THE DISTANCE SCALE BEYOND THE LOCAL GROUP - A PROGRESS REPORT ON WORK IN THE SOUTHERN HEMISPHERE

Malcolm G. Smith

Cerro Tololo Interamerican Observatory
and
Royal Observatory, Edinburgh

Afin d'éviter la répétition du contenu de nombreuses revues récentes, cette contribution rapporte principalement les projets d'étude au-delà du groupe local, en cours de réalisation dans l'hémisphère Sud.

La majeure partie de ce travail n'ayant commencée que récemment, les résultats sont préliminaires. Divers sujets sont traités : le groupe du Sculpteur (§ II), des groupes proches de l'hémisphère Sud et des galaxies de champ (§ III), ainsi que les distances des amas denses les plus proches de l'hémisphère Sud. D'autres travaux seront cités dans certaines revues de la conférence: (i) les études sur les nuages de Magellan, et d'autres objets du groupe local, (ii) les problèmes d'anisotropie de l'expansion de Hubble, (iii) les estimations des distances des objets quasi stellaires.

"You say H_o is small. I say H_o is large. Gerard says there is no universal H_o at all."

(Christmas card from van den Bergh to Sandage ; the best concise review of the subject that I know.)

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

I. Introduction

The persistent discrepancy between recent estimates of the Hubble expansion parameter (ranging from about 50km s^{-1} Mpc^{-1} to about twice that value) illustrates our poor understanding of possible systematic errors in the application of distance indicators particularly in the critical range of distances beyond the Local Group but closer than the nearer dense clusters of galaxies. Combined with the chequered history of revision to over-optimistic estimates of H_o, the present discrepancy suggests that it is dangerous to pin one's faith in one or two so-called "precision" indicators. While making every effort to improve our understanding and calibration of individual indicators it seems wise to follow the philosophy outlined by van den Bergh (1975a):

"All determinations of the extragalactic distance scale are ultimately based on the assumption that recognisable types of distant objects are similar to nearby objects of the same type. Due to possible differences in age, evolutionary history and abundance of the elements, this assumption may not be correct for any particular type of distance indicator... Systematic errors resulting from differences in chemical abundances etc. will be minimised if the largest possible number of methods of distance determination is employed."

The problem of checking and refining observational estimates of the scale of the universe depends not only on a much better detailed understanding of the distance indicators themselves, but also on a satisfactory resolution of the controversy concerning the uniformity of the Hubble flow (see, e.g. Rubin, Ford and Rubin 1973; Sandage and Tammann 1975a; Sandage 1975; de Vaucouleurs 1976a; Rubin, Thonnard, Ford & Roberts 1976; Rubin, Ford, Thonnard, Roberts and Graham 1976). However, it seems more appropriate here to concentrate on recent southern work with distance indicators even though much of it is only in a very preliminary stage; we can leave discussion of the extent of non-uniformity in the

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

Hubble flow to the papers this afternoon, which, to paraphrase slightly Dr. Rubin's words "will review the many papers on anistropy and the equally numerous pitfalls".

II. The Sculptor (South Polar) Group

a) The Brighter Stars

Galaxies which belong to a different group than our own may provide more information concerning the scatter in those properties of individual distance indicators which might be associated with variations in evolutionary history and chemical abundances. The Sculptor group is of outstanding importance in this context because of its proximity to the Local Group; at a distance of perhaps 2-3 Mpc (see, e.g. de Vaucouleurs 1959, 1975; van den Bergh 1963; Sandage and Tammann 1975a) it is, for example, the only group beyond our own and the M81 - NGC 2403 complex in the northern hemisphere in which Cepheid variables can be studied. (Indeed from the nearest 10 groups beyond our own with $|b_{II}| \geq 40^{\circ}$, only Sculptor is located in southern skies). It is a valuable group in at least two other respects: (i) it is near the south galactic pole and hence galactic absorption is at a minimum and (ii) it has late-type members similar to objects within the Local Group.

Dr. Graham has observed a number of the galaxies in this group through standard broad-band filters using the C.T.I.O. 4-meter reflector under conditions of excellent seeing. The brightest blue and red supergiant stars in each galaxy are clearly resolved. Subject to reservations such as those outlined by van den Bergh (1975a) these supergiant stars may be used as indicators of distance, once appropriate sequences have been set up in the field; one may also be able to use this material to investigate further the relation between the absolute visual magnitude of the galaxies and ΔV, the difference in visual magnitude between the brightest blue and red

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

stars (van den Bergh 1974).

Work by Graham is in progress to try to resolve the old population II giants in these systems near $M_V = -3.0$ (see, e.g., Sandage 1971) ; such stars might just be resolved at the plate limit of the best Cassegrain-focus plates. However, care must be taken not to confuse these old population II giants with a brighter, intermediate-age population, such as that reported by de Vaucouleurs (1955) and Westerlund (1971) in certain regions of the Magellanic Clouds.

b) Cepheid Variables

During the last two observing seasons, NGC 300 was photographed on about a dozen different occasions at the prime focus of the CTIO 4-meter reflector as the first part of a programme by Graham, Madore and Smith to discover Cepheids in this galaxy and to determine their periods, mean magnitudes and colours. NGC 300 was chosen first as its orientation, structure and low surface brightness permit measurements to be made with minimal interference from background, reddening and crowding effects ; a very deep photoelectric sequence in this fiels is being planned by Blanco and Graham. For the brightest, longest-period Cepheids (period P greater than 100 days) a baseline of several years will be necessary;

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

however the faintest detectable Cepheids should have periods as short as a few weeks.

c) Novae

The plates taken to discover Cepheids will of course be used to search for other variables and any novae that may occur. If the administrative problems of following a nova's light curve to apparent magnitude 22 to 23 can be solved, such objects could become quite important distance indicators for the Sculptor group, independent of the fundamental calibrations of Cepheids and RR Lyraes in our galaxy; the region of intersection of the light curves of fast and slow novae about 15 days after maximum is found by de Vaucouleurs to be close to absolute magnitude $\overline{M}_{15} = -5.3 \pm 0.1$. Inclusion of data on two recent fast novae has significantly reduced the scatter in this region present in the original data of Buscombe and de Vaucouleurs (1955) and Schmidt (1957).

d) HII Regions

The most extensive effort to calibrate the diameters of HII regions as a function of galaxy type has been reported by Sandage and Tammann (1974a, "ST-1"); indeed, these objects are used by them as the major precision indicator for calibrating the distance scale beyond the distance to which Cepheid variables can be measured. I have therefore made an attempt to apply the ST-1 method to estimate the distances to NGC 300 and NGC 7793. The plates (of the Local Group galaxies LMC, SMC, M33 and IC 1613, along with NGC 300 and NGC 7793) were all taken in two successive nights of very good seeing, with the same combination of telescope, filter, emulsion and exposure time (see Table 1). A series of repeated trial-and-error measurements of HII

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

TABLE 1

APPARENT ANGULAR DIAMETERS OF HII REGION NGC 604 (ARC SECS.)

		MAJOR	MINOR
PALOMAR 5-METER:	HALO	106	80
PALOMAR SCHMIDT:	HALO	146	Uncertain
TOLOLO 4-METER*:	HALO?	105	78
TOLOLO 4-METER:	FAINTEST FEATURES VISIBLE ON PLATE	140	Poorly defined

* All Tololo plates were exposed for 45 minutes on nitrogen-baked 098-04 plates through a 100Å passband H-alpha filter at the prime focus of the CTIO 4-meter reflector.

---

regions in the Local-Group objects were used in conjunction with the qualitative description in ST1 in order to try to arrive at a working personal definition or "calibration" of "core" and "halo" boundaries. Identification of the boundaries used by Sandage and Tammann was found to be possible in most cases.

Unfortunately, ambiguity did arise in a number of cases. An example occurs in the original calibration measures for NGC 604, reproduced in Table 1. It was found that "calibration of one's personal system of measurement" was not possible in those cases where two apparent discontinuities can be found in the density profile of the image. Hodge (1976) in a much more extensive programme than mine, also believes that while he "must have been measuring nearly the same thing "as in ST1, he finds large discrepancies in individual cases, as well as a possible systematic error with distance associated with the method. Hence, my preliminary distance estimates of 1.5 Mpc for NGC 300 and 2.4 Mpc for NGC 7793, based on this method

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

should probably be given low weight.

Efforts to make more effective use of this material are now being directed along two channels: (a) microphotometry of the larger HII regions on my plates has recently been completed by Hodge and Kennicutt; Hodge (1976) has already reported preliminary results of Hα flux measurements from the brightest HII regions in 17 northern galaxies. Being a photometric parameter (which scales as H_o^{-2}) it is, in principle, potentially superior to diameter measures, which scale only as H_o^{-1}. This is of course, only true if the dispersion in the parameter is small; in this regard, one would expect at first sight to have to treat the outstanding giant HII regions such as 30 Doradus and NGC 604 differently from other, less spectacular, HII regions in the same galaxy in attempting to derive corrections for size-of-sample effects. Hodge's (1976) Figure 3 summarises the present state of efforts to minimise the scatter: (b) search for HII rings similar to those discussed by Gum and de Vaucouleurs (1953) and by de Vaucouleurs and Ables (1965). The diameter to be measured is fairly well defined in a given object and may not vary greatly as a function of galaxy type (see, e.g. the ring in GR8 discussed by Hodge, 1974 b). However, in order to recognise the types of rings to use as indicators, it seems to me that some improvement in the classification of ring-like formations on interference-filter plates is necessary. It is still not sufficiently clear what type of ring-like structure is to be measured.

III Nearby Groups, and Galaxies in the General Field

a) The Centaurus Group

As mentioned earlier, observers in the southern hemisphere have access to very few of the nearest groups. The distance to the Centaurus group (or chain) centered

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

on NGC 5128, the next southern group beyond Sculptor I, is still very much in doubt; recent data do not make it possible to improve significantly upon earlier estimated distances in the range 4-9 Mpc. Hubble (1936) reports resolution of the brightest stars in the ScI-II galaxy, NGC 5236 at 18-19 magnitude. One might expect the brightest globulars around NGC 5128 to appear somewhere near this magnitude, yet globular clusters have never been reported around this object, although many plates have been taken which go much deeper than apparent magnitude 20. Sandage and Tammann (1974d) list a distance of 8.9 Mpc for NGC 5236 based on applying their HII-region method to one "relatively poor" plate. I found difficulty with my Hα plate of this ScI-II galaxy because of the crowding of "individual" regions along its spiral arm. Because of the poor definition in ST1 of the concepts of "halo" boundaries and particularly of "discrete structure", a number of difficult value judgements had to be made, all of which tended to increase the final estimate of distance; I failed to find a reasonably objective way to isolate the largest "discrete" structure.

b) Other Groups and Bright Field Galaxies

Substantial catalogues of apparent magnitudes and redshifts for bright galaxies beyond the Local Group are now becoming available. The recently published Second Reference Catalogue of Bright Galaxies contains magnitudes with redshifts for over 1000 objects. Sandage (personal communication) has obtained redshifts for nearly all

Shapley-Ames galaxies in the North and South, not included in Humason, Mayall and Sandage (1956); a catalogue of about 640 new values is in preparation. In an addendum to his original article for the "Stars and Stellar Systems" series, de Vaucouleurs (1975) provides individual distance estimates for 54 northern and southern groups of galaxies, while Sandage (1975) provides estimates for 22 southern groups and clusters. Presumably we shall hear more about this data in Dr.Rubin's review.

c) Colours of Southern Elliptical Galaxies

Sandage and Visvanathan (1975) are in the process of analysing their four-colour multi-aperture photometry of a subset of E and SO Shapely-Ames galaxies (about 450 entries), which is more than 95% complete. They have extended earlier studies (e.g. de Vaucouleurs 1961, Sandage 1972), to include the Fornax cluster. From the colour of the field galaxies, using the relation between reddening-corrected ultraviolet colour and apparent magnitude V_{26} they hope to be able to obtain relative distances, scaled to the Virgo Cluster. The galaxies are well distributed over the sky, so a combination of these distances with the redshifts from the new catalogues should allow a further test to be made for any anisotropy in the Hubble flow.

However, there is the possibility that a significant difference may exist between the intrinsic properties of elliptical galaxies in clusters and those of field ellipticals (see e.g. Sandage 1972, van den Bergh 1975b, p244). Thus it is with interest that we await the outcome of the study by Frogel.Persson and Aaronson of the infrared properties of field ellipticals and the calibrating ellipticals in Virgo. Preliminary results indicate a tight correlation between the V-K colours of field ellipticals and their absolute visual magnitudes. They have recently

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

completed observing runs at Las Campanas and Tololo devoted to observations of Sandage's calibrating ellipticals in Virgo, as well as to observations of program galaxies in several southern clusters from Abell's (1958) catalogue.

d) Galaxies with Internal Ring Structure

Galaxies of type SB(r) present a indicator of special potential value for work in this critical range of distance as

(i) They are very easy to distinguish from other objects by their sharply outlined theta - like structure.

(ii) The diameter to be measured is well defined and probably not sensitive to inclination corrections.

(iii) The range of application is great (up to ~100 to 200 Mpc), as the SB(r) galaxies have mean diameters for their inner rings of ~ 4-5 kpc (de Vaucouleurs 1970b)

(iv) This is one of the few well-defined geometric (i.e. non-photometric) distance indicators.

However much more work is still needed to calibrate this indicator and particularly to estimate the dispersion in its properties; some application to southern groups has already been made by de Vaucouleurs (1956).

IV. The Distance to the Great Clusters of Galaxies

a) Nuclear Magnitudes

Weedman (1976) has isolated and studied a new indicator which can be applied easily to an independent determination of the relative distances of the nearer dense clusters of galaxies using only small telescopes. Weedman's indicator is based on the luminosities, within central diameters of about 5kpc ("nuclear magnitudes") for a number of the

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

brightest galactic nuclei in each cluster (the number of nuclei used to derive a mean is found not to be critical - a small number is chosen to allow penetration to greater distances).

The primary disadvantage of measuring nuclear magnitudes in this way is of course the necessity of observing regions of the same absolute diameter within the different galaxies to be compared. The observing apertures have to be scaled to the distances, and luminosity profiles for the inner regions of galaxies have to be known in order to correct for slight errors in this scaling. In practice, these aperture corrections were made by first assuming that the cluster distances are scaled with their redshifts and that the mean luminosity profile for the brightest galaxies is the same as the observed mean profile for galaxies in Virgo measured by means of multi-aperture photometry. Had non-Hubble components of the cluster redshifts been detected, an iterative procedure would have been used to derive the true aperture correction that applies for the actual cluster distance.

If the mean magnitudes of the five brightest nuclei in each cluster are considered, Weedman finds that the σ (Δ m) from the mean Hubble line is only 0.15 mag, and the σ (Δ log cz) is 0.029 ; he concludes from this that there is no evidence for significant non-Hubble velocities for 1 000 km $s^{-1} \leq cz \leq 11\,000$ kms^{-1}. Dr. Rubin's review will include discussion of some particularly interesting features of the distribution of Weedman's points about the mean Hubble line. In particular she will emphasize the importance of using limited velocity ranges when making tests of motion of the Local Group.

b) UBVR Photometry of Brightest Galaxies

Frogel (personal communication) is presently engaged in a programme of photoelectric UBVR photometry of the ten brightest galaxies in a sample of 40 to 50 northern and southern Abell clusters, using large apertures. Magnitudes

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

are corrected to a standard isophote via tracings of photographic plates. Frogel hopes to be able to refine some of the corrections made by Sandage and Hardy (1973) to their Hubble diagram by investigating quantitatively the following parameters and their inter-relationships: (a) Bautz-Morgan class (b) Cluster richness (c) The luminosity function of the bright end of the distribution of galaxies (d) Absolute magnitudes and colours of the brightest galaxies in clusters (and differences among them).

c) Globular Clusters

Globular clusters offer a potential advantage as nearby direct distance indicators with coverage out to several tens of megaparsecs as their calibration bypasses the series of step-by-step comparisons with Population I distance indicators and relies only on the adopted magnitude level of the horizontal branch (i.e. of RR Lyrae stars) in globular clusters (van Herk 1965; Wooley and Savage 1971; Heck 1973; Hemenway 1975).

Early work by Racine (1968), and Sandage (1968) had suggested that a sharp upper limit exists in the absolute magnitude of the brightest globulars around M87. de Vaucouleurs (1970a), Hodge (1974a, 1976) and Hanes (1971, 1975) have all shown since then that in fact this sharp cut off does not exist. Hanes' (1971, 1975) new work on M87 has resulted in a revision of the apparent magnitude $B_1(\Theta)$ of the brightest globular cluster from Racine's original value of 21.2 to 20.4 mag (quoted by Dawe and Dickens 1976). The first published work using Hanes' new data appears to be that of van den Bergh (1975a) who obtained an apparent modulus of $(m-M)_B \sim 30.7$ for the Virgo cluster; Dawe and Dickens (1976) and de Vaucouleurs (1976b) have since obtained values $(m-M)_B = 30.4$.

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

These recent efforts by Hanes to determine the apparent magnitude $B_1(\Theta)$ of the brightest globular in M87 and by de Vaucouleurs (1976b) to derive estimates of the corresponding absolute magnitude are of course important to workers in the southern hemisphere. Kinman (personal communication) has recently discovered a large system of globular clusters around NGC 1399 in Fornax using the Tololo 4-meter reflector. Dawe and Dickens (1976) report possible detection of globular clusters around several other galaxies in the Fornax I cluster, especially NGC 1374, on uncalibrated plates. They estimate $B_1(\Theta) = 21.0 \pm 0.6$ for Fornax and derive an apparent distance modulus $(m-M)_B = 30.8$ for NGC 1399. Combining a refined version of this estimate, a distance based on magnitudes and diameters of the 5 brightest and/or largest galaxies corrected for size of sample (de Vaucouleurs 1975) and his new estimate for the distance to Virgo, de Vaucouleurs (1976b) derives a geometric distance modulus $(m-M)_o = 30.97 \pm 0.18$ (corresponding to ~ 15.7 Mpc) for the Fornax I cluster.

Smith and Weedman (1976), by reaching magnitudes $B \sim 24.5$ at the prime focus of the CTIO 4-meter on plates of the Hydra I cluster (Abell 1060), have discovered a significant excess of faint objects around the central elliptical galaxies NGC 3309 and NGC 3311; this excess becomes obvious at about 24 mag. and fainter. A similar effort on NGC 4696 in the Centaurus cluster was not successful, probably because the plates do not appear to have reached 24th magnitude. de Vaucouleurs (1976b) has used Figure 2 of the paper by Smith and Weedman to estimate $22.8 < B_1(\Theta) < 23.8$, and adopts $B_1(\Theta) = 23.3 \pm 0.2$: from this. Using the same recipe as that used for Virgo, he derives an apparent distance modulus of $(m-M)_B = 33.25 \pm 0.25$:

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

These distance estimates for the southern clusters are, however, by no means beyond question. Tammann (personal communication) has recently concluded that an analysis of Hanes' photometric data shows that the large revision in the estimate of the apparent magnitude B_1 ($\oplus$) is not justified. In view of the fact that most of the acknowledged experts in this field have been using globular clusters in recent discussions of the value of the Hubble parameter, I think it might be profitable for us to hear a discussion between Hanes, de Vaucouleurs, Tammann, van den Bergh and others here at this conference who have attempted to use globular clusters as extragalactic distance indicators. The discussion might consider the following points of view, one or more of which have been adopted in various recent studies by different observers : -

(i) That one cannot obtain even the apparent magnitude of the brightest globular cluster in a single, distant, extragalactic system with useful accuracy ; (by distant, I mean that the images of globulars are star-like on even the best direct plates) ;

(ii) That combination of the estimate of B_1 ($\oplus$) for several extragalactic systems at a common distance (as in the case of Virgo) does lead to a meaningful result ; choice of (say) the fifth-ranked globular might lead to a more stable statistic.

(iii) That fits to simple relations involving the apparent and absolute magnitudes of the brightest globulars and photometric properties of the parent galaxy are significant, and are unlikely to undergo significant future revision.

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

(iv) That fits of gaussian models to the bright end of the luminosity function of globular clusters are excessively sensitive to the value of the intrinsic dispersion, σ, adopted (even assuming that a universal gaussian fit at a constant, well-defined, absolute mean magnitude is justified). A change of 0.1 in σ is equivalent to a change in the Virgo distance modulus of 0.4 mag., yet this modulus is often quoted to 2 decimal places.

(v) That the results of this discussion have a significant effect on each participant's latest estimate for the value of the Hubble parameter.

V. CONCLUSIONS . One can conclude from all this that : (a) Future progress is most likely to be made by studying a given distance-measurement problem from several different angles and from these adopt the result which seems most consistent with these several views : (b) There is a depressing lack of security in the published data (especially in the quoted uncertainties) and in the interpretation of data for observational cosmology. There is a general tendency to gloss over the difficulties encountered in the application of each distance indicator, and : (c) Work in the southern hemisphere has not matured to the point of being able to provide an estimate of H_o of significance comparable even to those cited in the Christmas card (perhaps you should also refer to Sandage and Tammann 1975 a, b, c, d ; 1976 a, b ; van den Bergh 1975 a ; Heidmann, Heidmann and de Vaucouleurs 1971).

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press

REFERENCES

Abell, G.O. 1958, Ap. J. (Suppl.), 3, 211.

Buscombe, W., and de Vaucouleurs, G. 1955, Observatory, 75,170.

Dawe, J.A., and Dickens, R.J. 1976, Nature, in press.

Gum, C.S., and de Vaucouleurs, G. 1953, Observatory, 73, 152.

Hanes, D.A., 1971, M.Sc. Thesis, University of Toronto.

Hanes, D.A., 1975, Ph.D. Thesis, University of Toronto.

Heck, A., 1973, Astron. and Ap., 24, 313.

Heidmann, J., Heidmann, N., and de Vaucouleurs, G., 1971, Mem. R.A.S., 75, 141.

Hemenway, M.K., 1975, A.J., 80, 199.

Hodge, P.W., 1974 a, P.A.S.P., 86, 289.

Hodge, P.W., 1974 b, ibid, p645.

Hodge, P.W., 1976, preprint (Tercentenary Symposium, Royal Greenwich Observatory).

Hubble, E., 1936, Ap. J., 84, 158.

Humason, M.L., Mayall, N.U., and Sandage, A., 1956, A.J., 61, 97.

Racine, R., 1968, J. Roy. Astron. Soc. Canada, 62, 367.

Rubin, V.C., Ford, W.K. Jr., and Rubin, J.S. 1973, Ap. J. (Letters), 183, L111.

Rubin, V.C., Ford, W.K. Jr., Thonnard, N., Roberts, M.S., and Graham, J.A. 1976, A.J., in press.

Rubin, V. C., Thonnard, N., Ford, W. K. Jr., and Roberts, M. S., 1976, A. J., in press.

Sandage, A. R., 1968, Ap. J. (Letters), 152, L149.

Sandage, A. R., 1971, Nuclei of Galaxies, ed. D. J. K. O'Connell (American Elsevier, New York) p601.

Sandage, A. R., 1972, Ap. J., 176, 21.

Sandage, A. R., 1975, Ap. J., 202, 563.

Sandage, A. R., and Hardy, E. 1973, Ap. J., 183, 743.

Sandage, A. R., and Tammann, G. A., 1974 a, Ap. J., 190, 525.

Sandage, A. R., and Tammann, G. A., 1974 b, Ap. J., 191, 603.

Sandage, A. R., and Tammann, G. A., 1974 c, Ap. J., 194, 223.

Sandage, A. R., and Tammann, G. A., 1974 d, Ap. J., 194, 559.

Sandage, A. R., and Tammann, G. A., 1975 a, Ap. J., 196, 313.

Sandage, A. R., and Tammann, G. A., 1975 b, Ap. J., 197, 265.

Sandage, A. R., and Visvanathan, N., 1975, reported by O. Eggen in Annual Report of the Australian National University, Department of Astronomy, p21.

Schmidt, T., 1957, Zs. f. Ap., 41, 182.

Smith, M. G., and Weedman, D. W., 1976, Ap. J., 205, 709.

van den Bergh, S., 1963, Observatory, 83, 257.

van den Bergh, S., 1974, I. A. U. Symposium #58, The Formation and Dynamics of Galaxies, ed. J. R. Shakeshaft, (Reidel, Dordrecht-Holland), p157.

van den Bergh, S., 1975 a, Structure and Evolution of Galaxies, ed. G. Setti, (Reidel, Dordrecht-Holland), p247.

van den Bergh, S., 1975 b, Ann. Rev. Astr. and Ap., 13, 217.

van Herk, G., 1965, B. A. N., 18, 71.

de Vaucouleurs, G., 1955, A. J., 60, 219.

de Vaucouleurs, G., 1956, Mem. Comm. Obs. Mt. Stromlo, 3, #13.

de Vaucouleurs, G., 1959, Ap. J., 130, 718.

de Vaucouleurs, G., 1961, Ap. J. Suppl., 5; 233.

de Vaucouleurs, G., 1970 a, Ap. J., 159, 435.

de Vaucouleurs, G., 1970 b, I. A. U. Symposium 38, The Spiral Structure of our Galaxy, eds. Becker and Contopoulos, (Reidel, Dordrecht-Holland), p18.

de Vaucouleurs, G., 1975, Galaxies and the Universe, eds. A. R. Sandage, M. Sandage and J. Kristian, (Chicago : University Press), p 557.

de Vaucouleurs, G., 1976 a, Ap. J., 205, 13.

de Vaucouleurs, G., 1976 b, Nature, submitted.

de Vaucouleurs, G., and Ables, H. D. 1965, P. A. S. P., 77, 272.

de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. G. Jr. 1976, Second Reference Catalogue of Bright Galaxies, (Austin : University of Texas Press).

Weedman, D. W., 1976, Ap. J., 203, 6.

Westerlund, B. E., 1971, Vistas in Astronomy, 12, 335.

Woolley, R. v. d. R., and Savage, A. 1971, Roy. Obs. Bull., #170.

DISCUSSION

D.A. HANES: I have presented photometry in my thesis and subsequent papers which establishes the population dependence of globular clusters associated with twenty bright Virgo cluster galaxies. It is evident that the Hodge and De Vaucouleurs technique of using the single brightest globular cluster in a galaxy as a distance indicator is not a useful one. First, the unambiguous identification of such a cluster is impractical, and the method is very sensitive to this (errors of $\sim$ 1 mag in distance modulus are introduced by erroneous identification of the fifth-brightest as the first-brightest cluster). More importantly, there is no simple scaling of total globular cluster population with galaxian B(o) magnitude, as Hodge and De Vaucouleurs assume. In particular, M87 (the Virgo galaxy used by De Vaucouleurs) is overabundant by a factor of 3 in globular clusters when compared with other Virgo ellipticals.

Intercomparison of the full globular cluster luminosity functions avoids this problem. I have shown that these are all of the same shape for the Virgo galaxies, with only the total population a free parameter. A normally-distributed globular cluster luminosity function, calibrated in the Galaxy, implies a Virgo distance modulus near $(m-M)_{app}=30.5\pm0.5$ mag, when fitted to the Virgo photometry. This estimate, which reflects a slight model dependence, is supported by a model-independent direct comparison of the luminosity functions for Local Group and Virgo galaxies.

https://doi.org/10.1017/S0252921100053525 Published online by Cambridge University Press