A&A manuscript no.
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3(11.03.2; 11.05.1; 11.06.2)

ASTRONOMY AND ASTROPHYSICS

M32–like galaxies: still very rare

M32 analogues do not exist in the Leo group

B. L. Ziegler ⋆ **and R. Bender**

Universitäts–Sternwarte, Scheinerstraße 1, 81679 München, Germany
email: ziegler@usm.uni-muenchen.de

Received August, 1997; accepted October, 1997

Abstract. New observations of galaxies in the direction of the Leo group, which were classified as being candidates for M32–like dwarf galaxies by Ferguson & Sandage (1990), show that these galaxies are normal elliptical galaxies at redshifts between $z = 0.02$ and $z = 0.06$. This result adds further evidence that the faint end of the luminosity function of elliptical galaxies falls off very steep and that objects like M32 are extremely rare.

Key words: galaxies: compact – galaxies: elliptical and lenticular, cD – galaxies: fundamental parameters

1. Introduction

M 32 is a galaxy with very unusual characteristics. Compared to dwarf galaxies having similar absolute brightness (M_B) its central surface brightness (μ_o) is 4 orders of magnitudes higher and its core radius (r_c) 3 orders of magnitude smaller (Kormendy, 1985). Within the two planes '$\mu_o$vs.M_B' and '$r_c$vs.M_B', M 32 lies approximately on the extension of the sequence defined by elliptical galaxies and is clearly distinct from the low surface brightness dwarf galaxies following a different sequence (cf. with Fig. 1). Therefore, M 32 is often denoted as a dwarf elliptical galaxy and the other dwarf galaxies as dwarf spheroidals (dSph) (Kormendy, 1987; Djorgovski, 1992), whereas other authors use the term compact elliptical for M 32 and dwarf elliptical for the low surface brightness objects only (Sandage and Binggeli, 1984; Bender et al., 1993)). So far, only very few other galaxies with properties similar to M 32 have been found (Sandage and Binggeli, 1984; Nieto and Prugniel, 1987; Davidge, 1991; Kormendy and Bender, 1994). But none of these galaxies has such extreme properties as M 32.

Ferguson & Sandage (1990) classified a number of galaxies in nearby groups as possible M32-type objects due to their compact appearance on photographic plates (similar to NGC 4486B in Sandage & Binggeli (1984) though NGC 4486B is still 2 mag brighter than M 32). We obtained spectroscopy of these candidate galaxies in the Leo group during a longer observing run within our project to study the evolution of elliptical galaxies (Bender et al., 1996; Ziegler and Bender, 1997). The galaxies were drawn from Table II of Ferguson & Sandage (1990) and are designated in the following as Leo #, where # corresponds to the number assigned in that table.

In the following sections we briefly describe the observations and their analysis, present the results and draw our conclusions.

Send offprint requests to: B. L. Ziegler

⋆ Visiting astronomer of the German–Spanish Astronomical Center, Calar Alto, operated by the Max–Planck–Institut für Astronomie, Heidelberg, jointly with the Spanish National Commission for Astronomy.

2. Observations and data analysis

Spectroscopic observations were made at the 3.5m telescope on Calar Alto using the Boller&Chivens TWIN spectrograph. The spectra cover the wavelength range $\lambda\lambda = 4500 - 6100$ Å and have an instrumental resolution of $\sigma_{\rm i} = 105 {\rm km\,s}^{-1}$. The exposure time was 1 h. The CCD images were reduced in the usual way and the spectra were extracted and integrated with an algorithm introduced by Horne (1986). Absorption line indices of Hβ, Mg$_2$, Mg$_{\rm b}$, Fe 5 ($\lambda_0 \approx 5270$ Å) and Fe 6 ($\lambda_0 \approx 5335$ Å) were measured in the one-dimensional spectra following Faber et al. (1985). They were corrected for velocity dispersion broadening and normalized to the Lick system by means of observed reference stars. Velocity dispersions were derived using the FCQ-method by Bender (1990). Details of the observational set-up, the reduction procedure and the derivation of the data can be found in Ziegler & Bender (1997).

To get an estimate of the apparent size, surface brightness and total brightness, the Leo galaxies were imaged with a CCD camera at the 80 cm telescope of the Wendelstein Observatory. A filter corresponding to the Cousins R band was used. A calibration accurate to about 0.1 mag was achieved by the observation of the standard star cluster NGC 4147 (Christian et al., 1985), which is located in the vicinity of the Leo group. The effective radius (R_e), effective surface brightness at R_e (SB$_e$) and total apparent magnitude (M_t) were derived with the isophote fitting technique introduced by Bender & Möllenhoff (1987) and using an $r^{1/n}$ growth curve.

Table 1. Spectroscopic parameters

galaxy	v_r ($\mathrm{km\,s^{-1}}$)	σ ($\mathrm{km\,s^{-1}}$)	$\mathrm{Mg_b}$ (Å)	$\Delta\mathrm{Mg_b}$ (Å)	Fe 5 (Å)	ΔFe 5 (Å)	Fe 6 (Å)	ΔFe 6 (Å)	Hβ (Å)	ΔHβ (Å)
Leo12	7299	≤81	1.27	0.14	1.22	0.15	1.58	0.18	1.22	0.10
Leo16	16494	385	4.82	0.08	3.00	0.09	1.92	0.10	1.81	0.06
Leo18	14357	134	3.51	0.12	2.19	0.14	1.62	0.16	1.95	0.10
Leo44	17992	259	2.61	0.10	2.86	0.11	2.42	0.12	1.73	0.07
Leo51	6518	154	3.43	0.12	2.72	0.14	1.79	0.16	1.87	0.10
M32	–220	78	2.40	0.03	2.84	0.03	2.49	0.03	2.11	0.03
NGC1600	4973	382	5.25	0.03	3.04	0.04	3.19	0.04	1.50	0.03
NGC2300	1954	289	5.07	0.03	2.97	0.03	2.84	0.04	1.53	0.02

3. Results and conclusions

In addition to the program galaxies Leo 12, Leo 16, Leo 18, Leo 44 and Leo 51, spectroscopy was also obtained of the giant elliptical galaxies NGC 1600 and NGC 2300 as well as of M 32 itself for reference. Table 1 contains the spectroscopic data: the heliocentric radial velocity (v_r), the velocity dispersion (σ) and the absorption indices corrected for velocity dispersion broadening. The measurement errors of v_r and σ are less than $10\,\mathrm{km\,s^{-1}}$. Our instrumental resolution is too low to get a correct value of σ for M 32 and that's why we use the measurement of Davies et al. (1987). These authors used an aperture size which is effectively the same as ours.

For one M32 candidate – Leo 38 – we did not succeed in getting a spectrum but we obtained an image and it is included in Table 2. There, the effective radius (R_e), the effective surface brightness at R_e (SB_e) and the total apparent magnitude (M_t) in the R band are listed. To convert this magnitude to the B band, we use a $(B-R)$ color index of 1.8 which is typical for an elliptical galaxy at $z=0.04$ (Bruzual and Charlot, 1993). We estimate the error in magnitude to be roughly 0.1 mag and in effective radius $0\farcs5$. In Table 2, we also indicate the appearance of a substantial exponential component in the surface brightness profile.

Table 2. Photometric parameters

galaxy	R_e ($''$)	SB_e (mag/□$''$)	$M_t(R)$ (mag)	profile
Leo12	5.1	21.7	15.0	disk
Leo16	8.2	21.5	13.6	
Leo18	2.5	20.3	15.4	
Leo38	4.0	22.3	16.5	disk
Leo44	7.1	21.8	14.1	
Leo51	4.5	20.3	14.0	disk

The Leo galaxies have all non-zero redshifts already indicating brightnesses too high for dwarf galaxies and placing them well beyond the Leo group of galaxies. All measured quantities lie within the parameter range typical for normal elliptical galaxies. In particular, the Leo galaxies obey the well-known Faber-Jackson ($M_B-\sigma$), Fundamental Plane and Mg$-\sigma$ relation of elliptical galaxies. As an example, we show the location of the Leo galaxies in the surface brightness-absolute magnitude diagram in Fig. 1 in comparison to the compilation of dynamically hot galaxies given by Bender et al. (1993, BBF). The mean effective surface brightness within R_e was computed according to $\langle \mathrm{SB}_e\rangle = B + 5\lg(R_e) + 2.5\lg(2\pi) - 10\lg(1+z)$ with B being the total apparent B magnitude. It is evident that the Leo galaxies are not similar to M 32, but are giant or intermediate ellipticals in the nomenclature of BBF. Leo 12 could also well be classified as a bright dwarf elliptical. Leo 38 has a much too low surface brightness to be an M32 analogue and, so, even without a spectrum we can safely conclude that it is either a high luminosity giant elliptical at $z \approx 0.04$ or a dwarf spheroidal at $z \lesssim 0.01$.

In Fig. 2, we compare the absorption indices of the Leo galaxies to the sample of elliptical galaxies given by González (1993). Most of the measured values agree well with the González sample for the same velocity dispersion. The velocity dispersion of Leo 12 is so low that our instrumental resolution is insufficient to give an accurate value. Its small absorption indices indicate also the presence of a substantial stellar disk component that fills Hβ with emission and produces an [O III] emission line. Therefore, Leo 12 might even be a spiral galaxy seen face-on. The $\mathrm{Mg_b}$ absorption of Leo 44 is extraordinarily low which indicates low age and may be due to a disk component. This is supported by the Hγ absorption that is just redshifted enough to be visible at the blue end of the spectrum.

Both, the spectroscopic and the photometric parameters of the observed Leo galaxies demonstrate that they are not M32-analogues. M 32 is still a quite unique object with only very few other galaxies having similar properties and constituting the family of compact ellipticals, however none of these is as faint as M 32. If this family is taken as the natural extension of all elliptical galaxies to lower luminosities the absence of M32-type objects in Leo adds further evidence that the faint end of the luminosity function of elliptical galaxies falls off very steeply at absolute blue magnitudes fainter than –17 (Binggeli

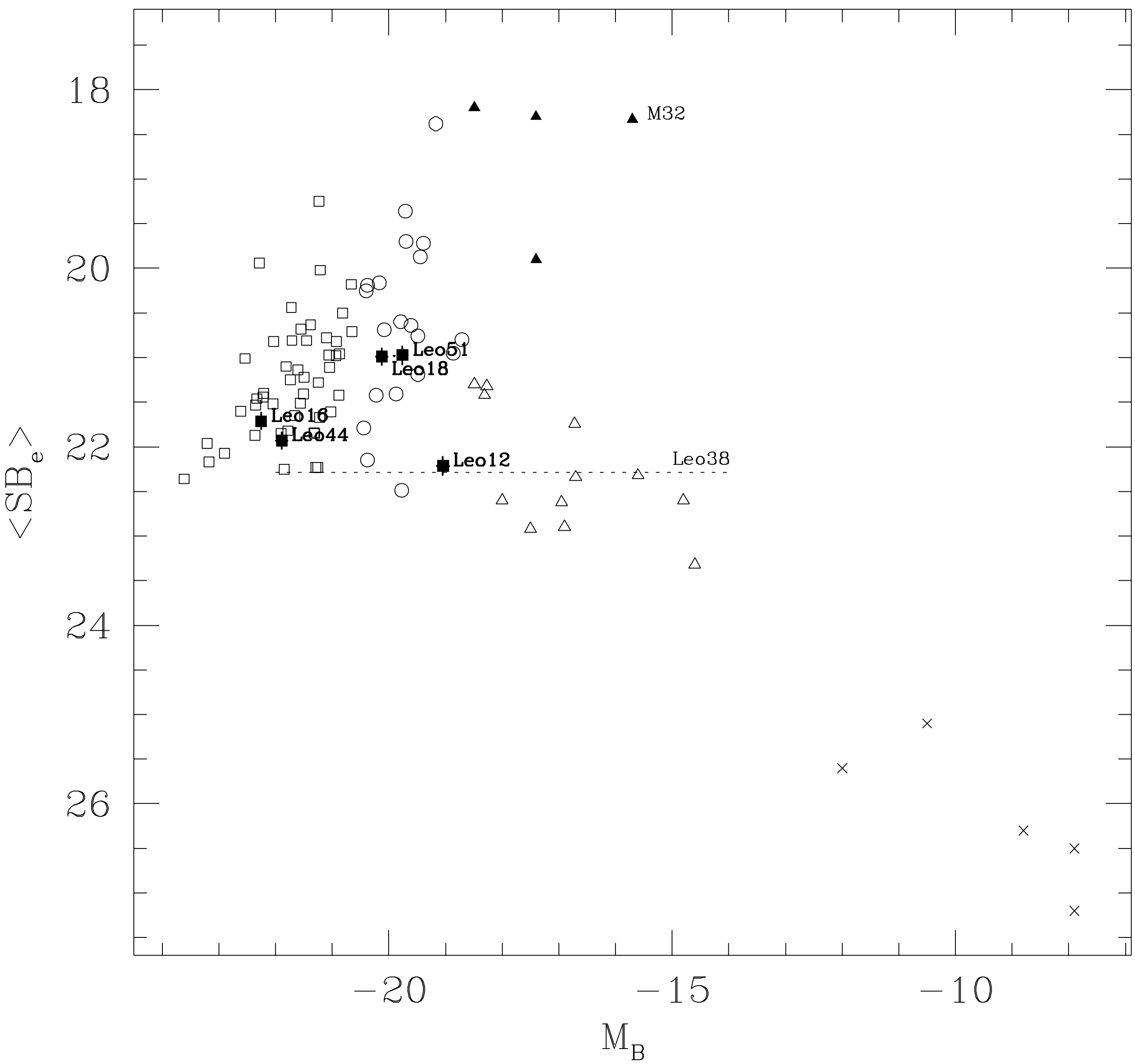

Fig. 1. The location of the Leo galaxies (filled squares) in the surface brightness vs. absolute magnitude plane in comparison to the BBF sample: giant Es (open squares), intermediate Es (open circles), bright dEs (open triangles), compact Es like M 32 (closed triangles) and dSphs (crosses). The dashed line indicates possible positions of Leo 38. To calculate M_B, $H_o = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ was used

et al., 1988). Our results also show that in general only spectroscopy can prove whether a galaxy is of the type of M32.

Acknowledgements. This research was partially supported by the Sonderforschungsbereiche 328 and 375 and DARA grant 50 OR 9608 5.

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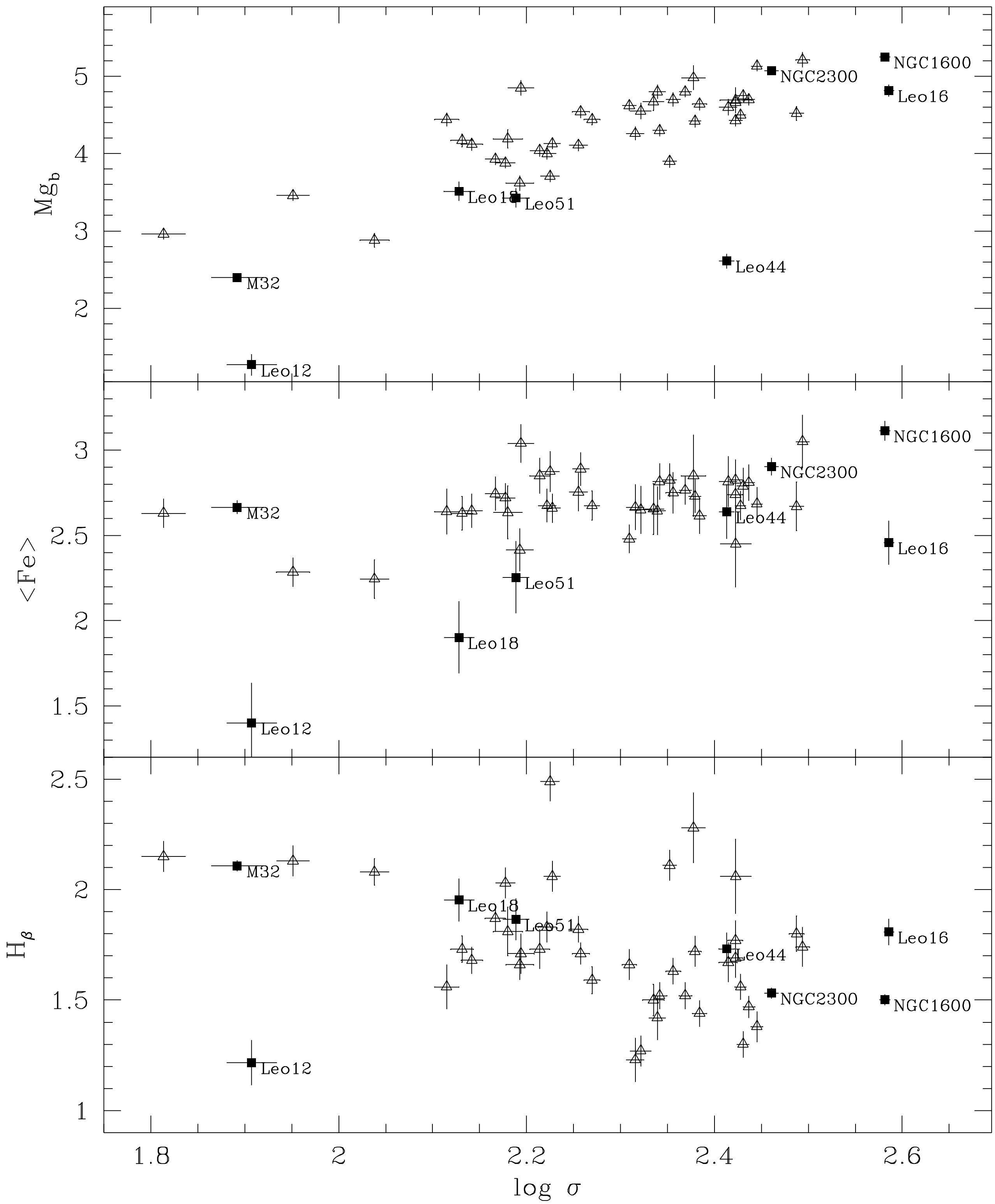

Fig. 2. The measured absorption indices of the Leo galaxies (filled squares) in comparison to the González sample (open triangles). ⟨Fe⟩ is the arithmetic mean of Fe 5 and Fe 6