DISTANCE MODULI FROM THE TULLY-FISHER RELATION

E. Giraud
European Southern Observatory
Karl-Schwarzschild-Strasse 2
D-8046 Garching bei München, F.R.G.

ABSTRACT. When the Bottinelli et al. version of the Tully-Fisher relation is applied to derive distances, and when the observed parameters are used to predict the Malmquist bias at a given distance, the observed variation of the Hubble ratio as a function of kinematic distance is about 2.5 times the predicted variation.

1. INTRODUCTION

It is now well-known that the sample used by de Vaucouleurs and his collaborators in 1981 to derive the mean Hubble ratio through the Tully-Fisher method or the tertiary distance indicators, is such that the Hubble ratio is an increasing function of the velocity. A similar deviation was reported many years ago by de Vaucouleurs at the IAU Symposium 44 in 1972.

Because H is a velocity/distance ratio, some dependence between H and the velocity would be obtained in the case of a poor representation of the velocity field. However, 1) if the distances are well estimated, 2) if after correction for the perturbation caused by the overdensity of Virgo, the velocity field is quiet and 3) if there is no bias in the data, then a [velocity - Hubble ratio] diagram must be random. We know that there is a similar increase in H, even after correction for infall velocities toward Virgo through Peeble's spherical infall model.

I recall the selection rules of the data. The set consisted of 254 galaxies from the catalogue of Bottinelli and her collaborators selected such that:

a) the inclination of a galaxy is larger than 35°
b) internal errors are lower than 0.45 mag
c) de Vaucouleurs' morphological types are between 2 and 7.

The HI velocities were corrected to the centroid of the Local Group and then were converted to kinematic distances. The parameters are: velocity of Virgo: 1000 km s^{-1}; infall velocity of the Local Group toward Virgo: 330 km s^{-1}.

The main difference between this sample and the sample of

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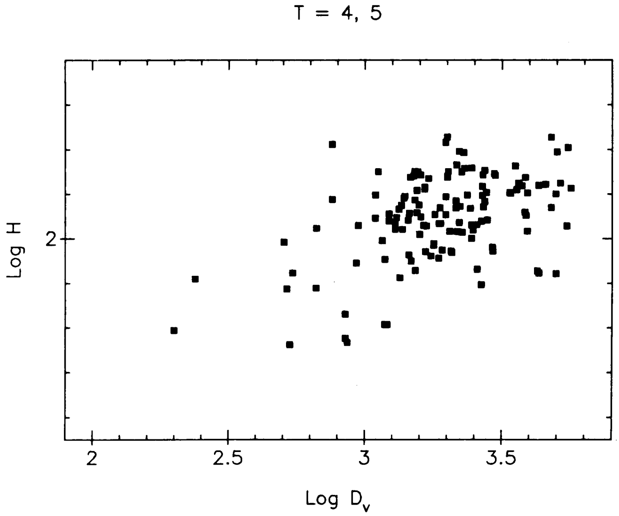

Fig. 1a. The logarithm of the Hubble ratios H vs. the logarithm of the kinematic distances D_v (in km s^{-1}) for Sbc-Sc galaxies. The distance moduli are derived from the B-band Tully-Fisher relation with slope of 5.

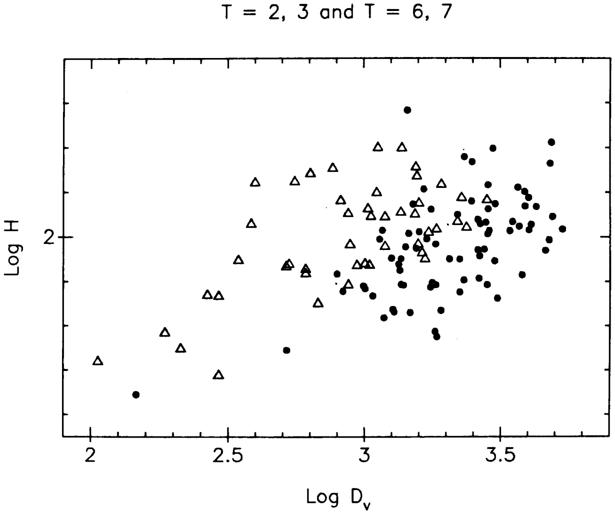

Fig. 1b. Same as 1a for Sab-Sb and Scd-Sd galaxies.

Bottinelli and her collaborators is that they do not exclude data with large internal errors. So they have many galaxies with known errors larger than 1 mag.

The distances are derived from the version of the Tully-Fisher relation adjusted on the de Vaucouleurs distance indicators. In this

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method the slope of the relation between the maximum rotational velocity of a spiral galaxy and its absolute magnitude in the B-band has a value of 5 and, at a given rotation velocity, the luminosity does not depend on Hubble type.

With these hypotheses we obtain the relation between the kinematic distances and the Hubble ratios shown in figures 1a and 1b presented separately for the Sbc-Sc, the Sab-Sb and the Scd-Sd galaxies. I use a logarithmic scale because the distances are in magnitudes.

These figures show two main features:

1) the Hubble ratio increases with respect to the velocities
2) in the shell log D_V between 2.8 and 3.3 the mean Hubble ratio for the Scd-Sd is larger than that of the Sab-Sb's suggesting that there is a small type offset.

2. MALMQUIST BIAS

The Malmquist bias has played a crucial role in the value of the Hubble constant and apparent non-linearities in the Hubble flow. In a magnitude-limited sample, when the distances become larger than some critical value, intrinsically faint galaxies are progressively lost. Sandage and Tammann pointed out that neglect of the Malmquist effect gives higher values of H in the biased part of the sample in which the fainter objects are absent and gives only an apparent correlation of H with velocities.

Bottinelli and her collaborators have investigated the effect of the Malmquist bias using substantially the same plot of log H versus log D_V as in the last figures. The main objection to their analysis may follow from what they call normalized kinematic distances. In

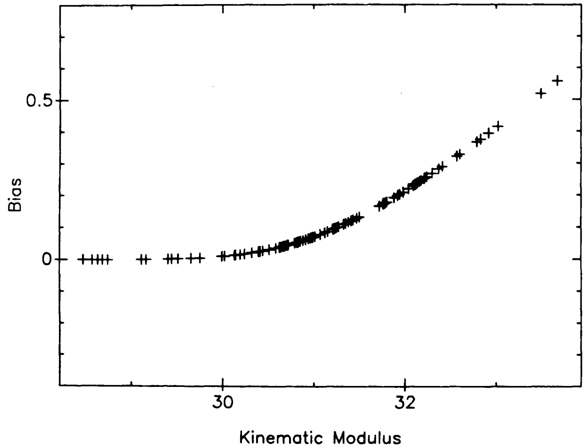

Fig. 2. The bias (in mag) in the determination of absolute magnitudes through the Tully-Fisher relation plotted as a function of the kinematic modulus $\mu = 5(\log D_V + 3)$ (in mag).

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particular they use a dispersion of 0.5 mag of classes of galaxies instead of the observed dispersion of the luminosity function of spirals which is about 1 mag for the sample. I have remade the analysis of Malmquist bias with the observed parameters. We need to know the mean absolute magnitude M_0 of the sample, the dispersion and the shape of the luminosity function, the magnitude-limit and the dispersion of the Tully-Fisher relation. We do not know the true mean absolute magnitude but we can find the biased mean absolute magnitude and dispersions to determine approximately the maximum value of distance within which the sample is not much biased. Then we assume that the parameters in that range are good estimates of the true mean absolute magnitude and dispersion. The variation in the mean absolute magnitude is the Malmquist effect but is not the bias in the value of absolute magnitudes estimated through the Tully-Fisher relation. This bias depends on the accuracy of the Tully-Fisher relation and is illustrated by figure 2 in the case of the observed parameters of the sample. When the observed parameters are used the variation of the Hubble ratio as a function of the kinematic distance in the case of Bottinelli's version of the Tully-Fisher relation is 2.5 to 3 times the expected variation due to the Malmquist bias at a given distance.

After correction for Malmquist bias the remaining variation is shown in Figure 3. Here the zero point is adjusted in the value of the mean Hubble ratio at small distance in the short scale (see Giraud 1986c). We note in passing that the low value of the Hubble ratio at small distance is not due to the Local Group deceleration.

We know that the problem that we have to face is more difficult than a Malmquist bias because:

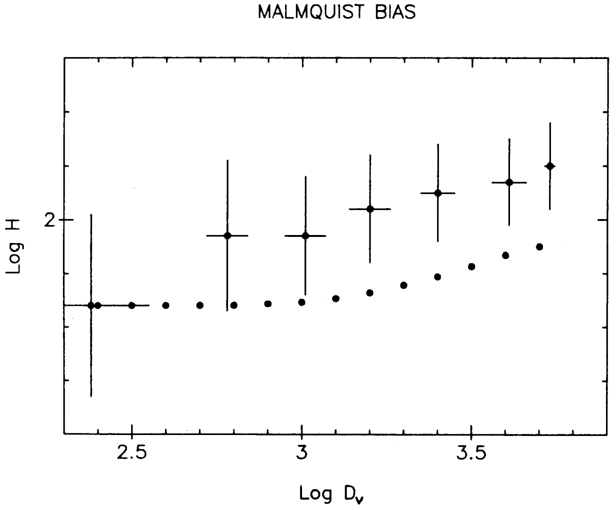

Fig. 3. The observed and the predicted variation in <log H> binned as a function of kinematic distance (the bars are the dispersions). The adjustment is made at <log H> = 1.84 for log $D_V < 2.7$.

1) The dispersion of the absolute magnitudes derived from the field is larger than that derived from the Tully-Fisher relation with a slope of 5 and without type offset.

2) If we select galaxies with large rotation velocities, the variation of H as a function of absolute magnitudes derived from the velocity field remains almost the same.

3. TYPE EFFECT

A source of uncertainty in the B-band comes from the unknown amount of scatter introduced by the wide range in morphological types. In particular we have seen that there is a small type offset between Sab-Sb and Scd-Sd in the shell log D_V between 2.8 and 3.3. Part of this offset is due to a differential Malmquist bias because the sample of

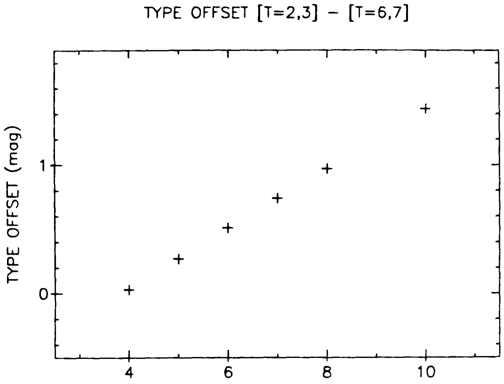

Fig. 4a. The type offset in the zero-point of the Tully-Fisher relation between Sab-Sb and Scd-Sd plotted as a function of the slope of that relation (after correction for differential Malmquist bias).

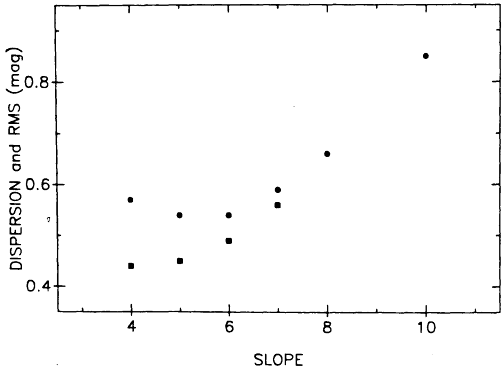

Fig. 4b. The weighted mean dispersion of the Tully-Fisher relation for various types plotted as a function of the slope. The filled squares are for a non-linear Hubble flow.

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Scd-Sd galaxies being less luminous is more biased. The differential Malmquist bias has been found to be of 0.25 mag in the shell. The rest is a true type offset.

Many authors have found values of the slope of the B-band Tully-Fisher relation in the range 6 to 10. I have measured the dispersion by type and the offset between Sab-Sb and Scd-Sd corrected for differential Malmquist bias for various values of the slope (fig. 4). The values of the dispersion favour low values of the slope of the Tully-Fisher relation between 5 and 6 and a true type offset of 0.3 to 0.5 mag. A slope of 10 would give very poor results but we note that the values of the type offset and of the dispersions in that case are more or less in agreement with the results obtained by Rubin and her collaborators. Finally if we assume that the Hubble flow is not linear we obtain the dispersions marked by filled squares in the figure.

CONCLUSIONS

1. The observed variation in log H with kinematic distance is not due to the Malmquist effect.

2. The values of the dispersion favour slopes of the B-band Tully-Fisher relation between 5 and 6 and a true type offset of 0.3 to 0.5 mag.

3. The low value of the Hubble ratio at small distance is not due to the Local Group deceleration.

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DISCUSSION

ARP: With the most accurate possible correction for Malmquist effect you get a clear difference between a "local" value of H_o and the value of H_o at greater distances. What is the H_o you get at close distances and what value further away?

GIRAUD: 75 kms^{-1} Mpc at small distance; 90 kms^{-1} Mpc at the location of Virgo (depending on the infall velocity); and 100-110 kms^{-1} Mpc further away.

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