Evolution of the Tully–Fisher Relation

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Abstract The study of the evolution of the Tully-Fisher relation has raised some problems during the last years. The main difficulty is determining the required parameters of intermediate redshift galaxies. In the present work, the rotational velocities obtained from the widths of different optical lines using DEEP2 spectra are compared. The apparent magnitudes are K and extinction corrected, and the absolute magnitudes are derived using the concordance cosmological model. Finally the B, R, and I–band Tully–Fisher relation up to $z = 1.3$ is derived.

Although most studies (this included) find evidences for evolution, the results are not conclusive enough, given that the possible luminosity evolution is within the scattering of the relation and the evolution in slope is difficult to determine because at high redshift only the brightest galaxies can be measured. Nevertheless, this study shows a clear tendency, that is the same for all bands, favouring a luminosity evolution where galaxies were brighter in the past for a fixed rotation velocity.

1 Introduction

The Tully-Fisher relation (hereafter TFR) relates the luminosity with the maximum rotational velocity of spiral galaxies (Tully & Fisher 1977). This valuable information about the relation between dark and luminosity matter (Zwaan et al. 1995) has important implications in determining fundamental cosmological parameters, in the study of structure formation and the evolution of disc galaxies (Navarro & Steinmetz 2000).

In the last years, some groups have measured the TFR at different redshifts. Pioneer studies, most of them in the B-band, seem to show evolution, although there

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was not a consensus whether this evolution was on slope, zero point or both. Ziegler et al. (2002) and Böhm et al. (2004) found a shallower relation at high redshift (z=1), and evidence for a luminosity evolution with look-back time of $\Delta M_B \approx -1$ magnitudes at redshift z=1. However, other groups, such as Rix et al. (1997), or Bamford et al. (2006), found luminosity evolution but not a slope change. Moreover, these authors found differences in luminosity evolutions ranging from 0.2 to 2 magnitudes. Conselice et al. (2005), and Flores et al. (2006) studied the infrared TFR and did not find evolution in K-band. However, in a recent work, Puech et al. (2008) did find evolution in the sense that galaxies had been fainter in the past, a result opposite to that found in the optical bands (for example, Böhm et al. 2004). These results suggest that the TFR could be dependent on the observed photometric band. An alternative method for studying the TFR was derived by Bell & De Jong (2001) using the stellar-mass obtained from the mass–to–light ratio. Some studies have used this method (e.g., Conselice et al. 2005, Kassin et al. 2007), finding no evolution on the stellar-mass TFR.

The rotation velocity measurement is challenge for TFR studies. At high z, the spatial resolution required to resolved the rotation curve is comparable to the atmospheric seeing and the integrated velocities are the most convenient way to estimate the velocity field of disc galaxies. From the relation between the velocity field obtained from line widths and from rotation curves, Vogt (2007) concluded that both methods are equivalent.

2 Data

The sample consists of galaxies in a $16' \times 16'$ field in the Groth Strip Survey (GSS) sky region, that will be observed by the OTELO project (OSIRIS Tunable Emission Line Object Survey)(Cepa et al. 2008).

The baseline for spectroscopy target pre–selection was the galaxies for which DEEP2 (Davis et al. 2003, 2007) spectra (Data Release 3, DR3) in this field were available. In the redshift range $0.1<z<1.3$, there are 1200 galaxies with a B-band limiting magnitude of 24.

The objects selection (Böhm et al. 2004, and Nakamura et al. 2006) is of outstanding importance to draw conclusive results on the evolution of the TFR because at high–z, interactive and anomalous galaxies are frecuently included in the sample. As a preliminary procedure and with the aim to segregate E/S0 galaxies from non–E/S0 in our sample, we compared the DEEP2 spectra with a synthetic, early-type galaxy spectrum, which is part of the Bruzual & Charlot (2003) collection of galaxy templates used by Tremonti et al. (2003) in the analysis of SDSS galaxy spectra. The result was that about one–third of the spectra could be associated with E/S0 galaxies. Nevertheless, when the HST images of a statistically significant subsample of each group were visually analyzed, the classification mismatch for the non–E/S0 group was ∼3%, whereas that associated with the group of E/S0 galaxies was significantly worse. This result forced us to proceed to a visual classification of every galaxy using HST images, as the most reliable procedure for an accurate determination of morphological types. The HST images used are part of AEGIS survey (Davis et al. 2007) and were taken with the ACS camera. In addition, GIM2D (Simard 1998) was used for objects without a clear visual classification. All galaxies belonging to Elliptical/S0 and interactive groups were discarded. The irregular galaxies were, nevertheless, included, since they can not be distinguished from spiral galaxies at high redshift.

The inclination angle (i) is an usual selection criterion as well. With the aim to avoid inclination selection that can bias the results, galaxies with three different inclination ranges were represented. No correlation between magnitude and rotation velocity was observed for inclinations lower than 25°. Also, galaxies almost edge-on will be more affected for extincion and the error in inclination angle will be larger. For these reasons, only galaxies with inclinations between 25° and 80° were considered.

3 Deriving Tully–Fisher relations

The local TFR has been historically obtained from radio measurements, specifically from 21cm line width. Mathewson et al. (1992) compared the projected rotation velocity measured from H_α rotation curves with the velocity measured from integrated HI profiles at the 50% level. They obtain a difference of 10 km/s, which is attributed to HI widths, that measure rotational velocity plus internal galaxy turbulence. The rotational velocities obtained from the widths of different optical lines, are compared in Fig 1. Although all velocities are similar, there is a great dispersion in the third case (H_β vs [OIII]). The reason is that H_β has low signal to noise in most spectra so that this line is not used in the study. In the last panel ([OIII] vs [OII]), only four objects have both lines, but the fit of them is quite good. There was other galaxy for which [OII] velocity was 50 km/s greater than [OIII] velocity. When its spectrum was analized, we saw that the object was an AGN or other active object and it was removed from the objects list. Finally, there are 241 galaxies for which the rotation velocity was calculated.

The DEEP2 magnitudes are corrected for Galactic reddening based on Schlegel, Finkbeiner & Davis (1998) dust maps. So the absolute magnitudes have been obtained K–correcting these B, R, and I band apparent magnitudes using Blanton & Roweis (2007), applying a concordance cosmology for determining the luminosity distance from the redshifts, and correcting for intrinsic extinction (Tully et al. 1998).

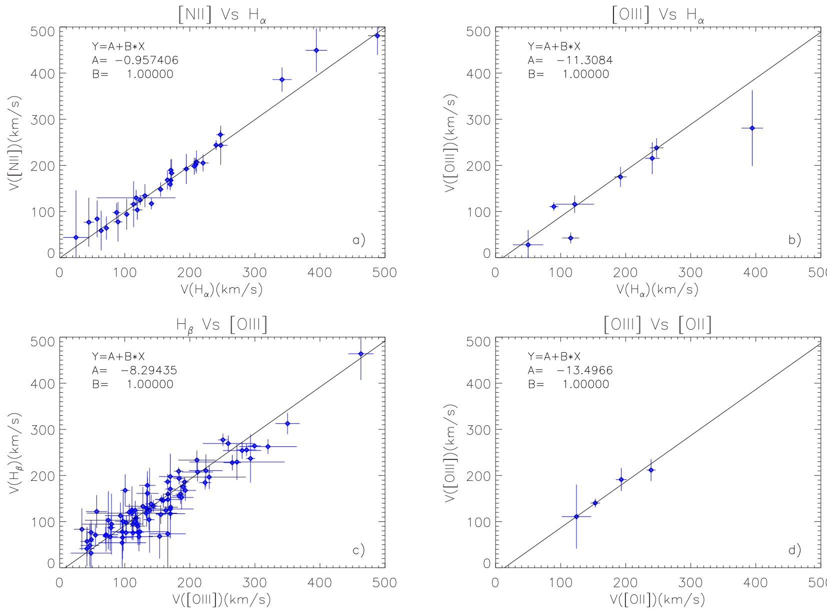

Fig. 1 Comparison of the velocity widths from five optical lines. In each panel, the solid line shows the least–square fits with slope 1. All zero–points are within the errors. a) Velocity obtained from [NII]6583 and H_α6563, b) comparison is between [OIII]5007 and H_α6563, c) velocity from H_β4861 versus [OIII]5007, d) comparison between [OIII]5007 and [OII]3727 velocities.

4 Tully-Fisher Relations in B, R, and I–Band

The Verheijen (2001) local relations are the most used in the last evolution studies of the TFR. Here, different relations are calculated in different samples as a function of the rotation velocity. For this reason, we compared our local fits with the Verheijen (2001) relations as reference.

The DEEP2 data points in the redshift range $0.1<z<0.3$ was linear fitted with the aim to calculate the local TFR in B, R and I–band. A change in the stellar populations of field galaxies is not observed in this range of redshift, so we can assume that TFRs are the same that locally. The fit was done by least–squares weighed with velocity errors. The better aproximation between our data and the Verheijen (2001) local TFRs is obtained from the maximum velocity (V_{max}) in a sample of galaxies with $V_{max} \geq V_{flat}$ (the velocity at flat region of the rotation curve).

For R and I–band, all parameters are within the Verheijen (2001) errors as zero-point in B–band. The slope in B–band is out of them, but the difference is $\sim 1\sigma$. Despite this difference in the B–band slope, local relations obtained from DEEP2 data in the redshift range $0.1<z<0.3$ were adopted as local TFR, due to these objects have been processed in the same way as high–z galaxies.

The B, R and I–band TFRs were obtained in 6 redshift ranges. Fig. 2 shows the

TFR in the B–band for two of these ranges. The zero–point of the relation changes with the redshift, being the difference with the local zero–point greater than 2 sigma in the redshift range $(1.1 < z < 1.3)$.

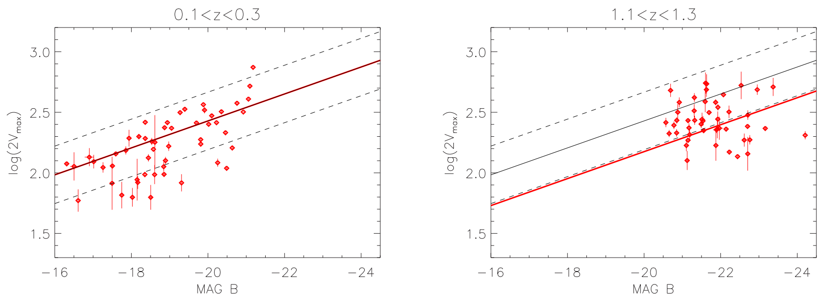

Fig. 2 Tully–Fisher relation in the B–band in 2 redshift ranges. Thin and dotted lines represent the local TFR and its 2 sigma scatter amplitud. The wide red line is the fit to the data weighted by errors in $\log(2V_{max})$. The relation slope has been set to local relation slope in order to study the zero–point variations with redshift.

The same change on zero–point can be seen in R and I–bands. A similar result was found by Vogt (2007) where all fits had lower zero–point that local TFR. Nevertheless, in her work, all fits were inside 2 sigma, being the last redshift range 0.9<z<1.1. She concludes about no evolution of TFR. In Fig. 2, we present the next redshift range (1.1<z<1.3), and not only the zero–point is greater than 2 sigma, but rather, the most of the galaxies ($\sim$ 85%) are brigther than locally.

The difference on zero–point at z=1 is ΔM= -1.0 ± 0.2 in the three bands. It would agree with the evolution found by Bamford et al. (2006) and Böhm et al. (2004), but these studies were carried out only in B–band. On the other hand, it seems that the evolution of the TFR up to z=1.3 is at the level of the relation scatter. To confirm the evolution of this relation, a higher redshift or lower errors will be necessary. This type of works can be to carry out with the new generation of 30 meters telescopes, or with the more deep observations of DEEP3. Portinari & Sommer–Larsen (2007) discussed the TFR evolution as predicted by cosmological simulations of disk galaxy formation. They found a luminosity evolution in the same way that us, due to an ageing of the stellar population, as consequence of a star formation decrease up to z=0.

5 Conclusions

This study investigates the Tully–Fisher relation and its evolution with redshift in B, R and I–band. Using HST imaging data and DEEP2 spectroscopy, the galaxy characteristic parameters, rotation velocity and absolute magnitude, have been derived. With the spectroscopic sample, a study about optical lines has been carried out, concluding that all of them can be used to determine the rotation velocity of the spirals galaxies if the signal to noise is enoughly high.

In addition, we use three different techniques for morphological classification: comparison of the spectra with an elliptical/S0 template, visual classification and GIM2D. The best method was the visual classification, and we found an error of ∼25% in the selection based on the Sérsic index.

Local Tully–Fisher relations have been constructed from DEEP2 data, in the redshift range 0.1<z<0.3 and have been compared with Verheijen (2001) relations. Despite the differents ways used to determine rotation velocity, this work relations are consistent with his results, so our local TFRs have been adopted as low redshift comparison patterns.

The B, R and I–band TFRs were obtained in 6 redshift ranges. We find a systematic tendency with the redshift to the galaxies were brighter ($\Delta M = -1.0 \pm 0.2$) in the past. The same change on zero–point can be seen in R and I–bands.

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