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THE RELATIVE SIZE OF THE MILKY WAY

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Using Cepheid distances to 17 spiral galaxies we calculate the true linear diameters of those galaxies. These diameters are then compared to that of the Milky Way which is found to be, at most, an averagely sized spiral galaxy. When compared to galaxies of approximately the same Hubble type ($2 < T < 6$) the Milky Way is found to be slightly undersized. This suggests that the Hubble constant is at the lower end of the currently accepted range of possibilities.

Introduction

Before the confirmation by Hubble[1] that many 'nebulae' are, in fact, external galaxies, the Milky Way was thought by many to be the entire Universe. Even after the identification of external galaxies, it seemed at first that these were much smaller objects than the Milky Way, relatively close to our Galaxy[2]. Successive revisions of the cosmic distance scale have placed external galaxies further away from us with the implication that they are correspondingly bigger, reducing the perceived importance of the Milky Way in the Universe.

Over the past few decades two rival schools of thought have found evidence for two different distance scales: one corresponding to a value of the Hubble constant, H_0, above 80 km s^{-1} Mpc^{-1} (see refs. 3, 4) and the other to a value around 50 km s^{-1} Mpc^{-1} (see refs. 5, 6). In recent years these two distance scales have shown signs of convergence, as advocates of the former ('short') distance scale[7] have obtained estimates of H_0 around 70 km s^{-1} Mpc^{-1} while proponents of the latter ('long') distance scale[8] have shifted their ground closer to a value of $H_0 = 60$ km s^{-1} Mpc^{-1}. Nevertheless, some more extreme estimates of the Hubble parameter (above 80 km s^{-1} Mpc^{-1}) have continued to appear in the literature[9,10].

The short distance scale still implies that the Milky Way must be an unusually large spiral galaxy; the long distance scale, on the other hand, would imply that the Milky Way is a very ordinary spiral. This issue will ultimately be resolved by the completion of the *HST* 'Key Project'[11]; but there is already enough data from that project for us to put the Milky Way in perspective in terms of the sizes of relatively nearby spirals with well-determined distances from Cepheid observations. When we do this, we find (contrary to the previously accepted belief that the Milky Way is "a large spiral": see, for example, refs. 12–14) that we live in an ordinary spiral galaxy, with a diameter very close to the average for its Hubble type.

The diameters of other galaxies

The external galaxies in our sample were chosen because they have distances that have been determined *via* the application of the Cepheid period-luminosity relation, which has long been recognised as the most reliable primary, extragalactic distance indicator. The availability of an accurate, independent distance estimate removes any requirement to assume a Hubble constant or correct for any peculiar motion in estimating the galaxy diameter. We chose 17 calibrating galaxies, mainly targets of the *HST* 'Key Project' survey[11] whose distances have recently been collated in the literature[7,15].

The diameter of a galaxy is problematic to define and here we take it to be the face-on diameter of the 25 B-mag $arcsec^{-2}$ isophote, allowing direct comparison between external galaxies and the Milky Way. We present calculations of the true 25 B-mag $arcsec^{-2}$ isophotal diameters of 17 spiral galaxies with independent distance estimates derived from Cepheid-variable observations, mostly carried out in the past few years with the *Hubble Space Telescope*, and compare these with the inferred diameter of the Milky Way at this same surface brightness.

All of these galaxies are included in the RC3 bright-galaxy catalogue[16] from which their Hubble type, T, and isophotal angular diameters, denoted $D_{25(\mathrm{ang})}$, were taken. These isophotal diameters have been corrected for galactic extinction but not for inclination, as the RC3 catalogue assumes that the discs are optically thick and hence the major-axis diameter is used directly. The removal of this correction can significantly change the inferred diameters of inclined spiral galaxies. In the earlier RC2 catalogue[17] and the *Nearby Galaxies Catalogue*[18], for example, application of an inclination correction to M31 yielded a diameter at the 25 B-mag $arcesc^{-2}$ isophote of ~ 155 arcmin, while without the inclination correction the diameter from RC3 is 204 arcmin. This difference accounts for most of the discrepancies between the diameters quoted here and those quoted in other studies[19,20].

Clearly the issue of whether one should, or should not, apply inclination corrections to the isophotal diameters is potentially a very important one, and depends crucially on whether the assumption that spiral discs are optically thick is valid. There is no consensus about this question in recent literature. Studies which support the idea of optically thick discs include those by Disney *et al.*[21], Valentijn[22], Burstein *et al.*[23], Cunow[24], James & Puxley[25] and, of course, de Vaucouleurs *et al.*[16]. On the other hand Huizinga & van Albada[26], Byun[27] and, more recently, Xilouris *et al.*[28] have reached the opposite conclusion.

While it seems to us that the balance of observational evidence still favours the view adopted in RC3 — that spirals *are* substantially optically thick — for completeness we have also repeated our calculations using the corrected angular diameters published in RC2, and we show in the results section below that using the RC2 diameters does *not* significantly change the conclusions of this paper.

Table I summarises the (RC3) angular diameters, distances, and inferred linear diameters of the 17 spiral calibrating galaxies.

The size of the Milky Way

The 25 B-mag arcsec^{-2} isophotal diameter of the Milky Way has been calculated by assuming that the galactic disc is well represented by an exponential disc[29] and re-arranging the surface-brightness profile equation[30] to give

$$r = \frac{h(\mu(r) - \mu_0)}{1\cdot086} \tag{1}$$

TABLE I

Properties of the 17 spiral calibrating galaxies

NGC	*M*	*T*	$D_{25(\mathrm{ang})}$	*d*	$D_{25(\mathrm{true})}$
		arcmin	*Mpc*	*kpc*	
224	31	3	204	0·77	45·7
300		7	22·4	2·15	14·0
598	33	6	74·1	0·85	18·4
925		7	11·0	9·38	30·0
1365		3	11·2	18·2	59·3
2366		10	8·32	3·44	8·32
2403		6	22·9	3·18	21·2
3031	81	2	27·5	3·63	29·0
3109		9	20·0	1·23	7·16
3351		3	7·59	10·1	22·3
3368	96	2	7·59	11·6	25·6
3621		7	13·5	6·80	26·7
4321	100	4	7·59	16·1	36·2
4496		9	3·98	16·8	19·5
4536		4	7·59	16·7	36·8
4639		4	2·82	25·1	20·6
5457	101	6	28·8	7·38	61·8

The Hubble type T, face-on angular 25 B-mag arcsec^{-2} isophotal diameters $D_{25(\mathrm{ang})}$, Cepheid distances d, and actual 25 *B-mag* arcsec^{-2} isophotal diameters $D_{25(\mathrm{true})}$.

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where μ_0 is the central surface brightnes of a galaxy and h is the disc scale length. For the Milky Way we have adopted $\mu_0 = 22 \cdot 1 \pm 0 \cdot 3$ B-mag arcsec^{-2} and $h = 5 \cdot 0 \pm 0 \cdot 5$ kpc (see refs. 14, 31). This leads to a derived 25 B-mag arcsec^{-2} isophotal diameter for the Milky Way of

$$D_{25(\mathrm{true})} = 26 \cdot 8 \pm 1 \cdot 1 \text{ kpc}$$

Other, smaller, values for the disc scale length have been quoted in recent literature — as low as 2·5 kpc (Robin *et al.*[32] and references therein) compared with van der Kruit's value of 5 kpc. Such a small value is not necessarily problematic for our purposes, however, as a lower disc scale length estimated from the local surface brightness would also imply a higher central surface brightness — the Robin *et al.* result, for example, leading to a $D_{25(\mathrm{true})}$ of around 22 kpc. As the main purpose of this paper is to test the hypothesis that the Milky Way is an overly large spiral galaxy, it would seem that the adoption of a smaller disc scale length would, if anything, reinforce our conclusions concerning this hypothesis.

It should be noted that the disc scale length is also highly dependent upon the photometric band with which it is observed. Infrared scale lengths, for example, have been found to be significantly smaller than the B-band scale length (e.g., ref. 33). De Vaucouleurs & Pence[34] use different methods and values for the parameters for their determination of the Milky Way disc scale length resulting in the lower value of 23 kpc. Karachentsev[20], on the other hand, quotes a larger diameter at this isophotal level of 30 kpc. It should also be noted that Karachentsev quotes isophotal diameters for other nearby galaxies (M31, M33, M81, and M101) approximately 12–20% smaller than those in Table I (leading to the conclusion in that paper that the galaxy is large for its Hubble type, albeit based on a sample of only 8 Local Group galaxies with $2 < T < 6$).

In order to test the validity of the above formula for the isophotal radius, we applied it to the two galaxies in the calibrating sample for which values of h and μ_0 were available to us: M31 and M100 (refs. 14, 31). The D_{25} diameter for M31 was found to be 43·2 kpc (5·5% below the RC3 value) and that for M100 was found to be 36·3 kpc (0·3% above the RC3 value). This gives us confidence that the assumption of an exponential disc is justified and reasonable.

There is some uncertainty as to the Hubble type of the Milky Way. Evidence appears to favour a classification of the Milky Way as an Sbc galaxy ($T = 4$); however, morphologies between Sab and Scd ($T = 2$ to 6) cannot be ruled out[14,31]. There has also been recent evidence indicating the presence of a triaxial bar-like structure in the central region of the Milky Way, with a major-axis scale length of the order of 1 kpc (refs. 35, 36). It seems unlikely that the existence of such a bar would significantly bias the determination of the disc scale length for the Milky Way quoted above, although we intend in future work to carry out a more detailed comparison of disc sizes in barred and unbarred galaxies.

Results

Fig. 1 shows a histogram of the distribution of spiral galaxy sizes for all of the 18 galaxies in our sample, with the positions of the Milky Way (MW), M31 and M33 indicated. The Milky Way lies almost exactly on the mean of the galaxy sizes (actually, just below the average as $\langle D_{25(\mathrm{true})} \rangle = 28 \cdot 3$ kpc).

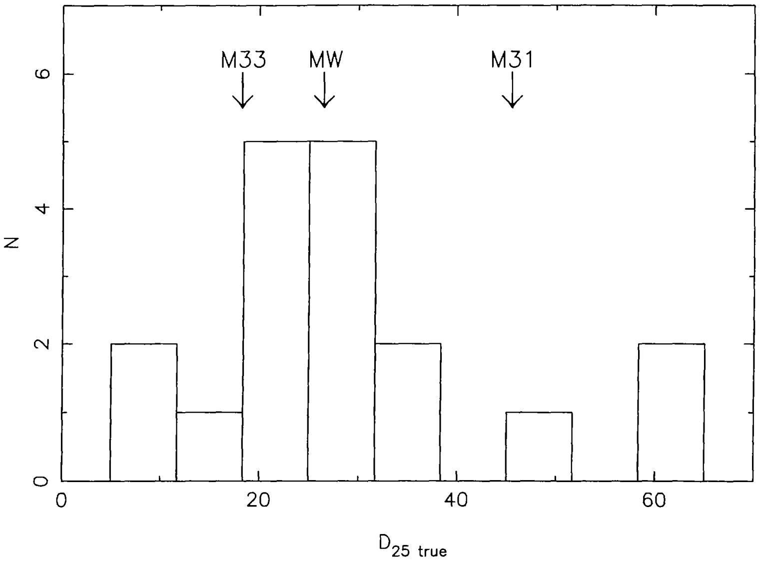

FIG. 1

A histogram of the true diameters of all 18 spiral galaxies in the sample. The diameters of the Milky Way (MW), M31, and M33 have been marked,

It is even more interesting to compare the Milky Way with galaxies of a similar Hubble type. Fig. 2 shows the histogram obtained for the 12 galaxies of Hubble types 2 through 6. In this case the Milky Way lies further below the average linear diameter of 33·6 kpc; one should not read too much into this, however, since the Milky Way still lies well within one standard deviation of the sample mean. A more quantitative statistical analysis would clearly require a larger calibrating sample and also a more realistic model for the distribution of linear diameters. For example, Sodre & Lahav[37] adopt an exponential-type model for the distribution of linear diameters, for which the median value might be regarded as a more useful descriptor of the 'typical' linear diameter. Notwithstanding this distinction, the sample median linear diameter of our calibrating sample with $2 < T < 6$ is in any case equal to 27·9 kpc, which is very close to the value derived for the Milky Way. In addition, if one considers the natural logarithm, l, of linear diameter — which one might more reasonably expect to be described by a distribution function which is approximately symmetric about the mean value — then one finds a weighted mean value of $< l > = 3 \cdot 36$, with standard error $\sigma = 0 \cdot 12$, for the 12 galaxies with $2 < T < 6$. Comparing this with $l = 3 \cdot 29$ for the Milky Way we again see that the Milky Way is by all accounts a typical spiral for galaxies of similar Hubble type.

These results are similar to those of Ingram & Hogan[19], who used the B-band Tully-Fisher relation of Pierce & Tully[38] to derive redshift-independent distance estimates — and hence linear diameters — for the sample of 20 nearby M31 'lookalike' galaxies collated by Sandage[39,40]. They found a mean linear diameter of 28·7 kpc — somewhat lower than the value found here for the sample restricted to $2 < T < 6$, but in any event very similar to the linear diameter of the Milky Way. Ingram & Hogan then used the correlation between linear diameters and rotation velocities derived from the sample of Tully[18] to *predict* a linear diameter of 38·3 kpc for M31 given its observed rotation velocity.

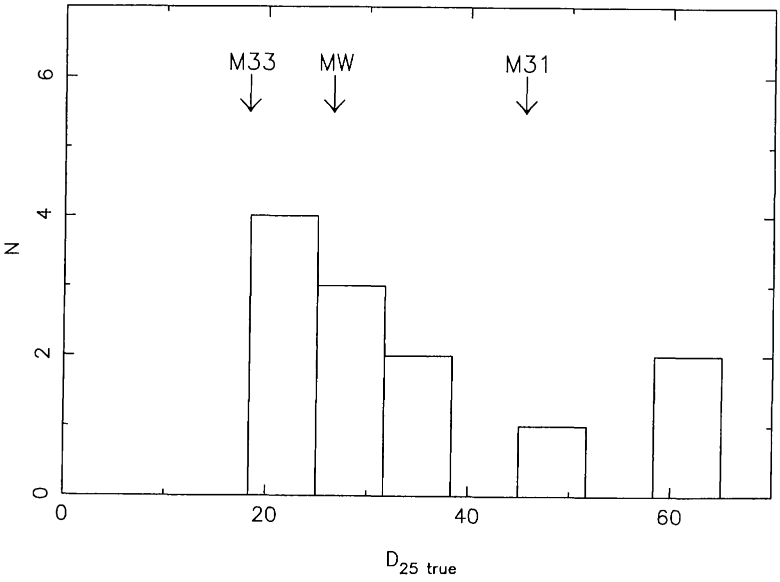

FIG. 2

A histogram of the true diameters 12 galaxies in the sample with Hubble types 2 to 6 (the range of possible Milky Way values). Again the diameters of the Milky Way (MW), M31, and M33 have been marked.

They concluded on this basis that the linear diameter of M31 does not reliably represent the mean diameter among galaxies of similar morphology, as assumed by Sandage[39,40]. Clearly this conclusion is readily supported here, since we derive a linear diameter of 45·7 kpc for M31 based on its Cepheid distance and the diameter uncorrected for inclination.

Finally, as mentioned above, we consider the impact on our results of applying inclination corrections to our galaxy diameters, assuming spiral discs to be optically thin. Using the RC2 corrected isophotal diameters for the calibrating galaxies with $2 < T < 6$ we obtain a mean linear diameter of $< D_{25(\mathrm{true})} > =$ 29·5 kpc, a median diameter of 25·3 kpc, and a mean log-linear diameter of $l = 3{\cdot}26$ with standard error 0·12. Thus, using the RC2 diameters we again conclude that the Milky Way is a very average spiral galaxy compared with the other calibrators of similar Hubble type.

Completeness and bias

Although the sample size considered here represents a great improvement over the reliable data available prior to the advent of the *HST* Key project, it is certainly not complete. One must still, therefore, consider the question of whether our sample adequately represents the full range of linear diameters of local galaxies with $2 < T < 6$, or whether it might — for example — be systematically biased in favour of larger galaxies.

An examination of the distribution of angular diameters in local redshift space taken from the RC3 catalogue ($cz \lesssim 1000$ km s^{-1}) shows 19 apparently very small galaxies ($D_{25(\mathrm{ang})} \lesssim 6$ arcmin) nearby ($cz \lesssim 800$ km s^{-1}), none of which are included in the sample in Table I. A closer examination of these galaxies, however, shows 13 to be associated with nearby galaxy clusters, suggesting that their small apparent size may be the result of them having significant peculiar velocities. In particular, eight of these galaxies are members of the Virgo cluster. If we assume them all to lie at the mean Virgo distance of 17·8 Mpc adopted in Freedman[7], this would imply that their linear diameters range from 12 kpc (NGC 4413) to 41 kpc (NGC 4216). Only IC 3483 and NGC 4995 seem overly small with diameters of only 4·2 kpc and 6·9 kpc at distances of 28·8 Mpc and 13·6 Mpc respectively from Tully-Fisher[41]. Notwithstanding the well-documented line-of-sight extent of the Virgo cluster, it seems unlikely that these galaxies are all foreground objects — and thus of smaller linear diameter; if anything, their small observed redshifts suggest that some or all may be background objects falling back into the core of the Virgo cluster.

Of the remaining six galaxies only one (NGC 4605) is noted in surveys of nearby galaxies (*e.g.*, ref. 42) and is there assigned a distance of 5·18 Mpc. This corresponds to a linear diameter of 8·7 kpc, which is comparable in size to the smallest two galaxies in our Table I.

The application of secondary distance indicators to derive estimates of the linear diameters of nearby galaxies has, in the vast majority of cases, generally yielded values in excess of 10 kpc (*e.g.*, ref. 19) — further suggesting that our sample does not under-represent small galaxies of the appropriate morphological type. (Note that many distances quoted in the literature for other 'nearby' galaxies assume a Hubble constant and local velocity field correction; we have not considered such galaxies here.)

From these considerations we therefore conclude that the sample given in Table I fairly represents the full range of diameters for local spirals of similar morphological type to the Milky Way. We are currently conducting a more detailed analysis of possible sources of bias in the sampled diameter distribution but it seems likely that any such bias is small.

Finally it is interesting to note that if we were to consider a strictly distance-limited sample of only Local Group galaxies we would find that only three galaxies — the Milky Way, M31 and M33 — are of the correct Hubble types, *i.e.*, $2 < T < 6$. The range and mean diameter of these three Local Group galaxies are, however, suprisingly similar to those of the larger, incomplete, sample.

Conclusion

There seems no doubt that the Milky Way is *not* one of the largest spiral galaxies. NGC 1365 and NGC 5457 (M101), in particular, are the local giants, more than twice as large as the Milky Way. This confirms Eddington's[43] prescient comment, made more than 60 years ago, that the "relation of the Milky Way to the other galaxies is a subject upon which more light will be thrown by further observational research, and that ultimately we shall find that there are many galaxies of a size equal to and surpassing our own". This further supports the principle of terrestrial mediocrity: that there is nothing special about where or when we live and observe from[44]. We seem to live on an ordinary planet orbiting an ordinary star, and it is natural to infer that the Solar System resides in an ordinary galaxy.

The implications of this conclusion for estimates of the Hubble constant are clear: specifically, if the Milky Way is an average spiral this may favour estimates of H_0 at the lower end of the range of accepted values. Surprisingly de Vaucouleurs & Pence[34] do not mention this when they conclude, like ourselves, that the Milky Way is very averagely sized. A detailed application of galaxy linear diameters to estimate the Hubble constant, using the calibrating sample of spiral galaxies described in this paper, is presented elsewhere[45].

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