Total Magnitudes of Virgo Galaxies. I. Construction of a Self-consistent Reference Dataset Spanning 8th to 18th mag.

Christopher Ke-shih Young

Shanghai Astronomical Observatory, Chinese Academy of Sciences,
80 Nandan Road, Xuhui District, Shanghai 200030, China
cky@center.shao.ac.cn

National Astronomical Observatories, Chinese Academy of Sciences,
20A Datun Road, Chaoyang District, Beijing 100012, China

Department of Astrophysics and Optics, School of Physics,
the University of New South Wales, Sydney 2052, Australia
cky@bat.phys.unsw.edu.au

Abstract

The main objectives of this series of papers are: (1) to demonstrate the existence of serious mutual disagreements between established total (and other integrated) magitude scales for Virgo galaxies; (2) to attempt to quantify both the systematic and random errors present within these magnitude scales; (3) to investigate the origins of any large error uncovered; and thereby (4) to encourage the general adoption of rigorous total-magnitude measurement procedures by the astronomical community. The ramifications of the findings presented in this series of papers will be discussed in detail at a later date.

In this paper, the first in the series, a self-consistent dataset of trustworthy total-magnitude measurements is compiled for a sample of Virgo galaxies spanning a range of 10,000 in apparent brightness, based on only the most reliable measurements and photometry currently available. This reference dataset, which includes luminosity-profile shape information, will be used in subsequent papers as one of the bases for assessing existing magnitude scales for Virgo galaxies. As most published magnitudes are based on B-band observations, this series of papers will also focus primarily on B-band measurements.

Keywords: catalogues – galaxies: clusters: individual: Virgo – galaxies: fundamental parameters – galaxies: photometry – methods: data analysis – techniques: photometric

1 Introduction

Although galaxy total magnitudes are required for a large number of astronomical applications, they are notoriously difficult to estimate accurately or even consistently. There are a very large number of reasons for this unfortunate state of affairs.

One major problem is that atmospheric seeing effects can distort the luminosity profiles of galaxies very sigificantly. Under such conditions, profile extrapolation based on standard growth curves generally leads to spurious results, as demonstrated by Young et al. (1998). This problem is of course most acute when dealing with very distant galaxies and/or observations made under poor seeing conditions.

Another serious problem is that it is often technically difficult (or at least impractical) to determine reliably the luminosity profiles of many galaxies out to large enough radial distances so as to be able to avoid large extrapolations. The situation is of course most adverse when dealing with very low surface-brightness objects for which very deep photometry is really essential.

By contrast, one of the greatest difficulties to be overcome in the CCD photometry of bright galaxies is how to determine the level of the sky accurately, when the target galaxies are often large enough to fill entire CCD frames. Although wide-field photographic photometry does not suffer from this hazard, photographic emulsions are deficient in terms of their dynamic ranges. In order to prevent the saturation of photographic emulsions, only short-exposure or 'shallow' photographic photometry is therefore possible for bright galaxies.

In the case of the Virgo direction, the sheer diversity of objects we are confronted with poses what may well be the ultimate challenge to anyone trying to construct a self-consistent and reliable total-magnitude scale. Not only do cluster members systematically catalogued to date span an apparent brightness range of 8th–18th mag., but a full complement of different morphological types is present too. Furthermore, on account of the relatively loose clustering of member galaxies and Virgo's uniquely large angular extent on the sky, backgound galaxies begin to dominate the galaxy number counts at 16th mag.

In this paper, we isolate several sources of total-magnitude measurements and photometry for Virgo galaxies that we have good reason to believe are reliable. In some cases, we are able to adopt the published magnitude measurements without modification, whilst in other cases, it was necessary to derive new total-magnitude values based on existing photometry. Papers II, III and IV will deal with the magnitude scales of: the *Catalog of Galaxies and Clusters of Galaxies* of Zwicky et al. (Volume I: 1961, Volume II: 1963), the *Reference Catalogs of Bright Galaxies* of de Vaucouleurs et al. (RC2: 1976, RC3: 1991), and the *Virgo Cluster Catalog* (VCC) of Binggeli et al. (1985) respectively; whilst further papers in the series will deal with the magnitude scales of smaller datasets.

2 Faint galaxy sample (18th–14th mag.)

At present, the most reliable souce of blue total magnitudes for large numbers of faint Virgo galaxies is Young & Currie's (1998a) *Virgo Photometry Catalogue* (VPC), which presents U, B_J and R_C photographic photometry for over one thousand galaxies in the direction of the Virgo Cluster's core. Curiously, the VPC is actually the first independently calibrated general catalogue of galaxies to cover Virgo since Volumes I and II of Zwicky et al.'s (1961 & 1963) *Catalog of Galaxies and Clusters of Galaxies.* It is based on numerically integrated plate-scan data obtained from U.K.-Schmidt plates using the Royal Observatory Edinburgh's *COSMOS* microdensitometer. All total magnitudes listed in the VPC are derived according to the t system of Young et al. (1998).

Unfortunately, the VPC does not present B_J-band photometry for any galaxy brighter than 14th mag., on account of saturation effects. As its B-band total magnitudes are transformed values based on the original B_J-band values and $B_J - R_C$ colours, the VPC lists B-band values only for objects for which $B_J - R_C$ colours could be obtained and whose B_J-band photometry was unsaturated. Comparisons between the VPC's B_t magnitude scale and the total-magnitude scales of other works, specifically Young (1994 & 1997) and Young & Currie (1998b), have therefore previously been restricted to faint Virgo galaxies exclusively. However, as the VPC's U-band photometry was slightly shallower than its B_J-band photometry, there are actually 48 objects for which new U-band photometry is presented in the VPC, even though their B_J-band surface-brightness profiles are saturated.

In order to investigate the possibility of extrapolating the VPC's B_t magnitude scale brightward of 15th mag. by combining U_t values from the VPC with published $(U - B)$ measurements from other sources, a literature search was conducted for $(U - B)$ measurements of faint Virgo galaxies. It was found that Caldwell (1983) and Gallagher & Hunter (1986) had observed a total of 16 objects for which the VPC quotes new B_t values. These objects are listed in Table 1. A comparison was then made between the B_t values quoted in the VPC and alternative $B_t{}' = U_t - (U - B)$ values. The mean $B_t{}' - B_t$ offset between the two sets of values was found to be only $+0.08(\pm 0.07)$ mag. ¿From Fig. 1, there is no evidence for any scale error either, and the mean offset collapses to $+0.01(\pm 0.05)$ mag. if the two outliers, IC 3355 and VPC 937 (=VCC 1539), are excluded. As the $(U - B)$ aperture photometry measurements are susceptible to errors arising from colour gradients (when present) not being taken into account and/or centering problems, particularly when small apertures are used, the $B_t{}'$ values are probably on average of similar accuracy to the VPC's B_t values (for which transformation from B_J was necessary). They can however, only be derived for a small number of objects on account of the scarcity of published $(U - B)$ colours for faint objects. In the case of VPC 937, the cause of the 0.53 mag. discrepancy between its $B_t{}'$ and B_t is unclear. However, in the case of IC 3355, the 0.59 mag. discrepancy may well be due to the proximity of several giant galaxies (see Section 8 of Young & Currie 1998a).

3 Intermediate galaxy sample (14th–12th mag.)

In the light of the high level of consistency found between B_t values derived from the VPC's U and B_J-band photometry for faint objects, another literature search was conducted for $(U - B)$ colours for those 48 objects with unsaturated U-band but saturated B_J-band photometry. The apparent brightnesses of these galaxies lie within the range $16.72 \geq U_t \geq 12.90$ mag. Those 13 objects for which colours could be found are listed in Table 2, together with newly derived B_t estimates for them.

Table 1: VPC objects for which alternative $B_t{}' = U_t - (U - B)$ values (bold type) could be derived from a combination of VPC U_t values and non-VPC $(U - B)$ colours based on aperture-photometry measurements

Designation VPC/other	type	U_t (mag.)	$U_{25} - U_t$ (mag.)	$(U-B)$ (mag.)	$\sigma_{(U-B)}$ (mag.)	aperture (arcsec)	$(U-B)$ source	$B_t{}'$ (mag.)	B_t (mag.)	$B_{J_{25}} - B_{J_t}$ (mag.)
35/VCC 334	dI	15.99	0.16	−0.21	0.04	19.0	GH	**16.20**	16.49	0.25
256/IC 3239	dI	16.32	0.12	−0.28	0.05	40.0	GH	**16.60**	16.47	0.22
342/VCC 729	dE	15.77	0.25	0.10	0.04	35.6	NC	**15.67**	15.78	0.38
408/VCC 793	dI	17.14	0.28	−0.02	0.08	19.0	GH	**17.16**	17.17	0.50
420/VCC 810	dE	17.18	0.69	0.27	0.10	35.6	NC	**16.91**	17.12	0.69
502/IC 3355	dI	15.74	0.14	−0.20	0.04	60.0	GH	**15.94**	15.35	0.34
670/IC 3416	dI	15.37	0.25	−0.19	0.05	19.0	GH	**15.56**	15.51	0.24
801/VCC 1348	dE	15.72	0.73	0.34	0.05	39.0	NC	**15.38**	15.66	0.57
808/VCC 1352	dE	17.81	0.85	0.12	0.15	39.0	NC	**17.69**	17.60	0.66
829/VCC 1377	dI	16.61	1.23	0.11	0.11	40.0	GH	**16.50**	16.11	0.87
834/VCC 1386	dE	15.69	0.48	0.19	0.05	35.6	NC	**15.50**	15.26	0.52
835/VCC 1389	dE	16.65	0.42	0.21	0.08	35.6	NC	**16.44**	16.61	0.38
843/VCC 1407	dE	15.83	0.25	0.26	0.04	35.6	NC	**15.57**	15.61	0.40
856/VCC 1420	dE	17.47	0.40	0.24	0.08	35.6	NC	**17.23**	16.95	0.36
897/IC 3483	dI	15.22	0.28	0.04	0.04	19.0	GH	**15.18**	15.08	0.47
937/VCC 1539	dE	16.60	0.66	0.15	0.09	35.6	NC	**16.45**	15.92	0.76

Notes: (1) The sources of $(U - B)$ aperture-photometry measurements are NC: Caldwell (1983) and GH: Gallagher & Hunter (1986). Except for B_t', the other quantities are from the VPC. (2) The extrapolation terms $U_{25} - U_t$ and $B_{J_{25}} - B_{J_t}$ are the bases of the error budgets shown in Fig. 1. (3) The new B_t' values are probably less accurate for galaxies of type dI than for objects of type dE, as the former are more likely to possess significant colour gradients.

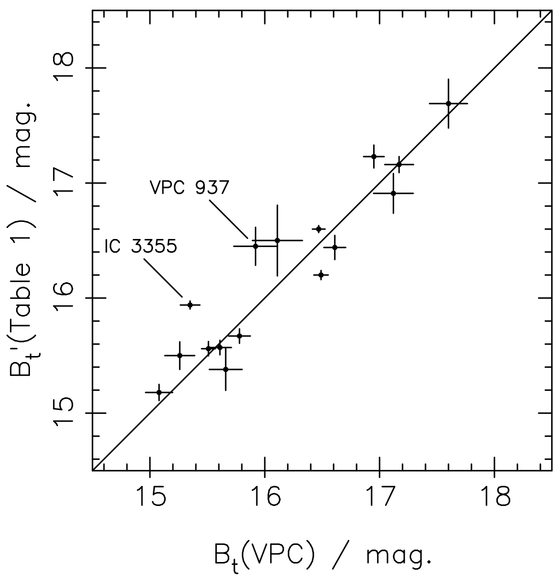

Figure 1: A comparison between B_t values derived from the VPC's U and B_J-band photometry (see Table 1). The error bars only represent uncertainties in the extrapolation terms beyond the limiting U and B_J isophotes, and have been set to one quarter of the $B_{J_{25}} - B_t$ and $U_{25} - U_t$ extrapolation terms (from Table 1) in mag. Datapoints represent individual galaxies and the equality line is shown for reference.

Table 2: New $B_t = U_t - (U - B)$ estimates (bold type) for galaxies with published $(U - B)$ colours for which the VPC's photometry was saturated in B_J but unsaturated in U

Designation VPC/other	VCC type/ membership	U_t (mag.)	$U_{25} - U_t$ (mag.)	$(U - B)$ (mag.)	$\sigma_{(U-B)}$ (mag.)	aperture (arcsec)	$(U - B)$ source	B_t (mag.)
178/NGC 4305	Sa/M	13.54	0.61	0.30	0.1	142.7	SV96	**13.24**
328/NGC 4352	S0/M	13.87	0.37	0.39	0.03	34.5	RC3e	**13.48**
				0.40	0.06	∞	RC3T	
532/NGC 4431	dS0/M	14.43	0.33	0.43	0.07	∞	RC3T	**14.00**
544/NGC 4436	dE-dS0/M	14.49	0.38	0.30	0.05	40.6	RC3e	**14.19**
				0.29	0.07	∞	RC3T	
665/NGC 4468	S0-Sa/M	14.16	0.40	0.33	0.1	89.3	SV96	**13.83**
				0.34	0.02	54.7	RC3e	
				0.33	0.03	∞	RC3T	
778/NGC 4491	SBa	13.89	0.19	0.25	0.1	89.3	SV96	**13.64**
820/NGC 4497	SB0-SBa/M	13.79	0.23	0.34	0.1	89.3	SV96	
				0.29	0.06	62.8	RC3e	**13.50**
				0.25	0.06	∞	RC3T	
838/IC 797	SBc/M	13.83	0.11	−0.05	0.1	89.3	SV96	**13.88**
855/NGC 4506	S(pec)/M	13.94	0.42	0.23	0.1	142.7	SV96	**13.71**
865/IC 3470	dE/M	15.18	0.21	0.36	0.1	32.0	WT73	**14.82**
885/IC 3481	E(pec)/B	14.54	0.86	0.55	0.04	25.6	RC3e	**13.99**
				0.51	0.04	∞	RC3T	
918/IC 3499	E-S0/M	14.74	0.17	0.25	0.05	∞	RC3T	**14.49**
948/NGC 4531	Sa(pec)/M	12.90	0.26	0.32	0.1	142.7	SV96	**12.58**

Notes: (1) Membership assignments are based on radial velocities: M (for member) if less than 3500 km s^{-1}; otherwise B (for background). (2) The sources of $(U - B)$ measurements are: WT73 for Tifft (1973); RC3 for de Vaucouleurs et al. (1991) (e for effective colour, T for total colour); and SV96 for Schröder & Visvanathan (1996). When the $(U - B)$ values listed are simply those corresponding to the largest aperture quoted by a particular source, $\sigma_{(U-B)}$ has been arbitrarily set to 0.1 mag. (3) The quantity 'aperture' is strictly only applicable to the SV96 and WT73 measurements. In the case of the RC3e measurements, the quoted values are the effective diameters (A_e/arcsec in the notation of the RC3). Although the RC3T measurements are based on extrapolations to infinite radial distances, they may suffer from systematic errors as demonstrated by Young et al. (1998). The new B_t values are therefore only based on RC3T measurements when alternative measurements are unavailable. (4) In order to minimise possible errors due to colour gradients not being taken into account, the new B_t value for NGC 4468 was based on the aperture measurement made with the largest aperture. In the case of NGC 4497 however, owing to considerable scatter in the published $(U - B)$ measurements, a median $(U - B)$ value was adopted instead.

4 Bright galaxy sample (14th–8th mag.)

As already mentioned, existing CCD photometry of the brightest Virgo galaxies is generally susceptible to sky-subtraction problems, whilst photographic emulsions are of limited use because of their small dynamic range. One dataset that stands out from existing CCD and photographic ones is the 'globally mapped' surface photometry of Caon et al. (1990 & 1994). This photometry couples wide-field photographic images, for which the sky can be determined accurately, with CCD images of the central parts of galaxies that are saturated on most photographic plates.

Caon et al. (1990) presented two different sets of total-magnitude estimates: those listed in their Table I and those listed in their Table VI. Each Table I value was obtained by means of an integration to the relevant limiting isophote followed by an $r^{\frac{1}{4}}$-law extrapolation (based only on the outer few isophotes of each luminosity profile) to an infinite radial distance. Each Table VI value on the other hand, was obtained by integration only, but this time to a relatively large radial distance greater than that of the limiting isophote of the published photometry. This latter distance was set as the point at which the surface brightness of the galaxy would fall to $\mu_B = 32$ mag.arcsec^{-2} if the $r^{\frac{1}{4}}$-law extrapolation (used to generate its Table I value) were an accurate description of the unmeasurable outer parts of the galaxy profile. The total magnitudes presented by Caon et al. (1994) were derived in the same way as Caon et al.'s (1990) Table VI values.

With a view to generating self-consistent t-system magnitudes independent of any $r^{\frac{1}{4}}$-law assumption, it was decided to derive new total-magnitude estimates from Caon et al.'s (1990, 1994) original surface-brightness profiles. This was done by integrating the actual light curves numerically between the galaxy centroids $r = 0$ and the faintest isophotes $r = r_{\max}$, where r represents azimuthally averaged radial distance. In order to maximise the accuracy of these integrations, the profiles were interpolated in linear-distance–linear-intensity space (rather than $r^{\frac{1}{4}}$–magnitude space in line with the units listed); and using Hill's (1982) interpolation routine INTEP. Note that the surface-brightness profiles of even the largest giants extended to large enough radial distances so as to include a substantial proportion of any halo light. The profile of NGC 4406 (=M86) for example, extended out to a radial distance of 10.4 arcmin.

We also re-fitted Caon et al.'s light curves with Davies et al.'s (1988) more natural form of Sérsic's law, ignoring isophotes flagged as unreliable and/or lacking ellipticity values. This yielded new global profile parameters for each galaxy which were then used for the extrapolation of each profile beyond the limiting isophote to an infinite radial distance. In practice, this involved integrating the best fitting Sérsic model from $r = 0$ to $r = \infty$ analytically according to Equation 7 of Young et al. (1998); and also integrating the same model from $r = 0$ to $r = r_{\max}$ numerically using Simpson's rule. The extrapolation term required was therefore the difference between these two values. The improved total magnitude values together with all relevant profile parameters and extrapolation terms are listed in Table 3. Note that we omitted NGC 4649 because Caon et al. (1990) noticed that its isophotes were distorted by the presence of a companion galaxy. Also, in the case of Caon et al.'s (1994) profiles, we only fitted those 16 Virgo objects listed in Table (a) of the machine readable version at the CDS.

5 Bright-end consistency checks

It is reassuring to find that for the 3 objects in common between Tables 2 and 3, the new total-magnitude values are in good agreement. For NGC 4352, NGC 4431 and NGC 4436, the differences (Table 2 minus Table 3) are -0.01, $+0.04$ and $+0.18$ mag. respectively.

For bright Virgo galaxies, another dataset was identified as likely to be of the highest quality–that of Michard (1982) whose total magnitudes, which were derived from photoelectric aperture photometry measurements, have been adopted here without modification. Note however, that whilst we have excluded all objects whose photometry Michard flagged as unreliable, we have not excluded objects when his only concern was that the extrapolation terms were large. One aspect of Michard's work that sets it apart from most other authors' is that it took into account systematic departures from the standard growth curves relevant to each galaxy's morphological type. This was done by applying the best fitting standard growth curve from the *Second Reference Catalog of Bright Galaxies* (RC2) of de Vaucouleurs et al. (1976) in each case, not the one listed as appropriate to the galaxy's morphogical type. A list of the values adopted is given in Table 4.

As is evident from Fig. 2, there is no evidence for any scale error between the new total magnitudes derived from Caon et al.'s original photometry and Michard's values, provided one excludes the six bright objects for which the profile-shape parameter n was found to be less than 0.25. This would appear to confirm that zero-point differences between the photometry of Caon et al. and Michard are small[1]. Note that the error terms on

[1] Caon et al. (1990, 1994) have already quantified the photometric offsets with respect to Michard's aperture photometry. These offsets are probably dominated by an off-centering bias effect and correspond to $\mu_{\rm Caon} = \mu_{\rm Michard} - 0.17$mag. for the smallest ($r = 11.8$ arcsec)

Table 3: Improved total magnitude values (bold type) derived in this paper from a re-analysis of Caon et al.'s (1990 & 1994) surface-brightness profiles; the hitherto undefined quantities ϵ, μ_{B_0}, and r_0, being ellipticity, Sérsic-model extrapolated central surface brightness and Sérsic-model scalelength respectively

Designation	VCC type/ membership	$B_{r<r_{\max}}$ (mag.)	$r_{\max}$ (arcsec)	ϵ	μ_{B_0} (mag.arcsec^{-2})	n	r_0 (arcsec)	B_t(syst.) (mag.)	B_t(integ.) (mag.)	ΔB (mag.)
1990 data:										
IC 3468	E/M	14.10	57.63	0.24	19.60	0.53	0.1817E+01	13.97	**13.97**	0.13
IC 3540	S0/M	14.77	31.18	0.12	19.39	0.72	0.2343E+01	14.64	**14.72**	0.05
IC 3653	E/M	14.56	27.06	0.06	18.42	0.64	0.1277E+01	14.53	**14.53**	0.03
IC 3773	d:S0/M	14.11	63.50	0.58	18.47	0.45	0.6294E+00	14.03	**14.04**	0.08
NGC 4168	E/M	12.34	110.08	0.24	16.09	0.28	0.4401E-01	12.05	**12.05**	0.29
NGC 4200	S0/M	14.01	47.25	0.41	17.74	0.42	0.3693E+00	13.90	**13.89**	0.11
NGC 4352	S0/M	13.56	68.08	0.38	17.33	0.40	0.3009E+00	13.50	**13.49**	0.07
NGC 4374	E/M	10.10	329.17	0.07	9.81	0.15	0.4891E-05	9.69	**9.71**	0.40
NGC 4387	E/M	13.16	85.61	0.24	16.24	0.38	0.1708E+00	13.14	**13.13**	0.03
NGC 4406	S0/M	9.79	484.53	0.40	11.59	0.15	0.1423E-04	9.15	**9.15**	0.64
NGC 4415	d:E/M	13.89	56.30	0.16	19.45	0.54	0.1967E+01	13.76	**13.76**	0.13
NGC 4417	S0/M	12.01	125.19	0.30	14.06	0.28	0.1835E-01	11.93	**11.95**	0.06
NGC 4431	dS0/M	14.21	43.50	0.33	19.84	0.54	0.2153E+01	13.96	**13.96**	0.25
NGC 4434	E-S0/M	13.18	65.63	0.14	14.94	0.30	0.2629E-01	13.06	**13.08**	0.10
NGC 4436	dE-dS0/M	14.15	62.06	0.41	18.65	0.42	0.5357E+00	14.00	**14.01**	0.14
NGC 4452	S0/M	12.86	95.38	0.60	17.88	0.48	0.1011E+01	12.89	**12.83**	0.03
NGC 4458	E/M	13.07	80.72	0.01	15.32	0.29	0.2641E-01	12.94	**12.94**	0.12
NGC 4459	S0/M	11.21	197.98	0.19	15.12	0.30	0.6466E-01	11.29	**11.15**	0.06
NGC 4464	E/M	13.53	47.53	0.07	15.05	0.36	0.6574E-01	13.46	**13.49**	0.04
NGC 4473	E/M	11.15	231.09	0.39	12.34	0.22	0.1525E-02	11.06	**11.07**	0.08
NGC 4474	S0/M	12.50	99.85	0.20	15.83	0.33	0.9517E-01	12.43	**12.42**	0.08
NGC 4476	S0/M	13.16	90.77	0.15	15.42	0.30	0.3278E-01	13.07	**13.09**	0.07
NGC 4478	E/M	12.42	63.42	0.08	16.78	0.50	0.8680E+00	12.39	**12.39**	0.04
NGC 4486	E/M	9.71	410.42	0.35	14.43	0.23	0.1314E-01	9.43	**9.43**	0.27
NGC 4550	E-S0/M	12.60	71.24	0.68	17.61	0.57	0.1665E+01	12.58	**12.57**	0.02
NGC 4551	E/M	13.11	62.71	0.21	17.56	0.50	0.9137E+00	13.07	**13.08**	0.03
NGC 4552	S0/M	10.80	245.11	0.17	9.32	0.15	0.2717E-05	10.47	**10.48**	0.32
NGC 4564	E/M	12.12	109.83	0.40	14.92	0.32	0.6149E-01	12.07	**12.07**	0.06
NGC 4578	S0/M	12.46	108.71	0.25	15.39	0.28	0.2836E-01	12.32	**12.31**	0.15
NGC 4621	E/M	10.63	310.37	0.09	9.87	0.15	0.3820E-05	10.29	**10.30**	0.34
NGC 4638	S0/M	12.16	82.43	0.38	16.07	0.45	0.5002E+00	12.13	**12.14**	0.02
NGC 4660	E-S0/M	12.14	90.29	0.16	12.73	0.26	0.5285E-02	12.06	**12.07**	0.07
1994 data:										
NGC 4215	S0/M	12.92	54.25	0.61	17.02	0.48	0.6589E+00	12.95	**12.88**	0.05
NGC 4255	S0/M	13.69	48.36	0.38	15.92	0.38	0.1180E+00	13.63	**13.64**	0.04
NGC 4261	E/M	11.35	171.60	0.25	12.61	0.19	0.3345E-03	10.99	**11.00**	0.36
NGC 4268	S0/M	13.74	46.08	0.44	17.58	0.52	0.7694E+00	13.70	**13.70**	0.03
NGC 4269	S0/M	13.86	50.93	0.21	9.74	0.15	0.8938E-06	13.31	**13.38**	0.48
NGC 4270	S0/M	13.20	60.02	0.45	17.69	0.54	0.1146E+01	13.17	**13.17**	0.03
NGC 4339	S0/M	12.56	98.48	0.12	15.82	0.30	0.5332E-01	12.41	**12.41**	0.15
NGC 4342	S0/M	13.22	39.99	0.23	11.72	0.26	0.2078E-02	13.08	**13.17**	0.06
NGC 4360	E/B	13.69	88.99	0.18	15.88	0.30	0.3175E-01	13.60	**13.61**	0.07
NGC 4365	E/M	10.72	210.48	0.32	12.82	0.19	0.5118E-03	10.28	**10.28**	0.43
NGC 4377	S0/M	12.79	64.20	0.18	15.32	0.35	0.9057E-01	12.72	**12.73**	0.07
NGC 4472	E-S0/M	9.21	622.25	0.15	13.38	0.20	0.2295E-02	8.93	**8.93**	0.28
NGC 4570	S0-E/M	11.85	65.71	0.69	15.87	0.42	0.4143E+00	11.77	**11.77**	0.08
NGC 4600	S0/M	13.60	64.94	0.16	19.56	0.67	0.3684E+01	13.56	**13.56**	0.04
NGC 4623	E/M	13.26	66.19	0.55	18.09	0.47	0.9093E+00	13.18	**13.18**	0.08
NGC 4636	E-S0/M	10.31	288.01	0.35	14.59	0.21	0.4698E-02	9.79	**9.79**	0.52

Notes: (1) Membership assignments are based on radial velocities: M (for member) if less than 3500 km s^{-1}; otherwise B (for background). (2) B_t(syst.) represents systemic total magnitudes derived by integrating the best fitting profile parameters from $r = 0$ to ∞. (3) B_t(integ.) represents the sum of $B_{r<r_{\max}}$ and the integral of the best fitting profile parameters from $r = r_{\max}$ to ∞. (4) $\Delta B = B_{r<r_{\max}} - B_t$(integ.). (5) For the sake of consistency, NGC 4215 was not treated differently from the other galaxies when its profile was fitted, even though it probably possesses a ring as noted by Caon et al. (1994). (6) NGC 4342 is also known as IC 3256.

Table 4: B_T values adopted from Michard (1982) in order to provide a consistency check on the improved values listed in Table 3

Designation	VCC type/ membership	B_T (mag.)	$B_{A_{\max}} - B_T$ (mag.)
NGC 4124	S0/M	12.10	0.42
NGC 4168	E/M	12.25	0.45
NGC 4262	SB0/M	12.43	0.16
NGC 4267	SB0/M	11.81	0.47
NGC 4339	S0/M	12.37	0.44
NGC 4365	E/M	10.64	0.44
NGC 4374	E/M	10.26	0.40
NGC 4382	S0(pec)/M	10.03	0.33
NGC 4387	E/M	12.97	0.22
NGC 4406	S0/M	10.08	0.59
NGC 4417	S0/M	12.02	0.27
NGC 4425	SBa/M	12.75	0.18
NGC 4429	S0-Sa(pec)/M	11.11	0.49
NGC 4435	SB0/M	11.68	0.37
NGC 4442	SB0/M	11.32	0.28
NGC 4458	E/M	12.85	0.44
NGC 4459	S0/M	11.39	0.43
NGC 4461	Sa/M	12.08	0.31
NGC 4472	E-S0/M	9.34	0.74
NGC 4473	E/M	11.07	0.56
NGC 4474	S0/M	12.57	0.29
NGC 4476	S0/M	13.17	0.29
NGC 4477	SB0-SBa/M	11.45	0.49
NGC 4486	E/M	9.65	0.72
NGC 4503	Sa/M	12.13	0.38
NGC 4526	S0/M	10.70	0.15
NGC 4550	E-S0/M	12.46	0.19
NGC 4564	E/M	11.96	0.32
NGC 4570	S0-E/M	11.79	0.24
NGC 4596	SBa/M	11.50	0.44
NGC 4638	S0/M	12.22	0.20
NGC 4649	S0/M	9.88	0.80

Notes: (1) The $B_{A_{\max}} - B_T$ extrapolation values listed here are based on the maximum aperture for which a reliable measurement was obtained. (2) Membership assignments are based on radial velocities: M (for member) if less than 3500 km s^{-1}. (3) NGC 4124 is not listed in the VCC. Its type was taken from the RC3 instead.

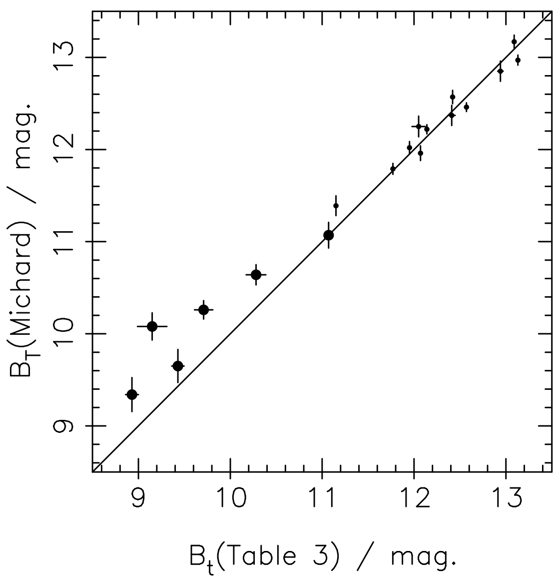

Figure 2: A comparison between the new B_t values derived from Caon et al.'s surface-brightness profiles (Table 3) and Michard's B_T values (Table 4) for the 18 galaxies in common between Tables 3 and 4. The datapoints represent individual galaxies and the equality line is shown for reference. The error bars only represent uncertainties in the extrapolation terms, and have been set to one quarter of the extrapolation terms in mag. Larger '•' symbols have been used to distinguish the 6 objects for which $n < 0.25$. These objects are listed in Table 5. If these objects are excluded, the mean B_T(Table 4) - B_t(Table 3) offset for the remaining 12 objects is only $+0.03(\pm 0.04)$ mag.

Michard's magnitudes are generally larger than those on our values due to larger extrapolation terms[2] and fewer measurements per luminosity profile.

Unfortunately there is only one object in common between Michard's galaxy sample and those objects listed in Table 2, namely NGC 4468. As Michard flagged most of the aperture measurements for this galaxy as unreliable, it has not been listed in Table 4. However, our value of $B_t = 13.82$ is in excellent agreement with Michard's value of $B_T = 13.79$.

In the cases of the six bright objects shown in Fig. 2 for which $n < 0.25$ then (see also Table 5), the large systematic differences between our new B_t values and Michard's B_T ones cannot be the result of zero-point differences, but must primarily be due to the different extrapolations applied. The RC2 set of standard growth curves available to Michard did not include any curve specific to galaxies more centrally concentrated than $n = 0.25$ objects, and so Michard necessarily applied the growth curve specific to the $n = 0.25$ case to his most centrally concentrated objects.

Consistency checks on our extrapolation terms for all of the objects listed in Table 3, including the most centrally concentrated ones, can be provided by comparisons with Caon et al.'s total magnitudes. It was found that for objects of $n \geq 0.25$ (with a scatter of 0.24 mag. about the mean offset):

$$\text{Extrapolated } B_T(\text{Caon et al.}) - B_t(\text{Table 3}) = -0.06(\pm 0.05) \text{ mag.} \tag{1}$$

and (with a scatter of 0.14 mag.):

$$\text{Integrated } B_T(\text{Caon et al.}) - B_t(\text{Table 3}) = -0.06(\pm 0.02) \text{ mag.}; \tag{2}$$

where 'extrapolated' values are from Caon et al. (1990) Table I and 'integrated' values are from Caon et al. (1990) Table VI or Caon et al. (1994). For objects of $n < 0.25$ on the other hand, it was found that (with a scatter of 0.31 mag.):

$$\text{Extrapolated } B_T(\text{Caon et al.}) - B_t(\text{Table 3}) = +0.40(\pm 0.12) \text{ mag.} \tag{3}$$

aperture used by Michard and $\mu_{\rm Caon} = \mu_{\rm Michard} + 0.07$mag. for the largest ($r = 99.3$ arcsec) aperture used.

[2]By extrapolation terms we mean the $B_{A_{\max}} - B_T$ terms listed in Table 4 for Michard's aperture photometry and the ΔB terms listed in Table 3 for our magnitudes.

Table 5: A comparison between the total magnitude values derived by Michard, Caon et al. and the author for galaxies listed in Table 3 that were found to possess luminosity profiles of $n < 0.25$

Designation	Table 3 n	Michard B_T (mag.)	Caon et al. B_T (1990) Table I (mag.)	Caon et al. B_T (1990) Table VI (mag.)	Caon et al. B_T (1994) (mag.)	Table 3 B_t (mag.)
NGC 4261	0.19	-	-	-	11.03	11.00
NGC 4269	0.15	-	-	-	13.32	13.38
• NGC 4365	0.19	10.64	-	-	10.35	10.28
• NGC 4374	0.15	10.26	10.26	9.71	-	9.71
• NGC 4406	0.15	10.08	10.06	9.63	-	9.15
• NGC 4472	0.20	9.34	-	-	8.87	8.93
• NGC 4473	0.22	11.07	11.10	11.02	-	11.07
• NGC 4486	0.23	9.65	9.58	9.48	-	9.43
NGC 4552	0.15	(10.91)	10.78	10.38	-	10.48
NGC 4621	0.15	(10.83)	10.76	10.30	-	10.30
NGC 4636	0.21	-	-	-	10.01	9.79

Notes: (1) Three objects were not observed by Michard: NGC 4261, 4269 and 4636; whilst Michard's B_T values for a further two are listed in parentheses because they were flagged by him as unreliable. Only the six objects for which Michard obtained reliable B_T measurements appear on Fig. 2. These objects are flagged with '•' symbols.

and (with a scatter of 0.17 mag.):

$$\text{Integrated } B_T(\text{Caon et al.}) - B_t(\text{Table 3}) = +0.05(\pm 0.05) \text{ mag.} \tag{4}$$

In the latter case, if NGC 4406 were excluded[3], we find that (with a scatter of 0.09 mag.):

$$\text{Integrated } B_T(\text{Caon et al.}) - B_t(\text{Table 3}) = +0.01(\pm 0.03) \text{ mag.} \tag{5}$$

The agreement with Caon et al.'s integrated magnitudes is therefore very good and much better than with Caon et al.'s extrapolated values. This is reassuring because integrations to large radii should yield relatively unbiased (even if often relatively noisy) estimates of total magnitude[4]. The disagreements with Caon et al.'s extrapolated magnitudes and Michard's values at the bright end are therefore no cause for concern. Both of the latter sources of magnitude estimates are strongly affected by the $r^{\frac{1}{4}}$-law extrapolations applied–especially in the cases of the most centrally concentrated objects.

As far as our profile fits and parameterisations for the most centrally concentrated objects are concerned, the almost perfect agreement between the B_t(systemic) and B_t(integrated to $r_{\max}$ & extrapolated) values listed in Table 3[5], would appear to confirm the superiority of our fits with respect to ones rigidly assuming $n = 0.25$. Furthermore, our finding that the profiles of the brightest early-type Virgo galaxies are best fitted by Sérsic profiles of $n < 0.25$ is in full agreement with Graham et al.'s (1996) conclusion that brightest cluster galaxies typically have $n < 0.25$[6].

6 The scope of this dataset

Although no new observations have been presented in this paper, 13 new B_t values have been derived for VPC objects of intermediate apparent brightnesses but previously lacking B_t estimates. Also, 48 new B_t values have been derived for bright Virgo galaxies through the re-analysis of existing photometry. Combining these 61 new B_t values (as tabulated in Tables 2 and 3) with the VPC enables us to define a reliable dataset covering a subset of Virgo galaxies spanning a range in apparent luminosity of 10,000 (or 10 mag.). Interestingly we find that the brightest Virgo galaxy is NGC 4472 (=M49) (8.93 mag.) followed by NGC 4406 (=M86) (9.15 mag.). This

[3] As noted by Caon et al. (1990), NGC 4406 overlaps with NGC 4374 at the $\mu_B = 26$ mag.arcsec^{-2} isophote and this may be the main cause of the 0.48 mag. discrepancy found for this galaxy.

[4] In the case of Caon et al.'s integrated magnitudes, there must still be a weak dependence on the $r^{\frac{1}{4}}$-law assumption because the determination of the radial limit of each integration was based on an $r^{\frac{1}{4}}$-law extrapolation.

[5] Of the eleven galaxies listed in Table 5, this concordance is at the 0.07 mag. level in one case and at the 0.02 mag. level in another, but it is at the 0.01 mag. level or better in all nine other cases.

[6] $n > 4$ in their notation

leaves NGC 4486 (=M87) (9.43 mag.) in third place. Of course, should there be significant spatial depth in the distribution of these objects, their relative rankings in terms of absolute magnitude may be quite different. Recent distance estimates are available for two of these giants from Gavazzi et al. (1999), who find NGC 4472 to be 0.24 mag. closer to us in distance-modulus space than NGC 4486. This would suggest that in terms of intrinsic luminosity NGC 4472 is only 0.26 mag. brighter than NGC 4486, even though in terms of apparent brightness it is 0.50 mag. brighter.

The main limitations of this dataset are: (1) it is restricted to elliptical and lenticular types at the bright end, (2) its coverage of 14th mag. objects is relatively thin (only 8 objects in total), and (3) large extrapolations[7] were necessary for some objects. As far as the extrapolations are concerned though, we have good reason to believe from Young et al. (1998) that for most bright early-type and fainter galaxies of all types t-system total magnitudes are relatively insensitive to the exact surface brightness of the limiting isophote.

At this stage, it is also worth mentioning that it will become evident from future papers in this series why most other sources were not included in our dataset. We have therefore chosen only to discuss the positive attributes of the selected sources here rather than the limitations of the others. As will be demonstrated, any minor error in the present dataset pales into virtual insignificance when most other sources of magnitudes for Virgo galaxies are investigated.

Acknowledgements

The author gratefully acknowledges a Chinese Academy of Sciences Senior Visiting Fellowship from Shanghai Astronomical Observatory as well as additional support from the K.C. Wong Education Foundation, Hong Kong, China. He would also like to thank the referees for useful comments.

References

Binggeli, B., Sandage, A., Tammann, G.A. 1985 AJ 90, 1681 (VCC)

Caldwell, N. 1983 AJ 88, 804

Caon, N., Capaccioli, M., D'Onofrio, M. 1994 A&AS 106, 199

Caon, N., Capaccioli, M., Rampazzo, R. 1990 A&AS 86, 429

Davies, J.I., Phillipps, S., Cawson, M.G.M., Disney, M.J., Kibblewhite, E.J. 1988 MNRAS 232, 239

de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H.G. 1976 Second Reference Catalog of Bright Galaxies, University of Texas, Austin (RC2)

de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H.G., Buta, R.J., Paturel, G., Fouque, P. 1991 Third Reference Catalog of Bright Galaxies, Springer-Verlag, New York (RC3)

Gallagher, J.S., Hunter, D.A. 1986 AJ 92, 557

Gavazzi, G., Boselli, A., Scodeggio, M., Pierini, D., Belsole, E. 1999 MNRAS 304, 595

Graham, A., Lauer, T.R., Colless, M., Postman, M. 1996 ApJ 465, 534

Hill, G., 1982 Publ. Dominion Astrophysical Observatory 16, 67

Michard, R. 1982 A&AS 49, 591

Schröder, A., Visvanathan, N. 1996 A&AS 118, 441

Sérsic, J.L. 1968 Atlas de Galaxias Australes, Observatorio Astronómico de Córdoba

Tifft, W.G. 1973 PASP 85, 283

Young, C.K. 1994 D.Phil. Thesis, University of Oxford

Young, C.K. 1997 in Galaxies, Proceedings of 21st Century Chinese Astronomy Conference, ed.s Chan, K.L., Cheng, K.S., World Scientific, Singapore

Young, C.K., Currie, M.J. 1998a A&AS 127, 367 (VPC)

Young, C.K., Currie, M.J. 1998b A&A 333, 795

Young, C.K., Metcalfe, N., Zhu, J., Wu, H., Chen, J.S. 1998 A&AS 130, 173

Zwicky, F., Herzog, E. 1963 Catalog of Galaxies and Clusters of Galaxies, 2, California Institute of Technology, Pasadena

Zwicky, F., Herzog, E., Wild, P. 1961 Catalog of Galaxies and Clusters of Galaxies, 1, California Institute of Technology, Pasadena

[7] Extrapolations of greater than 0.5 mag. were necessary not only for some faint dwarf ellipticals but also for two Table 2 and a further two Table 3 objects.