Astron. Astrophys. 352, 49–63 (1999)

ASTRONOMY AND ASTROPHYSICS

Internal extinction, population incompleteness bias and the faint-end of the B-band Tully-Fisher relation

D. Pierini

Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany (daniele.pierini@mpi-hd.mpg.de)

Received 26 February 1999 / Accepted 30 September 1999

Abstract. We analyse the distribution of three different samples of spiral galaxies of the Local Universe in the B-band luminosity-maximum rotational velocity ($\mathrm{L_B}$-$\mathrm{V_{Max}}$) plane, i.e. the B-magnitude Tully-Fisher (TF) relation. The first sample comprises $25 + 31$ late-type (from Sa to Im-BCD) galaxies, selected from, respectively, the Virgo and the Ursa Major clusters. In addition, a sample of 20 group extreme late-type (ELT) spiral (from Sd to Sm) galaxies and a sample of 13 dwarf late-type galaxies are selected. First, we analyse the influence of three different corrections for internal extinction (IE) on both the slope and the zero-point of the relation. These recipes reflect either i) the morphological type dependence of the IE or ii) the assumption of a “sandwich-model” for the distribution of the dust and the stellar components within the disk or iii) the existence of the metallicity-mass relation. As a first result we find that the latter recipe of IE correction systematically makes Sa-Sc galaxies brighter than later spirals. Since the former galaxies mainly populate the region of the bright, fast rotators, the slope of the corresponding TF relation becomes much steeper than in the other two cases. Under the hypothesis that the ELT spiral galaxies in clusters and in groups share the same LF, we show that the claimed skew of the group ELT spiral galaxies with respect to the extrapolated TF relation of more luminous systems (i.e. the local TF calibrators) is due both to the population incompleteness bias affecting such a template and to the type segregation. Finally, we confirm that the distribution of dwarf galaxies with comparable rotational and random velocities in the $\mathrm{L_B}$-$\mathrm{V_{Max}}$ plane is consistent with the relation of more luminous systems, while the rotationally supported dwarf galaxies are underluminous with respect to the ELT galaxies of the same $\mathrm{V_{Max}}$. However, the latter results may suffer from the heterogeneous methods of measurement of dwarf galaxy distances that were adopted.

Key words: galaxies: kinematics and dynamics – galaxies: spiral – galaxies: structure

1. Introduction

The luminosity L of the giant high-surface brightness spiral galaxies has for a long time been found to be proportional to their disk maximum rotational velocity V_{Max} (Tully & Fisher 1977) elevated to a power index dependent on the observational wavelength of L (Aaronson et al. 1979). The shape of the relation is also affected by the manner of determining the maximum rotational velocity (e.g Verheijen 1997) and the absolute magnitude (see however Federspiel et al. 1998).

Due to the intrinsic scatter and the galaxy morphological type dependence of the TF relation, different slopes and zero-points were derived from different samples at the same observational band (e.g., Kraan-Korteweg et al. 1988 and references therein). While the correlation is also found to hold for the low-surface brightness spiral galaxies (Zwaan et al. 1995), it is still unclear if it extends to the dwarf late-type galaxies, i.e. the Im-BCD galaxies. Recently, Matthews et al. (1998b) have inspected the dynamic properties of a sample of 44 extreme late-type (ELT) spiral (from Sd to Im) galaxies, selected in groups. According to the definition of Matthews and Gallagher (1997), the ELT spiral galaxies are “the lowest luminosity, late-type disk galaxies which still exhibit regular optical structures and centralized light concentrations”. Matthews et al. find that several faint rotationally-supported galaxies are underluminous (at the 2σ level) with respect to the extrapolation of the B-band ($\lambda = 0.55\ \mu\mathrm{m}$) TF relation obtained from its local calibrators (from Sa to Im) (see also Romanishin et al. 1982; Salucci & Persic 1997). This result is in agreement with Stil & Israel (1998), who surprisingly find that the rotationally supported dwarf galaxies deviate from two extrapolated TF relations of more luminous systems, one obtained from a sample of local calibrating galaxies (with Hubble types from Sa to Sd) and the other from the complete sample of 81 Virgo cluster galaxies (with Hubble types from Sab to Im) of Kraan-Korteweg et al. (1988). Moreover, Stil & Israel (1998) find that the dwarf late-type galaxies with comparable rotational and random velocities are instead distributed in consistence with the template relations. However, Pierini & Tuffs (1999) have found that $L \propto V_{Max}^4$ for a sample of late-type (from Sa to Im-BCD) galaxies of the Virgo cluster, in the Near-IR (K′-band, i.e. $\lambda = 2.1\ \mu\mathrm{m}$), where both the corrections for the internal extinction and the contributions of recent episodes of star-formation to the global luminosity have a lower impact on the determination of L itself, with respect to the optical bands. This result contrasts with the claimed non-linearity of the Near-IR TF relation, claimed by Aaronson & Mould (1983).

While Pierini & Tuffs' sample of galaxies spans a wide range of morphologies and luminosities, Matthews et al.'s sample focuses on the low-luminosity end of the disk-dominated spiral sequence. Moreover, Matthews et al. analysed the distribution of their sample of group ELT spiral galaxies with respect to the template B-band TF relation given by the standard sample of local TF calibrators of Pierce & Tully (1992), which is not complete and, therefore, liable to the population incompleteness bias (Bottinelli et al. 1987; Teerikorpi 1990; Sandage 1994; Sandage et al. 1995). They also assumed, in a conservative way, that both giant late-type galaxies and ELT spiral galaxies have the same intrinsic optical depth, and therefore, that they share the same standard recipes of correction for the internal extinction (IE).

Since any systematic deviations from the template TF relation may be a potential signature of a structurally and kinematically distinct class of objects, it is extremely important to understand any biasing of the template relation, due to the grasp in the galaxy luminosity function (LF) of the sample, to the type segregation and to the adopted methods of velocity and IE correction. Therefore, as a "comparison" sample, we select a sample of 25 and 31 late-type galaxies from, respectively, the massive Virgo Cluster (see Boselli et al. 1997) and the Ursa Major Cluster (Tully et al. 1996), which is at an earlier evolutionary state. This sample has better statistics with respect to the sample of local TF calibrators and is found to be representative of the average properties of any late-type galaxies (cf. Gallagher & Hunter 1986; Kraan-Korteweg et al. 1988; Gavazzi 1998), although it is still affected by the cluster population incompleteness bias (Teerikorpi 1990). It also gives us the opportunity to test the influence of three different recipes of IE corrections on the templates of galaxies with different Hubble types. These recipes rely either on i) a statistically proven dependence on the morphological type (Gavazzi & Boselli 1996) or on ii) a type-independent "sandwich-model" of the relative distributions of dust and stars within the disk (Tully & Fouqué 1985) or on iii) the recent statistical analysis of the global extinction in spiral galaxies of Tully et al. (1998).

The outcome of the paper is as follows. In Sect. 2 we describe the sample selection criteria. Different methods for velocity and IE corrections are discussed in Sect. 3. The corresponding B-magnitude TF relations for the cluster sample galaxies are determined in Sect. 4, where the effects introduced by the cluster population incompleteness bias, the type segregation and the cluster depth are also discussed. Sect. 5 approaches the question of the skewed distribution of the ELT spiral galaxies with respect to the template TF relation of more luminous spiral galaxies. The behaviour of the dwarf late-type galaxies is inspected in Sect. 6. Discussion and conclusions are given respectively, in Sects. 7 and 8.

2. The samples

The standard sample of TF calibrators of Pierce & Tully (1992) comprises 15 optically selected spiral and irregular galaxies, members of the Local and M 81 groups. Six of them have reliable independent distance estimates from a study of Cepheid variables. Although the sample spans the range 40–250 $\mathrm{km\,s^{-1}}$ in rotational maximum velocity and a range of 5 B-magnitudes in luminosity, it represents mainly galaxies later than Sbc. Given its characteristics, the sample is affected by the population incompleteness bias and the resultant TF relation may be eventually affected by type dependences (Kraan-Korteweg et al. 1988; Theaureau et al. 1997). Yasuda et al. (1997) and Federspiel et al. (1998) have used more and different calibrating galaxies (mainly earlier than Sd) with Cepheid distances (mainly obtained with HST). However, such a selection criterium does not guarantee that their distribution in luminosity and maximum rotational velocity reflects the cosmic distribution (Teerikorpi et al. 1999). Therefore, a sample of late-type galaxies populating both the bright and faint ends of the galaxy luminosity functions and spanning a wide range in rotational velocity and Hubble type is needed (cf. Kraan-Korteweg et al. 1988).

In order to fulfil these requirements, we consider galaxies in the Virgo Cluster (Binggeli et al. 1985; 1993) and in the Ursa Major Cluster (Tully et al. 1996). These clusters are characterized by two different dynamic states (Tully et al. 1996), although both are not virialized and lie within the same cosmological distance (heliocentric recessional velocities $\mathrm{V_h \leq 3000\ km\,s^{-1}}$). They provide us with a comparison sample of galaxies, whose stellar population properties are not strongly biased by the effects of a high-density environment (see Gallagher & Hunter 1986; Kraan-Korteweg et al. 1988; Tully et al. 1996; cf. also Gavazzi 1998) and of different cosmological epochs on the star-formation histories (cf. Heavens & Jimenez 1999).

The late-type galaxies of the Virgo Cluster Catalogue (Binggeli et al. 1985 - VCC), which is complete to $\mathrm{B_T} \leq 18\ \mathrm{mag}$, are selected according to the following criteria:

1. $\mathrm{B_T} \leq 16\ \mathrm{mag}$;
2. Hubble type later than S0a;
3. cluster membership according to Binggeli et al. (1993);
4. sky distribution according to Boselli et al. (1997);
5. $0.22 < \mathrm{b/a} \leq 0.82$, where b/a is the minor-to-major axis ratio, estimated at the 25 B-mag arcsec^{-2} isophote, listed in de Vaucouleurs et al. (1991) (RC3). We note that such a range corresponds to $35^{\circ} \leq \mathrm{i} < 80^{\circ}$, where the inclination, i, is derived from the Hubble-Holmberg formula that converts the axial ratio into inclination with a constant intrinsic flattening of 0.2 (cf. Yasuda et al. 1997).
6. No interacting or peculiar systems (see Tutui & Sofue 1997; Federspiel et al. 1998);
7. $\sigma_{\mathrm{W}}/\mathrm{W} < 1/3$, where W is the observed HI line-width (full width at 20% level of $\mathrm{I/I_{max}}$), in $\mathrm{km\,s^{-1}}$, and σ_{W} its error. The HI line-widths come from Bottinelli et al. (1990).
8. 25 B-mag arcsec^{-2} isophotal magnitude, $\mathrm{m_{B_{25}}}$, listed in the RC3.
9. HI deficiency (Haynes & Giovanelli 1984) <0.6. This parameter is derived from the HI fluxes listed in Bottinelli et al. (1990), according to Yasuda et al. (1997). Such a selection criterium prevents the inclusion of HI-truncated spiral galaxies, mainly earlier than Sbc (cf. Federspiel et al. 1998), which may blur the TF relation (cf. Kraan-Korteweg et al. 1988).

In addition, we require the existence of distance estimates from Yasuda et al. (1997), in order to determine the relevance of the choice of distances given by the galaxy cluster assignment vs. the individual galaxy distances in our results, for such a non-virialized cluster (see Sect. 4.3).

Only 25 galaxies satisfy the previous selection criteria. The resultant sample has an estimated completeness limit of $\mathrm{m_{B_{25}}} \sim$ 14.0 B-mag, comprises 16 objects with $1 \leq \mathrm{T} \leq 6$ (i.e., from Sa to Scd), where T is the RC3 type, and 9 objects with $7 \leq \mathrm{T} \leq 11$ (i.e. from Sd to Sm/BCD) and spans the range $81 \leq \mathrm{W} \leq 476\,\mathrm{km\,s^{-1}}$. Its optical properties are listed in Table 1 as follows:

Column 1: VCC denomination;
Column 2,3: celestial coordinates (epoch=1950.0);
Column 4: morphological classification;
Column 5: ratio between major and minor axes (RC3);
Column 6: $\mathrm{m_{B_{25}}}$ (RC3);
Column 7: HI observed line-width (W) and its error (σ_{W}).

Instead, from the Ursa Major (UMa) Cluster catalogue of Tully et al. (1996), which is complete to $\mathrm{B_T} \leq 14.5$ mag, we select 31 late-type galaxies according to the following criteria:

1. Hubble type later than S0a;
2. $0.22 < \mathrm{b/a} \leq 0.82$;
3. no interacting or peculiar systems;
4. $\sigma_{\mathrm{W}}/\mathrm{W} < 1/3$, where the HI line-widths (full width at 20% level of $\mathrm{I/I_{max}}$) are taken from Bottinelli et al. (1990);
5. isophotal magnitude $\mathrm{m_{B_{25}}}$ and axial ratio b/a (estimated at the 25 B-mag arcsec^{-2} isophote) listed in the RC3.
6. HI deficiency <0.6.

This sample comprises 19 objects with $1 \leq \mathrm{T} \leq 6$ and 12 objects with $7 \leq \mathrm{T} \leq 11$, spanning the range $107 \leq \mathrm{W} \leq 475\,\mathrm{km\,s^{-1}}$. Its optical properties are listed in Table 2 as follows:

Column 1: NGC/UGC denomination;
Column 2,3: celestial coordinates (epoch=1950.0);
Column 4: morphological classification;
Column 5: ratio between major and minor axes (RC3);
Column 6: $\mathrm{m_{B_{25}}}$ (RC3);
Column 7: HI observed line-width (W) and its error (σ_{W}).

The resultant sample comprises 56 late-type galaxies, predominantly erlier than Im, and has a completeness limit of $\sim$ 14.0 B-mag, mainly for spiral galaxies earlier than Sdm. Assuming distances to Virgo and to UMa of, respectively, 16.17 Mpc and 16.07 Mpc (Tully et al. 1996), with $\mathrm{H_0} = 82\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$, the previous completeness limit (equivalent to $\mathrm{M_B} \leq -17$ mag) gives comparable grasps into the galaxy luminosity function for the two cluster subsamples. We note that the distance of 16.17 Mpc for the Virgo cluster is within the values of 13.88 Mpc and 17.20 Mpc (with $\mathrm{H_0} = 82\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$), recently estimated by Federspiel et al. (1998) and Yasuda et al. (1997) respectively, via the B-magnitude TF relation.

In order to better study the distribution of galaxies at the faint end of the TF relation, we select two more samples. The first sample comprises 20 group ELT spiral galaxies, selected from Matthews et al. (1998b) (hereafter called the "ELT" sample), according to the following criteria:

1. $0.22 \leq \mathrm{b/a} < 0.82$, where b/a, the 25 B-mag arcsec^{-2} isophote axial ratio, is listed in the RC3;
2. no interacting or peculiar systems;
3. $\sigma_{\mathrm{W}}/\mathrm{W} < 1/3$, where the HI line-widths (full width at 20% level of $\mathrm{I/I_{max}}$) come from Matthews et al. (1998a,b). We assume that there is no systematic bias in the adoption of distinct catalogues of HI measurements for the ELT sample and the previous sample. The apparent 25 mag arcsec^{-2} isophotal blue magnitudes ($\mathrm{m_{B_{25}}}$) come from the ESO Catalogue (Lauberts & Valentijn 1989) and coincide with the few listed in the RC3.

Table 3 lists the optical properties of the 20 galaxies of the ELT sample as follows:

Column 1: ESO denomination;
Column 2,3: celestial coordinates (epoch=1950.0);
Column 4: morphological classification;
Column 5: ratio between major and minor axes (RC3);
Column 6: $\mathrm{m_{B_{25}}}$ (ESO/RC3);
Column 7: HI observed line-width (W) and its error (σ_{W}).

The ELT sample comprises 6 galaxies with $5 \leq \mathrm{T} \leq 6$ (i.e. from Sc to Scd) and 14 objects with $7 \leq \mathrm{T} \leq 9$ (i.e. from Sd to Sm). Its galaxies span the range $78 \leq \mathrm{W} \leq 189\,\mathrm{km\,s^{-1}}$. Galaxy distances are estimated via two methods, one assuming a simple linear Hubble law and the other adopting galaxy group assignments (see Matthews et al. 1998b) in order to evaluate eventual biases in our conclusions.

We note first that the ELT sample comprises galaxies with heliocentric recessional velocities $\mathrm{V_h} \leq 3000\ \mathrm{km\ s^{-1}}$ as well as the comparison sample. Second, according to the definition of ELT spiral galaxies (Matthews & Gallagher 1997), the latter sample contains 21 cluster counterparts.

Finally, we select 13 dwarf late-type galaxies from Stil & Israel (1998), of which 6 are rotationally supported systems and 7 are dwarfs with comparable rotational and random velocities, according to the following criteria:

1. $0.22 < \mathrm{b/a} \leq 0.82$;
2. no interacting or peculiar systems;
3. $\sigma_{\mathrm{W}}/\mathrm{W} < 1/3$, where the HI line-widths (full width at 20% level of $\mathrm{I/I_{max}}$) are taken from Bottinelli et al. (1990);
4. isophotal magnitude $\mathrm{m_{B_{25}}}$ and axial ratio b/a (estimated at the 25 B-mag arcsec^{-2} isophote) listed in the RC3.

Table 4 lists the optical properties of these 13 galaxies as follows:

Column 1: NGC/UGC denomination;
Column 2,3: celestial coordinates (epoch=1950.0);
Column 4: morphological classification;
Column 5: ratio between major and minor axes (RC3);
Column 6: $\mathrm{m_{B_{25}}}$ (ESO/RC3);
Column 7: HI observed line-width (W) and its error (σ_{W}).

The sample (hereafter called the "dwarf" sample) spans the range 35–153 $\mathrm{km\,s^{-1}}$ in HI line-width and comprises objects fainter than $\mathrm{M_B} = -16$ mag, i.e. which satisfy the commonly accepted distance-dependent luminosity definition of Tammann (1980). Distances to individual galaxies are derived from Stil &

Table 1. Parameters of the VCC sample galaxies

Denomination VCC	R.A. (1950) hh mm ss	DEC (1950) dd pp ss	Hubble Type	a_{25}/b_{25}	$m_{B_{25}}$ mag	W km s^{-1}
66	12 10 14	11 08 48	Sc	2.82	11.92	286.0±6.0
87	12 11 08	15 43 54	Sm	1.66	15.20	121.0±20.0
92	12 11 15	15 10 48	Sb	3.55	10.81	476.0±4.0
152	12 12 58	09 51 48	Scd	1.95	13.60	206.0±8.0
318	12 16 30	09 08 06	Scd	1.66	14.08	187.0±10.0
692	12 21 29	12 28 54	Sc	1.48	13.03	116.0±6.0
912	12 24 00	12 53 18	Sbc	1.55	12.99	186.0±5.0
950	12 24 21	11 50 18	Sm	1.70	14.70	81.0±3.0
1189	12 26 56	07 02 54	Sc	1.66	13.82	130.0±10.0
1356	12 28 51	11 46 00	Sm/BCD	2.29	15.63	167.0±10.0
1379	12 29 08	17 07 48	Sc	1.86	12.70	196.0±6.0
1410	12 29 32	16 57 48	Sm	1.86	14.61	181.0±8.0
1450	12 30 11	14 19 30	Sc	1.20	12.82	141.0±9.0
1554	12 31 47	06 44 42	Sm	2.57	12.16	229.0±5.0
1686	12 34 12	13 32 00	Sm	1.95	13.79	118.0±20.0
1725	12 35 09	08 50 00	Sm/BCD	1.95	14.89	114.0±20.0
1726	12 35 12	07 22 42	Sdm	1.29	14.70	87.0±20.0
1791	12 36 53	08 14 12	Sm/BCD	2.04	14.42	130.0±13.0
1811	12 37 21	15 34 24	Sc	1.55	12.96	152.0±12.0
1929	12 40 06	14 37 48	Scd	2.45	13.90	206.0±10.0
1932	12 40 03	14 34 12	Sc	3.80	13.48	280.0±13.0
1987	12 41 26	13 24 00	Sc	1.74	11.23	304.0±4.0
2023	12 43 00	13 36 24	Sc	1.95	13.66	176.0±5.0
2058	12 45 15	14 02 06	Sc	1.23	11.48	197.0±11.0
2070	12 45 51	08 45 36	Sa	1.62	11.72	417.0±4.0

Israel (1998), adopting $H_0 = 82\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$. We note that for such a sample, galaxy distances are heterogeneous, since they are taken from published stellar photometry or published group membership, with Hubble expansion and correction for Virgocentric infall adopted only for a small fraction of the sample.

3. Corrections to the fundamental observables

3.1. HI line-width corrections

The two observables linked through the TF relation, luminosity and maximum rotational velocity, must be corrected for the well-known inclination effects. Here, rotational velocities are derived from the HI line-widths and deprojected, according to the following two methods.

a) We determine the galaxy inclination via the Holmberg (1946) formula, adopting the constant value of 0.2 for the intrinsic flattening, and we do not make any corrections for turbulent/z-motions to the observed line-widths, in order to limit the introduction of systematic noise in the fitting procedure due to modelling (see Yasuda et al. 1997; Pierini & Tuffs 1999; cf. Stil & Israel 1998 for the dwarf systems).

b) We adopt the Holmberg formula for the inclination, where the intrinsic axial ratio, q_0, depends on the Hubble classification (as given in the RC3) of the galaxy as follows:

$$-\,log(q_0) = 0.60 + 0.045\,T$$

for $T \leq 7$ and

$$-\,log(q_0) = 0.65$$

for $T > 7$ (from Bottinelli et al. 1983).

The value of the intrinsic axial ratio is rather uncertain for spirals later than Scd and may not be realistic for dwarf galaxies. The latter systems have a large spread in the intrinsic distribution of axial ratios ($<q_0> = 0.57$), as found by Staveley-Smith et al. (1992). Therefore, we follow the estimate of the most likely inclination, i, for a dwarf galaxy, given its observed axial ratio, as derived by the latter authors:

$$\cos^2(\mathrm{i}) = \frac{(\mathrm{b/a})^2 - (0.65\ \mathrm{b/a} - 0.072\ (\mathrm{b/a})^{3.9})^2}{(1 - (0.65\ \mathrm{b/a} - 0.072\ (\mathrm{b/a})^{3.9})^2)}.$$

Moreover, we adopt the line-width corrections (ΔW) due to the velocity dispersion, given by Bottinelli et al. (1983), under the assumption of a purely gaussian velocity distribution:

$$\Delta W = 2\ 1.89\ [1.5/(2.25–1.25\ sin^2(i))]^{1/2}\ \sigma_z,$$

where σ_z is the velocity dispersion along the z-axis. We adopt $\sigma_z = 5\ \mathrm{km\ s^{-1}}$ for the ELT spiral galaxies (Rhee 1996) and the dwarf late-type galaxies (cf. Staveley-Smith et al. 1992; Stil & Israel 1998) and $\sigma_z = 10\ \mathrm{km\ s^{-1}}$, respectively, for the more luminous systems (e.g. van der Kruit & Shostak 1982; Lewis 1984).

We anticipate that although "Method a" and "Method b" lead to different formulations of the TF relations, they do not affect any of the following conclusions.

Table 2. Parameters of the UMa sample galaxies

Denomination NGC/UGC	R.A. (1950) hh mm ss	DEC (1950) dd pp ss	Hubble Type	a_{25}/b_{25}	$m_{B_{25}}$ mag	W $km\,s^{-1}$
UGC 6399	11 20 36	51 10 09	Sm	3.55	14.50	166.0±16.0
UGC 6446	11 23 53	54 01 21	Sd	1.55	13.80	143.0±6.0
NGC 3718	11 29 50	53 20 39	Sa	2.04	11.40	470.0±3.0
NGC 3726	11 30 39	47 18 20	Sc	1.44	11.02	284.0±4.0
NGC 3729	11 31 05	53 24 08	Sab	1.48	12.43	214.0±21.0
NGC 3769	11 35 03	48 10 10	Sb	3.16	12.42	272.0±9.0
NGC 3782	11 36 40	46 47 25	Scd	1.55	13.13	132.0±7.0
NGC 3893	11 46 00	48 59 20	Sdm	1.62	10.87	302.0±4.0
UGC 6818	11 48 10	46 05 09	Sd	2.14	14.30	182.0±7.0
UGC 6840	11 49 30	52 23 10	Sdm	3.16	15.20	149.0±6.0
NGC 3949	11 51 05	48 08 14	Sbc	1.74	11.64	276.0±7.0
NGC 3953	11 51 12	52 36 18	Sbc	1.99	10.83	425.0±7.0
NGC 3972	11 53 09	55 35 56	Sbc	3.63	12.77	263.0±8.0
UGC 6917	11 53 53	50 42 27	Sd	1.74	13.50	195.0±7.0
NGC 3985	11 54 06	48 36 48	Sd	1.55	13.11	165.0±11.0
UGC 6922	11 54 17	51 05 41	Scd	1.23	14.90	144.0±5.0
UGC 6923	11 54 14	53 26 19	Sdm	2.40	13.92	173.0±4.0
UGC 6930	11 54 42	49 33 41	Sd	1.58	13.50	133.0±8.0
NGC 3992	11 55 01	53 39 11	Sbc	1.62	10.55	475.0±3.0
UGC 6969	11 56 13	53 42 11	Sm	3.16	15.20	155.0±6.0
UGC 6983	11 56 35	52 59 08	Scd	1.44	13.80	194.0±5.0
NGC 4051	12 00 36	44 48 36	Sbc	1.35	11.23	293.0±4.0
NGC 4085	12 02 50	50 37 54	Sc	3.55	12.95	292.0±7.0
NGC 4088	12 03 02	50 49 03	Sbc	2.57	11.14	363.0±6.0
NGC 4100	12 03 36	49 51 41	Sbc	3.02	11.66	411.0±7.0
NGC 4102	12 03 51	52 59 22	Sab	1.74	12.00	315.0±8.0
NGC 4138	12 06 58	43 57 49	Sa	1.51	12.15	335.0±11.0
UGC 7218	12 10 27	52 32 36	Im	1.95	14.78	107.0±8.0
NGC 4218	12 13 17	48 24 36	Sm	1.66	13.40	160.0±4.0
NGC 4217	12 13 21	47 22 11	Sb	3.39	11.96	431.0±6.0
NGC 4389	12 23 09	45 57 41	Sbc	1.95	12.75	188.0±5.0

3.2. Magnitude corrections

Observed magnitudes are corrected for Galactic extinction according to RC3, while we adopt three different corrections for internal extinction. First, we recall that the standard empirical description of the extinction (in the B-band), A_B, as a function of the inclination (and, therefore, of the axial ratio) is:

$$A_B^{i-0} = \gamma_B \, log \, (a/b),$$

where the nomenclature in the superscript, $i-0$, implies corrections are in a face-on orientation but do not account for extinction in a face-on system.

From a statistical analysis of a sample of almost a thousand late-type galaxies of the Local Universe, Gavazzi & Boselli (1996) have confirmed that γ depends not only on the observational wavelength but also on the galaxy morphological type. Following their notation, we adopt:

$$A_B^{i-0} = -2.5 \, D \, log \, (a/b) \ , \tag{1a}$$

where D is a coefficient dependent on the Hubble type tabulated in Gavazzi & Boselli (1996). For Hubble types later than Sc, we use the same coefficient as for the irregular galaxies. Hereafter we refer to Eq. 1a as the GBIE correction.

The second method of IE correction (hereafter called TFIE correction), adopted by Matthews et al. (1998b), relies on a type-independent "sandwich-model" of the distribution of the dust and stellar components within the disk and prescribes:

$$A_B^i = -2.5 \, log \times \left[f \left(1 + e^{-\tau sec \, i}\right) + (1-2f) \, \frac{1 + e^{-\tau sec \, i}}{(\tau sec \, i)} \right] \ , \tag{1b}$$

where $\tau = 0.55$ is the optical depth, $\mathrm{f} = 0.25$ is the fraction of light in front of the sheet of finite thickness where the whole absorbtion is supposed to occur (see Tully & Fouqué 1985) and i is the galaxy inclination. The IE value is given by: $A_B^{i-0} = A_B^i - A_B^0$, where the extinction in a face-on system, A_B^0, is assumed constant and equal to 0.27 mag. We note that the adoption of such a recipe for dwarf systems has been criticized (e.g. Rhee 1996).

Finally, Tully et al. (1998) have found that the global extinction in spiral galaxies depends on their luminosity and, consequently, on their rotation rate (via the TF relation). Such a result is in agreement with the well-known existence of the metallicity-luminosity relation in dwarf irregular galaxies (Skillman et al.

Table 3. Parameters of the ELT sample galaxies

Denomination ESO	R.A. (1950) hh mm ss	DEC (1950) dd pp ss	Hubble Type	a_{25}/b_{25}	$m_{B_{25}}$ mag	W $km\,s^{-1}$
418008	03 29 28	-30 22 54	Sd	1.51	13.90	153.5±6.9
418009	03 29 54	-31 30 18	Sdm	1.26	14.07	104.0±6.6
358015	03 31 10	-34 58 30	Sdm	1.74	15.34	100.2±22.8
358020	03 32 58	-32 48 18	Sdm	1.58	14.58	117.7±21.0
549002	03 40 43	-19 10 48	Sdm	1.20	14.78	147.5±12.0
359029	04 10 56	-33 07 42	Sdm	1.48	14.77	141.1±6.6
422005	04 50 07	-28 40 30	Sdm	1.48	14.88	126.2±5.4
552066	05 03 02	-18 27 30	Sm	1.70	16.25	78.0±11.0
305009	05 06 26	-38 22 30	Sc	1.29	13.08	129.8±0.9
487019	05 29 45	-23 10 48	Sd	2.04	13.84	181.5±5.4
488049	05 56 38	-25 25 06	Scd	2.51	15.01	172.1±2.7
500032	10 20 30	-24 05 06	Scd	1.20	14.76	116.6±13.2
502016	11 02 48	-26 21 18	Sd	2.95	14.72	155.0±15.6
504010	11 40 32	-23 09 18	Sdm	3.02	15.54	145.0±13.0
440004	11 43 11	-28 05 24	Scd	2.45	14.21	189.0±4.0
504025	11 51 18	-27 04 18	Sd	1.35	14.34	137.0±6.0
443080	13 08 25	-27 44 36	Scd	1.62	14.14	170.2±3.3
445007	13 37 30	-31 26 54	Sm	1.78	16.65	110.0±10.0
510026	13 54 46	-25 32 54	Scd	1.58	15.49	141.0±3.0
446053	14 18 22	-29 02 06	Sdm	1.95	14.67	131.9±3.9

Table 4. Parameters of the dwarf sample galaxies

Denomination ESO	R.A. (1950) hh mm ss	DEC (1950) dd pp ss	Hubble Type	a_{25}/b_{25}	$m_{B_{25}}$ mag	W $km\,s^{-1}$
UGC 4483	08 32 07	69 57 16	Im	1.48	15.00	56.0±4.0
NGC 2915	09 26 31	-76 24 30	Sm	1.95	12.92	153.0±7.0
DDO 63	09 36 01	71 24 55	Im	1.23	14.50	44.0±3.0
DDO 64	09 47 25	31 43 17	Im	2.63	14.10	108.0±5.0
DDO 69	09 56 30	30 59 05	Im	1.66	12.80	46.0±5.0
DDO 83	10 33 54	31 48 23	Im	1.74	14.40	120.0±5.0
DDO 125	12 25 15	43 46 12	Im	1.78	13.90	46.0±4.0
ESO 381-G20	12 43 18	-33 33 54	Im	2.51	14.21	94.0±10.0
DDO 154	12 51 39	27 25 11	Im	1.38	13.50	98.0±5.0
DDO 165	13 04 39	67 58 16	Im	1.82	13.60	62.0±11.0
DDO 168	13 12 16	46 11 00	Im	2.63	13.50	79.0±5.0
DDO 187	14 13 38	23 17 07	Im	1.29	14.30	49.0±5.0
DDO 216	23 26 03	14 28 18	Im	1.86	14.30	35.0±3.0

1989) and in spirals (Zaritsky et al. 1994). Therefore, as a third recipe of IE correction (hereafter called T98IE correction), we use:

$$\gamma_B = 1.57 + 2.75\,(log\;W^i - 2.5)\;, \qquad (1c)$$

where $W^i \simeq 2V_{Max}$ is the inclination corrected equivalent width.

3.3. Systematic differences between the IE corrections

Before determining the corresponding three Tully-Fisher relations, it is instructive to understand eventual systematic differences among the previous methods of estimating the internal extinction. Fig. 1 shows the differences in absolute magnitudes (due to different IE corrections) of the galaxies of all the three samples vs. their maximum rotational velocities, obtained via "Method b".

It is evident that for giant galaxies both the GBIE and the T98IE corrections provide absolute magnitudes $\sim$ 0.2–1.8 mag brighter than the ones obtained via the TFIE recipe, at any values of the velocity. The latter effect was already pointed out and discussed by Tully et al. (1998). Moreover, although the GBIE and the T98IE corrections for giant galaxies are in good agreement (within ±0.5 mag), the former corrections provide absolute magnitudes brighter/fainter than the latter for systems with $V_{Max} \leq 125\,km\,s^{-1}$/$V_{Max} \geq 200\,km\,s^{-1}$. Differences increase especially for slow rotators. This effect is mirrored in the correlation of the magnitude residuals with the morphological type in Fig. 2b: the spiral galaxies earlier than Sc are on aver-

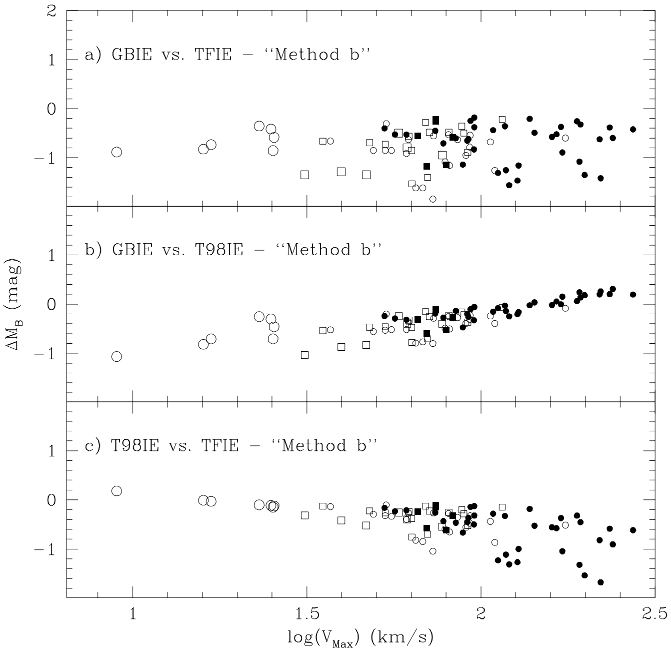

Fig. 1a–c. Plots of the differences in absolute magnitude in the cases of the GBIE and the TFIE corrections (panel **a**), the GBIE and the T98IE corrections (panel **b**) and the T98IE and the TFIE corrections (panel **c**) vs. the maximum rotational velocities, corrected for inclination and turbulent/z-motions ("Method **b**") for the whole sample of 76 late-type galaxies. Hereafter, filled and empty symbols represent, respectively, late-type galaxies with $1 \leq T \leq 6$ and $T \geq 7$. Moreover, small circles represent galaxies of the Virgo and Ursa Major clusters (i.e. of the "comparison" sample), mid-size squares represent ELT galaxies and big-size squares and circles represent rotationally supported dwarf systems and dwarfs with comparable rotational and random velocities from Stil & Israel (1998), respectively.

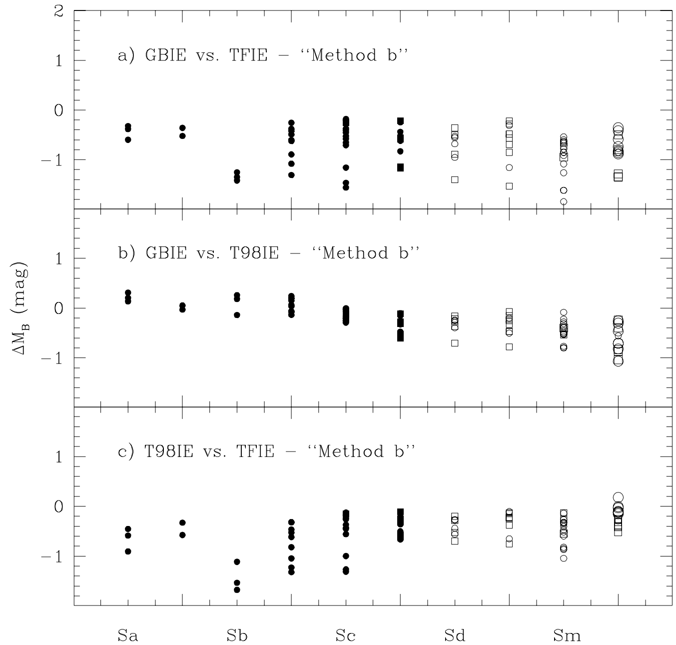

Fig. 2a–c. Plots of the differences in absolute magnitude, obtained in the same cases as in Fig. 1, vs. the galaxy Hubble types. See the caption of Fig. 1 for the meaning of the different symbols.

age fainter via the GBIE estimates than via the T98IE ones, and vice-versa for the later morphological types. We interpret these systematic behaviours as due to the complex interconnection of the metallicity-luminosity relation, the differential contribution of the bulge to the total luminosity of the system and the dependence of the star-formation history on the mass (e.g. Gavazzi & Scodeggio 1996) and/or on the morphological type (Kennicutt et al. 1994) of the galaxy. The giant spiral (Sa-Sc) galaxies are expected to have higher metallicities, since their rotational velocities and luminosities are, on average, higher than in later spiral galaxies. However, the different contributions are difficult to disentangle. In fact, while the GBIE corrections are separated into Hubble types and therefore comprise potentially the differential contribution of the bulge to the total luminosity and the morphology-dependence of the star-formation history, they do not discriminate galaxies with the same Hubble type but with different velocities, i.e. masses. On the contrary, the T98IE corrections are obtained through the binning in K'-band luminosity classes (i.e. approximately in mass classes - cf. Gavazzi et al. 1996), neglecting the morphological information. Moreover, in both the approaches the aspects of the spectral energy distribution, i.e. of the stellar populations, and of the global mass content and the spatial distribution of the dust in individual galaxies are not taken into account. However, the large differences of the face-on corrected magnitudes of luminous systems via the TFIE method, with respect to the values obtained via the GBIE and the T98IE corrections, are a clear signature of the limits of the assumptions of the Tully & Fouqué (1985) model of dust distribution in any real spiral galaxies.

The question is more complex when dwarf galaxies are considered. For such systems, we find that the T98IE corrections are surprisingly in better agreement (within ± 0.5 mag) with the TFIE corrections than with the GBIE corrections. As a matter of fact, it seems that the consistency between the TFIE and T98IE corrections improves towards the slow and faint end of our late-type galaxy sample, whose internal extinction is, on the other hand, coarsely characterized in the analysis of Gavazzi & Boselli (1996). Therefore, the T98IE corrections do not seem to produce overestimated magnitudes for the ELT and dwarf spiral galaxies, when compared to the TFIE corrections, although the uncertainties about the true intrinsic optical depths and dust geometries of these systems still exist (see Rhee 1996).

4. Template B-band TF relation of cluster late-type galaxies

The influence of different methods of correction and deprojection of the HI line-widths on the ensuing TF relation has already been inspected in the literature (e.g. Heidmann et al. 1971; Bottinelli et al. 1983). Therefore, in Sect. 4.1 we focus on the influence of different IE corrections.

The high reliability of the cluster membership for both the subsamples of the VCC (Binggeli et al. 1993) and the UMa

(Tully et al. 1996) galaxies gives us the opportunity of determining their absolute magnitudes via the method of galaxy cluster assignment. On the other hand, recent results in the literature have confirmed the existence of a large depth along the line-of-sight in Virgo (Yasuda et al. 1997; Federspiel et al. 1998; Gavazzi et al. 1998). The cluster depth adds noise in case of complete samples, otherwise it introduces different (and differential) selection effects. Pierini & Tuffs (1999) have shown that the cluster depth does not bias the slope of the TF relation of their sample galaxies, in the Near-IR. However, in the B-band the selection effects are expected to be exploited, because of the strong dependence of the optical LF on the morphological type (e.g. Sandage et al. 1985). In Sect. 4.2 we discuss the relevance of this effect on the shape of the TF relation, thanks to the availability of individual distances for the 25 VCC galaxies of the comparison sample, estimated independently and differently by Yasuda et al. (1997) via the method of the B-magnitude TF relation.

Finally, in order to derive the TF relation, we adopt the algorithm executing a bivariate least-squares fit, taking into account the uncertainties in both the x- and y-variables at the same time, implemented in the task "FITEXY" of the Numerical Recipes (Press et al. 1988), consistent with both Pierini & Tuffs (1999) and Matthews et al. (1998b). We note that the uncertainties of the T98IE corrected magnitudes are affected by the uncertainties of the observed velocities.

4.1. The influence of the IE correction

Here we determine the B-magnitude TF relation for the subsample of 35 giant late-type (from Sa to Scd) cluster galaxies, since for these galaxies the adopted dependence of the intrinsic axial ratio on the Hubble type from the observations is better understood.

First, we show the results obtained by adopting "Method a" for inclination determination and velocity correction for turbulent/z-motions (see Sect. 3.1). When the IE corrections of Gavazzi & Boselli (1996) (Eq. 1a) are adopted, we obtain:

$$\mathrm{M_B} = -5.84(\pm0.61) \times \log(\mathrm{V_{Max}}) - 6.43(\pm1.35)\ , \quad (2a)$$

with ${\chi^2}_{\rm red} = 1.17$.

Instead, when the Tully & Fouqué's (1985) corrections (Eq. 1b) and the Tully et al.'s (1998) corrections (Eq. 1c) are adopted, we obtain, respectively:

$$\mathrm{M_B} = -5.85(\pm0.57) \times \log(\mathrm{V_{Max}}) - 5.61(\pm1.27)\ , \quad (2b)$$

with ${\chi^2}_{\rm red} = 1.69$, and

$$\mathrm{M_B} = -7.04(\pm0.66) \times \log(\mathrm{V_{Max}}) - 3.82(\pm1.44)\ , \quad (2c)$$

with ${\chi^2}_{\rm red} = 1.19$.

When "Method b" is adopted, we obtain:

$$\mathrm{M_B} = -4.78(\pm0.49) \times \log(\mathrm{V_{Max}}) - 9.11(\pm1.04)\ , \quad (3a)$$

with ${\chi^2}_{\rm red} = 1.30$ (GBIE),

$$\mathrm{M_B} = -4.70(\pm0.46) \times \log(\mathrm{V_{Max}}) - 8.51(\pm0.98)\ , \quad (3b)$$

with ${\chi^2}_{\rm red} = 1.90$ (TFIE) and

$$\mathrm{M_B} = -5.80(\pm0.51) \times \log(\mathrm{V_{Max}}) - 6.90(\pm1.08)\ , \quad (3c)$$

with ${\chi^2}_{\rm red} = 1.40$ (T98IE).

Two major conclusions can be easily drawn:

i) when no corrections for Hubble type to the inclination determination and for turbulent/z-motions to the line-width are applied ("Method a"), the TF relation has a steeper slope and a fainter zero-point than in the opposite case ("Method b"), for any IE corrections;
ii) the T98IE corrections always produce a TF relation which is steeper and with a fainter zero-point with respect to the GBIE and TFIE corrections. The latter two IE corrections, instead, produce TF relations with slopes consistent within the errors and with zero-points consistent with the difference of the average absolute magnitude of the subsample $|\delta < \mathrm{m_{B_{25}}} > | = 0.68$ mag.

Effect i) is already known in the literature (Bottinelli et al. 1983) but effect ii) is a new result (cf. Federspiel et al. 1998). Different IE corrections produce different grasps in the galaxy LF for the same sample of galaxies and, therefore, different forms of the relation. However, the steepening may indeed be due to the coupling of the correlation between differences in the IE corrections and morphological types (found in Sect. 3) to the distribution of different Hubble types in the $\mathrm{L_B}$-$\mathrm{V_{Max}}$ plane (cf. Theureau et al. 1997). In fact, earlier spiral galaxies are faster rotators (e.g., Kraan-Korteweg et al. 1988).

As a final result, we find that $L_B \propto V_{Max}^{1.9-2.3}$ ("Method b"), and therefore, we conclude that the IE estimates have a significant impact on the shape of the B-magnitude Tully-Fisher relation!

4.2. Cluster population incompleteness bias and type segregation

In the previous section we have produced template TF relations for a flux-limited non complete subsample of cluster giant late-type galaxies with a dynamic range of less than two orders of magnitude in luminosity. As already demonstrated in the literature (Teerikorpi 1990; Sandage et al. 1995; Giovanelli et al. 1997), such a sample experiences the cluster population incompleteness bias. The effect consists of the biasing of the fiducial scaling relations, such as for example the Tully-Fisher relation, as a consequence of an insufficiently deep sampling of the galaxy luminosity function of the parent cluster sample. The average selection effect is that the galaxies at the low-velocity end tend to be overluminous with respect to the overall template TF relation. As a consequence, the slope of the best-fit relation is shallower with respect to the slope which characterizes the intrinsic relation of the parent sample.

The estimate of such a bias depends on the *intrinsic dispersion* of the true luminosity-maximum rotational velocity relation of late-type galaxies (cf. Sandage et al. 1995) and on the grasp of the sample into the parent galaxy LF. The latter is $\sim$ 2 magnitudes for the previous subsample of 35 giant spirals, as roughly estimated from the difference of the average luminosity of the subsample with the luminosity of its brightest member. If we adopt the modelling of Sandage et al. (1995), such a grasp does not enable us to fully recover the slope and the intrinsic dispersion of the parent TF relation. As a consequence, we expect that the slope of our templates and the *observed dispersion* increase, when the faint-end of the galaxy luminosity function is better sampled. In fact, when the whole sample of 56 cluster late-type (from Sa to Im-BCD) galaxies is adopted, we obtain respectively for the GBIE, TFIE and T98IE corrections (Method b):

$$\mathrm{M_B} = -5.58(\pm 0.38) \times \log(\mathrm{V_{Max}}) - 7.32(\pm 0.78) \ , \qquad (4a)$$

with $\chi^2{}_{\rm red} = 1.44$,

$$\mathrm{M_B} = -5.96(\pm 0.36) \times \log(\mathrm{V_{Max}}) - 5.73(\pm 0.74) \ , \qquad (4b)$$

with $\chi^2{}_{\rm red} = 2.36$ and

$$\mathrm{M_B} = -6.90(\pm 0.40) \times \log(\mathrm{V_{Max}}) - 4.44(\pm 0.82) \ , \qquad (4c)$$

with $\chi^2{}_{\rm red} = 1.76$.

Figs. 3a–c show the corresponding distributions of the 56 galaxies in the $\mathrm{L_B}$-$\mathrm{V_{Max}}$ plane. The solid lines in panels a–c represent the corresponding templates, while the short-dashed lines show the $\pm 1\sigma$ TF relations. The long-dashed lines represent the TF relations of the subsample of 35 giant late-type galaxies (Eq. 3a–c). The biasing of the latter fiducial TF relation is evident.

Since increasing the grasp into the galaxy LF is equivalent to widening the range in morphological types, in Figs. 4a–c and 5a–c, we plot the residuals of the B-magnitude TF correlations (Eq. 4a–c) vs., respectively, the maximum rotational velocities and the Hubble types of the systems. We note that galaxies earlier/later than Scd tend to be overluminous/underluminous on average with respect to the GBIE and T98IE template relations (Eq. 4a,c), at maximum rotational velocity lower than 100 km s^{-1}. Such an effect almost disappears when "Method a" is adopted (not shown). Moreover, at least in Virgo, it does not seem to be due to any bias in the distribution of early and late spiral galaxies within the cluster. In fact, this behaviour does not appear in the TF relations derived from the sample of 25 VCC late-type galaxies, when adopting "Method a" and both cluster distance and individual distances from Yasuda et al. (1997), although the statistics are poor (not shown).

The behaviour shown in Fig. 5 may be the consequence either of the cluster incompleteness bias or of the type dependence of the TF relation (cf. Kraan-Korteweg et al. 1988). The type segregation in the inverse diameter Tully-Fisher relation has been modelled by Theureau et al. (1997) as the result of the different mass-luminosity structure of different morphological types. Unfortunately, given the poor-statistics in single bins of Hubble type (see Fig. 5) we cannot discuss these aspects in detail. Moreover, we cannot inspect whether either differences in structure or in the intrinsic optical depth, or an inaccurate adopted value of the intrinsic axial ratio for galaxies later than Scd lead to such a slight discrepancy.

However, the previous results strengthen the idea that the B-magnitude Tully-Fisher relation derived for the sample of local TF calibrators of Pierce & Tully (1992) is strongly affected by the population incompleteness bias and is liable to type segregation. Moreover, although the present sample of cluster late-type galaxies is still affected by the former bias, undoubtedly it provides us with a better template TF relation, given the deeper sampling of the galaxy LF for different Hubble types.

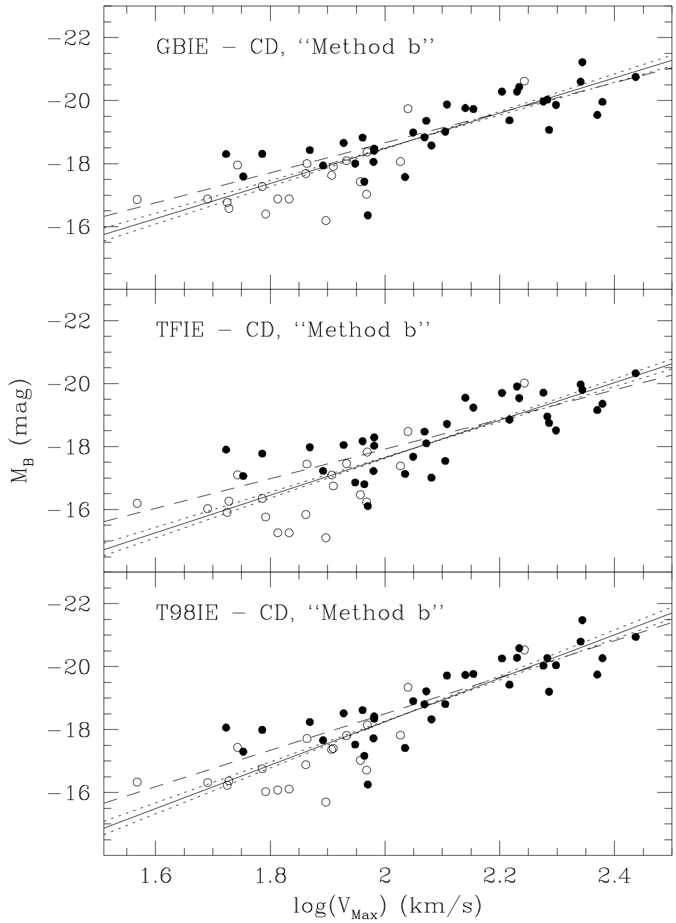

Fig. 3a–c. The distribution of the comparison sample of 56 cluster late-type galaxies in the luminosity-maximum rotational velocity plane, when corrections for Hubble type to the inclinations and corrections for turbulent/z-motions to the observed line-widths are adopted ("Method b"). Distances are derived via the method of galaxy cluster assignment. GBIE corrections are adopted in panel **a**, while TFIE corrections and T98IE corrections are adopted in panels **b** and **c**, respectively. In each panel, the thin continuous line shows the template TF relation (determined from the whole sample of 56 cluster galaxies – see Eq. 3a–c in Sect. 4.2) and the two thin short-dashed lines represent the $\pm 1\sigma$ relations. Instead, the thin long-dashed line represents the TF relation determined from the subsample of 35 late-type galaxies with Hubble type between Sa and Scd (see Eq. 2a–c in Sect. 4.1), under the previous conditions. See the caption of Fig. 1 for the meaning of the different symbols.

4.3. The cluster depth effect

The assumption that cluster galaxies lie at the same distance from us is, of course, a first order approximation. The depth

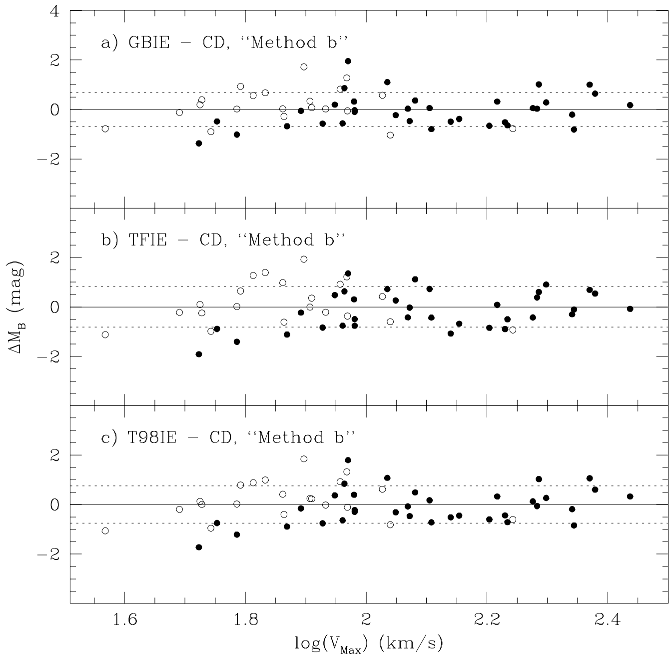

Fig. 4a–c. Plots of the residual magnitudes of the comparison sample of 56 late-type galaxies, with respect to the three different TF relations shown in Fig. 3, vs. the maximum rotational velocities of the galaxies. The short-dashed lines represent $\pm 1\sigma$ values. See the caption of Fig. 1 for the meaning of the different symbols.

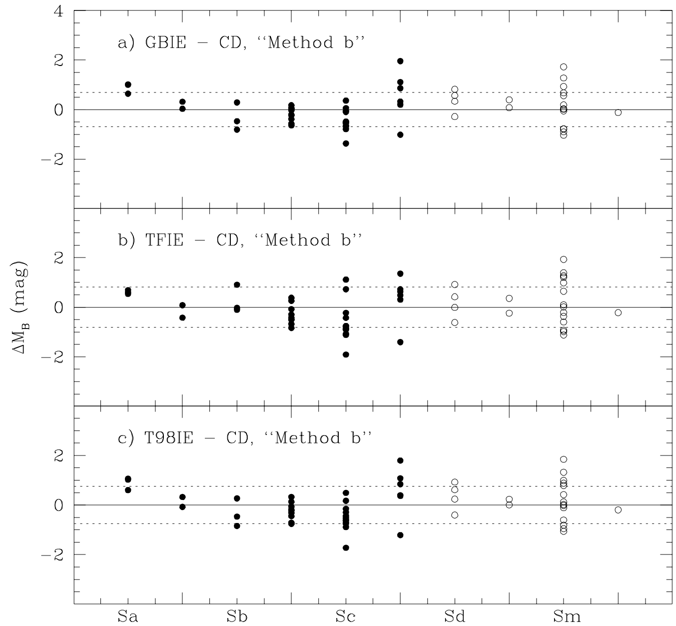

Fig. 5a–c. Plots of the residual magnitudes of the comparison sample of 56 late-type galaxies, with respect to the three different TF relations, shown in Fig. 3, vs. the Hubble types of the galaxies. The short-dashed lines represent $\pm 1\sigma$ values. See the caption of Fig. 1 for the meaning of the different symbols.

effect, as proved, for example, by the complex structure of the Virgo cluster (e.g., Yasuda et al. 1997; Federspiel et al. 1998; Gavazzi et al. 1999), strongly couples to i) the dynamic range and the statistics of the sampled B-magnitudes, ii) the large observed scatter of the B-band TF relation, as a consequence also of the different star-formation activities (cf. Gavazzi & Scodeggio 1996) and intrinsic optical depths of the individual galaxies, iii) the type distribution along the TF relation and iv) the cluster population incompleteness bias.

Since the cluster environment obviously modifies the free Hubble flow of the member galaxies, galaxy distances cannot be estimated from the individual recessional velocities, as for group galaxies (cf. Matthews et al. 1998b). In the latter case, however, we note that the internal group dynamics can affect the distances derived from the observed galaxy recessional velocity, assuming a simple linear Hubble law, in an unpredictable way.

For the Virgo cluster subsample, individual galaxy distances have been determined by Yasuda et al. (1997), via the method of the B-magnitude Tully-Fisher relation. Therefore, we can compare the template relations for the subsample of 25 VCC giant and ELT spiral galaxies, obtained adopting "Method a", consistent with the previous authors, and either the common cluster distance of 17.20 kpc (cf. Yasuda et al. 1997) or the individual galaxy distances. In the former case we obtain:

$$\mathrm{M_B} = -6.64(\pm 0.75) \times \log(\mathrm{V_{Max}}) - 4.87(\pm 1.56)\ , \qquad (5a)$$

with ${\chi^2}_{\rm red} = 1.75$ (GBIE),

$$\mathrm{M_B} = -6.48(\pm 0.69) \times \log(\mathrm{V_{Max}}) - 4.36(\pm 1.43)\ , \qquad (5b)$$

with ${\chi^2}_{\rm red} = 2.47$ (TFIE) and

$$\mathrm{M_B} = -7.95(\pm 0.81) \times \log(\mathrm{V_{Max}}) - 1.99(\pm 1.66)\ , \qquad (5c)$$

with ${\chi^2}_{\rm red} = 1.99$ (T98IE).

Instead, when the individual galaxy distances are adopted, the corresponding templates are:

$$\mathrm{M_B} = -6.42(\pm 0.53) \times \log(\mathrm{V_{Max}}) - 5.47(\pm 1.11)\ , \qquad (6a)$$

with ${\chi^2}_{\rm red} = 0.41$ (GBIE),

$$\mathrm{M_B} = -5.62(\pm 0.44) \times \log(\mathrm{V_{Max}}) - 6.18(\pm 0.93)\ , \qquad (6b)$$

with ${\chi^2}_{\rm red} = 1.72$ (TFIE) and

$$\mathrm{M_B} = -7.27(\pm 0.59) \times \log(\mathrm{V_{Max}}) - 3.53(\pm 1.23)\ , \qquad (6c)$$

with ${\chi^2}_{\rm red} = 0.49$ (T98IE).

As a first result, we find that the shapes of the templates change as a consequence of the cluster depth effect, although both the differences in slope and in zero-point are within the (large) uncertainties. In particular, we note that in the case of the GBIE corrections, the depth effect is marginal, in agreement with the analysis of the Near-IR TF relation for the Virgo cluster galaxies of Pierini & Tuffs (1999).

The adoption of two subsamples selected from different clusters in Sect. 4.1 gives us some protection against templates strongly affected by cluster depth. However, as a conclusion, these results mainly stress the importance of homogeneity in the method of distance determination for studies of the TF relation, as will be discussed in the following analysis.

5. The field ELT spiral galaxies and the faint-end of the Tully-Fisher relation

It is crucial now to assess if ELT spiral galaxies in groups and in clusters share the same properties (e.g., the B-band LF). Actually, the Virgo and Ursa Major clusters are two of the best sources of faint and low surface brightness cluster galaxies, with also a reliable morphological classification, due to their proximity to us (e.g. Gallagher & Hunter 1986; Kraan-Korteweg et al. 1988; Schröder & Visvanathan 1996; Almoznino & Brosch 1998). Gallagher & Hunter (1986) made a photometric (UBV) survey of 65 dwarf irregular Virgo cluster galaxies and concluded that, although the latter galaxies cover a wider range in colours than typical samples of field irregulars, most of the Virgo Sm-Im galaxies are actively forming stars as well as any field Sm-Im galaxies, without any evidence of ongoing environmental modification of the evolutionary processes reflected in their stellar populations (cf. Tully & Shaya 1984). Moreover, Kraan-Korteweg et al. (1988) found that Sa-Im galaxies, members of the Virgo and Ursa Major clusters, and Sa-Im field and group galaxies follow consistent (B-H)/line-width relations, where H is the H-band ($\lambda = 1.65\ \mu$m) magnitude.

The luminosity functions of the Virgo cluster galaxies with different Hubble types have been determined and discussed by Sandage et al. (1985). The authors confirmed the trend of fainter $< \mathrm{M_B} >$ with advancing morphological type (van den Bergh 1960) for the Scd-BCD galaxies and also pointed out that such a trend was expected to be even stronger for types later than Im IV, when taking into account the incompleteness effect at $\mathrm{B_T} > 18\,\mathrm{mag}$. The availability of modern photographic surveys with large Schmidt telescopes in dark southern hemispheres, has made it possible to reach one magnitude fainter in surface brightness than the survey of the Virgo cluster, made by Binggeli et al. (1985) using the plates of the Las Campanas Observatory (at the same limit of the original Palomar Sky Survey). Therefore, the completeness of the sample of Matthews et al. (1998b) at the faint end of the LF is higher than in any previous samples. Moreover, the ELT spiral galaxies of the latter sample are biased toward the smallest and faintest objects among the Sd-Sm galaxies, which are found to be the extension of the normal, disk-dominated spiral sequence to lower optical luminosities and less organized structures (cf. Gallagher et al. 1995 and references therein). Given the previous results, we conclude that it is reasonable to assume that the ELT spiral galaxies in clusters and in groups belong to the same B-band LF.

In Figs. 6a–c, for the group ELT galaxies, we plot the residuals of their absolute magnitudes, determined from the apparent magnitudes via different IE corrections and "Method b", with respect to the corresponding TF estimates (Eq. 4a–c), vs. their maximum rotational velocities. Consistent with the assumption beyond Eq. 4 that cluster galaxies have the same distance, the distances of the members of the ELT sample are derived via the method of galaxy group assignments. We note that the adoption of individual distances would reduce the comparison sample to the 25 VCC galaxies, therefore increasing the strength of the population incompleteness bias.

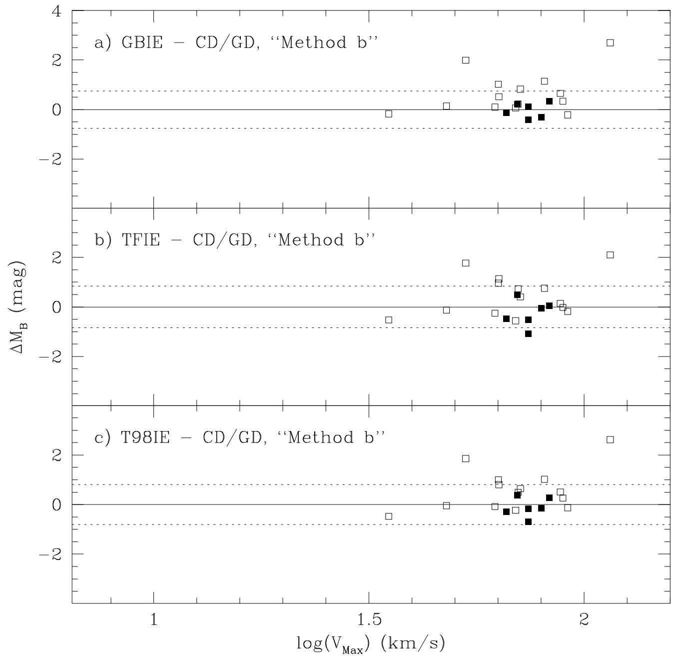

Fig. 6a–c. Plots of the residual magnitudes of the group ELT late-type galaxies with respect to the three different TF relations, shown in Fig. 3, vs. their maximum rotational velocities. Distances of the ELT sample galaxies are derived via the method of galaxy group assignment, while velocities are derived via "Method b". The short-dashed lines represent $\pm 1\sigma$ values. See the caption of Fig. 1 for the meaning of the different symbols.

As a general result, the 20 group ELT galaxies distribute consistently (within 1σ) with the templates of the cluster galaxies, except for two outliers (ESO 445007 and ESO 549002), independently of the IE corrections adopted. This is true in particular for the case of the TFIE corrections, the same adopted by Matthews et al. (1998b). Interestingly we note that the 6 Sc-Scd galaxies of the ELT sample galaxies are, on average, more luminous than later ELT spirals of the same $\mathrm{V_{Max}}$ (see the discussion in Sect. 4.2). Consistent results are obtained when adopting "Method a". Therefore we claim that the group ELT spiral galaxies distribute in the $\mathrm{L_B}$-$\mathrm{V_{Max}}$ consistent with both the cluster ELT and giant spiral galaxies. This conclusion is not affected by the claimed colour difference between giant galaxies in clusters and in less dense environments (e.g., Federspiel et al. 1998) (not shown).

As a consequence, we are allowed to determine new B-band TF relations for the whole sample of 76 non-dwarf late-type galaxies. Adopting the method of cluster/group assignments for galaxy distance determination, the TF relations, in the cases of the GBIE, TFIE and of the T98IE corrections, are respectively, as follows:

$$\mathrm{M_B} = -6.38(\pm 0.33) \times \log(\mathrm{V_{Max}}) - 5.61(\pm 0.65)\ , \qquad (7a)$$

with ${\chi^2}_{\mathrm{red}} = 1.62$;

$$\mathrm{M_B} = -6.84(\pm 0.30) \times \log(\mathrm{V_{Max}}) - 3.88(\pm 0.60)\ , \qquad (7b)$$

with $\chi^2{}_{\mathrm{red}} = 2.44$, and

$$\mathrm{M_B} = -7.83(\pm 0.34) \times \log(\mathrm{V_{Max}}) - 2.48(\pm 0.68)\ , \qquad (7c)$$

with $\chi^2{}_{\mathrm{red}} = 1.88$.

From the analysis of the magnitude residuals of the latter templates plotted vs. the maximum rotational velocity and the morphologycal type (not shown), we conclude that:

1. our sample of group and cluster ELT spiral galaxies does not show any systematic underluminosity with decreasing rotational velocity and increasing lateness. In addition no type segregation is evident anymore;
2. The B-band Tully-Fisher relation is linear even at the faint luminosities sampled by the ELT spiral galaxies: $\mathrm{L_B} \propto \mathrm{V_{Max}^{2.5-3.1}}$ according to the three different methods of estimating the internal extinction;
3. the 2 Sa galaxies of the sample are systematically underluminous, whichever IE corrections are adopted;
4. the population incompleteness bias still affects the sample of 76 objects at rotational velocities lower than $65\,\mathrm{km\,s^{-1}}$. The latter result is no surprise, since completeness is not guaranteed even when adding fainter ELT spiral galaxies to the comparison sample!

The fact that the Sa galaxies have higher velocities with respect to later spirals of the same blue luminosity was already noted in the literature (e.g., Rubin et al. 1985). Of course, the presence of a dominant bulge influences the dynamics of the disk-component and also the estimate of the IE corrections. However, since all three IE corrections adopted lead to the same conclusion we infer that the effect is due:

i) either to a significant systematic overestimate of the characteristic disk rotational velocity;
ii) or to any differences, in age and/or metallicity, of the stellar populations of the bulge and the disk;
iii) or to any differences in the mass-luminosity structure for different morphological types.

In the first case, we may conclude that the Tully-Fisher relation expresses properties only of the disk-component, e.g. as in the scenario proposed by Silk (1997). Concerning the second interpretation, we only observe that there are different conclusions in the literature (see Peletier & Balcells 1996 and references therein). For the third explanation we refer the reader to the model of Theureau et al. (1997) but we note that the estimated effect in the inverse B-magnitude TF relation is small. Anyway, it is interesting to stress that, when the galaxy LF is better sampled, the type segregation found within the comparison sample disappears.

Finally, we observe that when "Method a", GBIE corrections and galaxy cluster/group assignments are adopted, $\mathrm{L_B} \propto \mathrm{V_{Max}^{2.8^{3.0}_{2.7}}}$ is consistent with both the B-H colour-dynamical mass relation of Gavazzi et al. (1996) and the Near-IR TF relation of Pierini & Tuffs (1999).

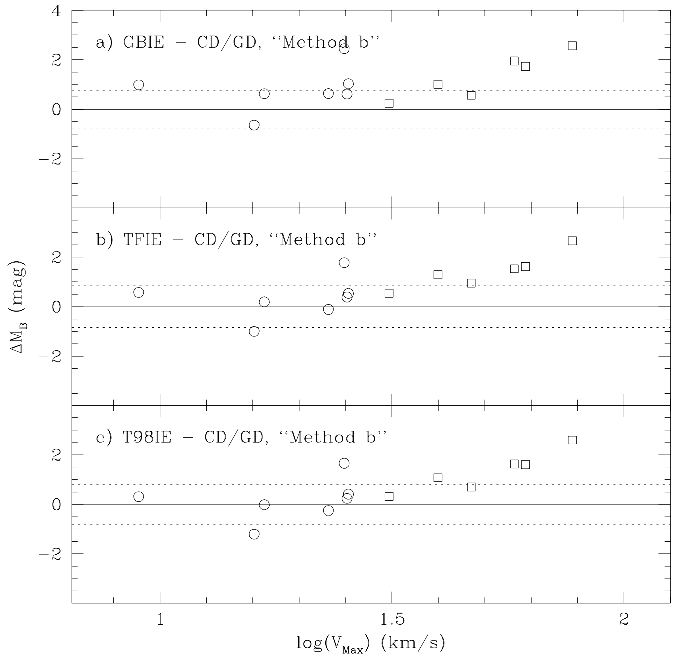

Fig. 7a–c. Plots of the residual magnitudes of the dwarf late-type galaxies with respect to the three different TF relations obtained from the comparison sample of 56 cluster galaxies and the sample of 20 group ELT spiral galaxies (see Eq. 7a–c in Sect. 5) vs. their maximum rotational velocities. Galaxy cluster/group assignments and "Method b" are adopted, as well as distances of dwarf galaxies from Stil & Israel (1998). The short-dashed lines represent $\pm 1\sigma$ values. See the caption of Fig. 1 for the meaning of the different symbols.

6. Dwarf late-type galaxies and the faint-end of the Tully-Fisher relation

Here, we analyse the distribution of the sample of 13 dwarf late-type galaxies with respect to the templates given by Eq. 7a–c, under the assumption that the latter give the best representation of the luminosity-velocity relation of more luminous systems, avoiding any type segregation.

Fig. 7a–c show the magnitude residuals of each TF template (Eq. 7a–c) vs. the maximum rotational velocities of the systems. It emerges that the distribution of dwarf galaxies with comparable rotational and random velocities in the $\mathrm{L_B}$-$\mathrm{V_{Max}}$ plane is consistent with the relation of more luminous systems, while the rotationally supported dwarf galaxies are underluminous with respect to any templates and in particular, to the ELT galaxies of the same $\mathrm{V_{Max}}$ (cf. Fig. 6a–c).

These conclusions are still valid when "Method a" is adopted and when template relations are derived from the subsample of 25 VCC late-type galaxies + 20 group ELT spiral galaxies with individual distances (not shown). However, we note that the distribution of individual galaxies in Fig. 7 may be affected by the true value of the velocity dispersion along the z-axis (σ_{z}) of the system. Here we assume $\sigma_{\mathrm{z}} = 5\,\mathrm{km\,s^{-1}}$ for all the dwarf galaxies, consistent with the mean line-of-sight velocity dispersion of $9\,\mathrm{km\,s^{-1}}$ found by Stil & Israel (1998) for their sample galaxies.

Therefore, we confirm the result of the previous authors, although under different assumptions concerning the intrinsic properties of dwarf late-type systems (cf. Sect. 3) and with a different comparison sample. For the interpretation of such different behaviours we refer the reader to Stil & Israel (1998). However, we stress that the distances of the sample dwarf galaxies are derived via heterogeneous methods (cf. Sect. 2).

7. Discussion

Although the physical origin of the luminosity-maximum rotational velocity relation in late-type galaxies is still unknown (e.g., Silk 1997; Mo et al. 1998; Steinmetz & Navarro 1999), the Tully-Fisher relation is both a benchmark for current theories of galaxy formation and structure and a standard technique for the estimate of cosmological distances. Therefore, it is straightforward to understand the importance of any systematic departure from the linear relation historically found for giant spiral galaxies (Tully & Fisher 1977). The faint skew of several group extreme late-type spiral galaxies with respect to the B-band luminosity-velocity relation of the local TF calibrators of Pierce & Tully (1992) claimed by Matthews et al. (1998b) may have enormous theoretical consequences (see also previous claims of Aaronson & Mould 1983; Aaronson et al. 1986; and Stil & Israel 1998 for the dwarf late-type galaxies). However, as we have already pointed out in the Introduction, the previous results have to face the uncertainties and flaws introduced by the inclination corrections, the population incompleteness bias (e.g. Teerikorpi 1997) and the type segregation (Kraan-Korteweg et al. 1988) affecting the comparison sample.

Therefore, here we substitute the sample of local TF calibrators of Pierce & Tully (1992), with a comparison sample of late-type galaxies of the Local Universe (selected from the Virgo and Ursa Major clusters), with a better sampling of the galaxy distribution in luminosity and in morphological type. We limit the uncertainties due to deprojection of the observed line-widths by selecting galaxies with inclinations higher than 35 degrees. Since we focus on the B-magnitudes of galaxies with different morphological types, we have to face the main question of the internal extinction of the individual galaxies, while accepting the unpredictable "noise" due to the contributions of the recent episodes of star formation to the global galaxy luminosity. Such episodes are correlated to the galaxy star-formation activity, which is universally accepted to be type-dependent (e.g., Kennicutt et al. 1994). Therefore, we select galaxies with inclination which is also less than 80 degrees.

Other authors have pointed out how the shape of the TF law depends on the corrections to the fundamental observables, e.g. on the corrections for turbulent/z-motions (Bottinelli et al. 1983). In Sect. 4 we have confirmed the steepening of the template relations of 35 cluster giant late-type (from Sa to Scd) galaxies, when such corrections are ignored. On the other hand, we have tested the robustness of any following conclusions with respect to any biases due to the adoption of different corrections for turbulent/z-motions for giant and dwarf spiral galaxies.

Instead, we focus on the influence of the corrections for internal extinction. The standard IE corrections are usually determined either from models of the relative distribution of dust and stars within the disk-component of spirals, irrespective of the morphological classification, (e.g., the "sandwich model" in Tully & Fouqué 1985), or from the statistical analysis (i.e., in a model-independent way) of samples of galaxies binned in morphological type (e.g., Gavazzi & Boselli 1996) or in luminosity/metallicity (e.g., Tully et al. 1998). As a result, we find that different IE corrections produce different shapes of the template TF relation, regardless of the adopted methods of estimating galaxy distances (see Sect. 4.3), especially when the sampling of the galaxy LF is sufficiently deep (cf. Federspiel et al. 1998). Although this effect can be induced by the ensuing different sampling of the galaxy luminosity function, via the cluster incompleteness bias, it is reasonable to assume that it is simply due to the distribution of the different Hubble type galaxies within the L_B-V_{Max} plane. In fact, early-type spirals are usually the fastest rotators and the most luminous galaxies at the same time (Kraan-Korteweg et al. 1988; Pierini & Tuffs 1999).

However, the population incompleteness bias affects our templates obtained from the cluster giant galaxies (see Sect. 4.2). In fact, when the grasp in the galaxy luminosity function is progressively increased, pushing faintly the limiting apparent magnitude of subsamples extracted from the sample of cluster galaxies, the behaviour of the slopes of the ensuing TF relations, is consistent with the theoretical expectations (e.g. Sandage et al. 1995) (not shown). However, although affected by such a bias, the final template for the whole sample of 56 cluster late-type (from Sa to Im/BCD) galaxies is more reliable as a comparison for any samples of spiral galaxies of later types than the sample of local TF calibrators.

In the case of the field ELT spiral galaxies selected from Matthews et al.'s (1998b) sample, which is considered the extension of the normal, disk-dominated spiral sequence to lower optical luminosities (Gallagher et al. 1995), we have shown that they can be reasonably considered to share the same luminosity function of their cluster counterparts (see Sect. 5). This conclusion is also strengthened by the consideration of the particular selection criteria of Matthews et al.'s (1998b) sample (cf. Matthews & Gallagher 1997). Therefore, we are able to compare their distribution in the L_B-V_{Max} plane with respect to the faint end of the B-magnitude TF relation, obtained from our sample of 56 cluster late-type galaxies. As a consequence, we find that the claimed faint skew of the ELT spiral galaxies with respect to any template TF relations, derived from any incomplete samples of brighter galaxies (e.g., the sample of local TF calibrators) and/or dominated by earlier type systems, is the reflection of both the population incompleteness bias affecting the template and/or of type segregation.

In Sect. 4.2, we note that cluster spiral galaxies later than Scd are, on average, slightly underluminous with respect to the template cluster relation, while earlier types seem to be overluminous, on average. It is not easy to disentangle the effect of the previous bias from the existence of systematic differences for different Hubble types. In this respect, Theureau et al. (1997) have shown that only the zero-point is affected by morphological dependencies, in the inverse diameter Tully-Fisher relation of a large statistically complete sample of Sa-Sdm galaxies of the local universe. The previous authors also modelled the systematic discrepancies in the zero-points in terms of differences in the mass-luminosity structure of the systems and predicted milder discrepancies in the inverse B-magnitude TF relation. In the further course of the analysis, we find that this behaviour disappears when the deeper sample of field ELT spiral galaxies is included in the determination of the TF relation (see Sect. 5). Although this may be a consequence of the increased statistical weight of the fraction of bulge-less systems, considering also the estimated small size of the effect, we claim that the discrepancies shown in Fig. 5 are driven by the population incompleteness bias. Although there is the possibility that the underluminosity of the Sa galaxies traces a true difference in the mass-luminosity structure with respect to later spirals, uncertainties in the derivation of the fundamental observables of Sa systems still remain (see also Rubin et al. 1985; Kraan-Korteweg et al. 1988).

The existence of a linear B-band Tully-Fisher relation even at the luminosities sampled by the ELT spiral galaxies is consistent with the result obtained by Pierini & Tuffs (1999) in the Near-IR and with theoretical expectations, whether or not it is dependent on any cosmological model of galaxy formation (e.g., Silk 1997; Somerville & Primack 1998; Elizondo et al. 1999). According to the three different IE corrections adopted, from the whole sample of 76 cluster and group non-dwarf late-type galaxies, we find that $\mathrm{L_B} \propto \mathrm{V_{Max}^{2.6-3.1}}$.

We note that when the optical and the Near-IR TF relations are obtained via the same corrections to the fundamental observables (see Sect. 3) and for samples of late-type galaxies with comparable grasps into the galaxy LF and statistics as in Pierini & Tuffs (1999) (see Sect. 5), the wavelength dependence of the TF slope may be reasonably explained by the optical-near infrared colour-dynamic mass relation of the late-type galaxies (see Fig. 1 in Gavazzi et al. 1996). Therefore, the present results suggest the existence of a link between dynamic properties and stellar populations of the rotationally-supported disk-systems (cf. Gavazzi et al. 1996; Gavazzi & Scodeggio 1996; Silk 1997; Pierini & Tuffs 1999).

Finally, the availability of Tully-Fisher template relations for different IE corrections and from a sample of both bright and faint spiral galaxies ranging from Sa to Im-BCD, gives us the possibility to better interpret the distribution of the dwarf late-type galaxies in the $\mathrm{L_B}$-$\mathrm{V_{Max}}$ plane. We confirm the result of Stil & Israel (1998) that dwarf galaxies with comparable rotational and random velocities distribute consistently with the relation of more luminous systems, while the rotationally supported dwarf galaxies are underluminous with respect to the ELT galaxies of the same $\mathrm{V_{Max}}$, but under different assumptions for the intrinsic properties of such systems. The explanation of such a discrepancy may lie in the current status of star-formation activity of dwarf galaxies of different dynamic properties, as claimed by Stil & Israel (1998).

8. Conclusions

We analyse the distribution of three different samples of spiral galaxies of the Local Universe in the B-band luminosity-maximum rotational velocity ($\mathrm{L_B}$-$\mathrm{V_{Max}}$) plane (i.e. the B-magnitude Tully-Fisher (TF) relation). The first sample comprises $25+31$ late-type (from Sa to Im-BCD) galaxies, selected from the Virgo and the Ursa Major clusters, respectively, whose completeness limit is estimated to be -17 B-mag. Moreover, a sample of 20 group extreme late-type (ELT) spiral (from Sd to Sm) galaxies and a sample of 13 dwarf (fainter than -16 B-mag) late-type galaxies are selected.

First, we analyse the influence of three different corrections for internal extinction (IE) on both the slope and the-zero point of the relation. These recipes reflect either i) the morphological type dependence of the IE or ii) the assumption of a type-independent “sandwich-model” for the distribution of the dust and the stellar components within the disk or iii) the existence of the metallicity-mass relation. As a first result we find that the latter recipe of IE correction systematically makes Sa-Sc galaxies brighter than later spirals. Since the former galaxies mainly populate the region of the bright, fast rotators, the slope of the corresponding TF relation becomes much steeper than in the other two cases.

Under the hypothesis that the ELT spiral galaxies in clusters and in groups share the same LF, we show that the claimed skew of the group ELT spiral galaxies with respect to the extrapolated TF relation of more luminous systems (i.e. the local TF calibrators of Pierce & Tully 1992) is due both to the population incompleteness bias affecting such a template and to the type segregation.

For the sample of 56 cluster late-type galaxies+20 group ELT spiral galaxies, we find that: $\mathrm{L_B} \propto \mathrm{V_{Max}^{2.6-3.1}}$, according to the previous three different IE corrections. We have also proved the robustness of the existence of such linear B-magnitude TF relations with respect to i) two methods of inclination determination and HI line-width correction for turbulent/z-motions, to ii) the adoption of individual galaxy distances vs. the method of cluster/group galaxy assignment.

Finally, we confirm that the distribution of dwarf galaxies with comparable rotational and random velocities in the $\mathrm{L_B}$-$\mathrm{V_{Max}}$ plane is consistent with the relation of more luminous systems, while the rotationally supported dwarf galaxies are underluminous with respect to the ELT galaxies of the same $\mathrm{V_{Max}}$. However, the latter results may suffer from the heterogeneous methods of measurement of dwarf galaxy distances adopted.

Acknowledgements. The authour is extremely indebted to the referee, Dr. L. Gouguenheim, whose interesting comments and hints improved the final version of this paper.

References

Aaronson M., Mould J., 1983, ApJ 265, 1
Aaronson M., Huchra J., Mould J., 1979, ApJ 229, 1
Aaronson M., Bothun G., Mould J., 1986, ApJ 302, 536
Almoznino E., Brosch N., 1998, MNRAS 298, 920
Binggeli B., Sandage A., Tammann G.A., 1985, AJ 90, 1681

Binggeli B., Popescu C., Tammann G.A., 1993, A&AS 98, 275
Boselli A., Tuffs R.J., Gavazzi G., et al., 1997, A&AS 121, 507
Bottinelli L., Gouguenheim L., Paturel G., de Vaucouleurs G., 1983, A&A 118, 4
Bottinelli L., Fouqué P., Gouguenheim L., et al., 1987, A&A 181, 1
Bottinelli L., Gouguenheim L., Paturel G., 1990, A&AS 82, 391
de Vaucouleurs G., de Vaucouleurs A., Corwin et al., 1991, Third Reference Catalogue of Bright Galaxies. Springer-Verlag, New York, (RC3)
Elizondo D., Yepes G., Kates R., et al., 1999, ApJ 515, 525
Federspiel M., Tammann G.A., Sandage A., 1998, ApJ 495, 115
Gallagher J.S., Hunter D.A., 1986, AJ 92, 557
Gallagher J.S., Littleton J.E., Matthews L.D., 1995, AJ 109, 2003
Gavazzi G., Boselli A., 1996, Astroph. Lett. & Comm. 35, 1
Gavazzi G., Scodeggio M., 1996, A&A 312, L29
Gavazzi G., Pierini D., Boselli A., 1996, A&A 312, 397
Gavazzi G., 1998, In: Mazure A., Casoli F., Durret F., Gerbal D. (eds.) Untangling Coma Berenices: A New Vision of an Old Cluster. Vol. 1, WSP, Marseille, p. 73
Gavazzi G., Boselli A., Scodeggio M., et al., 1999, MNRAS 304, 595
Giovanelli R., Haynes M.P., Herter T., et al., 1997, AJ 113, 53
Haynes M., Giovanelli R., 1984, AJ 89, 758
Heavens A.F., Jimenez R., 1999, MNRAS 305, 770
Heidmann J., Heidmann N., de Vaucouleurs G., 1971, Mem. R. Astron. Soc. 75, 85
Holmberg E., 1946, Medd. Lunds Obs. II, No. 177
Kennicutt R.C., Tamblyn P., Congdon C.W., 1994, ApJ 435, 22
Kraan-Korteweg R.C., Cameron L.M., Tammann G.A., 1988, ApJ 331, 620
Lewis B.M., 1984, ApJ 285, 453
Lauberts A., Valentijn E.A., 1989, The Surface Photometry Catalogue of the ESO-Uppsala Galaxies. European Southern Observatory, Garching bei München
Matthews L.D., Gallagher J.S., 1997, AJ 114, 1899
Matthews L.D., van Driel W., Gallagher J.S., 1998a, AJ 116, 1169
Matthews L.D., van Driel W., Gallagher J.S., 1998b, AJ 116, 2196
Mo H.J., Mao S., White S.D.M., 1998, MNRAS 295, 319
Peletier R.F., Balcells M., 1996, AJ 111, 2238
Pierce M.J., Tully R.B., 1992, ApJ 387, 47
Pierini D., Tuffs R., 1999, A&A 343, 751
Press W.H., Flannery B.P., Teukolsky S.A., Vetterling W.T., 1988, Numerical Recipes. Cambridge
Rhee M.-H., 1996, Ph.D. Thesis, University of Groningen, NL
Romanishin W., Krumm N., Salpeter E., et al., 1982, ApJ 263, 94
Rubin V.C., Burstein D., Kent Ford W., Thonnard N., 1985, ApJ 289, 81
Salucci P., Persic M., 1997, In: Persic M., Salucci P. (eds.) Dark and Visible Matter in Galaxies. Vol. 117, ASP, San Francisco, p. 1
Sandage A., Binggeli B., Tammann G.A., 1985, AJ 90, 1759
Sandage A., 1994, ApJ 430, 1
Sandage A., Tammann G.A., Federspiel M., 1995, ApJ 452, 1
Schröder A., Visvanathan N., 1996, A&AS 118, 441
Silk J., 1997, ApJ 481, 703
Skillman E.D., Kennicutt R.C., Hodge P.W., 1989, ApJ 347, 875
Somerville R.S., Primack J.R., 1998, astro-ph/9802268
Staveley-Smith L., Davies R.D., Kinman T.D., 1992, MNRAS 258, 334
Steinmetz M., Navarro J.F., 1999, ApJ 513, 555
Stil J.M., Israel F.P., 1998, astro-ph/9810151
Tammann G.A., 1980, In: Tarenghi M., Khar K., (eds.) ESO/ESA Workshop on Dwarf Galaxies, Knudsen, Geneva, pp. 3, 45
Teerikorpi P., 1990, A&A 234, 1
Teerikorpi P., 1997, ARA&A 35, 101
Teerikorpi P., Ekholm T., Hanski M.O., Theureau G., 1999, A&A 343, 713
Theureau G., Hanski M., Teerikorpi P., et al., 1997, A&A 319, 435
Tully R.B., Fisher J.R., 1977, A&A 54, 661
Tully R.B., Shaya E.J., 1984, ApJ 281, 31
Tully R.B., Fouqué P., 1985, ApJS 58, 67
Tully R.B., Verheijen M.A.W., Pierce M.J., et al., 1996, AJ, 112, 2471
Tully R.B., Pierce M.J., Huang J.-S., et al., 1998, ApJ 115, 2264
Tutui Y., Sofue Y., 1997, A&A 326, 915
van den Bergh S., 1960, Publ. David Dunlap Obs. II, No. 6, p.159
van der Kruit P.C., Shostak G.S., 1982, A&A 105, 351
Verheijen M.A.W., 1997, Ph.D. Thesis, University of Groningen, NL
Yasuda N., Fukugita M., Okamura S., 1997, ApJS 108, 417
Zaritsky D., Kennicutt R.C., Huchra J.P., 1994, ApJ 420, 87
Zwaan M.A., van der Hulst J.M., de Block W.J.G., McGaugh S.S., 1995, MNRAS 273, L35