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# Kinematic scaling relations of CALIFA galaxies: A dynamical mass proxy for galaxies across the Hubble sequence

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## ABSTRACT

We used ionized gas and stellar kinematics for 667 spatially resolved galaxies publicly available from the Calar Alto Legacy Integral Field Area survey (CALIFA) third Data Release with the aim of studying kinematic scaling relations as the Tully & Fisher (TF) relation using rotation velocity,  $V_{rot}$ , the Faber & Jackson (FJ) relation using velocity dispersion,  $\sigma$ , and also a combination of  $V_{rot}$  and  $\sigma$  through the  $S_K$  parameter defined as  $S_K^2 = K V_{rot}^2 + \sigma^2$  with constant  $K$ . Late-type and early-type galaxies reproduce the TF and FJ relations. Some early-type galaxies also follow the TF relation and some late-type galaxies the FJ relation, but always with larger scatter. On the contrary, when we use the  $S_K$  parameter, all galaxies, regardless of the morphological type, lie on the same scaling relation, showing a tight correlation with the total stellar mass,  $M_*$ . Indeed, we find that the scatter in this relation is smaller or equal to that of the TF and FJ relations. We explore different values of the  $K$  parameter without significant differences (slope and scatter) in our final results with respect to the case  $K = 0.5$  besides a small change in the zero-point. We calibrate the kinematic  $S_K^2$  dynamical mass proxy in order to make it consistent with sophisticated published dynamical models within 0.15 dex. We show that the  $S_K$  proxy is able to reproduce the relation between the dynamical mass and the stellar mass in the inner regions of galaxies. Our result may be useful in order to produce fast estimations of the central dynamical mass in galaxies and to study correlations in large galaxy surveys.

**Key words:** galaxies: evolution – galaxies: fundamental parameters – galaxies: kinematics and dynamics.

## 1 INTRODUCTION

Galaxy scaling relations describe trends that are observed between different properties of galaxies. They are assumed to be the consequence of their formation and evolution. Probably the kinematic scaling relation most widely studied for spiral galaxies is the Tully–Fisher relation (hereafter TF) – a correlation between luminosity and rotational velocity, first reported by Tully & Fisher (1977). It was originally established as a tool to measure distances to spiral galaxies (Giovanelli et al. 1997). It has been suggested that the slope, zero-point, and tightness may have a cosmological origin

helping us to understand the formation and evolution of galaxies (Cole et al. 1994; Eisenstein & Loeb 1996; Avila-Reese, Firmani & Hernández 1998; Mo, Mao & White 1998; Courteau & Rix 1999; Firmani & Avila-Reese 2000; Navarro & Steinmetz 2000). In the local universe the TF relation is very tight (Verheijen 2001; Bekeraïté et al. 2016; Ponomareva et al. 2017), locating galaxies with rising rotation curves on the low-velocity end and galaxies with declining rotation curve on the high-velocity end (Persic, Salucci & Stel 1996). The luminosity-based TF is more directly accessible, however, the amount of light measured from the stellar population is a function of passband, and therefore different TF relations emerge when observing galaxies at different wavelengths. A physically more fundamental approach instead of luminosity is based on stellar mass,  $M_*$ . The resulting TF relation is well approximated

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by a single power law with small scatter at least for disc galaxies more massive than  $\sim 10^{9.5} M_{\odot}$  (McGaugh et al. 2000; Bell & de Jong 2001; Avila-Reese et al. 2008). A similar correlation between the luminosity (or the stellar mass) of elliptical galaxies and the velocity dispersion in their central regions was established by Faber & Jackson (1976) (hereafter FJ). The shape and scatter of the FJ relation has been less frequently studied because its large residuals show a significant correlation with galaxy size, i.e. a third parameter within the so called fundamental plane (Djorgovski & Davis 1987; Dressler et al. 1987; Cappellari et al. 2013; Desmond & Wechsler 2017).

It is presumed that galaxy internal kinematics as tracer of the gravitational potential provide the dynamical mass. If spiral and elliptical galaxies were completely dominated by rotation velocity and velocity dispersion, respectively, the TF and FJ relations would provide insights into the connection between galaxies and their dark matter content. However, structural properties, environmental effects, or internal physical processes perturb the kinematics of late-type galaxies producing non-circular motions that under/overestimates the circular velocity (Valenzuela et al. 2007; Holmes et al. 2015; Randriamampandry et al. 2015). On the other hand, elliptical galaxies, although dominated by velocity dispersion, often present some degree of rotation (Lorenzi, Debattista & Gerhard 2006; Emsellem et al. 2007; Cappellari et al. 2011; Emsellem et al. 2011; Rong et al. 2018). Non-circular motions on disc galaxies and rotation on ellipticals may contribute to miss a fraction of the gravitational potential, modifying the scaling relations and precluding them from being directly comparable to theoretical predictions.

Weiner et al. (2006) introduced a new kinematic parameter involving a combination of rotation velocity and velocity dispersion in order to study high-redshift galaxies, where in some cases random motions were not negligible. Weiner et al. (2006) showed that such parameter provides a better proxy to the integrated line-width of galaxies emission lines than rotation velocity or velocity dispersion alone, regardless of the galaxy morphology. The parameter is defined as:

$$S_K^2 = K V_{rot}^2 + \sigma^2, \quad (1)$$

where  $V_{rot}$  is the rotation velocity,  $\sigma$  is the velocity dispersion, and  $K$  a constant that could be extremely complicated function of the formation history, dynamic state, and environment of galaxies. Kassin et al. (2007) found that by adopting a value of  $K = 0.5$ , the  $S_{0.5}$  parameter presents a tight correlation with the stellar mass for a sample of galaxies at redshift  $z \leq 1.2$  extracted from the All Wavelength Extended Groth Strip International Survey and the Deep Extragalactic Evolutionary Probe 2. This correlation seems to be independent of the morphological type. Other analyses, focused on the evolution of the TF relation at high redshift ( $z \sim 2$ ), explored the  $M_{*}-S_{0.5}$  relation confirming that turbulent motions might play an important dynamical role (Cresci et al. 2009; Gnerucci et al. 2011; Vergani et al. 2012; Price et al. 2016; Christensen & Hjorth 2017). Zaritsky, Zabludoff & Gonzalez (2008) provided a possible explanation of the  $M_{*}-S_{0.5}$  relation as a virial one, including all galaxy evolution, geometrical and dynamical complications into the  $K$  coefficient.

Cortese et al. (2014) (hereafter C14) performed the only systematic study of this relation at low redshift ( $z \leq 0.095$ ). They used the stellar and ionized gas kinematics integrated within one effective radius,  $r_e$ , for galaxies observed with the Sydney-AAO Multi-object Integral Field survey (SAMI, Croom et al. 2012). C14 confirmed that all galaxies, regardless of the morphological type, lie on the same kinematic scaling relation  $M_{*}-S_{0.5}$  with a significant

improvement compared with the TF and FJ relations. Although the result is encouraging, the spatial covering of the observations ( $1r_e$ ) and the coarse spatial resolution of the data may contribute to the uncertainties in a similar way as they do it in HI line-width TF estimations (Ponomareva et al. 2017). Therefore, it is needed to repeat this analysis using data with better spatial resolutions and coverage.

The aim of this paper is to explore and calibrate the TF, FJ, and  $S_K$  scaling relations in the local universe for galaxies from the Calar Alto Legacy Integral Field Area survey (CALIFA, Sánchez et al. 2012). These data present a larger spatial coverage and better physical resolution (Sánchez et al. 2016c).<sup>1</sup> In a recent study, Gilhuly et al. (in preparation), presented an exploratory study of these relations for a limited sample of galaxies. They perform a systematic and detailed analysis of the limitations of the kinematics parameters, and in particular the velocity dispersion in the CALIFA data set. The current study would explore a larger sample, being focused on the nature of these scaling relations.

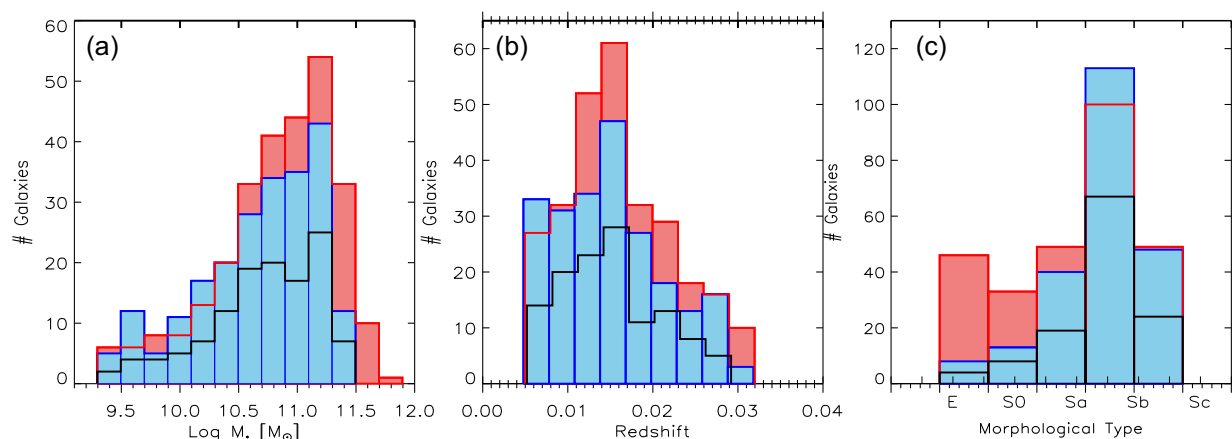
The structure of this article is as follows. In Section 2 we briefly describe the CALIFA sample, including a summary of the delivered data sets. Details of the analysis performed over the data are presented in Section 3.1. In Section 3.2 we estimate the kinematics parameters within  $1r_e$ , following the same methodology as C14. In Section 3.3 we perform a detailed modelling of the 2D spatially resolved velocity maps for a subsample of good quality data sets. With this modelling we estimate the possible effects of aperture and non-circular motions in disc galaxies and obtain a more precise derivation of the maximum rotational velocity,  $V_{max}$ . In Section 4, we present the main results of this study. In Section 5, we discuss the results and their physical implications and finally we summarize the main conclusions in Section 6.

## 2 DATA SAMPLE

We use the data provided by the CALIFA survey (Sánchez et al. 2012) that has delivered publicly available integral field spectroscopy data for 667 galaxies (Sánchez et al. 2016c), although the current samples comprises more than 700 galaxies (Sánchez et al. 2017). Details of the observational strategy and data reduction are explained in these two articles. All galaxies were observed using PMAS (Roth et al. 2005) in the pPaK configuration (Kelz et al. 2006), covering a hexagonal field of view (FoV) of  $74 \text{ arcsec} \times 64 \text{ arcsec}$  that is sufficient to map the full optical extension of most of the galaxies up to two to three effective radii. This is possible due to the diameter selection of the CALIFA sample (Walcher et al. 2014). The final observed sample comprises galaxies of any morphological type (See Fig. 1). It covers, with a good sampling, the colour-magnitude diagram and the stellar mass distributions of the Local Universe in a representative and statistically significant way for galaxies more massive than  $10^{9.5} M_{\odot}$  (Walcher et al. 2014; Sánchez et al. 2016c).

The observing strategy guarantees a complete coverage of the FoV, with a final spatial resolution of Full Width at Half Maximum (FWHM)  $\sim 2.5 \text{ arcsec}$ , corresponding to  $\sim 1 \text{ kpc}$  at the average redshift of the survey (García-Benito et al. 2015; Sánchez et al. 2016c). CALIFA observed the galaxies in two configurations: (i) the V500 setup, a low-resolution mode that covers a wavelength range between 3745 and 7500 Å, with a resolution of  $\lambda/\Delta\lambda \sim 850$

<sup>1</sup>Both surveys present a similar projected PSF FWHM of  $\sim 2.5 \text{ arcsec}$ . However CALIFA sample galaxies observed in a considerable lower redshift and narrower redshift range.



**Figure 1.** Galaxy Sample distributions in (a) total stellar masses, (b) redshift, and (c) morphological type. The blue and red histograms indicate galaxies with ionized gas and stellar kinematics, respectively, whereas the unfilled black histogram indicate galaxies with both, ionized gas and stellar kinematics.

(FWHM  $\sim 6 \text{ \AA}$ ), and (ii) the V1200 setup, an intermediate resolution mode, that covers the wavelength range between 3700 and 4800  $\text{\AA}$ , with a resolution of  $\lambda/\Delta\lambda \sim 1650$  (FWHM  $\sim 2.7 \text{ \AA}$ ). The delivered data set was reduced using version 2.2 of the CALIFA pipeline, whose modifications with respect to the previous ones (Sánchez et al. 2012; Husemann et al. 2013; García-Benito et al. 2015) are described in Sánchez et al. (2016c). The final data-product of the reduction is a data-cube comprising the spatial information in the  $x$ - and  $y$ -axis, and the spectral one in the  $z$  one. For further details of the adopted data format and the quality of the data consult Sánchez et al. (2016c).

### 3 ANALYSIS

We describe here the analysis performed to estimate the stellar mass distribution and the kinematics parameters for the different galaxies included in the current data set.

#### 3.1 Spectroscopic analysis

In this paper, we use the data-products (ionized gas kinematic maps) derived for the CALIFA V500 setup data set by Pipe3D pipeline (Sánchez et al. 2016b) based on the Fit3D fitting tool (Sánchez et al. 2016a), together with the stellar line-of-sight velocity and intrinsic dispersion maps for the V1200 setup performed using pPXF by Falcón-Barroso et al. (2017).

Pipe3D models the stellar continuum adopting a multi Single Stellar Population (SSP) template library, taking into account the velocity, dispersion, and dust attenuation of the stellar populations. Then, it estimates the main properties of the nebular emission lines. The current implementation of Pipe3D adopted the GSD156 (Cid Fernandes et al. 2013) template library for the analysis of the stellar population properties. This library comprises 156 templates covering 39 stellar ages (from 1 Myr to 13 Gyr), and four metallicities ( $Z/Z_{\odot} = 0.2, 0.4, 1, \text{ and } 1.5$ ). A spatial binning for the stellar population analysis was applied to reach a homogeneous signal-to-noise (S/N) of 50 across the FoV. The stellar population fitting was applied to the coadded spectra within each spatial bin. Finally, following the procedures described in Cid Fernandes et al. (2013) and Sánchez et al. (2016a), the stellar-population model was estimated for each spaxel by rescaling the best-fitting model within each spatial bin to the continuum flux intensity in the cor-

responding spaxel. The stellar-population model spectra are then subtracted from the original data-cube to create a gas-pure cube comprising only the ionized gas emission lines. For this pure-gas cube, the stronger emission lines were then fitted spaxel by spaxel using single Gaussian models for each emission line in each individual spectrum to derive the corresponding flux intensity and line-of-sight kinematics. In addition, the spatial distribution of the stellar mass densities and the integrated stellar masses at different apertures are recovered from the Pipe3D analysis by taking into account the decomposition in SSPs, the Mass-to-Light ratio of each of them, and the integrated light at each spaxel within the FoV. For this derivation was assumed the Salpeter Initial Mass Function (Salpeter 1955). More details of the fitting procedure, adopted dust attenuation curve, and uncertainties of the process are given in Sánchez et al. (2016a, b).

Falcón-Barroso et al. (2017) performed a detailed analysis to extract the stellar kinematics for the intermediate resolution CALIFA data (V1200 setup). The data-cubes were spatially binned with the Voronoi 2D binning method of Cappellari & Copin (2003) to achieve an approximately constant S/N of 20 per spaxel taking into account the correlation in the error spectrum of nearby spaxels (see Husemann et al. 2013 for details). This S/N value conserves a good spatial resolution while still being able to reliably estimate the line-of-sight velocity distribution. The stellar kinematics was estimated using the pPXF code of Cappellari & Emsellem (2004). The stellar templates were taken from the Indo-US spectral library (Valdes et al. 2004) with  $\sim 330$  selected stars. The stellar rotation velocity, the velocity dispersion, and corresponding error were estimated by  $\chi^2$  minimization in pixel space as the biweight mean and standard deviations of a set of 100 Monte Carlo realizations of the fitting.

#### 3.2 Integrated kinematics

The original data set comprises 734 galaxies for the V500 data set observed within the framework of the CALIFA survey (Sánchez et al. 2017), and the 300 galaxies for the V1200 data set described by Falcón-Barroso et al. (2017). From this data set we perform a selection of the optimal data for the proposed analysis following the methodology described by C14. First, spaxels are discarded if the error in velocities is greater than  $20 \text{ km s}^{-1}$  and  $50 \text{ km s}^{-1}$  for gaseous and stellar kinematics, respectively. This conventional cut corresponds to one third of the spectral FWHM

( $\sim 6 \text{ \AA}$ , i.e.  $\sim 150 \text{ km s}^{-1}$ ) of V500 CALIFA data. Secondly, we selected only those galaxies for which at least 80 per cent of the spaxels within an ellipse of semimajor axis equal to  $1r_e$  fulfill this quality criterion. This criterion guarantee that we are tracing well the kinematics parameters up to  $1r_e$ . Finally, galaxies under merging and clear traces of interactions are discarded based on morphological distortions and the abundance of galaxy neighbors with a comparable size. Following this procedure our final sample comprise 223 galaxies with ionized gas kinematics (V500 setup), 278 with stellar kinematics (V1200 setup), and 123 with both of them.

### 3.2.1 Velocity dispersion: $\sigma$

Stellar velocity dispersions were estimated as the linear average of the velocity dispersion of all spaxels within the ellipse mentioned in the previous section using the velocity dispersion maps from the V1200 data set without correction for inclination. Following C14 we use linear instead of luminosity-weighted averages to be consistent with our velocity width measurements which are not luminosity-weighted. Ionized gas velocity dispersions were estimated fitting the integrated spectrum within a diameter of 5 arcsec with Pipe3D for the V500 data set using the template library described above. Regarding the determination of the stellar and gaseous velocity dispersions (up to  $1r_e$ ), which dominate in early-type galaxies, we rely on the detailed kinematic analysis presented in Zhu et al. (2018a, b).

### 3.2.2 Rotation velocity: $V_{\text{rot}}$

Once more, we followed C14, to derive the stellar (V1200 data set) and gaseous (V500 data set) rotation velocities. They adopted the same classical procedure developed to analyse the integrated HI emission profiles in galaxies, i.e. through the width parameter,  $W$  (Mathewson, Ford & Buchhorn 1992; Vogt et al. 2004). First, a histogram is derived of the velocities estimated for all the good spaxels within the  $r_e$ . Then, it is calculated the difference between the 10th and 90th percentile points of this velocity histogram, defined as the width:  $W = V_{90} - V_{10}$  (Catinella, Haynes & Giovanelli 2005). Finally, the rotation velocity is defined as:

$$V_{\text{rot}} = \frac{W}{2(1+z)\sin(i)}, \quad (2)$$

where  $z$  is the redshift and  $i$  is the galaxy inclination determined from the observed ellipticity  $\epsilon$  as:

$$\cos(i) = \sqrt{\frac{(1-\epsilon)^2 - q_0^2}{1 - q_0^2}}, \quad (3)$$

with  $q_0$  being the intrinsic axial ratio of edge-on galaxies. Following Catinella et al. (2012) and C14, we adopted  $q_0 = 0.2$  for all galaxies and set the inclination to  $90^\circ$  edge-on if  $\epsilon \geq 0.8$ .

Integrated rotation velocity estimated by equation (2) is a good representation of the maximum rotation velocity,  $V_{\text{max}}$ , if the kinematics of the galaxy is axisymmetric (i.e. without non-circular motions). However, this is not always the case. Some galaxies show deviations from a pure rotational pattern due to warps, lopsidedness, arms, bars, outflows, inflows, nuclear activity, etc. (Bosma 1978; Schoenmakers, Franx & de Zeeuw 1997; Verheijen 2001; Holmes et al. 2015; Kalinova et al. 2017; Sánchez-Menguiano et al. 2017), producing non-circular motions and distorting the velocity profile (i.e. velocity histogram). In the next subsection, we try to

quantify these effects in the derivation of  $V_{\text{max}}$  by performing a more detailed analysis on a limited sample of galaxies and comparing the results.

### 3.3 Spatially resolved kinematics: $V_{\text{max}}$

Kinematic maps of spiral galaxies are often treated as being consistent with a purely circular flow pattern. This means that the kinematics of a galactic disc at a certain galactocentric radius can be described by a single tilted ring model defined by three parameters: the rotation velocity and two parameters that describe the local disc orientation with respect to some reference system (Rogstad, Lockhart & Wright 1974). Several routines exist to fit kinematic maps based on this method. The most extensively used is the ROTCUR routine (Begeman 1989), which fits a set of inclined rings to a velocity field. However, as we mentioned above, the kinematics could be affected by the presence of non-circular motions and in some cases the tilted-ring model is an oversimplification. A more precise kinematic analysis requires tools that consider non-circular motions.

Spekens & Sellwood (2007) and Sellwood & Sánchez (2010) developed the VELFIT code specifically to characterize the non-circular motions in the kinematics of spiral galaxies expressed in a Fourier series. We used this code with some improvements (E. Aquino-Ortíz in preparation) to derive the properties of the velocity maps. This fit provides an estimate of the rotation curve, the kinematic inclination, and position angle of the galaxy, together with the amplitude of the non-circular motions as a function of radius. A bootstrap procedure is adopted to estimate the uncertainties on the derived parameters.

The current procedure is not performed over the full data set, since in many cases the kinematics present clear deviations due to external perturbations or is strongly affected by random motions. We discarded those cases whose kinematics appeared highly disturbed by the presence of large nearby companions or clear indications of being in a merging process. Therefore, we select a control sample, with good quality spatially resolved kinematics, comprising those isolated galaxies with low velocity dispersion, and inclinations in the range  $30^\circ < i < 70^\circ$ . This sample of galaxies, that are the best suited for modelling their velocity maps, comprises 42 galaxies for ionized gas kinematics (V500) and 92 galaxies for stellar kinematics (V1200).

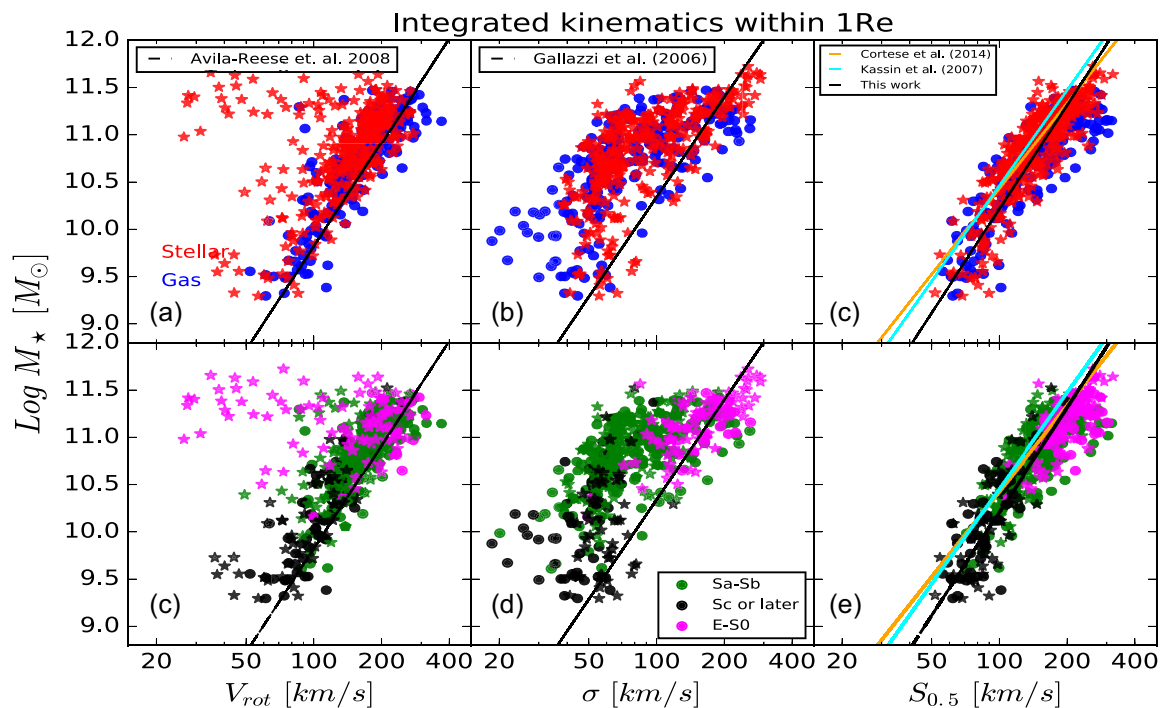
The estimated rotation curves for all these galaxies present a great diversity, in agreement with previous results (Kalinova et al. 2017). For a limited fraction of galaxies ( $\sim 10$  per cent) the spatial coverage was insufficient to measure the maximum velocity,  $V_{\text{max}}$ . In order to still estimate  $V_{\text{max}}$  we follow Bekeraité et al. (2016) and parametrize the rotation curve using the formula proposed by Bertola et al. (1991):

$$v(r) = v_0 + \frac{v_c r}{(r^2 + k^2)^{\frac{\gamma}{2}}}, \quad (4)$$

where  $v_0$  is the systemic velocity of the galaxy,  $v_c$  is a parameter governing the amplitude of the rotation curve and  $k$  describes its sharpness, and finally  $\gamma$  allows modelling rising or falling curves, with  $\gamma = 1$  for a flat rotation curve.

## 4 RESULTS

Fig. 2 shows the analysed kinematic scaling relations using the total stellar mass (unless noted otherwise) and the integrated kinematics, segregated by stellar and ionized gas kinematics (upper panels) and by morphology (lower panels), respectively. In each panel is



**Figure 2.** Kinematic scaling relations with integrated kinematics. Left-hand panel: TF relation with the black line representing the orthogonal best-fitting TF relation from Avila-Reese et al. (2008). Middle panel: FJ relation with the black line the best-fitting FJ relation from Gallazzi et al. (2006). Right-hand panel: The  $M_\star - S_{0.5}$  relation, cyan and yellow lines indicate the best-fitting  $M_\star - S_{0.5}$  relation from Kassin et al. (2007) and Cortese et al. (2014), respectively, whereas the black line represent our best-fit. *Top panels:* The red stars and blue circles represent galaxies with stellar and ionized gas kinematics. *Bottom panels:* Galaxies with different morphological types; the magenta stars indicate elliptical and lenticular galaxies, the green stars are Sa and Sb galaxies, and the black circles are Sc galaxies.

included some reference relations found by previous results, and the best-fitting relations for the  $M_\star - S_{0.5}$  distribution. Fig. 3 shows the same distributions for the resolved kinematics.

Table 1 summarizes the results of an orthogonal linear fit along the horizontal axis, considering the total stellar mass on the vertical axis as the independent variable, using the routines presented by Akritas & Bershady (1996), for each of the kinematic scaling relations and data set. It includes the zero-points and slopes, together with the scatter around the best-fitting relations estimated from the ‘error-in-variable’ of the corresponding fit as the standard deviation of residuals. In addition, there are listed the reference results for the TF, FJ, and  $S_{0.5}$  scaling relations extracted from the literature shown in Figs 2 and 3.

#### 4.1 TF relation

The TF relation including early type galaxies based on the integrated analysis are shown in the left-hand panels of Fig. 2. These relations show a large scatter, 0.084 dex in  $\log V_{rot}$  for ionized gas kinematics and 0.20 dex for stellar kinematics. The value for ionized gas kinematics is in agreement with the one reported for the luminosity TF relation estimated by Bekeraité et al. (2016),  $\sim 0.09$  dex, despite the fact that their study was based on a detailed analysis of the rotation velocity of a subsample of the CALIFA galaxies. In that study they analysed their velocity within a radius containing 83 per cent of all light,  $V_{opt}$ . On the other hand, our scatter for stellar kinematics is lower than the one reported by C14 ( $\sim 0.25$  dex). The difference with this later study is not surprising because the SAMI sample is dominated by Sc low-mass galaxies, where the rotation curves are still rising at  $1r_e$ , being far from  $V_{max}$ , whereas

our sample is dominated by Sa and Sb galaxies (see lower panels of Fig. 2).

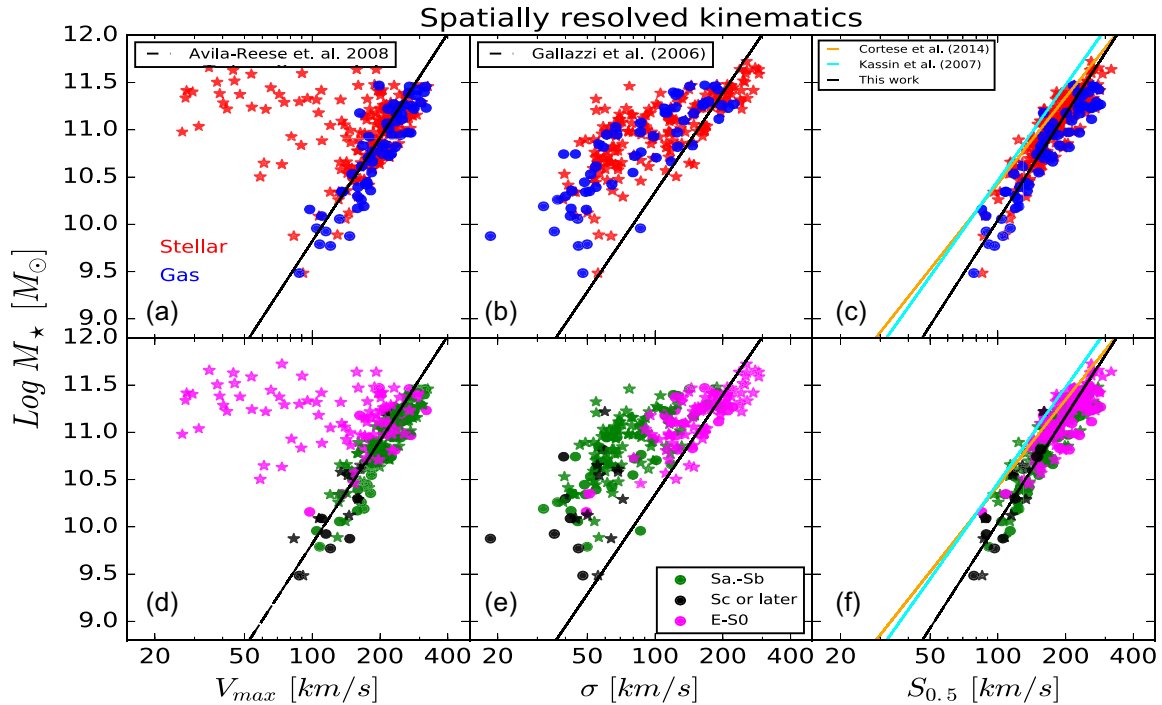
The left-hand panel of Fig. 3 shows the TF relation also including early-type galaxies based on the spatially resolved analysis (i.e. using  $V_{max}$ ). The parameters of the best-fitting relation to these data are listed in Table 1. When adopting this improved estimation of the velocity, the scatter decreases to  $\sim 0.07$  dex for the ionized gas kinematics, but it increases to  $\sim 0.24$  dex for the stellar one. This later value agrees with the one reported by C14. The scatter for our stellar kinematics TF relation increases due to that late-type galaxies move to higher velocities and also for the inclusion of early-type galaxies in the relation. Such galaxies are undetected in the gas component, being the analysed sample limited to mostly late-type galaxies.

As a reference we include in Figs 2 and 3 the derivation of the stellar TF relation as presented in Avila-Reese et al. (2008).<sup>2</sup> We use their orthogonal linear fit considering the stellar mass as the independent variable. As expected, there is an offset between this classical derivation and our results for the integrated kinematics. However, for the resolved kinematics, which determines  $V_{max}$ , the offset tends to disappear, at least for the spiral galaxies.

#### 4.2 FJ relation

Central panels of Figs 2 and 3 show the FJ distributions including late-type galaxies using the integrated kinematics sample and

<sup>2</sup>We have increased the stellar mass in Avila-Reese et al. (2008) by 0.15 dex in order to convert from diet-Salpeter to Salpeter IMF.



**Figure 3.** Kinematic scaling relations for our control sample with spatially resolved kinematics. Left-hand panel: TF with the black line as the stellar mass TF from Avila-Reese et al. (2008). Middle panel: FJ with the black line as the Gallazzi et al. (2006). Right-hand panel: The  $M_*$ – $S_{0.5}$  relation, cyan and yellow lines are the best-fits of Kassin et al. (2007) and Cortese et al. (2014), respectively, whereas the black line represents our best-fit. *Top panels:* The red stars and blue circles represent galaxies with stellar and gas kinematics. *Bottom panels:* The colour-code represents different morphologies.

**Table 1.** Orthogonal linear fit parameters to scaling relations.

Relation	Tully–Fisher				Faber–Jackson				$S_{0.5}$	
	Galaxies	scatter	slope	zero-point	scatter	slope	zero-point	scatter	slope	zero-point
<b>Integrated kinematics at <math>R_e</math></b>										
Gas	223	0.084	$0.27 \pm 0.01$	$-0.65 \pm 0.12$	0.171	$0.36 \pm 0.02$	$-2.03 \pm 0.27$	0.087	$0.29 \pm 0.01$	$-1.03 \pm 0.12$
Stellar	278	0.200	$0.16 \pm 0.02$	$0.32 \pm 0.30$	0.160	$0.31 \pm 0.03$	$-1.37 \pm 0.25$	0.075	$0.26 \pm 0.01$	$-0.67 \pm 0.10$
Total	501	0.171	$0.20 \pm 0.01$	$-0.01 \pm 0.18$	0.165	$0.34 \pm 0.02$	$-1.71 \pm 0.18$	0.082	$0.27 \pm 0.01$	$-0.79 \pm 0.07$
Cortese et al. (2014)		0.26	–	–	0.16	–	–	0.10	$0.33 \pm 0.01$	$-1.41 \pm 0.08$
Kassin et al. (2007)		–	–	–	–	–	–	0.10	$0.34 \pm 0.05$	$1.89 \pm 0.03$
<b>Resolved kinematics, <math>V_{max}</math></b>										
Gas	59	0.07	$0.25 \pm 0.02$	$-0.41 \pm 0.17$	0.10	$0.31 \pm 0.01$	$-1.47 \pm 0.19$	0.053	$0.29 \pm 0.01$	$-0.92 \pm 0.13$
Stellar	167	0.24	$-0.10 \pm 0.09$	$3.34 \pm 1.07$	0.14	$0.53 \pm 0.03$	$-3.88 \pm 0.34$	0.052	$0.27 \pm 0.01$	$-0.72 \pm 0.12$
Total	226	0.22	$0.08 \pm 0.04$	$1.37 \pm 0.48$	0.13	$0.44 \pm 0.02$	$-2.79 \pm 0.22$	0.054	$0.27 \pm 0.01$	$-0.71 \pm 0.11$
<b>Only spiral galaxies, <math>V_{max}</math></b>										
Gas	42	0.043	$0.27 \pm 0.01$	$-0.63 \pm 0.15$	0.076	$0.35 \pm 0.02$	$-1.84 \pm 0.21$	0.043	$0.29 \pm 0.01$	$-0.88 \pm 0.13$
Stellar	92	0.053	$0.30 \pm 0.02$	$-1.00 \pm 0.02$	0.091	$0.35 \pm 0.03$	$-1.94 \pm 0.34$	0.052	$0.28 \pm 0.02$	$-0.92 \pm 0.21$
Total	134	0.052	$0.28 \pm 0.01$	$-0.73 \pm 0.13$	0.098	$0.33 \pm 0.02$	$-1.69 \pm 0.22$	0.051	$0.27 \pm 0.01$	$-0.80 \pm 0.13$
Avila-Reese et al. (2008)		0.045	$0.27 \pm 0.01$	$-0.69 \pm 0.12$	–	–	–	–	–	–

*Note.* All scatters are estimated from the linear fit as the standard deviation of all residuals, we consider stellar mass,  $M_*$ , as independent variable.  $\log(V, \sigma, S_{0.5}) = a + b \log(M_*)$ .  $V, \sigma$ , and  $S_{0.5}$  are given in  $[\text{km s}^{-1}]$ ,  $M_*$  in  $M_\odot$ .

the spatially resolved one, respectively. A reference FJ relation, derived by Gallazzi et al. (2006), has been included for comparison. Our stellar FJ relations show a scatter of  $\sim 0.16$  dex ( $\sim 0.14$  dex) and  $\sim 0.17$  dex ( $\sim 0.10$  dex) for gaseous and stellar kinematics, respectively, for the integrated (spatially resolved) subsamples. These dispersions are similar to the ones found by C14 ( $\sim 0.16$

dex), but larger than the one reported by Gallazzi et al. (2006) ( $\sim 0.07$  dex).

On a parallel situation as the one found for the TF relation, the stellar velocity dispersions and those derived for early-type ones are more in agreement with the FJ relation than the gaseous dispersions and/or those derived for late-type galaxies.

### 4.3 $M_*$ – $S_K$ relation

The right-hand panels of Fig. 2 show the  $M_*$ – $S_{0.5}$  distribution for the integrated kinematics segregated by gas and stellar kinematics (upper panel) and by morphology (lower panel). As a reference the  $S_{0.5}$  relations, derived by C14 and Kassin et al. (2007), have been included together with the best-fitting relation derived with our own data. As in the previous cases, the best-fitting parameters for the linear regression have been included in Table 1. The distribution is clearly tighter than those of the FJ relations, with scatter very similar or lower to the one found for the TF relation ( $\sim 0.08$  dex).

The right-hand panels of Fig. 3 show the same distributions for the resolved kinematics subsample. For this control sample, the scatter decreases significantly to 0.053 dex and 0.052 dex for both the ionized gas and stellar kinematics, respectively. As we mentioned above, the slope, zero-point, and scatter of the TF and FJ relations could depend on several factors including (i) the morphology of the galaxies, (ii) the adopted shape for the rotational curve, and even (iii) the methodology used to measure both the rotational velocity and/or the velocity dispersion (see Colleen et al., for an example of the effects of the uncertainties). For the  $S_{0.5}$  parameter, the dependence on morphology and the described offsets between gaseous and stellar kinematics eventually disappear. Thus, galaxies of any morphology lie on the same scaling relation in agreement with previous studies.

C14 found a good agreement in the slope of the  $S_{0.5}$  relation derived using integrated kinematics up to  $1r_e$  for the SAMI data set with that derived by Kassin et al. (2007) for a sample of star-forming galaxies, using the maximum rotational velocities. However, they found larger differences in the zero-point of their relations. In our analysis the behaviour is similar. The slope remains unchanged between both the integrated and resolved kinematics, with small differences compared with the ones derived by Cortese et al. (2014) and Kassin et al. (2007). However, our best-fit for the total sample (gas + stars) presents a scatter clearly lower than the one found by previous studies, being  $\sim 0.082$  dex for the integrated kinematics and  $\sim 0.054$  dex for the spatially resolved one. The reduction in the scatter combining rotation velocity and velocity dispersion in a single parameter, indicate that together they trace the gravitational potential than each one separately. Actually, this latter value is in agreement with the physical interpretation of Zaritsky et al. (2008).

## 5 DISCUSSION

We discuss here the implications of the results listed in the previous section, trying to understand how the uncertainties may affect them and the physical nature of the described relations.

### 5.1 Narrowing down the uncertainties

A critical challenge giving a physical interpretation to galaxy scaling relations are the uncertainties because they can potentially modify or erase the dependence between the analysed properties. We have tried to narrow down their effects by performing the analysis twice. Once using the integrated kinematics, following C14, and then, we improved the accuracy using a spatially resolved kinematic analysis. This second analysis is performed at the expenses of the statistics. We consider that this second data set is best suited to derive a more accurate  $S_{0.5}$  relation.

Table 1 shows there is a clear improvement in the TF and  $S_{0.5}$  relations (in most of the cases) when adopting the spatially resolved

kinematics. On the other hand, there is only a mild improvement in the FJ relation (since this relation does not involve rotation velocities). To verify the scatter we tried to reproduce the ‘classical’ TF relation using the spatially resolved kinematics. For doing so, we select only the spiral galaxies and compare their distribution in the  $M_*$ – $V_{max}$  diagram with that of a well-established comparison sample: the compilation and homogenization presented in Avila-Reese et al. (2008). The left-hand panel of Fig. 4 shows this comparison. The parameters derived for the TF relation for both subsamples match pretty well, with very good agreement, in particular for the gas kinematics, as shown in Table 1. Therefore, the spatially resolved kinematic sample seems to be the best one to characterize the scaling relations involving rotation velocities.

Using this new subsample we derive the most precise estimation of the  $M_*$ – $S$  relation, shown in the right-hand panel of Fig. 4<sub>0.5</sub>. The parameters of this relation are listed in Table 1. The first result emerging from this analysis is that the scatter is of the order of the  $S_{0.5}$  relation found for the completely resolved kinematics ( $\sim 0.05$  dex). Therefore, to select a better subsample in terms of the TF relation does not seem to affect the result. In other words, the inclusion of early-type galaxies affects the TF relation, but it does not affect the  $S_{0.5}$  one. Another interesting result is that the scatter in this relation is very similar to that of the TF relation for the same subsample. Therefore, the inclusion of the effects of random motions does not increase the scatter, even for galaxies clearly supported by rotation.

Finally, the slope and zero-point of the  $S_{0.5}$  relations found for (i) this particular subsample of galaxies that reproduces the better TF relation, (ii) the completely resolved kinematics sample, and (iii) the integrated kinematics sample, when considering both the gaseous and stellar kinematics, agree with each other. Thus, only the precision is increased by performing a detailed resolved kinematics for a TF-compatible subsample, but the general trends are the same. The result of this test suggests that our analysis is not dominated by velocity uncertainties and the early tight correlation presented by C14 and in this paper is real and not the result of the poorly constrained in velocity for dispersion-dominated systems.

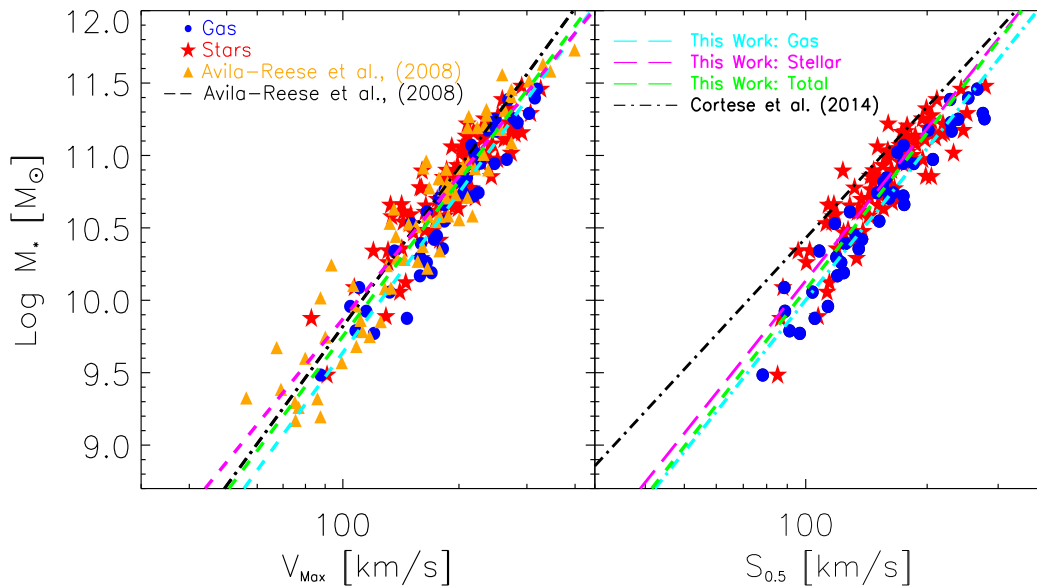
### 5.2 $S_K$ as a proxy of the dynamical mass

The observed kinematics of a galaxy is often used to infer the total (dynamical) mass enclosed at different radii (Persic & Salucci 1988; Zavala et al. 2003; Courteau et al. 2014; Ouellette et al. 2017). Assuming that the  $M_*$ – $S_{0.5}$  scaling relation is a consequence of a more physical relation between the dynamical mass and the stellar mass in the inner regions, we suppose that the  $S_{0.5}$  parameter traces the dynamical mass as follow:

$$M_{dyn} \propto S_{0.5}^2 \Rightarrow M_{dyn} = \eta \frac{r_r S_{0.5}^2}{G} = \eta \frac{r_r (0.5V_{rot}^2 + \sigma^2)}{G}, \quad (5)$$

where  $r_r$  is a characteristic radius of the galaxy,  $G$  the gravitational constant, and  $\eta$  is a structural coefficient which encapsulate information of the shape of the galaxy, projection effects, dynamical structure, etc., in fact it can be included into the  $K$  coefficient of the  $S_{0.5}^2$  parameter, however it is useful to introduce  $\eta$  in order to compare with former studies. Dynamical models such as Jeans Anisotropic Models (JAMs, Cappellari 2008) or Schwarzschild (Schwarzschild 1979) are considered the state-of-the-art inferences of galaxies mass distribution including dynamical enclosed mass. Cappellari et al. (2006) calibrated equation (5) for a sample of early-type galaxies from the SAURON project (Bacon et al. 2001) using the velocity dispersion instead of the  $S_{0.5}$  parameter in combination with





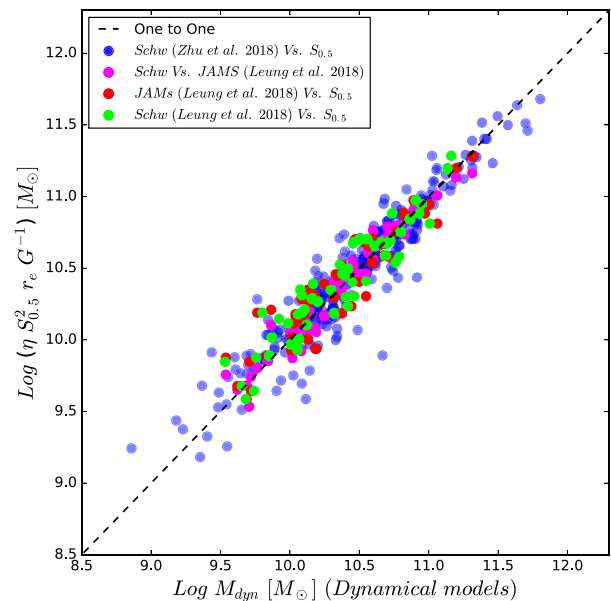
**Figure 4.** Scaling relations for our control subsample. The left-hand and right-hand panels show the TF and  $S_{0.5}$  scaling relations, respectively. The blue and red symbols represent gaseous and stellar kinematics for galaxies with inclinations in the range  $30^\circ < i < 70^\circ$ . The Cyan, magenta, and green lines are the best-fits for gas, stellar, and total (gas + stellar). In the TF relation we recover in great detail the result of the data compilation from Avila-Reese et al. (2008); their masses were corrected to convert to a Salpeter IMF. It is clear that in galaxies where the random motions are negligible, the  $S_{0.5}$  relation tends to be the TF.

Schwarzschild dynamical models. They found that the dynamical mass within the effective radius can be robustly recovered using a coefficient  $\eta \approx 2.5$ , which varies little from galaxy to galaxy.

Leung et al. (2018) performed a detailed comparison of JAMs and Schwarzschild models for 54 of the CALIFA galaxies included here. We use these dynamical masses,  $M_{dyn}^{JAMS}$ , to calibrate the equation (5) based on the  $S_{0.5}$  parameter. We found that the enclosed dynamical mass within the effective radius [i.e. using  $r_e$  as the characteristic radius in equation (5)] can be robustly recovered using a single coefficient  $\eta \approx 1.8$  for all the galaxies, with a narrow dispersion of 0.15 dex. To validate that calibration we compare the estimated dynamical masses by the equation (5) with those derived using dynamical models for a sample of 300 galaxies analysed by Zhu et al. (2018a, b), together with the ones by Leung et al. (2018). Fig. 5 shows the comparison between the different estimations of the dynamical masses. As expected, the agreement between the values derived using JAMs and Schwarzschild dynamical models for the galaxies studied by Leung et al. (2018) agree with each other with a low scatter of 0.08 dex. Interestingly, we still find a very good agreement using  $\eta = 1.8$  between our  $S_{0.5}$  derived dynamical masses and sophisticated dynamical mass estimations, with a scatter of  $\sim 0.15$  dex. We may wonder why is the  $S_{0.5}$  parameter such a good mass tracer. This is remarkable in view that, we do not systematically study IMF effects (Martín-Navarro et al. 2015) and kinematic anisotropy (Zhu et al. 2018a). The enclosed mass within  $r_e$  is an integrated quantity weakly sensitive to the specific mass and shape density profile, a similar discussion has been presented by Wolf et al. (2010) for dwarf spheroidal galaxies, only on such grounds the  $S_{0.5}$  is a competitive  $M_{dyn}$  proxy.

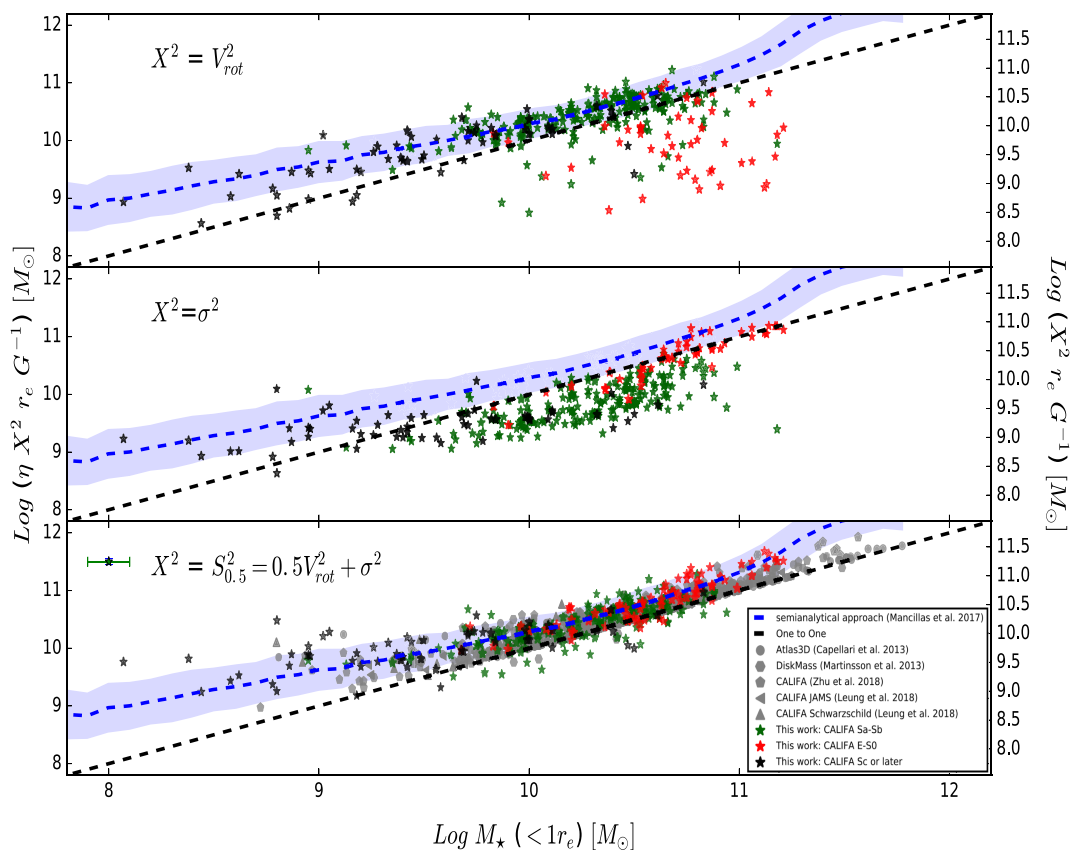
### 5.3 The Dynamical-to-stellar mass relation

We explore the literature in order to compile the most recent state-of-the-art derivations of the dynamical mass in the central regions of galaxies using dynamical models. Cappellari et al. (2013) estimated



**Figure 5.** One-to-one relation between dynamical masses inferred from dynamical models and kinematic parameter  $S_{0.5}$ . The blue symbols are the comparison between the Schwarzschild models by Zhu et al. (2018a) with our estimations. The red and green symbols are the comparison between JAMs and Schwarzschild models by Leung et al. (2018) with our estimations, respectively. Both comparisons show a scatter of  $\sim 0.15$  dex. The magenta symbols are the comparison between Schwarzschild and JAMs estimations with a scatter of 0.08 dex.

the dynamical mass within the effective radius for 258 early-type galaxies from the *ATLAS<sup>3D</sup>* project (Cappellari et al. 2011) using the JAMs dynamical models and compared it with the stellar masses. Martinsson et al. (2013) performed a similar study for 24 late-type galaxies extracted from the Disc Mass survey (Bershady



**Figure 6.** Accuracy of the  $M_{\text{dyn}}-M_{\star}$  relations based on the  $S_{0.5}$  parameter. In the top and medium panels we assume that galaxies are rotation or velocity dispersion dominated to estimate the dynamical mass within the effective radius. The red, green, and black stars represent our CALIFA sample, whereas the grey symbols are from the literature compilation. The  $S_{0.5}$  dynamical mass estimations perform better than the ones based either only on rotation or dispersion. In the bottom panel we used the  $S_{0.5}$  parameter to estimate the dynamical mass using equation (5) and compare them with theoretical predictions based on detailed dynamical models. All the estimated  $M_{\text{dyn}}-M_{\star}$  relations are comparable and consistent with observations within the uncertainties. As a reference we also show the semi-empirical predictions of Mancillas et al. (2017) (blue shaded region; see text) which use  $\eta = 1$  and are also consistent with our estimations.

et al. 2010). Zhu et al. (2018a, b) constructed orbit-superposition Schwarzschild models at different radii that simultaneously fit the observed surface brightness and stellar kinematics for 300 galaxies included in the CALIFA-V1200 resolution subsample studied here. In Zhu et al. (2018b) they constrained the stellar orbit distribution and found that a fraction of stars are within a plane with unperturbed orbits tracing the rotation velocity, while others are out of the plane with perturbed orbits tracing the velocity dispersion. This result implies that the kinematics in galaxies is more complex than just rotation or velocity dispersion: both components are present in all types of galaxies and should be considered to trace the potential. The bottom panel of Fig. 6 presents the comparison between the distributions of dynamical masses along the stellar ones between this compilation of data extracted from the literature and the ones derived using the equation (5) within the effective radius, based on the  $S_{0.5}$  parameter with  $\eta = 1.8$ . In addition, we present the dynamical masses derived if we consider only the rotational velocities or the velocity dispersions.<sup>3</sup> All these dynamical masses, derived at  $r_e$  are listed in Table A1. We observe a clear offset and a large scatter between our dynamical masses and those derived using detailed models when we use only rotation velocity (mostly

for ellipticals) or velocity dispersion (mostly for spirals). However, when we use the dynamical mass proxy based on the  $S_{0.5}$  parameter, the distribution along the stellar mass is in agreement with the results extracted from the literature. Thus, it seems that the  $S_{0.5}$  parameter is indeed a good proxy for calculating the dynamical mass.

Our distribution of  $M_{\text{dyn}}-M_{\star}$  follows a linear and nearly one-to-one relation for masses in the range  $3 \times 10^9 \lesssim M_{\star} [M_{\odot}] \lesssim 5 \times 10^{10}$ . The fact that for some galaxies (both from our sample and from other works), the stellar mass seems to be higher than the dynamical one shows the presence of several systematic uncertainties both in the stellar and dynamical mass determinations. Within these uncertainties, what we learn from Fig. 6 is that in the above-mentioned mass range luminous matter strongly dominates within  $1r_e$ . Below  $\sim 3 \times 10^9 M_{\odot}$  there is a clear deviation, with galaxies showing larger dynamical masses than their stellar masses, which indicates that in the low-mass regime galaxies are more dark matter dominated as less massive they are, even within the effective radius. In the high-mass end, there is some weak evidence of a deviation, with the few E/S0 galaxies at these masses showing again larger dynamical masses than their stellar masses. This difference could be due to more bottom-heavy IMF (Lyubenova et al. 2016) and/or due to the contribution of dark matter.

<sup>3</sup>Corrections for different adopted values for the effective radius and IMFs offset have been considered when required.

Both our data and literature collected ones show similar trends. Indeed, this result is predicted by different theoretical studies, including hydrodynamical cosmological simulations (Oman et al. 2015) from the Evolution and Assembly of Galaxies and their Environments project (Crain et al. 2015; Schaye et al. 2015), and semi-empirical modelling approaches (Mancillas et al. 2017). We include the latter theoretical predictions for comparison in Fig. 6. In Mancillas et al. (2017), a population of galaxies with bulge-to-disc mass ratios lower than  $\sim 0.7$  was generated by loading the bulge/disc systems into Lambda cold dark matter haloes, taking into account the adiabatic contraction of the inner halo by the baryons. The modelled population reproduces well the TF relation, radius-mass,  $B/T$ -mass, and gas-to-stellar mass relations, and by construction follows the stellar-to-halo ( $M_{\star}-M_{vir}$ ) relation constrained from a semi-empirical approach for blue galaxies (Rodríguez-Puebla et al. 2015). The predicted inner mass distributions, in particular the stellar-to-dynamical masses within  $1r_e$ , inherit partially the shape of the latter relation, which bends to lower  $M_{\star}/M_{vir}$  ratios both at lower and higher masses. This explains the bends seen for the predictions in Fig. 6 (dashed blue line and shadow region around it). It is encouraging that our observational inferences based on the  $S_{0.5}$  parameter agree with these predictions, showing the possibility to attain a connection between the inner galaxy dynamics of the local galaxy population and the properties of the cosmological dark matter haloes.

## 6 CONCLUSIONS

Originally the  $S_K$  parameter was introduced as a tool to deal with galaxies difficult to classify or with high amount of velocity dispersion like clumpy high-redshift galaxies. The remarkable reduction of scatter in the  $S_{0.5}$  relationship compared with TF and FJ relations found by previous studies (Cortese et al. 2014) and confirmed with higher accuracy by our study, points towards a more complex internal kinematics in galaxies even in the local Universe: non-circular motions in disc galaxies and some amount of rotation in elliptical galaxies.

In summary, we demonstrate that (i) the  $M_{\star}-S_{0.5}$  is a tighter correlation than the TF relation or the FJ relation when galaxies of all morphological types are considered, and (ii) this relation is a consequence of  $S_{0.5}$  being a proxy of the dynamical mass and the relation between this later parameter with the stellar mass. Finally, we propose a simple but competitive procedure to estimate the dynamical mass in galaxies, easier to apply to massive surveys than more detailed analysis, although with lower precision.

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## APPENDIX A: STELLAR AND DYNAMICAL MASSES

Dynamical masses were estimated within  $1r_e$  using equation (5)

**Table A1.** Stellar masses and dynamical masses within the effective radius.

Name	$M_*$ [ $M_\odot$ ]	$M_{dyn}$ [ $M_\odot$ ]	$r_e$ [arcsec]
(1)	(2)	(3)	(4)
IC5376	10.16 ± 0.10	10.53 ± 0.04	11.62
NGC 0036	10.76 ± 0.09	10.82 ± 0.02	19.34
UGC00148	9.71 ± 0.09	10.26 ± 0.06	13.54
MCG-02-02-030	10.00 ± 0.09	10.25 ± 0.03	13.86
UGC00005	10.62 ± 0.09	10.78 ± 0.01	14.45
NGC 7819	10.00 ± 0.08	10.14 ± 0.03	15.02
UGC00029	10.93 ± 0.10	11.19 ± 0.04	12.79
IC1528	10.04 ± 0.09	10.16 ± 0.03	16.95
NGC 7824	10.64 ± 0.09	10.75 ± 0.12	9.64
UGC00312	9.75 ± 0.09	10.57 ± 0.07	13.28
MCG-02-02-040	9.44 ± 0.09	10.11 ± 0.05	11.62
UGC00335NED02	10.43 ± 0.10	10.72 ± 0.04	16.64
NGC 0216	8.78 ± 0.09	9.38 ± 0.08	13.22
NGC 0214	10.66 ± 0.09	10.46 ± 0.04	14.88
NGC 0217	10.37 ± 0.09	10.83 ± 0.01	20.44
NGC 0237	10.11 ± 0.09	10.01 ± 0.05	11.05
NGC 0234	10.50 ± 0.08	10.00 ± 0.04	17.36
MCG-02-03-015	10.94 ± 0.10	10.62 ± 0.02	11.56
NGC 0257	10.61 ± 0.09	10.57 ± 0.02	15.10
NGC 0364	10.36 ± 0.09	10.66 ± 0.01	9.04
NGC 0429	10.09 ± 0.09	10.38 ± 0.04	7.14
IC1652	10.21 ± 0.09	10.27 ± 0.05	10.62
NGC 0447	10.55 ± 0.09	10.71 ± 0.05	18.56
NGC 0444	9.71 ± 0.10	10.22 ± 0.04	17.37
UGC00809	9.02 ± 0.08	10.21 ± 0.03	11.01
UGC00841	9.73 ± 0.11	10.28 ± 0.05	13.73
NGC 0477	10.39 ± 0.09	10.54 ± 0.03	18.58
IC1683	10.31 ± 0.09	10.18 ± 0.03	9.97
NGC 0499	10.64 ± 0.08	11.01 ± 0.03	13.16
NGC 0496	10.40 ± 0.11	10.30 ± 0.03	16.47
NGC 0504	9.72 ± 0.10	10.38 ± 0.03	8.53
NGC 0517	10.13 ± 0.10	10.40 ± 0.03	7.52
UGC00987	10.33 ± 0.09	10.40 ± 0.03	10.95
NGC 0528	10.46 ± 0.10	10.59 ± 0.02	9.01
NGC 0529	10.63 ± 0.09	10.84 ± 0.05	11.75
NGC 0551	10.33 ± 0.10	10.46 ± 0.04	14.37
UGC01057	10.11 ± 0.10	10.31 ± 0.03	11.00
UGC01271	10.28 ± 0.10	10.47 ± 0.04	8.17
NGC 0681	9.99 ± 0.08	10.28 ± 0.04	23.63
NGC 0741	11.17 ± 0.09	11.56 ± 0.02	25.68
NGC 0755	9.18 ± 0.08	9.91 ± 0.09	19.11
IC1755	10.43 ± 0.09	10.95 ± 0.01	13.50
NGC 0768	10.39 ± 0.08	10.67 ± 0.02	15.59
NGC 0774	10.50 ± 0.10	10.54 ± 0.03	13.31
NGC 0776	10.53 ± 0.08	10.07 ± 0.04	13.28
NGC 0781	11.18 ± 0.09	10.07 ± 0.04	8.99
NGC 0810	10.77 ± 0.10	11.39 ± 0.02	13.56
NGC 0825	8.95 ± 0.10	9.79 ± 0.03	2.02
NGC 0932	10.64 ± 0.09	10.47 ± 0.04	16.43
NGC 1056	9.87 ± 0.09	9.55 ± 0.07	7.90
NGC 1060	11.13 ± 0.09	11.40 ± 0.03	20.46
UGC02222	10.51 ± 0.10	10.47 ± 0.03	8.36
UGC02229	10.68 ± 0.09	10.96 ± 0.02	11.77
NGC 1093	10.23 ± 0.08	10.31 ± 0.02	8.50
UGC02403	10.21 ± 0.09	10.24 ± 0.02	11.71
NGC 1167	10.99 ± 0.09	11.04 ± 0.01	21.55
NGC 1349	10.87 ± 0.09	10.83 ± 0.02	14.13
NGC 1542	9.99 ± 0.10	10.24 ± 0.03	9.53
NGC 1645	10.43 ± 0.10	10.76 ± 0.01	14.09
UGC03151	10.41 ± 0.10	10.56 ± 0.03	15.50
NGC 1677	9.20 ± 0.08	9.68 ± 0.10	8.59
IC2101	9.82 ± 0.10	10.26 ± 0.05	14.10

Table A1 – continued

Name	$M_*$ [ $M_\odot$ ]	$M_{dyn}$ [ $M_\odot$ ]	$r_e$ [arcsec]
(1)	(2)	(3)	(4)
UGC03253	10.07 ± 0.09	10.31 ± 0.02	12.67
NGC 2253	9.79 ± 0.10	9.59 ± 0.03	4.08
UGC03539	9.26 ± 0.08	10.02 ± 0.04	13.67
NGC 2347	10.50 ± 0.09	10.58 ± 0.03	13.78
UGC03899	8.95 ± 0.10	9.88 ± 0.08	9.55
UGC00036	10.45 ± 0.09	10.71 ± 0.01	10.05
NGC 0001	10.42 ± 0.09	10.19 ± 0.04	9.18
NGC 0023	10.83 ± 0.08	10.59 ± 0.06	10.78
NGC 2410	10.49 ± 0.09	10.76 ± 0.02	17.91
UGC03944	9.57 ± 0.12	10.00 ± 0.03	11.79
UGC03969	10.34 ± 0.11	10.70 ± 0.01	11.16
UGC03995	10.64 ± 0.09	10.74 ± 0.02	21.78
NGC 2449	10.30 ± 0.09	10.58 ± 0.01	12.86
UGC04029	10.09 ± 0.08	10.39 ± 0.01	14.97
IC0480	9.42 ± 0.10	10.19 ± 0.02	11.49
NGC 2476	10.36 ± 0.11	10.37 ± 0.05	7.99
NGC 2480	8.86 ± 0.10	9.69 ± 0.10	10.82
NGC 2481	9.68 ± 0.10	9.97 ± 0.03	7.54
NGC 2486	10.43 ± 0.09	10.51 ± 0.03	12.96
NGC 2487	10.51 ± 0.08	10.36 ± 0.04	18.81
UGC04132	10.40 ± 0.10	10.70 ± 0.02	13.18
UGC04145	10.01 ± 0.11	10.34 ± 0.03	7.93
NGC 2513	10.71 ± 0.08	11.21 ± 0.02	19.23
UGC04197	9.82 ± 0.10	10.57 ± 0.03	14.93
NGC 2540	10.31 ± 0.10	10.48 ± 0.02	15.42
UGC04280	9.76 ± 0.09	10.11 ± 0.05	11.18
IC2247	10.30 ± 0.09	10.53 ± 0.02	16.30
UGC04308	9.99 ± 0.08	10.15 ± 0.03	21.43
NGC 2553	10.21 ± 0.09	10.52 ± 0.03	8.52
NGC 2554	10.79 ± 0.09	10.87 ± 0.01	17.50
NGC 2592	9.83 ± 0.10	10.04 ± 0.01	7.62
NGC 2604	9.28 ± 0.10	9.77 ± 0.08	20.19
NGC 2639	10.41 ± 0.08	10.70 ± 0.01	13.36
UGC04722	8.07 ± 0.12	9.76 ± 0.05	17.59
NGC 2730	9.68 ± 0.08	9.96 ± 0.03	14.56
NGC 2880	9.90 ± 0.08	9.98 ± 0.01	13.71
IC2487	10.00 ± 0.10	10.45 ± 0.02	16.77
IC0540	9.35 ± 0.10	9.74 ± 0.03	14.88
NGC 2906	9.94 ± 0.08	10.10 ± 0.02	15.23
NGC 2916	10.40 ± 0.08	10.55 ± 0.02	20.60
UGC05108	10.48 ± 0.10	10.81 ± 0.03	9.58
NGC 2918	10.71 ± 0.10	10.93 ± 0.02	9.32
UGC05113	10.19 ± 0.10	10.71 ± 0.02	8.91
NGC 3106	10.83 ± 0.08	10.77 ± 0.03	17.30
NGC 3057	8.80 ± 0.09	9.26 ± 0.09	18.08
UGC05498NED01	9.71 ± 0.11	10.67 ± 0.02	10.52
NGC 3158	11.14 ± 0.10	11.64 ± 0.03	22.29
NGC 3160	10.28 ± 0.10	10.76 ± 0.01	12.77
UGC05598	9.84 ± 0.10	10.15 ± 0.04	11.40
NGC 3300	10.10 ± 0.10	10.30 ± 0.01	13.31
NGC 3303	10.63 ± 0.10	10.75 ± 0.03	9.24
UGC05771	10.54 ± 0.10	10.81 ± 0.03	8.01
NGC 3381	9.18 ± 0.07	9.18 ± 0.10	14.84
UGC05990	8.44 ± 0.12	9.24 ± 0.09	9.36
UGC06036	10.32 ± 0.10	10.94 ± 0.02	11.16
IC0674	10.53 ± 0.09	10.84 ± 0.02	11.48
UGC06312	10.55 ± 0.09	10.80 ± 0.02	12.77
NGC 3615	10.87 ± 0.09	11.10 ± 0.03	10.85
NGC 3687	9.99 ± 0.08	9.75 ± 0.04	15.42
NGC 3811	10.16 ± 0.09	10.08 ± 0.04	14.71
NGC 3815	9.90 ± 0.08	10.12 ± 0.03	8.81
NGC 3994	10.09 ± 0.10	10.27 ± 0.05	7.14

Table A1 – continued

Name	$M_*$ [ $M_\odot$ ]	$M_{dyn}$ [ $M_\odot$ ]	$r_e$ [arcsec]
(1)	(2)	(3)	(4)
NGC 4003	10.48 ± 0.09	10.52 ± 0.05	9.41
UGC07012	9.39 ± 0.08	9.79 ± 0.10	11.88
NGC 4047	10.34 ± 0.09	10.41 ± 0.11	14.79
UGC07145	9.96 ± 0.10	10.38 ± 0.02	11.75
NGC 4149	9.70 ± 0.10	10.35 ± 0.04	11.48
NGC 4185	10.20 ± 0.08	10.51 ± 0.02	22.60
NGC 4210	9.85 ± 0.10	9.97 ± 0.02	16.92
NGC 4470	9.58 ± 0.09	9.33 ± 0.07	11.54
NGC 4644	10.11 ± 0.09	10.40 ± 0.02	14.27
NGC 4711	9.97 ± 0.08	10.18 ± 0.02	12.28
NGC 4816	10.75 ± 0.09	11.29 ± 0.03	20.36
NGC 4841A	10.82 ± 0.09	11.29 ± 0.05	13.68
NGC 4874	11.12 ± 0.09	11.68 ± 0.02	38.42
UGC08107	10.80 ± 0.09	11.29 ± 0.03	17.66
NGC 4956	10.53 ± 0.09	10.35 ± 0.03	8.68
NGC 4961	9.42 ± 0.09	9.68 ± 0.06	9.74
UGC08231	9.05 ± 0.11	10.28 ± 0.06	16.86
UGC08234	10.62 ± 0.10	10.51 ± 0.02	5.53
NGC 5000	10.22 ± 0.09	10.02 ± 0.04	10.18
NGC 5016	9.98 ± 0.10	10.00 ± 0.03	15.29
NGC 5029	10.86 ± 0.10	11.40 ± 0.03	15.45
NGC 5056	10.32 ± 0.08	10.30 ± 0.05	13.77
NGC 5205	9.43 ± 0.09	9.78 ± 0.04	16.41
NGC 5216	10.08 ± 0.08	10.33 ± 0.06	15.28
NGC 5218	10.15 ± 0.09	10.23 ± 0.01	12.30
UGC08733	8.96 ± 0.10	9.86 ± 0.04	19.90
IC0944	10.46 ± 0.11	10.84 ± 0.02	9.80
UGC08778	9.65 ± 0.10	10.08 ± 0.04	11.90
UGC08781	10.59 ± 0.08	10.70 ± 0.04	12.01
NGC 5378	10.04 ± 0.08	10.22 ± 0.03	19.29
NGC 5406	10.46 ± 0.08	10.70 ± 0.01	14.93
NGC 5480	9.56 ± 0.09	9.64 ± 0.06	17.41
NGC 5485	10.20 ± 0.08	10.48 ± 0.02	21.81
UGC09067	10.51 ± 0.09	10.69 ± 0.03	11.26
NGC 5520	9.63 ± 0.10	9.89 ± 0.03	11.87
NGC 5614	10.73 ± 0.08	10.67 ± 0.04	15.67
NGC 5631	10.20 ± 0.08	10.29 ± 0.03	17.44
NGC 5633	9.91 ± 0.09	9.93 ± 0.04	12.93
NGC 5630	9.37 ± 0.09	9.90 ± 0.05	13.78
NGC 5657	9.97 ± 0.10	10.13 ± 0.04	11.59
NGC 5682	8.87 ± 0.09	9.89 ± 0.10	19.63
NGC 5720	10.58 ± 0.10	10.66 ± 0.02	11.87
NGC 5732	9.77 ± 0.10	10.07 ± 0.06	12.28
UGC09476	9.78 ± 0.10	9.91 ± 0.03	15.46
UGC09537	10.57 ± 0.09	11.20 ± 0.05	15.76
UGC09542	9.98 ± 0.10	10.31 ± 0.03	12.89
NGC 5784	10.75 ± 0.08	10.88 ± 0.02	11.91
NGC 5797	10.47 ± 0.09	10.49 ± 0.02	13.71
IC1079	10.91 ± 0.10	11.23 ± 0.03	19.34
UGC09665	9.44 ± 0.10	9.88 ± 0.04	11.61
NGC 5876	10.19 ± 0.09	10.67 ± 0.01	15.05
NGC 5888	10.68 ± 0.10	10.99 ± 0.01	12.07
NGC 5908	10.28 ± 0.08	10.71 ± 0.01	14.60
NGC 5930	10.13 ± 0.08	10.18 ± 0.02	14.40
NGC 5934	10.20 ± 0.10	10.43 ± 0.06	6.75
UGC09873	9.85 ± 0.09	10.30 ± 0.03	14.82
UGC09892	9.96 ± 0.09	10.19 ± 0.02	13.68
NGC 5953	10.06 ± 0.09	9.63 ± 0.03	9.09
NGC 5971	9.96 ± 0.11	10.16 ± 0.04	10.18
NGC 5966	10.58 ± 0.09	10.88 ± 0.03	20.30
IC4566	10.49 ± 0.09	10.59 ± 0.01	13.16
NGC 5987	10.42 ± 0.09	10.71 ± 0.02	22.53

**Table A1** – *continued*

Name	$M_\star$	$M_{dyn}$	$r_e$
(1)	[ $M_\odot$ ] (2)	[ $M_\odot$ ] (3)	[arcsec] (4)
NGC 5980	10.39 ± 0.09	10.50 ± 0.03	12.64
NGC 6004	10.27 ± 0.07	10.21 ± 0.03	20.41
UGC10097	10.80 ± 0.10	10.96 ± 0.02	10.39
NGC 6020	10.38 ± 0.10	10.62 ± 0.04	11.59
NGC 6021	10.53 ± 0.09	10.51 ± 0.04	8.47
IC1151	9.49 ± 0.09	9.82 ± 0.05	19.34
UGC10123	9.88 ± 0.10	10.29 ± 0.02	11.01
NGC 6032	9.83 ± 0.10	10.16 ± 0.03	14.79
NGC 6060	10.49 ± 0.08	10.66 ± 0.01	20.20
UGC10205	10.69 ± 0.11	10.98 ± 0.02	13.95
NGC 6063	9.75 ± 0.10	10.05 ± 0.03	17.78
IC1199	10.33 ± 0.08	10.67 ± 0.01	18.76
UGC10257	9.86 ± 0.09	10.28 ± 0.04	15.25
NGC 6081	10.52 ± 0.10	10.75 ± 0.01	10.43
UGC10297	8.62 ± 0.09	9.53 ± 0.04	10.85
UGC10331	9.50 ± 0.10	10.14 ± 0.08	15.41
NGC 6125	10.66 ± 0.09	10.93 ± 0.01	15.38
UGC10337	10.61 ± 0.10	11.01 ± 0.01	14.85
NGC 6132	10.00 ± 0.09	10.36 ± 0.03	11.89
NGC 6146	11.06 ± 0.09	11.26 ± 0.02	11.00
UGC10380	10.52 ± 0.10	10.98 ± 0.03	12.83
NGC 6150	10.65 ± 0.10	11.11 ± 0.03	9.26
UGC10384	9.95 ± 0.11	10.35 ± 0.05	9.27
UGC10388	10.23 ± 0.09	10.44 ± 0.02	10.91
NGC 6173	11.18 ± 0.09	11.51 ± 0.02	18.52
NGC 6168	9.40 ± 0.10	9.85 ± 0.05	16.28
NGC 6186	9.96 ± 0.09	9.94 ± 0.04	12.67
UGC10650	8.80 ± 0.09	10.48 ± 0.10	15.29
NGC 6278	9.96 ± 0.10	10.38 ± 0.01	9.56
UGC10693	10.77 ± 0.09	11.28 ± 0.03	15.24
UGC10695	10.81 ± 0.09	11.12 ± 0.03	15.73
UGC10710	10.48 ± 0.09	10.88 ± 0.03	12.01
NGC 6310	10.02 ± 0.10	10.41 ± 0.02	15.84
NGC 6301	10.88 ± 0.08	10.94 ± 0.02	20.01
NGC 6314	10.57 ± 0.08	10.52 ± 0.03	8.72
NGC 6338	11.06 ± 0.10	11.50 ± 0.02	19.15
UGC10796	9.16 ± 0.12	9.78 ± 0.10	14.70
UGC10811	10.46 ± 0.09	10.90 ± 0.04	11.82
IC1256	10.19 ± 0.09	10.35 ± 0.02	14.60
NGC 6394	10.32 ± 0.09	10.68 ± 0.02	9.05
UGC10905	10.81 ± 0.09	11.04 ± 0.03	12.37
NGC 6411	10.54 ± 0.09	10.77 ± 0.03	17.82
NGC 6427	10.00 ± 0.10	10.30 ± 0.02	8.88
UGC10972	10.22 ± 0.10	10.51 ± 0.03	19.31
NGC 6478	10.83 ± 0.09	10.97 ± 0.02	17.36
NGC 6497	10.52 ± 0.08	10.74 ± 0.01	11.99
NGC 6515	10.79 ± 0.09	10.97 ± 0.04	13.07
UGC11228	10.55 ± 0.10	10.48 ± 0.03	7.23
NGC 6762	9.91 ± 0.09	10.03 ± 0.06	11.21
MCG-02-51-004	10.66 ± 0.09	10.75 ± 0.01	15.80
NGC 6941	10.64 ± 0.09	10.72 ± 0.01	15.04
NGC 6945	9.11 ± 0.08	10.41 ± 0.02	12.80
NGC 6978	10.49 ± 0.10	10.73 ± 0.01	12.15
UGC11649	10.14 ± 0.08	10.28 ± 0.02	14.54
UGC11680NED01	10.84 ± 0.09	10.94 ± 0.01	14.56
NGC 7025	10.82 ± 0.09	11.05 ± 0.02	18.20
NGC 7047	10.51 ± 0.10	10.70 ± 0.02	19.97
UGC11717	10.66 ± 0.09	10.44 ± 0.17	11.77
MCG-01-54-016	8.38 ± 0.11	9.82 ± 0.07	12.07
NGC 7194	10.75 ± 0.09	11.20 ± 0.05	11.96
UGC12054	8.58 ± 0.10	9.44 ± 0.07	10.41
NGC 7311	10.59 ± 0.09	10.59 ± 0.02	10.60

**Table A1** – *continued*

Name	$M_\star$	$M_{dyn}$	$r_e$
(1)	[ $M_\odot$ ] (2)	[ $M_\odot$ ] (3)	[arcsec] (4)
NGC 7321	10.65 ± 0.08	10.74 ± 0.03	12.04
UGC12127	11.01 ± 0.09	11.46 ± 0.04	18.86
NGC 7364	10.60 ± 0.10	10.57 ± 0.02	10.56
UGC12185	10.36 ± 0.08	10.57 ± 0.04	9.71
NGC 7436B	11.21 ± 0.10	11.52 ± 0.02	22.59
UGC12274	10.64 ± 0.09	10.85 ± 0.02	12.39
UGC12308	8.95 ± 0.10	10.03 ± 0.07	20.19
NGC 7466	10.55 ± 0.09	10.63 ± 0.02	12.64
NGC 7489	10.53 ± 0.08	10.42 ± 0.04	16.66
NGC 7550	10.87 ± 0.09	11.07 ± 0.03	16.66
NGC 7549	10.38 ± 0.09	10.60 ± 0.02	16.64
NGC 7563	10.28 ± 0.09	10.59 ± 0.01	8.88
NGC 7562	10.68 ± 0.09	10.85 ± 0.03	14.03
NGC 7591	10.62 ± 0.10	10.51 ± 0.03	13.08
UGC12494	9.33 ± 0.10	10.09 ± 0.17	14.49
IC5309	10.47 ± 0.11	10.05 ± 0.07	13.31
NGC 7608	9.13 ± 0.09	9.72 ± 0.03	7.61
NGC 7611	10.20 ± 0.11	10.71 ± 0.07	9.76
UGC12519	9.84 ± 0.09	10.12 ± 0.03	11.73
NGC 7619	10.80 ± 0.08	11.15 ± 0.02	21.44
NGC 7623	10.20 ± 0.09	10.14 ± 0.03	7.97
NGC 7625	9.64 ± 0.08	9.51 ± 0.03	9.80
NGC 7631	10.21 ± 0.09	10.28 ± 0.02	14.10
NGC 7653	10.46 ± 0.09	10.17 ± 0.04	12.28
NGC 7671	10.31 ± 0.10	10.60 ± 0.02	9.26
NGC 7683	10.46 ± 0.10	10.69 ± 0.03	12.80
NGC 7684	10.47 ± 0.10	10.48 ± 0.02	9.04
NGC 7691	10.25 ± 0.09	10.21 ± 0.03	22.82
NGC 7711	10.53 ± 0.09	10.69 ± 0.03	13.47
NGC 7716	10.17 ± 0.08	9.94 ± 0.04	14.16
NGC 7722	10.74 ± 0.09	10.91 ± 0.07	18.01
UGC12723	9.78 ± 0.13	10.27 ± 0.02	15.94
NGC 7738	10.67 ± 0.10	10.64 ± 0.01	11.51
UGC12810	10.43 ± 0.09	10.72 ± 0.02	13.56
UGC12816	9.74 ± 0.11	10.29 ± 0.05	12.85
NGC 7783NED01	10.64 ± 0.10	11.08 ± 0.03	9.98
NGC 7787	10.56 ± 0.10	10.59 ± 0.04	13.55
UGC12857	9.55 ± 0.10	9.83 ± 0.06	18.39
UGC12864	9.69 ± 0.10	9.95 ± 0.06	14.00
NGC 7800	8.93 ± 0.08	10.10 ± 0.07	16.30
NGC 5947	10.28 ± 0.10	10.26 ± 0.03	10.55
NGC 5947	10.28 ± 0.10	10.26 ± 0.03	10.55
NGC 5947	10.28 ± 0.10	10.26 ± 0.03	10.55
NGC 0180	10.72 ± 0.08	10.59 ± 0.04	20.19
NGC 0192	10.46 ± 0.09	10.49 ± 0.02	13.90
NGC 0155	10.72 ± 0.10	10.82 ± 0.02	13.55
NGC 0160	10.73 ± 0.09	10.87 ± 0.01	19.42
NGC 0169	10.88 ± 0.10	10.98 ± 0.06	19.42
NGC 0171	10.29 ± 0.08	9.89 ± 0.04	15.81
NGC 0177	10.35 ± 0.10	10.45 ± 0.04	17.53

Notes. Col. (1): Galaxy name. Col. (2): Stellar mass within  $r_e$  estimated from PIPE3D. Col. (3): Dynamical mass estimated from the kinematic parameter  $S_{0.5}$ . Col. (4): Effective radius  $r_e$ .

## APPENDIX B: LINEAR FIT PARAMETERS AND SCATTERS FOR THE $M_\star$ – $S_{0.5}$ CORRELATIONS

All scatters are estimated from the linear fit as the standard deviation of all residuals, we consider stellar mass,  $M_\star$ , as independent variable.  $\log(S_{0.5}) = a + b \log(M_\star)$ .  $S_{0.5}$  is given in [ $\text{km s}^{-1}$ ] and  $M_\star$  in  $M_\odot$ .

Fit	zero-point(a)	slope(b)	scatter
<b>Integrated kinematics</b>			
<i>Gas</i>			
Forward	$-0.95 \pm 0.11$	$0.29 \pm 0.01$	0.087
Inverse	$-1.99 \pm 0.18$	$0.38 \pm 0.01$	0.100
Bisector	$-1.46 \pm 0.13$	$0.33 \pm 0.01$	0.090
Orthogonal	$-1.03 \pm 0.12$	$0.29 \pm 0.01$	0.087
<i>Stellar</i>			
Forward	$-0.61 \pm 0.10$	$0.25 \pm 0.01$	0.075
Inverse	$-1.52 \pm 0.14$	$0.34 \pm 0.01$	0.086
Bisector	$-1.06 \pm 0.11$	$0.29 \pm 0.01$	0.078
Orthogonal	$-0.67 \pm 0.10$	$0.26 \pm 0.01$	0.075
<i>Total (Gas+Stellar)</i>			
Forward	$-0.72 \pm 0.07$	$0.26 \pm 0.01$	0.082
Inverse	$-1.73 \pm 0.11$	$0.36 \pm 0.01$	0.096
Bisector	$-1.22 \pm 0.08$	$0.31 \pm 0.01$	0.086
Orthogonal	$-0.79 \pm 0.07$	$0.27 \pm 0.01$	0.082
<b>Resolved kinematics</b>			
<i>Gas</i>			
Forward	$-0.89 \pm 0.14$	$0.28 \pm 0.01$	0.053
Inverse	$-1.29 \pm 0.18$	$0.32 \pm 0.02$	0.056
Bisector	$-1.09 \pm 0.15$	$0.30 \pm 0.01$	0.054
Orthogonal	$-0.92 \pm 0.13$	$0.29 \pm 0.01$	0.053
<i>Stellar</i>			
Forward	$-0.67 \pm 0.12$	$0.26 \pm 0.01$	0.052
Inverse	$-1.40 \pm 0.17$	$0.33 \pm 0.01$	0.056
Bisector	$-1.03 \pm 0.14$	$0.29 \pm 0.01$	0.050
Orthogonal	$-0.72 \pm 0.12$	$0.27 \pm 0.01$	0.052
<i>Total (gas+stellar)</i>			
Forward	$-0.66 \pm 0.08$	$0.26 \pm 0.01$	0.054
Inverse	$-1.31 \pm 0.13$	$0.32 \pm 0.01$	0.059
Bisector	$-0.98 \pm 0.10$	$0.29 \pm 0.01$	0.055
Orthogonal	$-0.71 \pm 0.11$	$0.27 \pm 0.01$	0.054
<b>Only spiral galaxies</b>			
<i>Gas</i>			
Forward	$-0.87 \pm 0.15$	$0.28 \pm 0.02$	0.043
Inverse	$-0.98 \pm 0.11$	$0.29 \pm 0.01$	0.044
Bisector	$-0.93 \pm 0.14$	$0.29 \pm 0.01$	0.043
Orthogonal	$-0.88 \pm 0.09$	$0.28 \pm 0.01$	0.043
<i>Stellar</i>			
Forward	$-0.88 \pm 0.10$	$0.28 \pm 0.01$	0.051
Inverse	$-1.35 \pm 0.12$	$0.32 \pm 0.02$	0.057
Bisector	$-1.12 \pm 0.13$	$0.30 \pm 0.01$	0.054
Orthogonal	$-0.92 \pm 0.12$	$0.28 \pm 0.01$	0.052
<i>Total (gas+stellar)</i>			
Forward	$-0.77 \pm 0.12$	$0.27 \pm 0.01$	0.051
Inverse	$-1.16 \pm 0.10$	$0.31 \pm 0.01$	0.056
Bisector	$-0.96 \pm 0.16$	$0.29 \pm 0.01$	0.053
Orthogonal	$-0.80 \pm 0.11$	$0.27 \pm 0.01$	0.051

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