COMPACT ELLIPTICAL GALAXIES

Jean-Luc Nieto and Philippe Prugniel
Observatoire du Pic-du-Midi et de Toulouse
14 Avenue Edouard Belin
31400 Toulouse
France

ABSTRACT. We summarize our present knowledge on low-mass high-surface brightness elliptical objects near massive galaxies that are often called M32-type or compact elliptical galaxies. The origin of the low mass of these objects is a controversial matter: is it intrinsic to their formation or produced, as classically believed, by tidal stripping from the massive neighbor? We present new observational data allowing to define better the characteristics of these objects and a simple theoretical model whose consequences support the idea that the precursors of compact ellipticals are related to the low-mass end of the luminosity function of elliptical galaxies.

1. A CLASSICAL VIEW ON COMPACT ELLIPTICALS

Compact elliptical galaxies are those objects limited in size, probably by the tidal field of their large neighbor, as first suggested by King (1962) for M32. Two other galaxies, beside M32, have been classically incorporated into this class: NGC 4486B, at 7'3 from the center of M87, and NGC 5846A, at 0'6 from the center of NGC 5846. Often called "M32-type", this class of elliptical galaxies suffers from several aspects: it is depopulated, numbering only as yet three objects, and the common characteristics of its galaxies are not defined with certainty.

From King's (1962) first discussion and following the classical model proposed by Faber (1973), these (gas-depleted) galaxies, once normal ellipticals (e.g. of the NGC 3379 type) lost their external mass by tidal interaction with the massive neighbor so that their three caracteristics are, classically :

i) they are close to a bright galaxy;
ii) they have a high-surface brightness;
iii) they are tidally-truncated.

The high surface-brightness of these objects is illustrated in Figure 1 showing the blue effective magnitude (in magarcmin^{-2}) versus the absolute magnitude for different types of elliptical-like galaxies, all taken from the Second Reference Catalogue of Bright Galaxies (de

T. de Zeeuw (ed.), Structure and Dynamics of Elliptical Galaxies, 99–107.

https://doi.org/10.1017/S0074180900185092 Published online by Cambridge University Press

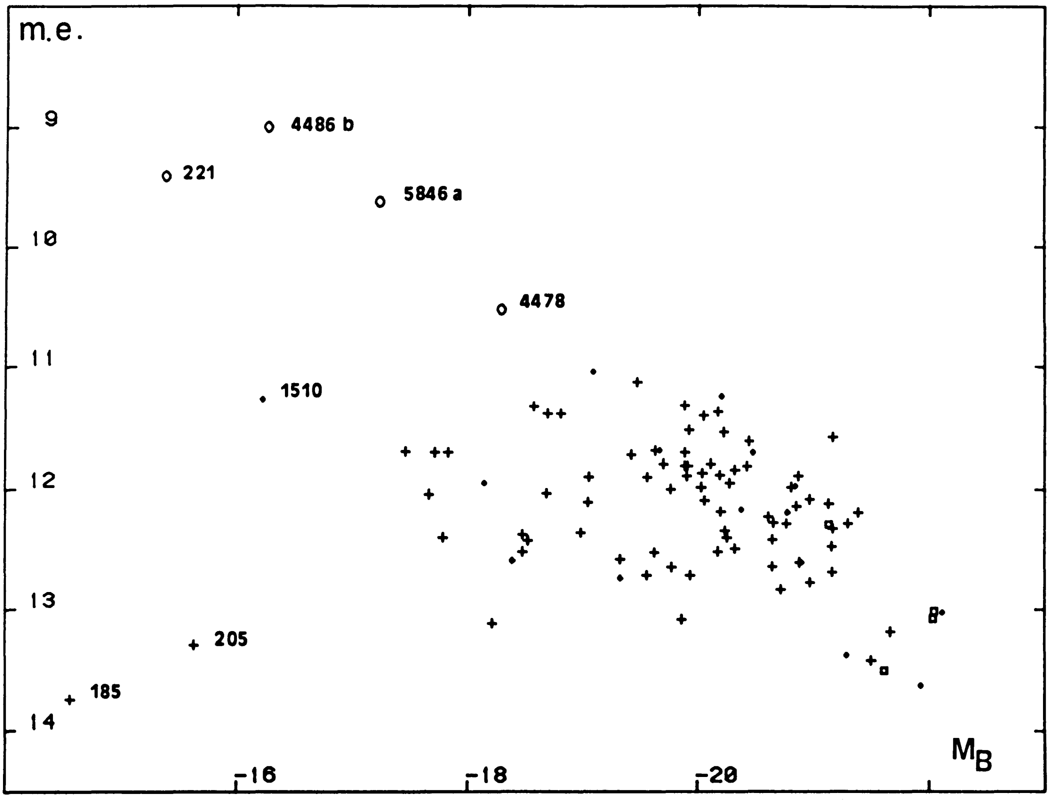


Figure 1: Blue effective magnitude (in mag arcmin^{-2}) versus absolute magnitude for different types of elliptical-like galaxies, taken from the RC2. The absolute magnitudes were calculated after de Vaucouleurs and Olson (1983) or with H_0 = 100 kms^{-1}Mpc^{-1}. Details are in Nieto and Prugniel (1987).

Vaucouleurs et al., 1976; RC2). The three compact ellipticals (and NGC 4478) are represented as well as NGC 185 and NGC 205, prototypes of spheroidal galaxies, normal elliptical galaxies and cDs.

Several papers were addressed to defining the specificity of these three objects : Rood (1965), King and Kiser (1973), Kormendy (1977), Tonry (1981). Almost all other candidates for this class, taken either from the RC2 or from the list of the Virgo cluster cE candidates provided by Binggeli et al. (1985), have not been photometrically investigated for tidal truncation. One of them, NGC 1510, was rejected on the basis of its young star emission spectrum and its HII regions (Eichendorf and Nieto, 1984).

2. "STONES IN THE POND"

Wirth and Gallagher (1984) suggested the possibility for M32-like dwarf galaxies to be the natural low-mass continuation of normal ellipticals, essentially for two reasons :
i) the main body of M32 presents an $r^{1/4}$ profile as normal ellipticals do,
ii) there seems to exist (at least one) "free-flying" M32-like isolated elliptical.

Reason i) means that M32 is not structurally basically different, except for its low mass, from a normal elliptical galaxy. Both reasons i) and ii) suggest that the low mass of the so-called compact objects should not be attributed to the tidal interaction with the neighbor.

In addition, the expected signature of galaxies of this class, e.g. tidal truncation, is by no means observable in the outer regions of M32 because of the strong contamination by the spiral arm of M31 so that, after all, M32 itself could not belong to the M32-type class (see the discussion following this paper)! We shall go back to this point later.

3. WHY STUDY THE SO-CALLED COMPACT ELLIPTICALS?

a) The above considerations raise a fundamental question concerning the formation and evolution of ellipticals as a whole : what is the low-mass end of the luminosity function of elliptical galaxies ? Because of the strong discontinuity of the physical parameters between normal ellipticals and dwarf spheroidals (see Saito, 1978; Kormendy, 1985 and this symposium), other objects but dwarf spheroidals should be the low-mass continuation of normal ellipticals. It is therefore quite crucial to investigate in great detail whether compact ellipticals could be those. In other words, the relevant question is : "are their characteristics (low mass, compactness) intrinsic or due to tidal interaction ?"

If tidal effects are observable, compact ellipticals provide a unique ground to study the mechanisms of galaxy interactions involving two galaxies of quite different relative masses.

4. OUR APPROACH

We have started a long-term project to investigate these questions, based on two-dimensional photometric or spectroscopic observations of known or possible candidate cEs, whether isolated or not. These observations are completed by theoretical considerations. The photometric observations were made with photographic (prime focus CFH plates + Schmidt plates of CERGA) and CCD (Pic du Midi 2m telescope) material. We report here on high-resolution (FWHM ~ 0.7-1.0 arcsec) CFH photographic observations in the UBV bands of three small-sized early-type galaxies around M87 (NGC 4476, 4478, and 4486B) and of NGC 5846A. Two of them, NGC 4486B and NGC 5846A, were already known as cE. NGC 4478

https://doi.org/10.1017/S0074180900185092 Published online by Cambridge University Press

was suggested to us as candidate for compact elliptical by de Vaucouleurs (1983). For more details, see Prugniel et al.(1987).

5. OBSERVATIONAL RESULTS

Fig. 2a,b,c,d shows the photometric equivalent and geometric profiles of the four galaxies considered. We note the following :
i) NGC 4476 follows a perfect $r^{1/4}$ law. Since it bears a ring of dust, it should be considered as another dusty elliptical galaxy.
ii) NGC 4478 and NGC 5846A appear truncated and do not follow an $r^{1/4}$ law. This is also true to a lesser extent for NGC 4486B. In that sense, these three galaxies seem to behave differently from NGC 4476.....taken as an $r^{1/4}$ prototype obtained with the same data. They fit reasonably well a King model (King, 1966) in their main body. NGC 4478 is then a fourth (but intermediate) case of tidally-truncated object.
iii) There is no apparent color (mass?) gradient in these objects within the uncertainties of our data.
iv) There is a trend in all cases for the outer isophotes to be more circular than the inner isophotes. This is also the case in M32 from our unpublished data (and from Tonry (1984) for the inner regions).

6. TREND FOR CIRCULARITY OF THE EXTERNAL ISOPHOTES

This trend should not pertain specifically to compact ellipticals since most of isolated ellipticals (certainly for other reasons) seem to show this property (di Tullio, 1979). However, there is certainly an idea of non-elongation linked to the intuitive idea of "compactness". If this trend for circularity is related to tidal effects, this means that the effect of tidal stripping would be to attenuate the intrinsic flattening of the isophotes: this is at first sight surprising since evidences for tidal interactions between galaxies reported in the literature often correspond to distorsions and elongations in the direction of the nearby massive galaxy. It seems as if the (intrinsically elongated) shape of the compact object is affected not by the instant potential but instead by the average of this potential over several orbits about the massive galaxy. Numerical simulations should quantify this suggestion.

7. THEORETICAL INVESTIGATIONS: A FRAMEWORK

Following Faber (1973), we shall assume that the compact object was once a normal elliptical galaxy that was captured by the massive neighbor. Dynamical friction (given by the local Chandrasekhar formula) is responsible for slowing down the galaxy on its orbit. The increasing tidal effects modify the characteristics of the companion.

We shall assume also that the present stellar distribution and dynamics follow an energy-truncated isothermal model (King, 1966).

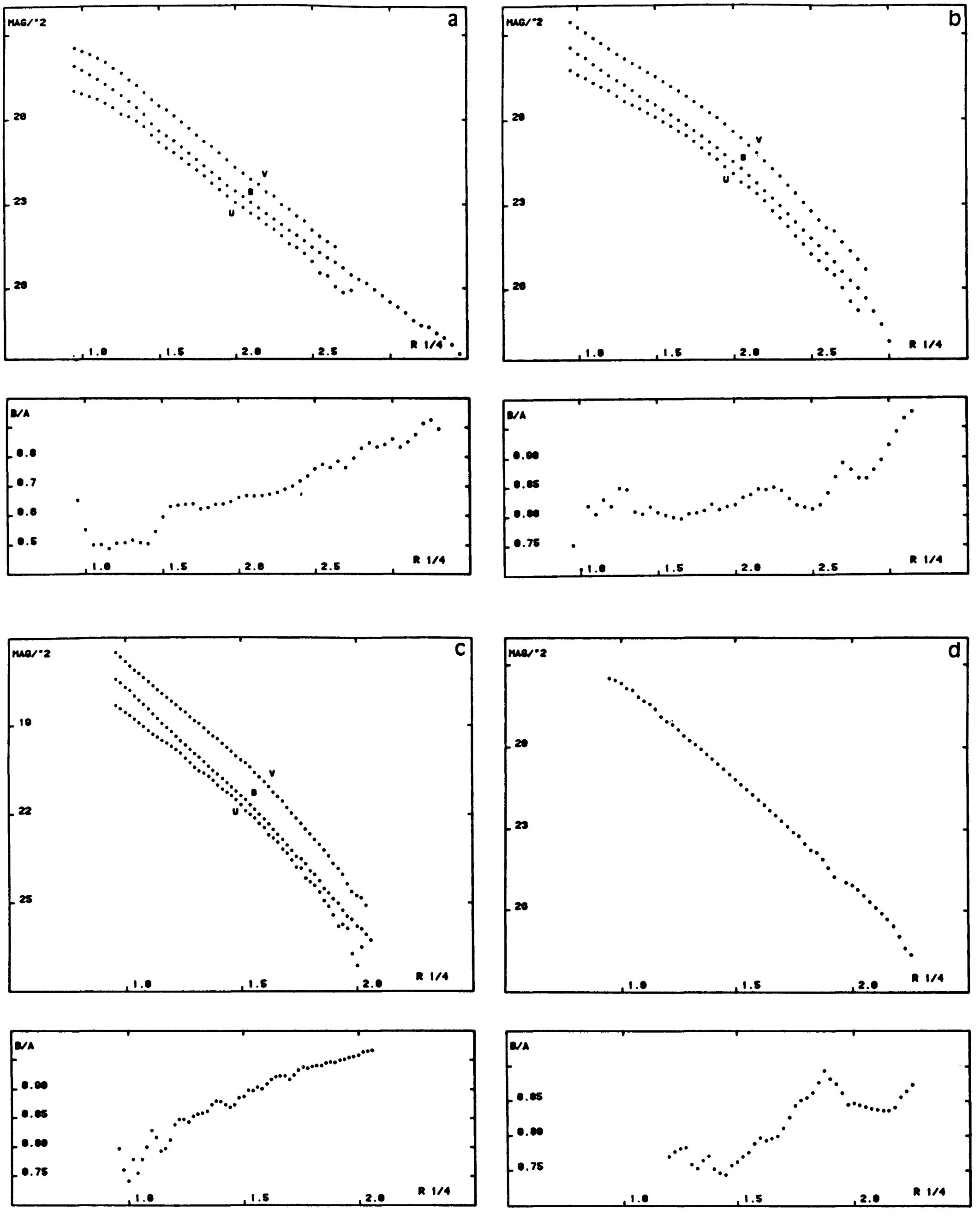


Figure 2: Equivalent photometric and ellipticity profiles of the three companions of M87, NGC 4476(a), NGC 4478(b), NGC 4486B(c) and of NGC 5846A (d).

https://doi.org/10.1017/S0074180900185092 Published online by Cambridge University Press

Since, as currently believed (e.g. Faber, 1973), the stripping should not affect the center of the captured system, we shall assume that the core radius, r_c and the central density are constant during the evolution: only the concentration, $c = r_t/r_c$, where r_t is the tidal radius, varies. (We shall assume that the capture has not affected the structure of the system).

Consequently, in a first approximation, the mass of the object is proportional to its tidal radius. This is at variance with previous considerations (e.g. Byrd (1979) where the mass of the compact was taken constant. For more details, see Nieto and Prugniel (1987).

8. TYPICAL PHOTOMETRIC EVOLUTION OF A COMPACT ELLIPTICAL

In such a framework, a typical galaxy such as NGC 4486B should have evolved from log c = 2.25 (assumed to be typical of normal ellipticals) to log c $\sim$ 1.7 (derived from our data). Assuming a constant M/L during its evolution, the mass of NGC 4486B should have been about three to four times its present mass, which is about 2×10^9 $M_\odot$ after Nieto and Monnet (1984). We conclude that the precursor of NGC 4486B was originally a low-mass object. What could it be? An effect of the capture would be to decrease its binding energy per unit mass and yield a lower surface-brightness object. Since the present object has a high surface brightness, it would be very difficult to conceive that it could come from a low surface-brightness object. It is more logical to assume that the precursor is instead a low-mass elliptical.

9. DECAY TIME SCALE

The orbital decay of a typical compact galaxy (NGC 4486B) can be followed from the time of the capture to present. The decay time scale R/(dR/dt) is much longer for a variable-mass King model than for a constant mass toward the end of the decay. A first estimate seems to indicate that it is even longer than the Hubble time by a large factor. We assume that the decay stops at a disruption radius, r_d, estimated to be reached when the central density of the compact is equal to the mean density of the tidally-limited system orbiting at a distance r_d from the center of the massive neighbor. For compact ellipticals, the disruption radius is of the same order as the core radius, a very small value indeed (3 pc).

This very long time scale for the orbital decay of the compact object means that we should see many such compact ellipticals in the core regions of giant (or normal) galaxies, a prediction that is not confirmed by the observations (Sandage et al., 1985). We see for this three non-exclusive reasons:

i) the constraints on this type of capture are very severe and/or

ii) the destruction rate of such compact objects about massive galaxies is very high and/or

iii) the precursors of such compact objects are very rare.

https://doi.org/10.1017/S0074180900185092 Published online by Cambridge University Press

10. THE PRECURSORS OF COMPACT ELLIPTICALS

We are tempted to conclude from Sect. 8 that the precursors of such compact ellipticals are already low-mass elliptical objects that started to become tidally-truncated with the capture of the massive neighbor. Interestingly enough, one of the possible consequences of the slow decay (Sect 9), e.g. the precursor being rare, is quite consistent with this conclusion, since low-mass -e.g. faint- ellipticals are rare (Binggeli et al., 1985). Therefore, tidal stripping should not be responsible for the low mass of these objects. Even if compact ellipticals look more circular outwards than inwards, their precursors could as well have been elongated throughout.

11. THE LOW-MASS END OF THE LUMINOSITY FUNCTION OF ELLIPTICALS

We summarize the arguments favoring the idea that compact ellipticals (and not dwarf spheroidals) should be associated with the low-mass end of the luminosity function of ellipticals :

i) The luminosity profile of compact ellipticals is closer to an $r^{1/4}$ law than an exponential law (Wirth and Gallagher, 1984).

ii) Their metallicity indices are similar to those of ellipticals (Faber, 1973)

iii) Low-mass isolated ("free-flying") galaxies may exist (e.g. Wirth and Gallagher, 1984). This has to be confirmed (see the discussion following this paper).

iv) There is a well-marked discontinuity between the parametric and physical parameters of normal ellipticals and dwarf spheroidals (e.g. Saito, 1978, Kormendy, 1985).

v) A simple theoretical model calls for a low-mass elliptical precursor (this paper).

12. CONCLUSION

We are attempting a long-term study of compact elliptical galaxies. We derive from the observations presented here that NGC 4478 is a fourth object of this class, and that, in all cases considered, external isophotes are more circular outwards than inwards. A simple theoretical model as well as a few other arguments found in the literature supports the idea that compactness is intrinsic to the way these galaxies were formed. It also suggests that we should find isolated low-mass ellipticals morphologically similar - except for truncation - to these tidally-truncated ellipticals. How rare could they be?

REFERENCES

Binggeli, B., Sandage, A.R. and Tammann, 1985, Astron. J., **90**, 1681
Byrd, G.G., 1979, Astrophys. J., **231**, 32
Eichendorf, W., and Nieto, J.-L., 1984, Astron. Astrophys., **132**,342
Faber, S.M., 1973, Astrophys. J.,**179**, 423
King, I.R., 1962, Astron. J., **67**, 471
King, I.R., 1966, Astron. J., **71**, 64
King, I.R., and Kiser, J., 1973, Astrophys. J., **181**,27
Kormendy, J., 1977, Astrophys. J., **214**, 359
Kormendy, J., 1985, Astrophys. J., **295**, 73
Nieto, J.-L., Monnet, G., 1984, Astron. Astrophys., **139**, 464
Nieto, J.-L., Prugniel, Ph., 1987, in preparation.
Prugniel, Ph., Nieto, J.-L., Simien, F., 1987, in preparation.
Rood, H.J., 1965, Astron. J., **70**, 689.
Saito, M., 1978, Pub. Astron. Soc. Japan, **31**, 181.
Sandage, A.R., Binggeli, B. and Tammann, G.A., 1985, ESO Workshop on the Virgo Cluster, O.-G. Richter and B. Binggeli Ed., p. 239
Tonry, J.L., 1981, Astrophys. J., **261**, L1.
Tonry, J.L., 1984, Astrophys. J., **283**, L27.
Tremaine, S.D., 1976, Astrophys. J., **203**, 72.
di Tullio, G.A., 1979, Astron. Astrophys. Suppl ts., **37**, 591.
de Vaucouleurs, G., 1983, private communication
de Vaucouleurs G., Olson, D.W., 1983, Astrophys. J., **256**, 346
de Vaucouleurs, G., de Vaucouleurs A., and Corwin, H.G., 1976, Second Reference Catalogue of Bright Galaxies, University of Texas Press, Austin (RC2)
Wirth, A. and Gallagher, J.S., 1984, Astrophys. J., **282**, 85.

DISCUSSION

Richstone: I was under the (perhaps mistaken) impression that M32 is better fit by an $I(R) \propto R^{-1}$ law than by an $r^{1/4}$ law.

Nieto: I think that M32 is the most difficult case to analyse if we want to find a tidal truncation, that, in principle, should occur at rather faint brightness levels. This requires a perfect subtraction of the background light of M31 throughout M32. This background light of M31 is clumpy, and undesirable effects can occur. This is why we left M32 aside for the time being and concentrated on the other cases where the background removal is easier.

Kent: I have recently obtained photometry of M32 with a CCD and an 8 inch telescope. I was able to subtract the background light from M31. The luminosity profile shows a power law with a slope of -1.2 out to 18″ and a de Vaucouleurs profile past that radius. I find no obvious tidal truncation of the profile. Because compact galaxies have such a high characteristic surface brightness, the logarithmic slope of the luminosity profile is quite steep at the limiting radius seen on a photographic plate, even though the shape of the profile is like that of more normal ellipticals.

Kormendy: Tonry found, and I confirm, that the projected brightness profile of M32 is $I(r) \propto r^{-1.2}$ out to $r \sim 20''$.

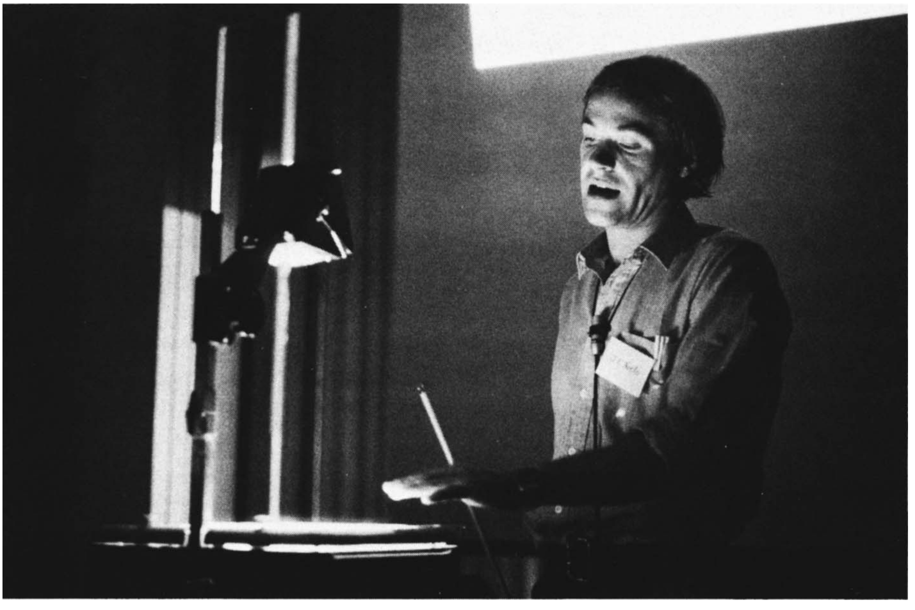
Djorgovski: The reason that we do not have more "free-flying" compact ellipticals is a very strong selection effect: such galaxies nearby are indistinguishable from L^* galaxies in the background. The reason that the three classical cases are found near other, larger, galaxies is that the big ones draw the attention, so that the small ones are noticed. Tidal interaction may not be important at all.

Nieto: I fully agree.

Sadler: We know from the luminosity function of elliptical galaxies that low-luminosity ellipticals are very common in terms of their space density. Any galaxy sample that is magnitude-limited strongly selects against such objects, giving the false impression that they are scarce. There is certainly no shortage of the low-luminosity galaxies which you suggest as progenitors of tidally-truncated systems.

Nieto: Possibly. The point is that they are difficult to find because of observational effects that makes us focus instead on those near (larger) galaxies.

White: I don't think we have a good idea of what a tidally truncated galaxy *should* look like, so it may be dangerous to identify features in luminosity profiles as evidence of truncation. Perhaps the fact that the outer part of M32 is seen to follow an $r^{1/4}$ law implies that even tidal truncation cannot beat the theorem that de Vaucouleurs is always right!



Jean-Luc Nieto.

https://doi.org/10.1017/S0074180900185092 Published online by Cambridge University Press

François Schweizer with one of his pet galaxies.

https://doi.org/10.1017/S0074180900185092 Published online by Cambridge University Press