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CALIBRATION OF DIAMETER-HI LINE WIDTH RELATION FOR EDGE-ON SPIRAL GALAXIES

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Abstract. Calibrated B and I-band diameter Tully-Fisher relations for edge-on spiral galaxies are derived from published data. In order to apply TF calibration for edge-on spiral galaxies, the diameters of the calibrators are corrected into edge-on view, before the TF constructions. Two versions of TF relations are compared showing the differences in the resulting ditance estimation from applying HI line width data and maximum rotational velocity data. The standart error (SE) of $(\log A_{edge-on} - \log W_{20})$ TF relation is 0.25 and 0.30 for B and I-band, respectively, corresponding to relative distance error of 12% and 14%, whereas the SE of the $(\log A_{edge-on} - \log V_{max})$ TF relation is 0.27 and 0.28 for both photometrical bands, respectively. This corresponds to larger relative distance error of 13% and 14% and means that the choise of the rotational parameters is important for the distance determination to the spiral galaxies. The diameter-HI line width TF relation appear to be better distance estimate than the diameter-rotation velocity TF relation.

1. INTRODUCTION

In recent years the analysis of the peculiar velocity field using redshift-independent galaxy distance indicators has significantly enhanced our underestanding of the formation and evolution of large scale structure. The most prevalent example of these indicators have been the Tully-Fisher (TF) relation. TF relation is one of the most popular extragalactic distance indicators. This is due to the large number, up of thousands of spiral galaxies, and wide distance range, $\rightarrow 100h^{-1}Mpc$, of the objects applicable for TF studies. The correlation between the absolute magnitude and the logarithm of the maximum rotational velocity of spiral galaxiy is known as TF relation after Tully and Fisher (1977).

Although, the most commonly used version of this relation is with the participation of the galaxy luminosity (or absolute magnitude) as dependent variable, there is other version of the TF relation in which the dependent parameter is replaced by the galaxy linear size (absolute diameter). In these both cases the relation have the following analytical form:

$$M = a \log W_{20} + b$$

$$\log A = a \log W_{20} + b$$

Here a is the TF slope, b the zero point and $\log W_{20}$ is the logarithm of the rotational parameter - HI line width measured at the 20% level in km/s. It is a distance independent quantity, which often is replaced by the logarithm of the maximum rotational velocity of the galaxy $\log V_{max}$. Independence of distance means that $\log V_{max}$ or $\log W_{20}$ observations are not affected by any selection effects caused by limitations in detector sensitivity for distant, apparently dim objects. The other observables, the luminosity and linear diameter of a galaxy, suffer from such effects. This and the scatter of the derived distances around the true average, lead to systematic errors known as the Malmquist biases, which produce underestimation of the derived distance moduli.

But actually this is not the focus of this paper. Here we only present the B and I-band diameter TF relations with two rotational parameters for the spiral galaxies in the calibration sample published in Macri and Huchra (2000). The TF rlations are constructed with the edge-on magnitudes after applying internal extinction correction into edge-on view. Furthermore our aim is to find out how these both TF relations contribute to the final galaxy distance derivation.

The physical basis of the TF relation comes from the fact that both the rotational velocity and the luminosity (or linear diameter) are related to the mass of a galaxy when a constant mass to light ratio is assumed. This means that the mass plays an intermediary role between luminosity and rotation velocity. Keeping in mind the galaxy luminosity-size relation, this is true for the two variations of the TF relation – with magnitudes and the diameters, respectively.

The mean shape of the mass-luminosity and mass-rotation velocity relations, determine the slope of the observed TF relation, while the scatter of each of the two relations contributes to the dispersion in the luminosity at a fixed maximum rotation velocity (see Rhee and van Albada, 1996; see also Djorgovski, de Carvalho and Han, 1988).

$$V_{rot}^2 = \frac{G m_{gal}(R)}{R} \propto L(R)$$

where $V_{rot}(R)$ is the rotational velocity at R, $m_{gal}(R)$ is the mass, and $L(R)$ the integrated luminosity inside radius R from the center of a galaxy.

2. CALIBRATION OF THE DIAMETER TULLY-FISHER RELATION

The main task of the calibration is the determination of accurate distances to relatively close spiral galaxies of suitable type and inclination. Among all extragalactic distance indicators currently only Cepheid-based distances are considered accurate enough (error less than 10%) and obtainable for a reasonable large sample of galaxies.

There is several important problems concerned with the calibration of the TF relation. Some of these problem are disscused here very shortly.

For the proper calibration of the TF relation we need a calibration sample containing spirals galaxies in all morphological types and accurate derived Cepheid distances. To have accurate distance determination to the target galaxies, the precise derivation of the Cepheid distances to the calibrator galaxies is important. The completeness of the calibrator sample is other crucial point concerned with the application of the calibration technique. The absence of galaxies from some morphological type in the calibration sample would be crucial for the distance derivation if the target sample is more complete in morphological types. This mean the calibrator sample must be representative for the whole target sample, otherwise there would arise selection bias. But the situation is more complex when we concern our attention to the problems about the Cepheid Period-Luminosity (PL) relation which is the basis for the derived calibrator distances. There are some problems about the Cepheid PL relation (see Allen and Shanks, 2004). The first one is the bias due to incompleteness in the PL relation at faint magnitudes. Usually the effect of the magnitude limited bias tends to make the slope of the PL relation shallower.

Other problem is the effect of the metallicity on the Cepheid PL relation. The dependence of the metallicity with the rms dispersion of this relation is discussed in details in Allen and Shanks, (2004).

There is increasing evidence that Cepheid distances require significant corrections for the effects of metallicity and incompleteness bias with important potential consequences for the distance scale, Hubble constant and cosmology. The better understanding on these effects is of importance for the accurate distance determination to the spiral galaxies calibrated on the Cepheid-based distances.

2.1. DIAMETER TRANSFORMATION INTO EDGE-ON VIEW

In order to calibrate the TF relation for distant sample of edge-on spiral galaxies, it is important to have homogeneity in the derived inclination dependent parameters for both calibration and target samples. Before the construction of the TF relations with both rotational parameter ($\log W_{20}$ or $\log V_{rot}$) we make correction of each calibrator diameter into edge-on view.

Let consider the following dependence between the galaxy diameter and galaxy axial ratio:

$$\log\left(\frac{A_o}{A}\right) = c_A \log\left(\frac{a}{b}\right) \tag{1}$$

Here A_o is the inclination corrected galaxy linear diameter in kpc, A - the linear diameter of a galaxy at arbitrary inclination angle, c_A - coefficient accounting for the diameter-inclination dependence, and (a/b) is the apparent axial ratio of the galaxy. From now on if we denote the inclination corrected diameters at 0° and 90° to the line of sight as "edge-on" and "face-on", respectively, then the linear size of each galaxy may be corrected in edge-on view in the following way:

$$\log A_{face-on} = \log A + c_A \log \left(\frac{a}{b}\right) \tag{2}$$

$$\log A_{edge-on} = \log A_{face-on} - c_A \log \left(\frac{1}{q_0}\right) \tag{3}$$

Here q_0 is the galaxy intrinsic axial ratio. This parameter is morphologically dependent and in this work we use the following values: q_0=0.13 for the late type spirals and q_0=0.20 for the early type galaxies (Sakai et al., 2000; Tully et al., 2000; Kannappan et al., 2002; Courteau, 1997). When the galaxy is corrected into edge-on view it is expected to increase its linear diameter, because of accumulation of more ligtht in the plan of the galaxy and the sharpening of the peripheral surface brightness gradients.

Finally for the galaxy edge-on linear diameter we obtain:

$$\log A_{edge-on} = \log A + c_A \log \left(\frac{a}{b}\, q_0\right) \tag{4}$$

We use this equation for the calculation of the edge-on diameters of the calibrator galaxies. The values for the coefficient $c_A = -0.21$ was taken from Nedialkov (1994) and the galaxy axial ratio (a/b) was determined using the Holmberg equation:

$$\cos^2 i = \frac{(b/a)^2 - q_0^2}{1 - q_0^2} \;\Rightarrow\; \left(\frac{a}{b}\right) = \frac{1}{\sqrt{\cos^2 i(1-q_0^2) + q_0^2}}$$

Thus derived edge-on linear diameters we use for the B and I-band TF relations with the galaxies from the calibration sample. The calculated edge-on diameters as well as te used rotational parameters for the TF relations are shown in Table 1.

2.2. THE DIAMETER TF RELATION

The homogeneous data for 21 nearby spiral galaxies with accurate determined distances, collected in the paper of Macri and Huchra (2000), are used. The distances are based on observations of Cepheid variable stars. Most of the observations were made with the *Hubble Space Telescope* (Freedman et al., 1997; Sandage et al., 1996). The morphological types of the galaxies are Sb – Sd. With respect to the HI linewidth, the linear diameter and inclination angles, the calibrator galaxies cover the following ranges:

- $238 < W < 553$ km/s
- $1.11 < \log A_{edge-on} < 1.89$ kpc
- $42 < i < 78$ deg

The data about the angular diameters at 25 mag/arcsec^2 surface brightness level in B-band are taken from LEDA, whereas the data in I-band are taken from Macri and Huchra (2000).

After applying extinction correction in our Galaxy and internal extinction correction into edge-on view, the linear diameters of the calibrators were obtained as:

Table 1: Calculated B and I-band edge-on diameters of the calibrator sample. The data about B-band diameters are taken from LEDA and they are within the isophote of 25 mag.arcsec^2 surface brightness level. The I- band diameters are taken from Macri and Huchra (2000). They are within the isophote of 23.5 mag.arcsec^2 surface brightness level.

$Name$	$\log A_{25}$ [kpc]	$\log A_{23.5}$ [kpc]	$\log W_{20}$ [km/s]	$\log V_{rot}$ [km/s]
NGC0925	1.55	1.46	2.420	2.058
NGC1365	1.91	1.79	2.682	2.356
NGC1425	1.67	1.63	2.621	2.251
NGC2090	1.54	1.45	2.501	2.187
NGC2541	1.40	1.31	2.370	1.988
NGC3198	1.56	1.49	2.531	2.183
NGC3319	1.49	1.39	2.405	2.031
NGC3351	1.43	1.44	2.586	2.168
NGC3368	1.53	1.50	2.674	2.321
NGC3621	1.41	1.34	2.499	2.167
NGC3627	1.55	1.54	2.626	2.266
NGC4414	1.57	1.51	2.743	2.342
NGC4535	1.69	1.65	2.586	2.311
NGC4536	1.64	1.60	2.562	2.207
NGC4548	1.56	1.54	2.617	2.291
NGC4725	1.71	1.26	2.671	2.382
NGC7331	1.72	1.16	2.746	2.409
NGC4603	1.76	1.73	2.575	2.367
NGC4639	1.40	1.35	2.519	2.256
NGC4651	1.63	1.68	2.584	2.358
NGC4654	1.51	1.44	2.487	2.201

$$A = \frac{a_o}{206265} 10^{[0.2(m-M)-10]} \tag{5}$$

where the last term is the distance expressed in kpc. Data for the used distance modulus are taken from Tully and Pierce, (2000).

The HI line width data are corrected for inclination and turbulence and taken from Tully and Pierce (2000). V_{rot} data are taken from LEDA (*Lyon-Meudon Extragalactic Database*).

Further we compare both TF relations depending on the rotational parameter used - $\log W_{20}$ and $\log V_{rot}$. This relations are shown in Fig. 1 and Fig. 2.

It is expected that the TF relation with $\log W_{20}$ must be more accurate than that with the participation of $\log V_{rot}$ parameter. This is due to the fact that the first parameter represents the rotation of the galactic disk as a whole. The HI line width come from the broadening of the 21 cm radio emission line in neutral hydrogen, due to the motions of atomic hydrogen to the observer's line of sight. The other rotational

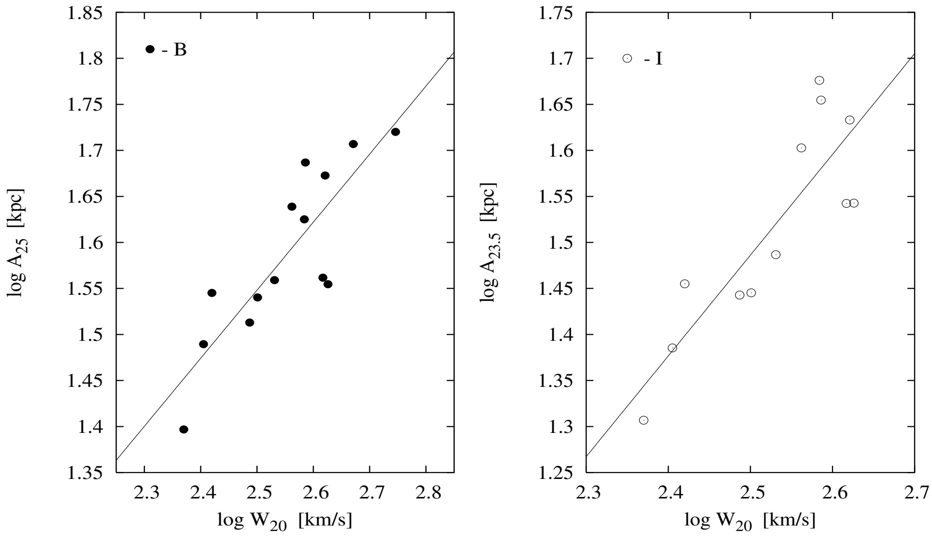

Figure 1: Diameter TF relation for the calibration sample. Both graphs present diameter TF relation with the logarithm of HI-line width $\log W_{20}$. The left panel shows B-band TF relation for 14 galaxies from the calibration sample. The right panel shows the I-band TF relation with 12 galaxies. The linear fits are made using standard least square technique.

parameter – maximum rotational velocity is parameter in some sense fixed at given distance from the center of the galaxy. Its value depends on the specific shape of the galaxy rotation curve. In general this produce some scatter on the TF relation because of the "intrinsic" properties of the galaxies.

In Fig. 1 is shown the diameter TF relation for the calibration sample with the HI line width rotational parameter. The data for B-band diameters are taken from LEDA, whereas these about I-band are taken from Macri and Huchra (2000). The diameters participating in the forthcoming TF relation in B and I-bands are corrected for Galactic extinction and recalculated into edge-on view through equation (4). The TF relation in B-band is constructed for 14 galaxies from 21 calibrators in the sample. The galaxies NGC 1365, NGC 3351, NGC 3368, NGC 3621, NGC 4414, NGC 4603 and NGC 4639 do not participate in the relation and they are excluded as outliers. Three of the above listed galaxies – NGC 3351, NGC 3368 and NGC 4639 are classified as galaxies with ring and all galaxies, with exception of NGC 4414, are barred. The relation in I-band is with the participation of 12 calibrators. In addition two calibrators are excluded as outliers - NGC 4725 and NGC 7331. The first calibrator is barred galaxy with ring and the second is classified just as Sb galaxy. The SE of the both B and I-band TF relations are $\sigma_\mu \sim 5\sigma_{\log A}$, which makes 0.25 mag. and 0.30 mag., respectively. That corresponds to relative distance error of 12% and 14%.

Fig. 2 presents B and I-band TF relation with maximum rotational velocity parameter. To make comparison the same galaxies are used in both TF relation as these

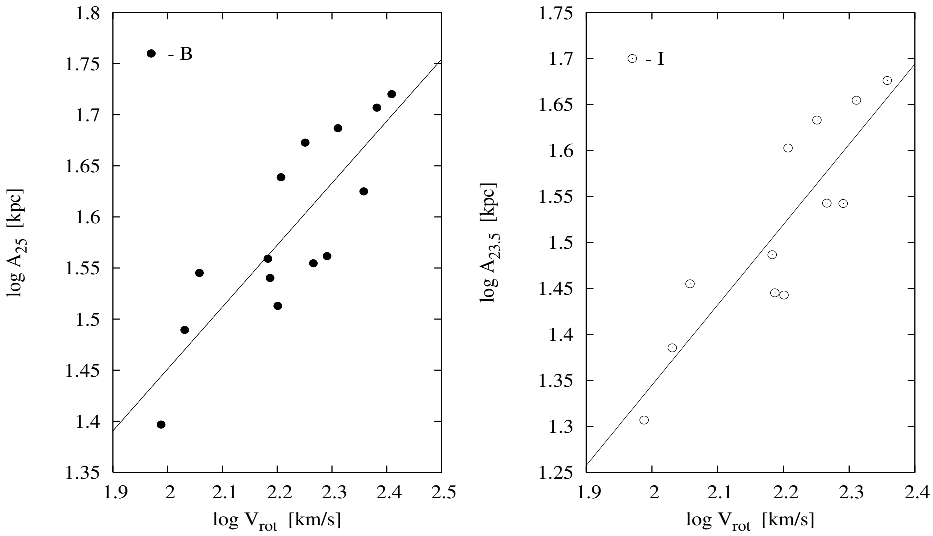

Figure 2: B and I-band diameter TF relations for the calibration sample with $\log V_{rot}$ rotation parameter. The notations are similar to these in Fig. 1.

in Fig. 1. Here the SE from the linear least square fits is 0.27 mag. and 0.28 mag. for B and I-band, respectively. With respect to the $\log A_{edge-on} - \log W_{20}$ relations this corresponds to larger relative distance error of 13% and 14%.

The diameter TF relations presented above show that as for the case with the magnitude TF relation here using the diameters, $\log W_{20}$ rotational parameter produces more accurate distance estimation in comparison with $\log V_{rot}$ parameter. Apparently the better distance determination could be produced when the HI line width is used as independent variable in TF relation.

3. CONCLUSIONS

In this paper we present calibration TF relation for diameters of the spiral galaxies. That is why we have used B and I-band data taken from LEDA and Macri and Huchra (2000). We recalculate the galaxy diameters into edge-on view in order to be used for calibration of the TF relation for target samples with highly inclined galaxies. TF relations are constructed with the participation of two rotational parameters: HI line width ($\log W_{20}$) and maximum rotational velocity ($\log V_{rot}$). The comparison between the relations with these both parameters shows that using $\log W_{20}$ parameter more accurate distance estimation can be reproduced. We obtain 12% and 14% relative distance error for B and I-band ($\log A_{edge-on} - \log W_{20}$) TF relation and 13% and 14% for ($\log A_{edge-on} - \log V_{max}$) relation. This mean that the first version of the diameter TF relation is better distance estimator and can be used for distance determination to edge-on spiral galaxies.

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