ASTRONOMY FROM WIDE-FIELD IMAGING

Part Thirteen:

PROPERTIES AND CLUSTERING OF GALAXIES AND CLUSTERS

SURFACE PHOTOMETRY OF GALAXIES IN THE PISCES-PERSEUS REGION

M. WATANABE[1], T. ICHIKAWA[2], M. FUKUGITA[3], K. TARUSAWA[2] and S. OKAMURA[1]
[1] *Department of Astronomy, School of Science*[†], *University of Tokyo, Tokyo 113, Japan*
[2] *Kiso Observatory, Institute of Astronomy, Faculty of Science, University of Tokyo, Nagano 397-01, Japan*
[3] *Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606, Japan*

ABSTRACT. We have obtained B-band photographic surface photometry of ~ 2000 galaxies in the Pisces-Perseus region. Combining these photometry data with redshift and HI 21 cm line-width data for spiral galaxies in the region, we have studied the Hubble constant and large-scale peculiar motions. Taking biases into account quantitatively we obtain $H_0 = 80 \pm 9^{+17}_{-22}$ km/s^{-1}Mpc^{-1}. The prevalent infalling motion in the region is found to be still controversial if the biases are carefully considered.

1. Introduction

Redshift, V_0, and HI 21 cm line-width, Δv, data of a deep and complete sample of spiral galaxies in the Pisces-Perseus region included in the CGCG (Zwicky et al. 1968) and UGC (Nilson 1973) catalogues (Fig. 1a) have been compiled (Giovanelli & Haynes 1985, 1989; Giovanelli et al. 1986). However, the available photometric data were not accurate enough for studies of galaxy properties and motions.

We have obtained homogeneous photographic surface photometry of galaxies in this region and analysed their Tully-Fisher relation. We present a determination of the Hubble constant using these data as well as a first analysis of the large scale peculiar motions claimed by Willick (1990).

2. Observations and Data Reductions

B-band photographic observations (Kodak IIa-O plate plus Schott GG385 filter) were made using the 105 cm Schmidt telescope at Kiso Observatory. We observed the region of $22^h < \alpha < 4^h$ and $22° < \delta < 33°$, using 19 x 2 slightly overlapping plates. All CGCG and UGC galaxies, and all optically identified IRAS galaxies in the region (Ichikawa & Watanabe 1993) were selected for our program. About 2000 galaxies were measured. The plates were scanned with a

[†] Formerly Faculty of Science

H. T. MacGillivray et al. (eds.), Astronomy from Wide-Field Imaging, 603–609.

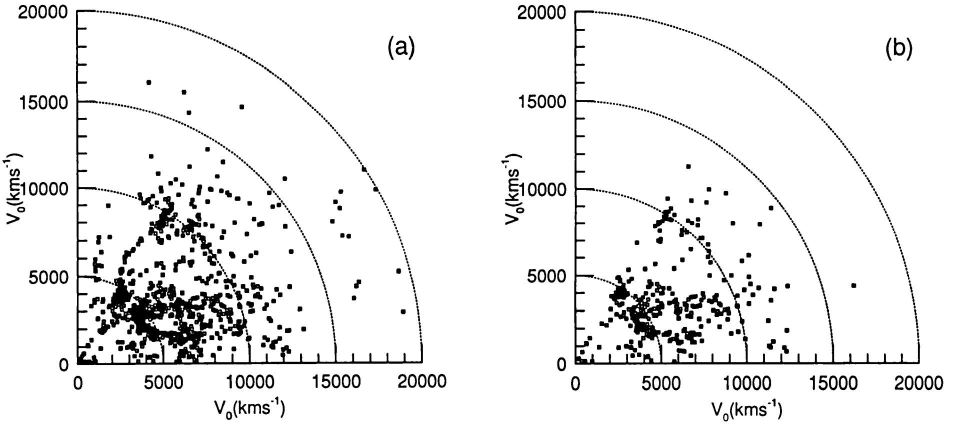

Figure 1. a) Distribution of the 1119 spiral galaxies in redshift space for which redshift and HI 21 cm line-width data are available. **b)** Distribution of the 363 spiral galaxies used for the Tully-Fisher analysis (see text).

PDS2020GMS microdensitometer and ordinary data reduction methods were applied to the density data. The absolute flux calibration was made for each plate using the aperture photometry data given by Longo & de Vaucouleurs (1983) and Burstein et al. (1987). We obtained the total magnitude, B_T using the scheme of the RC3 (de Vaucouleurs et al. 1991). In addition to B_T, the isophotal magnitude B_{25}, major axis diameter, D_{25}, and axial ratio, R_{25}, were derived at the 25 mag arcsec^{-2} level.

The internal error of our photometry was estimated using 251 galaxies in the overlapping areas of photographic plates, and was found to give an rms magnitude difference of 0.09 mag. The external consistency was checked using the three data sources: RC3, Bothun et al. (1985) and CGCG. A comparison of our magnitudes with those of the RC3 and Bothun et al. show quite good agreement (Figs. 2a, 2b), while the CGCG magnitudes show an offset of ~0.15 mag and a large dispersion, ~0.3 mag (Fig. 2c). We estimate ~0.15 mag as the total error of photometry. The present data are accurate enough for the application of the Tully-Fisher relation, which is known to have an intrinsic dispersion of no less than 0.3 mag in the B-band.

3. Determination of the Hubble Constant

We used the Tully-Fisher relation to estimate the distances of 363 spiral galaxies in our sample (Fig. 1b) which were selected using the following criteria: Type Sa-Sd, inclination $i > 45°$, $2.3 < \log(\Delta v/\mathrm{km/s^{-1}}) < 2.8$, $2000 < V_0 < 15{,}000$ km/s^{-1}. The apparent magnitudes of these galaxies were corrected for Galactic absorption, internal absorption and the K-effect. We adopted the absolute calibration of the Tully-Fisher relation by Fukugita et al. (1991) based on 8 local calibrators.

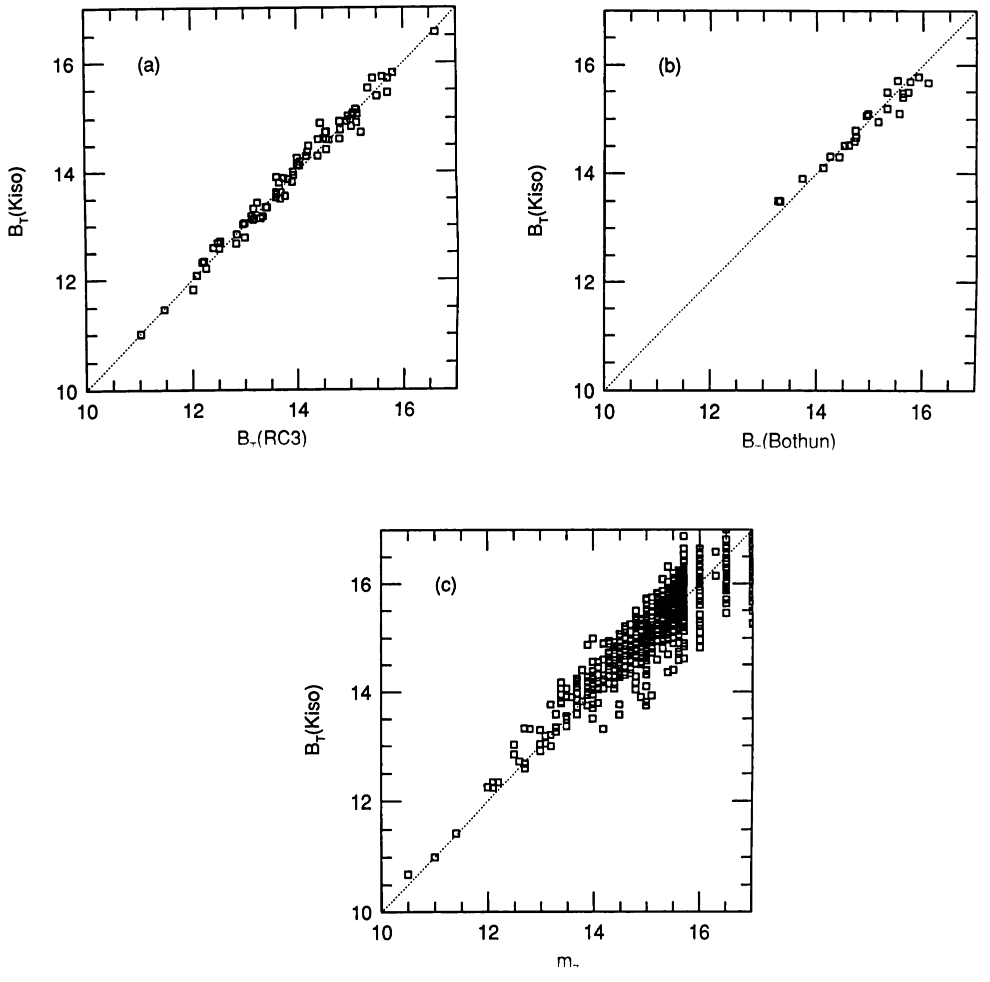

Figure 2. Comparison of our magnitudes with data from **a)** RC3 (N = 78), **b)** Bothun et al. (1985) (N = 24), and **c)** CGCG (N = 918). Rms differences are 0.17 mag, 0.19 mag and 0.33 mag, respectively.

Tully-Fisher distances, $r_{TF}^{(i)}$, were then calculated for individual galaxies. Note that our sample galaxies are extended over a wide distance range up to V_0 ~15,000 km/s^{-1}, and *not* at the same distance like the cluster members. Accordingly the effects of the various biases have to be carefully corrected for:

1) *The sampling incompleteness bias* (cf. Ichikawa & Fukugita 1992) increases the mean absolute luminosity of the sample galaxies beyond the true value due to the limiting magnitude of the observation and the finite dispersion of the Tully-Fisher relation, σ_{TF}. Thus, we would estimate a distance modulus smaller, or a Hubble ratio larger, than the true value. The effect

https://doi.org/10.1017/S007418090004818X Published online by Cambridge University Press

is larger for more distant or for intrinsically fainter galaxies.

2) *The Malmquist bias* is well known as an effect of $1.382\sigma^2$ in the distance modulus, where σ is the absolute magnitude dispersion.

3) *The inhomogeneity bias* is a correction for the Malmquist bias due to the inhomogeneous galaxy distribution.

We computed a Hubble ratio $H_{obs}^{(i)} = V_0^{(i)} / r_{TF}^{(i)}$ for individual galaxies. In order to derive the Hubble constant H_0 from $H_{obs}^{(i)}$ we calculated the surface of the distribution of the predicted Hubble ratios H_{pre} as a function of V_0 and log Δv (Fig. 3) taking the aforementioned biases into account. Two other parameters affect the surface: one is H_0, which shifts the surface vertically without changing its shape, and the other is σ_{TF}, which determines the degree of curvature of the surface. The distribution of $H_{obs}^{(i)}$ are shown in Fig. 4 for the galaxies within $2.6 < \log\Delta v < 2.7$ and $2.7 < \log\Delta v < 2.8$ bins. We can see the effects of the biases in our data (Fig. 4) as predicted in Fig. 3.

To find the most probable value of H_0 we performed a χ^2 test for H_0 and σ_{TF}:

$$\chi^2 = \sum_i \frac{\{H_{obs}^{(i)} - H_{pre}^{(i)}(V_0^{(i)}, \log\Delta v^{(i)}; H_0, \sigma_{TF})\}^2}{\sigma_{H^{(i)}}{}^2} \qquad (1)$$

In the present study, we fixed $\sigma_{H(i)} = 30$ km/s^{-1}Mpc^{-1} for all sample galaxies, which follows directly from the distribution of $H_{obs}^{(i)}$. Error ellipses as function of H_0 and σ_{TF} are shown in Fig. 5. From this analysis we obtain

$$H_0 = 80 \pm 9^{+17}_{-22} \text{ km/s}^{-1}\text{Mpc}^{-1} \qquad (2)$$

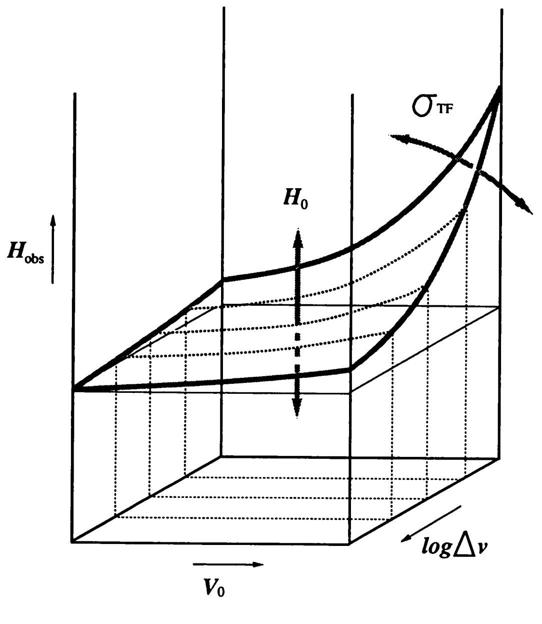

Figure 3. Schematic representation of the H_{pre} surface. (See text.)

https://doi.org/10.1017/S007418090004818X Published online by Cambridge University Press

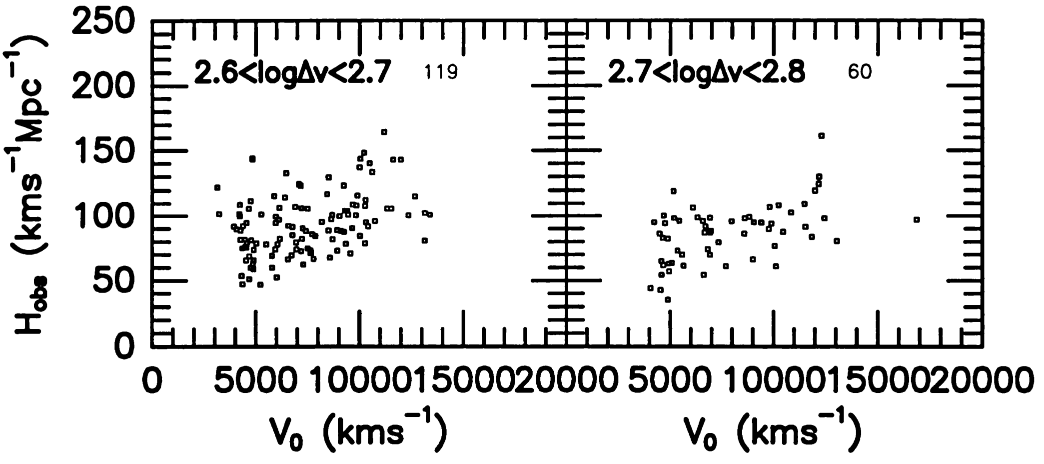

Figure 4. Distribution of H_{obs} in two logΔv bins. The number of included galaxies is shown as well.

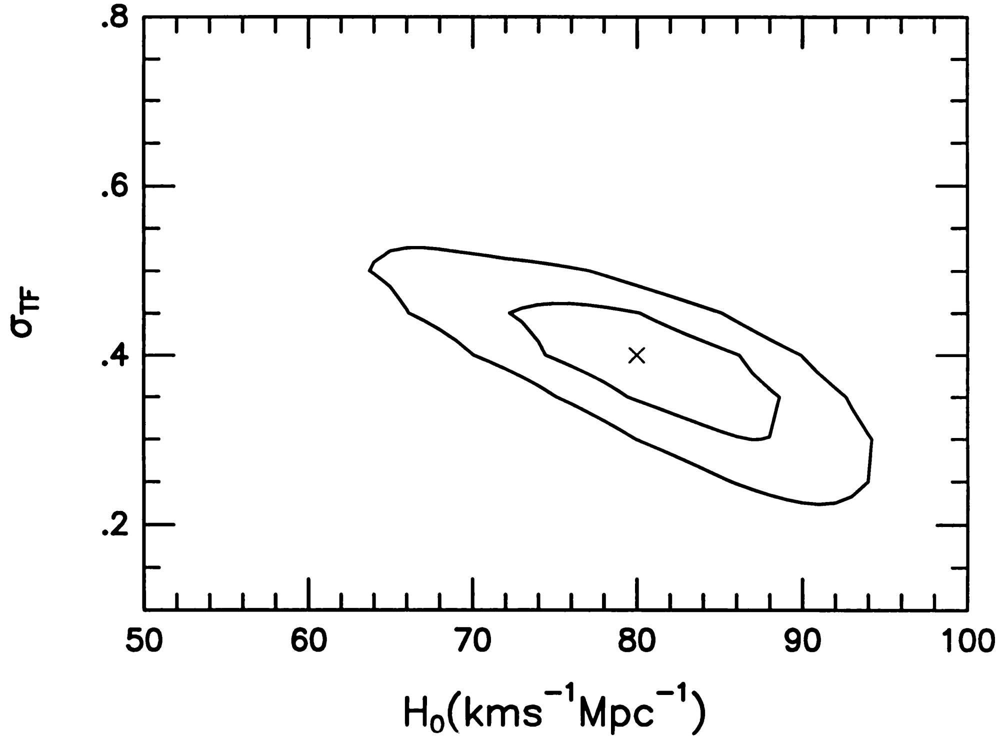

Figure 5. Error ellipses of the χ^2 test (ν = 363 - 2). Inner and outer contours correspond to the 90% and 99% confidence level, respectively.

https://doi.org/10.1017/S007418090004818X Published online by Cambridge University Press

where the random error, ±9 km/s^{-1}Mpc^{-1}, include both the internal error in the χ^2 test and external errors such as photometry and the calibration of the Tully-Fisher relation. We also show the systematic errors, (+17, -22) km/s^{-1}Mpc^{-1}, which were estimated primarily from errors in the absorption correction and the distance of local calibrators. These systematic errors have often been neglected in previous studies.

4. Peculiar Motions in the Pisces-Perseus Region

We also examined the large-scale peculiar motion. Willick (1990) claimed that galaxies in the Pisces-Perseus region were falling toward us, i.e. to the direction of the *Great Attractor* (Dressler et al. 1987; Lynden-Bell et al. 1988). Mean amplitudes of these motions were -440 km/s^{-1} and –840 km/s^{-1} for galaxies in the redshift range of $3800 < V_0 < 7000$ km/s^{-1} and $7000 < V_0 < 8000$ km/s^{-1} respectively.

If these infall motions are real, we would expect that corrections for them will give a smaller minimum χ^2 per degree of freedom than obtained in the χ^2 test described in section 3, where a uniform expansion of galaxies was assumed. Therefore we performed a new χ^2 test after adding 440 km/s^{-1} and 840 km/s^{-1} to V_0 of all galaxies in the two regions. The minimum χ^2 per degree of freedom is now *1.18* compared with *1.02* in the previous test. This increase may be significant, since the number of galaxies is large. In fact the confidence level for the value of 1.18 is only 1% while that for 1.02 is 50%. This result indicates that the infall motions claimed by Willick (1990) are in fact *less* appropriate, for the interpretation of our data, than a uniform expansion.

There are a few differences, however: first, Willick made photometric *CCD* observations in *R-band* where the Tully-Fisher relation shows a smaller dispersion than in the *B*-band, but it seems unlikely that the difference in colour band can cause the discrepancy, unless there is an unknown systematic error in either or both of the data sets. Second, Willick considered the effects of the biases mentioned in section 3 to be negligible in his study. We are presently investigating if these two points could be responsible for the discrepancy.

Acknowledgements

We thank K. Shimasaku for useful discussion and Win van Driel for comments improving the manuscript.

References

Bothun, G.D. et al., 1985. *Astrophys. J. Suppl.*, **57**, 423.
Burstein, D. et al., 1987. *Astrophys. J. Suppl.*, **64**, 601.
de Vaucouleurs,G. et al., 1991. 'Third Reference Catalogue of Bright Galaxies (RC3)' Springer-Verlag.
Dressler, A. et al., 1987. *Astrophys. J. Lett.*, **313**, L37.
Fukugita, M. et al., 1991. *Astrophys. J.*, **376**, 8.
Giovanelli, R. and Haynes, M.P., 1985. *Astron. J.*, **90**, 2445.

Giovanelli, R. and Haynes, M.P., 1989. *Astron. J.*, **97**, 633.

Giovanelli, R. et al., 1986. *Astron. J.*, **92**, 250.

Ichikawa, T. and Fukugita, M., 1992. *Astrophys. J.*, **394**, 61.

Ichikawa, T. and Watanabe, M., 1993. In preparation.

Longo, G. and de Vaucouleurs, A., 1983. 'A General Catalogue of Photoelectric Magnitudes and Colors in the U, B, V System of 3,578 Galaxies Brighter than the 16th V-Magnitude (1936-1982)', The University of Texas Monographs in Astronomy, No. 3.

Lynden-Bell. D. et al., 1988. *Astrophys. J.*, **326**, 19.

Nilson, P., 1973. 'Uppsala General Catalogue of Galaxies (UGC)', Acta Uppsala Univ. Ser. V:A, Vol 1.

Willick, J.A., 1990. *Astrophys. J. Lett.*, **351**, L5.

Zwicky, F. et al., 1961-1968. 'Catalogue of Galaxies and of Clusters of Galaxies (CGCG)', L. Speich, Zurich.