Scaling Relations of Field Spirals at intermediate Redshift

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Abstract. In the last few years, galaxies at redshifts up to $z \sim 1$ have become accessible for medium–resolved spectroscopy thanks to the new generation of 10m-class telescopes. With kinematic and photometric information on spiral galaxies in this regime, well-known scaling relations like the Tully–Fisher relation (TFR) can be studied over half a Hubble time. By comparison to local samples, these studies facilitate simultaneous tests of the hierarchical merging scenario and stellar population models.

Using the Very Large Telescope, we obtained spatially resolved rotation curves of 78 spiral galaxies in the FORS Deep Field (FDF), covering all Hubble types from Sa to Sm/Irr at redshifts $0.1 < z < 1.0$. We find evidence for a $B$-band luminosity increase of up to 2 mag for low–mass spirals, whereas the most massive galaxies are of the same luminosity as their local counterparts. In effect, the TFR slope decreases significantly. This would explain the discrepant results of previous observational studies. We also present the velocity–size relation and compare it to the predictions of numerical simulations based on the hierarchical merging scenario.

Keywords: galaxy evolution, cosmology

1. Motivation and Sample Selection

The scaling relations between the basic parameters of spiral galaxies — luminosity $L$, maximum rotation velocity $V_{\text{max}}$ and scalelength $r_d$ — are correlated via a two–dimensional plane which is similar to the well-known Fundamental Plane for ellipticals (e.g., Koda, Sofue and Wada, 2000). Most famous among the projections of this plane is the Tully–Fisher relation (TFR) between $V_{\text{max}}$ and $L$ (Tully and Fisher, 1977). A study of such scaling relations over different cosmic epochs offers powerful tests of different aspects of the hierarchical merging scenario and stellar population models.

Nevertheless, spectroscopy of galaxies at redshifts up to $z = 1$ with sufficient (spectral and spatial) resolution and S/N for gaining robust information on their kinematics is a great observational challenge and
has become feasible just within the last few years with 10m-class telescopes. Additionally, any selection on emission line strength or disk size is likely to introduce biases in the results. To avoid this, we selected our targets purely on apparent magnitude \( R < 23 \) and inclination \( i > 40^\circ \). Our source was the FDF photometric redshifts catalogue (Appenzeller et al., 2000, Bender et al., 2001).

Throughout this article, we assume the concordance cosmology with \( \Omega_m = 0.3 \), \( \Omega_\Lambda = 0.7 \) and \( H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1} \).

2. Analysis

We derived rotation curves (RCs) by applying Gaussian fits row by row to the usable emission lines in our spectra. After the rejection of disturbed or “solid-body” RCs, the final sample consisted of 78 spirals at a median redshift of 0.45.

To derive proper intrinsic rotation velocities, we performed simulations of the spectroscopy for each galaxy by generating synthetic velocity fields. With these, we corrected for observational effects like seeing, disk inclination, angle between slit and major axis, and also the optical “beam smearing” which originates from the comparable sizes of the slit width (one arcsecond) and the galaxies’ apparent radii. Absolute \( B \)-band magnitudes were derived via synthetic photometry from observed \( B \), \( g \), \( R \) or \( I \), depending on the redshift, to keep the k-corrections small. For a more detailed description and a data table of our spiral sample, see Böhm et al. (2002).

3. Results

The final \( B \)-band TFR is shown in figure 1. Only RCs which show a region of constant rotation velocity (due to the Dark Matter Halo) were used for the bootstrap fit to our sample. In comparison to the local sample of Haynes et al. (1999), which comprises \( \sim 1200 \) spirals, we find \( 2 \sigma + \) evidence for a change of the TFR slope at intermediate redshift. This may be caused by a mass-dependent luminosity evolution which is stronger for lower mass systems, possibly combined with an additional population of blue, low-mass galaxies which is underrepresented in the local universe. As early-type spirals have, on the mean, higher maximum rotation velocities than late-type spirals, our result offers an explanation for the discrepant results of earlier studies, which were limited to small number statistics and mostly biased towards certain sub-types like low-mass systems with blue colors (e.g., Rix et al., 1997)
Figure 1. The $B$-band Tully–Fisher relation of our intermediate redshift sample compared to the $N = 1200$ local sample of Haynes et al. (1999). Typical error bars are shown for two objects. Solid lines show the 100 iteration bootstrap bisector fits along with $1\sigma$ errors (dashed and dotted lines). Only rotation curves which show a constant rotation velocity at large radii are used for the fit to the FDF data. Both samples are corrected for incompleteness bias and morphological bias following Giovanelli et al. (1997). A TFR slope change between the local universe and intermediate redshift is found on $\gtrsim 2\sigma$ confidence level.

or, in contrast, luminous early–type spirals due to the selection upon large scalelengths (Vogt et al., 1996).

In figure 2 we show the velocity–size diagram of our sample. The slightly decreased disk sizes of the FDF spirals are in good agreement with the predictions of the hierarchical merging scenario following Mao, Mo and White (1998), though the scatter is relatively large since the imaging is ground–based yet. We will improve the accuracy of the measured scalelengths and inclinations with HST-ACS observations during cycle 11.

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Figure 2. The velocity–size diagram for our intermediate redshift sample compared to the $N = 1200$ local sample of Haynes et al. (1999). Typical error bars are shown for two objects. The solid and long–dashed lines give the bisector fits to the local and intermediate redshift samples, respectively. The dot–dashed line denotes the predicted smaller disk sizes at $z \sim 0.5$ within the ΛCDM hierarchical merging model following Mao, Mo and White (1998).

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