxies in our sample. On the other hand, 2/3 of the galaxies in the CALIFA sample are disk-dominated, as shown in Figure 1. The sample is dominated by field galaxies, but will effectively include galaxy populations in groups, low-density clusters, and even dense environments such as the Coma cluster which is partially covered by the CALIFA footprint and redshift range, so we expect to have a sample that is representative of the galaxy population in the near universe (except for the case of very low-luminosity systems). With CALIFA we aim to establish the local anchor point of any future study of the cosmological evolution of galaxies to be focused on 3D spectroscopy (see Förster Schreiber et al. (2009) for some early studies in this regard).

## 3. Science Drivers

One of the most fundamental astrophysical problem is to understand the origin of the observed diversity of galaxies, and the physical intrinsic and environmental mechanisms that

[1] CALIFA Survey Official Webpage: `http://www.caha.es/sanchez/legacy/oa/`

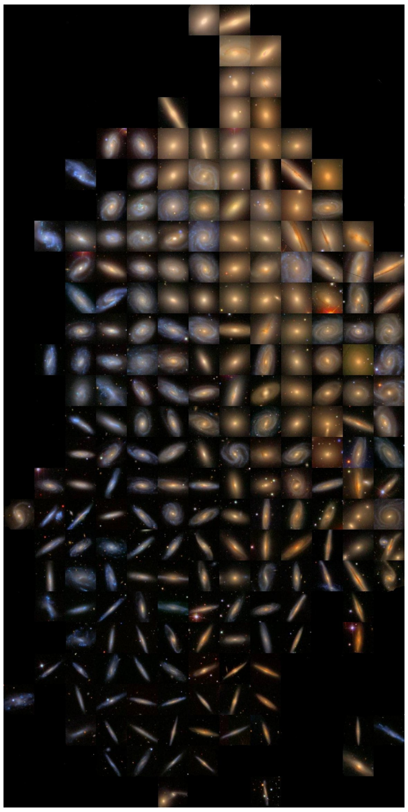

**Fig. 1.** SDSS images of a set of the CALIFA survey. The galaxies are sorted by color (from blue galaxies at left to red ones at right) and by *g* magnitude (the brightest ones at top).

are responsible for the differences as well as similarities between them. Detailed studies of nearby galaxies can help by revealing structural properties that can be interpreted as fossil records of the formation and evolution process. An old but still unanswered question is the problem of "nature vs. nurture", i.e. the relative importance of environmental processes such as merging and accretion, relative to intrinsic secular processes that inevitably occur in an evolving complex dynamical system. A more recently posed puzzle is the bimodality of the galaxy population: Why tend galaxies to be either red and dead or blue and star forming, and in particular: What happens to galaxies in the intermediate *green valley* of the color-magnitude diagram? The CALIFA survey will be of critical importance to come closer to answering these questions.

## 4. Current Status

In April 2009 a total of 15 nights of Director's Discretionary Time (DDT) were allocated for a pilot study that should ensure that the time estimates and observing strategy proposed for CALIFA were appropriate. During those nights we used the V300 grating, and a three-dithering observing strategy. A total of 24 objects were observed and for 21 of them we could complete the observations. A pilot version of the fully automatic reduction procedure was implemented and tested on these data. In October 2009, the new CCD was installed. Despite the fact the new CCD is roughly twice larger in the spectral direction the spectral coverage is not increased by the same amount due to vignetting. The vignetting affects ~15% of the pixels where the degradation of the transmission ranges between 15% and 100%. This effectively decreases the wavelength range for a given setup. However, the use two instrumental setups guarantees that the proposed wavelength range is free of vignetting.
A total of 7 nights were allocated to perform extensive tests with the new data configuration. In total, 48 objects were observed in 13 nights (accounting for both clear and cloudy nights). The reduction pipeline was adapted to the new CCD, taking into account its new instrumental features (as well significant optical vignetting is present in the data), and it is now completely automatized for this new configuration. The pilot sample will be presented in Mármol-Queraltó et al. 2010 and in Viironen et al. 2010. In July 2010 were started regular CALIFA observations with the two set-up (V500 and V1200) and actually we have completed data for 21 galaxies.

## 5. Our inmediate Science Goals and pre-CALIFA studies

Even before the pilot program for CALIFA was carried out some of the members of the CALIFA team took some test observations to analyze the feasibility of a larger program. One of these test included the observation of the nearby disk galaxy NGC 5668 that we describe below. The formation and evolution of galaxy disks is a complex process as many are the mechanisms that might alter their photometric, chemical, and kinematical properties. Our group at the Universidad Complutense de Madrid (UCM) is interested in the study of the stellar population and metallicity gradients of the CALIFA disk galaxies in order to understand the mechanism governing the evolution of disks and, in particular, the study of the growth of disks and the roles of gas infall and stellar migration on this growth. In this regard, the few studies on the chemical composition of HII regions (that trace the sites of massive SF) at large galactocentric distances suggest that the extended disks are relatively unenvolved systems ($Z \sim Z_{\odot}/10$) (Gil de Paz et al. 2007). Our aim is to determine metal abundances at different radii using either direct or strong-line methods in order to establish the chemical evolution of disks as a function of galaxy mass and environment. We are working on a subsample of disk-galaxies that was observed with the PPAK IFU (V300 grating). In this context we first investigated the properties of individual HII regions within the nearby spiral galaxy NGC 5668. The main results that we find are that while the inner disk the O/H ratio follows the radial gradient known from previous investigations, $12 + log(O/H)_{r=0} = 8.9$ and a gradient value of $0.140 \pm 0.016$ (dex/kpc), the outer abundance profile flattens out beyond a radius of $35.8''$ ($\sim 260$ kpc) to an approximately constant value of $12 + log(O/H)_{r=0} = 8.27$ and even reverses Marino et al. 2010, which might be interpreted in the context of the effects of stellar migration or it could imply different star formation histories between the inner and outer parts of the disk of this galaxy (Bresolin et al. 2009). We plan to extend this type of analysis to all disk-galaxies in the CALIFA sample for a better understanding of the process that drive the evolution of this type of galaxies.

## 6. Conclusions

CALIFA will provide integral field spectroscopy for a sample of $\sim$ 600 galaxies in the Local Universe ($0.005 < z < 0.03$) with a spectral resolution R $\sim$ 800-1700 in the entire optical range between 3700 and 7000 Å. The CALIFA survey will address several fundamental issues in galactic structure and evolution where only integral field spectroscopy provides an unbiased, not pre-selected, spectroscopic coverage, which has been demonstrated to be superior to characterize the spectroscopic properties of the objects under study (e.g., the SAURON survey, PINGS Survey, Rosales-Ortega et al. (2010), Sánchez et al. (2010a)). Our interest in the CALIFA survey is study the stellar populations and chemical abundances throughout disks in order to understand the mechanisms that drive the evolution of disk galaxies (gas infall, stellar migration, etc.).

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