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ASTRONOMY AND ASTROPHYSICS

Distance indicators based on the luminosity-profile shapes of early-type galaxies–a reply

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Abstract. In a recent paper, Binggeli & Jerjen (1998) question the value of the extragalactic distance indicators presented by Young & Currie (1994 & 1995) and state that they have refuted 'the claim that the Virgo dEs [dwarf-elliptical galaxies]...are distributed in a prolate structure stretching from 8 to 20 Mpc distance (Young & Currie 1995).' even though no such claim was ever made.

In this paper, we examine Binggeli & Jerjen's claims that intrinsic scatter rather than spatial depth must be the main cause of the large scatters observed in the relevant scaling relationships for Virgo galaxies. We investigate the accuracy of Binggeli & Jerjen's photometric parameters and find that while their profile curvature and scalelength measurements are probably useful, their total magnitude and central surface-brightness measurements are not useful for the purpose of investigating scaling laws because they suffer from serious systematic and random errors. We also investigate Binggeli & Jerjen's criticisms of our (1995) analysis. We demonstrate that their test for strong mutual dependence between distance estimates based on the two different scaling laws is invalid because of its prior assumption of negligible cluster depth. We further demonstrate that the [relative] distance estimates on which their kinematical arguments are based cannot be meaningful, not only because of the seriousness of the photometric errors, but also because they are undermined by the prior assumption that depth effects can again be neglected.

Interestingly, we also find that Binggeli & Jerjen's own dataset does itself contain evidence for large depth. Using the observed correlation between scale-length and profile-curvature, (the only correlation that can be investigated meaningfully using their dataset), we find that the frequency distribution of residuals with respect to the best fitting curve deviates significantly from that expected from a uni-modal Gaussian distribution. Clearly, if as Binggeli & Jerjen claim, the very large scatter observed in this scaling relationship for Virgo galaxies (which is not observed for Fornax or Local Group ones) were intrinsic, one would expect a uni-modal Gaussian distribution.

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1. Introduction

Binggeli & Jerjen (1998) conclude that the shape of a dwarf-elliptical galaxy's surface-brightness profile (as quantified by the curvature parameter n from Sérsic's (1968) r^n law) is not a useful distance indicator. Their conclusion is based on their finding that the scatter on the relevant correlations 'can be reduced...never below $\sigma_{rms} \approx 0.7$ mag., at least for the Virgo cluster.'

Should the intrinsic scatter on the relevant correlations be as large as 0.7 mag., the profile-shape indicator would indeed be of only limited value, and there would be strong grounds for believing that Virgo dwarf ellipticals define a single cluster of galaxies of small depth. Should however, the intrinsic scatter be about 0.5 mag. or lower, profile shape would be a valuable indicator of distance and there would be strong grounds for believing that the Virgo Cluster's depth is significant. Note however, that the latter interpretation does not require the existence of a 'prolate structure' as presumed by Binggeli & Jerjen. There are of course alternative models, notably the substructure model we favoured in Young & Currie (1995) (hereunder YC95). The central issue in this debate is therefore whether Binggeli & Jerjen have demonstrated that the intrinsic scatter in the scaling relationships is, as they claim, of the order of 0.7+ mag., or whether or not they have at least put forward strong circumstantial evidence in support of their case.

2. Limits on the generality of the indicators

As Binggeli & Jerjen have mis-interpreted certain aspects of the luminosity-n (L-n) and scalelength-n (R-n) distance indicators of Young & Currie (1994) (hereunder YC94) and YC95, it would probably be pertinent to re-emphasize the scope of the indicators and how they are related to one another.

The indicators can be interpreted as follows. Dwarf and intermediate elliptical galaxies of the same n are approximately the same physical size [i.e. they have similar $R(n)$]. Only therefore, when such galaxies have very similar stellar populations can they be expected to have similar central and mean surface brightnesses, whence similar luminosities[1]. It follows that galaxies of different colours can be expected to have different stellar populations and therefore cannot be compared directly using the L-n method. The converse is not always true however, as objects of the same overall colour may have different stellar populations. The L-n relationship appears to be most useful for those dwarf ellipticals with colours of $(B-V) \approx 0.7$, because other dwarfs are generally bluer (i.e. $(B-V) \lesssim 0.7$) regardless of whether they are higher or lower surface-brightness objects (YC95).

Another important caveat is that if the stellar populations within a galaxy are not well mixed, the surface-brightness profile shape may deviate significantly from that which one might expect on the basis of its size. The n based distance indicators should therefore, ideally, not be applied to galaxies with internal colour gradients. Although the absence of any colour gradient within a galaxy does strictly not imply that its stars are well mixed, in such cases it is probably safe to assume that they are. This is because a conspiracy of many different factors would be required in order to balance the colour gradients that would otherwise inevitably arise from segregated stellar populations. With the above in mind, the Local Group early-type dwarf, NGC 205, should not be used as an absolute-distance calibrator for n-based scaling laws if those target galaxies possessing colour gradients can be screened out. However, it can be used as a calibrator if, as in YC94 and YC95, colour-gradient information is not available for target galaxies.

Since the distance indicators were first presented, Graham et al. (1996) and Gerbal et al. (1997) have found that the correlations on which they are based probably apply not only to dwarf and intermediate ellipticals, but also to classical ones, including the brightest cluster ellipticals. Also, Binggeli & Jerjen have also shown that the correlations probably apply to dwarf lenticulars as well, while de Jong (1996) has demonstrated that even the bulges of spiral galaxies appear to exhibit a continuous range of n values.

It should be remembered however, that colour gradients are more common and often much larger in classical ellipticals and lenticulars than in dwarfs. When dealing with samples of classical early-type galaxies, it is therefore even more important to screen them for objects with colour gradients as such objects cannot be expected to conform to the R-n relationship [or the L-n relationship].

[1] A very deep sample of galaxies should therefore not exhibit a tight correlation between central surface-brightness (μ_0) and n. It could, however, exhibit a bright-end cut off defined by those objects with particularly luminous stellar populations.

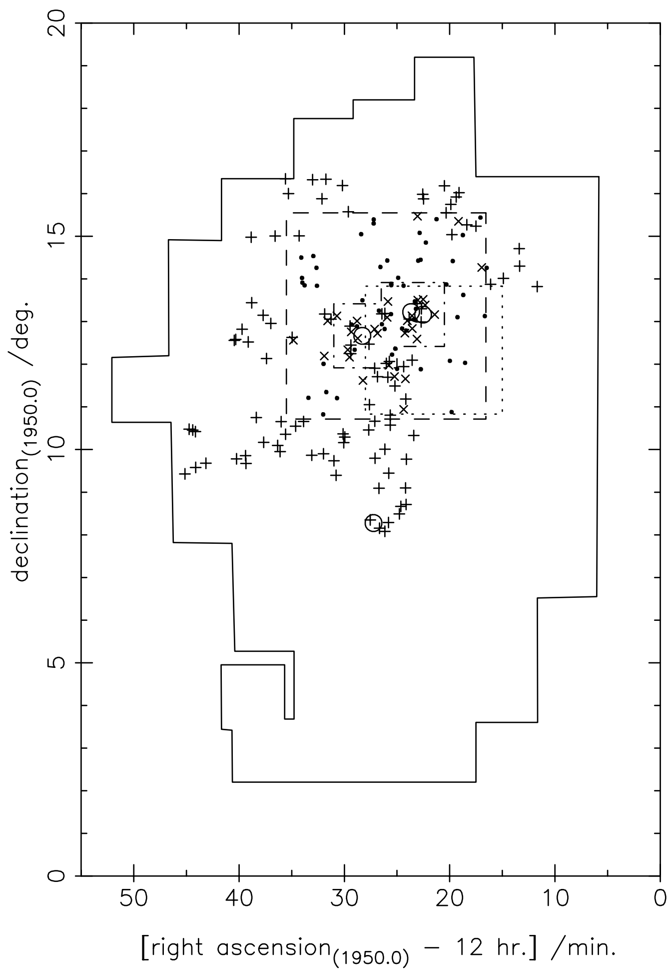

Fig. 1. The distribution of Binggeli & Jerjen's 128 dwarf galaxies on the sky: '×' symbols if also YC95 objects or '+' symbols if not YC95 objects. YC95 objects not in Binggeli & Jerjen's sample are plotted as '.' symbols and the four giant early-type galaxies: M49, M84, M86 and M87, are plotted as '○' symbols for reference. The largest polygon (solid line) represents Binggeli et al.'s (1985) *Virgo Cluster Catalog* survey area while the largest square (dashed line) represents our (1998) *Virgo Photometry Catalogue* survey area. The areas covered by Börngen (1980 & 1984) and Ichikawa et al. (1986) are outlined with dotted and dashed-dotted lines respectively.

3. How useful is Binggeli and Jerjen's dataset?

Binggeli & Jerjen presented Sérsic profile parameters for 128 dwarf elliptical and dwarf lenticular galaxies, which they derived from the surface photometry of Binggeli & Cameron (1991 & 1993). The distribution of their objects on the sky is shown in Fig. 1, from which it is evident that only to the south-west of the cluster core direction (defined collectively by M84, M86 and M87) is there detailed coverage.

Turning now to Binggeli & Jerjen's total magnitudes, we were surprised to discover that the B_T values they quoted were in fact those of Binggeli & Cameron rather than the systemic magnitudes (obtained by integrating Sérsic's law to $r = \infty$) that we would have expected. Binggeli & Cameron's photometric zero points were based on the total-magnitude scales

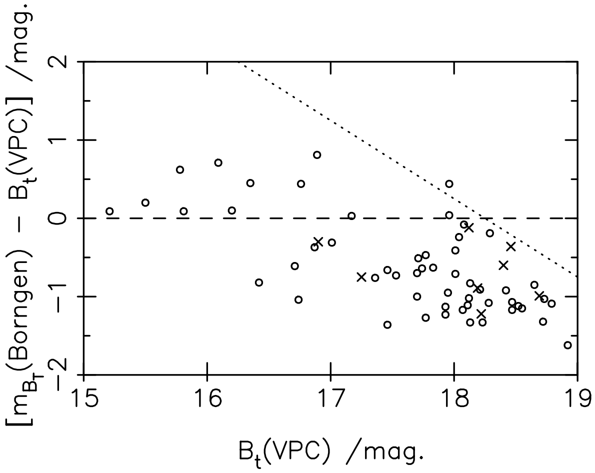

Fig. 2. A comparison between the B-band magnitude scales of Börngen (1984) and the VPC, based on the 62 galaxies in common between the two samples. Binggeli & Cameron used 13 of Börngen's objects as standards for calibrating their Plates 18 and 26. Eight of these calibrators are also VPC objects, and are depicted as '×' symbols, while the remaining 54 VPC objects are shown for reference as '∘' symbols. Note that the large scale discrepancy must extend to the faint end despite the faint-end limit to the galaxy sample of $m_{B_T} \sim 18.25$ mag. (dotted line). This is because the data points at $17.5 < B_t(\mathrm{VPC}) < 18.5$ are concentrated well below the dotted line (by ~ 1.0 mag.).

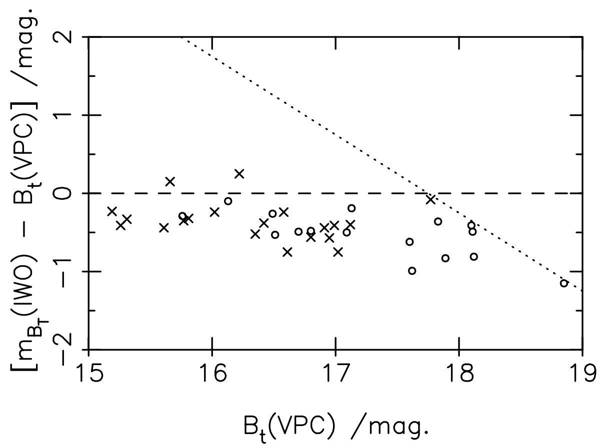

Fig. 3. A comparison between the magnitude scales of Ichikawa et al. (1986) (IWO) and the VPC, based on the 36 early-type galaxies in common between the two samples. Binggeli & Cameron's sample of dwarf galaxies had 33 objects in common with Ichikawa et al.'s sample, and the mean zero-point discrepancy based on their objects in common was only 0.04 mag. (Binggeli & Cameron's magnitudes being brighter). The zero points for their Plates 17, 18 and possibly 26 too, were therefore probably heavily influenced by Ichikawa et al.'s magnitude scale. VPC objects in common with Ichikawa et al.'s sample are depicted as '×' symbols when also common to Binggeli & Cameron's sample, or otherwise as '∘' symbols. Note that there is not necessarily a large scale discrepancy at the faint end because Ichikawa's et al.'s galaxy sample is strongly biased against galaxies fainter than m_{B_T} ~17.75 mag. (dotted line).

of de Vaucouleurs & Pence (1979); Börngen (1980 & 1984[2]) and the *Virgo Cluster Catalog*, hereunder VCC, of Binggeli et al. (1985). Ichikawa et al.'s (1986) total-magnitude scale was probably also used for the calibration of two or three plates, but Binggeli & Cameron were ambiguous on this point.

Although, Binggeli & Cameron were quite modest about the limitations of their photometry, Binggeli & Jerjen allowed for a photometric error of only 0.2 mag. in their correlation analyses. There are several reasons why the real photometric errors must be very much larger than this. These reasons are outlined below.

From comparisons with our independently calibrated *Virgo Photometry Catalogue* (Young & Currie, 1998)[3], hereunder VPC, it is clear that Binggeli & Cameron's adopted magnitude-scale standards do not define a single mutually consistent magnitude scale. This point is evident from Figs. 2, 3 and 4, in which serious scale discrepancies between the different sources are also noticeable[4].

We are confident that our VPC magnitude scales are not to blame for these scale discrepancies, as amongst other reasons,

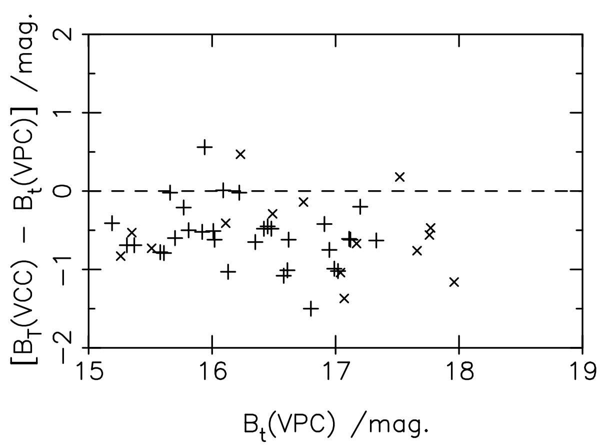

Fig. 4. A comparison between the magnitude scales of the VCC and the VPC, based on the 48 galaxies also common to Binggeli & Cameron's sample of dwarfs. Galaxies are depicted as × symbols unless they are also common to Binggeli & Jerjen's sample, in which case they are depicted as '+' symbols. VCC magnitude values were used by Binggeli & Cameron as standards for the determination of their photometric zero-points. The mean offset is 0.61 mag. (VCC values being brighter than VPC ones) while the scatter is 0.52 mag.

our photometry was calibrated with many hundreds of photoelectric aperture-photometry as well as simulated aperture-photometry measurements derived from CCD images. Furthermore, the agreement between VPC magnitude measurements and those of Durrell (1997), which were based on deep CCD

2 Binggeli & Cameron cited this work as Börngen (1983).

3 This catalogue presents, amongst other data for over 1000 galaxies in the direction of the Virgo Cluster, t-system total magnitudes in the B_J and B bands, as well as $U - B_J$ and $B_J - R_C$ colours. The t system is described in detail by Young et al. (1998), and its application to the VPC is described by Young & Currie (1998).

4 Unfortunately there are no objects in common between the VPC and those 7 standard objects listed in Table 1 of Binggeli & Cameron for which de Vaucouleurs & Pence's total magnitude values were quoted. This has prevented us from presenting an additional figure here to enable comparisons with these extra standards.

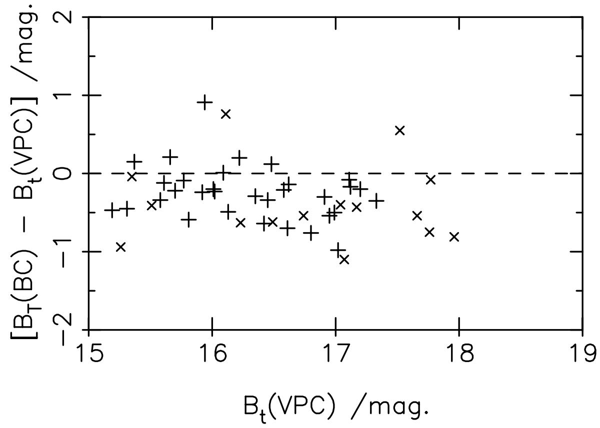

Fig. 5. A comparison between the magnitude scales of Binggeli & Cameron and the VPC, based on the same 48 galaxies shown in Fig. 4 and using the same symbols. The mean offset is 0.34 mag. (BC values being brighter than VPC ones) while the scatter is 0.49 mag.

photometry of relatively faint Virgo dwarfs, is better than 0.04 mag. We are also confident that the zero point of the VPC's B-band total magnitude (B_t) scale is accurate to several percent (note that it is independent of the general transformation we adopted to calibrate our B_J plates with B and V-band photoelectric photometry measurements). For detailed comparisons with existing photoelectric photometry for VPC galaxies, see Sect. 8 of Young & Currie (1998).

Another [albeit related] reason why Binggeli & Jerjen must have severely under-estimated their photometric errors is that Binggeli & Cameron did not calibrate their photometry directly. Instead, they first calibrated their extrapolated total-magnitude scale with existing total-magnitude scales. The other Sérsic profile parameters derived by Binggeli & Jerjen were presumably derived on the basis of these magnitude-scale calibrations. The obvious weakness in this approach is that even if the different sources of standard objects had been accurately calibrated, there would be systematic differences between them on account of the different extrapolation (or in the cases of Börngen's and the VCC datasets, visual total-magnitude estimation) procedures.

A further problem is likely to be the scarcity of calibrators in certain fields. Binggeli & Cameron's Plate 1 was for example only calibrated with one galaxy.

If one compares Figs. 5 with Figs. 2, 3 and 4, it is clear that Binggeli & Cameron's magnitude-scale does not, as a whole, bear much resemblance to any of the scales invoked for calibration purposes. Binggeli & Jerjen must therefore have severely under-estimated the errors in both their total magnitude values and their central surface brightness, μ_0, measurements.

Young (1994 & 1997) has already presented some preliminary findings on the sizes of and origins of systematic errors in the faint ends of existing magnitude scales for Virgo galaxies. A much more detailed paper on this subject, covering the whole magnitude scale and dealing with the ramifications of the zero-point and scale errors uncovered, will be presented by Young et al. (in preparation).

In spite of the calibration problems described above, the Sérsic scalelength, r_0, and the shape parameter, n, should be independent of zero point, so we would expect Binggeli & Jerjen's measurements of these quantities to be useful. Binggeli & Jerjen noted 'quite good' agreement with Durrell's n values, with a rms (1σ) scatter of 0.10. Note that one should not be alarmed by the much larger scatter between these authors' $\log r_0$ values, because this quantity is a strong function of n, assuming that the R-n correlation is genuine (which even Binggeli & Jerjen don't question–though they believe that it has a large intrinsic scatter).

In summary then, Binggeli & Jerjen's galaxy sample is not a complete sample of galaxies down to a well-defined total magnitude limit. Also, its coverage of the Virgo Cluster direction is very patchy. However, it does contain a large number of dwarf galaxies and is therefore useful on the basis of its size. Unfortunately the photometric zero points adopted for different plates are not mutually consistent, thereby rendering the B_T and μ_0 values of little use. However, this should not affect the n or r_0 values, which are probably more useful than the YC95 values because they are based on higher-resolution photometry.

4. Binggeli and Jerjen's correlation analyses

Binggeli & Jerjen investigated the following four correlations: B_T versus $\log(n)$, B_T versus $0.712\mu_0 - 3.385\log(n)$, B_T versus μ_0, and $\log(r_0)$ versus $\log(n)$; for Virgo galaxies. They observed rms scatters in these correlations of 0.92, 0.73, 0.76 and 0.85 mag. respectively, and asserted that: 'A scatter of 0.7 mag. is what one can already get from the relation between the mean effective surface brightness $< \mu >_{\rm eff}$ and total magnitude'.

As is evident from Fig. 5 there is a significant and not necessarily linear scale error in their magnitude scale for galaxies that lie within the VPC survey area (corresponding to their Plates 17, 18 and 26 but with two objects on their Plate 4). The sense of this error is such that the luminosities of their fainter galaxies were over-estimated with respect to their brighter objects. In the case of the outlying fields their scale errors are almost certainly even larger as the only calibrators used were VCC galaxies with total-magnitude values taken from either the VCC or de Vaucouleurs & Pence (1979). As mentioned in Sect. 3, there are very large systematic errors in both of these sources of magnitudes. In fact the preliminary work of Young (1994 & 1997) finds that these sources over-estimate luminosities by about 0.7 mag. at the faint end.

As already demonstrated in Sect. 3, Binggeli & Jerjen's photometry was based on differentially zero-pointed plates (i.e. objects on each of the 13 different plates received different absolute calibrations). Furthermore, their B_T values were not systemic ones (i.e. obtained by integrating Sérsic's function through 360° to $r = \infty$), but those of Binggeli & Cameron (1993), which were obtained using a different extrapolation procedure and including the nuclear light contribution when present. The effects of both of these limitations in their reduction procedures would be to increase the observed scatters in the B_T versus $\log(n)$, the B_T versus $0.712\mu_0 - 3.385\log(n)$ and the B_T versus μ_0

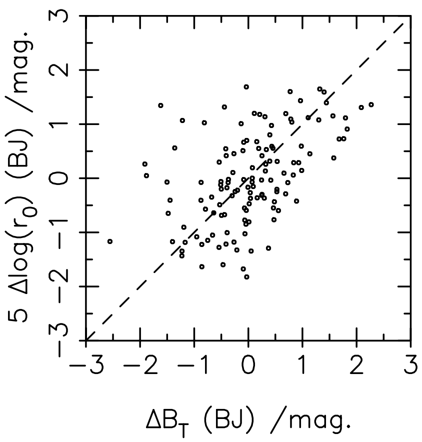

Fig. 6. Binggeli & Jerjen cited the *strength* of this correlation they found using their own dataset as evidence that the analysis of YC95 was flawed. Their reasoning was that this correlation must be the product of dependence between distance estimates derived by different methods, rather than due to genuine depth in the spatial distribution of Virgo galaxies.

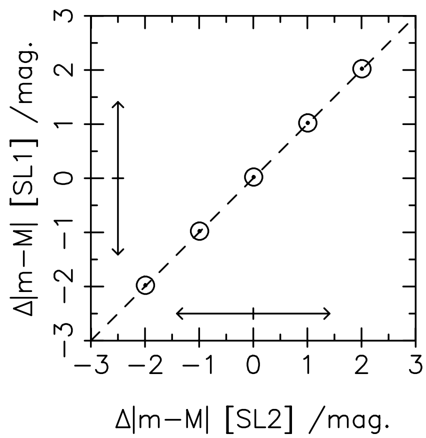

Fig. 7. This plot is analogous to Fig. 6, but invokes hypothetical galaxy data (⊙ symbols) and two hypothetical distance indicators that are based on mutually independent scaling laws, denoted SL1 and SL2. Both indicators are capable of yielding precise distance measurements. For each indicator, the lengths of the arrows represent the value of the rms scatter in the distance residuals with respect to the mean distance obtained for the galaxy sample. According to Binggeli & Jerjen, the rms scatters with respect to the equality line should both be 2 mag. when in fact they are zero!

correlations. Of these three correlations, the first would be affected the most. This is because the μ_0 term in the other two correlations can to a certain extent compensate for the errors in the B_T values adopted (even if neither the measured μ_0 nor the measured B_T bear much resemblance to the actual values). Also, the B_T versus $\log(n)$ correlation is the one most susceptible to increased scatter when, as by Binggeli & Jerjen, applied indiscriminately to objects of different stellar populations in the absence of galaxy-colour information.

We therefore find that Binggeli & Jerjen's dataset is useful only for investigating the $\log(r_0)$ versus $\log(n)$ correlation, assuming of course that Binggeli & Cameron's (1993) background subtraction procedures were adequate. We are therefore confronted with an observed scatter of 0.85 mag. in a scaling relationship based on a sample of 128 Virgo galaxies. Clearly, even if the measurement errors in the parameters r_0 and n introduced a random component as high as 0.30 mag., we are still left with a scatter of 0.80 mag. to explain. Binggeli & Jerjen attribute this remaining component mainly to intrinsic scatter, while we would attribute a large part of it to spatial depth.

5. Dependence of L-n and R-n distances

Binggeli & Jerjen make a big issue of the mutual dependence between the residuals in magnitude space with respect to their B_T versus n correlation and the residuals in angular-distance space with respect to their r_0 versus n correlation. They plot these residuals in their Fig. 9. While they are correct in pointing out that there must be some dependence between the two sets of residuals, whether this dependence is significant enough to affect our previous findings is another matter.

We have re-plotted their Fig. 9 here as Fig. 6, this time using equal axis scales. They claim that in the absence of any dependence between the residuals, Fig. 6 should be devoid of any correlation. However, their test for dependence is fatally flawed because it is based on the prior assumption of negligible depth–as illustrated by the following example.

Imagine that we have five galaxies, which collectively constitute a complete sample of galaxies devoid of any Malmquist bias. The nearest galaxy is at $(m - M) = 28$ while the farthest is at $(m-M) = 32$, and the spatial separation between each object is $\Delta(m-M) = 1$. The mean distance modulus of these five galaxies [in log(distance) space] is therefore $(m - M) = 30$. Now, let us imagine that we have two perfect distance indicators based on two completely independent scaling laws which we shall denote SL1 and SL2. Both indicators can measure the distances of these objects precisely because both methods are perfect. If we were now to construct a diagram analogous to Fig. 6, we would end up with a plot like Fig. 7. The rms scatter in the residuals with respect to SL1 would be identical to that with respect to SL2, and both of these quantities would be equal to $\sqrt{2}$ mag. Now, according the Binggeli & Jerjen, for two such 'independent but equivalent' measurements, we would expect the scatter with respect to the equality line on Fig. 7 to be 2 mag. However, because the distance indicators are perfect, the actual scatter with respect to the equality line is *zero* [regardless of which axis it is measured parallel to]. The reason for this is that while the two different measurements for an individual galaxy are 'equivalent'; the measurements for different objects are not, simply because each object is at a different distance.

In spite of the above, we accept that in Sect. 4 of YC95, we did indeed under-estimate our formal internal distance errors, because there must be some [non-distance related] dependence between the distance estimates based on the different scaling laws. However, even if our formal internal errors [including both intrinsic scatter and photometric errors] were as high as, say, 0.6 mag. [cf. 0.47 mag. as quoted in YC95], that would still leave room for a cluster depth of 0.54 mag., as the observed scatter per relationship in YC95 was 0.81 mag. Note that a cluster with a depth of 0.54 mag. would be half as deep as it is distant, with a further one-third of its objects lying even further out from its centroid.

We should also like to emphasize that our 'independent information on the intrinsic scatter' was not 'seized...by applying both the n-M and n-$\log r$ relation at the same time'. The independent information was in fact, the much smaller scatter found in our samples of Fornax and Local Group galaxies. As long as our Fornax and Local-Group samples are representative and as long as they contain galaxies structurally similar to their counterparts in Virgo, the depth interpretation still holds.

6. Virgo and Fornax dwarfs: a dichotomy?

Binggeli & Jerjen state that: 'If the intrinsic dispersion of the n-M or the n-logr_0 relation is much smaller for Fornax dwarfs than for Virgo dwarfs as it appears (which, however, might be caused by the incompleteness of YC's Fornax sample) we are in need of an explanation for this difference'.

In response to their criticisms that we excluded three suspected non-cluster members when investigating the scatter in our R-n relationship, we have re-measured the scatter in our R-n correlation without excluding any outlier. For a polynomial of the form $R = an^{-3} + bn^{-2} + cn^{-1} + d$, which has the advantage over Eq. 1 in YC95 of being monotonic, the scatter in R based on all 26 of the objects listed in Table 2 of YC95 is [in terms of magnitudes]: 0.55 mag. Allowing for a conventional Fornax-Cluster depth of 0.15 mag., but not making any allowance for possible foreground or background objects, places an upper limit on the intrinsic scatter of 0.53 mag. This is very much lower than the scatter found in the same relationship for Virgo galaxies (see Sect. 4). If, as Binggeli & Jerjen maintain, the much larger scatter observed for Virgo galaxies were intrinsic, we would therefore indeed be in need of an explanation as to why these Fornax dwarf galaxies differ so radically from their counterparts in Virgo.

As Binggeli & Jerjen concede, King (1966) profiles do not fit Virgo dwarf-elliptical galaxy profiles well. This suggests that tidal truncation is not a significant contributor to the luminosity profile shapes at the radii of interest. We therefore consider it unlikely that tidal effects could offer the explanation. Furthermore, on the basis of the colour information presented by Caldwell & Bothun (1987) and YC95, it is clear that most of the brighter Fornax and Virgo dwarf ellipticals have very similar colours, suggesting that they may well have very similar stellar populations and histories. We therefore remain to be convinced of Binggeli & Jerjen's suggestion that there is probably a dichotomy between Virgo and Fornax dwarfs.

7. Effective surface brightness versus magnitude

This relationship was cited by Binggeli & Jerjen as being of comparable value to the profile-shape parameter, n, as a distance indicator. We do not deny that it is a reasonably useful

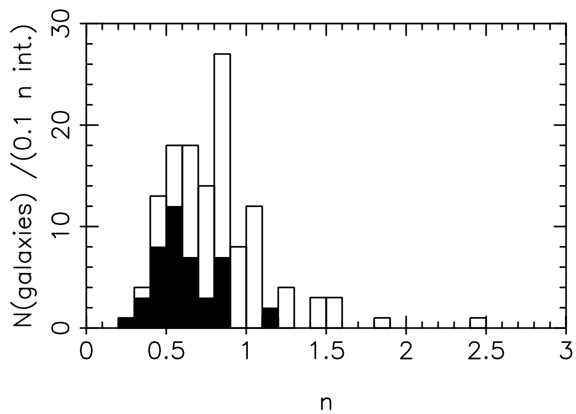

Fig. 8. A histogram of the number of galaxies in Binggeli & Jerjen's sample of 128 dwarfs per unit profile curvature, n, interval. The shaded regions represent that subsample of 43 objects with published radial velocities.

relationship. In fact, it is related to the L-n and R-n relationships, and probably a direct consequence of them. However, it can be expected to be significantly harder than the L-n and R-n relationships to measure accurately, because it invokes the effective surface-brightness parameter, which is a tertiary parameter (unlike n and r_0 which are primary parameters and total magnitude which is a secondary one).

In order to measure effective surface brightness accurately, a model profile must first be fitted, then the profile must be extrapolated to obtain a total-light estimate and then the profile model must be integrated to the half-light radius. Clearly, an extra stage is involved. We therefore cannot accept Binggeli & Jerjen's assertion that no profile modeling is required in the measurement of either total magnitude or effective surface brightness. Young (1997) and Young et al. (1998) have already demonstrated that for dwarf galaxies in particular, total magnitude values (and therefore effective parameters too) are critically dependent on the profile model adopted.

8. Cosmic expansion and cluster kinematics

Binggeli & Jerjen expected to find a 'well-defined velocity-distance relation' based on their 'fairly large' subsample of 43 objects with known velocities, if there were significant depth in the spatial distribution of Virgo dwarfs. They cited the lack of such a relationship based on their L-n and L-μ_0 'pseudo-distance' estimates, as evidence against the depth interpretation.

The most fundamental problem with their argument is that in order to generate relative distances based on each of two different scaling relationships, they have already assumed negligible depth when they estimate these relationships directly from the residuals with respect to the best-fitting curves to their data. The crucial point here is that should there be significant depth, the mean distance of their high-n objects must be lower than the mean distance of their low-n objects, due to Malmquist bias. The relative distance scales they construct for each relationship should therefore not be based on a best fit to data for Virgo galaxies, but on a curve defined by a best fit to data from either a sample of objects known to be at similar distances (e.g. Fornax-Cluster galaxies) and/or a sample of objects whose distances are known (e.g. Local-Group galaxies). In Fig. 8 the differential frequency of galaxies should increase monotonically with increasing n if their galaxy sample were unbiased. As this is not what is observed, we can conclude that their galaxy sample suffers from bias against high n objects. Should there be depth in the spatial distribution of their sample galaxies, the mean distance of their lower n objects must be greater than the mean distance of their higher n objects. Their residuals can, at best, therefore only yield meaningful relative distances for galaxies within very small ranges in n for which the degree of the Malmquist bias can be assumed to be constant.

Furthermore, as already demonstrated in Sect. 3, the 'pseudo-distances' derived by Binggeli & Jerjen for their Figs. 10 and 11, must indeed be highly inaccurate on account of the errors in their photometry. Also, they apply the B_T versus n and B_T versus μ_0 relationships to all early-type dwarfs indiscriminately, in the absence of e.g. colour information.

The existence of so many outliers (two of which are objects with negative radial velocities) on Binggeli & Jerjen's Figs. 10 & 11 is therefore not surprising. However, as previously suggested in YC95, there may well be significant line-of-sight substructure in the spatial distribution of Virgo galaxies, complicating the kinematics of the galaxy populations present. Significant spatial depth therefore need not necessarily imply the 'quiet' velocity-distance relationship presumed by Binggeli & Jerjen.

We have been interested in the kinematics of the dwarf-galaxy populations in Virgo for a number of years now, and a major programme to measure large numbers of redshifts for early-type dwarf-candidates is already well underway. The Virgo galaxies targeted by Drinkwater et al. (1996) with the multi-fibre spectrograph on the United Kingdom Schmidt Telescope (UKST), were, on account of the observing constraints at the time, generally of high surface brightness. Consequently, most of them were found to be in the background. However, 8 objects were confirmed to be dwarf or intermediate early-type galaxies. In 1997, early-type objects of low surface-brightness were targeted by Drinkwater et al. (in preparation), again using the UKST, and 67 velocity measurements were obtained. Further measurements made in 1997 with a different telescope and and future ones (from two separate telescope-time allocations in 1998) will be presented in subsequent papers. A detailed investigation into the Virgo-dwarf velocity field will then be based on these new data.

9. Intrinsic scatter or spatial depth effects?

Even without any new datum, we still have one potentially decisive test that might be able to help us decide whether the large scatter observed in Binggeli & Jerjen's $\log(r_0)$–$log(n)$ relationship is due primarily to intrinsic scatter or depth effects. This test involves looking for departures from uni-modality and/or normality in the differential frequency distribution of scale-length residuals with respect to the best-fit curve for the data (not in this case a curve defined by galaxies from an external galaxy sample). Should the distribution not be consistent with a uni-modal Gaussian [measured in log(distance) space to be rigorous], we can say that the scatter is not consistent with the intrinsic scatter origin hypothesis.

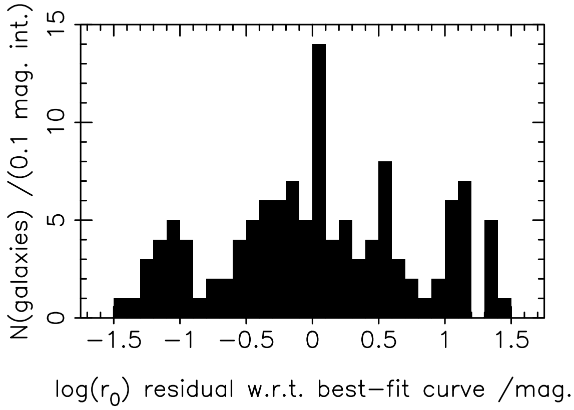

Fig. 9. The frequency of scale-length residuals with respect to Binggeli & Jerjen's best fit curve to their data as a function of the residuals in magnitude space. Note that the abscissa scale cannot be interpreted as a [negative] relative distance scale because no correction has been made for the differential Malmquist bias effects discussed in Sect. 8.

In Fig. 9, we find some evidence for a tri or quad-modal distribution. Such a distribution could arise if early-type dwarfs exist in three or four discrete size ranges within the same cluster. However, not only does this seem most unlikely, but it would also be very hard to reconcile such a scenario with the theoretical work on the subject (Hjorth & Masden 1995, Gerbal et al. 1997, Prugniel & Simien 1997 & Ciotti & Lanzoni 1997). It is perhaps more likely that any multi-modality present is due to line-of-sight substructure in the galaxy sample's spatial distribution, albeit smoothed considerably due to the relative distance scales being different for different ranges in n.

We have performed several non-parametric statistical tests as described by Lucey et al. (1986) and references therein. Comparing the Fig. 9 data against 100,000 Monte-Carlo realisations drawn from a Gaussian distribution having the standard deviation of the residuals, yielded probabilities that the Fig. 9 distribution could arise by chance. For the Kolmogorov-Smirnov (Lillefors) test and Geary's a-test (mean absolute deviation/standard deviation), the probabilities were 0.255 and 0.222 respectively; which were suggestive but not by any means conclusive. However, for the skewness and kurtosis tests and the u-test (data range/standard deviation) the probabilities were 0.041, 0.011 and 0.005 respectively. We take these results as significant evidence against Binggeli & Jerjen's intrinsic scatter interpretation.

10. Conclusions

The findings presented in YC95 were based on the assumption that the relatively small scatters observed in two scaling relationships found for Fornax and Local Group dwarfs, are also applicable to Virgo dwarfs. Although, we still consider this assumption to be a most reasonable one, we concede that we should have stated it explicitly in YC95. Unlike Binggeli

& Jerjen, we (YC95 & this work) did not make any prior assumption as to the actual depth of Virgo when making our case. Also, contrary to the impression given by Binggeli & Jerjen, our case is not undermined by any dependence between the scaling laws–which merely means that we slightly under-estimated our internal errors in YC95. In this paper, we have also presented further statistical evidence to support our case based on Binggeli & Jerjen's own dataset.

Binggeli & Jerjen claim to have presented evidence both that (1) profile shape is not a useful distance indicator because scaling laws based on it have large intrinsic scatters and that (2) the spatial depth of the Virgo Cluster must be small. However, all that they have in fact achieved in their paper, is merely to point out that if one first assumes that the depth of the cluster is small enough, then there must be large intrinsic scatters in the scaling laws in question for Virgo galaxies. In order to explain away the smaller intrinsic scatters found in Fornax and Local Group samples of galaxies, they suggest [in the absence of any supporting evidence] that either there is a dichotomy between Virgo and non-Virgo dwarfs or that our samples of non-Virgo dwarfs are not representative. They therefore cannot legitimately claim to have presented evidence for both (1) and (2) simultaneously; or to have presented evidence for (1) or (2) without first assuming (2) or (1) respectively.

The Virgo Cluster is not a suitable target for investigating the reliability of the curvature-based indicators. Reliable photometry of galaxies in other clusters and groups, where there is no controversy concerning line-of-sight depth, are required for this purpose.

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