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Morphological classification and structural parameters of galaxies in the Coma and Perseus clusters⋆

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Abstract. We present the results of an isophotal shape analysis of galaxies in the Coma and Perseus clusters. These data, together with those of two previous papers, provide two complete samples of galaxies with reliable Hubble types in rich clusters:

1) all galaxies brighter than $m_{\rm b} = 16.5$ falling within one degree (= 2.3 Mpc) from the center of the Coma cluster (187 galaxies),

2) all galaxies brighter than $m_{\rm Zwicky} = 15.7$ in a region of $5°3' \times 5°27'$ around the center of the Perseus cluster (139 galaxies).

These two complete samples cover 5 orders of magnitude in galaxy density and span areas of 91 and 17 Mpc^2, clustercentric radii up to 6.4 and 2.3 Mpc, for Perseus and Coma respectively. They will be used in subsequent papers to study the dependence of galaxy types on cluster environment and as reference samples in comparisons with distant clusters.

Key words: galaxies: clusters: individual: Coma (Abell 1656) — individual: Perseus (Abell 426) — Galaxies: elliptical and lenticular, cD — galaxies: fundamental parameters

1. Introduction

In two previous papers, we presented an isophotal shape analysis with morphological type estimates for a large number of galaxies in two clusters of galaxies. Our analyses, based on CCD images and photographic plates, concerned more than 200 galaxies in three regions of Coma (Andreon et al. 1996, hereafter Paper I) and about 100 galaxies in the Perseus cluster (Poulain et al. 1992). The aim of both works was to collect as many galaxies as possible in these two clusters for subsequent studies of galaxy properties (e.g. Michard 1996; Andreon 1994, 1996; Andreon et al. 1997). The galaxies observed with a CCD were selected mainly because they had previously been classified as early-type.

Once the data accumulate and the samples grow to a reasonable size, it becomes possible to trace some notable properties of the Hubble types, but we convinced ourselves that slight differences among the properties of the morphological types were not properly measured with *incomplete* samples. Using samples with various degrees of completeness, different authors have in fact reached different conclusions on many galaxy properties: on the galaxy mean surface brightness of the types (Andreon 1996), on the optical luminosity function of boxy Es and disky Es (Andreon 1994 and 1996), on the radio luminosity function of boE and diE (Lowen & Owen 1995). The two previously available samples of galaxies in Coma and Perseus, although large in size and almost complete in (small) selected areas and within restricted magnitude ranges, were not quite complete in magnitude. Therefore we decided to observe the galaxies unobserved in these previous surveys. We also reobserved some galaxies whose detailed morphological type was unsatisfactory.

Since it was beyond our observing capabilities to complete the two samples down to the magnitude of the faintest observed galaxy and out to the distance of the most peripheral galaxy, we set the more limited goal of completing our samples within an area and down to a magnitude limit that does not exclude too many faint galaxies already observed by our team and at the same time does

⋆ Based on observations made with the 2-meter Telescope Bernard Lyot of Pic-du-Midi Observatory, operated by INSU (CNRS) and the Schmidt telescope at the Calern Observatory (OCA). All tables are only available in electronic form at the CDS anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

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not include an unreasonable number of new galaxies to be observed.

In order to complete the observation of the samples rapidly, we gave up the idea of obtaining independent morphologies from images in different passbands (e.g. V and r) and from different observing material (CCD images and small-scale plates), properties characterizing the two previous surveys. Furthermore, since high resolution conditions are not necessary for classifying spiral galaxies with obvious spirals arms, we also made use of Schmidt plates, thus innovating with respect to our two other papers.

The availability of a thinned CCD at the 2-meter Telescope Bernard Lyot (hereafter TBL), with a good quantum efficiency in blue and the fact that spiral galaxies are easier to classify in visible than in red, prompted us to observe the program galaxies in Johnson V, instead of Gunn r. The increased CCD quantum efficiency largely compensates for the decrease in luminosity of early-type galaxies from r to V, allowing us to image the program galaxies in V within the allocated telescope time.

The paper is organized as follow. We present the data completing the two samples of galaxies in Coma and in Perseus in Sect. 2. The techniques of analysis used in the present study are briefly summarized in Sect. 3. The results are given in the form of tables (Tables 2, 3, 4 and 5) and are presented only in electronic form; the tables include global photometric and geometrical parameters as well as detailed morphological information, but not the photometric and geometrical profiles as a function of radius. Notes on individual galaxies are included in the Tables. An estimate of the quality of our measures is presented in Sect. 4, and the results of the paper are summarized in Sect. 5.

We adopt a Hubble constant of $H_0 = 50$ km s^{-1} Mpc^{-1}.

2. The sample

2.1. Coma

This sample of galaxies was taken from the catalogue of Godwin et al. (1983; hereafter GMP), which lists all galaxies down to magnitude $m_b = 21.0$ in a 2.63 degree square area, centered on the Coma cluster. We selected all the galaxies down to magnitude $m_b = 16.5$, within one degree from the cluster center whose morphological type is not published in Paper I. Furthermore we reobserved all SAB0 galaxies (i.e. S0s for which the presence of a bar is uncertain) and unE (i.e. Es where boxiness or diskiness is undetermined) observed under mediocre seeing conditions by Andreon et al. (1996), as well as other galaxies of borderline type between two classes. We discarded from the observations 3 galaxies (GMP 978, 1646, 1741) which do not belong to the Coma cluster, as they have velocities[1] of more than 4000 km s^{-1} relative to the cluster center. Figure 1 shows the spatial distribution of the Coma galaxies. With the present sample, all (187) galaxies brighter than $M_b = -19.2$ mag in the surveyed area have been observed.

The galaxies of this sample were first inspected on two Schmidt plates, OCA #2849 and OCA #2842, taken at the Calern Observatory and kindly provided by C. Pollas. These plates were digitized at the MAMA[2] with a 5 and 10 micron ($= 0.33''$ and $0.65''$) step respectively, and with an aperture of 10 microns. The digitization produces image files with pixel readings proportional to plate density.

All galaxies with evident asymmetric or irregular isophotes or with spiral arms were classified as S and eliminated from further observations with CCDs. We nevertheless already had CCD images for half of them, because they were published by other authors or in the field of view of other program galaxies. The CCD images confirm the type estimates based on our Schmidt plates for all galaxies; this confirms the reliability of this method for classifying obvious spiral galaxies, even at the distance of the Coma cluster.

Finally, we found 5 galaxies in our CCD-image archives which had not been classified in Paper I; these 5 were not reobserved.

Three suspected spiral galaxies were observed in December 1994 with the TBL, and the remaining 28 galaxies were observed during one observing run in February 1995 with the same instrument and setup. The CCD was a Tektronics 1024×1024, with a pixel size of 24 μ corresponding to 0.30 arcsec on the sky. The seeing was 1.0–1.1 arcsec (FWHM) and the nights were photometric. The exposure time was 20 minutes for all galaxies. With the present observations, the median seeing of the complete sample reduces from 1.48 arcsec in Paper I to 1.2 arcsec, which is a large improvement since less than one third of the sample had been observed. This corresponds to a restframe resolution of 0.75 Kpc, not very different from the resolution that the *Hubble Space Telescope* offers for distant ($z \sim 0.4$) galaxies.

2.2. Perseus

The sample is composed of all (141) galaxies listed in the Zwicky catalogue (Zwicky 1961-1968) in a box of $5°3' \times 5°27'$ centered on $3^h14^m42^s$, $41°13'30''$ to which we added two Tifft (1977) galaxies. NGC 1233 is listed twice in the Zwicky catalogue (Zw 525-6, Zw 524-65). Three galaxies (Zw 525-21, Zw 540-65 and Zw 541-19) certainly

[1] Velocities of the program galaxies in Coma and Perseus were mainly collected from public databases, such as NED and LEDA, and by a survey of the literature.

[2] MAMA (Machine Automatique à Mesurer pour l'Astronomie) is operated by CNRS/INSU.

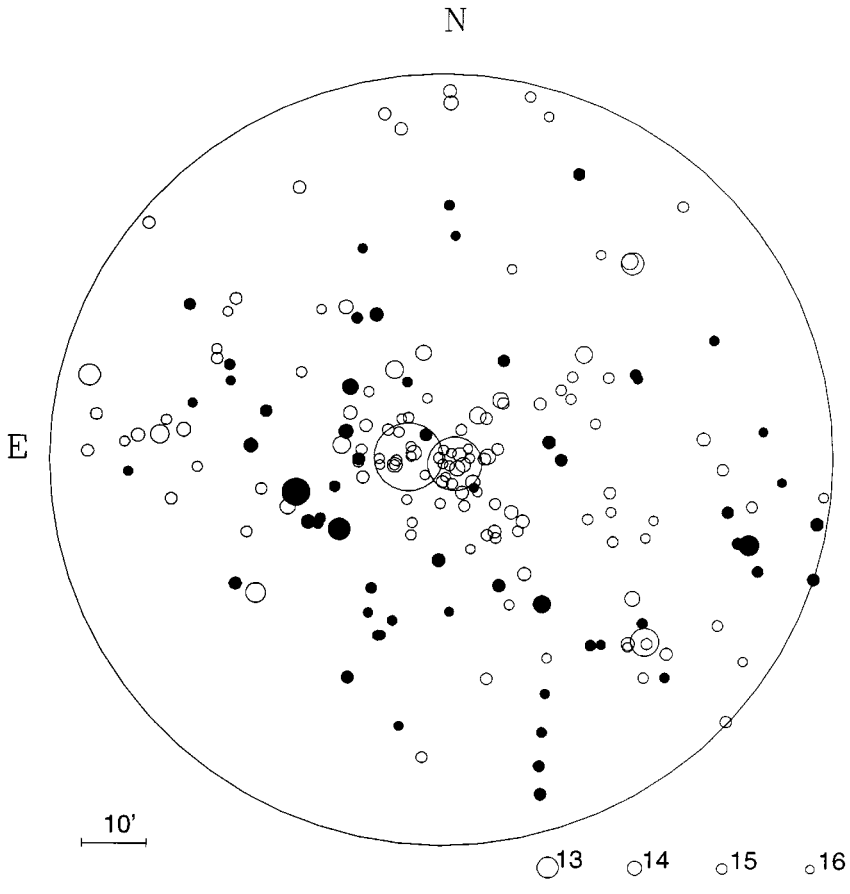

Fig. 1. The galaxies of the Coma sample. Full and open circles represent galaxies whose morphological type is presented in this paper and in Paper I, respectively. The size of the circles is proportional to the magnitude of the galaxy. The radius of the field is one degree. There are 187 galaxies in this field. The morphological types of 59 of them are presented in this paper, and the others can be found in Paper I

do not belong to the cluster because their velocity relative to the cluster center is larger than 4000 km s^{-1}; they were eliminated from the list of galaxies to be observed, together with all galaxies whose morphological type is listed in Poulain et al. (1992). Note however that some of the observed galaxies might still be fore- or background objects, in particular some of the galaxies for which the radial velocity is unknown or some galaxies in the outskirts of the studied region and with intermediate relative velocities with respect to the cluster center. Figure 2 shows the spatial distribution of the galaxies in the studied region.

54 of these galaxies were first inspected on Schmidt plate OCA #2977 taken at the Calern Observatory in December 1992 and digitized, as the preceding one, at the MAMA with a 5 micron (= 0.33″) step and with an aperture of 0.65″. The remaining galaxies are outside the region covered by our plate. All the galaxies were further inspected on the Digitized Palomar Sky Survey[3]. Obvious spiral galaxies were classified as such and eliminated from the list of galaxies to be observed in CCD.

We found images of 3 galaxies in our CCD-image archives which had not been classified by Poulain et al. (1992); they were not reobserved.

Finally, we observed in CCD almost all galaxies not classified as S. Five observing runs (35 nights) at TBL were used for completing this sample, since bad weather, technical problems with the filter wheel and with data aquisition, and the pear-shaped PSF of many images, made the completion of the program very slow, largely compensating the good luck of Poulain et al. (1992). During the first 3 runs (February 1993, December 1993, February 1994) we used a 1024 × 1024 Thompson CCD with a pixel size of 19μ corresponding to 0.24 arcsec on the sky and the galaxies were observed in the Gunn r filter and calibrated in the Cousin R filter, to make the measures consistent with those of Paper I. During the last two runs (December 1994 and February 1995) the CCD was the same Tektronics 1024 × 1024 as for the Coma sample and we observed the galaxies in Johnson V.

[3] The Digitized Sky Survey was produced at the Space Telescope Science Institute under US Government grant NAG W-2166.

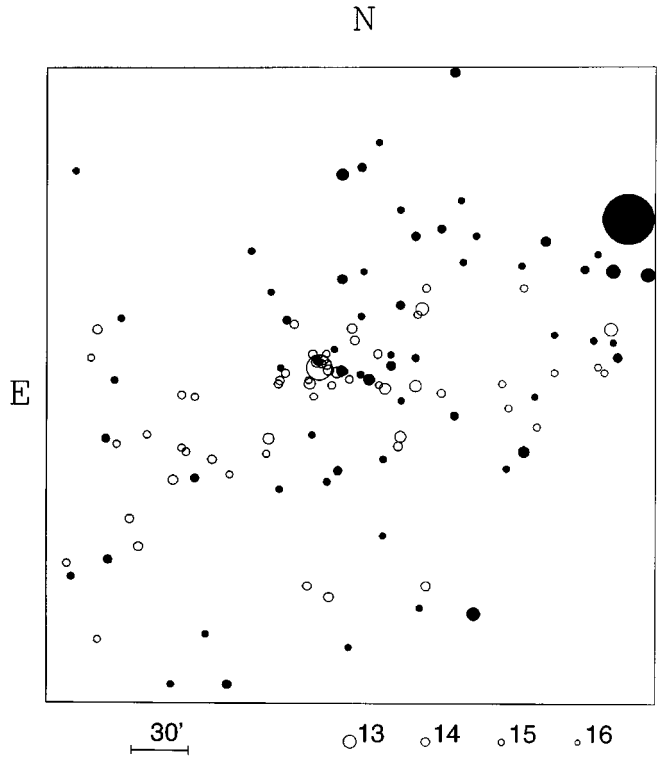

Fig. 2. The galaxies of the Perseus sample. Full and open circles represent galaxies whose morphological types are presented in this paper and in Poulain et al. (1992), respectively. The size of the circles is proportional to the magnitude of the galaxy. The size of the studied region is $5°3' \times 5°27'$. There are 139 galaxies in this field. The morphological types of 80 of them are presented in this paper, and the others can be found in Poulain et al. (1992)

Thanks to the fact that the sample is largely composed of obvious spirals, whose large-scale spiral structure is visible even on defective images (missing pixels, pear-shaped PSF, unidentified filter), we were able to collect images of sufficient quality for the morphological classification of all but 4 galaxies (Zw 540-73, 540-80, 540-83 and 525-36).

For the first three galaxies, we only used our Calern plates, whose densities had been transformed into intensities by means of a contour to contour correspondence between plate-image output and CCD-image intensity for a set of galaxies, as we did in Paper I. Plate OCA #2977, like those used for Coma galaxies, is a Kodak panchromatic 4415 emulsion sensitive from the near UV to 6000−7000 Å and was taken without filter. The fact that its sensitivity does not match the CCD V or r band prevented us from absolutely calibrating this plate, and therefore from computing passband dependent quantities (magnitudes, radius at a given surface brightness, etc.); but, for galaxies without pronounced color gradients, such as Es, we can still compute the density to intensity transformation (in arbitrary units) without significant errors.

For Zw 525-36, we did not have any image of sufficient quality for the morphological classification, and its type remains unknown.

Table 1 details the observing log. The median seeing was 1.4 arcsec, which corresponds to a restframe resolution of 0.66 Kpc, still comparable to the resolution available with the *Space Telescope* for distant galaxies.

The method of analysis and the classification scheme are described in details in Paper I and references therein, and do not need to be presented anew.

3. Results of the photometric and isophotal shape analyses

3.1. Spirals

Table 2 presents the parameters of 31 galaxies in Coma classified as spirals from visual inspection of the two plates OCA #2842 and OCA #2849, with our notes and from the morphological appareance on CCD data when available. In that Table, we also list separately three Coma galaxies classified as S from CCD data taken on December 27 and 28, 1994, and two Coma galaxies classified as spirals from images in our archives.

Table 3 presents the parameters of 36 galaxies in Perseus classified as spiral or peculiar, from their visual appearance on plate OCA #2977, on the Digitized Palomar Sky Survey and/or on our CCD images.

3.2. Early-type galaxies

The data presented in Tables 4 and 5, for early-type galaxies in Coma and Perseus respectively, include the usual photometric parameters in Cousin's R or Johnson V band, namely the asymptotic magnitude, the effective radius, the corresponding isophotal major axis, and the average surface brightness (hereafter SuBr) inside the effective isophote. Geometrical parameters are given next, the minimum axis ratio (or alternatively its value at the effective isophote), the representative e_4 coefficient (see Paper I for the definition of e_4 and f_4), the axis ratio in the envelope, i.e. at the isophote $\mu_R = 24$ mag arcsec^{-2} or $\mu_V = 24.85$ mag arcsec^{-2}, and a representative value for the isophotal twist. Next is a coded description, indicating the detection or absence of components such as bar, disk, spiral pattern, and the classification of disks and envelopes.

We emphasize that the units of angular measures in this paper and in Paper I are arcsec, not 0.1 arcmin as incorrectly stated in Paper I.

Table 4 lists the parameters of 28 early-type galaxies in Coma. The first 4 columns concern the catalogue data, the others list the measured data.

Table 5 lists the parameters of 27 early-type galaxies in Perseus. The first 2 columns concern the catalogue data, the others list the measured data.

In the notes to Table 4 and 5, we give qualitative remarks for galaxies which present either peculiar morphological properties or practical problems for classification.

4. Quality of the parameters and types

A detailed comparison of the morphological types of the whole Coma sample of galaxies with other published studies is presented in Andreon & Davoust (1997). It shows that the main objective of this work and of Paper I, *reliable estimates of morphological types*, has been reached, since these types are at least as good as the traditional ones, because less subjective, more reproducible and based on images of adequate quality.

The quality of the parameters listed in Tables 4 and 5 (magnitudes, effective radii, representative ellipticities, etc.) does not differ from that of the parameters presented in Paper I, because of the close similarity of the data and of the analyses.

Some discrepancies have been found between our values of representative quantities (such as ellipticity or e_4) and published ones, but we stress that they are largely due to differences in the definition of what is a "representative" quantity, whether it is an intensity averaged quantity, or the quantity at the galaxy effective radius, at its maximum or at the extremum, and of what is its value when not just an extremum is present or when we only measure an incomplete range of galaxy radii (i.e. always because of seeing or sky brightness limitations). In Paper I, the comparison of these "representative" quantities shows that the typical errors are of 0.06 on ellipticity (and our ellipticities are systematically larger than the others by 0.05) and of 1.3% on e_4 (and our e_4 are larger than the others by 0.7%). These figures, based on more than 200 comparisons, are also valid for the data presented in this paper.

Aside from errors on sky determination, the effective radii suffer from the existence of two definitions, the radius containing half the light, measured by extrapolating the luminosity growth curve and taking the radius where the integrated magnitude is 0.75 mag fainter than the total one, or the slope of the SuBr profile, measured by the best fit of the SuBr profile with a de Vaucouleurs' law. Adopting the former method, the subjective extrapolation of the growth curve implies a typical error of 0.02 in $\log(r_e)$ and $\log(l_e)$ for galaxies of range 0.5 to 1.0 in $\log(r_e)$ (where r_e is in units of arcsec), or, more precisely, this is the typical scatter between estimates of different observers, all using the same growth curves. Much larger differences have sometimes been found for galaxies whose growth curves differ from the standard ones listed in RC3 (de Vaucouleurs et al. 1991), used by us as standards.

5. Summary

We present morphological type estimates, together with a detailed coded description for 59 galaxies in Coma and 80 in Perseus. The material for the morphological type estimates is adapted to the difficulty of morphological classification, ranging from Schmidt plates for obvious Ss to CCD data with a median restframe resolution of $0.65-0.75$ Kpc for early-types.

In the present paper and in two previous ones (Paper I; Poulain et al. 1992) we classify two magnitude complete samples of galaxies: all (187) galaxies in Coma brighter than $M_b = -19.2$ mag within 1 degree from the cluster center and all (139) galaxies in Perseus brighter than $M_{Zwicky} = -19.5$ mag in a box of $5°3' \times 5°27'$. At the distance of these two clusters, we sample an area of 17 and 91 Mpc^2 and distances of up to 2.3 and 6.4 Mpc from the cluster center, for Coma and Perseus respectively, and 4 to 5 orders of magnitude in galaxy density. The ranges of explored clustercentric distances and galaxy densities allow us to study how the cluster affects the galaxy properties. The results for Coma, based on these data, are presented in Andreon (1996). For Perseus, work is in progress.

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