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A Critical Review of the Evidence for M32 being a Compact Dwarf Satellite of M31 rather than a More Distant Normal Galaxy

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Abstract Since Baade's photographic study of M32 in the mid 1940s, it has been accepted as an established fact that M32 is a compact dwarf satellite of M31. The purpose of this paper is to report on the findings of our investigation into the nature of the existing evidence. We find that the case for M32 being a satellite of M31 rests upon Hubble Space Telescope (HST) based stellar population studies which have resolved red-giant branch (RGB) and red clump stars in M32 as well as other nearby galaxies. Taken in isolation, this recent evidence could be considered to be conclusive in favour of the existing view. However, the conventional scenario does not explain M32's anomalously high central velocity dispersion for a dwarf galaxy (several times that of either NGC 147, NGC 185 or NGC 205) or existing planetary nebula observations (which suggest that M32 is more than twice as distant as M31) and also requires an elaborate physical explanation for M32's inferred compactness. Conversely, we find that the case for M32 being a normal galaxy, of the order of three times as distant as M31, is supported by: (1) a central velocity dispersion typical of intermediate galaxies, (2) the published planetary nebula observations, and (3) known scaling relationships for normal early-type galaxies. However, this novel scenario cannot account for the high apparent luminosities of the RGB stars resolved in the M32 direction by HST observations. We are therefore left with two apparently irreconcilable scenarios, only one of which can be correct, but both of which suffer from potentially fatal evidence to the contrary. This suggests that current understanding of some relevant fields is still very far from adequate.

Key words: galaxies: individual: M32 — galaxies: distances and redshifts — galaxies: dwarf — galaxies: elliptical and lenticular, cD — galaxies: fundamental parameters

1 INTRODUCTION

As M32 appears projected onto the disc of M31, separation of the two galaxies' integrated light and constituent stars is notoriously difficult. Consequently, hardly any formal distance measurements are available for M32. On the other hand, much effort has gone into attempting to demonstrate the existence of physical associations between M31 and M32 (which would imply physical proximity) and/or that M32 is in front of M31's disc (which would place a hard upper limit on M32's distance). This is because since Baade (1944) it has been generally accepted that M32 must be a satellite of M31. M32's distance has therefore not been regarded as a major issue as it has generally been assumed to be similar to M31's (and therefore to be known at least approximately). Note though that before Baade (1944) there was no consensus on M32's status with respect to M31 or on its distance.

Assuming that M32 is at a similar distance to that of M31 (whose distance we take to be 0.76 Mpc from e.g. van den Bergh 2000a) then, on account of its angular size and degree of central concentration, it must be an unusually compact dwarf galaxy–regardless of whether it is elliptical or lenticular in nature. Note that although M32 has long been presumed to be an elliptical galaxy, the possibility that it may instead be a lenticular needs to be taken seriously (Graham 2002). Since e.g. de Vaucouleurs (1961), it has been accepted that M32 is a red compact galaxy (RCG). Most members of this extremely rare class of galaxy appear to be associated with larger neighbours and since King (1962) it has been accepted that their compactness arises due to tidal truncation by their neighbours. Red compact dwarfs (RCDs) are all the more unusual (and rare) because their red intrinsic colours and high degree of central concentration with respect to mass are characteristic of early-type giants and intermediates, not dwarfs. In addition to M32, only five other candidates have been identified (Chilingarian et al. 2007). However, as is evident from figures 3 and 4 of Chilingarian et al. (2007), M32 remains the faintest, smallest and most compact RCD [candidate] known, and therefore the most extreme case in terms of its deviation from most known scaling relationships for normal galaxies.

In Appendix A, in a radical departure from current practices, we treat M32 as if it were a normal galaxy in order to investigate what distance it would need to be projected to in order for it to fit as many scaling relationships as possible. We find that if M32 were projected to a distance of $2.3(\pm 0.8)$ $[-0.77 A_B(\mathrm{M31})\ \mathrm{mag}^{-1}]$ Mpc and if A_B(M31) (B-band absorption due to M31) were small, it would obey the known scaling relationships defined by normal early-types, and a physical explanation for its inferred extreme compactness would not be necessary. With this result in mind, in this paper, we test our radical new hypothesis against the existing evidence, the null hypothesis being that M32 is an RCD satellite of M31.

Unfortunately, in the testing of any controversial new hypothesis a critical approach is often unavoidable, and this paper is no exception. It is not our aim to be unnecessarily critical of the existing results, but as we hope most readers will agree, we believe that it is a necessary exercise to investigate the possibilities for re-interpreting evidence that runs contrary to the new hypothesis. Only this way can robust evidence (that is not open to re-interpretation) be separated from circumstantial arguments (that are). Having said this, our aim is to find the truth and we do not have a vested interest in the outcome. This paper merely documents a thought experiment that we have conducted. However, it may also be of historical interest and even shed some light on how science is done.

In Sections 2, 3 and 4, italic type is used for the existing evidence in order to distinguish it from our own analysis. It was found to be impractical to present the existing evidence in strict chronological order. Instead, we have attempted to introduce readers to the issues in an order that requires minimal prior knowledge of the subject, whilst at the same time minimizing the need for any repetition. With a view to remaining objective throughout this paper, we have adopted wordings that neither imply that M32 is an RCD nor imply that it is a background galaxy.

2 DISTANCE-RELATED ISSUES

2.1 Evidence of association with M31

• *The centroid-to-centroid distance on the sky for M31 and M32 is a mere 24 arcmin (or a separation tangential to the line of sight of 5.3 kpc at a distance of 0.76 Mpc). Also, the heliocentric radial velocities of the two galaxies are reasonably similar:* $-205\ \mathrm{km\ s^{-1}}$ *for M32 cf.* $-301\ \mathrm{km\ s^{-1}}$ *for M31. This suggests that they are neighbours.*

This piece of evidence is of course circumstantial and does not exclude the possibility that the Milky Way, M31 and M32 might actually be in approximate geometrical alignment, with M32 lying up to a few Mpc to the rear of M31. Furthermore, if such an approximate alignment existed, it would not necessarily need to be a chance alignment. Instead it might be a product of the structure of the Local Group itself.

• *Since King (1962), it has been the common wisdom that M32 is tidally truncated by M31, thereby requiring that the two galaxies be very close neighbours.*

The deepest luminosity profiles of M32 available are those of Kent (1987) and Choi, Guhathakurta & Johnston (2002). In spite of the differences in photometric pass band and isophote-fitting procedures, as noted by Graham (2002) these profiles are qualitatively very similar to one another. Both profile datasets exhibit a luminosity excess (with respect to a single-component Sérsic 1968 model) at radial distances (r) of ∼200 to 250 arcsec and both exhibit a very minor downturn (with respect to both one and two-component models) at $r \sim 250$ arcsec (Graham 2002).

That Kent (1987) found "no evidence that the profile is truncated", whilst Choi, Guhathakurta & Johnston (2002) followed their mention of "a subtle downturn ... at $r \sim 250$ arcsec" with a note of caution, is a clear indication as to how ambiguous the existing observations remain. In galaxy surface photometry, reliable 'background' subtraction is often difficult at the best of times, but in the case of M32, the difficulties are extreme due to the need to remove the irregular 'background' light contribution of M31. At $r \sim 250$ arcsec, the existing profiles are simply not reliable enough to resolve the truncation issue. Whether M32's luminosity profile is truncated or not therefore remains a wide open question.

• *Since Mayall (1950), Schwarzchild (1954) and Arp (1964), it has been known that M31's disc exhibits some rotation curve and optical asymmetries. Although Roberts (1966), Rubin & Ford (1970) and Emerson (1974) showed these asymmetries to be much smaller than originally thought, the view that the two galaxies must be very close neighbours has been reinforced (a) by recent maps compiled by Gordon et al. (2006) that revealed asymmetries in M31's dust lanes (as distinct from its spiral arms) and (b) by computer simulations (Byrd 1976 through Gordon et al. 2006) that demonstrated that a gravitational encounter between M31 and M32 could produce these asymmetries .*

This piece of evidence is circumstantial. It does not exclude alternative explanations for the asymmetries, especially as many spirals with no major satellite galaxy also exhibit similar asymmetries in their dust lane distribution (e.g. M94) and those with a large satellite often exhibit asymmetries in the dust lanes most distant from the satellite (e.g. M51).

• *Very recent numerical simulations by Block et al. (2006) suggest that two off-centre inner dust rings in M31 are likely to be density waves caused by a companion galaxy colliding head on with the centre of M31's disc 210 million years ago. M32 is cited as the most likely culprit.*

It should be remembered though that the probability of a head-on collision having occurred between M31 and M32 is orders of magnitude lower than that of a chance [approximate] alignment between the same two galaxies. Block et al. (2006) did not rule out other companion galaxies of M31 as possible culprits and we therefore believe that it is premature to lay the blame on M32. For this piece of evidence to be more than circumstantial, a correlation would need to be established between analogous inner dust rings in other giant spirals and the presence of disturbed satellites nearby.

• *M32 does not appear to possess globular clusters even though it might be expected to possess about 15–20 (Harris 1991) or 10–20 (van den Bergh 2000b) such objects [should it be a dwarf galaxy at the same distance as M31]. This suggests that M32 must have been tidally stripped of its clusters by M31.*

It should be noted however, that this standard line of argument was not endorsed by Harris (1991) who pointed out that: "no one [had] quantitatively demonstrated that any original population of clusters could have been totally removed by a combination of tidal stripping from M31 and dynamical friction and tidal shocking from the dense nucleus of M32 itself"[1]. As this situation is still the case today, the evidence for the standard argument is therefore necessarily circumstantial.

If M32 really were three times more distant than M31 though, how many globular clusters might it be expected to possess? Since Hanes (1977) and Harris & Racine (1979) it has been known that the total number of clusters scales approximately with galaxy luminosity. It should also be remembered though that ellipticals in small groups tend to have only about half the number of clusters of their counterparts in the Fornax and Virgo clusters, and that some field ellipticals have even fewer (Harris 1991). If M32 were a background galaxy, it would be an isolated system and might therefore be expected to possess between $\lesssim 50$ and ∼100 clusters.

However, due to distance effects alone, these clusters would be about 2.5 mag fainter than M31's [2]. They would therefore only have been relatively sparsely sampled even by the deepest globular cluster surveys of the M31 field to date (Galleti et al. 2004; Kim et al. 2007). Also, it is quite possible that many clusters bright enough to be observed may have been mistaken for individual stars or blended double or triple

[1] Note also that Harris & Racine (1979) estimated that M32 has $\lesssim 3$ globular clusters (cf. the figure of zero normally assumed).

[2] van den Bergh (2007) has found that the brightest metal-poor clusters in NGC 5128 are of the order of 2 mag intrinsically less luminous than the brightest metal-rich clusters in the same galaxy. If M32's clusters were mostly metal-poor, there is then a possibility that the brightest ones might be of the order of 4.5 mag fainter than M31's brightest clusters.

stellar images. Furthermore, especially in the cases of the faintest definite and candidate globular clusters, surely it is an assumption that they are all associated with M31, rather than with M32 in at least some cases? Unfortunately, due to M31 and M32's close proximity on the sky, their similar recession velocities, the irregular nature of M31's dust lanes and the serious reddening/extinction problem, should M32 be a background galaxy with its own globular cluster system, reliable separation of the two systems might not be a straightforward task.

It is therefore not known how many (if any) globular clusters M32 has and further study is clearly needed[3]. Unfortunately, the M31 field is a problematical one. To quote from Harris (1991): "With M31, we encounter a uniquely frustrating morass of observational and interpretative difficulties involving combinations of sample contamination, large and uncertain reddening corrections for the many clusters projected on the M31 disk, and a highly nonuniform photometric data base." With the recent surveys of Galleti et al. (2004) and Kim et al. (2007) more uniform databases are becoming available. However, the uncertainties over reddening and extinction persist with no immediate prospect of being resolved.

2.2 Evidence that M32 is in front of M31

• *Were M32 situated to the rear of M31, it has long been presumed that it would be intrinsically significantly bluer than its observed colour, which was measured by Sharov & Lyutyi (1983) to be $(B-V)$ =0.95 mag. Although a more recent CCD-based study (Peletier 1993) gives $(U-B)$ =0.57 mag (cf. the generally accepted value of 0.50 mag from Sharov & Lyutyi 1983) suggesting that the actual apparent $(B-V)$ value might be of the order of 0.05 mag redder than $(B-V)$=0.95 mag, absorption must be small should M32 lie behind M31, as evident from Figure A.1(g). Ford, Jacoby & Jenner (1978) have estimated that M31 would redden M32 by 0.44 mag if M32 lies behind M31. The foreground would contribute an extra 0.064 mag using an up-to-date value for $E(B-V)$ from Schlegel, Finkbeiner & Davis (1998) implying an intrinsic colour of 0.45 $\lesssim (B-V) \lesssim$ 0.50 mag, which is too blue even for an intermediate elliptical or lenticular galaxy.*

However, if $E(B-V)_{(\mathrm{M31})} \sim 0$ mag and A_B(M31)~ 0 mag, in line with the findings of e.g. Xilouris et al. (1999) that many spirals are optically thin in their outer regions, as well as with Figure A.1(a), (b) & (c) and Figure A.2; then M32's intrinsic colour would no longer be too blue.

• *The lack of absorption clouds seen superimposed onto M32 has been cited by Ford, Jacoby & Jenner (1978) as evidence that M32 must be in front of M31.*

Most of M31's visible absorption features lie on the side of its disc opposite to M32 whilst those that lie on the same side are mainly found at lower radial distances from M31's bulge. Likewise, the absence of detected optical absorption gradients across M32 is only circumstantial evidence.

• *Some planetary nebula candidates detected in the M32 field are not sufficiently reddened for them to lie behind M31 (based on the estimate of Ford, Jacoby & Jenner 1978 that M31 would redden objects behind it by 0.44 mag).*

As this piece of evidence is potentially conclusive, it deserves careful attention. The published data available for planetary nebulae in the M32 direction prior to those of Merrett et al. (2006) are presented in Table 1. On the one hand, the very low $E(B-V)$ value of $0.01(\pm0.01)$ mag derived for the 2nd ranked object (an almost certain member of M32) and the much higher values derived for two definite non-members, support the prevailing view that M32 must lie in front of M31. However, the corresponding values of $0.17(\pm0.03)$, $0.31(\pm0.10)$, $0.11(\pm0.01)$ and $0.20(\pm0.01)$ mag, derived for the 7th, 9th and 12th ranked objects and an unranked object respectively, all four of which are almost certainly members, are significantly larger than the Galactic reddening component of 0.064 mag (from Schlegel, Finkbeiner & Davis 1998) and require 0.11, 0.25, 0.05 and 0.14 mag respectively of additional reddening. This extra reddening component is unlikely to be due to M32's interstellar medium as none has been detected to date (Emerson 1974; Sage, Welch & Mitchell 1998) and so if M32 is in front of M31 then it must be intrinsic to the planetary nebulae. Clearly, there are some inconsistencies with the existing picture that need further investigation. Could M31's disc be optically thin in places and/or could some of the objects be unresolved

[3] Ironically, the nearby large elliptical galaxy, NGC 5128, was originally thought to possess few, if any globular clusters (van den Bergh 1979; Harris 1991). However, following the discovery of its first cluster by Graham & Phillips (1980) large numbers of clusters were subsequently discovered by van den Bergh, Hesser & Harris (1981), Hesser at al. (1984) and Hesser et al. (1986). NGC 5128 is now known to have a large cluster system which Harris et al. (1984) have estimated to comprise of between 1200 and 1900 clusters.

Table 1 Published data for planetary nebula candidates in the direction of M32. Planetary nebulae are ranked by m_{5007} (from Ciardullo et al. 1989) when available. Membership status is generally based on radial velocity measurements (Nolthenius & Ford 1986; Hurley-Keller et al. 2004) when available (mean values having been used when values from both sources are available). Reddening estimates (Richer, Stasinska & McCall 1999), equatorial coordinates (Ciardullo et al. 1989; Hurley-Keller et al. 2004) and designations, denoted C for Ciardullo et al. (1989) and H-K for Hurley-Keller et al. (2004), are also listed.

Rank	m_{5007} (mag)	Velocity (km s^{-1})	Member?	$E(B-V)$ (mag)	R.A. (J2000) (h m s)	Dec. (J2000) (deg arcmin arcsec)	C	H-K	Notes
1	20.70	-	?	-	00 42 41.94	+40 51 57.9	27	-	Close to nucleus
2	20.93	−229	Yes	0.01 ± 0.01	00 42 39.61	+40 52 39.8	5	-	-
3	21.04	−142	Yes	-	00 42 40.20	+40 51 01.9	3	4	-
4	21.09	-	?	-	00 42 42.24	+40 51 38.6	21	-	Close to nucleus
5	21.14	-	?	-	00 42 55.99	+40 51 12.1	29	-	-
6	21.22	−409	No	0.15 ± 0.02	00 42 31.07	+40 53 04.5	4	-	-
7	21.31	−195	Yes	0.17 ± 0.03	00 42 40.36	+40 52 43.1	6	-	-
8	21.39	−242	Yes	-	00 42 42.23	+40 52 00.7	26	-	Close to nucleus
9	21.37	−156	Yes	0.31 ± 0.10	00 42 42.70	+40 51 56.1	25	-	Blended with C24
10	21.50	-	?	0.15 ± 0.03	00 42 42.54	+40 51 56.2	24	-	Blended with C25
11	21.61	−253	Yes	-	00 42 42.25	+40 51 48.5	23	-	-
12	22.00	−193	Yes	0.11 ± 0.01	00 42 35.91	+40 53 00.1	1	-	-
13	22.05	−161	Yes	-	00 42 40.09	+40 49 40.9	9	3	-
14	22.15	−423	No	0.57 ± 0.01	00 42 26.96	+40 49 41.5	17	-	-
15	22.48	−212	Yes	-	00 42 41.68	+40 51 30.7	20	-	-
16	22.57	-	?	-	00 42 23.13	+40 50 22.2	30	-	-
17	22.65	-	?	-	00 42 49.88	+40 51 10.0	22	-	-
18	22.83	-	?	-	00 42 45.00	+40 52 47.5	10	-	-
19	22.85	−154	Yes	-	00 42 40.24	+40 50 59.6	14	-	-
20	23.28	−174	Yes	0.05 ± 0.02	00 42 56.99	+40 51 01.2	11	7	-
21	> 23.30	−261	Yes	-	00 42 36.50	+40 51 27.9	15	-	-
22	> 23.30	-	No?	-	00 42 36.87	+40 50 02.4	19	-	Nolthenius & Ford (1986) non-member
23	> 23.30	−664	No	-	00 42 54.58	+40 52 06.8	12	-	-
24	23.33	-	No?	-	00 42 31.43	+40 53 22.6	18	-	Nolthenius & Ford (1986) non-member
-	-	−212	Yes	0.06 ± 0.01	00 42 53.05	+40 48 59.5	2	6	Not ranked
-	-	−174	Yes	0.03 ± 0.01	00 42 48.20	+40 54 12.9	7	-	Not ranked
-	-	−151	Yes	0.20 ± 0.01	00 43 02.10	+40 49 30.4	8	8	Not ranked
-	-	−181	Yes	-	00 42 44.51	+40 48 07.7	13	-	Not ranked
-	-	−182	Yes	-	00 42 23.24	+40 46 28.7	-	1	Not ranked
-	-	−158	Yes	-	00 42 28.93	+40 44 39.0	-	2	Not ranked
-	-	−184	Yes	-	00 42 50.63	+40 45 28.4	-	5	Not ranked

H II regions in M32 or (in the absence of velocity data) even in M31? Certainly, from a recent ultra-violet photometric study by Gil de Paz et al. (2005) we would expect a large number of M31's H II regions to be projected onto M32.

3 EVIDENCE BASED ON DISTANCE INDICATORS

3.1 Planetary nebulae

• *M32's planetary nebula luminosity function (PNLF) has been used by Ciardullo et al. (1989) to investigate approximate limits on M32's distance. The 1-σ maximum-likelihood confidence contours presented in their figure 6 corresponded to distances of* $0.91^{+0.10}_{-0.30}$ *Mpc for M32 and* $0.72^{+0.02}_{-0.04}$ *Mpc for the bulge of M31.*

A more accurate estimate of m^*_{5007} was not possible for M32 because of the small planetary nebula sample size. However, the 1-σ error bars would have been even larger for M32 if membership had not been assumed for objects lacking velocities e.g. the 1st, 4th, 5th and 10th ranked objects in Table 1. Also, based on the means of the $E(B-V)$ values derived for subsets of both the M32 and M31 bulge planetary nebula samples (Richer, Stasinska & McCall 1999) the M31-bulge objects typically suffer from 0.2 mag *more* extinction at $\lambda = 5007$ Å than do the M32 objects. If this were taken into account, M32's PNLF-based distance relative to that of M31's bulge would increase by 10 per cent. In the absence of a reliable value of

m^*_{5007}, it may still be a useful exercise to compare M32's brightest definite member planetary nebula, for which $m_{5007} = 20.93$ mag and $E(B-V) = 0.01 \pm 0.01$ mag, with its counterpart in the bulge of M31, for which $m_{5007} = 20.28$ mag and $E(B-V) = 0.20 \pm 0.02$ mag (Ciardullo et al. 1989; Richer, Stasinska & McCall 1999). This leads to a distance ratio of about 1.8 for M32's distance with respect to M31's. Although using the 1st ranked object in Table 1 (whose membership of M32 has yet to be confirmed) would reduce this distance ratio by 10 per cent, using a lower ranked M31 planetary nebula with a higher $E(B-V)$ value, e.g. M31 PN 31 for which $m_{5007} = 20.49$ mag but $E(B-V) = 0.40 \pm 0.25$ mag (Ciardullo et al. 1989; Richer, Stasinska & McCall 1999) would increase the ratio by about 30 per cent. Bearing in mind that $E(B-V)$ values are only available for a small fraction of M31-bulge planetary nebulae, this 30 per cent figure should be treated as a lower limit. This suggests that if M32 really lies at a distance of about 0.76 Mpc then its PNLF is intrinsically $\gtrsim 1.5$ mag fainter than that of M31's bulge. Alternatively though, both galaxies' PNLFs could be similar if M31 is optically thin in the M32 field and M32 lies well to the rear of M31 at a distance of the order of $\gtrsim 1.5$ Mpc.

Very recently, Merrett et al. (2006) have published m_{5007} measurements for 46 emission-line objects that are probable members of M32 based on their projected positions and measured radial velocities. Of these, 4 are extended objects, leaving 42 planetary nebula candidates. The brightest planetary nebula candidate is of $m_{5007} = 20.78$ mag (cf. 20.70 mag for the first ranked object in Table 1) whilst the majority of the candidates (31 out of 42) are of 23rd, 24th, 25th or 26th mag. This new dataset therefore confirms our finding that planetary nebulae in M32 appear to be systematically fainter than their counterparts in the bulge of M31, consistent with M32 being at least of the order of twice as distant.

3.2 RR Lyraes

• *RR Lyraes detected in the M32 direction by Alonso-García, Mateo & Worthey (2004) were found to be of very similar apparent magnitudes to others detected in an M31-only field. If RR Lyraes have indeed been found in M32 as presumed, then there would be a very strong case for M32 and M31 being at similar distances. This study was based on HST observations.*

The main issue here is over the membership status of the 22 RR Lyraes found in the M32∪M31 field cf. the 10 found in the M31-only control field, or in other words, whether this over-density is necessarily due to M32. We note that if M32's distance were three times that of M31, its RR Lyraes would be too faint to have been detected. All of the RR Lyraes found would therefore have to be members of M31. Such a scenario cannot be ruled out because we would expect large differences in the column number densities of detectable RR Lyraes in different M31-only fields due not only to Poisson statistics but also to differences in absorption. Stronger absorption would reduce the detectable number of RR Lyraes, particularly those on the far side of M31. It may therefore be significant that the control sample was taken from a field affected by visible absorption regions whilst the M32 sample was taken from a field devoid of absorption features (see fig. 1 of Alonso-García, Mateo & Worthey 2004). Further evidence for this difference in absorption includes the greater redward spread in $(V-I)$ exhibited by stars in the control field (see fig. 2 of Alonso-García, Mateo & Worthey 2004).

3.3 Surface-brightness fluctuations

• *A distance of 0.83 Mpc was derived by Tonry & Schneider (1988) for M32 based on surface-brightness fluctuations (SBFs) observed in CCD images of the core of M32 with its nucleus excised. This estimate probably constitutes the first formal distance measurement for M32. Consistent results were also found by Tonry (1991) and Luppino & Tonry (1993) using I and K-band observations respectively.*

Any SBF distance determination requires a prior estimate of the bright end of the stellar luminosity function (LF) in the target galaxy concerned. In practice, this information is generally based on the known stellar LFs of resolved Local Group galaxies of the same morphological type and colour, and whose distances are known (based on independently made distance measurements).

At the time of the first SBF distance determinations for M32, red-giant branch (RGB) stars had yet to be resolved in any [known] intermediate/giant early-type galaxy and had only just been resolved in M32 [whose type and distance we necessarily treat as unknown here] by Freedman (1989) and Davidge & Jones (1992) using the Canada-France-Hawaii telescope (CFHT). Also, M32's intrinsic colour and the value of A_B(M32) were of course unknown as they still are today (see Section 2.2). The required LF information was therefore unavailable. Note that in order to calibrate the absolute magnitude scale of M32's stellar LF from stellar photometry, one would need to assume M32's distance a priori–a procedure that would clearly invalidate any SBF distance determination based on such an LF. Consequently, assumptions about the bright end of M32's stellar LF had to be inferred from galaxies of other morphological types. The SBF distance determinations of Tonry & Schneider (1988), Tonry (1991) and Luppino & Tonry (1993) therefore awaited confirmation (1) that the morphology of M32's colour-magnitude diagram (CMD) was similar to that previously found in other Local Group galaxies (of different morphological types) including M31, as opposed to objects with anomalous SBFs suggestive of much brighter stellar populations, such as the isolated RCG, NGC 4489 (Pahre & Mould 1994; Jensen, Luppino & Tonry 1996; Jensen, Tonry & Luppino 1998; Mei, Silva & Quinn 2001); and (2) that the CMD morphologies of intermediate ellipticals would turn out to be similar to that of M32.

Confirmation that these assumptions appear to have been well justified came in two stages. First, the HST stellar photometry of Grillmair et al. (1996); Alonso-García, Mateo & Worthey (2004) and Worthey et al. (2004) found M32's CMD morphology and stellar apparent LF to be very similar to that of M31. More recently, Rejkuba et al. (2005) have resolved RGB stars in the halo of the nearby peculiar intermediate elliptical/lenticular NGC 5128 using the HST. Their study found an upper-RGB CMD morphology similar to that of M31 and M32. This finding is quite significant although it has two possible limitations. First, NGC 5128 is an active galaxy–the giant double radio source Centaurus A, which is believed to be a merger between an intermediate elliptical and a spiral galaxy. It is therefore certainly not an ideal model galaxy, but unfortunately there are no better candidates as no normal intermediate/giant elliptical galaxy is near enough for resolved stellar photometry. Secondly, the field studied was 33.3 arcmin (or $\sim$38 kpc) from the centre of NGC 5128. van den Bergh (1976) found the effective radius (r_e) of NGC 5128 to be 5.5 arcmin, so the halo field corresponds to a radial distance of about $6r_e$. This would correspond to a field at about 3 arcmin from the centre of M32, whereas the SBF distance measurements were based on the core of M32. If there are often major differences between the stellar populations of the cores of intermediate/giant ellipticals and their haloes, then the upper RGB stars observed in NGC 5128 may not necessarily be representative of the brightest stellar populations in the core of M32. Evidence has already been found for variations in stellar chemical composition and mean age (hence stellar LF too) between the inner and outer regions of M32 (Davidge, De Robertis & Yee 1990; Davidge 1991; Davidge & Jones 1992; Davidge & Nieto 1992; Rose et al. 2005) though the variations found are not large enough to invalidate the finding that M32 is at a similar distance to M31.

3.4 Red-giant-branch stars

• *Using the 2.5-m Mount Wilson telescope, Baade (1944) obtained red-sensitive photographic plates of M32, NGC 205 and the central region of M31 itself. On these plates, he found large numbers of faint stellar images associated with each galaxy. The images were just above the detection limit of his red plates but were not present on blue-sensitive plates of the same fields taken previously. This finding suggested that M32, NGC 205 and M31 had all been resolved into red-giant stars of similar magnitude (m_{pg} ∼21.3 mag), indicating that they were all at similar distances.*

In the 1940s, red giants were considered to be a homogeneous type of star and therefore any red giant was considered to be a viable distance indicator. We now know that there is a considerable range in intrinsic luminosity (and even colour) for red giants, depending on what the masses and abundances of their progenitors were and what stage of evolution they are in. A further complication might be variations in stellar chemical composition and mean age (hence stellar LF too) between M32, M31 and NGC 205; as well as between the inner and outer regions of M32 itself (Davidge, De Robertis & Yee 1990; Davidge 1991; Davidge & Jones 1992; Davidge & Nieto 1992; Rose et al. 2005). Therefore, the brightest red giants detected cannot be used as distance indicators in the straightforward way that Baade (1944) used them. At the very least, CMDs and/or stellar LFs are needed.

In the case of M32 (as opposed to NGC 205) crowding and contamination by stars in M31 are also major issues. Baade (1944) noted that: "the central part of M32 is completely burnt out", i.e. no stars could be resolved in the region where stars from M32 heavily outnumber those from M31. He further noted that: "at greater distances from the center of M32 the members of the two systems are hopelessly mixed". For intermediate radial distances, we note that crowding would affect annular regions centered on M32, which would appear to be centered on the centroid of M32–even if a significant component were due to stellar images from M31 merged with others due to M32. The brightest point-like images could therefore have been artifacts of both crowding and contamination by M31.

In the absence of reproductions of the plates taken by Baade (1944) and information detailing specifically which fields were used to identify the red-giant members of M32, it is not possible to quantify the degree of crowding or contamination by M31. However, it is probably significant that in the optical, red giants were not resolved unambiguously in M32 [again] for another fifty years–until HST images became available in the mid 1990s. Although successful in detecting bright RGB stars in M32 and M31, even the CFHT 3.5-m *VRI* stellar photometry of Freedman (1989) was subsequently found to suffer from the effects of crowding (Grillmair et al. 1996)[4].

• *A distance of 0.63±0.6 Mpc (with minor adjustments for different assumed metallicities and different interpretations of the data) was derived for M32 by Freedman (1989) based on [ground-based] CFHT VRI-band stellar photometry of RGB stars in M32 and M31. In a major advance on the earlier study of Baade (1944), RGB stellar LFs were used instead of the vague concept of the 'brightest' stars.*

A clear and concise discussion of those issues in Freedman (1989) relevant to the distance determination is given by Freedman (1990) to which readers are referred. As explained by Freedman (1990) in order to proceed with the distance estimation, an assumption was needed regarding the type of stellar population being observed. On the assumption that the tip of the RGB was being observed, two slightly different alternative distance estimates were obtained, based on the interpretation of two separate minor discontinuities found in the derived LFs (at $I = 20.1$ and 20.5 mag) as the tip of the RGB.

Although the ground-based photometry of Freedman (1989) was found by the later HST-based study of Grillmair et al. (1996) to suffer from some crowding problems, the basic assumption of Freedman (1989) that the tip of the RGB had been observed was confirmed by Grillmair et al. (1996). Whilst the ground-based photometry only penetrated 1-to-2 mag below the observed discontinuities, the photometry of Grillmair et al. (1996) was about 3-to-4 mag deeper.

• *HST Wide-field Planetary Camera 2 (WFPC2) optical stellar photometry of M32 and M31 has yielded stellar LFs that are so similar that no difference in [relative] distance was detectable (Worthey et al. 2004). This result is supported by CMDs also constructed from WFPC2 photometry which show little difference in morphology or apparent magnitude between the RGB stars resolved in M32 and M31 (Grillmair et al. 1996; Alonso-García, Mateo & Worthey 2004; Worthey et al. 2004). Deeper stellar photometry obtained very recently using the HST's Advanced Camera for Surveys (ACS) also supports this result (Worthey, private communication).*

Both WFPC2-based studies (Grillmair et al. 1996 on the one hand and Alonso-García, Mateo & Worthey 2004 and Worthey et al. 2004 on the other) derive $(V - I)$ versus I CMDs for M32 and M31, yielding a single RGB of similar apparent brightness for each galaxy. Now, let us consider what kind of CMDs we might expect to see should M32 lie at three times the distance of M31. Assuming that the RGBs in both galaxies are of similar intrinsic brightness[5], M32's RGB would be observed to be about 2.5 mag fainter than M31's, making it largely undetectable. This is because for a star to appear on a $(V - I)$ versus I CMD, not only must it be bright enough in I, but it must also be detected in V (in order to have a colour assigned to it at all). Figure 8 of Grillmair et al. (1996) incorporates a $V = 26$ mag approximate cutoff, shown as a diagonal dotted line. If the RGB found for M32 (or that found for M31) were shifted 2.5 mag faintward, it would lie completely below this dotted line. Similar selection effects must apply to figure 2 of Alonso-García, Mateo & Worthey (2004) (which shares the same dataset as Worthey et al. 2004). This would mean that the RGBs observed in the CMDs for the M32∪M31 field with an estimate for M31's

[4] By contrast, ground-based infra-red stellar photometry of M32 (Freedman 1992; Davidge & Nieto 1992; Elston & Silva 1992) has generally been more successful as it does not appear to have suffered from significant crowding.

[5] Until very recently, it was impossible to predict the precise nature of the stellar populations in normal intermediate or giant early-type galaxies because none had been resolved. However, as mentioned in Section 3.3, RGB stars have very recently been resolved in the halo of the nearby galaxy, NGC 5128 by Rejkuba et al. (2005). The results suggest that its upper-RGB CMD morphology is very similar to that already found for M31 and M32 by Grillmair et al. (1996), Alonso-García, Mateo & Worthey (2004) and Worthey et al. (2004). Although NGC 5128 is by no means an ideal model galaxy, the absence of any brighter hitherto unknown red-giant population suggests that intermediate and giant ellipticals probably possess similar RGBs to those of M32 and M31. However, we note that early-type galaxies with anomalously bright, but as yet unresolved, populations seem to exist, in the form of the RCG, NGC 4489 (Pahre & Mould 1994; Jensen, Luppino & Tonry 1996; Jensen, Tonry & Luppino 1998; Mei, Silva & Quinn 2001).

component subtracted, could not be comprised of stars from M32. They would have to be comprised of crowding peaks and/or members of M31. Is such a scenario possible though?

Crowding that was not taken account of by the stellar photometry software would result in the merging of fainter stellar images into brighter peaks. This would affect the denser M32∪M31 fields more than the M31-only control fields, and M32's RGB would appear brighter than it really was. However, in order to achieve a brightening of 2.5 mag, typically 10 red giants would be needed per crowding peak. Such a level of crowding would presumably alter the morphology of the RGB by stretching it in magnitude space. As the observed RGBs do not show obvious signs of broadening in magnitude space, crowding is probably not a serious problem.

On the other hand, contamination due to M31 could be quite significant, because each WFPC2-based study was based on a single M31-only control field. Also, in each case, the correction for contamination by M31 was derived from the M31-only control field by the application of a simple multiplicative factor designed to account for the differences in the surface-brightness of M31 based on elliptical-isophote surface photometry. As A_B(M31) was an unknown quantity throughout, no account could be taken of the irregularities in M31's surface brightness or of the differences in absorption between the control fields and the M32∪M31 fields. As already mentioned in Section 2.2, the M32 direction appears to be devoid of absorption features and this may account for part of the over-density of bright resolved objects found in the M32∪M31 fields with respect to the M31 fields. Note also that the M32∪M31 fields were necessarily located far away enough from the centroid of M32 for severe crowding to be avoided. Whilst the M32∪M31 field of Grillmair et al. (1996) spanned a range in radial distance from M32's centre of about 1 to 2 arcmin, the field of Alonso-García, Mateo & Worthey (2004) and Worthey et al. (2004) was further out and spanned a range of about 3 to 4 arcmin. Particularly in the latter case, contamination due to M31 could be extremely serious. Alonso-García, Mateo & Worthey (2004) estimated that 41% of the stars found in their M32 ∪M31 field were due to M31, but, this figure is understandably highly uncertain. Whilst a significant upward revision of this percentage would probably not affect significantly the morphology of the inferred red clump for M32 alone, it could cause significant thinning of the much more sparsely populated RGB. However, it is very unlikely that this thinning could be sufficient to shift the tip of the RGB faintward by as much as 2.5 mag (albeit $<$2.5 mag, should the M31-only control field suffer from significant absorption).

We therefore find that although the WFPC2-based studies had some limitations, their findings nevertheless provided the first corroborative evidence in support of the existing view that M32 and M31 are at similar distances. Also, in a new development, we understand that recent ACS observations that reach even deeper than $I \sim 28$ mag do not show any sign of a second, fainter, RGB, which would be expected if M32 were a more distant galaxy (Worthey, private communication). When published, this new ACS photometry should provide further corroborative evidence that M32 is not a background galaxy.

4 RED COMPACT DWARFS BEYOND THE LOCAL GROUP

• *The existence of five other RCD candidates beyond the Local Group; namely NGC 4486B, NGC 5846A, two objects in Abell 1689 discovered by Mieske et al. (2005) and one object in Abell 496 discovered by Chilingarian et al. (2007)*[6]*; suggests that M32's compactness is not unique and that its defiance of most known scaling relationships defined by normal early-type galaxies is therefore not a problem.*

This line of argument assumes that it has been established that the other candidates are definitely RCDs. Whilst it would be strengthened if it were proven that these other objects were indeed genuine RCDs, it would not follow that M32 must also be one–especially as M32 would have to be the most extreme example of all (cf. fig.s 3 and 4 of Chilingarian et al. 2007). Likewise, if it were ever demonstrated that M32 were definitely a background galaxy, it would not follow that other RCD candidates must also be background galaxies. Linkages of this nature can at best only provide circumstantial evidence.

It could also be argued that the extreme rarity of RCD candidates calls into question the very existence of this morphological type of galaxy. In fact Graham (2002) has already called into question the existence of compact ellipticals (cf. lenticulars). Considering the vast numbers of galaxies that have been observed to date (including a large number of ongoing and recent mergers) and that there have been [unsuccessful]

[6] Note that giant or intermediate RCGs are too large to be relevant to the present discussion. Likewise, ultra-compact dwarfs (UCDs) are too small. UCDs, which were discovered in the Fornax cluster by Hilker et al. (1999) and Drinkwater et al. (2000) are typically 5 mag less luminous than M31's main companions.

systematic searches for RCDs in nearby clusters (Drinkwater & Gregg 1998; Ziegler & Bender 1998) the scarcity of examples may be more significant than the existence of several RCD candidates.

We note that whilst the extreme rarity of RCD candidates could be due to abnormal physical conditions that only last for relatively short periods, e.g. galaxies in the process of being tidally stripped by larger neighbours[7], it could possibly be the product of some rare observational selection effects, e.g. galaxies' discs being submerged beneath the signal and noise of the bright discs or haloes of larger neighbours and the inherent difficulties involved in subtracting off the 'background' light from these giant neighbours. We would like to see a definitive study of the 'background'-subtraction issues in order to rule out (or rule in) this possibility. Note also that the fact that there are so few RCD candidates allows for a different explanation for each individual case.

• *Based on certain well-known scaling relationships, RCDs (as opposed to normal [lower surface-brightness] dwarf ellipticals) are known to be the low-luminosity relatives of normal giant ellipticals (Wirth & Gallagher 1984; Kormendy 1985). RCDs, including M32, are therefore not abnormal at all as they are structurally similar to giant ellipticals.*

This issue has already been dealt with briefly in Appendix A and readers are referred to Graham & Guzmán (2003) and Graham (2005). To this it should be added that the notion of a dichotomy between normal early-type giants on the one hand, versus normal [low surface-brightness] early-type dwarfs on the other, has been renounced even by its staunchest proponents (see e.g. Jerjen & Binggeli 1997 cf. Binggeli & Cameron 1991).

5 SUMMARY, DISCUSSION AND CONCLUSIONS

Prior to Baade (1944) it was not known whether M32 was a dwarf satellite of M31 or a background galaxy. However, following Baade (1944) it became established as an unquestionable fact that M32 must be a dwarf satellite of M31. We have demonstrated that contrary to popular belief, the only robust evidence for this case is very recent in nature and ultimately rests entirely on resolved stellar photometry obtained with the HST. In other words, in the absence of these HST observations, the hypothesis that M32 might be a background galaxy would still be irrefutable. The assumptions on which the distance measurements derived from SBFs (Tonry & Schneider 1988; Tonry 1991; Luppino & Tonry 1993) and ground-based resolved stellar photometry (Freedman 1989) were based, have been confirmed by later HST observations [8], but all of the preceding evidence beginning with that of Baade (1944) was found to be circumstantial.

We accept that M32 could well be an RCD satellite of M31. Unfortunately however, we would be left with the well known problem of explaining why M32 (and to a lesser extent five other less extreme RCD candidates) should defy most known scaling relationships defined by normal early-type galaxies. This is regardless of whether M32 is an elliptical or a lenticular. Presumably this might be because RCDs are in the process of being tidally stripped and are therefore stellar systems that are not in equilibrium. More specifically though, a major problem we are left with is why as a dwarf galaxy, M32 should have a central stellar velocity dispersion several times higher than that of M31's other main companions (which are of similar apparent brightness to M32). Could this be because M32 used to be a much larger normal galaxy prior to the commencement of the stripping process? If so, perhaps it could have retained its original central velocity dispersion. However, such a scenario would contradict the findings of Nieto & Prugniel (1987) and Choi, Guhathakurta & Johnston (2002) who concluded that the precursor of M32 was unlikely to have been a [larger] normal intermediate/giant elliptical galaxy. Alternatively, Bekki et al. (2001) have suggested that the precursor of M32 might have been a late-type spiral bulge. If so, this might help to explain M32's anomalously high central velocity dispersion. Another outstanding issue though is why M32's planetary

[7] Clear evidence for tidal truncation has yet to be demonstrated for any RCD candidate including M32. Although King & Kiser (1973) found the profile of NGC 5846A to be significantly truncated, this result may have been due to sky-level determination problems (Capaccioli & de Vaucouleurs 1983; Prugniel, Nieto & Simien 1987). Also, Prugniel, Nieto & Simien (1987) found that the profile of NGC 4486B did not appear to be severely truncated, though they found that the profile of an RCG also in the vicinity of M87 (i.e. NGC 4486), namely NGC 4478, did appear to be severely truncated. This latter galaxy is intrinsically about 2 mag brighter than NGC 4486B (Prugniel, Nieto & Simien 1987) (and about 3 mag brighter than M32 if it is at the same distance as M31). It is therefore an intermediate galaxy.

[8] As SBF studies amount to unresolved stellar photometry, they are related to (and complementary to) resolved stellar photometry but do not constitute independent evidence.

nebulae appear to be systematically fainter in apparent magnitude than M31's if the two galaxies are at the same distance.

The main arguments in favour of M32 being a normal background galaxy are as follows.

(1) M32's central velocity dispersion is typical of intermediate galaxies (including the bulges of lenticulars), and not of dwarfs. The homogenized mean value listed by the Hyperleda database is 72 km s $^{-1}$ cf. 23 km s^{-1} for NGC 205, 20 km s^{-1} for NGC 185 and 22 km s^{-1} for NGC 147 (homogenized mean values from Hyperleda)[9]. However, recent high-resolution measurements have yielded even higher values for M32 e.g. 126 $\pm$10 km s^{-1} (van der Marel et al. 1997) and 130 km s^{-1} (based on a Gaussian fit) or $\gtrsim$ 175 km s^{-1} (when corrected for the wings) (Joseph et al. 2001).

(2) Published planetary nebula observations from a variety of sources (Ciardullo et al. 1989; Hurley-Keller et al. 2004; Merrett et al. 2006) are all consistent in suggesting that M32 is at least twice as distant as M31.

(3) M32 would obey known scaling relationships defined by normal intermediate/giant early-type galaxies including the Fundamental plane (Djorgovski & Davis 1987) if it were of the order of three times more distant than M31.

(4) A physical explanation for M32's apparent compactness would no longer be needed.

However, this scenario cannot explain the results of space-based resolved stellar photometry of M32, which find its RGB to be very similar to M31's in both general morphology and apparent brightness–thereby requiring that the two galaxies are at almost identical distances. Only in the event of these results becoming open to re-interpretation could the new hypothesis become a viable explanation.

Unfortunately, as is evident from Figures A.1, A.2 and A.3, there does not appear to be any middle ground between these two scenarios. If M32 were behind M31 but close enough to M31 to be interacting with it, explanations for M32's high central velocity dispersion and faint planetary nebulae would still be needed. We therefore find that we are left with two apparently irreconcilable scenarios, only one of which can be correct, but both of which suffer from potentially fatal evidence to the contrary. This suggests that current understanding of some relevant fields is inadequate and that further study is urgently needed.

As far as further work on M32 is concerned, the optical thicknesses of the relevant regions of M31 are critical quantities that remain to be determined, and more studies on this problem would therefore be welcomed. Another remaining long-standing problem with wide-ranging implications is how the irregular component of the light contribution from M31 should be accounted for. The most rigorous subtraction of light from M31 to date is probably that performed for the surface photometry of Choi, Guhathakurta & Johnston (2002)[10]. As these authors noted though, their elliptical isophotal model of M31 was unable to account for fine-scale structure such as dust lanes and spiral structure. With this in mind and on account of the newly-found importance of the HST-based stellar photometry, there is clearly a need for future space-based resolved stellar population studies, to obtain not just one, but several such M31-only control fields and at more carefully chosen locations. Longer telescope-time allocations will therefore be needed.

6 ACKNOWLEDGEMENTS AND AUTHOR CREDITS

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Appendix A: DISTANCE ESTIMATION BASED ON SCALING RELATIONSHIPS

First, in Figure A.1, we consider a wide range of known two-parameter relationships for early-type galaxies based on a sample of 43 Fornax Cluster (FC) elliptical and lenticular galaxies. This sample includes giants, intermediates and [normal] dwarfs; which are currently accepted as defining a continuous sequence in Sérsic luminosity-profile shape index n (Sérsic 1968) as well as in many other physical properties, as discussed by

[9] The Lyon-Meudon Extragalactic Database (Hyperleda) is maintained by the Centre de Recherches Astronomiques de Lyon and available online at http://leda.univ-lyon1.fr

[10] Following the example of Choi, Guhathakurta & Johnston (2002) meaningful tests of the viability of models for M31 and M32's light distributions are possible. Synthetic images can be generated for the entire M31$\cup$M32 field, in which (1) only M32 has been subtracted, (2) only M31 has been subtracted, and (3) both M32 and M31 have been subtracted.

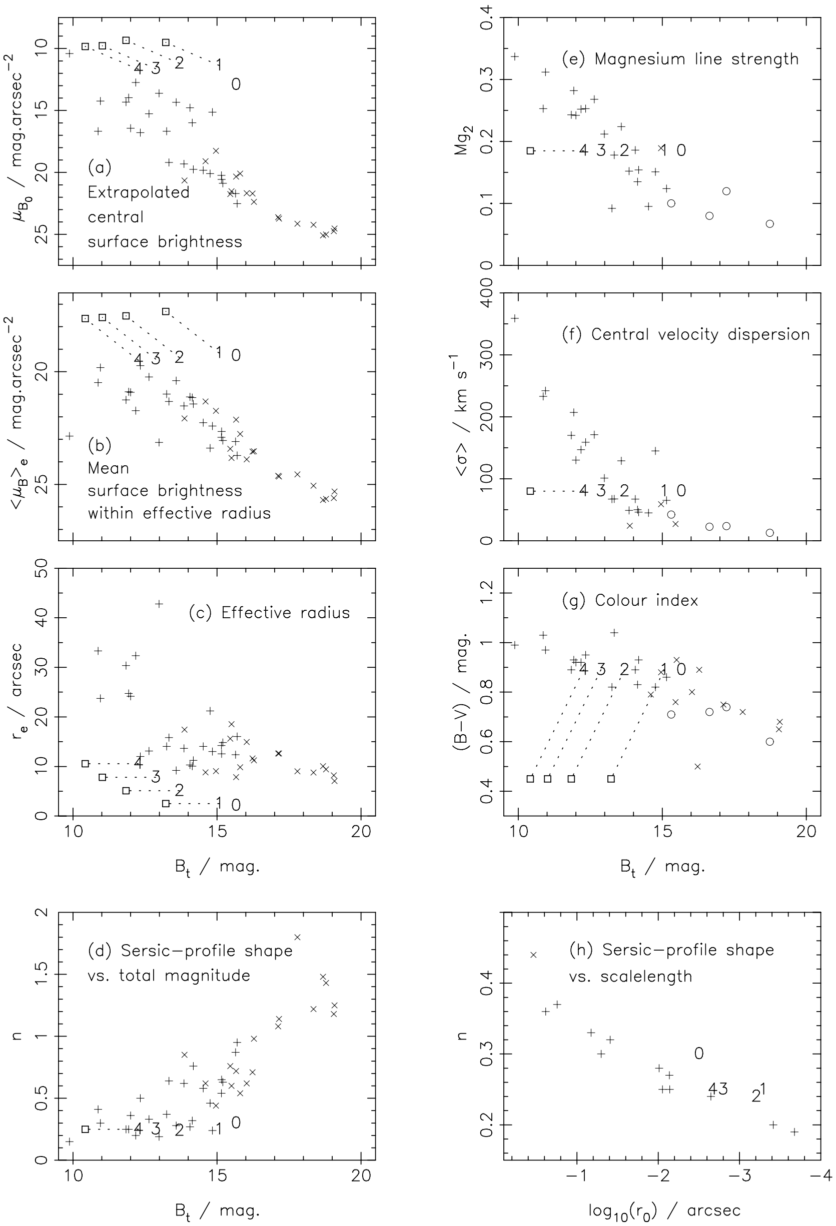

Fig. A.1 Expected positions (after relocation to the FC's distance of 20 Mpc) of M32 as a function of its true distance (which is unknown) relative to two-parameter relationships for 43 early-type FC galaxies (including Es, dEs, S0s and dS0s). Numeral symbols '0' denote a true distance of 0.76 Mpc whilst the other integer symbols denote integral true distances in Mpc, all assuming A_B(M31)=0 mag; '□' symbols denote corresponding distances of 1 through 4 Mpc [or 4 Mpc only in the cases of (d), (e), (f) and (h)] assuming A_B(M31)=1.85 mag from Ford, Jacoby & Jenner (1978); whilst the dotted lines denote $0.0 < A_B$(M31)< 1.85 mag. '+' and '×' symbols denote Caon, Capaccioli & D'Onofrio (1994) and Caldwell & Bothun (1987) B-band FC surface-photometry data respectively; the former, whose sky subtraction procedures were superior, having been used for the nine common objects. '○' symbols denote the Local Group galaxies NGC 205, 185 and 147, as well as the Fornax dwarf spheroidal, when published data were available. Magnesium line strengths, 'Mg_2'; central velocity dispersions, '$\langle\sigma\rangle$' and '$(B-V)$' colour indices were collated from Hyperleda. For M32, the Hyperleda values of $\langle\sigma\rangle$ exhibited a large scatter, so we adopted the median value of 81 km s^{-1}. 'B_t', 'μ_0', r_0 and 'n' denote the Sérsic (1968) parameters total magnitude, central surface brightness, scale length and profile shape respectively; whilst 'r_e' and '$\langle\mu\rangle_e$' denote effective radius and mean surface-brightness within r_e respectively.

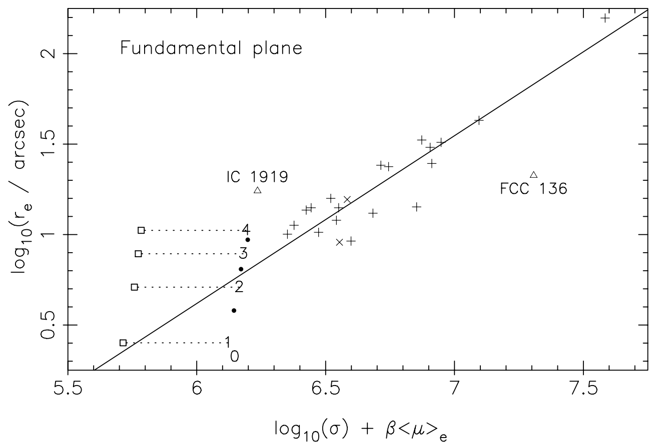

Fig. A.2 Expected positions (after relocation to the FC's distance of 20 Mpc) of M32 as a function of its true distance (which is unknown) relative to the Fundamental plane, $\log_{10} r_e = 0.928(\log_{10}\langle\sigma\rangle + 0.220\langle\mu\rangle_e) - 4.95$, for early-type FC galaxies (both Es and S0s) with velocity dispersion measurements. The notation follows Fig. A.1 except that the '•' symbols denote true distances of 1.5, 2.5 and 3.5 Mpc; all assuming A_B(M31)=0 mag. The solid line represents the best r_e-space minimized least-squares planar fit to the FC galaxies after the removal of the two outliers ('△' symbols).

Graham & Guzmán (2003) and Graham (2005) [11]. Recent measurements place the FC at a distance of about 20 Mpc (Freedman 2001; Tonry et al. 2001; Jerjen 2003). In this section, we investigate where M32 would lie with respect to these relationships, if it were re-located to a distance of 20 Mpc and imaged at the same resolution as the FC galaxy observations used. However, instead of assuming the actual distance for M32 to be 0.76 Mpc, we have treated this quantity as an unknown variable lying somewhere within the range 0.76 to 4.0 Mpc. We find that M32 defies all of the relationships except for Figure A.1(g), the colour-magnitude diagram (CMD) (which it fits only very poorly) if its actual distance were about 0.76 Mpc, but would fit all of them including the CMD (which it would fit extremely well) should its real distance be about 2-to-3 Mpc and A_B(M31) be small. Although most of the two-parameter correlations are not strong enough for the purpose of accurate distance estimation, several of them are nevertheless of great relevance because they have long been used (e.g. by Binggeli & Cameron 1991) to demonstrate and characterize the anomalous characteristics of RCGs.

Applying the three-parameter Fundamental plane of Djorgovski & Davis (1987) leads to an absorption-dependent distance estimate of $2.3 - 0.77(A_B(\text{M31})\ \text{mag}^{-1})$ Mpc, the random error component being largely due to intrinsic scatter in the FC locus. This result is shown in Figure A.2. Note that recent evidence that the Fundamental 'plane' becomes a curved sheet for normal [i.e. low surface brightness] dwarf ellipticals (Graham & Guzmán 2003; Graham 2005) may reduce the accuracy of the above calculation but does not invalidate it. This is because the curvature is such that should M32's true distance be similar to that of M31, it would be even more deviant from the low-luminosity end of the Fundamental 'sheet' than it already is from the low-luminosity linear extrapolation of the plane as shown in Figure A.2. Also, should M32's true distance be of the order of 2.3 Mpc, it would no longer be a dwarf galaxy and could therefore be expected to conform to the essentially planar part of the Fundamental plane for early-type giant and intermediate galaxies.

[11] According to the traditional view (Wirth & Gallagher 1984; Kormendy 1985) that red compact dwarfs such as M32 (as opposed to normal dwarf ellipticals) are the low-luminosity relatives of giant ellipticals, M32 should obey most of the scaling relationships defined by giant ellipticals whereas normal dwarf ellipticals should defy them. However, as evident from Fig. A.1, this is clearly not the case.

FC-galaxy Sérsic (1968) parameters were derived from the surface photometry of Caldwell & Bothun (1987) and Caon, Capaccioli & D'Onofrio (1994)[12] following procedures (and nomenclature) previously used by Young (2001) for Virgo photometry. As Sérsic (1968) parameters are seeing dependent (Young 2004 and references therein) and Caldwell & Bothun (1987) did not quote seeing discs for their FC photometry, we estimated their seeing by fitting Gaussians to the nuclei of the 9 nucleated dwarf ellipticals in their sample. The overall mean seeing full-width half maximum (FWHM) for both sources of photometry was subsequently found to be 1.8 arcsec. A more detailed description of these procedures will be given by Young et al. (in preparation).

Computation of M32's global parameters involved reconstructing a 1-arcsec pixel two-dimensional image of the galaxy from the surface photometry of Kent (1987). We transformed the r_{TG}-band photometry to B-band photometry according to $B = r_{TG} + 1.21$ mag and evaluated μ_B for each pixel by fitting a cubic spline to points on the straight line that passed through both the image centroid and the centre of the pixel concerned. The points fitted were the intersections between the radial line and the published elliptical isophotes taking full account of the differing position angles of each isophote. For all pixels exterior to the outermost isophote, μ_B values were estimated by linear extrapolation in μ_B-r space. The synthetic image was then scale reduced to a series of images corresponding to the angular sizes that would be subtended if the galaxy's actual distance were 0.76 through 4.0 Mpc, and it were subsequently relocated to 20 Mpc. This scale reduction was accompanied by simultaneous re-gridding in order to create 1/3-arcsec pixel images, which were then convolved with point-spread functions (modelled using Equation 6 of Racine 1996 which has a dynamic range of 14 mag arcsec^{-2}) in order to mimic the effects of a seeing disc of 1.8-arcsec FWHM. Surface photometry was then performed and Sérsic (1968) models fitted to the final profiles excluding isophotes corresponding to $r < 0.9$ arcsec in each final image and to $r > 220$ arcsec in the original image. Extrapolated regions exterior to the outermost isophote of the published surface photometry therefore underwent convolution but were not fitted by the profile models.

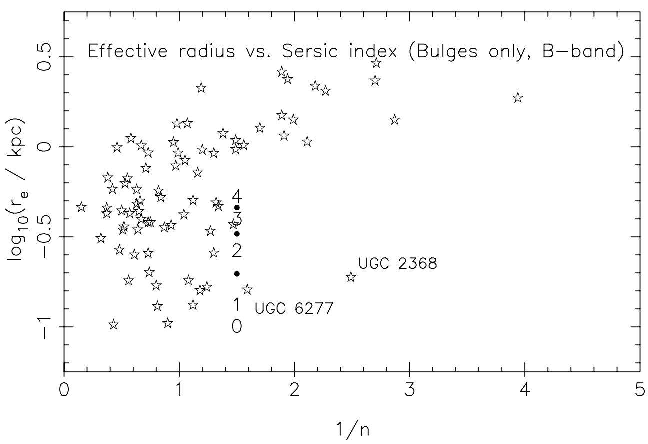

Fig. A.3 Expected positions of M32's bulge as a function of its true distance (which is unknown) relative to the bulges of those 86 spiral galaxies in the sample of de Jong & van der Kruit (1994) with B-band data. Parameters for M32 are from Graham (2002) without further seeing corrections applied, whilst all Sérsic (1968) indices (n), effective radii (r_e/arcsec) and radial velocities for the spiral bulges are from the addendum to Graham (2001) as opposed to the original paper. Note that n in our notation is equivalent to $1/n$ in the notation of Graham (2001, 2002). Some of the [significant] scatter in the locus defined by the spiral bulges must be due to the sample galaxies being at widely differing distances that could only be estimated approximately–via their radial velocities (assuming $H_0 = 75$ km s^{-1} Mpc^{-1}) and with corrections for Virgocentric infall from Mould et al. (2000). However, uncertainties in Sérsic (1968) profile parameters are also quite significant for some galaxies. The notation for M32 follows Fig. A.2 whilst spiral bulges are denoted by $\star$ symbols.

[12] There were 44 galaxies in this combined sample, but NGC 1428 is now known to be affected by a bright foreground star (Merluzzi et al. 1998) and therefore had to be excluded from the analysis.

So far we have compared the global properties of M32 and early-type galaxies in the FC. Should M32 be a lenticular galaxy, i.e. a two-component system, as first proposed by Graham (2002), we should be able to refine our comparisons by comparing bulge-specific properties after profile de-composition. Now, Graham (2002) finds the Sérsic (1968) index of M32's bulge to be $n = 0.67$ in our notation, and has already demonstrated that many of M32's properties are characteristic of normal lenticular systems e.g. (1) its luminosity excess at intermediate radial distances with respect to a single component Sérsic (1968) luminosity-profile model, (2) its significant ellipticity gradient (suggesting the increasing dominance of a disc at high radial distances) as well as (3) its bulge-to-disc size and luminosity ratios. In the present study though, our main interest is in distance-dependent parameters, notably the effective radii (r_e) of the bulges of both M32 and known two-component systems. As evident from Figure A.3, the small effective radius of M32's bulge (which Graham 2002 found to be 27 arcsec or $\sim$100 pc if M32's distance is similar to that of M31) is highly consistent with it being a background galaxy.

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