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Internal Kinematics of Spiral Galaxies in Distant Clusters

B. L. ZIEGLER[1], A. BÖHM[1], K. JÄGER[1], A. FRITZ[1], and J. HEIDT[2]
(1) Universitäts–Sternwarte, Göttingen, Germany
(2) Landessternwarte, Heidelberg, Germany

Abstract

We present first results from our project to examine the internal kinematics of disk galaxies in 7 rich clusters with $0.3 \leq z < 0.6$. Spatially resolved MOS spectra have been obtained with FORS at the VLT. We concentrate here on the clusters MS 1008.1–1224 at $z = 0.30$ and Cl 0413–6559 (F1557.19TC) at $z = 0.51$. Out of 22 cluster members, 12 galaxies exhibit a rotation curve of the universal form rising in the inner region and passing over into a flat part. The other members have intrinsically peculiar kinematics. The 12 cluster galaxies for which a maximum rotation velocity could be derived are distributed in the Tully–Fisher diagram very similar to field galaxies from the FORS Deep Field with corresponding redshifts. The same is true for 6 galaxies observed in the cluster fields that turned out not to be members. In particular, these cluster spirals do not show any significant luminosity evolution as might be expected from certain clusterspecific phenomena. Contrary to that, the other half of the cluster sample with disturbed kinematics also shows a higher degree of structural assymetries on average indicating ongoing or recent interaction processes.

1.1 Introduction

Galaxies in clusters experience various interactions, some mechanisms of which can cause substantial distortions of the internal kinematics of disk galaxies leading to "rotation curves" that no longer follow the universal form (Persic et al. 1996) of spirals in the field. In a study of 89 galaxies in the Virgo cluster, Rubin et al. (1999), for example, classified half of their sample galaxies as kinematically disturbed ranging from modest (e.g. asymmetric) to severe (e.g. truncated curves) peculiarities. On the other hand, many cluster galaxies, for which only velocity widths (in contrast to spatially resolved velocities) were measured, follow a tight Tully–Fisher relation (e.g. Giovanelli et al. 1997). Furthermore, it is not yet clear whether the halo of dark matter and, therefore, the total mass of a galaxy can also be affected by certain interaction phenomena. In numerical simulations of cluster evolution that can resolve substructure and use semianalytic recipes to describe the galaxies' stellar populations, the dark matter halo of a galaxy that falls into the cluster does survive until redshift zero and does not get stripped (Springel et al. 2001).

A significant contribution to our comprehension of the environmental dependence of galaxy kinematics would be made by observations at higher redshifts, since in models of hierarchically growing structure clusters are still in the process of forming at $z \approx 1$ so that a higher infall rate and more interactions are expected (e.g. Kodama & Bower 2001). A first

(published) attempt was made by Metevier et al. (2002 & this conference) with 10 Tully–Fisher galaxies in the cluster CL 0024+1654 ($z = 0.40$) and by Milvang–Jensen et al. (2003) with 8 spirals in MS 1054.4–0321 ($z = 0.83$). While the first study sees a larger scatter of their sample galaxies in the TF diagram without evidence for an evolution of the zero point, the second one finds a trend towards brighter luminosities (0.5–1 B mag) with respect to local cluster spirals. It is argued that either truncation of star formation or starbursts may cause an increased or decreased mass–to–light ratio, respectively.

1.2 Project Aims and Observations

We have conducted a campaign (5 nights with FORS 1&2 at the ESO–VLT) to gain spectra of spiral galaxies within seven distant clusters in the redshift range $0.3 \leq z < 0.6$. One of our main goals is the derivation of spatially resolved rotation curves for the analysis of the internal kinematics of the galaxies and the construction of the distant cluster TFR. Furthermore, we aim to determine the star formation rates, structural parameters and morphologies to investigate possible effects of transformation mechanisms like merging, tidal interaction, harassment, strangulation or interaction with the intra–cluster medium. To complement our own ground–based imaging, HST/WFPC2 images of the core regions were retrieved from the archive.

Here, we present first results based on data of two of the clusters, CL 0413–65 ($z = 0.51$) and MS 1008–12 ($z = 0.30$), which were observed in November 1999 and March 2000, respectively. We used the FORS1 instrument mounted at the Cassegrain focus of the ESO–VLT with grism 600R providing a spatial scale of 0.2 arcsec/pixel and a dispersion of $\sim$1.08 Å/pixel. At a slitwidth of 1 arcsec, the spectral resolution was $R \approx 1200$. To meet our signal–to–noise requirements, the total integration time was set to 2.5 hrs. Seeing conditions ranged between 0.7 and 1.3 arcsec FWHM. Two MOS setups have been observed for each cluster, yielding 76 spectra of galaxies with apparent magnitudes of $18.0 < R < 22.8$.

1.3 Derivation of Rotation Velocities

Redshifts could be determined for 62 of the galaxies, of which 38 have late–type SEDs, 19 are early–type, and 5 peculiar or unidentified. In total, 38 objects are cluster members. 22 of these are spirals with sufficient signal–to–noise of their emission lines to derive the internal kinematics.

Rotation curves (RCs) were determined using either the [O II]3727, Hβ or [O III]5007 emission line (Fig. 1.1 gives some examples). Gaussian fits have been applied stepping along the spatial axis with a median filter window of typically 0.6 arcsecs to enhance the S/N. Since the apparent disk sizes of spirals at intermediate redshifts are only slightly larger than the slit width (1 arcsec), the spectroscopy covers a substantial fraction of the two–dimensional velocity field. Thus, the maximum rotation velocity $v_{\rm max}$ (the constant rotation in the outer part of a galaxy due to the Dark Matter halo) cannot be determined "straightforward" from the observed rotation. To tackle this problem, we simulated the spectroscopy of each galaxies' velocity field with the respective inclination and position angle, also taking seeing and luminosity weighting into account (see Ziegler et al. 2001 for a more detailed description). The simulated rotation curves which best reproduced the observed ones yielded the values of $v_{\rm max}$ entering our TF diagram (Fig. 1.2).

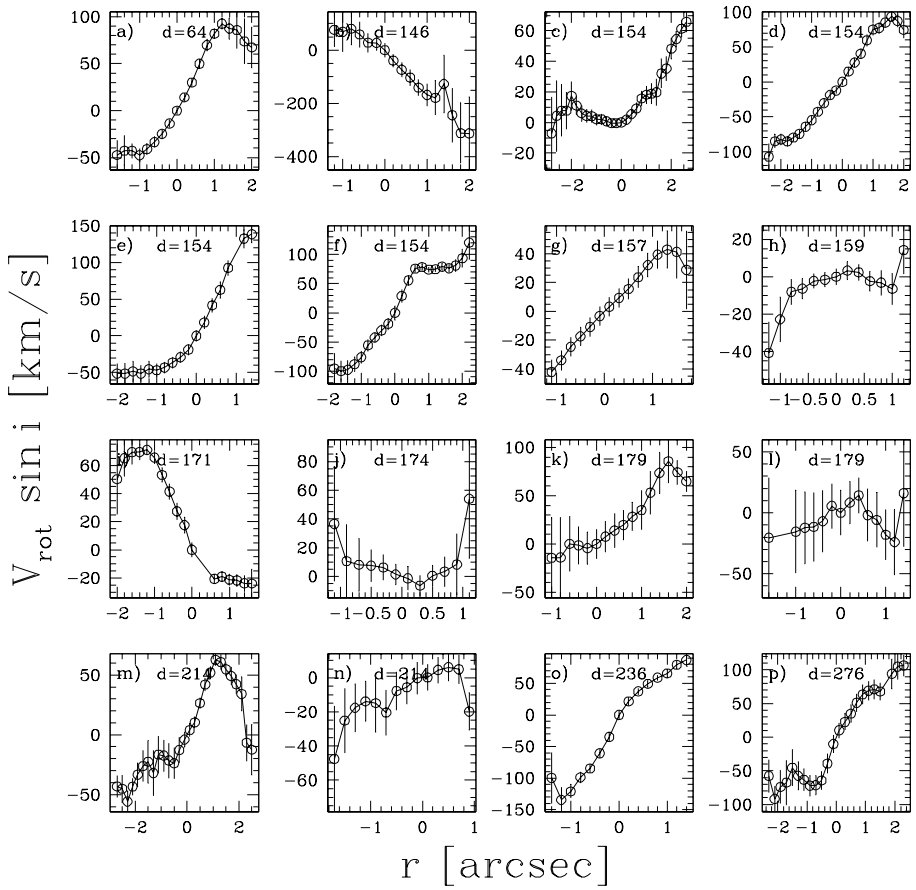

Fig. 1.1. Position–velocity diagrams for 12 disk galaxies in the cluster MS 1008–12 at $z = 0.30$. Note, panels c&d, e&f, k&l and m&n represent the same galaxy, rsp., but observed with different slit positions (the rotation angles of the two MOS masks differed by 67°). Panels a–p are ordered according to the distance d (given in arcsec) of the galaxies from the cluster center. Values of the maximum rotation velocity could be determined robustly for cases a, d, e, f, g, i, o & p. These galaxies enter the TFR shown in Fig. 1.2. In all other cases, the kinematics are too disturbed.

1.4 Results and Discussion

For our sample, a significant number of the cluster members show peculiar kinematics in contrast to the "rise–turnover–flat" RC shape of large, isolated spirals. In the case of MS 1008–12 (Fig. 1.1), no trend is visible of the RC form with (projected) clustercentric distance. But since all observed galaxies are located within the virial radius, this is in accordance with dynamical models in which the galaxy population of a cluster is well-mixed within that region. In particular, we most probably do not have any new arrivals from the field in our sample.

We point out that the peculiarities of some "rotation cuves" reflect mainly intrinsic kine-

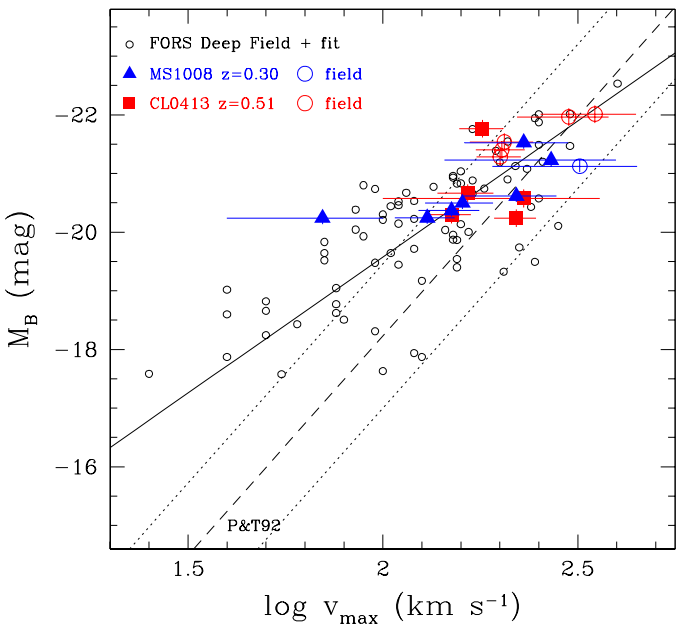

Fig. 1.2. Tully–Fisher diagram of cluster spirals in MS 1008–12 at $z = 0.30$ (triangles) and in CL 0413–65 at $z = 0.51$ (squares). Also shown are six field objects (large open circles) that were also observed in the clusters' field–of–view. In comparison to our FORS Deep Field sample of 77 field galaxies (Ziegler et al. 2001, Böhm et al. 2003) with a mean redshift of 0.5 (small open circles), the cluster galaxies are similarly distributed and do not deviate significantly from the linear fit to the FDF sample (solid line). The cluster members follow the same trend with respect to the local TFR (the fit $\pm 3\sigma$ to the Pierce & Tully 1992 sample is given) as the distant field galaxies. Since we observed mostly bright cluster galaxies, their luminosities are not significantly increased in accordance with an undisturbed evolution. (Restframe B magnitudes were calculated for a flat $\Omega_\lambda = 0.7$ cosmology with $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.)

matic properties of the resp. galaxy. This is in contrast to the significantly smaller fraction of peculiar curves in our sample of 77 distant FORS Deep Field spirals, which have been observed with exactly the same instrument configuration (Ziegler et al. 2001, Böhm et al. 2003). Only those rotation curves which show no strong perturbations are eligible for a determination of the maximum rotation velocity as needed for the TF diagram. In the case of MS 1008–12, this could be done for 7 cluster members, in CL 0413–65 for 5 members. Thus, in total 12 cluster galaxies enter our TF diagram which is shown in Fig. 1.2. The luminosities were derived from total magnitudes of FORS images in the V (MS 1008–12) and I (CL 0413–65) band, rsp., corrected for Galactic and intrinsic extinction, transformed to restframe Johnson B according to SED type, and calculated for a flat $\Omega_\lambda = 0.7$ cosmology ($H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$).

An inspection of our preliminary TF diagram reveals that the distant cluster spirals are distributed very much alike the field population that covers similar cosmic epochs ($\langle z_{\mathrm{FDF}} \rangle =$

0.5). No significant deviation from the distant field TFR is visible and the cluster sample has not an increased scatter, but the low number of cluster members prohibits any quantitative statistical analysis. Nevertheless, we can conclude that the mass–to–light ratios of the observed distant cluster spirals cover the same range as the distant field population indicating that no clusterspecific phenomenon dramatically changes the stellar populations. In particular, there was no starburst in the recent past of the examined cluster galaxies that would have significantly risen their luminosity. With respect to the Tully–Fisher relation obeyed by local galaxies (e.g. Pierce & Tully 1992), our cluster sample follows the same trend as the FDF galaxies. Since we mostly selected bright galaxies, the cluster members occupy a region in the TF diagram where no significant luminosity evolution is visible.

But we emphasize that this conclusion is true only for those objects that enter the TF diagram. Since almost half of our cluster galaxies can not be used for a TF analysis due to their disturbed kinematics the above conclusions are not generally valid for the whole cluster sample. The objects with peculiar velocity curves may actually be subject to ongoing or recent interactions. Indeed, a morphological classification of the cluster spirals in terms of their concentration and asymmetry indexes (Abraham et al. 1996) reveals that they have a higher degree of asymmetry in the mean than the kinematically less disturbed ones. The asymmetric spirals show peculiarities like diverging rotation curves or no significant rotation at all. In one case (panels m&n) of Fig. 1.1), we observe a prominent bar that causes a highly asymmetric rotation curve. This correlation between morphological and kinematical disturbance hints to a common origin for both in "strong" interactions like close encounters with tidal effects, accretion events or even mergers. Such processes most probably also influence the stellar populations of a galaxy changing its integrated luminosity as well.

A more detailed discussion on the efficiency of the various interaction mechanisms, however, needs to be put on the basis of robust statistics and will be given for our complete sample of 7 clusters in future papers.

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