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A comprehensive study of the spatially-resolved SFR in nearby disk galaxies using CALIFA IFS data

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Abstract

A detailed analysis of the Star Formation Rate (SFR) distribution in nearby galaxies is essential to understand the mechanisms that drive the formation and evolution of galaxies. Although measurements of the integrated SFR in galaxies as a whole are also required to fulfill this goal, we focus here on the relative contribution of the SFR in the different components that shape galaxies (bulges, bars and disks). With this aim in mind, we combine for the first time in a large sample of nearby galaxies from the CALIFA survey, 2D multicomponent photometric decomposition with Integral Field Spectroscopy (IFS) data to enable measurements of the SFR in the different galaxy components. We find that not only more massive galaxies are being quenched more efficiently but also more massive disks tend to exhibit lower SFRs for a fixed value of their disk stellar masses in the SFR-$M_\star$ plane. We show that type-2 AGN host galaxies are mostly found in galaxies with the higher values of their stellar masses and that they contribute to decrease the specific SFR for bulges and disks, being this effect more important for the case of the bulges.

1 Introduction

Exploring the spatial distribution of the star formation rate (SFR) in nearby galaxies is crucial to have a better understanding of their evolution through cosmic time. Unresolved questions about quenching and enhancement of the SF arise at different spatial scales and in different regions throughout galaxies. Quantifying how these mechanisms compete as a function of different galaxy properties is utterly important. In order to shed some light on these processes we aim to quantify the distribution of the SFR in the different components of the galaxies such as bulges, bars and disks. For this purpose, we take advantage of the CALIFA Integral

Field Spectroscopy (IFS) data combined with 2D photometric decomposition that enables us to estimate the SFR in each photometric component. That way we can identify the mechanisms that regulate star formation in galaxies (e. g. AGN, environment) as they should act differently on the SFR of each of these components.

2 Sample selection

In order to perform this study we make use of a subset of 227 galaxies from the CALIFA survey [4]. These galaxies have been observed with the V500 grating and are part of the Data Release 3 (DR3) [5]. Additional criteria imposed to the original sample in order to be elegible for the 2D photometric decomposition are the following: (1) they should not be forming a pair, an interacting system or show heavily distorted morphology and (2) their inclination should not be very high to avoid projection effects that might affect the results (typically i < 70 deg). Finally, we also imposed a S/N > 5 criteria in the Hα and Hβ emission lines in the spectrum of each galaxy component.

3 Analysis: Two-dimensional multi-component photometric decomposition and extinction-corrected Hα SFR measurements

We aim to study the distribution of the H$\alpha-$based SFR in the different morphological components of our galaxies: bulges, bars and disks (truncated or not). This will help to clarify how the internal and external parts of the galaxies grow in mass due to in-situ star formation. For that purpose, a 2D multicomponent decomposition analysis is necessary. We used the recently derived CALIFA by-products in Méndez-Abreu et al. (2016) [3] to properly recover the structural parameters of our galaxies. In this study, g, r and i SDSS images are used to derived these parameters. For our study, we use the g-band as it is the best compromise between showing a smooth light distribution (i. e. can be fitted by simple analytical functions) and tracing the distribution of relatively young stellar populations. In any case, g-band is only used to generate weight maps for each stellar component (i. e. the ratio between the light in each galaxy component and the total luminosity of the galaxy). Then, these weight maps are applied to the CALIFA datacubes to generate a 3D datacube for each galaxy component (bulge, bar and disk). To finish the process, the integrated spectrum for each stellar component is obtained using the previous weighted-datacubes. This means that the actual SFR is measured using the extinction-corrected Hα over the derived spectra.

Along this work we use absorption- and extinction-corrected Hα luminosity as our SFR reference indicator. In a previous work (see [1] for more details), we justified the use of this tracer and verified that our measurements successfully reproduce the values derived from different SFR tracers (single-band and hybrids) in a representative sample of 272 CALIFA galaxies. We follow the same method here to compute the extinction-corrected Hα emission, this time for the integrated spectrum derived from the weighted-datacube associated with

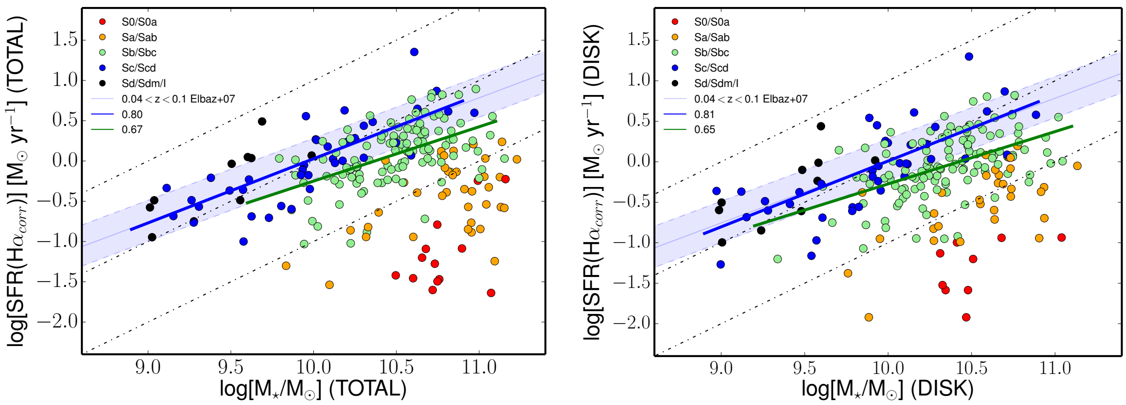

Figure 1: Left panel: Distribution of the integrated galaxies in the SFR-$M_\star$ plane showing in blue band the position of the Main Sequence (MS) using the fitting by Elbaz et al. (2007) [2]. Galaxies appear color-coded as a function of their morphological type. Blue line is the best fit for Sc/Scd and Sd/Sdm galaxies while the green one is for Sb/Sbc objects. Right panel: Color-coded and symbols are the same as in the left-hand panel but this time for the disk component of the galaxies only.

each morphological component. Thus, we refer the reader to [1] for an extensive explanation on the derivation of the SFR values.

4 Results: a deep look into the star-forming Main Sequence of galaxies by galaxy components

The importance of the well-known Main Sequence (MS) of galaxies, i.e., the correlation between the SFRs and their corresponding stellar masses[1], has been broadly discussed in the literature [2]. Nevertheless, how the different structural components of the galaxies are placed in this diagram is still an open question. We aim here to explore whether there is or not a significant difference between the MS of galaxies as a whole in comparison with their star-forming disks. This will help to understand whether the disks of galaxies that are quenched (i. e. are found away from the MS) still populate the MS. Left-hand panel in Figure 1 shows the distribution of the galaxies as a whole in the SFR-$M_\star$ plane. For the sake of clarity, we include here the fitting by Elbaz et al. (2007) [2] that shows the region of the diagram where local SF galaxies are commonly placed. The morphological type is also used for the representation. We find that S0/S0a, Sa/Sab and some Sb/Sbc galaxies are comparatively less efficient at forming stars at the present time than most late-type galaxies, meaning that for the same stellar mass the former objects are placed outside the MS. Some authors suggest

[1] CALIFA total stellar masses were calculated by Walcher et al. (2014) [7] using UV to NIR SEDs while stellar masses for each component have been derived using *(g - i)* color-dependent *i*-band mass-to-light relation (as in [6]).

that a turnover is present in the MS. We explore this possibility here by dividing our sample into two groups, Sb/Sbc objects (green line) and Sc/Scd together with Sd/Sdm galaxies (blue line). It can be seen from the left panel in Figure 1 that Sc/Scd and Sd/Sdm objects exhibit a stepper slope in comparison with Sb/Sbc galaxies.

We can now also explore whether this is due to the increasing contribution of the bulges or to a decrease in the SFR in the disks themselves. The distribution of what we have called the 'Disks MS' (the relation between the SFR in the disk component and the stellar mass of the disk) appears in the right-hand panel in Figure 1. It can be seen from this figure that also more massive disks (which belong to early-type spirals in most cases) appear outside the MS as well.

5 Results: specific SFR by galaxy components

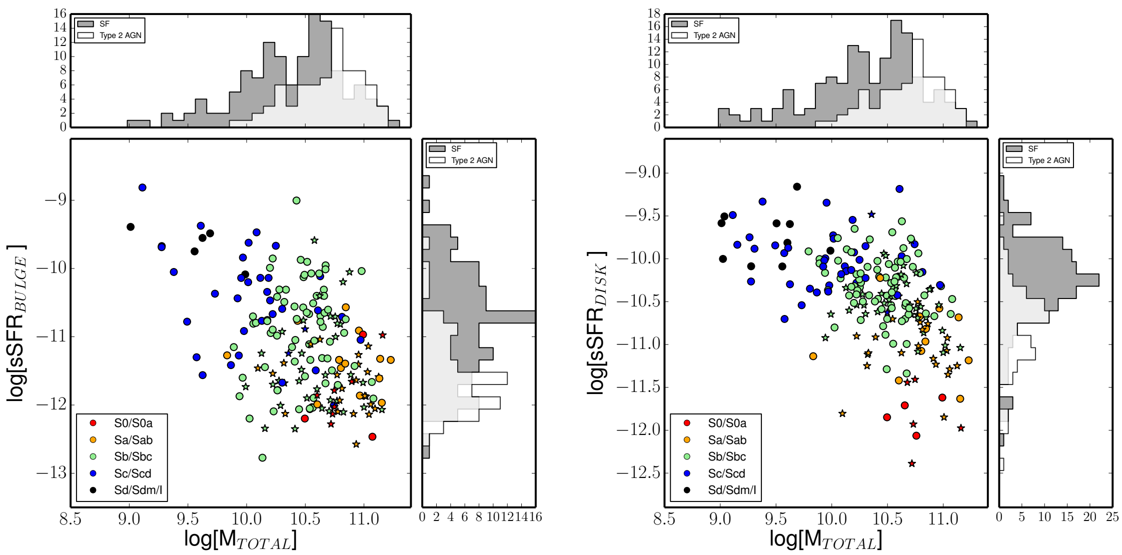

Figure 2: Left panel: sSFR for the bulge component as a function of the total stellar mass. Purely star-forming (SF) galaxies are represented by circles while galaxies that show nuclear activity (type-2 AGN) are represented by stars. Galaxies are also color-coded by their morphological type. Right panel: same description as the previous panel this time for the sSFR of the disk component.

We have explored in the previous section the role of the stellar mass in the quenching of their disks. It is also interesting to know how the specific star formation rate (sSFR = SFR/$M_\star$) of the different stellar components correlate with their corresponding stellar masses.

Figure 2 shows the sSFR of both bulges (left-hand panel) and disks (right-hand panel) as a function of the total stellar mass for each of the previous components. Galaxies appeared color-coded by their morphological type. It can be seen from this figure that at low-to-intermediate masses sSFR(bulge) declines with the stellar mass in a more pronounced way than disks do. Thus, sSFR(disk) need to reach a certain stellar mass, typically around $10^{10.5}$ $M_\odot$, to show a stepper decrease in the sSFR.

We also explore the possibility of type-2 AGNs (star symbols in Figure 2) being responsible for the quenching of the SF in both components, bulges and disks. The majority of type-2 AGN hosted galaxies show greater stellar masses and lower values of their sSFR, even for the same stellar mass. This point out to an scenario where the AGN is affecting not only its surroundings but also it has an impact in the quenching of the external parts of the galaxies, i. e. the disk component.

6 Conclusions

In this work we make use of 227 galaxies that come from the CALIFA survey to better understand the distribution of the SFR in the different morphological components of the galaxies (bulges, bars and disks) and how the inner and outer regions of galaxies grow in mass due to in-situ star formation. With this aim in mind, we apply a 2D decomposition of multi-band photometry on IFU spectral datacubes.

The main results derived from this study can be summarized in the following points:

- More massive disks are placed outside the MS pointing to the fact that these objects have been more efficiently quenched than less massive disks.
- Type-2 AGN host galaxies are mostly found in the more massive systems of our sample with stellar masses typically between [10^{10} - $10^{11.5}$] $M_\odot$.
- The sSFR of bulges and disks decreases when a type-2 AGN is present, being this effect more pronounced for the bulge component.
- The sSFR-$M_\star$ plane shows that the sSFR of the bulges declines with their stellar mass while the decrease of the sSFR of the disk component is more significant beyond $10^{10.5}$ $M_\odot$.

More details about the role that other parameters such as environment or the kinematics of galaxies will appear in a forthcoming paper (Catalán-Torrecilla et al., in prep.)

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