THE LOCAL TULLY–FISHER RELATION FOR DWARF GALAXIES

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ABSTRACT

We study different incarnations of the Tully–Fisher (TF) relation for the Local Volume (LV) galaxies taken from Updated Nearby Galaxy Catalog. The UNGC sample contains 656 galaxies with $W_{50}$ H I-line-width estimates, mostly belonging to low-mass dwarf galaxies. For them, 296 objects have distances measured with accuracies better than 10%. For the sample of 331 LV galaxies having baryonic masses $M_{\text{bar}} > 5.8 \log M_\odot$, we obtain a relation $\log M_{\text{bar}} = 2.49 \log W_{50} + 3.97$ with an observed scatter of 0.38 dex. The largest factors affecting the scatter are observational errors in $K$-band magnitudes and $W_{50}$ line widths for the tiny dwarfs, as well as uncertainty of their inclinations. We find that accounting for the surface brightness of the LV galaxies or their gas fraction, specific star-formation rate, or isolation index does not essentially reduce the observed scatter on the baryonic TF diagram. We also notice that a sample of 71 dSph satellites of the Milky Way and M31 with a known stellar velocity dispersion $\sigma^*$ tends to follow nearly the same bTF relation, having slightly lower masses than that of late-type dwarfs.

Key words: catalogs – cosmology: dark matter – galaxies: dwarf – galaxies: kinematics and dynamics

Supporting material: machine-readable table

1. INTRODUCTION

Since the first wholesale observations of galaxies in the H I 21 cm line, some tight correlations between different integral properties of spiral galaxies were exposed (Roberts 1969; Balkowski et al. 1974). Later, Tully & Fisher (1977) noticed the clear power-law correlation between the H I 21 cm line width and the optical luminosity of galaxies and suggested to use this dependence to measure distances of galaxies. Since then, more than a thousand articles have appeared, addressing the Tully–Fisher (TF) relation in different bands of optical and infrared wavelength with different indicators of inner rotation amplitudes. Tully & Pierce (2000) have calibrated the TF relation in $B$, $R$, $I$, and $K$ bands, noting that the slope of the TF relation grows systematically with wavelength. According to these authors, scatter on the diagram is small for massive disk galaxies, allowing the ability to measure distances of spiral galaxies with an accuracy of about 20%. A linear relation between the H I line width $W_{50}$ measured at the 50% level of the maximum and standard optical diameter for flat edge-on galaxies (Karachentsev 1989; Karachentsev et al. 1999) is one particular instance of the TF relation. For Sc–Sd galaxies with an apparent axis ratio $a/b > 7$, this method also yields the distance accuracy of $\sim 20\%$.

Later, McGaugh et al. noted that the TF relation connecting the mass of a dark halo and the baryonic mass of a galaxy should additionally account for the mass of a gas component (McGaugh 2005, 2012; McGaugh et al. 2010). This correction turned out to be mostly significant for dwarf irregular galaxies evolving slower than spirals, with extant primordial gas presumably prevailing over the star component. This version of TF diagram is known as the baryonic TF (bTF) relation.

The observed scatter in the TF diagram keeps steadily growing from massive spirals to dwarf galaxies. The main reason for the scatter is the growth of observational uncertainties in apparent magnitudes and line widths, $\log W_{50}$, increasing toward dwarfs. Another reason may be the shallow potential well of a dwarf galaxy where gas can easily escape due to some external factors. One more reason for the scatter may be the irregular shape of dwarfs making it difficult to determine an inclination of rotation axis to the line of sight. Moreover, a H I imaging study of low-mass dwarf irregular (dIrr) galaxies performed with the Giant Metrewave Radio Telescope (GMRT) showed that a direction of the HI major axis for some tiny dwarfs does not always coincide with the direction of their optical major axes (Begum et al. 2008b). It should be noted that the neutral hydrogen layers of many galaxies may be warped: the inclination may significantly change in the outer parts (e.g., Garcia-Ruiz et al. 2002). Optical inclinations are often inappropriate for warped H I discs; these circumstances make the correction of rotation amplitude for dwarf galaxy inclination rather uncertain, unless spatially resolved HI observations are available. Finally, dwarf galaxies usually have slowly rising rotation curves and reach the $V_{\text{flat}}$ value in hardly detected peripheric regions. As a result, their $V_m = W_{50}/(2 \times \sin i)$ corresponds to only a part of the full rotation amplitude (Swaters et al. 2009). It should be also noted that bursts of star formation in a dwarf galaxy affect its integral luminosity more significantly than in a massive galaxy, causing one more source of scatter toward dwarf sector of the TF diagram.

The main goal of this paper is to improve a calibration of the TF relation on its low-mass end using local dwarf galaxies with accurately measured distances; this allows us to update the distances of many remaining nearby dwarfs with already known H I line widths.

2. THE LOCAL VOLUME SAMPLE

For obvious reasons, the most representative and homogeneous sample of dwarf galaxies can be obtained examining the closest volume of the universe; Kraan-Korteweg & Tammann (1979) made the first attempt to compile such a sample. Their list included 179 galaxies with radial velocities $V_{\text{LG}} < 500$ km s$^{-1}$ relative to the centroid of the Local Group.

Due to the systematic-sky surveys in the optical range and H I
Table 1
Number of Local Volume Galaxies with Distances Measured by Different Methods

| Method          | N_{HI} | N_{HI,1} |
|-----------------|--------|----------|
| TRGB, Cep, SN, RR, CMD, HB | 459    | 296      |
| SBF             | 18     | 9        |
| mem             | 269    | 85       |
| TF, bTF         | 189    | 188      |
| bs, PN, txt     | 38     | 24       |
| h, h’           | 76     | 54       |
| All methods     | 1049   | 656      |

21 cm line, the number of nearby galaxies with similar velocities grew rapidly. Twenty-five years later, the Catalog of Neighboring Galaxies (CNG; Karachentsev et al. 2004) amounted to 450 galaxies in the volume limited to depth of 10 Mpc. The refined and up-to-date version of this catalog, the Updated Nearby Galaxy Catalog (UNGC; Karachentsev et al. 2013) contains 869 galaxies with individual distance estimates $D < 11$ Mpc or radial velocities $V_{LD} < 600$ km s$^{-1}$. More than 85% of this sample are dwarf galaxies with luminosities less than those of Magellanic Clouds. Various observational data on these objects, including their images, are compiled in the Catalog and Atlas of the Local Volume (LV) Galaxies (Kaisina et al. 2012, http://www.sao.ru/lv/lvdb/). The database is still being enlarged with new, mainly dwarf, galaxies and already contains (as of 2016 September) 1049 objects distributed all over the entire sky. We use this sample below to construct the TF diagram in its different incarnations.

According to Paturel et al. (1997), the data of H1 fluxes of galaxies, $F(H1)$, expressed in H1-magnitudes, $m_{21} = 17.4 - 2.5 \log F(H1)$, and H1 21 cm line widths, $W_{50}$, originate mainly from H1-sky surveys, such as the HI Parkes All-Sky Survey (HIPASS; Koribalski et al. 2004; Meyer et al. 2004; Wong et al. 2006; Staveley-Smith et al. 2016), Arecibo Legacy Fast ALFA Survey (ALFALFA; Giovanelli et al. 2005; Haynes et al. 2011), Westerbork Survey (Kovac et al. 2009), and special observations of selected dwarf galaxies (Huchtmeier et al. 2000, 2001, 2003; Begum et al. 2008b). The individual references to these and other HI data are represented in the Local Volume (LV) database (http://www.sao.ru/lv/lvbd/).

Table 1 presents the numbers of LV galaxies with distances measured via different methods. The first column corresponds to the total UNGC sample updated with recent observations, the second column refers to UNGC objects detected in the H1 line. The first row shows the number of galaxies whose distances are measured with errors less than 10%: from the tip of red giant branch (TRGB), Cepheid luminosity (Cep), Supernovae (SN), RR Lyra variables (RR), color–magnitude diagram (CMD), and the horizontal branch (HB). The second row gives the number of galaxies with distance estimates obtained from surface brightness fluctuations (SBF). The accuracy of this method, according to Tonry et al. (2001), is also about 10%, but this method is suitable for early-type galaxies with low amounts of dust and gas; this leads to the risk that the $W_{50}$ value for them can differ systematically from that of late-type galaxies of the same luminosity. The third row of the table refers to galaxies with distances determined from their membership (mem) in groups, where other (usually brighter) members have individual distance estimates. From recent TRGB-distance measurements for galaxies with earlier fixed membership, we estimate the mean distance error for this category of galaxies to be 17%. Galaxies with distances determined from the ordinary Tully–Fisher relation (TF) or its baryonic version (bTF) are denoted in the fourth row. The fifth row corresponds to galaxies with distance estimates collected from less reliable methods: luminosity of the brightest stars (bs), planetary nebula luminosity function (PN), or from the apparent texture of an object (txt). The sixth row shows the number of galaxies with kinematic distance estimates obtained from their radial velocities where the Hubble parameter is set to $H_0 = 73$ km s$^{-1}$ Mpc$^{-1}$ and the virgocentric velocities are factored (h’) or not (h). Finally, the total number of the LV galaxies with different distance estimates is shown in the last row.

As can be seen, our LV sample contains a total of 656 galaxies with estimates of $W_{50}$ and $m_{21}$. Almost half of the galaxies have distances measured with an accuracy of 5%–10%. This circumstance is particularly significant for nearby galaxies, because their small radial velocities cannot be a robust indicator of distance being affected by peculiar motions.

A literature review shows that authors often preselect galaxies by some specific properties complicating the interpretation of the TF diagram. For instance, in their study of the baryonic TF relation for heavily gas-dominated ALFALFA objects, Papastergis et al. (2016) selected only galaxies with apparent axial ratios less than 0.25, omitting a huge number of low-mass galaxies that are gas-rich, but intrinsically thick. Sometimes authors do not completely specify their selection criteria or neglect galaxies that deviate significantly from the TF regression line, which results in artificially reducing scatter in the TF relation. Below, we look toward keeping as many objects as possible in our sample, eliminating only face-on disks or galaxies located in the Zone of Avoidance, or those with ambiguous distance estimates. In particular, we did not omit from our analysis a case of M82, a nearby bright galaxy having accurate photometric data, a reliable estimate of the distance, $W_{50}$ width, and inclination $i$, though this is a known starburst galaxy involved in a strong interaction with M81 that is impressively visible in H1 (Yun et al. 1994).

3. INTRINSIC AXIAL RATIO AND INCLINATION CORRECTIONS

The distribution of apparent axis ratios for the LV galaxies of different morphological types is shown in Figure 1. The galaxies are marked by small circles, and many of them overlap with each other. The large circles and vertical rectangles indicate the mean values and standard deviations for each type in de Vaucouleurs scale. The left side of the diagram ($T < 1$) contains mostly HI undetected objects. In general, the intrinsic axial ratio is larger for lenticular and irregular galaxies than for spirals, and among the spirals, it is smaller for late types than for early ones. The minimum flattening corresponds to Sd galaxies ($T = 7$), though a thin edge-on galaxy would be classified as Sd instead of Sc or Sm, since one cannot appreciate the degree of structure in the pattern at $i \approx 90^\circ$.

As previously mentioned, uncertainties in inclination correction of dwarf galaxies may cause scatter in the TF diagram. For oblate ellipsoids, an inclination of the rotation axis of a galaxy to the line of sight is defined as

$$\sin^2 i = [1 - q_i^2]/[1 - q_0^2],$$  \hspace{1cm} (1)
where \( q = b/a \) is the apparent axial ratio. In the case of the CNG sample, the intrinsic flattenings \( q_0 = (b/a)_0 \) were taken to be equal to 0.07 for morphological types \( T = 6 \) or 7, 0.12 for types 5 or 8, 0.18 for types 4 or 9, and 0.20 for all other morphological types, according to the Second Reference Catalog (RC2) by de Vaucouleurs et al. (1976). This relation between the intrinsic axial ratio and de Vaucouleurs morphological type is represented in Figure 1 by a dotted line with open circles. Analyzing the apparent axial ratio statistics for dwarf galaxies taken from the UNGC, Roychowdhury et al. (2013) confirmed the known fact that disks of dwarf galaxies are much thicker than was assumed in RC2. These authors obtained a mean intrinsic flattening of 0.57; the exact same value was found by Sanchez-Janssen et al. (2016) for the dwarf population of the Virgo cluster. The authors of both papers noted that the apparent axial ratio statistics for dwarf galaxies is better described by a model of oblate triaxial spheroids with axes ratio 1.00:0.94:0.57. Also, Roychowdhury et al. (2010) derived approximately the same axial ratio for H1 images of dIrr galaxies based on FIGGS data from GMRT (Begum et al. 2008b).

Paturel et al. (1997) suggested a refined set of \( q_0 \) values depending on morphological type \( T \), which was used in UNGC to determine the inclination \( i \) from Equation (1):

1. \( \log(q_0) = -0.43 - 0.053 \times T \) for \( T \leq 8 \),
2. \( \log(q_0) = -0.38 \) for \( T = 9, 10 \).

The behavior of intrinsic flattenings versus morphological type in this case is depicted by the dashed line with gray circles in Figure 1. The recipe of Paturel et al. (1997) for \( q_0 \) seems to be significantly more realistic than the previous scheme used in RC2. Yet, Equation (2) presumably underestimates the actual thickness of the disks of dwarf galaxies, resulting in their inclination \( i \) estimates. Here, we note a big leap in Equation (2) passing from morphological type \( T = 8-9 \). A typical scatter in morphological classification of \( \Delta T = \pm 1 \) can lead to a significant error in galaxy inclination.

Yuan & Zhu (2004) analyzed a sample of 14988 disk galaxies taken from LEDA database and derived for them the relation

\[
\log(q_0) = -0.580 - 0.067 \times T \quad \text{for } T \leq 7, \\
\log(q_0) = -2.309 + 0.185 \times T \quad \text{for } T = 8, 9, 10.
\]

This distribution is shown in the Figure 1 by the solid line with black circles. It looks as intermediate between those adopted in CNG and UNGC samples for most morphological types.

Another way to evaluate the intrinsic axial ratio is by using the stellar mass instead of optical morphology. Sanchez-Janssen et al. (2010) investigated the role of stellar mass in shaping the intrinsic thickness of dwarf systems. They found that the intrinsic axial ratio varies with stellar mass in a parabolic fashion having the minimum value near the stellar mass \( M^* = 2 \times 10^9 M_\odot \). In our LV sample, the distribution of all 1049 galaxies according to their total luminosity in K band, \( L_K \), and morphological type is shown in Figure 2. Assuming an approximate ratio of \( M^*/L_K \approx 1 M_\odot/L_\odot \) (Bell et al. 2003), this diagram can be transformed into the \( M^* \) versus \( T \) distribution. The mean values of \( L_K \) and standard deviations are marked, like in Figure 1, by large circles and rectangles.
The shape of diagram resembles a parabola, with the maximum near Sb-type and a scatter increasing toward both the sides.

The number distribution of all LV galaxies with their K-band luminosities is illustrated by Figure 3. Among them, the 656 H I-detected galaxies are marked in dark blue. As one can see, a fraction of LV galaxies with H I detections decreases systematically from bright to faint objects. More than 99% of the H I-detected galaxies are concentrated within the luminosity
range \( \log(L_K) = 6.0-11.0 \). Such a segregation along the \( L_K \)-axis may be a source of specific bias in the statistics of apparent and intrinsic attenings.

Figure 4 represents the distribution of 1049 LV galaxies with their apparent axial ratio and \( K \)-band luminosity. Galaxies detected and undetected in HI are indicated by filled and open small circles, respectively. The large circles and vertical rectangles correspond to the average value of \( q \) and its dispersion in bins of \( \Delta \log(L_K) = 1.0 \). The diagram shows a clear tendency for minimal values of \( q \) to follow the parabolic envelope line with the absolute minimum \( q = 0.05 \) near \( \log(L_K) \approx 9 \). Some dwarf gasless galaxies, like UMaI, deviate from the envelope line. They are usually located close to a massive neighboring galaxy (Martin et al. 2008), and their elongated shape can be caused by tidal perturbation.

Bradford et al. (2016) explored a sample of 930 isolated galaxies with axial ratios determined from the Sloan Digital Sky Survey (SDSS) and suggested a relation between the true flattening and the stellar mass of a galaxy as \( q_0 = 0.85 - 0.057 \times \log(M^*/M_\odot) \). According to this formula, \( q_0 \) value grows monotonically from 0.2 for massive galaxies up to 0.5 for dwarfs. However, there is still no place for the common fact that the minimal values \( q_0 \approx 0.05 \) only correspond to the low-mass galaxies of Sd–Sdm types.

Following Sanchez-Janssen et al. (2010), Lelli et al. (2016a) adopted the parabolic relation

\[
q_0 = 5.2125 - 1.125 \log(M^*) + 0.0625 \log(M^*)^2, \tag{4}
\]

which reaches a minimum value of \( q_0 = 0.15 \) at \( \log(M^*) = 9.0 \) and gives \( q_0 = 0.4 \) at \( \log(M^*) \) equal to 7.0 and 11.0. Both the relations by Bradford et al. (2016) and Lelli et al. (2016a) are shown in Figure 4 with dotted and dashed lines, respectively.

Exploring properties of the LV galaxies and taking into account axial ratio statistics for ultra-flat galaxies (Karachentseva et al. 2016), we re-parametrized the parabolic relation and found the optimum parameters

\[
q_0 = 5.128 - 1.114 \log(M^*) + 0.0612 \log(M^*)^2. \tag{5}
\]

This modified parabolic distribution, shown in Figure 4 with a solid line, reaches a minimum value of \( q_0 = 0.059 \) at \( \log(M^*) = 9.10 \). We stress here that Equations (4) and (5) should not be extrapolated for stellar masses below \( \sim 10^6 \) \( M_\odot \), since they will give unphysical results (\( q_0 > 1 \)).

If the distribution of galaxies over their intrinsic attenings as a function of type or stellar mass is specified correctly, then, in the case of random spatial orientation of galaxy planes, the distribution of inclination angles will correspond to the \( \sin i \)-law (Yuan & Zhu 2004). Figure 5 represents the distribution of LV galaxies over inclination \( i \) with steps of 10° under different assumptions (2)–(5) about intrinsic axial ratios. The solid line traces the expected distribution with uniformly random orientation of galaxy spin vectors over the sky. Vertical bars denote statistical errors.

As one can see from Figure 5, the model (2) for galaxy distribution over intrinsic axial ratios as well as cases (4) and (5), reproduces the expected \( \sin i \)-law much better than the RC2 scheme adopted in the CNG. The most significant deviations from the expected law in all the cases are owed to under-estimating the number of face-on galaxies: \( i < 20^\circ \). However, we must exclude such galaxies from further consideration due to the large uncertainties in the corrected HI line width: \( W_{50} = W_{50}/\sin i \). Another significant difference is seen in
the $i > 70^\circ$ sector, but has little effect on the corrected H i line width. One may suggest that the observed mismatch with the $\sin i$ law may be driven by E, S0, and dSph galaxies. To test this hypothesis, in the UNGC sample we consider only galaxies with $M^* > 10^6 M_{\odot}$ and $T > 0$. As seen, this case, shown by gray squares, does not reduce the mismatch noticeably. Finally, we intend to use the modified parabolic relation (5) connecting $q_0$ with $M^*$ in future studies.

4. STELLAR TF RELATION FOR DWARFS

After considering different kinds of TF relations for the LV dominated by objects with low mass and luminosity, we have confined ourselves to a sample of galaxies with accurate distances (TRGB, Cep, SN, RR, CMD, HB). We then excluded two galaxies from this sample: Maffei2 and HIZSS03 with Galactic extinction of $A_B^G > 3.0^m$, according to Schlafly & Finkbeiner (2011). To reduce errors caused by the uncertainty in $W_{50}$ correction due to a galaxy inclination $i$, we further consider only galaxies with $i > i_{lim} = 45^\circ$. This condition decreases our sample from 296 to 206. The analysis shows that a stronger limitation does not significantly change the scatter in the TF diagram, though it notably diminishes the sample volume.

Figure 6 reproduces the classical TF diagram as the relation between the blue absolute magnitude of a galaxy, corrected for Galactic and internal extinction, and the H i line width for 206 galaxies taken from the LV database. The internal extinction was accounted according to Verheijen & Sancisi (2001):

$$A_B^G = [1.57 + 2.75(\log W_{50} - 2.5)] \log(a/b),$$

(6)

if $W_{50} > 78$ km s$^{-1}$, otherwise $A_B^G = 0$.

In the upper panel of Figure 6, the measured width $W_{50}$ is plotted as an abscissa covering the range 10 to 500 km s$^{-1}$. The median value of $W_{50}$ for this sample amounts to 54 km s$^{-1}$, which is much lower than that for other TF-samples examined by Geha et al. 2006, Bradford et al. 2015, 2016, Brook et al. 2016, Papastergis et al. 2016, and Sales et al. 2016. The $M_B$ versus log($W_{50}$) relation is well described by the linear regression (a straight line) in the entire range of $W_{50}$ with a slope of $-6.85$ and a dispersion of $\sigma_M = 1.06^m$. Here and below, the straight line in the TF diagram is a robust fit to the ensemble with errors in magnitudes. As seen, the dispersion increases appreciably while passing from massive spirals to dwarfs, due mainly to observational errors. In the bottom panel, the corrected value of width, $W_{50} = W_{50}/\sin i$, is plotted on the horizontal axis. The view of the diagram has been changed subtly: the slope, $-6.96$, and the scatter, $\sigma_M = 1.10^m$, remained nearly the same.

To evaluate the behavior of scatter on the TF diagram as a function of limiting inclination angle $i_{lim}$, we have consistently taken $i_{lim} = 30^\circ$, $35^\circ$, $40^\circ$, $45^\circ$, $50^\circ$, $55^\circ$, $60^\circ$. We determined the new regression line and calculated dispersion $\sigma_M$ for each subsample. The results are presented in two panels of Figure 7. The left panel corresponds to the case when the inclinations were determined from Equation (2) via optical morphology, and the right panel illustrates the manner of Equations (5) accounting for stellar masses. The numbers over the upper border of both panels indicate galaxy numbers in each subsample. The solid line and dashed line correspond to observed, $W_{50}$, and corrected, $W_{50}$, line widths, respectively. These data show that by giving away half of the initial sample at $i_{lim} = (55–60)^\circ$, we may decrease the scatter only by 10%–20%. Also, the correction of the line width for inclination does not noticeably improve the dispersion on the TF diagram inhabited mainly by dwarf galaxies. In other words, the $W_{50}$ correction for inclination in the realm of dwarfs looks to be just a formal, optional
procedure. This curious peculiar phenomenon was noticed by Obreschkow & Meyer (2013).

As noted by many authors (Aaronson et al. 1979, 1986; Giovanelli et al. 1997; Tully & Pierce 2000), the dispersion in the TF diagram decreases systematically toward long wavelengths where the effects of internal extinction and starbursts are not so significant. Near-infrared J, H, K, photometry of galaxies fulfilling in the 2MASS all-sky survey (Jarrett et al. 2000, 2003) provides the background for constructing TF diagrams for spiral galaxies (Karachentsev et al. 2002). Yet, due to short expositions, the 2MASS survey has been found to be undersensitive for detecting low surface brightness objects, especially those ones having blue stellar populations. About half of the LV galaxies stayed below the threshold of detectability. For many nearby dwarf galaxies, the integral K magnitude obtained in 2MASS does not trace the appreciable contribution of the galaxy’s periphery. According to the data on deep photometry of dwarf galaxies in K and H bands (McCall et al. 2012; Young et al. 2014), the typical error of these magnitudes for dwarfs in 2MASS is about 0.6 mag. If the accurate photometry was lacking, we estimate K magnitudes in UNGC from B magnitudes using the correlation between the mean color index \( \langle B - K \rangle \) and morphological type of a galaxy (Jarrett et al. 2003): \( \langle B - K \rangle = 4.10 \) for the early morphological types E, S0, Sa; \( \langle B - K \rangle = 2.35 \) for the late types Sm, Im, BCD, Ir; and \( \langle B - K \rangle = 4.60 - 0.25 \times T \) for intermediate types T from 3 to 8.

The K-band luminosity versus \( W_{50} \) or \( W_{60} \) relation for 206 LV galaxies having accurately measured distances and \( i > 45^\circ \) is presented in the upper and lower panels of Figure 8, respectively. The galaxies with \( K \) magnitudes from 2MASS are labeled with filled circles, while galaxies with \( K \) estimates made from the mean color index \( \langle B - K \rangle \) and morphological type T are marked with open ones. These data show, once again, that galaxies without 2MASS photometry tend to reside in the lower-left part of the diagram. The median value of \( W_{50} \) is 36.5 km s\(^{-1}\), while for galaxies with 2MASS magnitudes, their median is twice as much. Notably, both categories of objects—with 2MASS magnitudes and with \( K \) estimates from the blue magnitude and morphological type—follow the same regression line. Its slope, 2.87, and dispersion, 0.46, are actually the same in the both panels of Figure 8.

As found by Noordermeer & Verheijen (2007) and Schombert (2011), there is a systematic bias in 2MASS total magnitudes caused by some 2MASS surface photometry routines underestimating the luminosity of galaxies. This specific bias is especially significant for bright extended galaxies plentiful in the LV. Since high-mass galaxies are star-dominated, a systematic underestimation of their K-luminosity may give shallower TF slopes.

It should be also noted that the scheme of converting \( B \) magnitudes to \( K \) magnitudes adopted by Jarrett et al. (2003) is quite reliable in most cases. With a characteristic error of \( \Delta T = \pm 1 \) in the morphological typing of a galaxy, the expected error in \( K \) magnitude is \( \pm 0.25 \) mag. However, for a special class of transition dwarf galaxies (dSph/dlr), a morphological typing mistake \( T = -1 \) (dSph), else \( T = 10 \) (dlr)) leads to a leap of 1.75" in their \( K \) magnitudes; albeit,
there are only five objects of this class in our sample: ESO 410-005, ESO 294-010, LGS-3, Antlia, and HS 117.

5. GASEOUS TF RELATION FOR DWARFS

Besides the stellar mass of a galaxy, its hydrogen mass,

\[ M_{\text{H}_1} = 2.356 \times 10^5 \times D^2 \times F(\text{H}_1), \]

also shows a tight correlation with the H line width. In the relation above, the distance \( D \) is expressed in Mpc and the flux \( F(\text{H}_1) \) in Jy km s\(^{-1}\). The distribution of 206 LV galaxies over their hydrogen mass and H I line width \( W_{50} \) is presented in the upper panel of Figure 9. The regression line has a slope of 2.08, and the dispersion amounts to \( \sigma (\log M_{\text{H}_1}) = 0.43 \). Passing from \( W_{50} \) to \( W'_50 \) (middle panel) leaves the regression slope and the dispersion unchanged.
As is known, some early-type galaxies and transition-type dwarfs strongly deviate downward from the regression line in the gaseous TF diagram. On the bottom panel of Figure 9, we excluded 16 gas-poor galaxies with color index $m_{21} > 6.0$ from our sample, which approximately corresponds to the expression $M_{\text{HI}}/M^* < 4\%$. This procedure slightly increases the slope (2.29) and decreases the dispersion (0.40). We find that the TF dispersion of hydrogen mass for the late-type LV galaxies is on the same order as the TF dispersion of their stellar masses.

Figure 9 outlines the upper limit for the $M_{\text{HI}}/(W_{50})^2$ value marked as a dashed straight line in the lower panel. According to Zasov (1974), active star formation in disks of galaxies usually occurs near the threshold for their gravitational instability. This condition corresponds to the linear relation between the total mass of gas in a disk and its angular momentum, $M_{\text{HI}} \propto V_m \times A_{25}$, where $A_{25}$ is a standard linear diameter of disk. Taking into account the scaling relation $A_{25} \propto V_m \propto W_{50}$ for UCNG galaxies (Karachentsev et al. 2013), the presence of the upper limit of $M_{\text{HI}}/(W_{50})^2$ value agrees well with the idea of Zasov. Examples of the galaxies residing close to the dashed line are NGC 6744 ($W_{50} = 323$, $\log(M_{\text{HI}}) = 10.31$, $\log(L_K) = 10.91$) and KDG177 ($W_{50} = 30$, $\log(M_{\text{HI}}) = 8.33$, $\log(L_K) = 8.22$).

### 6. BARYONIC TF RELATION FOR THE LV GALAXIES

Over the last decade, a consensus has been achieved that a classical TF relation between the stellar mass (or luminosity) and the rotation amplitude, definable by dark halo mass, should also be contributed by the gas mass of a galaxy (McGaugh et al. 2000; Verheijen 2001; McGaugh 2005). Such a correction is particularly essential for galaxies of extremely low luminosities where the significant part of the gas has not yet been turned into stars. The TF relation for the total (stars plus gas) mass is known as the baryonic Tully–Fisher relation (bTF).

Many authors have explored the slope of bTF relation (Geha et al. 2006; Begum et al. 2008a; Stark et al. 2009; Gurovich et al. 2010; McGaugh et al. 2010; Reyes et al. 2011; Torres-Flores et al. 2011; Catinella et al. 2012; McGaugh 2012; Bradford et al. 2015; Lelli et al. 2016b; Papastergis et al. 2016). According to McGaugh & Schombert (2015), the bTF diagram $\log(M_{\text{gas}}) \propto \beta \times \log(V_m)$ has a slope of $\beta = 4.0$ in a wide range of galaxy masses, which is not consistent with the expected value of $\beta \approx 3.0$ for the standard cosmological model ΛCDM. The steep $\beta \approx 4$ slope has been also determined by Verheijen 2001, McGaugh 2005, Stark et al. 2009, Catinella et al. 2012, Lelli et al. 2016b, and Papastergis et al. 2016. Yet, other authors have obtained notably less steep $\beta$ values: 2.2 (Begum et al. 2008a), 2.1 (McCall et al. 2012), and 2.5 (Kirby...
et al. 2012). As was discussed by Brook et al. (2016), Brook & Shankar (2016), and Bradford et al. (2016), the slope value $\beta$ can vary from 2 up to 4, depending on methodological details of converting observational values $W_{50}$, $W_{20}$, or $V_{\text{flat}}$ to the amplitude of rotation curve, $V_{\text{rot}}$. Also, as the most gas-rich dwarf galaxies follow the shallow relation $M_{\text{HI}} \propto W_{50}^{-2}$, then the high or low proportion of irregular dwarfs in the sample can appreciably affect the slope $\beta$. It must be noted that the $W_{50}$ line widths derived from spatially unresolved (single dish) observations give systematically shallower TF relation slopes than flat rotational velocities, $V_{\text{flat}}$, from interferometric H I observations. The reason for this is due to the known effect that dwarf galaxies have slowly rising rotation curves and reach $V_{\text{flat}}$ only in the outermost regions where the H I surface densities are low and the S/N goes down (Swaters et al. 2009; Lelli et al. 2014).

To determine the baryonic mass of a galaxy,

$$M_{\text{bar}} = M^* + M_{\text{gas}} = \Upsilon_K^* \times L_K + \eta \times M_{\text{HI}},$$

two parameters should be held fixed: the stellar-mass-to-$K$-luminosity ratio (or a similar ratio for any other photometric band) and the $\eta$ factor used for converting neutral hydrogen mass to the total gas mass. The published values of $\Upsilon^* = M^*/L_K$ stay within the range of $[0.5–1.0]M_*/L_\odot$. They are based on different models of synthetic stellar populations. According to an analysis performed by McGaugh & Schombert (2014), the optimal value

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**Figure 9.** Relation between hydrogen mass and line width for LV galaxies with accurately measured distances. Upper and middle panels indicate the line width observed and corrected for inclination, respectively. Bottom panel corresponds to 190 gas-rich galaxies with $m_K - K < 6.0^m$. The dashed line indicates the upper limit for the ratio $M_{\text{HI}}/W_{50}^2$ interpreted as a threshold of gravitation instability favoring star formation.
The value of stellar-mass-to-luminosity ratio is $T^* = 0.60$ and gaseous mass-to-$\text{H} \text{I}$-mass ratio $\eta = 1.33$.

The factor $\eta$ is usually set to 1.33 taking into account the correction for Helium abundance. According to Fukugita & Peebles (2004), adding molecular gas into consideration leads to a value of $\eta = 1.85$. However, this higher factor is typical only for disks of massive galaxies. The data by Young & Knezek (1989) and McGaugh & de Blok (1997) show that molecular-to-atomic hydrogen mass ratio decreases rapidly toward dwarf galaxies as

$$M_{\text{H}_2}/M_{\text{H} \text{I}} = 3.7 - 0.8 \times T + 0.043 \times T^2,$$

and it does not exceed 0.05 for dwarfs ($T \geq 8$).

Yet, the situation with $\eta$ value remains rather uncertain. It is commonly known (see, for example, Fukugita & Peebles 2004) that the observable quantity of baryons in galaxies and in hot intergalactic gas of clusters ($\sim 0.005\Omega$) is less than expected from the standard cosmological model of nucleosynthesis ($0.045\Omega$) by an order of magnitude. It is suggested that the bulk of baryons escaping from observations is distributed as warm or hot intergalactic gas, which can be partially associated with galaxies. Attempts of detecting hot gaseous coronas were undertaken based on observations of absorption lines O VII and O VIII in quasar spectra (Stocke et al. 2013). According to Miller & Bregman (2015), the mass of ionized gas around the Milky Way is $(3.8 \pm 0.3) \times 10^9 M_\odot$ within the radius of 50 kpc, and $(4.3 \pm 0.9) \times 10^{10} M_\odot$ within 250 kpc. The last value is matching with the total stellar mass of the Milky Way ($6 \times 10^{10} M_\odot$) is several times more than the mass of neutral hydrogen in our Galaxy. If such a warm gaseous halo is typical for other massive and dwarf galaxies, then the dimensionless factor $\eta$ can amount to $\sim 5$. Varying the $\eta$ parameter, Pfenniger & Revaz (2005) and Begum et al. (2008a) concluded that the minimum dispersion in the bTF diagram is reached within a wide range of $\eta = (3-10)$. This result implicitly confirms that a large number of hot baryons may be associated with galaxies beyond the known amount of neutral gas in them.

The distributions of LV galaxies over baryonic mass and $\text{H} \text{I}$ line width, $W_{50}$ or $W'_{50}$, are presented in the upper and lower panels of Figure 10. For factors converting $M^*$ and $M_{\text{H}_1}$ to baryonic mass, we have adopted $\Upsilon_K^* = 0.60$ (McGaugh & Schombert 2014) and $\eta = 1.33$. The slope of the regression line and dispersion are $\beta = 2.55$, $\sigma = 0.36$ (for $W_{50}$) and $\beta = 2.61$, $\sigma = 0.38$ (for $W'_{50}$), respectively.

As previously mentioned, the correction for inclination in the case of dwarf galaxies does not play any significant role, so we included another 56 faint dwarf galaxies with $M_B > -16.0^m$ and inclinations $i < 45^\circ$ (marked as crosses in Figure 11) into our analysis. We also added 69 mainly dwarf galaxies with distance estimates (mem) obtained from their membership in the known groups. The typical distance error for these galaxies is $\sim 17\%$ or 0.14 dex in the scale of $M_{\text{baryon}}$, which is three times less than the observed TF scatter. These objects with arbitrary inclinations of $M_B > -16.0^m$, or $i > 45^\circ$ otherwise, are labeled as open diamonds. The regression line for the complemented sample of 331 galaxies has a slope of $\beta = 2.49$ and dispersion of $\sigma (\log M_{\text{baryon}}) = 0.38$.

**Figure 10.** Baryonic mass vs. observed (upper panel) and corrected for inclination (bottom panel) line width for 206 LV galaxies with accurate distances. The adopted value of stellar-mass-to-luminosity ratio is $T^* = 0.60$ and gaseous mass-to-$\text{H} \text{I}$-mass ratio $\eta = 1.33$. 

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To optimize the choice of $\mathcal{T}_K^*$ and $\eta$ parameters for the LV galaxies, we calculated their baryonic mass with various values of $\mathcal{T}_K^*$ from 0.40 to 1.00 and $\eta$ from 1.33 to 5.0. The rms deviations from the regression line for each combination of parameters are presented as matrix in Table 2. The differences in $\sigma(\mathcal{T}_K^*, \eta)$ turn out to be small. The minimum value of dispersion, 0.352, is found along the matrix diagonal going from $\mathcal{T}_K^* = 0.40$ and $\eta = 2.50$ to $\mathcal{T}_K^* = 1.00$ and $\eta = 5.0$. This result could be interpreted in favor of the presence of dark (warm) gas around the LV galaxies; however, the TF scatter in the current sample is rather dominated by various observational errors. Hence, its variations cannot really be used to constrain intrinsic galaxy properties like $\mathcal{T}_K^*$ and $\eta$.

The obtained parameters of regression lines for the different kinds of TF relations are summarized in Table 3.

### 7. A SECONDARY PARAMETER IN THE bTF DIAGRAM

In literature, one can find different attempts of reducing the scatter of galaxies in the TF diagram by introducing some additional parameters (Kashibadze 2008; Kudrya et al. 2009; McCall et al. 2012). Apparently, these parameters should be chosen as been independent on galaxy distance. Examples of such variables include a galaxy’s surface brightness, gas fraction index, morphological type, apparent axial ratio, specific star-formation rate, and isolation index. Strictly speaking, all of them still show a slight dependence on distance due to different effects of observational selection. We note that the listed parameters may be mutually correlated. Nevertheless, the search for a secondary parameter in the bTF relation offers a chance to improve the accuracy of measuring galaxy distances by such an approach (if the application of the corresponding parameter does not drop the sample number essentially).

As candidates, we have tested the following parameters available in the UNGC.

1. The mean surface brightness in $B$ band within the Holmberg isophote,
   \[ SB = B_F^c + 5 \log a_{26} + 8.63, \]
   where the total apparent magnitude $B_F^c$ and the angular diameter in arcminutes, $a_{26}$, are corrected for extinction and inclination effects.
2. The gas fraction index ($B_F^c - m_{24}$).

### Table 2

| $\mathcal{T}_K^*$ | $\eta$ | 1.33 | 1.85 | 2.50 | 3.00 | 4.00 | 5.00 |
|-------------------|--------|------|------|------|------|------|------|
| 0.40              | 0.357  | 0.353| 0.352| 0.353| 0.356| 0.360|
| 0.50              | 0.362  | 0.355| 0.352| 0.352| 0.353| 0.356|
| 0.60              | 0.366  | 0.358| 0.354| 0.352| 0.352| 0.354|
| 0.75              | 0.371  | 0.363| 0.357| 0.354| 0.352| 0.352|
| 1.00              | 0.380  | 0.370| 0.363| 0.359| 0.354| 0.352|

### Table 3

| LV sample | $N$ | $\beta$ | C   | $\sigma$ |
|-----------|-----|---------|-----|---------|
| $M_B$ versus $W_{50}$, TRGB, $i > 45$ | 206 | $-6.85$ | $-2.78$ | 1.06 |
| $M_B$ versus $W_{50}$, TRGB, $i > 45$ | 206 | $-6.96$ | $-2.19$ | 1.10 |
| $L_K$ versus $W_{50}$, TRGB, $i > 45$ | 206 | 2.87   | 3.16 | 0.46 |
| $L_K$ versus $W_{50}$, TRGB, $i > 45$ | 206 | 2.91   | 2.91 | 0.47 |
| $M_B$, versus $W_{50}$, TRGB, $i > 45$ | 206 | 2.08   | 4.24 | 0.43 |
| $M_B$, versus $W_{50}$, TRGB, $i > 45$ | 206 | 2.14   | 4.01 | 0.44 |
| $M_{B*}$ versus $W_{50}$, $M_{B*}/M^* > 0.04$ | 190 | 2.28   | 3.79 | 0.40 |
| $M_{B*}$ versus $W_{50}$ | 206 | 2.55   | 3.91 | 0.36 |
| $M_{B*}$ versus $W_{50}$ | 206 | 2.61   | 3.64 | 0.38 |
| $M_{B*}$ versus $W_{50}$, extended | 331 | 2.49   | 3.97 | 0.38 |

(3) The specific star-formation rate,
   \[ P = \log(SFR) - \log L_K + 10.14, \]
   normalized to the age of universe. Here, the integral star-formation rate was defined either from apparent magnitude in far-ultraviolet based on GALEX data (Gil de Paz et al. 2007)
   \[ \log(SFR[M_\odot \times yr^{-1}]) = 2.78 - 0.4m_{FUV}^c + 2 \log D \]
   or via $H\alpha$ flux (Karachentsev & Kaisina 2014)
   \[ \log(SFR[M_\odot \times yr^{-1}]) = 8.98 + \log F_{H\alpha} + 2 \log D \]
   considering galactic and internal extinction, $A(FUV) = 1.93(A_V^G + A_H^G)$ and $A(H\alpha) = 0.538(A_V^G + A_H^G)$, where $A_V^G$ is from Schlafly & Finkbeiner (2011) and $A_H^G$ from Equation (6).
All three parameters are independent from the distance $D$, and their values are available in our database for most LV galaxies. We also tested two parameters, characterizing the local environment of a galaxy: the index of isolation, and their values are available in our database for most LV galaxies. The index of isolation, $\Theta_1 = \max[\log(M_n/D_n^3)] + C$, $n = 1, 2, \ldots N$, (7)

which distinguishes the most significant neighbor (the “main disturber”; MD) from the plenty of nearby galaxies, whose tidal force, $F_n \sim M_n/D_n^3$ dominates all other neighbors (Karachentsev et al. 2013). Here, $D_n$ is the three-dimensional separation of a neighboring galaxy, and the value of constant $C = -10.96$ was chosen so that at $\Theta_1 = 0$ the neighbor “n” is located on the zero velocity sphere relative to the MD. At that point, the galaxies with $\Theta_1 > 0$ turned out to be members of a certain group, and the negative values of $\Theta_1$ corresponded to isolated galaxies. The tidal index $\Theta_1$ or a stellar density contrast contributed by one most important neighbor, i.e., the MD, can significantly change with time due to orbital motions of galaxies. This is why we also used another isolation index,

$$\Theta_2 = \log \left( \sum_{n=1}^{5} M_n/D_n^3 \right) + C,$$

which is the sum of the density contrasts produced by five most important neighbors. The value of constant C here is the same as in Equation (7).

Four panels of Figure 12 show the relation between a galaxy deviation from the regression line and the value of each of four mentioned parameters. The galaxy subsample designations are the same as in Figure 11. Table 4 provides the values of the regression slope $\beta$ with its error, the rms scatter $\sigma$, and the Pearson ($\rho$) and Kendall ($\tau$) correlation coefficients with their statistical significance $p$-values. No correlation is statistically significant, since absolute values of all correlation coefficients are well below 0.2. The observed lack of environmental dependence of the bTF relation looks to be a rather unexpected result.

8. BALD (DSPH) DWARFS IN THE TF DIAGRAM

As is seen from Figures 3 and 4, only 656 out of 1049 LV objects have been detected in H I. The fraction of objects without H I data is growing rapidly toward the low-mass galaxies. About one-third of the H I-undetected objects have never been observed in H I because they are located outside the HIPASS and ALFALFA surveys. The majority of the remaining undetected objects are dwarf spheroidal (dSph) and dwarf elliptical (dE) galaxies with a small admixture of transition dwarfs (dTr) and outlying globular clusters around M31. The relative number of true gas-poor dSph and dE galaxies (bald dwarfs) in the LV sample amounts to $\sim$20%. However, this quantity is rather uncertain. Lack of evidence of gas or structure details, as well as low surface brightness, make dSphs very difficult to determine their distances and radial velocities. In fact, most of their distances were estimated from supposed membership in known groups. There are no deep systematic surveys for dSphs over the entire sky. In practice, dSph galaxies can be identified as LV objects only after resolving them into stars, which is possible only to reach with existing ground-based telescopes within the Local Group and its immediate surroundings.

At present, radial velocities and stellar-radial velocity dispersion, $\sigma_v$, are measured for 69 dSph and 2 dE satellites of the Milky Way and M31. We compiled a summary of their $\sigma_v$ and stellar masses, based on the data from Collins et al. (2013, 2014) and Wheeler et al. (2015) with additions from Walker et al. (2016) and Irwin & Tolstoy (2002). Their distribution is presented in Figure 13, where horizontal bars indicate the measurement errors. As one can see, for many tiny dwarfs, velocity dispersion is comparable with its typical error of $\sim$2–5 km s$^{-1}$.

Then, we incorporated the data of dSph and dE companions of the Milky Way and M31 into the bTF diagram, adopting the value $W_s = 2\sqrt{2}\ln2 \times \sigma_v$ as an analogue of the line width $W_{50}$ for the Gaussian function, and setting $M_{bary} = M^*$. The combined bTF diagram for 404 late-type and early-type galaxies is shown in Figure 14. The gas-poor dwarfs are indicated by red stars. As seen, the population of dSphs forms a wide tail curved downward with much steeper bTF slope. An essential part of their scatter is caused by errors in $\sigma_v$ themselves. In the range of $W > 20$ km s$^{-1}$, most early-type dwarfs follow nearly the same bTF relation as gas-rich galaxies, as found by McGaugh & Wolf (2010) and den Heijer et al. (2015), although, in our opinion, the dSphs show, on average, lower masses than dIrs. Being improved in $\sigma_v$ errors, this diagram will be useful to test different scenarios describing transformations of late-type dwarfs into quenched dSphs. McGaugh & Wolf (2010) also noted that the deviations of dSphs from bTF relations are considerably more susceptible to tidal effects in modified Newtonian dynamics (MOND) than in the standard dark matter paradigm.

The raw observational data on 402 galaxies of the LV, including 71 dSphs, are compiled in Table 5. Its columns contain (1) galaxy name; (2) equatorial coordinates; (3) morphological type; (4) apparent axes ratio; (5) H I line width $W_{50}$ (or $\bar{W}$, marked by asterisk); (6) galaxy distance in Mpc and the method used to determine it; (7) logarithm of the K-band luminosity in solar units; (8) logarithm of hydrogen mass in solar masses; and (9) logarithm of baryonic mass with parameters $\Gamma^* = 0.60$, $\eta = 1.33$. The full text of the Table is available online in http://www.sao.ru/lv/lvdb/.

9. DISCUSSION AND CONCLUDING REMARKS

Estimating the budget of errors responsible for the observed scatter of galaxies in the bTF diagram we have taken into account five different sources of the scatter.

(1) Many dwarf galaxies in the UNGC sample have eye-ball estimates of apparent $B$ magnitude with an accuracy of $\sim$0.5 m. An additional error appears while converting $B$ magnitudes to $K$ ones. Suggesting the total error $\sigma(K) \approx 0.6m$, we obtain its contribution to the baryonic mass error as $\sigma(\log M_{bary}) = 0.25$.

(2) Inspection of the H I line width errors in our sample yields the average mean-square value of 17% or 0.07 dex. At the slope of the regression line as $\beta = 2.6$, the contribution of $\sigma(W_s)$ errors accounts to $\sim$0.18 dex, i.e., slightly less than the contribution of photometric errors.

(3) According to Meidt et al. (2014), the scatter on the stellar-mass-to-NIR luminosity ratio for galaxies amounts $\sim$0.11 dex.

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Figure 12. Residuals in the baryonic TF diagram as a function of the galaxy surface brightness (upper panel), $(B - m_{21})$ gas fraction index (upper-middle panel), specific star-formation rate expressed in the age of universe (lower-middle panel), and isolation index (bottom panel). Designation of galaxy sub-samples is the same as in Figure 11. The straight lines display regression lines with corresponding slope $\beta$ and scatter $\sigma$. 

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The uncertainty in distances for the LV objects (∼10%) produces the error in calculating baryonic mass of ∼0.08 dex, being lower than previous observables.

The typical observed error of HI flux for our sample galaxies is ∼20%, which gives ∼0.08 dex on the bTF plot.

Therefore, after adding quadratic errors, the resulting expected error from these observables is $\sigma(\log M_{\text{bar}}) = 0.35$. Performing its quadratic subtraction from the observed scatter of galaxies in the bTF diagram (0.38 dex), we obtain the intrinsic (cosmic) scatter in the baryonic mass to be $\sigma(\log M_{\text{bar}})_{\text{cosmic}} = 0.15$. A part of this residual scatter is

| SB      | $-0.078$ | 0.023  | 0.376 | $-0.160$ | 0.003  | $-0.107$ | 0.004 |
|---------|----------|--------|-------|----------|--------|----------|-------|
| $B_m - m_{21}$ | $-0.034$ | 0.015  | 0.380 | $-0.077$ | 0.164  | $-0.082$ | 0.027 |
| P       | 0.006    | 0.040  | 0.380 | 0.008    | 0.891  | $-0.008$ | 0.825 |
| $\Theta_3$ | 0.008    | 0.014  | 0.380 | 0.019    | 0.732  | 0.038    | 0.301 |
| log($b/a$) | 0.044    | 0.102  | 0.383 | 0.018    | 0.746  | $-0.029$ | 0.430 |

Table 4: Various Residual Non-correlations

Figure 13. Stellar mass vs. stellar radial velocity dispersion for 69 dSph and 2 dE galaxies around the Milky Way and M31. Horizontal bars indicate measurement errors.

Figure 14. Baryonic TF relation for 402 LV galaxies. dSph companions of the Milky Way and M31 are indicated by red stars.

(4) The uncertainty in distances for the LV objects (∼10%) produces the error in calculating baryonic mass of ∼0.08 dex, being lower than previous observables.
(5) The typical observed error of HI flux for our sample galaxies is ∼20%, which gives ∼0.08 dex on the bTF plot.
caused by imperfect recipe used to account inclinations of very low-mass galaxies often having irregular shapes.

Our evaluation of the observed (0.38 dex) and intrinsic (0.15 dex) scatter in $M_{\text{bar}}$ for the sample of 331 nearby dwarf galaxies can be compared with other estimates from the literature. We note that in most papers devoted to baryonic TF relations, the analysis is based on samples consisting of spiral galaxies with a typical H I line width $W_{50} > 100$ km s$^{-1}$, where dwarf galaxies are only a kind of supplement.

McGaugh (2012) selected 47 gas-rich galaxies in the range of $\log(M_{\text{bar}}) = [7-11] \log(M_\odot)$ and found for them the observed scatter of 0.24 dex. The same observed scatter, 0.24 dex, was obtained by McCall et al. (2012) based on a deep K-band photometry of 19 late-type dwarf galaxies of the LV. Their sample has a median value of $\log(M_{\text{bar}})$ about 8.3 $\log(M_\odot)$. Lelli et al. (2016b) studied a sample of 118 spiral and irregular galaxies with high-quality data on their photometry and extended H I-rotation curves. For this sample covering the baryonic mass range of $\log(M_{\text{bar}}) = [8.0-11.5] \log(M_\odot)$, the authors found the observed scatter of 0.22 dex and estimated the intrinsic scatter as 0.10 dex. Almost the same quantities of the observed and intrinsic scatter were obtained by McGaugh & Schombert (2015) for a sample of 26 S and dIrr galaxies with the median $V_{\text{rot}}$ velocity of 130 km s$^{-1}$. The sample of 97 gas-rich spiral and irregular galaxies selected by Papastergis et al. (2016) probes the bTF relation over the $\log(M_{\text{bar}}) = [8.5-10.5] \log(M_\odot)$. The authors derived the observed scatter of baryonic mass to be ~0.22 dex for the samples. A close value, 0.25 dex, was found by Bradford et al. (2015) for a sample of 148 gas-rich galaxies from SDSS with stellar masses ranging between $10^7$ and $10^{10.5} M_\odot$. Recently, Bradford et al. (2016) performed a comprehensive analysis of slope and dispersion of the bTF relation using a sample of 930 isolated galaxies that have accurate photometry from the SDSS. Their sample extends over the baryonic mass range $\log(M_{\text{bar}}) = [7.4-11.3] \log(M_\odot)$. The observed bTF scatter for the total sample is found to be 0.25 dex. In the same time, the subsample of 271 low-mass galaxies with $W_{20} < 200$ km s$^{-1}$ is characterized by larger scatter of 0.41 dex.

We suppose that improving the measurement accuracy of $K$ magnitudes, as well as $W_{50}$ widths, expected in forthcoming deep optical, NIR, and HI-sky surveys, may reduce the observed scatter of $\log(M_{\text{bar}})$ for the low-mass dwarfs until 0.20 dex, and thereby achieve the accuracy of bTF distances for them ~0.10 dex, i.e., ~25%. This improvement will be important to refine the peculiar velocity field in the local universe.

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Table 5
Initial Data for Local Volume Galaxies

| name      | j2000         | $T$ | $b/a$ | $W_{50}$ | D method | $\log(L_K)$ | $\log M_{11}$ | $M_{bar}$ |
|-----------|---------------|-----|-------|----------|-----------|--------------|---------------|-----------|
| WLM       | 000158.1–152740 | –9  | 0.35  | 53       | 0.98 TRGB | 7.70         | 7.84          | 8.09      |
| And XVIII | 000214.5–450520 | –3  | 0.99  | 23$^*$   | 1.31 TRGB | 6.56         | 6.65          | 6.34      |
| ESO409-015| 000531.8–280553 | 9   | 0.46  | 53       | 8.11 TRGB | 8.10         | 8.10          | 8.39      |
| AGC748778 | 000634.4+153039 | 10  | 0.52  | 16       | 6.22 TRGB | 6.39         | 6.64          | 6.86      |
| And XX    | 000730.7+350756 | –3  | 0.70  | 17$^*$   | 0.80 TRGB | 5.26         |               | 5.04      |

(This table is available in its entirety in machine-readable form.)
