Galaxy kinematics in the XMMU J2235-2557 cluster field at $z \sim 1.4$ ★

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ABSTRACT

Aims. The relationship between baryonic and dark components in galaxies varies with the environment and cosmic time. Galaxy scaling relations describe strong trends between important physical properties. A very important quantitative tool in case of spiral galaxies is the Tully-Fisher relation (TFR), which combines the luminosity of the stellar population with the characteristic rotational velocity ($V_{\max}$) taken as proxy for the total mass. In order to constrain galaxy evolution in clusters, we need measurements of the kinematic status of cluster galaxies at the starting point of the hierarchical assembly of clusters and the epoch when cosmic star formation peaks.

Methods. We took spatially resolved slit FORS2 spectra of 19 cluster galaxies at $z \sim 1.4$, and 8 additional field galaxies at $1 < z < 1.2$ using the ESO Very Large Telescope. The targets were selected from previous spectroscopic and photometric campaigns as [OII] and H_{α} emitters. Our spectroscopy was complemented with HST/ACS imaging in the $F775W$ and $F850LP$ filters, which is mandatory to derive the galaxy structural parameters accurately. We analyzed the ionized gas kinematics by extracting rotation curves from the two-dimensional spectra. Taking into account all geometrical, observational, and instrumental effects, we used these rotation curves to derive the intrinsic maximum rotation velocity.

Results. $V_{\max}$ was robustly determined for six cluster galaxies and three field galaxies. Galaxies with sky contamination or insufficient spatial rotation curve extent were not included in our analysis. We compared our sample to the local B -band TFR and the local velocity-size relation (VSR), finding that cluster galaxies are on average 1.6 mag brighter and a factor 2–3 smaller. We tentatively divided our cluster galaxies by total mass (i.e., $V_{\max}$) to investigate a possible mass dependency in the environmental evolution of galaxies. The averaged deviation from the local TFR is $\langle \Delta M_B \rangle = -0.7$ for the high-mass subsample ($V_{\max} > 200 \text{ km s}^{-1}$). This mild evolution may be driven by younger stellar populations (SP) of distant galaxies with respect to their local counterparts, and thus, an increasing luminosity is expected toward higher redshifts. However, the low-mass subsample ($V_{\max} < 200 \text{ km s}^{-1}$) is made of highly overluminous galaxies that show $\langle \Delta M_B \rangle = -2.4$ mag. When we repeated a similar analysis with the stellar mass TFR, we did not find significant offsets in our subsamples with respect to recent results at similar redshift. While the B -band TFR is sensitive to recent episodes of star formation, the stellar mass TFR tracks the overall evolution of the underlying stellar population. In order to understand the discrepancies between these two incarnations of the TFR, the reported B -band offsets can no longer be explained only by the gradual evolution of stellar populations with lookback time. We suspect that we instead see compact galaxies whose star formation was enhanced during their infall toward the dense regions of the cluster through interactions with the intracluster medium.

Key words. galaxies: kinematics and dynamics – galaxies: clusters: individual: XMMU J2235.3-2557 – galaxies: high-redshift – galaxies: evolution

1. Introduction

In the past years, we have achieved a good understanding of galaxy evolution from both observations and simulations. To mention a few examples, it is well established now that cosmic star formation (SF) rises strongly out to redshift 1 (Lilly et al. 1996) and then turns into a plateau (Bouwens et al. 2007). At similar epochs, quasar (AGN) activity of $L_{\ast}$ -galaxies peaks (Hasinger et al. 2005). Deep fields reveal that $z = 1$ galaxies can already have obtained both regular elliptical and spiral morphologies. Hubble volume simulations are able to reproduce these basic facts (Angulo & White 2010). On the other hand, difficulties persist in some aspects like the mass-dependent shutting-down of SF by feedback processes (Bower et al. 2012) and the gas infall rate sustaining too high SF rates (Tonini et al. 2011). While it is possible to empirically model certain aspects (Peng et al. 2010), we still lack knowledge of the underlying

physical mechanisms. For example, the relative contributions to galaxy mass growth by major mergers and gas accretion (Dekel et al. 2009) are still controversial.

A very important quantitative tool in case of spiral galaxies is the Tully-Fisher relation (TFR), which combines the luminosity of the stellar population (SP) with the characteristic rotational velocity taken as proxy for the total mass (including dark matter). It is well established in the local Universe (Pierce & Tully 1992) and was examined for evolution in recent years out to redshift 1, including work by our own group (Ziegler et al. 2003; Böhm et al. 2004; Böhm & Ziegler 2007, 2016).

The traditional TFR is a subset of a more fundamental relation between baryonic mass (stellar and gas content) and rotational velocity. However, the gas mass fraction can only be observed directly for $z \sim 0$ galaxies. For nearby massive $L_{\ast}$ -galaxies only a mild brightening was detected that translates into little overall evolution in the baryonic TFR (McGaugh et al. 2000). At higher redshift, Puech et al. (2010) constructed this relation by converting multicolor photometry into stellar masses

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assuming some SP model and estimating the gas mass fraction, finding no evolution up to $z \sim 0.6$. This indicates that a significant fraction of spirals have well-established disks at $z = 1$ and do not undergo major mergers until $z = 0$. [Dutton et al. \(2011\)](#) furthermore showed that the observed evolution of the scaling relations involving circular velocity, mass, and size are consistent with a simple CDM-based model of disks growing inside evolving Navarro-Frenk-White (NFW) dark matter haloes. However, challenging measurements of 2D velocity fields at $z \approx 0.5$ reveal disturbances that can be explained by ongoing mass growth through accretion or minor mergers ([Puech et al. 2008](#); [Kutdemir et al. 2008](#); [Kutdemir et al. 2010](#)).

In contrast, massive SF galaxies around $z \geq 2$ can display various kinematic behaviors from disk rotation through dispersion dominance to major mergers (e.g., [Genzel et al. 2006](#); [Förster Schreiber et al. 2009](#); [Lehnert et al. 2009](#)). It was recently found by [Wisnioski et al. \(2015\)](#) using data from the *KMOS*^{3D} survey that 93% of galaxies at $z \sim 1$ and 74% of galaxies at $z \sim 2$ are rotationally supported, as determined from a continuous velocity gradient and $v_{\text{rot}}/\sigma_0 > 1$, while they showed a disk fraction of 58% when applying the additional stricter criteria that the projected velocity dispersion distribution peaks on or near the kinematic center, the velocity gradient is measured along the photometric major axis (for inclined systems), and the kinematic centroid is close to the center of the galaxy continuum. In contrast, applying the morpho-kinematic classification to a *KMOS*^{3D} subsample, [Rodrigues et al. \(2017\)](#) found that only 25% of $z \sim 1$ galaxies are virialized spirals according to their morpho-kinematic classification. [Simons et al. \(2016\)](#) studied 49 galaxies from CANDELS fields with the Keck/MOSFIRE spectrograph and found that high-mass galaxies ($\log M/M_\odot > 10.2$) at $z \sim 2$ are generally rotationally supported and fall on the TF relation, large portion of less massive galaxies at this epoch are in the early phases of assembling their disks.

A sample of 14 galaxies at $z \sim 2$ was studied by [Cresci et al. \(2009\)](#), who found a significant offset in the M_* -TFR with increased scatter compared to local samples, which is even more prominent in the $z = 3$ study of [Gnerucci et al. \(2011\)](#). This implies a strong evolution within 2–3 Gyr with massive SF galaxies changing their dynamical state dramatically before settling into a more quiescent epoch at $z = 1$. This demands thorough measurements of spatially resolved emission lines of galaxies at $z = 1$ –2 in order to understand this transition and its possible causes. A first study by [Miller et al. \(2012\)](#) exploited ultra-deep Keck spectroscopy of the most suitable targets in five deep fields (EGS, SSA22, GOODS N&S, and COSMOS) that benefit from multi-wavelength coverage. They found that most galaxies follow an M_* -TFR with a mild offset but strongly increased scatter compared to the local TFR. In a similar way, [Vergani et al. \(2012\)](#) found a lack of any strong evolution of the fundamental relations of star-forming galaxies in at least the past 8 Gyr using a sample of 46 galaxies at $1 < z < 1.6$ from MASSIV (Mass Assembly Survey with SINFONI in VVDS). In contrast, [Tiley et al. \(2016\)](#) found an offset of the TFR for rotationally supported galaxies at $z \sim 1$ to lower stellar mass values (−0.41 dex) for a given dynamical mass but no significant offset in the absolute K -band TFR over the same period, contrary to some previous studies conducted at similar redshift but in agreement with the predictions of hydrodynamical simulations of EAGLE.

Most of these studies were restricted to the field population, while in clusters, additional specific effects should affect the content and structure of galaxies. Galaxy clusters provide special environments to test galaxy evolution across different cosmic epochs. Compared to the field, the number density of

galaxies is high, as are the relative velocities. The gravitational potential of a cluster is filled by the intracluster medium (ICM), a hot X-ray emitting gas, and the overall mass-to-light ratio is much higher than for the individual galaxies, indicating the presence of vast amounts of dark matter. This environment exerts a strong influence on the evolution of the cluster galaxies superposed on the (field) evolution that arises from the hierarchical growth of objects and the declining star formation rates over cosmic epochs. In addition to tidal interactions between galaxies, including merging, cluster members are affected by cluster-specific phenomena related to the ICM (such as ram pressure stripping) or the structure of the cluster (such as harassment). Imprints of these interactions can be seen not only in present-day clusters, but they also manifest themselves in a strong evolution of the population of cluster galaxies. One example is the photometric Butcher-Oemler effect of an increasing fraction of blue galaxies with redshift ([Butcher & Oemler 1978](#)), implying a rising percentage of star-forming galaxies.

However, comparisons between the TFRs of cluster and field galaxies show no clear results. [Milvang-Jensen et al. \(2003\)](#) and [Bamford et al. \(2005\)](#) found higher B -band luminosities in clusters compared to the field, while [Moran et al. \(2007\)](#) presented a larger scatter for cluster galaxies. On the other hand, cluster and field populations follow the same trends with no significant differences between these two environments according to [Ziegler et al. \(2003\)](#), [Nakamura et al. \(2006\)](#), [Jaffé et al. \(2011\)](#), [Mocz et al. \(2012\)](#), and [Bösch et al. \(2013\)](#). These discrepancies may stem from the necessity to use only regular rotation curves (RC) for a proper TF analysis that is based on the virial theorem.

In order to extend such measurements to higher redshifts and to investigate possible biases, we here present a kinematic study of the massive cluster XMMU J2235-2557 ([Mullis et al. 2005](#)) at $z \sim 1.4$. Making use of the multiwavelength data including HST imaging ([Rosati et al. 2009](#); [Strazzullo et al. 2010](#)), which allows determining morphologies and accurate deriving of structural parameters (needed for a proper kinematic analysis), we scrutinize the environmental dependence of disk galaxy scaling relations at the highest redshift to date.

The structure of this paper is as follows: in Sect. 2 we describe the target selection, observation conditions, and spectroscopic data reduction. The description of the photometric properties of our sample and details on the derivation of the structural parameters and maximum rotation velocities are shown in Sect. 3. We present and discuss our results in Sects. 4 and 5, followed by a short summary in Sect. 6. Throughout this article we assume a [Chabrier \(2003\)](#) initial mass function (IMF) and adopt a flat cosmology with $\Omega_\Lambda = 0.7$, $\Omega_m = 0.3$, and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$. Magnitudes quoted in this paper are in the AB system.

2. Sample selection and observations

We carried out multi-object spectroscopy (MXU) with FORS2 between September 2013 and July 2014 to obtain the spectra of 27 galaxies with one mask. We chose the holographic grism 600z+23, which covers $\sim 3300 \text{ Å}$ in the wavelength range 7370–10 700 Å. The slits were tilted and aligned to the apparent major axis of the targets in order to minimize geometrical distortions. Slit tilt angles θ were limited to $|\theta| < 45^\circ$ to ensure a robust sky subtraction and wavelength calibration. We used a slit width of $0.7''$, which delivers an instrumental resolution of $\sigma_{\text{ins}} = 65 \text{ km s}^{-1}$. This configuration yielded a spectral resolution of $R \sim 1400$ and an average dispersion of 0.81 Å/pix

Table 1. Summary of the imaging data used in this work.

Telescope	Instrument	Filter	Exp. time (s)	PSF <i>FWHM</i> ($''$)	PID
VLT	VIMOS	<i>U</i>	21 600	0.80	079.A-0758
...	FORS2	<i>B</i>	1590	0.72	087.A-0859
...	...	<i>R</i>	2250	0.75	072.A-0706, 073.A-0737
...	...	<i>z</i>	1200	0.40	274.A-5024, 091.B-0778
...	HAWKI	<i>J</i>	10 560	0.47	060.A-9284(H)
...	...	<i>Ks</i>	10 740	0.32	...
CTIO/Blanco	ISPI	<i>H</i>	1200	1.07	2009B-0484
HST	ACS/WFC	<i>F775W</i>	13 500	0.10	10496, 10531, 10698
...	...	<i>F850LP</i>	14 400	0.10	...
<i>Spitzer</i>	IRAC	$3.6 \mu\text{m}$	6262	1.95	20760
...	...	$4.5 \mu\text{m}$	6262	2.02	...

with an image scale of $0.25''/\text{pixel}$. The total integration time for the MXU observations was 9 h per target. In order to diminish the number of cosmic ray hits in our spectra, the observations were divided into 12 observing blocks (OBs) of one hour each, with three subexposures of 15 min per OB plus overheads. We achieved seeing conditions of 0.73 arcsec FWHM on average.

The primary targets for the kinematic analysis were 15 cluster galaxies with measured spectroscopic redshifts and $[\text{OII}]\lambda 3727 \text{ \AA}$ emission. These galaxies were extracted from two catalogs of previous spectroscopic campaigns in the same cluster field provided by M. Tanaka & V. Strazzullo (priv. comm.). Another set of 5 galaxies with photometric redshift from deep narrow-band imaging corresponding to the rest-frame wavelength of $H\alpha$ were selected from Grützbauch et al. (2012) at the cluster redshift. The remaining available mask space was filled with galaxies of disk-like appearance and appropriate position angle, but unknown redshift, yielding 27 targets in total.

We performed the spectroscopic data reduction mainly using the ESO-REFLEX pipeline for FORS2 (version 1.19.4). The main reduction steps were bias subtraction, flat normalization, and wavelength calibration. The last was improved by removing some lines from the catalog of arc lines. Additionally, we performed bad pixel and cosmic ray cleaning by coadding the exposures with a sigma-clipping algorithm using IRAF. We show the coordinates, redshifts, rest frame colors, and magnitudes of our final sample in Table A.1.

3. Methods

3.1. Imaging and photometry

To complement the spectroscopy, we made use of imaging data from a variety of sources, including HST/ACS (*F775W* and *F850LP*), VLT/FORS2 (*B*, *R*, *z*-bands), VLT/VIMOS (*U* band), VLT/HAWKI (*J* and *Ks* bands), CTIO/ISPI (*H* band), and *Spitzer* IRAC ($3.6 \mu\text{m}$ and $4.5 \mu\text{m}$), encompassing thus from the rest-frame UV to the near-infrared (NIR) at the cluster redshift. The characteristics of these datasets are described in Table 1.

The HAWKI data reduction is described in Lidman et al. (2008) and the processed images were subsequently released as Phase 3 products in the ESO archive, from where we retrieved them. Zero-points were also provided in the Vega system, which we transformed into the AB system.

The FORS2 and VIMOS images were also retrieved from the ESO archive as raw data. Similarly, the CTIO-Blanco/ISPI *H*-band raw frames were downloaded from the NOAO science archive. These datasets were processed with the THELI pipeline

(Schirmer 2013), which takes care of all basic reduction steps as well as the astrometric calibration and coaddition. Photometric calibration for the FORS2 *B* and *R* and the VIMOS *U*-band images was performed using a two step approach. First, zero-points were fixed to the official zero-points available at the ESO webpages. However, noticeable differences were detected in the color of stars in comparison to stellar libraries (Pickles 1998). We therefore produced synthetic colors for all available bands and compared them to the observed colors using the stellar locus method (e.g., Kelly et al. 2014), adjusting them until all differences were minimal. The applied corrections ranged from 0.3 to 0.6 mag.

There was no zero-point available for the FORS2 *z* band. Fortunately, the filter transmission curve is nearly identical to the HST/ACS *F850LP* filter available for a significant part of the field. Therefore the FORS2 *z* band was calibrated against that latter dataset. The ISPI *H* band was calibrated using 2MASS stars available in the field and transformed to the AB system. The remaining space-based images were retrieved fully processed and calibrated, so that no additional steps were necessary before performing the photometry.

The spatial coverage of the different datasets is shown in Fig. 1, where we also mark the targets of the spectroscopic campaign. Clearly, not all galaxies have measurements in all bands. However, they do have enough measurements across a wide wavelength range to reliably determine all parameters necessary for our analysis.

Because of the varying depth, field of view, point-spread function (PSF), pixel scales, and quality of the imaging, special care must be taken in performing the photometry for our target galaxies. We therefore deviated slightly from the standard approaches that use more homogeneous datasets. In particular, we chose to forego degrading the high-quality imaging (HST and HAWKI) to the worst seeing. We did not rebin the images to match the pixel sizes of the rest of the imaging either, as required by dual-band photometry. Instead, we chose to measure magnitudes within an elliptical Kron aperture (Kron 1980) matched to the seeing in each image. To calculate the size of the Kron aperture, we used SExtractor (Bertin & Arnouts 1996) in the high-quality data where we measured the coordinates, the Kron radius, the ellipticity, the position angle, and the Kron magnitudes (MAG_AUTO). These parameters were passed to the python PHOT_UTILS tools, which replicates many of the functionalities found in SExtractor in a more flexible environment.

To calculate by how much the Kron apertures need to grow to take into account the different seeing values in the other bands,

Fig. 1. Portion (8.25×8.25 arcmin²) of the *J*-band HAWKI image with *XMM-Newton* X-ray contours overlaid. The field of view of the different instruments used in this work is also shown. The HAWKI *J* and *K*s and ISPI *H*-band observations cover a field of view much larger than the figure. The FORS2 *B*-, *R*- and *z*-band coverage was obtained from different ESO programs. Most of the X-ray sources are likely distant AGNs, but the extended emission associated with the cluster can be appreciated in the center. The dashed circle marks the $R_{500} = 0.75$ Mpc radius derived by Rosati et al. (2009). We denote the position of the galaxies analyzed in this study by distinguishing between field and cluster and between those that yielded a $V_{\max}$ value and those that did not.

we used the software STUFF and SKYMAKER (Bertin 2009) to simulate realistic galaxy fields with different spatial resolutions, where we ran SEXTRACTOR with the same parameters over the same galaxies. In general, the Kron radii growth can be modeled as a simple linear function that depends only on the measurements in the high-quality imaging and the seeing in the lower quality imaging. Magnitudes computed by PHOT_UTILS using the derived apertures are in excellent agreement (at ~ 0.1 mag level) with those determined directly by SEXTRACTOR.

The above procedures were not applied to the *Spitzer* images, however. With a PSF FWHM of ~ 2 arcsec, distant galaxies are effectively unresolved in the IRAC images. We therefore used a fixed circular aperture of 6 arcsec and applied the standard correction factors for the missing flux (factors 1.205 and 1.221 in the 3.6 and 4.5 μ m bands, respectively). In conclusion, we estimate the total calibration for all bands to have an accuracy of 0.1 mag.

3.2. Stellar masses and rest-frame magnitudes

Rest frame magnitudes and stellar masses were determined using the code LEPHARE of Arnouts & Ilbert (2011; see also Ilbert et al. 2006), which fits stellar population synthesis models (Bruzual & Charlot 2003) to the spectral energy distribution (SED) derived from the photometry. The code is a simple χ^2

minimization algorithm that finds the best match of templates for the given data. To avoid overfitting, we restricted the possible ages to values lower than the age of the Universe at the redshift of the cluster. Thus, we have average errors in absolute magnitude and stellar masses of 0.12 mag. and 0.09 dex, respectively.

To place our sample of cluster galaxies into context, we present in Fig. 2 the color–magnitude diagram in *J* and *K* bands for XMMJ2235 galaxy members. The cluster red-sequence fit from Lidman et al. (2008) is shown with a black line, with red-sequence galaxies defined as galaxies redder than 0.2 mag blueward of this fit. The purpose of this comparison is to highlight the nature of our cluster galaxies with [OII]-based kinematics. We would like to mention that two of our galaxies (IDs 8 and 11 in Table A.1) were part of the *Herschel* sample of dust-obscured star-forming galaxies presented in Santos et al. (2013).

Edge-on disks have higher extinction (A_B) than face-on galaxies, and more massive disks are dustier than less massive disks Giovanelli et al. (1995). We corrected the rest frame *B*-band absolute magnitudes for intrinsic dust absorption following the approach by Tully et al. (1998):

$$A_B = \log(a/b) [-4.48 + 2.75 \log(V_{\max})]. \quad (1)$$

The extinction is dependent on the inclination angle i , which is related to the ratio between the axes (a/b), and on the $V_{\max}$

Fig. 2. Color–magnitude diagram. Red stars and circles define spectroscopic cluster members with and without derived kinematics in our sample, respectively. Blue stars and circles show field galaxies with and without derived kinematics in our sample, respectively. The cluster red-sequence fit derived by Lidman et al. (2008) is shown as a black line with a shaded area: red-sequence galaxies are defined as galaxies redder than 0.2 mag blueward of this fit, which is shown with a shaded area. Magnitudes and colors are given in the AB system.

of every galaxy. After applying the extinction correction, the typical errors in B -band luminosity range from 0.2 to 0.3 mag.

3.3. Structural parameters

Owing to the relatively small spatial coverage of the HST images in this cluster, we were able to derive the structural parameters of galaxies from the z -band ($F850LP$) images only in the central regions of the cluster. For galaxies far from the cluster center, we used ground-based HAWKI photometry in K band. We used the GALFIT package by Peng et al. (2002), which allows fitting multiple 2D surface brightness profiles simultaneously to the galaxy under scrutiny. We fit the surface brightness profiles of the galaxies of our sample using two different methods:

1. A single Sérsic profile with free index n_s .
2. A two-component model with an exponential profile ($n_s = 1$) for the disk and a de Vaucouleurs profile ($n_s = 4$) for the bulge.

The best parameters from the first method were used as initial guess values for the second. All fit residuals were visually inspected (Fig. A.1), and in a few cases, it was necessary to apply constraints on some parameters in order to avoid a local minimum in the fitting process. We used the bulge/disk decomposition to obtain the disk parameters when possible within the HST coverage. However, an accurate structural decomposition was not feasible with the ground-based K -band data because of the limited spatial resolution. We therefore restricted the GALFIT models to a single Sersic profile for galaxies without available HST imaging. We stress that for the analysis presented here, the most important parameters are the ratio between the axes (a/b), position angle θ , and scale length R_d of the disk.

However, observed scale lengths depend on the wavelength regime. It was shown in de Jong (1996) that the scale length (R_d) is smaller when galaxies are observed in redder filters. The HAWKI K -band photometry overlaps with the HST z band over a region where a subsample of 14 galaxies can be studied.

We carried out the structural parameter determination in both bands, finding that HAWKI K -band-based effective radii (R_e) are on average 25% smaller than z -band-based radii. We corrected HAWKI based R_e onto z band to make them comparable before computing the scale lengths. GALFIT only returns random errors on the best-fit parameters. These are very small ($<1\%$) throughout our sample. We relied on a previous analysis of HST/ACS images using GALFIT in Böhm et al. (2013) to obtain a more realistic estimate of the systematic errors on R_d . In that work, a typical systematic error of 20% on galaxy sizes was found for a negligible central point source. This value hence represents the systematic size error for galaxies with the light profiles of pure disks or disks with only weak bulges; this is the case for the vast majority of galaxies in our sample. We therefore adopt a 20% error on R_d in the following.

The inclination i is the angle between the normal vector of the disk and the line of sight. We computed it from the apparent major axis a and the apparent minor axis b following Heidmann et al. (1972):

$$\cos^2(i) = \frac{(a/b)^2 - q^2}{1 - q^2}. \quad (2)$$

Here the factor q is the ratio between disk scale length and scale height and is fixed to 0.2, which is the observed value for typical spirals in the local Universe (Tully et al. 1998). However, at high redshift, the intrinsic disk thickness (parameter q) may be different. Since GALFIT fitting parameter errors are negligible, the uncertainty in the assumption of parameter q is the main source of error in the determination of i . We allowed different values for the disk thickness in order to simulate a thick disk ($q = 0.3$) and an infinitely thin disk ($q = 0$). The systematic error on the inclination due to the different triaxial configurations is of a few degrees ($<5^\circ$) for high- i galaxies and almost negligible for low- i galaxies.

The position angle θ denotes the orientation of the apparent major axis in the plane of the sky. Throughout this paper, the convention is that θ gives the angle between the apparent major axis and the horizontal axis, counted counter-clockwise. To minimize the geometric distortions, we constrain the mismatch angle δ , which gives the deviations between the major axis and the slit direction of a certain galaxy to $\delta \leq 30^\circ$.

3.4. Rotation-curve extraction and modeling

Our approach to extract rotation curves from spatially resolved spectra and determine $V_{\max}$ is explained in detail in Böhm et al. (2004), Bösch et al. (2013), and Böhm & Ziegler (2016). A summary of the main steps is presented here.

Before the emission line fitting, we use an averaging boxcar of three pixels width, corresponding to $0.75''$, for each spatial position in the spectrum to enhance the signal-to-noise ratio (S/N). We then transform red- and blueshifts of the emission lines as a function of galactocentric radius into an observed position-velocity diagram. The kinematic center is determined by minimizing the asymmetry of the observed RC, with a maximum allowed mismatch between kinematic and photometric center of ± 1 pixel, corresponding to ~ 2 kpc at the redshifts of our targets.

To determine $V_{\max}$ for a given galaxy, we simulate its rotation velocity field by taking into account all geometric effects such as disk inclination angle and observational effects like seeing or the influence of the slit width. The simulated velocity field is generated by assuming a linear rise of the rotation velocity $V_{\text{rot}}(r)$

Fig. 3. A) Tully-Fisher B -band diagram. B) Velocity-size relation. C) TFR evolution diagram. Offsets ΔM_B of galaxies in our sample from the local TF relation, displayed as a function of redshift. D) VSR evolution diagram. Offsets ΔR_d of galaxies in our sample with respect to the local VSR, displayed as a function of redshift. In A) and B) the gray line represents the local TFR (Tully et al. 1998) and the local VSR (Haynes et al. 1999a), respectively, with 1σ , 2σ , and 3σ shaded regions. Two samples of field galaxies are plotted for comparison: the first comprises 124 disk galaxies out to $z = 1$ from Böhm & Ziegler (2016) and is plotted with black circles. Miller et al. (2011) provided a second field sample composed of 13 disk galaxies at $1 < z < 1.3$ plotted as olive diamonds. The three field galaxies at $1 < z < 1.2$ targeted in our observations are plotted with blue stars. Cluster galaxies are represented by red stars.

at $r < r_t$, where r_t is the turnover radius, and a convergence of $V_{\text{rot}}(r)$ into a constant value $V_{\max}$ at $r > r_t$ (Courteau 1997).

In most cases, the turnover radius was set as equal to the scale length, R_d , measured from the stellar morphology. However, some galaxies required R_d fitting because the stellar scale length and the turnover radius of our extracted rotation curves were mismatched. In the last step we extract from the synthetic velocity field a simulated rotation curve from which we obtain the intrinsic maximum rotation velocity $V_{\max}$ taking into account the structural and observational parameters. The error budget on $V_{\max}$ was computed following Eq. (3) in Böhm et al. (2004), taking into account the error from the χ^2 -fits of the synthetic to the observed rotation curve, and the propagated errors of the inclination and the misalignment angle. The typical error on $V_{\max}$ is $20\text{--}30 \text{ km s}^{-1}$. For a complete description of the full process, we refer again to Böhm et al. (2004). The synthetic velocity fields and simulated and observed rotation curves of our sample are shown at the end of this paper.

Although we observed 27 objects, only 25 of them turned out to be emission line galaxies after the analysis of their spectra.

Redshift values were computed using IRAF under visual determination of [OII] emission line center, that is, the only emission line available for cluster members. We detected 17 cluster members and 8 field galaxies. However, part of the cluster sample was affected by strong sky line contamination. As a result, 8 cluster galaxies were discarded because of noisy contamination. We extracted 6 RCs of cluster members from the remaining 9 galaxies, discarding 3 galaxies because of their very compact [OII] emission, which prevents us from reaching the flat part in the RC. In addition, 3 RCs were extracted from the field sample, discarding in the process 3 galaxies with sky contamination and 2 galaxies with compact emission.

4. Results

The primary results of this paper are shown in Fig. 3, where we present the TFR and VSR for cluster galaxies (red stars) at $z \sim 1.4$. In Fig. 3A we show the B -band TFR, which is related with recent episodes of star formation. The distribution of our

Fig. 4. Correlation diagram between the offsets, ΔM_B , from the TFR and the offsets, $\Delta \log R_d$, from the VSR for previously presented samples. The solid line shows the linear fit for galaxies studied in the local Universe (Haynes et al. 1999b). By definition, this line goes through the coordinates origin. The dashed black lines plotted in this diagram show the linear fit for galaxies studied in Böhm & Ziegler (2016) at $0.59 < z < 1$, showing that galaxies are shifting away with lookback time toward higher luminosities and smaller sizes. The dotted black line is the linear fit at a fixed slope for our cluster sample, whose zero-point is shifted by -0.69 dex in $\Delta \log R_d$ with respect to the local sample.

kinematic sample is compared with the local TFR by Tully et al. (1998) and the local VSR derived by Böhm & Ziegler (2016) using data from Haynes et al. (1999b). In addition, two field samples within $0.2 < z < 1.3$ are shown as comparison between different environments.

The first field sample comprises 124 disk galaxies out to $z = 1$ from Böhm & Ziegler (2016, hereafter BZ16) plotted as black circles. This is one of the largest kinematic samples of distant galaxies to date. A second field sample composed of 13 disk galaxies at $1 < z < 1.3$ selected by redshift from a larger sample provided by Miller et al. (2011, hereafter M11) is plotted as gray diamonds. We also display the 3 field galaxies targeted in our observations at $1 < z < 1.2$ (blue stars). On average, cluster galaxies in our sample are brighter by $\langle \Delta M_B \rangle = -1.6$ mag in B band than in the local TFR and smaller by a factor of 3 than in the local VSR (Figs. 3A and B, respectively). In order to determine environmental effects, we compared the results of our cluster sample with Miller’s field galaxies at similar redshift and found that our cluster galaxies are brighter on average by $\langle \Delta M_B \rangle = -0.3$ mag in B band and smaller by a factor of 2 than their field counterparts.

In order to explore a possible environmental mass-dependent evolution and considering the position of our cluster galaxies in the Tully-Fisher diagram (Fig. 3A), our cluster sample was divided into two groups: the first is composed of three high total mass ($V_{\max} > 200 \text{ km s}^{-1}$) galaxies lying below the 2σ region of the local TFR with $\langle \Delta M_B \rangle = -0.7 \pm 0.6$. The second group is composed of three low-mass galaxies lying between the 4 and 5σ region with respect to the local TFR and showing $\langle \Delta M_B \rangle = -2.4 \pm 0.6$. The cause of this discrepancy between groups might be different physical processes acting on them due to the cluster environment. The errors on ΔM_B are computed through error propagation from the errors on $V_{\max}$ and M_B according to Eq. (3) in Böhm & Ziegler (2016). Because of the limited size of our subsamples, the uncertainty on $\langle \Delta M_B \rangle$ represents the average measurement error.

Figures 3C and D display the offsets ΔM_B and $\Delta \log R_d$ from the local TFR and VSR as a function of redshift. In panel C

field galaxies show increasing overluminosities toward higher redshifts despite the scatter of the samples. This evolution is explained by the rise of SFR and the gradual evolution of SP with lookback time. A simple extrapolation of the luminosity evolution linear fit given by Böhm & Ziegler (2016, gray line) shows that $\Delta M_B = -1.2 \pm 0.4$ mag at $z = 1.4$. As explained in Figure 3A, our cluster sample can be divided into two groups by their total mass. We compare our results with the theoretical predictions of Dutton et al. (2011, dashed line), who found $\Delta M_B = -0.95$ mag at this redshift. Our high total mass group of galaxies is in agreement with the theoretical predictions within the errors, while the low total mass group of galaxies differ by 1.4 mag. In addition, our field sample of galaxies lie within the 1σ scatter area of the predicted luminosity evolution shown in Böhm & Ziegler (2016), and at the same time, they are compatible with predictions from numerical simulations by Dutton et al. (2011).

In panel D previous samples of field galaxies show decreasing sizes toward higher redshifts, although the scatter of the samples is similar to the scatter found in C. According to the extrapolation of the linear fit given in BZ16 (gray line), the size evolution reaches $\Delta \log R_d = -(0.22 \pm 0.14)$ at $z = 1.4$, where negative values in $\Delta \log R_d$ mean smaller sizes at a given maximum rotation velocity $V_{\max}$. In this plot the $z = 1.4$ cluster galaxies do not populate two separate groups, but cover a broader range in size evolution. On average, they are two to three times smaller than their local counterparts, showing $\langle \Delta \log R_d \rangle = (-0.47 \pm 0.15)$. Our three field galaxies cover a similar range of scale lengths with a slightly higher mean value, $\langle \Delta \log R_d \rangle = (-0.39 \pm 0.14)$. In contrast, predictions from numerical simulations by Dutton et al. (2011, dashed line) showed that $\Delta \log R_d = -0.2$ at the same redshift. Errors on $\Delta \log R_d$ are computed through error propagation from the errors on $V_{\max}$ and R_d following Eq. (6) in Böhm & Ziegler (2016).

To explore the connection between scaling relations for disk galaxies, we compare in Fig. 4 the offsets ΔM_B from the TFR with the offsets $\Delta \log R_d$ from the VSR. By definition, the median of the two parameters is zero in the local Universe. However,

there is a clear correlation between ΔM_B and $\Delta \log R_d$ because luminosity, size, and maximum velocity conform a 3D parameter space in which disk galaxies populate a plane. Thus, these three parameters are correlated, and deviations between local and distant galaxies reflect the evolution of one or several of the parameters. Figure 4 shows the projection of this 3D space on a luminosity-size plane represented by the offsets in disk scale length and absolute magnitude from the local VSR and TFR. This representation was recently used by BZ16 to quantitatively study the galaxy evolution in the field up to $z = 1$. Using fixed-slope fits to determine the offsets from the local relation in terms of $\Delta \log R_d$, these authors found a combined evolution in size and luminosity in their sample with a zero-point $\Delta \log R_d = -0.29$ for field galaxies at $0.59 < z < 1$, slightly larger offset of our field sample (blue stars in Fig. 4) at slightly higher redshift $1 < z < 1.2$. However, Our sample of cluster and field galaxies at $1.2 < z < 1.4$ shows larger offsets and a zero-point of $\Delta \log R_d = -0.74$. Although our cluster sample has large scatter, our data follow the general trend in the BZ16 sample at $0 < z < 1$: distant galaxies are shifting away from the local $\Delta M_B - \Delta \log R_d$ relation toward smaller sizes and higher luminosity with lookback time.

5. Discussion

The brightening detected in the B -band TFR for cluster galaxies can be partially explained by the increasing star formation galaxies experience toward longer lookback times. However, the division of our sample into two groups according to their total mass and B -band luminosity offsets might indicate additional effects that may explain their properties. Several possible explanations have to be considered.

5.1. Observational effects

First, $V_{\max}$ might be underestimated. Persic et al. (1996) studied the relation between the mass of a galaxy and the shape of its RC by introducing a complex definition of a universal rotation curve (URC). According to this study, very low-mass spirals show an increasing rotation velocity even at large radii, whereas the rotation curves of very high-mass spirals moderately decline in that regime. These gradients are found as far as 5 optical disk scale lengths. However, our cluster sample mainly covers intermediate masses ($10.03 < \log M_* < 10.91$), where the URC does not introduce a velocity gradient at large galactocentric radii. However, the spatial extent of the rotation curves in our sample (as well as other samples at similar redshifts) is around two to four times R_d , which is insufficient to constrain potential RC gradients in the outer disk. With our RCs, we probe out to radii similar to R_{opt} , and for galaxies with $V_{\text{rot}}(R = R_{\text{opt}}) > 100 \text{ km s}^{-1}$ (all of our galaxies), the largest possible underestimate in $V_{\max}$ due to RC gradients is 10–20% (see Fig. 4 in Persic et al. 1996).

We also checked whether these distributions are caused by a selection effect that is due to a magnitude limit in the spectroscopic and photometric campaigns from which we extracted our targets. Toward higher redshifts, such an apparent magnitude limit corresponds to higher luminosities and in turn higher masses. A fraction of the low-luminosity low-mass (slowly rotating) spiral population is therefore missed in the selection process, while the low-mass galaxies that are selected might preferentially be located at the high-luminosity side of the TF relation. This effect is commonly known as Malmquist bias. Thus, in all redshifts bins, at a given $V_{\max}$ any distant galaxy sample with a magnitude limit will show an overluminosity of the

low-mass galaxies compared to the local TFR, while the distributions are similar at the high-mass end. Some of the previous studies we used for target selection (Strazzullo et al. 2010; Grützbauch et al. 2012) have magnitude limits of $z_{\text{AB}} = 24$ and $H_{\text{AB}} = 24.4$. However, our sample is well inside the limits showing average observed magnitudes of $z_{\text{AB}} = 22.4$ and $H_{\text{AB}} = 21.3$, meaning that the magnitude bias in our target selection should not have a great impact. In addition, we studied the distribution of our targets in B -band luminosity. For the full sample, the mean B -band luminosity value before applying the absorption correction is $\langle M_B \rangle = -21.8$ mag with a scatter of $\sigma_{\text{total}} = 0.9$ mag. As stated in Sect. 2.4, 25 out of 27 galaxies showed [OII] emission, but we did not extract RC from all of them for diverse reasons (OH contamination, compactness, faintness). Neglecting galaxies whose emission lines are contaminated leaves us with a clean sample of 17 galaxies with the same $\langle M_B \rangle$ and scatter. This means that the removal of OH-affected galaxies does not introduce a luminosity bias to the clean sample. Now, if we focus on the cluster members, we see that they have similar M_B , but cover a wide range in $V_{\max}$. The high-mass (fast rotating) group shows higher M_B than the clean sample, $\langle M_B \rangle = -23.0$ with scatter $\sigma_{\text{high}} = 0.6$, and a high average maximum rotation velocity, $\langle V_{\max} \rangle = 308 \text{ km s}^{-1}$. On the other hand, the overluminous low-mass (slowly rotating) group presents similar M_B , but relatively low $V_{\max}$, $\langle M_B \rangle = -22.4$ with $\sigma_{\text{low}} = 0.7$ and $\langle V_{\max} \rangle = 154 \text{ km s}^{-1}$. Thus, both groups have similar B -band luminosities, but only the low-mass group is significantly offset with respect to the local TFR, which might point toward the presence of a magnitude bias. Nevertheless, the small number of galaxies make it hard to draw firm conclusions, and the large B -band offsets in the TFR ($\langle \Delta M_B \rangle = -2.4$ mag for the low-mass cluster galaxies) probably require additional cluster-specific effects to explain the enhanced luminosity.

5.2. Physical effects

The third scenario suggests that we might see rather compact galaxies that became enhanced in SF during their infall toward the dense regions of the cluster. If this is the case, this enhancement should be caused by a process that does not strongly affect galaxy gas kinematics, at least within the galactocentric radial regime probed by our RCs, up to ~ 3 scale lengths, and during the infall phase where the ICM density has low to intermediate values.

Kronberger et al. (2008b) and Kapferer et al. (2009) investigated the influence of ram pressure stripping (RPS) on the internal gas kinematics of simulated spiral galaxies by focusing on how the resulting distortions of the gaseous disk translate into the RC and the full 2D velocity field (VF) of galaxies. Distortions and declining RCs were found at distances larger than 12 kpc from the center of the galaxy, indicating the presence of an undisturbed inner part below that radius. The inclination of the galaxy relative to the line of sight changes the degree of disturbance and may shift the luminosity center from the kinematic center. In our sample the RCs cover radii up to ~ 10 kpc, and therefore we are not able to investigate possible distortions at larger radii. The absence of irregularities in the inner parts may be a hint toward this type of effect. In addition, the compression of the gas in the central parts that is due to the pressure of the intra-cluster medium (ICM) can trigger new star formation and a subsequent brightening of the ram-pressure affected galaxy, causing high-luminosity TF offsets. According to Kronberger et al. (2008a), RPS enhances the SFR by up to a factor of 3 over several hundred Myr for a Milky Way-like galaxy. In total, the mass

Fig. 5. Stellar mass TFR. Red and blue stars are cluster and field galaxies in our sample, respectively. Gray diamonds show a sample of 42 field galaxies at $1 < z < 1.7$ from Miller et al. (2011) and Miller et al. (2012), who found a well-established M_* -TFR at this redshift. Orange circles are 18 field galaxies from Cresci et al. (2009) at $z \sim 2$. The solid line is the local M_* -TFR from Fig. 23 in Reyes et al. (2011), taking $V_{2.2}$ as $V_{\max}$. The shaded area represents 1σ deviation from the previous relation.

of newly formed stars is about twice higher than in an isolated galaxy after 500 Myr of high ram pressure acting. However, these studies do not reach the ICM density conditions usually found in massive clusters. From the observational point of view, Ebeling et al. (2014) showed that cluster galaxies suffering strong RPS can increase their SF and become temporarily brighter than even the BCG of the cluster. Although this is only expected to occur rarely and only in very massive clusters and for small angles between the normal vector of the disk and the vector of movement through the ICM, several such cases have been discovered (e.g., Owen et al. 2006, 2012; Cortese et al. 2007; Ebeling et al. 2014).

However, individual events of this intensity may be rare, requiring a gas-rich galaxy to cross deep within the cluster core at very high velocity. Ruggiero & Lima Neto (2017) closed this gap by simulating Milky Way-like infalling galaxies in clusters around 10^{14} – $10^{15} M_{\odot}$ and choosing R_{200} at present time as the initial density conditions for the ICM at the beginning of the galaxy infall. This study takes into account three different orientations of the galaxy disk (0° , 45° , and 90°) for a radial infall speed of 0.5 to 2 times the velocity dispersion of the cluster. Their results show that star formation is always initially enhanced by a factor of 1.5 to 3 by the compression of the gaseous disk. Interestingly, the SFR increases by a factor of 2 before the gas loss becomes important ($<15\%$ of the total gas mass). On the other hand, Steinhauser et al. (2016) took a similar approach and studied different infalling orbits for three distinct clusters. They found that the SFR rises by up to 60% for galaxies with $V_{\max} = 170 \text{ km s}^{-1}$ and $\log M_* \sim 10.6$ in a cluster with similar properties to those we found in XMM2235-2557 after 0.5 Gyr and following an orbit that goes through the very central regions of the cluster. We translated the SFR rise predicted by Ruggiero & Lima Neto (2017) and Steinhauser et al. (2016) into a change in B -band luminosity using the EzGal python code (Mancone & Gonzalez 2012). EzGal is a tool that takes models of how the SED of a stellar population evolves with time and projects it through filters to calculate several physical properties, including magnitude evolution, as a function of redshift. In our case, we used the model libraries from Bruzual & Charlot (2003)

to study the evolution of the B -band luminosity evolution after a short starburst caused by the compression of the gas in the inner disk due to RPS. We find a brightening of 0.9 and 0.3 mag for Ruggiero & Lima Neto (2017) and Steinhauser et al. (2016) conditions, respectively.

In summary, results from previous RPS studies and simulations point toward an enhancement of the SFR of the central regions of infalling cluster galaxies after going through the cluster environment for <1 Gyr, but maintaining undisturbed velocity fields in the inner parts, as we find in our study. However, the variety of side effects playing a role in the process, such as inclination of the galaxy with respect to the infalling direction, density of the ICM, infalling velocity, and gas fraction, prevents us from extracting strong conclusions about the nature of the luminosity enhancement of our cluster galaxies without further observations.

5.3. Stellar mass TFR

In virialized galaxies, a higher maximum rotation velocity can only be explained by a higher total mass value, including Baryonic (stellar plus gas) and dark matter content. Since it is not possible to obtain direct information about the gas fraction for distant galaxies, M_* is the only available quantity we have to explore the evolution of the Baryonic mass in galaxies at this redshift. In Fig. 5 we investigate the stellar mass TFR (M_* -TFR) for the field and cluster galaxies in our sample. Again, our cluster sample is composed of two groups divided by their total mass ($V_{\max}$): three massive fast-rotating galaxies with $10.5 > \log M_* > 10.9$ embody the first group, while another three slow-rotating galaxies show slightly lower stellar masses, $10.0 > \log M_* > 10.4$. Our results follow the M_* -TFR for spiral galaxies established by Miller et al. (2012) at redshift $1.3 < z < 1.7$ and are in agreement with previous studies at similar redshift, like Miller et al. (2011) $z < 1.3$ and Cresci et al. (2009) at $z \sim 2$. We compare our dataset with the local M_* -TFR established by Reyes et al. (2011) using a subsample of local galaxies from SDSS DR7.

While the B -band TFR is sensitive to recent episodes of star formation, the M_* -TFR tracks the overall evolution of the underlying stellar population. From combining the results from both incarnations of the TFR, we draw the following conclusions: high total mass cluster galaxies show stellar mass $\log M_* \geq 10.5$ and lie within the 2σ region of the local B -band TFR, while at the same time they are offset by $\langle \Delta \log M_* \rangle = -0.66$ with respect to the local M_* -TFR. On the other hand, the group of low-mass cluster galaxies show lower stellar mass, $\log M_* \leq 10.5$, and are on average offset by 5 sigma toward higher B -band luminosity, with negligible deviations with respect to the local M_* -TFR, $\langle \Delta \log M_* \rangle = -0.05$.

One possible explanation for this behavior would be that high-mass distant galaxies have grown their stellar mass following star formation histories that are compatible with quiescent evolution, excluding starbursting episodes in the last few billion years. In contrast, low-mass galaxies at this epoch are still in the early phases of assembling their disk and are more prone to suffer environmental effects that could enhance their SFR and thus, their B -band luminosity. The tendency for high-mass galaxies to develop their disk first has recently been studied by [Simons et al. \(2016\)](#) for field galaxies at $z \sim 2$ using MOSFIRE. The most massive galaxies in their sample ($\log M_* \geq 10.2$) lie below the local M_* -TFR of [Reyes et al. \(2011\)](#) and exhibit similar rotation support as their local counterparts ($V_{\text{rot}}/\sigma \geq 2-8$), while at lower stellar masses, galaxies start to display small rotation support ($V_{\text{rot}}/\sigma \leq 1$) and lie on the other side of the relation. In an environmental frame, the combination of the degree of rotational support (V_{rot}/σ) with tracers of current star formation might be a useful tool to interpret offsets in the different representations of the TFR.

6. Conclusions

Using the FORS2 instrument at the ESO Very Large Telescope, we have studied a sample of 25 galaxies in the XMMU2235-2557 field of view. We carried out a kinematic analysis for 6 cluster members at $z \sim 1.4$ and 3 field galaxies at $1 < z < 1.2$ and determined their maximum rotation velocity V_{max} . Structural parameters (such as disk inclination and scale length) were derived on HST/ACS and HAWK-I images. We analyzed the distant Tully-Fisher and velocity-size relations in XMM2235-2557 and compared them with reference samples at similar redshift and the local Universe, taking into account additional results from galaxy evolution simulations. Our main findings can be summarized as follows:

1. At given V_{max} , cluster galaxies are more luminous (in rest-frame B band) and smaller (in rest-frame z band) than their local counterparts toward higher redshifts. By $z = 1.4$ we find for cluster members an average brightening of $\langle \Delta M_B \rangle = -1.6$ mag in absolute B -band magnitude and a decrease in size by a factor of $\sim 2-3$.
2. The cluster galaxies in XMM2235 were divided in two subsamples according to their V_{max} , occupying two different loci in the TFR. The first is composed of relatively slowly rotating (low total mass) galaxies that appear offset from the local TFR by $\sim 5\sigma$. The second lies within the 2σ deviation region, in agreement with previous observational findings ([Böhm & Ziegler 2016](#)) and semi-analytic models for field galaxies at similar redshift ([Dutton et al. 2011](#)). The galaxies in our sample show smaller offsets and scatter in the stellar mass TF diagram than in the B -band TF diagram. The subsample of fast-rotating galaxies show $10.5 > \log M_* > 10.9$,

while the others have slightly lower stellar masses, $10.0 > \log M_* > 10.4$. Although both subsamples have a similar stellar mass, they might be affected differently by cluster-specific processes, which might enhance the SFRs and, in turn, B -band luminosities in the low-mass subsample.

3. The origin of the TFR offsets for the group of slowly rotating (low total mass) galaxies is not clear. We have discussed several possibilities to explain our results, such as the underestimation of V_{max} as a result of the shape of the RC, a magnitude bias in our sample, and a temporary brightening in the B -band luminosity of these galaxies caused by the interaction with the environment. A combination of the two latter options appears to be the most likely explanation for our findings. The effect of the Malmquist bias is limited and cannot be the sole explanation for the offsets of the slowly rotating subsample: $\langle \Delta M_B \rangle = -2.4$. Results from previous ram pressure stripping studies and simulations show that it is possible to enhance the SFR in the central regions of infalling cluster galaxies (and thus the B -band luminosity) by maintaining undisturbed velocity fields (and RCs) at smaller radii than 3–4 scale lengths, as we find in our sample. However, the small size of our cluster sample together with the variety of effects playing a role in this process, such as the inclination of the galaxy with respect to the infalling direction, density of the ICM, infalling velocity and gas fraction, and the combined possible effect of the magnitude bias prevent us from drawing firm conclusions about the nature of these offsets without further observations.
4. Analysis of the combined offsets in our sample from the Tully-Fisher and velocity-size relations reveal there is a correlation between them. Galaxies with a strong offset toward high B -band luminosity with respect to the local TFR have a similar size than their local counterparts at comparable V_{max} , while galaxies offset toward smaller sizes with respect to the local VSR have a B -band luminosity compatible with the local TFR. These results are in agreement with what was shown in a previous paper by [Böhm & Ziegler \(2016\)](#).

In this paper we have explored the kinematics of galaxies in a high-redshift cluster. The distribution of our cluster subsamples in the TFR suggests that a population of galaxies exists that is consistent with the predicted evolutionary state of galaxies at this redshift, while cluster-specific interactions such as RPS might be responsible for the B -band luminosity enhancement suffered by the other half. However, it is not clear how likely this type of events is and whether the luminosity enhancement can be explained by a single process. Distinguishing between the origin of TFR offsets of bright cluster galaxies will require further work, such as examining the difference in star formation rate for distant cluster galaxies and the use of larger data sets covering a wide range of environments within the cluster.

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Appendix A

Fig. A.1. Our sample of cluster and field galaxies studied following the methods explained in Sect. 3 and presented in the same order as in Table A.2. The *first column* shows the HAWKI K-band or HST-F850LP image centered on the target galaxy. The *second column* displays the residuals after subtracting the 2D model of the galaxy. The *third column* presents the synthetic velocity field based on the observed structural parameters after fitting the simulated rotation curve to the observed curve. The black lines mark the position of the edges of the slit. The *fourth column* displays the rotation curve (black points) in the observed frame, and the fitted simulated RC (red line).

Fig. A.1. continued.

Table A.1. General properties of our cluster and field samples.

ID	RA (hh:mm:ss)	Dec (dd:mm:ss)	z	M_B (mag)	m_K (mag)	$J - K$ (mag)	$\log M_*/M_\odot$
1	22:35:21.6	-25:54:30.4	1.364	-22.91 ± 0.16	20.24	0.62	10.96 ± 0.12
2	22:35:21.7	-25:54:39.4	1.391	-22.50 ± 0.13	20.62	0.72	10.90 ± 0.08
3	22:35:33.5	-25:55:08.7	1.366	-22.87 ± 0.11	20.16	0.85	10.48 ± 0.16
4	22:35:21.9	-25:55:38.9	1.391	-22.46 ± 0.12	20.31	0.82	11.16 ± 0.06
5	22:35:33.1	-25:55:47.1	1.358	-21.82 ± 0.11	21.40	0.64	10.03 ± 0.10
6	22:35:27.1	-25:56:34.7	1.386	-21.78 ± 0.13	21.31	0.62	10.59 ± 0.05
7	22:35:19.4	-25:56:56.0	1.380	-21.64 ± 0.12	21.05	0.86	10.78 ± 0.06
8	22:35:21.8	-25:57:14.0	1.399	-20.96 ± 0.11	21.89	0.81	10.37 ± 0.05
9	22:35:21.6	-25:57:38.6	1.389	-20.33 ± 0.12	22.10	0.97	10.43 ± 0.05
10	22:35:33.0	-25:57:57.4	1.390	-22.36 ± 0.15	20.65	0.85	10.98 ± 0.14
11	22:35:18.1	-25:58:06.6	1.382	-22.11 ± 0.14	21.61	0.39	10.40 ± 0.07
12	22:35:17.1	-25:58:35.4	1.395	-22.14 ± 0.11	21.64	0.29	10.18 ± 0.11
13	22:35:26.0	-25:58:53.5	1.388	-22.57 ± 0.12	20.14	1.02	11.18 ± 0.06
14	22:35:21.0	-25:59:03.8	1.395	-21.56 ± 0.11	21.66	0.66	10.30 ± 0.09
15	22:35:27.8	-25:59:48.8	1.353	-22.17 ± 0.14	21.05	0.42	10.68 ± 0.03
16	22:35:17.1	-26:00:26.3	1.357	-22.60 ± 0.11	20.49	0.75	10.91 ± 0.10
17	22:35:21.1	-26:01:22.8	1.397	-21.33 ± 0.10	21.49	0.88	10.69 ± 0.13
18	22:35:23.0	-25:54:58.8	0.560	-19.26 ± 0.15	22.02	0.27	9.27 ± 0.11
19	22:35:24.8	-25:55:27.0	0.994	-21.38 ± 0.10	21.26	0.34	10.02 ± 0.07
20	22:35:17.8	-25:56:05.2	0.765	-23.00 ± 0.14	20.25	0.61	10.66 ± 0.05
21	22:35:22.2	-25:56:20.0	1.511	-21.83 ± 0.13	22.29	0.05	9.92 ± 0.05
22	22:35:21.5	-25:57:30.2	1.091	-21.47 ± 0.11	20.80	0.74	10.47 ± 0.06
23	22:35:17.7	-25:59:14.3	0.884	-20.64 ± 0.07	21.10	0.52	10.34 ± 0.12
24	22:35:28.8	-26:00:10.3	0.986	-21.36 ± 0.11	21.45	0.41	9.66 ± 0.06
25	22:35:19.4	-26:01:08.1	1.167	-21.33 ± 0.17	21.68	0.81	10.29 ± 0.20

Notes. IDs, J2000 coordinates, redshift, AB absolute B -band magnitude before correcting for intrinsic dust absorption, observed K -band magnitude, $J - K$ color, and logarithmic stellar mass.

Table A.2. IDs, redshift, structural parameters instrument (Inst.), intrinsic dust absorption (A_B), B -band-corrected luminosity ($M_{B_{\text{corr}}}$), and structural parameters of the cluster and field kinematic samples: scale length (R_d), inclination (i), position angle (θ), misalignment (δ), and logarithmic stellar mass.

ID	z	Inst.	A_B (mag)	$M_{B_{\text{corr}}}$ (mag)	R_d (kpc)	i ($^\circ$)	θ ($^\circ$)	δ ($^\circ$)	V_{max} (km s $^{-1}$)	$\log M_*/M_\odot$
3	1.366	HAWKI	-0.84 ± 0.12	-23.71 ± 0.23	1.4 ± 0.3	65 ± 4	-32	5	340 ± 24	10.48 ± 0.16
5	1.358	HAWKI	-0.76 ± 0.20	-22.58 ± 0.31	1.0 ± 0.2	75 ± 8	-34	4	156 ± 19	10.03 ± 0.10
8	1.399	HST/ACS	-0.56 ± 0.15	-21.52 ± 0.26	2.2 ± 0.4	70 ± 5	41	10	130 ± 12	10.37 ± 0.05
11	1.382	HST/ACS	-0.85 ± 0.17	-22.96 ± 0.31	2.5 ± 0.5	76 ± 9	2	4	174 ± 11	10.40 ± 0.07
15	1.353	HAWKI	-0.29 ± 0.07	-22.46 ± 0.21	2.8 ± 0.6	44 ± 1	13	26	249 ± 35	10.68 ± 0.03
16	1.357	HAWKI	-0.19 ± 0.06	-22.78 ± 0.18	1.9 ± 0.4	34 ± 1	34	14	334 ± 34	10.91 ± 0.10
19	0.994	HST/ACS	-0.30 ± 0.09	-21.68 ± 0.19	1.5 ± 0.3	50 ± 2	-46	16	172 ± 22	10.02 ± 0.07
22	1.091	HST/ACS	-0.16 ± 0.06	-21.64 ± 0.18	2.5 ± 0.5	40 ± 1	75	30	150 ± 22	10.47 ± 0.06
25	1.167	HAWKI	-0.27 ± 0.07	-21.60 ± 0.25	1.4 ± 0.3	44 ± 2	-24	18	220 ± 36	10.29 ± 0.20